IRMMW-THz 2023

48th CONFERENCE ON INFRARED, MILLIMETER AND TERAHERTZ WAVES

17 -22 September 2023
Montreal, Quebec, Canada

Conference Program

18 September 2023

08:30 - 09:00 **Opening Ceremony** **Symposia Theatre**

Chairperson(s): David Cooke,

09:00 - 09:45 **Plenary Session 1** **Symposia Theatre**

Chairperson(s): Lyubov Titova,

09:00 **Nonlinear Optics Of THz Radiation** **Mo-PL-1-1**

Robert Boyd
25 Templeton Street, room 456

Nonlinear Optics of THz Radiation

09:45 - 10:30 **Plenary Session 2** **Symposia Theatre**

Chairperson(s): Lyubov Titova,

09:45 **THz-driven Acceleration And Manipulation Of Electron Beams** **Mo-PL-2-1**

Steven Jamison[1]; Graeme Burt[2]; Darrren Graeme[3]; Robert Appleby[3]; Morgan Hibberd[3]

[1]Bailrigg, Lancaster; [2]Lancaster; [3]Manchester

Laser-derived THz sources are capable of acceleration or deflection of electron beams, with femtosecond temporal control. When combined with electron beam dynamics in free-space or magnetic transport systems, actively driven synchronization of electron beams to lasers becomes achievable. Maximizing the interaction between THz and electron beams requires solving challenges such as slow-light systems to obtain velocity phase-matching between wave and particle beam; generation of electromagnetic modes or interaction configurations that provide an electric field polarization collinear with wave and particle propagation; and design of dispersion free, or minimal dispersion, structures that maximizes the THz-electron interaction. Research of the THz acceleration group at Cockcroft Institute in these areas includes mode-tailored spintronic sources, high-field PPLN generation, slow-wave travelling source schemes, and dielectric and corrugated waveguide structures. The acceleration and manipulation of both relativistic and 100keV electron beams have been demonstrated. Relativistic beam concepts and are being developed further for ultrafast temporal compression and active synchronization control of high-energy beams, while boosting 100keV beams to MeV levels underpins the development of THz-driven electron injector technology.

11:00 - 12:00 **Quantum-Cascade Lasers I** **Symposia Theatre**

Chairperson(s): Xiang Lu,

Terahertz Near-field Mapping Of Plasmon-polaritons In Layered Nano

11:00 **Materials** **Mo-AM-1-1**

Miriam Vitiello
Piazza San Silvestro 12, Pisa

Terahertz near-field mapping of plasmon-polaritons in layered nano materials

11:30 **Spectral Shaping In Ultra-Thin Terahertz Quantum Cascade Laser Pairs** **Mo-AM-1-2**

Marie C. Ertl[1]; Michael Jaidl[1]; Benedikt Limbacher[1]; Dominik Theiner[1]; Miriam Giparakis[2]; Maximilian Beiser[2]; Aaron M. Andrews[2]; Gottfried Strasser[2]; Juraj Darmo[1]; Karl Unterrainer[1]
[1]Gusshausstrasse 27-29, Vienna; [2]Gusshausstrasse 25a, Vienna

We present optically coupled episide down bonded ultra-thin terahertz quantum cascade wire laser pairs. Episide down flip chip bonding facilitates the electrical contacting of ultrathin lasers. The resulting sandwich structure traps the radiation propagating outside the laser cavities. In subwavelength laser cavities up to half of the mode propagates along the outside. This radiation couples to the neighboring ridges which injection-locks them.

11:45 **THz Optical Solitons Formation In Double Ring Quantum Cascade Lasers** **Mo-AM-1-3**

Paolo Micheletti[1]; Urban Senica[1]; Andres Forrer[1]; Sara Cibella[2]; Guido Torrioli[2]; Martin Frankié[3]; Mattias Beck[3]; Jerome Faist[3]; Giacomo Scalari[3]
[1]ETH Hönggerberg, HPT F10 Auguste-Piccard-Hof 1, Zurich; [2]Via del Fosso del Cavaliere, 100, Roma; [3]ETH Honggerberg, Auguste-Piccard-Hof 1, Zurich

THz optical solitons are demonstrated in circular cavity Quantum Cascade Lasers (QCL) where a double ring waveguide design provides for the anomalous dispersion. Sech2 spectra featuring 12 ps pulses in the reconstructed emission time profile are presented which agrees well with numerical simulations based on Complex Ginzburg-Landau equation.

11:00 - 12:00 **THz Driven Electron Sources** **Cartier I**

Chairperson(s): Steven Jamison,

11:00 **Terahertz Surface Plasmon Polariton Amplification And Its Application In Electron Accelerations** **Mo-AM-2-1**

Ye Tian; Yushan Zeng
No.390, Qinghe Rd., Jiading Dist., Shanghai

Surface plasmon polaritons (SPPs) can drastically alter photonic densities to allow extraordinary light field properties that are otherwise inaccessible. Here, instead of exciting SPPs by free-space coupling, we demonstrate coherent amplification of the terahertz SPPs via the interaction with a synchronous femtosecond electron bunch, and disclose their time-resolved spatial, energy, and frequency evolutions during the amplification processes. Using the resultant intense terahertz SPPs as a driving source, we further report on the experimental evidence of tunable electron acceleration, with electron energy gain up to the mega-electronvolt range.

11:30 **THz-driven Electron Emission From Metallic Surfaces** **Mo-AM-2-2**

Tobias Buchmann; Matej Sebek; Simon Lange; Peter Uhd Jepsen
Otto Mønsteds Plads 343, Kongens Lyngby

We showcase THz-driven electron emission from metal-based metasurfaces. The effect of the gap-size of bow-tie antennas on the electron emission and emission threshold is investigated. Furthermore, the effect of a thin layer of

dielectric coating on top of metallic antenna structures is characterised. In both cases, conclusions on how to improve the local field enhancement and thus the tunneling current are drawn. A narrower gap-size leads to improved enhancement for bow-tie antennas, and thin coatings can increase or reduce the tunneling current, depending of their thickness.

11:45 **Terahertz-induced Electron Emission From Thin Films** **Mo-AM-2-3**

Matej Sebek[1]; Tobias Olaf Buchmann[2]; Jie Ji[3]; Yinqiu Zhou[3]; Abhay Shivayogimath[3]; Peter Bøggild[3]; Simon Jappe Lange[2]; Peter Uhd Jepsen[2]
[1]343 Ørsted Pl., Lyngby; [2]343 Ørsted Pl.; [3]309 Fysikvej

We use a strong THz field to induce electron emission from graphene monolayer and an ultrathin gold film. We analyze different emission pathways of the electrons and show an interplay between hot-electron emission and field emission.

11:00 - 12:00 **Biosensors** **Cartier II**

Chairperson(s): Jiro Hirokawa,

11:00 **Sensitive Biosensor Chip Based On Metamaterials And Microcavity Used To Detecting Living Cells** **Mo-AM-3-1**

Kanglong Chen[1]; Xiaofang Zhao[2]; Lulu Han[1]; Jun Yang[2]; Cunjun Ruan[3]
[1]No. 37 Xueyuan Road, Haidian District, Beijing; [2]49 North Garden Rd.,Haidian District, Beijing; [3]Professor Cunjun Ruan, Beihang UniversityNo. 37 Xu, Beijing

A biosensor chip consisting of metamaterial and microcavity has been designed to detect live cells. Detecting living cells can help reveal biological significance and ensure accurate discrimination. Pure culture medium, normal nerve cells solution, glioblastoma cells solution, and nerve cells (50%) and glioblastoma cells (50%) mixed solution are selected as analytes, and all the cell concentrations of solutions are 1Ã-105 cells/mL. The frequency shift of nerve cells solution, glioblastoma cells solution, and mixed cells solution is 20 GHz, 50 GHz, and 70 GHz according to the reference axis of pure culture medium resonance frequency. We have analyzed the measurement results, and the results follow the theory. These cell solutions have been successfully distinguished, and this biosensor paves the way for living cell detection.

11:15 **Selective Biodetection Platform For Melanoma Diagnosis Using Functionalized THz Metamaterials** **Mo-AM-3-2**

Merle Richter[1]; Yannik Loth[1]; Anna Katharina Wigger[1]; Nicole Rachinger[2]; Daniela Nordhoff[1]; Daniel Stock[1]; Anja Katrin Bosserhoff[2]; Peter Haring Bolívar[1]
[1]Hoelderlinstrasse 3, Siegen; [2]Fahrstrasse 17

In this contribution, we propose a promising diagnostic tool for melanoma diagnosis. It was capable of selective and sensitive detection of the early growth response protein 2 (EGR2), a transcription factor with an increased activity in melanoma cells, from a complex sample of nucleus proteins with the presented THz biosensor. The sensor fundamentally belongs to the frequency selective surface type metamaterials and consists of an array of asymmetrically, doubly split ring resonator unit cells. The single elements are slits in a metallic

layer and are complemented by an undercut etch. This allows a selective functionalization of the active area of the sensor and increases the sensitivity towards the target analyte. On one sensor chip, multiple query fields containing the metamaterial array are located, thereby enabling internal referencing and multiple analyses to take place in one measurement sequence.

11:30 **Breathalyzer-based Prompt Coronavirus Screening Test Using Terahertz Spectroscopy Of Viruses In LC-Resonant Metamaterial Nano-Antenna Array** **Mo-AM-3-3**

Rudrarup Sengupta[1]; Heena Khand[2]; Gabby Sarusi[2]

[1]Marcus Family Campus Ben-Gurion University of the Negev P.O.B. 653, Beer-Sheva; [2]Marcus Family Campus P.O.B 653

We propose a tested, sensitive and prompt COVID-19 breath-screening method that takes less than one-minute. The non-biological method is based on detection of shift in terahertz resonance frequency of a nano-engineered LC-resonant metamaterial chip, caused by viruses and related exhaled particles. The chip is enclosed in breathalyzer-like enclosure, which is shown to optically suppress Fabry-PÃ©rot, for the first time. Low scale clinical trials were conducted with asymptomatic, symptomatic coronavirus-patients and healthy individuals, where coronavirus-positive are effectively screened with 87% accuracy, from healthy individuals.

11:45 **Terahertz Ultrasensitive Biosensor Based On Wide-area And Intense Light-matter Interaction Supported By QBIC** **Mo-AM-3-4**

Yan Peng[1]; Binwei Liu[2]; Wu Xu[3]; Yiming Zhu[3]; Songlin Zhuang[3]

[1]Jungong Rd. 516, Shanghai; [2]Jungong Rd. 516, Yangpu Direct, Shanghai; [3]Jungong Rd. 516, Yangpu Direct

A quasi-bound state in the continuum (QBIC) has unique attraction in optical switch, nonlinearity, communication, and sensing due to its ultrahigh radiation quality (Q) factor. The QBIC observed in metasurfaces also provides a feasible platform to achieve in-plane strong light-matter interaction, as well as to develop ultrasensitive biosensor. However, the existing metasurface designs are difficult to realize highly efficient excitation and high-performance sensing of QBIC in terahertz (THz) band. Here, we manipulate the interference coupling between electric quadrupole and magnetic dipole by introducing an asymmetry ÃffZÃf‚Ã‚± into the metallic metasurface structure, which excites ultrahigh quality QBIC resonance with Q factor of up to 503. Correspondingly, light field energy constrained by the metasurface and effective sensing area achieved enormous increases of about 400% and 1300%, respectively, which greatly expands the spatial extent and intensity of light-matter interaction. Simulations and experiments show that the proposed QBIC metasurface deliver a high refractive index sensitivity reaching 420 GHz/RIU, where RIU is the refractive index unit, and its direct limit of detection (LoD) for trace homocysteine (Hcy) molecules is 12.5 pmol/ÃffZÃf‚Ã‚¼L. Its performance is about 40-times better than that of the classical Dipole mode.

11:00 - 12:00 **Metrology I** **International I**

Chairperson(s): Peter Uhd Jepsen,

In-fab Assessment Of Heat Budget In 3D NAND Flash Devices Using

11:00 **Terahertz Wave-based Metrology System** **Mo-AM-4-1**

Inkeun Baek; Sungyoon Ryu; Ikseon Jeon; Yoonkyung Jang; Suhwan Park; Eun Hyuk Choi; Wontae Kim; Martin Priwisch; Taejoong Kim; Myungjun Lee; Yusin Yang
1-1, Samsungjeonja-ro, Hwaseong-si

In this study, we introduce a non-destructive method for evaluating the heat budget in 3D NAND flash memory devices, utilizing an in-fab terahertz wave-based metrology system. Our approach enables the monitoring of electrical property variations in the devices, resulting from hydrogen concentration changes due to heat-related semiconductor fabrication processes. In this work, we demonstrate a robust correlation (R2=0.99) between hydrogen concentrations in thick SiO2 layer and transmitted THz signals in 3D NAND structures. This finding highlights the promise of in-fab THz-based measurement tools for examining dopant variation within high carrier density regions of transistors during the manufacturing process.

11:30 **Reference Materials For THz Spectroscopy** **Mo-AM-4-2**

Mira Naftaly
National Physical Laboratory, Hampton Road

Reference materials are an essential tool for testing the performance of THz spectroscopy instruments. There is insufficient information regarding suitable materials. Candidate materials are investigated and data presented.

11:45 **Single-shot Ultrafast Terahertz Imaging** **Mo-AM-4-3**

Junliang Dong[1]; Pei You[2]; Alessandro Tomasino[2]; Aycan Yurtsever[2]; Roberto Morandotti[2]

[1]1650 Boul. Lionel Boulet, Varennes; [2]1650 Boul. Lionel Boulet

In this work, we demonstrate a single-shot ultrafast terahertz imaging system that can capture multiple frames of a complex ultrafast scene in non-transparent media with sub-picosecond temporal resolutions. By multiplexing an optical probe beam in the time and spatial-frequency domains simultaneously, we encode the terahertz-captured spatiotemporal dynamics into distinct spatial-frequency regions of a superimposed image, which is then computationally decoded and reconstructed. Our technique provides a new diagnostic tool for the investigation of non-repeatable or destructive ultrafast phenomena that occur in optically-opaque scenarios.

11:00 - 12:00 **Novel Imaging Techniques I** **International II**

Chairperson(s): Hartmut Roskos,

11:00 **Nonparaxial Imaging Using Terahertz Structured Light** **Mo-AM-5-1**

Gintaras Valusis[1]; Rusne Ivaskevičiūtė-Povilauskienė[1]; Paulius Kizevičius[1]; Ernestas Nacius[1]; Domas Jokubauskis[1]; Kestutis Ikamas[1]; Alvydas Lisauskas[1]; Ieva Matulaitiene[1]; Karolis Mundrys[1]; Sergey Orlov[1]; Linas Minkevicius[2]

[1]Saulėtekio ave. 3, Vilnius; [2]Saulėtekio ave. 3

It is shown that structured nonparaxial terahertz (THz) light in the form of Gaussian, Bessel, and Airy beams can be generated using exclusively silicon diffractive optics elements fabricated by femtosecond laser ablation technology. The accelerating nature of the structured light is demonstrated via THz imaging

of objects partially obscured by a metallic obstacle. Lensless nonparaxial beam generation and application in THz imaging of single objects and stacked graphene layers are presented and discussed. Benchmarking revealed that the use of structured THz light in imaging consistently outperforms the conventional one in terms of resolution and contrast

11:30 **Multi-Modal Image Acquisition For AI-based Bulky Waste Sorting (incl. Terahertz Synthetic Aperture Radar)** **Mo-AM-5-2**

Dovilė Čibiraitė-Lukenskienė[1]; Dominik Gundacker[1]; Friedrich Schlüter[2]; Jochen Aderhold[2]; Manuel Bihler[3]; Michael Heizmann[3]; Lukas Roming[4]; Robin Gruna[4]; Joachim Jonuscheit[1]; Fabian Friederich[1]
[1]Fraunhofer-Platz 1, Kaiserslautern; [2]Bienroder Weg 54E, Brunswick; [3]Hertzstraße 16, Karlsruhe; [4]Fraunhoferstraße 1, Karlsruhe

This work presents the results of the initial acquisition of a multi-modal dataset that will be utilized to train and test a neural network for wood sorting. The aim of the project is to improve wood recycling from bulky waste by using four complementary sensing systems: visual, infrared, terahertz, and thermography. The four systems were combined to capture 57 multi-modal images of bulky waste samples moving on the conveyor belt at a speed of 10 cm/s. The images are labeled and provided to a semi-supervised multispectral neural network as teaching and testing material aiming to reach at least 50 % accuracy of wood detection from all wood content in bulky waste.

11:45 **A Multi-Channel Terahertz Tomography Setup** **Mo-AM-5-3**

Karl Henrik May; Andreas Keil; Fabian Friederich; Georg von Freymann
Fraunhofer-Platz 1, Kaiserslautern

Terahertz tomography allows for reliable non-destructive 3D inspection of plastic components at high resolution. The tomographic inspection from different projection angles avoids failure to detect details, which, in the case of one-sided inspection, would be obstructed by other features. The price to pay for this detailed imaging is long acquisition times for the tomographic data. To speed up the process of tomography imaging in the terahertz range, we demonstrate a setup for acquiring tomographic data utilizing an eight-channel array. This potentially allows for an increase in measurement speed by a factor of eight.

13:30 - 15:30 **Laser Sources & Detectors I** **Symposia Theatre**

Chairperson(s): Robert Boyd,

13:30 **Quantum Sensing In The Terahertz Frequency Range** **Mo-PM1-1-1**

Mirco Kutas; Björn Haase; Jens Klier; Georg von Freymann; Daniel Molter
Fraunhofer-Platz 1, Kaiserslautern

Although terahertz radiation has moved into the focus of technical applications, e.g. layer-thickness measurement, the generation and detection of radiation in this spectral range remains challenging as detectors are either cooled or expensive due to the laser systems they are based on. Thus, the generation and detection of terahertz radiation continues to be of great scientific interest. A novel quantum-optical concept offers the possibility to detect only visible light containing the measurement information gained in a different wavelength range. This represents an extremely attractive alternative for the terahertz

frequency range, since generation can be done with visible continuous-wave lasers while detection can be achieved with sophisticated and low-cost silicon-based detectors. We report on first demonstrations of this measurement technique in the terahertz frequency range.

14:00 **Research On 1THz Carbon-based Backward Wave Oscillator** **Mo-PM1-1-2**

Fan Deng[1]; Wenxin Liu[2]; Jianliang Wang[2]

[1]Beijing, China, Beijing, China, Beijing, China; [2]Beijing, China, Beijing, China, Beijing

This article introduces the research of 1THz carbon-based backward wave oscillator, which uses single-beam staggered double-grating as the high-frequency structure and graphene coating to increase the output power. According to PIC simulation, using a circular electron beam with a voltage of 25kV and a current of 15mA, the output power is 451mW and the oscillation frequency is 1014GHz without graphene. The output power is 1026mW and the oscillation frequency is 1013GHz after adding graphene. The output power is more than doubled without much change in the oscillation frequency. These results show that carbon-based materials have broad application prospects in the field of terahertz radiation sources

14:15 **Noncollinear Parametric Detection Of Broadband Terahertz Pulses** **Mo-PM1-1-3**

Sota Mine[1]; Gabriel Gandubert[2]; Léo Guiramand[2]; Xavier Ropagnol[2]; Kosuke Murate[3]; François Blanchard[2]

[1]1100 rue Notre-Dame ouest, Montreal; [2]1100 rue Notre-Dame ouest, Montreal; [3]Furocho, Chikusa, Nagoya, 4648603, Nagoya

We present a new method for broadband terahertz (THz) pulse detection by parametric process in a non-collinear phase matching geometry using a lithium niobate (LN) crystal. Counterintuitively, our results show the ability to spatially separate the broadband up-converted signal with a resolution of a few GHz. This striking result will have a significant impact for advanced sensing of THz light detection, whether for single-shot spectroscopy or for ultrafast information transmission in this frequency range.

14:30 **Sensitive Detection Of Terahertz Pulses Via Parametrically Upconverted Near-infrared Photons** **Mo-PM1-1-4**

Défi Junior Jubgang Fandio; Aswin Vishnuradhan; Eeswar Kumar Yalavarthi; Wei Cui; Nicolas Couture; Angela Gamouras; Jean-Michel Ménard

Department of Physics, 25 Templeton St, Ottawa

We combine electro-optic sampling with single-photon counting technology to resolve weak terahertz (THz) radiation. A gallium-phosphide (GaP) crystal is used as the nonlinear medium for the parametric frequency conversion of broadband terahertz radiation to near-infrared (NIR) photons. The upconverted photons are measured using a monochromator combined with a single-photon counting module (SPCM). Results show good agreement of the measured upconverted photons with the theory of sum-frequency mixing [1]. We also demonstrate that our detection technique is 180 times faster than standard electro-optic sampling and can access selected spectral components of the THz field with a resolution of 170 GHz. At 2.5 THz, results show a minimum detectable THz pulse energy of 2E-20 J, which corresponds to 3 photons/pulse. This THz detection technique based on a SPCM holds a strong potential for high-speed wireless THz communication systems as well as quantum sensing [2,3].

14:45 **Terahertz Parametric Generation By Collinear Injection Seeding** **Mo-PM1-1-5**

Sota Mine; Naoya Yamamoto; Kodo Kawase; Kosuke Murate
Furo-cho, Chikusa-ku, Nagoya
In the conventional injection-seeded terahertz (THz) parametric generator (is-TPG), THz-waves are generated by injecting pump and seed beam into a nonlinear optical crystal at a phase matching angle. In this study, we demonstrated is-TPG with collinear injection of pump and seed beam for the first time by utilizing parametric amplification of Cherenkov phase-matched THz-wave as a seed beam.

15:00 **Tunable Backward THz-Wave Parametric Oscillator Centered At A High Frequency Of 0.870 THz** **Mo-PM1-1-6**

Joselito Muldera[1]; Kouji Nawata[2]; Yuma Takida[3]; Deepika Yadav[4]; Hiroaki Minamide[5]
[1]519-1399 Aramaki-aza Aoba, Aoba-ku, Sendai; [2]35-1 Kasumi-cho, Yagiyama Taihaku-ku, Sendai; [3]519-1399 Aramaki-Aoba, Sendai City; [4]RIKEN, 519-1399 Aramaki-aza Aoba; [5]519-1399 Aramaki-Aoba, Sendai
We present the first demonstration of a "high frequency" backward THz-wave parametric oscillator designed for a center frequency of 0.870 THz by quasi-collinear phase matching in a slant-stripe-type periodically poled lithium niobate crystal when pumped with sub-nanosecond pulsed source of λ = 1064.44 nm. Along with the THz wave, an idler wave appears simultaneously with λ = 1067.75 nm. We also show that the oscillation frequency is tunable by a simple crystal rotation, spanning the range of 0.836-0.905 THz based on the change in the spectral line separation between the pump and idler beams. The threshold pump energy for BW-TPO was determined to be 12.4 mJ, equivalent to a pump intensity of 7.24 GW/cm^2 while obtaining a conversion efficiency as high as 8.39% at a pump energy (intensity) of 15.5 mJ (9.05 GW/cm^2).

15:15 **Pulse Train Terahertz Wave Parametric Generation** **Mo-PM1-1-7**

Kosuke Murate[1]; Sota Mine[1]; Toshiki Kinoshita[1]; Shin'ichiro Hayashi[2]; Kodo Kawase[1]
[1]Furocho, Chikusa, Nagoya; [2]4-2-1, Nukui-Kitamachi, Koganei
We generated terahertz (THz) pulse trains to enhance the average power of THz parametric generator. It was realized by dividing the pump beam into multiple pulses in an external cavity with amplifier and generating the THz wave. We confirmed pulse train generation of more than 20 pulses for the pump beam and observed an increase in THz wave output, suggesting that this method could potentially increase the average power.

13:30 - 15:30 **High Field THz Generation I** **Cartier I**
Chairperson(s): Koichiro Tanaka,

13:30 **Laser-driven Terahertz Pulses: From GV/m To TV/m Field Strengths** **Mo-PM1-2-1**

Bergé Luc
CEA, DAM, DIF, Arpajon
Laser-driven terahertz (THz) pulses are popular because of their numerous applications, e.g., in security screening, medical imaging, time-domain spectroscopy and remote detection. At non-relativistic intensity, two-color

optical pulses can create air plasmas that supply suitable emitters free of any damage, which are nowadays employed for an efficient molecular spectroscopy. Electrons are tunnel ionized by the asymmetric light field and the resulting photocurrent generates an ultrabroadband terahertz radiation with field strength > 0.1 GV/m. At relativistic intensities, plasma waves trigger strong longitudinal fields used in laser wakefield particle acceleration. THz field strengths approaching the TV/m level can then be delivered by immersing the plasma in strong external magnetic fields. This talk will review the different physical mechanisms involved in terahertz emissions by laser-gas interactions at various intensities. Recent results on air-plasma-based THz spectroscopy of solid materials will be presented in the context of the project ALTESSE. The last part of the talk will discuss new perspectives in the production of ultra-intense terahertz pulses from relativistic plasmas.

14:00 **Laser-induced Gas Breakdown By A Train Of Femtosecond long-wave Infrared FEL Pulses** **Mo-PM1-2-2**

Ryoichi Hajima[1]; Keigo Kawase[1]; James K. Koga[1]; Heishun Zen[2]; Hideaki Ohgaki[2]

[1]Umemidai 8-1-7, Kizugawa; [2]Gokasho, Uji

We observed the laser-induced breakdown of gases by a train of femtosecond long-wave infrared pulses generated from KU-FEL, the FEL oscillator at Kyoto University. We performed laser-induced breakdown experiments with different gas molecules and pressures and conducted simulations of cascade ionization. From the experimental and simulation results, we found that the breakdown was induced by cumulative cascade ionization by a train of FEL pulses.

14:15 **Generation Of Naturally Down-Chirped Few-Cycle Pulse From Free-Electron Laser Oscillator And Its Pulse Compression** **Mo-PM1-2-3**

Heishun Zen[1]; Hideaki Ohgaki[1]; Ryoichi Hajima[2]

[1]Gokasho, Uji; [2]8-1-7 Umemi-dai, Kizugawa

A Free Electron Laser (FEL) oscillator operating in the superradiance regime generates naturally down-chirped pulses with a few-cycle pulse duration. In the Kyoto University FEL facility, we observed naturally down-chirped 4.2 cycle FEL pulses with ringing sub-pulse structures at the wavelength of 10.7 μm. We performed 1st trial to compress the down-chirped pulse by inserting a thick germanium rod that has positive group velocity dispersion. As a result, the FEL pulse with a peak wavelength of 8.7 μm having a 5.0-cycle pulse duration (146 fs) was compressed down to a 3.7-cycle pulse duration (106 fs). It was also found that spectral broadening took place in the germanium rod and the FEL spectral width was broadened from 4 to 7.7 THz.

14:30 **Shot-to-Shot Detection Of The Carrier Envelope Phase Evolution In A THz FEL** **Mo-PM1-2-4**

J. Michael Klopf; Igor Ilyakov; Alexey Ponomaryov; Alexej Pashkin; Jan-Christoph Deinert; Thales V. A. G. de Oliveira; Pavel Evtushenko; Manfred Helm; Stephan Winnerl; Sergey Kovalev

Bautzner Landstraße 400, Dresden

The free-electron laser (FEL) is an ideal source of high-power coherent THz radiation for many applications. The FEL provides continuously tunable THz radiation, typically in ultrashort transform limited pulses with very high peak power. One limitation though is that the carrier envelope phase (CEP) of the FEL pulses is not fixed, making measurements of coherent THz-driven

processes extremely difficult, if not impossible. We present here, a novel technique that enables shot-to-shot measurement of the CEP of every FEL pulse up to very high repetition rates. This powerful technique enables phase-resolved measurements of the FEL pulses, which opens the door for the study of coherent THz-driven phenomena as well as the advanced FEL diagnostics needed in the pursuit of CEP stable operation of an FEL.

14:45 **Characterization Of High Energy THz Sources With Proton Radiography** **Mo-PM1-2-5**

Gerrit Bruhaug[1]; Hans Rinderknecht[1]; Mingsheng Wei[1]; Yiwen E[2]; Kareem Garriga[2]; Xi-Cheng Zhang[2]; Gilbert Collins[1]; J. R. Rygg[1]
[1]250 East River Road, Rochester; [2]500 Joseph C. Wilson Blvd., Rochester

10 to 100's of mJ scale THz sources generated by laser-solid interactions with 50-500 J, psec class lasers are very difficult to characterize due to the low repetition rate of the laser, high background radiation, harsh EMP environment, and limited detector options. Here we outline preliminary results of a new technique to directly measure the electric field of 100's of mJ scale THz pulses using the well-known technique of laser driven proton radiography. Initial results indicate GV/m fields, which are in line with the large THz pulse energies detected by THz pyrometers.

15:00 **Repetition Rate Dependence Of High-Power THz Generation In The Tilted-Pulse Front Geometry In Lithium Niobate** **Mo-PM1-2-6**

Celia Millon[1]; Samira Mansourzadeh[1]; Tim Vogel[2]; Clara Saraceno[2]
[1]Universität straße, 150, Bochum; [2]Universität straße, 150

One area of current interest is to reach higher THz average powers by making use of latest Yb-doped ultrafast laser technology, potentially bringing THz applications previously restricted to accelerator facilities to the laboratory. We present experimental evidence of repetition-rate dependent thermal effects that limit THz generation efficiency in the tilted-pulse front geometry in lithium niobate excited at high average power (>100 W) and high repetition rate (> 1 MHz). Our data shows a clear reduction in the achievable efficiency when increasing the repetition rate.

15:15 **Ultra-broadband Terahertz Radiation By Supercontinuum Generation And Optical Rectification In A Dispersion-engineered Waveguide: A Numerical Study** **Mo-PM1-2-7**

Aleksei Gaier; Ileana-Cristina Benea-Chelmus
Hybrid photonic laboratory, EPFL, Switzerland, Lausanne

In this work, we propose a numerical approach based on forward coupled mode modeling to simultaneously evaluate second- and third-order nonlinearities inside a dispersion-engineered waveguide towards the goal of generating broadband terahertz (THz) radiation by optical rectification (OR). While the model can be applied to various material platforms, we showcase it for the case of lithium niobate rib waveguides. By adequately choosing the waveguide parameters, and thereby its group velocity dispersion, we demonstrate numerically that it possible to generate the THz radiation in the 0.1-30 THz frequency range even at input pulse lengths of 160 fs, benefitting from intra-waveguide spectral broadening. We analyze the magnitude, spectral content, and phase of the THz emission in both farfield (in a silicon substrate) and nearfield.

13:30 - 15:30 2D Materials & Condensed Matter **Cartier II**

Chairperson(s): Takayuki Kurihara,

13:30 **Band Transport By Large Fröhlich Polarons In MXenes** **Mo-PM1-3-1**

Wenhao Zheng; Hai Wang; Mischa Bonn
Ackermannweg 10, Mainz

MXenes are promising materials for electrochemical energy storage and (opto-)electronic applications, but the debate on their charge transport mechanisms has remained unresolved. While theoretical studies suggest band transport, device measurements reveal hopping-type transport. Our study combines ultrafast terahertz and static electrical transport measurements to provide a unified understanding of charge transport in two model MXenes. We find that short-range intra-flake transport is dominated by band-like behavior, while long-range inter-flake transport occurs through hopping and limits charge percolation. We also identify the dominant carrier scattering mechanism as scattering from longitudinal optical phonons, with a small coupling constant, indicating the formation of large polarons. Our findings shed light on the polaronic nature of charges in MXenes and provide insights into their transport mechanisms for both fundamental studies and applications.

14:00 **Probing The Photoionization Of Liquid Water With Broadband Terahertz** **Mo-PM1-3-2**

Fabio Novelli[1]; Kaixuan Chen[2]; Adrian Buchmann[1]; Thorsten Ockelmann[1]; Claudius Hoberg[1]; Teresa Head-Gordon[2]; Martina Havenith[1]
[1]Universitaetstr. 150, Bochum; [2]Berkeley, California 94720, USA

The photolysis of liquid water is fundamental in many physical, chemical, and biological processes. We performed pump-probe experiments with ionizing optical pump pulses at 400 nm, while probing the photo-induced changes with broadband terahertz (THz) radiation (1-7 THz). We found three distinct transient signals in the THz range: a fast (<200 fs) and broadband response associated to the delocalized photo-generated electrons; a slow response (~150 ps) at low frequency (<2 THz) associated to the rearrangement of the water network subsequent to charge-separation; and a long-lasting signature (>250 ps) centered at 3 THz that reveals the hydration of the localized, solvated electrons.

14:15 **Interface Potential Estimation On VO2/Si Heterojunction By Terahertz Emission Spectroscopy With Temperature Variation** **Mo-PM1-3-3**

Dongxun Yang[1]; Fumikazu Murakami[1]; Shingo Genchi[2]; Hidekazu Tanaka[2]; Masayoshi Tonouchi[1]
[1]2-6 Yamadaoka,Suita,Osaka; [2]8-1 Mihogaoka, Ibaraki, Osaka

Terahertz emission spectroscopy has shown a lot of advantages in estimating the electric properties of semiconductor devices. In this research, we aim to observe the dynamic interface potential variation from VO2/Si heterojunction across the phase transition temperature by terahertz emission spectroscopy and attempt to evaluate the work function of VO2 film in different phase conditions.

14:30 **Terahertz Emission Spectroscopy On Eu-doped GaN Superlattice LEDs** **Mo-PM1-3-4**

Fumikazu Murakami[1]; Atsushi Takeo[2]; Brandon Mitchell[3]; Volkmar Dierolf[4]; Yasufumi Fujiwara[2]; Masayoshi Tonouchi[1]

[1]2-6 Yamada-oka, Suita; [2]2-1 Yamada-oka, Suita; [3]700 S High St, West Chester; [4]27 Memorial Dr W, Bethlehem
Eu-doped gallium nitride (GaN) is a promising candidate for GaN-based red light-emitting diodes (LEDs). By utilizing a multilayer structure (MLS) of alternating undoped and Eu-doped GaN as the active layer, the device performance of Eu-doped GaN LEDs was significantly enhanced. However, the mechanism of this improvement has not yet been understood. To better understand the enhanced device performance, we evaluated the carrier dynamics in the structures using terahertz (THz) emission spectroscopy. Our results suggest that the carrier mobility in the MLS is lower than in bulk Eu-doped GaN. Furthermore, the excitation photon energy dependence of the THz emission revealed that the Eu-doped layer had a smaller bandgap than the undoped GaN layer, resulting in the potential barriers within the MLS samples. We attributed the improvement in LED performance to improved electron capturing within the active regions in MLS.

14:45 **Terahertz Emission Enhancement Of Gallium-Arsenide-Based Photoconductive Antennas With AAO-Patterned Gold Nanoparticles** **Mo-PM1-3-5**

Regine Loberternos[1]; Hannah Bardolaza[1]; Neil Irvin Cabello[1]; Hideaki Kitahara[2]; John Paul Ferrolino[1]; Ivan Cedrick Verona[1]; Lourdes Nicole Dela Rosa[1]; Vince Paul Juguilon[1]; Alexander De Los Reyes[1]; Arnel Salvador[1]; Armando Somintac[1]; Masahiko Tani[2]; Elmer Estacio[1]

[1]National Institute of Physics, University of the Philippines, Diliman, Quezon City; [2]3-9-1 Bunkyo, Fukui-shi
We report on the enhancement of the terahertz (THz) emission characteristics of GaAs-based photoconductive antennas (PCAs) upon integration of AAO-patterned gold nanoparticles on the photoconducting antenna gap. The THz emission of the PCAs with gold nanoparticles was observed to increase up to 5.5 times compared to a reference PCA THz emitter. We tentatively attribute these enhancements to the gold nanoparticles becoming resonant with the optical excitation pulse that resulted to the collective oscillation of the electrons and the generation of surface plasmons. The results demonstrate a cost-effective and feasible method of utilizing nanostructures to improve PCA performance.

15:00 **Enhancement Of Terahertz Emission In Gallium Telluride Under Pressure** **Mo-PM1-3-6**

Kai Zhang[1]; Fuhai Su[2]; Tianwu Wang[3]

[1]B7 of Technology Enterprise Accelerator, No.11 of Kaiyuan Avenue, Huangpu District,Guangzhou City, Guagnzhou; [2]350 Shushanhu Road Hefei 230031, Anhui, Hefei; [3]Huangpu District, Guangzhou City, B7 of Technology Enterprise Accelerator, No.11 of Kaiyuan Avenue, Guangzhou
Transient terahertz responses and terahertz emission performances for the GaTe under pressure are examined by time-resolved terahertz spectroscopy. The terahertz emission strength rockets with increasing pressure whereas rapidly declines above 10 GPa, implying the insulator-metal transition. Decay time of the pumped hot carriers also shows incontinuity at the corresponding pressure. Our work not only proposes a novel routine to improve the terahertz emission efficiency but also provides important information for understandings the

emission mechanism in GaTe.

15:15 **Second Harmonic And Hyper-Rayleigh Generation Of (111) Silicon Wafer** **Mo-PM1-3-7**

Laetitia Dalstein; Marc Tondusson; Jerome Degert; Eric Freysz
351 cours de la liberation, Talence

Ultrafast time-resolved THz-induced SHG, also named hyper-Rayleigh generation, is performed at the surface of a (111) silicon wafer upon its excitation by a 50 fs IR optical pulse. The evolution of the SHG spectrum is recorded delaying in time the optical pulse with respect to the THz pulse. Upon excitation, we record a broad Stokes and anti-Stokes bands centered around the Si lattice phonon at ~610 cm-1. The spectral evolution of the SHG signal versus the delay between optical and THz pulses makes it possible to evidence the interference between volume and surface contributions as well as the ultrafast evolution of the hyper-Rayleigh susceptibility upon hot carrier generation.

13:30 - 15:30 **QCLs & Electronic Sources** **International I**

Chairperson(s): Giacomo Scalari,

13:30 **Phase Tuning Technique To Enhance The Output Power Of Sheet Beam Folded Waveguide Traveling Wave Tube** **Mo-PM1-4-1**

Yuan Zheng[1]; Yuxin Wang[2]; Shaomeng Wang[3]; Ping Zhang[3]; Shengpeng Yang[3]; Yubin Gong[1]

[1]Qingshuihe Campus:No.2006, Xiyuan Ave, West Hi-Tech Zone, Chengdu;

[2]Qingshuihe Campus:No.2006, Xiyuan Ave, West Hi-Tec, Chengdu;

[3]Qingshuihe Campus:No.2006, Xiyuan Ave, West Hi-Tec

A sheet beam folded waveguide (FWG) slow-wave structure (SWS) circuit for the compact E-band traveling wave tube amplifier (TWTA) is proposed. The structure is compatible with sheet electron beams and is predicted to produce high output power with reduced beam current density. Adding a phase shifter structure into the high-frequency circuit will turn the relative phase between the electron beam and electromagnetic (EM) wave, thus resetting the spent electrons into the deaccelerating region. Based on this phenomenon, a novel phase-tuning technique breaking through the saturation limitation and extracting more energy from the spent beam has been presented in this paper. PIC simulations were performed to validate the phase-tuning approach and determine the optimized phase-shifting value and position. There is 42 W of extra power extracted from the circuit equipped with this technique, and the peak output power of demonstrated SB-FWG TWT increased to 160 W from 118 W.

13:45 **Grating-Groove-Ladder Slow Wave Structure For W-band Traveling Wave Tube** **Mo-PM1-4-2**

Jingrui Duan[1]; Zhigang Lu[1]; Zhanliang Wang[2]; Shaomeng Wang[2]; Huarong School[2]; Yubin Gong[2]

[1]No. 819 Xisai Mountain Road, Huzhou; [2]Xiyuan Avenue No. 2006, Chengdu

In this paper, a novel slow wave structure (SWS) named grating-groove-ladder (GGL) SWS, is presented to expand the bandwidth of the conventional ladder

(CL) SWS. The transmission path of GGL-SWS could be modulated by alternately changing the gratings height on the cover plates. High-frequency results indicate that GGL-SWS exhibits a wider bandwidth, improved dispersion charactersitics. Meanwhile, GGL-SWS shows excellent interaction impedance and ohmic losses. Furthermore, the transmission characteristic of GGL in W-band was verified by the experiment.

14:00 **Additive Fabrication For Upper-Millimeter-Wave Traveling Wave Tube Amplifiers** **Mo-PM1-4-3**

Alan Cook; Colin Joye; Franklin Wood; Benjamin S. Albright; Reginald Jaynes; Jeffrey Calame
4555 Overlook Ave SW, Washington

We present an overview of additive fabrication methods for upper-millimeter-wave traveling-wave tube (TWT) amplifier slow-wave circuits, including ultraviolet lithography and Cu electroforming (UV-LIGA); 3D-printed mold electroforming (3D-PriME); and direct 3D printing in photopolymer with Cu plating. We describe example fabrication processes for traveling-wave circuits spanning the frequency range 94 GHz to 1 THz and present test data.

14:15 **Universal CUSP-Type Electron Gun For Helical Gyro-TWTs For DNP-NMR Applications** **Mo-PM1-4-4**

Max Vöhringer[1]; Alexander Marek[2]; Stefan Illy[2]; Gert Gantenbein[2]; Manfred Thumm[2]; Chuanren Wu[2]; John Jelonnek[2]

[1]Hermann-von- Helmholtz-Platz 1, Eggenstein-Leopoldshafen; [2]Hermann-von-Helmholtz-Platz 1

Gyro-TWTs with helically corrugated interaction region require a high-quality axis-encircling electron beam. In this work, a theoretical design of a CUSP-type electron gun for a 263 GHz helical gyro-TWT is presented. The theoretical design is optimized for an operation with an acceleration voltage of 50 kV, a beam current of 0.25 A and a pitch factor of ÃffZÃf‚Ã‚±=1.0. At this operating point, the spread of the pitch factor is as low as 3.5 % (RMS). Furthermore, the gun is capable to create an electron beam over a wide variety of pitch factors with different beam currents and acceleration voltages. In addition to the operation at 263 GHz, the gun can be operated at lower frequencies, e.g. at 140 GHz and at 94 GHz.

14:30 **Novel Split-well Resonant-phonon Terahertz Quantum Cascade Laser Supporting Clean Four-level System.** **Mo-PM1-4-5**

Asaf Albo[1]; Nathalie Lander Gower[1]; Shiran Levy[2]; Silvia Piperno[2]; Sadhvikas J. Addamane[3]; John L. Reno[3]

[1]Bar-Ilan University Ramat Gan , 5290002 , Israel, Bar-Ilan University Ramat Gan , 5290002 , Israel, Ramat Gan; [2]Bar Ilan University, Bar-Ilan University Ramat Gan , 5290002 , Israel, Ramat Gan; [3]New Mexico

We present a novel terahertz quantum cascade laser (THz QCL) scheme supporting a clean four-level system, 'four' being the number of the active laser states, as verified by the negative differential resistance (NDR) observed all the way up to room temperature.

14:45 **High-power Density, Single Plasmon, Terahertz Quantum Cascade Lasers Via Transverse Mode Control** **Mo-PM1-4-6**

Chao Song[1]; Mohammed Salih[2]; Lianhe Li[2]; Juliette Mangeney[1]; Jerome

Tignon[1]; Giles Davies[2]; Edmund Linfield[2]; Sukhdeep Dhillon[1]
[1]24 rue Lhomond, Paris; [2]University of Leeds
Terahertz (THz) quantum cascade lasers (QCLs) have been shown to emit peak powers greater than 1 W from a single facet in a single plasmon geometry. However, this is typically achieved by increasing the laser ridge width, resulting in higher-order transverse modes, limiting the achievable power density. Here we control and fully suppress these modes through thin metallic side-absorbers, showing laser action solely on the fundamental transverse mode operation without sacrificing high THz peak powers. This leads to enhanced power densities and electric fields of up to 1.8 kW/cm^2 and 1.17 kV/cm, respectively, opening up the possibility of applying THz QCLs as pump sources for investigations of non-linear THz physical phenomena.

15:00 **Amplitude Stabilization Of A THz Quantum-Cascade Laser Using A Photonic Integrated Circuit** **Mo-PM1-4-7**

Sanchit Kondawar[1]; Nicholas North[1]; Yingjun Han[1]; Diego Pardo[2]; Nick Brewster[2]; Mohammed Salih[1]; Michael Horbury[1]; Lianhe Li[1]; Paul Dean[1]; Brian Ellison[1]; Iman Kundu[3]; Alexander Valavanis[1]
[1]Woodhouse, Leeds, LS2 9JT; [2]Harwell Oxford, Didcot, OX11 0QX; [3]Wakefield, WF10 5HW
A method to stabilize the output power of a ~3.3 THz quantum-cascade laser (QCL) using a photonic integrated circuit is successfully demonstrated. The device consist of a racetrack resonator (RTR) coupled to a QCL ridge waveguide. This approach eliminated the need for external THz optical modulators. Amplitude stabilization was achieved for >300 seconds, without perturbation to the emission spectrum, by dynamically adjusting the electrical bias to the RTR, and hence the coupling between the QCL and RTR. This work could play a vital role in improving the performance of high-resolution spectroscopic systems useful in satellite integration for detecting gas species in the atmosphere.

15:15 **Widely Tunable Room-temperature Quantum-cascade Laser Sources In The Sub-THz To THz Frequency Range** **Mo-PM1-4-8**

Kazuue Fujita; Shohei Hayashi; Akio Ito; Masahiro Hitaka; Tatsuo Dougakiuchi; Atsushi Nakanishi
5000 Hirakuchi Hamakita-ku, 5000 Hirakuchi Hamakita-ku, Hamamatsu
We present versatile low-frequency quantum cascade laser sources that boast broad tunability by leveraging intra-cavity difference frequency mixing. By utilizing dual-upper-state active regions, which have been wavefunction-engineered for optimal performance, these devices exhibit significant advancements in their capabilities. As a result, they are now capable of producing terahertz radiation in the sub-THz to THz frequency range. A device has been observed to operate at a frequency of 231 GHz, which is the lowest reported operating frequency for room-temperature QCL sources. The feasibility of continuous-wave operation at room temperature will also be discussed.

13:30 - 15:30 Telecom 1 **International II**

Chairperson(s): Thomas Kürner,

13:30 **Utilizing High-Intensity Optical Subcarrier Signal For Conversion Gain Enhancement Of A UTC-PD-Integrated HEMT Photonic Double-Mixer** **Mo-PM1-5-1**

Tsung-Tse Lin[1]; Dai Nakajima[1]; Kazuki Nishimura[1]; Mitsuki Watanabe[1]; Keisuke Kasai[1]; Masato Yoshida[1]; Tetsuya Suemitsu[2]; Taiichi Otsuji[1]; Akira Satou[1]

[1]2-1-1 Katahira, Aoba-ku, Sendai; [2]6-6-10 Aramakiaoba, Sendai

We experimentally investigated the effect of high-intensity subcarrier signal input to the UTC-PD-integrated HEMT photonic double-mixer for optical-to-wireless carrier frequency down-conversion. The conversion gain linearly increased with increasing the subcarrier signal intensity from +0.63 dBm to +6.63 dBm without saturation. As a result, the conversion gain enhancement of about +6 dB from --51.0 dB to --44.2 dB was achieved.

14:00 **200 Gbit/s THz Tunneling Demultiplexer In The 300 GHz Band** **Mo-PM1-5-2**

Daniel Headland[1]; Withawat Withayachumnankul[2]; Masayuki Fujita[3]; Tadao Nagatsuma[3]; Pascal Szriftgiser[4]; Guillaume Ducournau[5]

[1]Universidad Carlos III de Madrid, Leganés; [2]The University of Adelaide; [3]Osaka University, Toyonaka; [4]Cité Scientifique, Villeneuve d'Ascq; [5]Avenue Poincaré, Avenue Poincaré, Villeneuve d'Ascq

We showcase here the experimental demonstration of demultiplexing THz channels with up to 200 Gbit/s aggregated data-rate, using 4 carrier frequencies. The demonstration is carried out in the 300 GHz band. Best EVM obtained values are in the range 6-9%, with 50 Gbit/s per channel, enabled by a recently-reported novel substrateless integrated passive demultiplexer, which was developed specifically to serve the particular requirements of terahertz waves.

14:15 **Coherent THz Wireless Communication Using A Microcomb And Photonic LO** **Mo-PM1-5-3**

Brendan Heffernan[1]; Yuma Kawamoto[2]; Keisuke Maekawa[2]; James Greenberg[1]; Rubab Amin[1]; Takashi Hori[3]; Tatsuya Tanigawa[3]; Tadao Nagatsuma[2]; Antoine Rolland[1]

[1]1551 S. Sunset St., Suite C, Longmont; [2]1-3 Machikaneyama, Building D, 3rd floor, Toyonaka; [3]2-1 Asahi-machi, Kariya

We present a microcomb-based THz source and use it in a coherent wireless communications demonstration at 300 GHz carrier frequency. In a homodyne setup with wireless transfer of both the data and local oscillator, data rates of 60 Gbps are achieved.

14:30 **Analyzing Performance Limitations Of THz Communication Systems Under Off-Axis Conditions And Channel Blockage** **Mo-PM1-5-4**

Xuan-Wei Miao[1]; Pouya Torkaman[2]; Fu-Kai Shih[2]; Po-Cheng Su[2]; Kai-Ming Feng[2]; Shang-Hua Yang[2]

[1]No.101, Section 2, Kuang-Fu Road, Hsinchu; [2]No.101, Section 2, Kuang-Fu Road, Hsinchu, Taiwan

This study investigates the channel conditions of a robust terahertz

communication system that employs radio over fiber at 150 GHz. The received signals with a bandwidth of up to 3 GBaud and a wireless distance of 3 meters are analyzed under different experimental conditions. The system is tested in various scenarios, with a specific focus on line-of-sight transmission, misalignment experiments, and penetration experiments that simulate actual communication environments. The signal-to-noise ratio and bit-error rate of the received signals are evaluated to analyze the performance of the terahertz wireless communication system. A path loss model of blockage with metal is proposed in this study. The results of this study have significant implications for the advancement and enhancement of the broadband terahertz wireless communication system. Additionally, the study provides a framework for estimating the terahertz communication model.

14:45 **Multiband OFDM-Based THz Wireless Communication System** **Mo-PM1-5-5**

PO-CHENG SU; Pouya Torkaman; Xuan-Wei Miao; Fu-Kai Shih; Kai-Ming Feng; Shang-Hua Yang
No.101, Section 2, Kuang-Fu Road, Hsinchu City

In the proposed system scheme, an overall 6 GHz effective signal bandwidth of 3-band M-QAM OFDM signal with various carrier frequencies (150 - 300 GHz) in a 1-meter wireless link distance by direct detection method is successfully demonstrated. The maximum 250 GHz wireless carrier frequency can achieve under the 20% FEC limit in the QPSK modulation format. 8 QAM and 16 QAM formats can also achieve the FEC limit at the 150 GHz carrier frequency. This work provides the potential to extend the spectral efficiency without additional components or cost. Further research could focus on the inherent impairments of OFDM, such as PAPR, inter-symbol interference, and inter-channel interference, which haven't been fully explored in a THz wireless link.

15:00 **Improved OFDM THz Communication System Performance Through Noise Suppression And Channel Estimation Via Channel Matrix Pruning Technique** **Mo-PM1-5-6**

pouya torkaman[1]; Shang-Hua Yang[2]; Kai-Ming Feng[1]; Xuan-Wei Miao[1]; Po-Cheng Su[1]; Fu-Kai Shih[1]

[1]No. 101, Sec. 2, Kuang-Fu Rd., Hsinchu 30013, Taiwan, R.O.C., Hsinchu;

[2]No. 101, Sec. 2, Kuang-Fu Rd- Hsinchu, Hsinchu

Channel estimation is a crucial factor in ensuring the quality of transmitted data in wireless THz communication. To evaluate the performance of different channel estimation techniques, we conducted an experimental transmission of 4 to 64 QAM-OFDM signals using intensity modulation and direct detection methods over a 4.5 meters wireless link distance. Subsequently, we proposed a pruning technique that utilizes only 1-block type symbol pilot to improve channel estimation. Our results demonstrate that using this technique and 1-block type pilot OFDM symbols leads to better mean square error compared to utilizing 8- block type pilots when transmitting 64 OFDM data symbols. This highlights the effectiveness of our proposed pruning technique in improving channel estimation for wireless THz communication.

15:15 **140 Gbit/s Wireless Sub-THz Communication Using Ultra-Low Phase Noise Light Source** **Mo-PM1-5-7**

keisuke maekawa[1]; Takashi Hori[2]; Weijie Gao[3]; Toki Yoshioka[3]; James Greenberg[4]; Brendan Heffernan[4]; Antoine Rolland[4]; Tadao Nagatsuma[5]

[1]I-502 1-3 Machikaneyamacho Toyonaka, Osaka, Toyonaka; [2]2-1 Asahi-machi, Kariya, Aichi, Japan; [3]1-3 Machikaneyamacho Toyonaka; [4]1551 South Sunset St, Suite C, Longmont, Colorado; [5]1-3 Machikaneyama, Toyonaka, Osaka, Japan

We succeeded in achieving a 140 Gbit/s real-time Sub-THZ wireless system within the HD-FEC limit. Additionally, we confirmed the impact of phase noise on the BER using several light sources.

16:00 - 18:00 **Advanced THz Sources I** **Symposia Theatre**

Chairperson(s): Tobias Kampfrath,

16:00 **A 300-GHz Slotline-coupled Double-oscillator Emitter Integrated In 65-nm CMOS** **Mo-PM2-1-1**

Marta Ferreras; Jesús Grajal
Avda. Complutense 30, ETSI Telecomunicación, Madrid

This contribution presents the design and experimental characterization of a submillimeter-wave source composed of two coupled harmonic oscillators that emit coherent radiation at around 300 GHz. The unitary oscillators are based on a self-feeding topology, which incorporates an on-chip slot antenna for second-harmonic radiation. Both units are injection-locked by each other through their respective slotline resonators so that, in the desired synchronous state, a standing wave is sustained across the array with a virtual short circuit at the connection point. The implemented circuit layout is fully compliant with the used 65-nm CMOS technology from TSMC. All measured samples oscillate at approximately 290 GHz, indicating an offset of less than 3.5% from the target oscillation frequency.

16:15 **High-Power And High-Efficiency 1.3 THz Transmitter Using Discrete Schottky Diode Technology** **Mo-PM2-1-2**

Diego Moro-Melgar; Artur Negrus; Eduard Mueller; Frank Gorski; Ion Opra; Oleg Cojocari
Josef-Bautz-Str. 15, Hanau

We report the development, manufacture and characterization of a commercial THz source operating in the 1.23-1.41 THz range. The source is based on the active multiplication chain (AMC) technology approach including all commercially available components with a total DC power consumption of 15 W. The reported AMC can provide 400 Ãf‚Ã‚µW peak RF power and a typical 200 Ãf‚Ã‚µW of RF output power. These kinds of sources can be used for a wide range of application, being the characterization of the 1.2 THz Heterodyne JUICE-SWI receiver the main purpose of the presented example.

16:30 **Stabilizing A SiGe BiCMOS Transmitter On A Molecular Absorption Line** **Mo-PM2-1-3**

Alexandra Glück; Nick Rothbart; Heinz-Wilhelm Hübers
Rutherfordstraße 2, Berlin

In many applications, highly stable frequency references are desired which at the same time take up little volume and consume little power. Transmitters and receivers in SiGe BiCMOS technology can be realized on chip-scale, working at in the THz/Millimeter-wave range where many molecules have strong rotational transitions. We stabilized a SiGe BiCMOS transmitter on a rotational

transition of carbon monoxide, reaching stabilities of <1E-10 at 100 s integration.

16:45 **Observation Of Terahertz Vector Beam Generated Directly In ZnTe Crystal** **Mo-PM2-1-4**

Seigo Ohno[1]; Hiroaki Iwase[2]
[1]6-3 Aramaki Aoba, Sendai, Sendai; [2]6-3 Aramaki Aoba, Sendai

Earlier, we reported a theoretical method for the direct generation of terahertz (THz) vector beams in nonlinear crystals. In this method, a cylindrical vector beam is generated by tightly focusing a circularly polarized pump pulse on a symmetric direction of a nonlinear crystal where THz generation is forbidden. This time, we chose the [111] direction as the symmetric direction in the ZnTe crystal and experimentally measured the polarization state of the generated THz beams using a home-built THz spectroscopic polarization imaging system. We succeeded to observe a radially polarized vector beam within entire of the generated spectral region. We consider that such broadband feature of the generated vector beam is due to the topological nature of the focused pump beam, where the wavevectors rotate once about the optical axis.

17:00 **Photonic Terahertz Source Frequency Stabilized To The Part Per Trillion Level Through Molecular Spectroscopy** **Mo-PM2-1-5**

James Greenberg; Brendan Heffernan; Antoine Rolland
1551 S Sunset St, Suite C, Longmont

Photonic sources for terahertz (THz) generation demonstrate unrivaled phase noise. The resulting THz waves can be used for precision spectroscopy of molecular rotations. Here, we show that a rotational transition of nitrous oxide (N2O) can be used to stabilize the THz frequency of a photonic oscillator to a few parts per trillion, 5 x 10^(-12), after only 10 seconds of averaging time. The core of the photonic oscillator utilizes a dissipative Kerr soliton generated in a micro-ring resonator, and the THz spectrometer is purely built in a waveguide. With these techniques combined, this demonstration represents a low-noise, low-drift THz source that is feasibly miniaturized.

17:15 **High Spectral Purity Solid-state Dual-frequency Laser For The Generation Of Ultra-low Phase Noise Millimeter-wave To Terahertz CW Signals** **Mo-PM2-1-6**

Loic MORVAN[1]; José-Javier Fernandez-Pacheco[1]; Daniel Dolfi[1]; Vincent Crozatier[1]; Fabien Bretenaker[2]
[1]1 avenue Augustin Fresnel, Palaiseau; [2]Bâtiment 505, Campus d'Orsay,, Orsay

We present our latest results related to the development of solid-state dual-frequency lasers for the generation of stable, ultra-low phase noise millimeter-wave and terahertz signals. After presenting the architecture of such lasers delivering sub-Hz Lorentzian linewidth signals, and their stabilization setups based on electro-optical frequency division, we describe the specific setup that we have assembled to further study the origin of the optical and beatnote phase noise. It includes a specific laser setup and a custom-made optical phase noise test bench. Preliminary results are presented, and perspectives are discussed.

17:30 **Nanowire-based THz Polarimetry** **Mo-PM2-1-7**

Michael Johnston
Clarendon Laboratory, Parks Rd, Oxford

Semiconductor nanowires show extreme polarization selectivity for both visible and terahertz photons. We are utilising an in-depth knowledge of ultrafast charge-carrier dynamics in nanowires to develop unique devices for THz polarimetry. Our photoconductive THz sensors based on a hash-nanowire architecture are compact and recover the full polarisation state of THz pulses. These nanowire-based devices are showing promise in areas including semiconductor characterisation and the development of metamaterials for THz polarisation manipulation.

16:00 - 18:00 **Spectroscopy I** **Cartier I**

Chairperson(s): Sebastian Maehrlein,

16:00 **Quantitative Measurement Of The Dispersion Of ?(3) In Silica And Silicon Nitride In The 1-25 THz Range** **Mo-PM2-2-1**

Binbin Zhou; Mattias Rasmussen; Siqi Yan; Narwan Kabir Noori; Oliver Nagy; Yunhong Ding; Simon Jappe Lange; Peter Uhd Jepsen
DTU Electro, Blg. 343, Kongens Lyngby

Nonlinear optics is a highly developed topic in the near-infrared (near-IR) region. In the THz range, nonlinear effects are well known but have been studied to a much smaller extent than in the near-IR. Here we demonstrate a method for the quantitative measurement of the third-order nonlinearity of materials. The measurements directly reveal the absolute magnitude as well as the dispersion of the nonlinearity across an extended range up to 1-45 THz.

16:30 **Refractive Index And Extinction Coefficient Measurement Of Reflective THZ-FDS Based On SSKK Method For Solid Sample** **Mo-PM2-2-2**

Yubo Wu[1]; Cunjun Ruan[2]; Yufeng Jiao[2]
[1]No. 37 Xueyuan Road,Haidian District, Beijing; [2]No. 37 Xueyuan Road,Haidian District

We study the spectral information of highly resistive silicon samples by employing terahertz frequency domain reflection spectrometry. The phase shift owing to the tiny displacement between sample and reference could be eliminated by a modified single subtraction Kramers-Kronig method. The refractive index and extinction coefficient of doped silicon range from 0.2THz to 1.0THz has been obtained.

16:45 **Using Terahertz Time-domain Spectroscopy To Measure Coating Thickness On Li-ion Electrodes** **Mo-PM2-2-3**

Faezeh Zarrin Khat[1]; Alasdair Pentland[1]; Carl Reynolds[2]; Emma Kendrick[2]; Philip F. Taday[1]
[1]1, Enterprise Cambridge Research Park, Cambridge; [2]University of Birmingham, Birmingham

Terahertz sensing is competently used in non-destructive testing such as paint coating inspection on the car bodies, plastic inspection etc. In this paper, for the first-time, terahertz spectroscopy is applied to inspect cathodes in battery manufacturing process. A terahertz signal distribution across a cathode detect a defect in the cathode coating on the edge of the cathode. Also, the thickness of two lithium nickel manganese cobalt (NMC) cathodes are measured by a terahertz sensor and their thickness difference is reported.

17:00 **Terahertz Resonant Nano-spectrum Of Red Mineral Pigments** **Mo-PM2-2-4**

Xiaoqiuyan Zhang[1]; Tianyu Zhang[2]; Zhuocheng Zhang[2]; Xingxing Xu[2]; Feng Xiao[2]; Shigao Zhao[2]; Min Hu[2]
[1]No.2006, Xiyuan Ave, West Hi-Tech Zone, 611731, Chengdu; [2]No.2006, Xiyuan Ave, West Hi-Tech Zone, 611731
Current terahertz spectroscopy is limited by the diffraction limit, hindering its applications in material and biomedicine. Terahertz near-field nano-spectrum combines terahertz spectroscopy with scanning near-field optical microscopy to enable nanometer-scale imaging and spectroscopic studies. However, current systems have poor signal-to-noise ratios, and near-field responses of samples are obscured by stronger antenna resonance effects. This study proposes a probe-effects-free Terahertz Time-Domain Nano-spectrum methodology to distinguish intrinsic material responses and recognize different matters with nanometer spatial resolution. The method provides insights into the spectroscopic properties of various materials at the nanoscale, including molecular vibration of cinnabar and red lead in ancient fresco pigments.

17:15 **Dielectric Characterization Of Low-Loss Glasses And Polymers For 6G Microelectronic Packaging Applications** **Mo-PM2-2-5**

Min Zhai[1]; Pragna Bhaskar[2]; Haolian Shi[1]; Madhavan Swaminathan[2]; Alexandre Locquet[1]; David Citrin[1]
[1]2 Rue Marconi, Metz; [2]225 N Ave NW, Atlanta
Asahi EN-A1 alkali-free boroaluminosilicate glass as well as Ajinomoto Build-up Film (ABF) and ADFLEMA laminated on soda-lime float glass substrate, are characterized using a commercial terahertz time-domain spectroscopy (THz-TDS) system. The refractive index n(ν), attenuation coefficient α(ν), permittivity ε(ν), and loss tangent tanδ(ν) of EN-A1 glass as well as laminated ABF and ADFLEMA are n(EN-A1)=2.376, α(EN-A1)=31.1 cm-1, ε'(EN-A1)=5.64, tanδ(EN-A1)=0.062, n(ABF)=1.9, α(ABF)=30 cm-1, ε'(ABF)=3.8, tanδ(ABF)=0.072, and n(ADFLEMA)=2.79, α(ADFLEMA)=10 cm-1, ε'(ADFLEMA)=7.67, tanδ(ADFLEMA)=0.017, all at 1 THz. Both EN-A1 glass and laminated ABF and ADFLEMA seems to be low loss materials within THz frequency regime.

17:30 **Ultrathin MXene Assemblies Reaching Thin-film Absorption Limit In 0.5-10 THz** **Mo-PM2-2-6**

Tao Zhao; Hujie Wan; Tianpeng Ding; Peiyao Xie; Jinlin Xie; Min Hu; Xu Xiao
No.2006, Xiyuan Ave, West Hi-Tech Zone, Chengdu
We demonstrate that ultrathin 10.2-nm-thick (~Î»/30000) Ti3C2Tx MXene assemblies can reach the intrinsic thin-film absorption limit (50%) in the entirety of 0.5-10 THz. Such ultra-broadband absorption limit is attributed to the high concentration of free electrons (~10^21 cm^-3), short relaxation time (~10 fs), and unique intra- and inter-flakes (hopping) electron transport properties in Ti3C2Tx MXenes. Besides, we validate that the ultra-broadband THz absorption should be explained by alternating current impedance theory using the Drude-Smith model rather than classic direct current impedance matching. These findings presented here will stimulate more studies in broadband THz technologies with MXenes and beyond, which also provides an attractive route for developing compact, supercontinuum terahertz optoelectronic or photothermoelectric devices.

17:45 **Nonlinear Refractive Index Of Solids At THz Frequency** **Mo-PM2-2-7**

Soheil Zibod[1]; Ksenia Dolgaleva[2]
[1]25 Templeton Street, Room 344, Ottawa; [2]25 Templeton Street, Ottawa

We report on the nonlinear spectroscopy of crystalline quartz in the terahertz (THz) region. We observe that with increasing of the THz peak amplitude, the pulse experiences a larger delay in travelling through the sample. We estimate a nonlinear refractive index of the order of 10^-13 m2/W, which is several orders of magnitude larger than the typical values for nonlinear refractive indices of solids in the visible region. Furthermore, a negative fifth-order susceptibility of the order of 10^-30 m4/V4' is measured. In the second part, we present a simple method to model the propagation of a broadband THz pulse in a nonlinear medium with nonlinear refractive index dispersion using a spectral solution to the wave equation based on Fourier analysis. This method is a useful tool to investigate the effects of the nonlinear dispersion on the propagation of ultrashort THz pulses in a straightforward fashion. Furthermore, based on the same model, we derive an expression to extract the nonlinear refractive index dispersion for broadband sources and compare it with the approximate methods previously proposed: monochromatic approximation and sharp-resonance approximation. We perform a simulation on a sample with an arbitrary dispersion for nonlinear refractive index, and successfully extract the dispersion from the simulated propagation output.

16:00 - 18:00 **Condensed Matter I** **Cartier II**

Chairperson(s): Mischa Bonn,

16:00 **Observation Of Terahertz Spin Hall Conductivity Spectrum In Bulk GaAs At Room Temperature** **Mo-PM2-3-1**

Tomohiro Fujimoto; Takayuki Kurihara; Yuta Murotani; Natsuki Kanda; Tomohiro Tamaya; Changsu Kim; Jun Yoshinobu; Hidefumi Akiyama; Takeo Kato; Ryusuke Matsunaga
5-1-5 Kashiwanoha, Kashiwa

We investigated ultrafast dynamics of light-induced anomalous Hall conductivity in a bulk semiconductor GaAs at room temperature using a circularly polarized near-infrared pump pulse and a terahertz (THz) probe pulse. Polarization rotation of the THz pulse was observed as a manifestation of the inverse spin Hall effect (ISHE) for optically injected spin-polarized carriers. The spin Hall conductivity spectrum is experimentally evaluated for the first time and shows excellent agreement with the microscopic theories of ISHE, demonstrating that the extrinsic impurity scattering dominates ISHE in the DC limit, whereas the intrinsic Berry-curvature mechanism becomes dominant for THz frequency. Our study paves a way toward ultrafast study of spin Hall effect with quantitative analysis of spin Hall conductivity spectrum.

16:30 **Optical Pump THz Probe Spectroscopy On Metal-Organic Frameworks** **Mo-PM2-3-2**

Jens Neu[1]; Sarah Ostresh[2]; James Nyakuchema[3]; Jier Huang[4]
[1]210 Avenua A, Room 324, Denton; [2]225 Prospect Street; [3]Milwaukee; [4]Chestnut Hill, MA

Optical Pump THz Probe (OPTP) Spectroscopy is an outstanding technique to understand photoconductivity in emerging materials. We utilized OPTP to explore the photoconductivity in porous crystalline metal-organic frameworks. The OPTP results agreed with catalytical activity measurements and demonstrate that the catalysis in this material is more determined by photoconductivity than by usual catalytic chemistry.

16:45 **Investigating The Effect Of Crystal Morphology On Optoelectronic Properties Of Zinc Phosphide Thin Films Via Optical-pump Terahertz Probe Spectroscopy** **Mo-PM2-3-3**

Yinghong Huang[1]; Xinyun Liu[1]; Rajrupa Paul[2]; Elias Stutz[2]; Mahdi Zamani[2]; Djamshid Damry[1]; Léa Buswel[2]; Simon Steinvall[2]; Jean-Baptiste Leran[2]; Mirjana Dimitrievska[2]; Anna Fontcuberta i Morral[2]; Jessica Boland[1]
[1]Oxford Road, Manchester; [2]1015, Lausanne

Zinc phosphide (Zn3P2) is a promising earth-abundant material for solar cell applications but calls for the further understanding of its optoelectronic properties. In this work, we perform contact-free and noninvasive optical-pump terahertz probe (OPTP) spectroscopy on various Zn3P2 thin film samples and extract the crucial material properties -- carrier lifetime and mobility - that dominate the electron transport and device performance, from the OPTP THz radiation response.

17:00 **Ultrafast THz Dynamics Of Photocarriers In CsPbBr3 Microcrystals** **Mo-PM2-3-4**

Sheng Lee; Kyeongdeuk Moon; Muhammad Shoaib; Seokhyoung Kim; Tyler Cocker
East Lansing

We study the ultrafast dynamics of photoexcited charge carriers in micron-scale single crystals composed of the inorganic perovskite CsPbBr3 with time-resolved THz spectroscopy. Exciting with photon energy close to the band edge, we find that a fast (< 10 ps) decay emerges with increasing fluence and decreasing temperature, dominating the dynamics at 4 K. This behavior is well explained by Auger recombination. The THz photoconductivity resembles a Drude response, yet an additional Lorentz component due to an above-bandwidth exciton resonance is needed to satisfactorily reproduce the data.

17:15 **Bandwidth-Activated Anharmonic Coupling** **Mo-PM2-3-5**

Megan Nielson; Lauren M. Davis; Aldair Alejandro; Brittany Knighton; Claire Rader; Jeremy A Johnson
BNSN C100 BYU, Provo

We examine nonlinear excitation pathways of CdWO4 using two-dimensional terahertz (THz) spectroscopy. We identify two anharmonic couplings occurring within the crystal and create a framework for identifying couplings in other crystalline materials. We use modeling to show that the THz bandwidth itself can activate otherwise inefficient anharmonic couplings.

17:30 **Probing How Dynamics, Disorder And Temperature Influence The Vibrational Spectra Of Molecular Crystals** **Mo-PM2-3-6**

Andrew Burnett; Calum Towler; John Kendrick
School of Chemistry, Woodhouse Lane, Leeds

It has long been known that THz spectra of molecular crystals is very sensitive to the long-range structure of these materials. Here using a combination of

measurement and calculations based on Density Functional Theory we explore how spectra of these materials are influenced by temperature, molecular dynamics and disorder within the crystalline environment, and in many cases, how these effects are crucial to spectral interpretation.

17:45 **Accounting For Nonlinear Photoconductivity In Time-Resolved Terahertz Spectroscopy** **Mo-PM2-3-7**

Leya Lopez[1]; J. Steven Dodge[2]; Derek G. Sahota[2]
[1]8888 University Dr, Burnaby; [2]8888 University Dr W, Burnaby

We examine a procedure that is commonly used to determine the photoexcited conductivity from time-resolved terahertz spectroscopy measurements. We show that this procedure introduces large systematic errors when the photoconductivity has a nonlinear dependence on the excitation density, and we show how to account for this in the case of a saturable nonlinearity. We calculate the reflection amplitude of a medium with a saturable photoconductivity, discuss its general features, and show how the nonlinearity appears in a conventional analysis. We show how to derive the surface photoconductivity from measurements of the reflection amplitude as a function of incident pump fluence.

16:00 - 18:00 **Quantum-Cascade Lasers II** **International I**

Chairperson(s): Miriam Vitiello,

16:00 **Quantum-cascade Lasers For Terahertz High-resolution Spectroscopy** **Mo-PM2-4-1**

Xiang Lu[1]; Benjamin Röben[2]; Klaus Biermann[1]; Lutz Schrottke[1]; Jente Wubs[3]; Uwe Macherius[3]; Klaus-Dieter Weltman[3]; Jean-Pierre H. van Helden[3]; Holger T. Grahn[1]
[1]Hausvogteiplatz 5-7, Berlin; [2]Abbestraße 2-12, Berlin; [3]Felix-Haussdorff-Str. 2, Greifswald

We have developed terahertz (THz) quantum-cascade lasers (QCLs) based on GaAs/AlAs heterostructures for the application-defined emission frequencies of 3.36, 3.92, and 4.75 THz, which correspond to fine-structure transitions of Al atoms, N+ ions, and O atoms, respectively. These THz QCLs can be operated in a mechanical cryocooler in continuous-wave mode, while a sufficient intrinsic tuning range of more than 5 GHz is maintained. This allows them to be implemented as local oscillators in airborne astronomical instruments and as radiation sources for high-resolution absorption spectroscopy to determine absolute densities of atoms and ions in plasmas.

16:30 **Five-Stack Heterogeneous Terahertz Quantum Cascade Laser For Ultra-Broadband Emission** **Mo-PM2-4-2**

Michael Jaidl[1]; Maximilian Beiser[2]; Miriam Giparakis[2]; Martin A. Kainz[1]; Dominik Theiner[1]; Benedikt Limbacher[1]; Marie C. Ertl[1]; Aaron M. Andrews[2]; Gottfried Strasser[2]; Juraj Darmo[1]; Karl Unterrainer[1]
[1]Gusshausstrasse 27-29, Vienna; [2]Gusshausstrasse 25a, Vienna

We present the design, fabrication and characterization of a heterogeneous

terahertz quantum cascade laser consisting of five individual active regions emitting at different wavelengths. The combination of these five designs in a single structure leads to ultra-broadband emission covering 2.6 THz between 1.9-4.5 THz, which corresponds to 1.37 octaves. The devices work in pulsed and continuous-wave operation, showing maximum operating temperatures of 143 K and 58.5 K, respectively. The former is a record value for heterogeneous terahertz quantum cascade lasers. In continuous-wave operation, peak output powers of 800 μW are detected.

16:45 **Integration Of A 2.1-THz Quantum Cascade Laser Within An IEEE WM-130 Rectangular Metallic Waveguide** **Mo-PM2-4-3**

Mohammed Salih[1]; Sanchit Kondawar[1]; Nick Brewster[2]; Lianhe Li[1]; Edmund Linfield[1]; Hui Wang[2]; Peter Huggard[2]; Joshua Freeman[1]; Daniel Gerber[2]; Alexander Valavanis[1]
[1]Woodhouse, Leeds; [2]Harwell Campus, Didcot

We have demonstrated the first integration of a THz QCL within a rectangular waveguide meeting the IEEE 1785.1-2012 standard. The single-mode emission, within the 1400--2200 GHz bandwidth of the waveguide, and the single-lobed, narrow far-field emission indicate that the waveguide is operating within its intended fundamental mode. This underpins the capability for future development of fully integrated receiver systems, in which a QCL local oscillator will be coupled with a mixer for satellite radiometry applications.

17:00 **Optical Beatnote Detection From A Portable THz QCL Comb At 80 K By Direct Free Space Mixing In A High-frequency Hot Electron Bolometer** **Mo-PM2-4-4**

Sara Cibella[1]; Guido Torrioli[2]; Pasquale Carelli[2]; Alessandro Gaggero[2]; Ennio Giovine[2]; Filippo Bolli[3]; Urban Senica[4]; Mattias Beck[4]; Jerome Faist[4]; Giacomo Scalari[4]
[1]Via del Fosso del Cavaliere 100, via del fosso del cavaliere 100, Rome; [2]IFN-CNR, via del fosso del cavaliere 100, roma; [3]University of Rome Torvergata, Via del Politecnico 1, rome; [4]Auguste-Piccard-Hof 1 8093 Zürich, Schweiz, Zürich

We present optical beatnote detection from a THz QCL comb operating at 80 K in a small nitrogen-cooled dewar. The 21.7 GHz comb beatnote is detected by downconversion, directly mixing free-space signals from the QCL and a microwave synthesizer onto an NbN HEB optimized for RF frequencies. The setup constitutes a very convenient platform for the study of QCL-based optical frequency combs and a building block for compact, portable frequency comb fast spectrometers.

17:15 **Strongly Modulated Quantum Cascade Lasers For Broadband And Fast Doppler-Based FTIR Spectroscopy** **Mo-PM2-4-5**

Alessio Cargioli[1]; Diego Piciocchi[1]; Mathieu Bertrand[1]; Sargis Hakobyan[2]; Richard Maulini[2]; Stéphane Blaser[2]; Tobias Gresch[2]; Antoine Muller[2]; Jerome Faist[1]
[1]Auguste-Piccard-Hof 1; [2]Avenue des Pâquiers 1

The possibility of making reliable, fast and broadband spectroscopy in the Mid-

IR region is extremely appealing, and it goes in hand with the availability of suitable light-sources. Here we prove that, by strongly RF modulating a Mid-Infrared Quantum Cascade Laser at low injection frequency compared to its natural repetition frequency it is possible to double its emission bandwidth up to 250cm^-1. In addition, we show it can be used in combination with a Doppler based FTIR, opening the possibility to fast and broadband FTIR spectroscopy.

17:30 **QCL-based THz Optical Wireless Communication Link** **Mo-PM2-4-6**

Alessia Sorgi[1]; Marco Meucci[1]; Ali Umair[1]; Francesco Cappelli[1]; Leonardo Viti[2]; Miriam Serena Vitiello[2]; Jacopo Catani[1]; Luigi Consolino[1]
[1]via Nello Carrara 1, Sesto Fiorentino; [2]Piazza San Silvestro 12, Pisa

In order to target high data-rates (1Tbps) with low latency (< 10 ms), THz frequency range seems to be the proper choice, allowing a higher carrier frequency with respect radio frequency (RF) or millimeter wave (mmWave) ranges, conventionally used in broadcasting methods. Furthermore, THz free space optical communication (FSOC) links are particularly interesting in harsh and industrial environments due to the larger wavelength which make the communication resistant to scattering with respect to near-IR and visible frequency ranges. Despite the growing interest, THz wireless communication (TWC) compact and reliable solutions have been realized especially in the sub-THz band (0.3- 0.6 THz), that can still benefit of electronic devices for both the source and the receiver. Up to now, TWC in the 2-5 THz band has been performed using quantum cascade lasers (QCLs) and quantum well infrared photodetectors (QWIPs) both requiring strong cryogenic cooling. Here we present the first cryogen-free realization of a Free Space Optical Communication (FSOC) link based on a 2.83 THz QCL, cooled by a transportable closed-cycle cryostat, and a Graphene-based field-effect transistor (GFET) as the room-temperature receiver.

17:45 **Broadband Antenna-coupled THz Quantum Cascade Laser Frequency Combs With Inverse-designed Waveguide Facets** **Mo-PM2-4-7**

Urban Senica; Sebastian Gloor; Paolo Micheletti; Mattias Beck; Jérôme Faist; Giacomo Scalar
Auguste-Piccard-Hof 1, Zurich

We present a broadband, monolithic outcoupler based on planarized double metal waveguides that addresses both the reflectivity design and broadband narrow beam emission in THz quantum cascade lasers. The waveguide mirror reflectivity can be adjusted by shaping the end facet, obtained with an efficient inverse design algorithm. The THz laser radiation is coupled to a broadband patch-array antenna for surface emission. All the components are optimized for octave-spanning spectra between 2-4 THz. We implement these concepts to demonstrate a broadband surface-emitting THz quantum cascade laser frequency comb featuring output powers of 13 mW, optical bandwidths in excess of 800 GHz and a single-lobed far-field pattern with a beam divergence below (20° x 20°).

16:00 - 18:00 Telecom 2 **International II**

Chairperson(s): Paul Goldsmith,

16:00 **Absolute Security With Diffraction Grating In Terahertz Communication Links** **Mo-PM2-5-1**

Yaseman Shiri[1]; Chia-Yi Yeh[1]; Zhaoji Fang[1]; Rabi Shrestha[1]; Hichem Guerboukha[1]; John Malowicki[2]; Ngwe Thawdar[2]; Daniel Mittleman[1]
[1]School of Engineering, 184 Hope Street, Providence; [2]26 Electronic Pkwy, Rome

We realize a new approach to absolute security by constructing and testing a point-to-point line-of-sight (LOS) outdoor link at 200 GHz. With a diffraction grating placed at an intermediate focus immediately after an emitter horn antenna we can engineer frequency-varying nulls that create blind regions in space where an eavesdropper is unable to detect at least one of the frequency channels, satisfying the security condition for absolute security. By measuring power and bit error rate at 41 different frequencies, we demonstrate a shift in nulls with each frequency and verify a bit error rate greater than 0.5 on the nulls.

16:15 **Load Analysis Of Wireless Backhaul Links At 300 GHz** **Mo-PM2-5-2**

Bo Kum Jung; Thomas Kürner
Schleinitzstraße 22, Braunschweig

Beyond 5G, wireless backhaul links are expected to be more frequently utilized due to their economic and practical advantages over fiber connections. The feasibility of high data rate transmission at 300 GHz for backhaul links has already been demonstrated at the link level. This study shows that the THz backhaul links can support future the seamless data transmission of the highly aggregated users' data traffic in densely populated areas.

16:30 **TeraHertz Vs Microwaves Ray-Launching Model In A 0.45 THz Indoor Wireless Scenario** **Mo-PM2-5-3**

Leyre Azpilicueta[1]; Alper Schultze[2]; Mikel Celaya-Echarri[1]; Fidel A. Rodríguez-Corbo[3]; Christopher Sumner[4]; Morgan Dryhurst[4]; Raed. M. Shubair[5]; Francisco Falcone[1]; Miguel Navarro-Cia[4]
[1]Av. Cataluña, s/n; [2]Einsteinufer 37; [3]Av. Eugenio Garza Sada 2501 Sur; [4]Edgbaston Campus; [5]Saadiyat Marina District

Ray tracing is the gold standard for microwave channel modelling. The lack of a comprehensive material library and ray tracing implementations capturing both surface scattering and atmospheric absorption represent a barrier for the use of ray tracing at millimeter-waves (mmw) and TeraHertz (THz). We report here a ray-launching algorithm implementation that includes a library of microwaves-to-THz material properties, surface scattering and atmospheric absorption that enables us to benchmark a 0.3 THz experimentally-validated THz ray-launching model against a microwaves one in the context of a meeting room 0.45 THz wireless system.

Continuous Asymmetric Beam Steering With A Reconfigurable Intelligent

16:45 **Surface In The Ka-Band At 31 GHz** **Mo-PM2-5-4**

Alexander Wolff[1]; Lars Franke[2]; Steffen Klingel[2]; Janis Krieger[2]; Lukas Mueller[2]; Ralf Stemler[2]; Marco Rahm[2]
[1]Paul-Ehrlich-Strasse 11, Kaiserslautern; [2]Paul-Ehrlich-Strasse 11

We present a reconfigurable metasurface for continuous asymmetric beam steering based on a patch antenna unit cell. A switching element in the unit cell allows for continuous phase shifting of the reflected wave between 0Â° and 180Â°. This continuous phase adjustment enables asymmetric far-field beam shapes with a global maximum at any desired deflection angle up to 65Â°. We experimentally implement such a RIS module and demonstrate beam steering of a normally incident beam.

17:00 **Rough Surfaces Scattering And Mobility-Resilient Terahertz Wireless Links** **Mo-PM2-5-5**

Ruiyi Shen; Yasaman Ghasempour
41 Olden St, Engineering Quadrangle, Princeton

We present a new perspective on the impact of diffuse scattering from rough surfaces on the resilience of wireless links against node mobility. We provide a theoretical model and conduct over-the-air experiments using commonly available indoor and outdoor surfaces. Our results show that non-line-of-sight links off of rough surfaces are more resilient toward mobility, albeit at the cost of a lower peak signal-to-noise ratio.

17:15 **An 83.2 Gbps SISO Wireless Communication System Utilizing Polarization And Frequency Division Multiplexing** **Mo-PM2-5-6**

Zheng Wang; Haoyi Cao; Weipeng Wang; Hongxin Zeng; Lin Huang; Ziqiang Yang; Yaxin Zhang
Qingshuihe Campus of UESTC, No.2006, Xiyuan Avenue, Chengdu

All-solid-state electronic communication system is an essential method to achieve terahertz communication, but the maximum transmission rate of a single channel will be limited by the operating bandwidth of RF components and the sampling rate of AD/DA. In this paper, a terahertz communication system is proposed, which combines frequency division multiplexing (FDM) and polarization multiplexing techniques to realize four-channel communication transmission in SISO. The system uses duplexer and ortho-mode transducer (OMT) to ensure independent transmission of four channels. With the 16-QAM modulation, the total communication rate reaches 83.2 Gbps (20.8 Gbps per channel), and a demonstration experiment at a distance of 1.5 m indoor is realized, with SNR all greater than 20 dB and BER lower than 1e-9.

17:30 **The Multipath Propagation Characteristics Of THz In Indoor Test-Room Environments** **Mo-PM2-5-7**

Jong Ho Kim[1]; Jinhyung Oh[1]; Jang Seok Choi[2]; Jae Ho Seok[2]
[1]218 Gajeong-ro, Yuseong-gu, Daejeon; [2]767 , Bitgaram-ro, Naju-si, Jeollanam-do

THz wireless system can replace the wire system, because it has hundreds of Gbps with low latency. Especially, when it uses at very short distance of wireless link, THz is an excellent choice. But multipath propagation of given environments limits the upper transmission rate due to inter-symbol

interference by delay spreads. In this paper, power delay profiles were measured in indoor test-room environments at 285 GHz with 20 GHz bandwidth, and submitted characteristics of propagation.

17:45 **Analysis Of Radio Propagation Characteristics In Data Center Environment With Rack In Terahertz Band** **Mo-PM2-5-8**

Jinhyung Oh[1]; Jong Ho Kim[1]; Jang Seok Choi[2]; Jae Ho Seok[2]
[1]Ga-jeong ro 218, Yu-seong gu, Daejeon; [2]Bitgaram-ro 767, Naju-si, Jeollanam-do

In this paper, we derive propagation channel characteristics such as relative received power and R.M.S. delay spread coefficient for wireless communication in a data center environment where server racks are located at 285GHz band. By measuring in consideration of various types of obstructions and different antenna beam widths, we tried to find out in detail the characteristics of the propagation channel when performing wireless communication using terahertz in a data center.

18:00 - 19:30 **Poster Session 1** **Foyer (3rd floor)**

6G Communications Push For Effective THz Sensing Technology: MOSFET Rectification Model Needs To Be Refounded **Mo-P1-01**

Fabrizio Palma[1]; Renato Cicchetti[2]; Stefano Perticaroli[3]; Orlandino Testa[2]
[1]Dip. DIET, Università di Roma La Sapienza, v. Eudossiana 18, Roma, 320 4357 257, Roma; [2]Rome University La Sapienza, Dip. DIET, Università di Roma La Sapienza, Roma; [3]Roma, Italy, Roma

CMOS technology can easily handle the modulation/demodulation process of a RF signal, but cannot reach, at least today, bands toward 1 THz. For this reason, there has been great interest in evaluating the intrinsic rectification process that occurs in a metal oxide semiconductor field effect transistor (MOSFET) structure. Recent results showed that high detection velocity can be achieved using a device with proper detection architecture. These results, combined with the intrinsic low cost of the CMOS technology, allows to foreseen this as a suitable solution for the large market of the future 6G communication systems. The MOSFET detector is studied by TCAD simulations, and its characteristics explained following the self-mixing model. Numerical results show a new picture of the device functioning, giving a new description of its external response. The knowledge of the self-mixing mechanisms allowed to achieve an accurate design of an array of 64 rectifiers, each one integrated with a suitable printed antenna.

Novel 0.22-THz Extended Interaction Oscillator Based On The Four-Sheet-Beam Orthogonal Interconnection Structure **Mo-P1-02**

Zhenhua Wu; Jielong Li; Diwei Liu; Wei Wang; Zongjun Shi; Renbin Zhong; Kaichun Zhang; Min Hu; Zhaoyun Duan; Yanyu Wei; Yubin Gong; Shenggang Liu
UESTC, Chengdu, China, Chengdu

This paper presents a novel high-frequency structure. Four conventional ladder line slow-wave structures are placed vertically to form a four-sheet-beam orthogonal interconnection structure that considerably increases the coupling efficiency between the cavities, improves output power and efficiency, and interacts perfectly with the TM81 mode. In this study, the dispersion characteristics and characteristic impedance are studied through numerical and simulation calculations, and the optimal working parameters are analyzed using PIC software. Next, a 0.22-THz extended interaction oscillator based on four-sheet-beam orthogonal interconnection structure is designed. Simulation results show the achievement of the output power of 0.22-THz wave over 500 W with four sheet beams at 16.6 kV and each current of 0.8 A. This novel structure provided an alternative for the development of terahertz extended interaction oscillators.

Selecting Hazelnuts By Coupling A Self-organizing Map (SOM) And An Experimental System Operating In Transmission Configuration. **Mo-P1-03**

Manuel Greco[1]; Sabino Giarnetti[2]; Emilio Giovenale[3]; Andrea Taschin[3]; Luca Senni[3]; Fabio Leccese[1]; Andrea Doria[3]

[1]Via della Vasca Navale, 84, Roma; [2]Via Casamari, 6, Via Marentino, 134, Roma; [3]Via Enrico Fermi, 45, Frascati

An experimental setup operating in transmission mode in the frequency range between 18 and 40 GHz is described. This study shows how the system is able to distinguish healthy and rotten hazelnuts. In addition, a Self-Organizing Map (SOM) trained with the Kohonen algorithm was used to classify the hazelnuts according to their quality.

Phase-sensitive Silicon CMOS TeraFETs **Mo-P1-04**

Michael Shur[1]; Xueqing Liu[2]; Trond Ytterdal[3]

[1]9433 van Arsdale Drive, 9433 van Arsdale Drive, Vienna; [2]Rensselaer Polytechnic Institute, 9433 van Arsdale Drive, Troy; [3]s O.S. Bragstads PlassAddress: N-7491, Trondheim

Short channel Si CMOS could detect both the intensity and phase of the impinging THz or sub-THz radiation enabling line-of-sight detection and spectroscopic operation. The phase control is also crucial for phase-synchronized TeraFET arrays. We introduce and calculate the characteristic phase control frequency for silicon NMOS as a function of the channel length. The response depends on the effect of momentum, relaxation time, and the viscosity of the electronic fluid. Parasitic elements such as source and drain series resistances, fringing gate capacitances, and scattering at the contacts also play an important role. Our analysis for 20nm, 65nm, and 130 nm technology nodes shows that Si NMOS could detect the phase of impinging THz radiation in the broad frequency range (from ~ 100 GHz (for 130 nm technology) to approximately 10 THz (for 20 nm technology) via the interference of the plasmonic oscillations propagating from the source and drain sides of the channel. This conclusion is confirmed by the simulation of the spectrometer response for 20 nm and 130 nm Si NMOS. These results could guide the development of future generations of Si sub-THz and THz phase-sensitive photodetectors.

All-printable And Mechanically-aligned Broadband Image Sensor Array Sheets **Mo-P1-05**

Yuto Matsuzaki[1]; Daiki Sakai[1]; Yuto Aoshima[1]; Daiki Shikichi[1]; Raito Ota[1]; Satsuki Yasui[2]; Kou Li[2]; Yukio Kawano[1]
[1]1-13-27, Kasuga, Bunkyo-ku; [2]2-12-1, Ookayama, Meguro-ku

This work develops all-printable carbon nanotube film-based ultrabroadband (millimeter-wave--infrared light) imager sheets. Mechanical alignment of each device material allows high-yield image sensor integration and printing conditions govern the fundamental device performances.

All-printable Stretchable Broadband Photo-thermoelectric Camera Sheets **Mo-P1-06**

Daiki Sakai; Yuto Aoshima; Yuto Matsuzaki; Kou Li; Yukio Kawano
1-13-27 Kasuga, Bunkyo-ku

This work successfully develops all-printable photo-thermoelectric broadband infrared rays (IR) to millimeter-waves (MMW) imagers. The device consists of flexible carbon nanotube (CNT) film channels and exhibits highly efficient absorption characteristics in broad IR--MMW regions. The use of ink-jet printing in the device fabrication allows mechanical alignment of each device component material. Each half region of the originally P-type CNT film channel is chemically doped into N-type, and the PN junction corresponds to the photodetection interface. The use of the enriched CNT solution, which is suitable for the printing process, exhibits sensitive photo-detection, and this work also successfully demonstrates the fundamental IR imaging inspection application with the all-printed imager.

Design Of A Circular Electron Injection Electron Optical System For 0.34 Terahertz Traveling Wave Tube **Mo-P1-07**

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This paper introduces an electron gun suitable for 0.34THz traveling wave tube, and realizes long-distance transmission under periodic focusing system. The electron gun produces a circular beam with a radius of 0.185mm at the waist, which can be transmitted by a periodic focusing system for 18 mm. The simulation results show that the electron beam produced under this system is transmitted in a cyclic manner, the voltage is 21.8kV, and the electron circulation rate reaches 100%.

A WR-3 Full Band Frequency Tripler Based On Planar Schottky Diode **Mo-P1-08**

Jianghua Yu; Yazhou Dong; Hongji Zhou; Hailong Guo; Jun Zhou; Yaxin Zhang
Chengdu China

In this paper, we present the design of a high-efficiency multi-core square layout tripler based on GaAs monolithic technology to cover the full frequency band of the WR-3 waveguide. The tripler has been accurately simulated using

the HFSS and ADS softwares. The simulation results demonstrate that the frequency tripling efficiency in the full frequency band can reach more than 4% when the input power is 200 mW, with an output power of more than 8 mW. The highest efficiency is 9%.

Numerical Research On Multi-objective Optimization Of Vacuum Electronic Devices Based On G-NSGA-II **Mo-P1-09**

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In order to solve the multi-objective optimization problem of high-power microwave devices, the g-NSGA-II algorithm based on electromagnetic particle simulation is proposed on the basis of the second generation non-dominated sorting genetic algorithm (NSGA-II). Moreover, the optimization objective functions of power and spectrum of high-power microwave devices are proposed. The algorithm is used to simultaneously optimize the two objectives of the relativistic return wave tube (RBWO): the output power and the spectrum within the specified frequency band. The optimization results show that the g-NSGA-II algorithm can obtain higher average output power and relatively pure spectrum in the specified frequency band, and has good optimization ability, and can effectively solve the multi-objective optimization problem of high-power microwave devices.

THz Detection In P-Type FETs **Mo-P1-10**

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The paper describes an experimental study on p-type field effect transistors (pFETs) working as detectors of THz radiation. These detectors have been rarely presented in the literature so far. The silicon p-type Junctionless FETs and pMOSFETs with patch antennas were fabricated in a technology similar to the SOI CMOS process. They were measured in 316 - 360 GHz EM radiation band. The focal point was visualized with a 32x32-pixel camera. The detectors were mounted on motorized stage and the maximum photoresponse was reached. P-type detector responsivities and S/N ratio were measured using lock-in technique and compared with parameters of n-type FETs with the same layout. The pJLFET and pMOSFET signal values were positive and significantly lower than for the nFETs. The photoresponse characteristics of both p-type FETs vs. gate bias were found to be analogous to those of n-FET detectors. The similarity of the characteristics suggests that a similar THz detection mechanism is expected in p- and n-type of the detector. A possibility of increasing the photoresponse by forcing a small DC drain current was also investigated. P-type FET detectors can be used in applications where, for design reasons, it is desirable to use a complementary pair of the detectors.

Terahertz Detector Integrated With Photonic Crystals Waveguide On Chip **Mo-P1-11**

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Three channels of microbolometer terahertz (THz) detectors integrated with silicon photonic crystal on the same chip was realized. This two-dimensional photonic crystal waveguide has the advantages of low transmission loss and wavelength division multiplexing. The photonic crystal waveguide was fabricated by MEMS technology, and it was packaged by the standard metal waveguide. The experimental results confirm the wavelength division multiplexing function of the waveguide, and it was also demonstrated that the coupling of terahertz signals with the microbolometer sensor was enhanced in a specific frequency band, making up for the shortcomings of the traditional free-space antenna coupled Nb5N6 microbolometer detector.

Study Of 0.65THz Extended Interaction Amplifier Based On Folded Waveguide Cavity **Mo-P1-12**

Yang Dong[1]; Jingyu Guo[2]; Shaomeng Wang[2]; Duo Xu[2]; Youfeng Yang[2]; Yuxin Wāng[2]; Yuxin Wang[2]; Yuan Zheng[2]; Ping Zhang[2]; Zhanliang Wang[2]; Yubin Gong[2]
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An extended interaction amplifier (EIA) based on folded waveguide cavity is proposed, which is designed to operate at 0.65 THz. The proposed EIA consists of four cavities all operating at 2ÃfÂ□? mode, and the whole length of the EIA is 17.0 mm. The particle-in-cell (PIC) results show that the output power can reach 1.32 W at 650 GHz with the input power of 1 mW, an ideal beam of 20 mA and 18.2 kV, conductivity of 2.5e7 S/m and a focusing magnetic field of 0.6 T. In addition, the output power is greater than 0.6 W from 648.8 GHz to 650.8 GHz with a 3dB bandwidth of 1.8 GHz.

A Full-band Tripler Based On A GaAs Monolithic For 460-700 GHz **Mo-P1-13**

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This article presents a full-band frequency tripler based on a 10 um thick GaAs single chip, designed for the frequency range of 460-700 GHz. The device achieves full-band output and utilizes "part-substrateless" technology, which significantly improves the coverage range of the output microstrip waveguide probes. Simulation results demonstrate that the device exhibits an overall efficiency of over 2% with an input power of 40 mW, and typical output power can reach approximately 1 mW.

Fabrication Error Study Of W-band Planar Beam-Wave Interaction Structure **Mo-P1-14**

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The beam-wave interaction structure is a crucial component for high-power compact THz sources. This paper presents the fabrication error study of a W-band (75-110 GHz) staggered double vane interaction structure. The simulation study of 0.1 THz staggered double vane structure (SDVS) has been carried out by COMSOL Multiphysics to analyze the effect of frequency shift due to the dimensional deviation and the effect of surface roughness on the power level of the wave in W-band. The analysis of frequency shift and other parameters have been studied for dimension deviation values ranging between 10-20 microns and the surface roughness ranging from 100-300 nm.

Terahertz Radiation Source Based On Two-stage Capillary Plasma Channel **Mo-P1-15**

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In this study, we propose a miniaturized design of terahertz radiation source based on electron beam-plasma interaction. The simple structure of the radiation source is consisted of a dielectric capillary with four electrodes, in which a two-stage plasma channel can be created by two-sectional neutral gas ionization. Simulation results shows that high-density electron beam can be drawn from the first-stage plasma and excite electromagnetic radiation in the terahertz band when it penetrates the second-stage plasma.

Crosstalk Resistant Integrated Uni-Traveling Carrier Photodetector **Mo-P1-16**

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Uni-traveling carrier (UTC) photodetectors are pivotal as photomixers in THz transmission systems owing to their high-speed and output power in the THz range. However, for an efficient transmitter, the laser, modulator, signal processing, and maybe even the amplification has to be integrated on the same chip. This might lead to problems with the thermal crosstalk induced by the thermally conductive chip components. Such crosstalk can severely reduce the performance of the UTC photodetector with regard to the dark current, bandwidth, and data transmission. Here, we show how a deep trench can reduce the thermal crosstalk for a UTC photodetector in densely packed circuits, which in turn reduces the dark current and device capacitance and thus, improves the performance.

Tunable Continuous-wave Terahertz Generator Based On Difference Frequency Generation With DAST Crystal **Mo-P1-17**

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A tunable continuous-wave (CW) terahertz (THz) source with DAST crystal via difference frequency generation has been demonstrated in this work. The THz tuning range was from 1.1 THz to 3 THz and the maximum output power of the THz wave was 2.58nW at 2.52THz. The output spectrum of the CW-THz source is in good agreement with the air absorption lines in Hitran database. The linewidth of the output THz wave was estimated to be 56.5 MHz based on gas absorption spectrum. Therefore, the CW-THz source will have good potential in THz high-precision spectroscopic detection and multi-spectral imaging.

Influence Of Current In The Spintronics Terahertz Emitter **Mo-P1-18**

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In this work, we mainly study on the influence of electric currents applied on the Spintronics terahertz emitter (STE) and the results can pave a way to the integration and manipulation of the STEs.

Electric Field Measurement For A 320GHz Wave By Rydberg-atom Based Sensor **Mo-P1-19**

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Research on Rydberg-atom based sensers, which realize the SI-traceable measurements for the electric field of Terahertz wave, have been started. The ladder-type EIT (Electromagnetically Induced Transparency) signals were observed by counterpropagating lasers of two distinct wavelength lasers corresponding to the S-P-D transitions of Cesium (Cs) atoms enclosed in a cylindrical glass cell. Irradiation of a 320GHz wave whose frequency matched the D-F transition then results in an observed Autler-Townes (AT) splitting of the EIT signals. The electric field strength was calculated by frequency measurement of the splitting separation.

Frequency Controlled Terahertz Wave Parametric Generation By A Spectral Drill Cavity **Mo-P1-20**

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We demonstrated terahertz wave parametric wavelength conversion between two frequency-controlled infrared beams and terahertz wave in a nonlinear crystal. The frequency stabilized pumping beam is amplified by an injection-seeded PPLN-OPG and KTA-OPA pumped by a Nd:YAG MOPA system. The seeding beam is stabilized 1.5 Î¼m beam as traceable to the national standard. The master laser of the MOPA system is a SLM Nd:YAG laser with duration of about 1 ns. The frequency of tunable seeding beam is monitored by using a "spectral drill" cavity. The cavity provides a continuous one-way sweep of the axis modes in a Fabry-PÃ©rot cavity without sweeping the cavity length. When a geometric phase shifter composed of fixed and rotating phase plates is

arranged within the cavity, the frequencies of the axis modes are controlled by the angle of the phase plate. The frequency of seeding beam is observed as intensity error signals. We used a nonlinear MgO:LiNbO3 crystal with a Si-prism as an efficient output coupler for the terahertz wave. The output terahertz wave was measured using a pyroelectric detector. We speculate that the frequency controlled terahertz wave could be powerful tools not only for solving real world but also fundamental physics.

High Peak Power Mid-infrared Optical Parametric Oscillator And Amplifier Based On BaGa4Se7 **Mo-P1-21**

Kai Chen[1]; Degang Xu[1]; Jining Li[1]; Kai Zhong[1]; Yuye Wang[1]; Jiyong Yao[2]; Jianquan Yao[1]

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In this work, we demonstrated a high peak power, high energy OPO-OPA system based on BaGa4Se7. Pumping by a 1064 nm laser, this system could achieve mid-infrared output with peak power of MW-level. The maximum output energy of 12.13 mJ/pulse was achieved at 3.89 Î¼m and the pulsed width of mid-infrared wave after OPA was 8.2 ns. No damage was observed on the surface of BGSe crystal in this work and the pump intensity could be further improved. By increasing the pump and seed energy, the output energy or peak power is expected to increase to twice of the results in this work.

Full-Wave Analysis Of A Complex Gyrotron Cavity With Coupled Smooth-Walled And Corrugated Resonators **Mo-P1-22**

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A full-wave analysis is used to investigate conversion of normal modes in a complex gyrotron cavity formed by coupled smooth-walled and corrugated cylindrical resonators. The analysis takes into consideration expansion of normal modes in terms of azimuthal harmonics. It is shown that the high-order azimuthal harmonics produce a minor effect on a pair of the second-harmonic operating modes of the complex cavity. The exception is a shift of the optimal corrugation depth, which provides the strongest coupling between the operating modes. It is found that the first-harmonic competing mode exhibits reduced purity and ohmic quality factor, which are caused by strong coupling between azimuthal harmonics due to the corrugations.

Calculation Model Of Klystron **Mo-P1-23**

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Abstract--In this paper, a large signal computation model of the beam-wave interaction in klystron is presented. This mode bases on the one dimensional electron disk model with considering the space charge. The motion of disks of

charge is tracked with time as the independent variable using Runge-Kutta integration. The simulation code named Kly_app has been compiled based on this model and it shows good agreement with the simulation results by AJDSIK. At the same time, Kly_app also adds simulated annealing algorithm for automatic optimization. Kly_app can be used in the large signal computer simulation of the beam-wave interaction in klystron. Keywords--klystron, beam-wave interaction, Runge-Kutta, Kly_app, AJDSIK, simulated annealing.

A Novel G-band Dual Sheet Beam Sine Waveguide Traveling-wave Tube **Mo-P1-24**

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This article introduces a new dual sheet beam (DSB) sine waveguide (SWG) traveling-wave tube (TWT) that operates in the terahertz band. The DSB SWG slow-wave structure (SWS) has flat dispersion in the 0.204 - 0.23 THz frequency range, enabling high frequency applications. The DSB SWG also shows a low loss of 6.7 dB in the 0.2 - 0.24 THz frequency range, indicating good signal transmission capabilities. The simulation results suggest that the DSB SWG TWT has excellent output power (>85 W) and gain performance (3 dB gain >26 GHz), making it a promising candidate for various applications in the terahertz frequency range.

Study And Design Of KFE Compact Gyrotron For KSTAR ECH System **Mo-P1-25**

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Korea Superconducting Tokamak Advanced Research (KSTAR) is planning to install an electron cyclotron (EC) system for a total of 6MW Radiofrequency (RF) output and is currently in progress. A total of 4 EC systems were installed in the 2022 KSTAR campaign, but only 2 EC systems are in operation. Both EC systems have a problem with the gyrotron and are currently being repaired. The 4 gyrotrons currently installed are 1MW, 105/140Ghz dual-frequency gyrotrons that can operate for up to 300 seconds. In the 2020 KSTAR campaign, an EC system called EC4 provided about 1450 shots to the tokamak. Of these, about 500 shots were used for start-up with a pulse length of less than 0.5 seconds. This is about 35% of the total shot. We conclude that it is inefficient to use a high-spec gyrotron for low power less than 500kW and short pulses. Therefore, we are developing a start-up gyrotron with an RF power of 500kW and a pulse length of less than 0.5 seconds. The design value was determined based on the specifications of the gyrotron, which are mainly required by KSTAR. We will explain the specifications of the Gyrotron for startups in this paper.

Study On Electromagnetic Characteristics Of Millimeter Wave Double Inner Conductor Bragg Structure **Mo-P1-26**

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Based on the theory of multimode coupling, the electromagnetic characteristics

of millimeter wave double internal conductor Bragg structure are studied by using the 3D electromagnetic simulation software CST. The results show that the dual-conductor Bragg structure can suppress the competitive mode compared with the coaxial Bragg structure, the reflectivity is stable and close to 1, and the electromagnetic characteristics of the symmetric structure is better than the asymmetric structure; With the increase of the distance between the double inner conductor and the coaxial axis, the frequency response bandwidth of the double inner conductor Bragg structure becomes wider, and when the inner conductor is far from the coaxial axis, the bandwidth becomes wider obviously, while the value of reflectivity tends to be stable. Therefore, selecting the millimeter wave double internal conductor Bragg structure can broaden its performance as a reflector or filter, improve the mode selectivity and mode purity, and improve the performance of the Bragg structure.

Investigation Of The Cause Of Two-beam Radiation In A Multi-frequency Gaussian Beam Output Gyrotron FU CW GVII **Mo-P1-27**

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A radiation pattern with two peaks was observed in the experiment of a multi-frequency Gaussian beam gyrotron FU CW GVII, which contains a mode converter designed for a co-rotating mode. To find out the cause of the two peaks, we investigated from both experimental and theoretical perspectives Experimentally, by changing the gun coil current to change the electron incident radius into the cavity, the intensity variation of the two peaks was observed. Theoretically, a code was developed to calculate the radiation pattern of the Gaussian beam converted from the counter-rotating mode. In result, the cause of the two peaks is that the co- and counter-rotating modes simultaneously oscillating in the cavity were independently converted into Gaussian beams by the mode converter, and then output from the window. It is indicated that even a mode converter designed for the co-rotating mode can convert the counter-rotating modes with small azimuthal number m into Gaussian beams.

Theoretical Study Of Losses In A 170 GHz Gyrotron with Confocal Resonator **Mo-P1-28**

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In this paper, ohmic loss and diffraction loss in a 170 GHz gyrotron with confocal resonator are introduced. Taking all the components of magnetic field into account, the ohmic loss of a 170 GHz confocal cavity gyrotron is investigated. The results show that the averaged ohmic loss densities on the confocal gyrotron have similar changes along with the axial direction in the cavity. The diffraction loss has different longitudinal distribution, and it's proportional to the power. The ohmic loss is found to be much smaller than the diffraction loss, so the corresponding quality factor is much larger. What's more, it's found that the width of mirror has little influence on the ohmic loss, while the diffraction loss is very sensitive to it.

Design Of A 28GHz Third Harmonic Gyrotron **Mo-P1-29**

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By using the self-consistence non-linear theory and stabilization theory, we have analyzed and designed a 28 GHz third harmonic gyrotron. Different factors including pitch factor and magnetic field are considered for attaining the highest at a beam voltage of 30KV and a beam current of 1.05A. The maximum output power of the gyrotron can reach 7.67kw with an efficiency of 24.36%.

Bowtie Loaded Meander Antenna With Asymmetric Multi-source Excitation **Mo-P1-30**

Mei Yu[1]; Jin Shi[2]; Weiwei Xu[3]; Huabing Wang[3]; Jian Chen[3]; Peiheng Wu[3]
[1]Seyuan Road 9, Nantong; [2]Seyuan Road 9; [3]Xianlin Avenue 163

For some applications the performance of the superconducting devices is limited by the fairly low impedance of the Josephson junction (JJ). Series JJ structure is a good choice to improve the impedance of the device so as to realize the impedance matching with the coupled antenna. Previously, we have proposed a novel antenna named bowtie loaded meander antenna for superconducting JJ devices. In this work, series simultaneous excitation in this antenna for series JJs is presented. The influence of asymmetric excitation on the antenna is mainly discussed at terahertz band. F-parameters, instead of S-parameters were introduced for the multi-source excitation. In addition, combined surface current distribution and radiation patterns are studied to characterize this multi-source excited antenna.

Effects Of Stoichiometric Ratio Of NbN Films On The Performance Of Hot Electron Bolometer Direct Detection **Mo-P1-31**

Hongkai Shi; Runfeng Su; Tao Xu; Yijun Zhe; Xiaoqing Jia; Lin Kang; Xuecou Tu; Jian Chen; Peiheng Wu
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The stoichiometric ratio of thin films may affect their electrothermal properties, thereby affecting the sensitivity of devices. We fabricated superconducting NbN/Nb5N6 hot electron bolometer terahertz detector using NbN films with different stoichiometric ratio. The current-voltage characteristics and terahertz response of the devices were preliminarily characterized. Next, we will further study the electrothermal properties of thin films and their impact on device performance.

Stabilization Of Lasing Frequency Of THz-QCLs In Free-running Using An External LED Light **Mo-P1-32**

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We are investigating long-term stabilization of terahertz quantum cascade lasers (THz-QCLs) which would be important for observations of spectral lines of astronomical or atmospheric molecules in future space missions. We have

already demonstrated consecutive phase-locking of a THz-QCL in ~8 days by suppressing a slow drift of the lasing frequency using an enclosure to prevent a water vapor adsorption on the laser device. We also confirmed ~35 consecutive days of frequency drift less than 10 MHz in free-running. In this measurement, we measured the lasing frequency in free-running hops by the ambient light. We suppressed this frequency hopping by continuously illuminating the device using a LED light. We have updated the record to two weeks using this system for a 3 THz-QCL.

MBE Growth Of 3 μM-thick InGaSb/AlInGaSb QCL Structures **Mo-P1-33**

Hiroaki Yasuda; Norihiko Sekine; Iwao Hosako
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We proposed the use of the InGaSb/AlInGaSb material system to improve THz-QCL performance. We performed molecular beam epitaxy (MBE) growth of 3 μm-thick InGaSb/AlInGaSb QCL structures on GaSb substrates. The threading dislocations were found locally. The dislocation density in the QCL layers increased compared to the samples with thinner QCL layers.

Sheet-Beam Higher Order Mode Extended Interaction Oscillator At 0.34THz **Mo-P1-34**

Jin Han[1]; Tianzhong Zhang[2]; Rongxing Zeng[2]
[1]Chengdu, Chengdu; [2]chengdu

In this paper, a sheet beam EIO operates in the TM31-2Ï? higher-order-mode to increase the cavity size which in turn increases the power-handling capability and relaxes the high machining-precision requirement at 0.34THz is designed. The best operating voltage and operating mode are obtained by analyzing the dispersion curve and R/Q competition in different modes. The PIC predicts the continuous wave output power of extended interactive oscillator tube at 0.34THz is 180.5W when the output is TE10 mode.

Additive Manufacturing And Characterization Of Hollow Core Metal And Topas waveguides For Sensor Systems **Mo-P1-35**

Abhijeet Shrotri[1]; Amlan kusum Mukherjee[2]; Sven Lohoefener[1]; Andre Springer[1]; Oliver Stuebbe[1]; Sascha Preu[2]
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Additive manufacturing provides a lucrative alternative for manufacturing of functional prototypes. This paper depicts the manufacturing and characterization of hollow core waveguide prototypes with circular cross-section using suitable metal and polymers for Terahertz sensing applications. These additively manufactured waveguide prototypes are characterized from 0.1 to 1.25 THz to evaluate the attenuation and coupling losses. The additively manufactured waveguides using stainless steel and TOPAS polymer material or combination of both of these materials yields a novel approach of cost-efficient manufacturing and testing of prototypes with expeditious errorelimination. These waveguide prototypes are applicable as a building block for disposable sensor systems applications such as in food industry, medicine and biotechnology.

Dielectric Properties Of Epoxy Composites Based On Ferroelectric And

MWCNTs At THz Frequency Range **Mo-P1-36**

Alexander Badin; Tatyana Shematilo; Victoria Moskalenko; Diana Pidotova; Daria Frolova; Kristina Lang; Grigorii Kuleshov
Lenina av.36, Tomsk

Results of research of dielectric properties of composite materials based on epoxy, BaTiO3 nanoparticles and multiwalled carbon nanotubes at 0.1--1.1 THz frequency range were presented. Influence of MWCNTs concentration in ferroelectric composite on dielectric properties is shown.

Terahertz Spectroscopy On CO2-CH4 β-hydroquinone Clathrate Replacement Reaction **Mo-P1-37**

Katharine Bancroft[1]; Johanna Koelbel[1]; Michael Ruggiero[2]; Daniel Mittleman[1]
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Gas clathrates contain more of the earth's hydrocarbon resources than all other forms combined, and therefore provide both a source of energy and an option for carbon sequestration. We performed a gas replacement reaction in hydroquinone clathrate in a high pressure cell, first creating a CO2 clathrate and then replacing the CO2 with CH4, and observed the spectra continuously throughout both reactions with terahertz time domain spectroscopy. The absorbance spectra show the initial enclathration phase transition and the replacement reaction from CO2 clathrate to CH4 clathrate.

THz Spectroscopy Of Cometary Simulants **Mo-P1-38**

Linus Stöckli; Mathias Brändli; Daniele Piazza; Rafael Ottersberg; Axel Murk; Antoine Pommerol; Nicolas Thomas
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A novel approach is reported to study the viability of applied THz spectroscopy to perform relevant in-situ measurements of cometary nuclei and other future space missions.

18:00 - 19:30 **Poster Session 2** **Foyer (4th floor)**

Quantification Of Anomalous Blueshifting With Increasing Temperature In The Terahertz Modes Of D-Glutamine **Mo-P2-01**

Thomas Sanders; Jackson Allen; Joseph Horvat; Roger Lewis
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New modes in the terahertz spectrum of D-glutamine have been found in the first low-temperature measurements. With a high-purity sample and temperatures as low as 6 K, eight intrinsic absorptions of D-glutamine in the frequency range below 4 THz have been identified. Tracking the frequency of the modes with temperature reveals anomalous blueshifting indicative of complex intermolecular hydrogen bond dynamics.

Nonlinear Study For Pair-Breaking In Superconducting Films Under Intense Terahertz Radiation **Mo-P2-02**

Jie Tian; Hao Zhang
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We study the effect of a strong and low frequency electrical field on a superconducting state. It is found that the superconducting gap decreases with the field intensity and wavelength. Physical mechanism for this dependence is the multi-photon absorption by a superconducting electron. By constructing the state of a superconducting electron dressed by photons, we determined the dependence of the superconducting gap on and temperature. We show that the critical temperature is determined by the parameter, which is distinct from that induced by the heating effect. The result is consistent with experimental findings. This result can be applied to study the terahertz (THz) nonlinear superconducting metamaterials.

Electro-Optical Determination Of The Spectral Characteristics Of Components For THz-based Plasma Diagnostic **Mo-P2-03**

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We will discuss a versatile Electro-Optical (EO) THz TDS spectrometer, realised to specifically target the measurement of materials and components of FIR and THz Plasma Diagnostics for Nuclear Fusion experiments, then show the main results achieved to date and the comparison with Photoconductive type spectrometry data.

The Method For Removing Splits In The Phase Singularity Of An Optical Vortex Generated By A Spiral Mirror **Mo-P2-04**

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This study discusses method for removing splits in the phase singularity of an optical vortex generated by the spiral mirror in the millimeter-wave regime from a numerical calculation perspective. The splits of the phase singularity occurs when the mirror surface has a structure where the height varies linearly with azimuthal angle θ. It is demonstrated that a new design method can eliminate the phase singularity split. This mirror surface is formed by satisfing the condition where the difference between the incident equiphase front of Gaussian beam and the desired reflected equiphase front of optical vortex is constant. Furthermore, this method can also generate optical vortices with arbitrary focal point.

Current Status Of The ECH Gyrotron System On The DIII-D Tokamak **Mo-P2-05**

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The ECH gyrotron system at DIII-D consists of five 110-GHz Communications and Power Industries (CPI) diode tubes with non-depressed collectors currently available for plasma experiments in the 2023 campaign. In addition, one recently repaired CPI gyrotron with a depressed collector has begun testing. The RF power is injected into DIII-D via four dual equatorial electron cyclotron (EC) launchers, as well as two top EC launchers. DIII-D is currently

preparing to design and install a fifth dual launcher and two transmission lines to accommodate new ITER-like, multifrequency gyrotrons in 2025

Rhodochrosite At High Temperatures: A Terahertz Perspective On Structural Dynamics **Mo-P2-06**

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Molecular orientations and structural distortions are the essential properties that enable us to understand how molecules respond to varying thermodynamic conditions of temperature (T) and pressure (P). The optimization of these properties under such conditions has repercussions in the field of geology and materials science. In this paper, we describe the comprehensive results of Terahertz (THz) and infrared (IR) spectroscopy on the naturally extracted mineral Rhodochrosite (MnCO3) at temperatures from ambient (25°C) to 800°C in the broad spectral range of 6.6 - 3000 cm-1. This study shows how molecule orientations and lattice modes affect bonding and structural properties under different thermodynamic conditions of T. Hence, the results of this study showed the importance of changes in lattice modes and molecule orientations, which are investigated using vibrational spectroscopic techniques and are in charge of bringing about structural phase transitions.

Further Optimization Of Resonant GHz Wave Absorption Coatings **Mo-P2-07**

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High power stray radiation is a problem that affects heating systems of fusion reactors. Due to the harsh environment in such a device an absorption mechanism was investigated in both experiment and modeling, which allows the use of thermically and chemically very stable ceramic coatings, while providing very good absorption. A transfer matrix model was designed to overcome the limitations of the previous model, which was shown to be consistent with both this and also measurements. This allowed for the optimization of both multi-layer coatings and the material proportions of compound materials. Estimates for material parameters depending on these proportions was provided for aluminum-titanium oxide compound materials at 170Ghz. It was shown, that both proportion optimization and multi-layer thickness optimization result in much better absorber coatings than single layer thickness optimization. Both advanced optimizations lead to a very similar improvement of absorption properties, the stacking order in the case of multi-layer materials was shown to be not a relevant factor.

Time Resolved Hyper-Raman Surface Spectroscopy Of (100) Silicon **Mo-P2-08**

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We performed time-resolved Hyper-Raman spectroscopy of a (100) silicon wafer upon its excitation by a near IR optical pulse. Upon excitation of the silicon wafer by the optical pulse, we record the broadening and increase of the Stokes and anti-Stokes bands centered around the Si lattice phonon and SiO2 mode centered at ~610 cm-1 and ~1100 cm-1, respectively. This unique technic

makes it possible to reveal the electron-phonon scattering which thermalizes the hot carriers with the lattice on time scale of 100 to 300 fs.

Terahertz And Dc Conductivity Of Pyrolyzed Photoresist Films **Mo-P2-09**

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Pyrolyzed photoresist films (PPFs), of 150 nm thickness were developed via vacuum annealing of a photoresist. The high frequency conductivity of PPF was investigated via contactless THz time-domain spectroscopy (TDS). The PPF sheet resistance was found to be comparable to that of CVD graphene. Our findings open a path for simple and scalable fabrication of graphitic-film-based high frequency nanocircuits.

Terahertz Time-Domain Spectroscopic Study Of Boson Peak Of Hydrogen-Bonded Glass-Forming Glycerol **Mo-P2-10**

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The universal excitation of glass, the boson peak (BP), was detected by terahertz time-domain spectroscopy in glassy glycerol, and the interaction between the BP and terahertz light was investigated. The BP frequency of the observed infrared spectra is about 1.4 times higher than that of the vibrational density of states spectra. Furthermore, the difference causes in the infrared light vibrational coupling constant (CIR(ν)), a linear behavior in the vicinity of the BP frequency. This behavior deviates from the CIR(ν) = A + Bν2 predicted by the Taraskin model and implies the need to modify the model.

Generation Of The THz Spin Current In Hematite Contributed By Spin Seebeck Effect **Mo-P2-11**

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The THz response provides deep insights into the study of spin injection in antiferromagnetic structures. The THz spin current can be generated in the Î±-Fe2O3/Pt structure via the ultrafast spin Seebeck effect. Compared with the prototype structure YIG/Pt for the ultrafast spin Seebeck effect, the spin current dynamics in the Î±-Fe2O3/Pt structure are faster. The distinct behavior in Î±-Fe2O3 may be attributed to the unexpected contributions from other mechanisms. Our finding is an important step towards a better understanding of THz current generation in antiferromagnetic structures.

Observation Of Anthracene Crystallization Under Irradiation Of Terahertz Free-Electron Laser **Mo-P2-12**

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Agulto[1]; Valynn Katrine Mag-usara[1]; Hiroshi Y. Yoshikawa[1]; Katsuo Tsukamoto[1]; Yuka Tsuri[2]; Goro Isoyama[3]; Takashi Onuma[4]; Ryutaro Shimada[4]; Tomohiko Tateshima[4]; Kazufumi Takano[5]; Yutaro Tanaka[1]; Shigeyoshi Usami[1]; Masayuki Imanishi[1]; Mori Yusuke[1]; Masashi Yoshimura[1]; Makoto Nakajima[1]
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We investigated the THz-FEL irradiation of a supersaturated solution of anthracene-cyclohexane and demonstrated the THz-FEL-induced crystallization of anthracene. A unique burst phenomenon was observed and found to be a precursor to the crystallization.

Temperature Dependence Of The Conductivity Of InSb Measured By Terahertz Time-Domain Spectroscopy **Mo-P2-13**

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[1]2-6 Yamadaoka, Suita; [2]Nirasaki; [3]Tempe, Arizona; [4]Bucharest-Magurele; [5]Fukui

In this study, we characterized the temperature-dependent electrical conductivity properties of undoped and lightly doped bulk InSb samples using terahertz time-domain spectroscopy. We obtained the permittivity spectra at low temperatures and analyzed the carrier density and mobility by fitting the spectra to the Drude model. Based on our analysis, we show the temperature dependence of the optical constants and explain the underlying physical mechanisms for the observed behavior. Our results provide important insights into the electronic properties of InSb.

A HEMT-embedded Metasurface For Terahertz Beam-Scanning Based On Amplitude-Phase Quantization Error Optimization **Mo-P2-14**

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Terahertz reconfigurable metasurfaces for beam steering have long-standing suffered from non-ideal amplitude and phase modulation. Herein, via an effective bottom-up solution combining optimizations of the array encoding efficiency and array-level coding, a 1-bit THz HEMT-controlled metasurface with minimized amplitude-phase quantization error and enhanced gain has been achieved.

Two-dimensional Niobium Carbide MXene, Nb2CTx: Intrinsic And Photoexcited Carrier Dynamics **Mo-P2-15**

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Garnering attention for high conductivity, nonlinear optical properties, and more, MXenes are water-processable 2D materials that are considered candidates for applications in electromagnetic interference shielding, optoelectronic and photonic devices among others. Herein we investigate the intrinsic and photoexcited conductivity in Nb2CTx, a MXene with reported high photothermal conversion efficiency. DFT calculations show that hydroxyl and/or fluorine-terminated Nb2CTx (Tx = OH or F) is metallic, in agreement with THz spectroscopy, which reveals the presence of free charge carriers that are highly localized over mesoscopic length scales. Photoexcitation of Nb2CTx, known to result in rapid heating of the crystal lattice, is found to produce additional free carriers and a transient enhancement of photoconductivity. Most photoexcited carriers decay over the sub-picosecond time scales while a small fraction remain for much longer, sub-nanoseconds, times.

Magnetostatic Field Assisted Tunability And Polarization Conversion In Patterned Graphene Terahertz Metamaterials **Mo-P2-16**

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Graphene metamaterials are ideal platforms for dynamically controlling THz waves due to their unique tunability and reconfigurability. However, most research focused on the electrostatic field based tuning method. Here, we numerically explored the distinct effect of external magnetostatic field on the transmission properties of patterned graphene metamaterials (SRR, H-shaped and eSRR-shaped resonators). Results show that magnetic tuning can serve as an effective method to modulate the properties of resonances. Additionally, polarization conversion and Faraday rotation in graphene metamaterials induced by magnetic field is analyzed. Our results will provide a new routine for the realization of tunable and functional graphene-based THz devices.

A Physics-driven Neural Network Framework For End-to-end Inverse Design Of Metasurface-based Holograms **Mo-P2-17**

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A novel unsupervised deep neural network framework driven by a physics model is introduced to design metasurface-based holograms. The proposed framework shows perfect reconstructions of holographic images with a shorter prediction time, higher peak signal-to-noise ratio and better structural similarity compared with the conventional Gerchberg-Saxton algorithm. An end-to-end design of metasurface-based holograms without requirements of complete light modulation is demonstrated. The proposed framework opens up a new approach to inverse design of metasurface-based photonic devices.

Reconfigurable Sub-terahertz Transmission And Reflection Integrated Metasurfaces Synergizing Polarization-encoding And Wavefront **Mo-P2-18**

Manipunation

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Reconfigurable multifunctional metasurfaces operating in both transmission-reflection (TR) state is intriguing for full-space coverage and integrated electromagnetic (EM) waves' regulations. Herein, a sub-terahertz reconfigurable metasurface consisting of a polarization-oriented coding-block layer and a grating layer is proposed that not only dynamically regulates the TR states of the x/y polarizations but also delivers independent TR phase coding. Unlike conventional TR-integrated reconfigurable metasurfaces, the proposed design integrates transmission units, reflection units, polarization selectors, and phase shifters on a single layer. The mechanisms of polarization regulation and phase shift are elucidated by the surface current distributions. As a proof-of-concept, a 1-bit sub-terahertz coding metasurface under different diode-state combinations attains a polarization-diverse full-space beam steering in a wide angular range. The proposed metasurface offers a feasible route to enable multifunction-integrated full-space wireless communication.

Active Terahertz Metasurface Devices **Mo-P2-19**

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Active functional wavefront modulation devices provide an approach to neatly control terahertz beams for high resolution imaging and communications. Two approaches for actively control of metasurface devices are demonstrated. One is mechanical rotating and another one is frequency selective optical pumping. Bessel beams with different order can be generated by relative rotating two metasurface and the part of a holography image can be controlled by selecting the frequency of pump light. Both two methods can enhance the function of terahertz metasurface devices.

Active Broadband Terahertz Metasurface Based On Mechanical Deformation Of Liquid Crystal Elastomer **Mo-P2-20**

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Active metasurfaces are emerging as the core of next-generation optical devices with their tunable optical responses and flat-compact topography. Liquid crystal elastomer (LCE) provides a very attractive platform for active metasurfaces due to its excellent optical/thermal-induced mechanical deformation properties. Here, the LCE-based terahertz metasurface is presented to control the phase and amplitude of the transmitted cross-polarization component according to the generalized Snell's law. The results pave the way for the development of reconfigurable metasurfaces based on mechanical deformation.

Graphene-Integrated Metasurface For THz Reconfigurable Polarization **Mo-P2-21**

Converter

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A terahertz graphene-integrated metasurface is designed for an electrically tunable polarization converter. A graphene/gold bilayer topology is developed to facilitate electrical tunability, while achieving good device performance. Good tunability of the polarization status at a fixed frequency and frequency tuning for a fixed polarization status has been demonstrated successfully

Electric-Field-Coupled Inductive-Capacitive Resonators For Terahertz Electromagnetically Induced Transparency Metamaterials **Mo-P2-22**

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Electromagnetically induced transparency (EIT) metamaterials (MTMs) address the enhancement of non-linear susceptibility and the control of the light group velocity, which enable them to find many fascinating applications in non-linear optics, slow-light devices, and quantum memories. Typically, an EIT MTM unit is constructed of a cut-wire (CW) acted as a bright-mode resonator and some split-ring resonators (SRRs) operated as dark-mode resonators. In this work, two kinds of electric-field-coupled inductive-capacitive (ELC) resonators with pure electric response rather than traditional SRRs with magnetic response are first proposed to mimic the EIT effect at terahertz frequencies. Both of the employed ELC resonators are axial and central symmetry instead of fourfold rotational symmetry, and thus they only couple to electric field component of the CWs in the proposed EIT MTMs. The Fano-type destructive interference between the CWs and ELC resonators leads to the EIT effect, which is verified by simulation and experimental results. This work provides a new method for the structural design of EIT MTMs, and opens up the possibility for some important functions of active EIT MTMs, such as the frequency shift of the EIT effect.

CRISPR/cas12-powered Platform For Specific And Sensitive Detection Of CtDNA Using A Terahertz Metamaterial Biosensor **Mo-P2-23**

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We developed a terahertz sensing platform based on the combination of the CRISPR-cas12a systems, DNA-Au probe, and metamaterial biosensors. The CRISPR-Cas12a systems can cleave unspecific single-strand DNA into two fragments which cross-link the DNA-Au probe onto the metamaterial surface, achieving sensitive and specific detection of the target circulating tumor DNA.

Morphological Dependence Of All-dielectric Terahertz Metasurfaces **Mo-P2-24**

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All-dielectric metasurface has been attractive attention in terahertz spectral range for low loss planar optical elements such as lens, beam splitter,

waveplate, vortex plate, and magnetic mirror. Various shapes of meta-atoms are used in many studies, but no systematic comparison study between each shape has not been reported. In this work, we report the optical properties of various shapes of metasurfaces through finite difference time domain (FDTD) simulation. For pillar type all-dielectric metasurface, it is the area, not the detailed shape, of the cross section that determine the phase. Therefore, with the square lattice geometry, the square shape meta-atom shows best performance in terms of full phase control at the lowest pillar height with negligible polarization dependence.

Multi-band Terahertz Switch Realized With Plasmon-induced Transparency Based On A Graphene Metamaterial Structure **Mo-P2-25**

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In this paper, a multi-band terahertz switch was proposed based on the plasmon-induced transparency (PIT) effect induced by an asymmetrical square split-ring resonator of graphene. Four "on" and "off" switching bands within 0.3 to 1.2 THz were realized by tuning the Fermi energy level of graphene.

Metamaterial Fresnel Zone Plate For Backward Terahertz-wave Parametric Oscillator Applications **Mo-P2-26**

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Metamaterial-based Rayleigh-Wood Fresnel-zone-plate (FZP) thin-film lenses, utilizing planar diffractive technology with artificial structures and subwavelength thickness, offer a flexible and distinctive optical design platform for terahertz (THz) applications. In this study, we designed a metamaterial-based and polarization independent FZP thin-film lens that can focus a monochromatic THz beam at 305 GHz with a high transmittance of 80% and a focal length of 78.7 mm. It can improve the shortcomings of traditional dielectric lenses and will be applied in an integrated backward THz-wave parametric oscillator (BW-TPO) system.

Electromechanically Reconfigurable Plasmonic Cantilevers **Mo-P2-27**

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We propose electromechanically reconfigurable nanogap cantilevers to overcome the pull-in instability limit of nano-opto-electromechanical metasurfaces by broadening plasmonic gaps. Finite element (FEM) simulations show that the electromechanical deformation in our asymmetric cantilever pair results in a gap 30 times wider than the initial value of 1 nm. As a result, the nanogap cantilever pair can function as a tunable plasmonic antenna with excellent optical performances. The simple geometry with efficient opto-mechanical coupling paves the way for the improvement of active metasurfaces and electromechanical tuning.

Mutual Coupling Effects Between Meta-atoms For Enhanced Bandwidth **Mo-P2-28**

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We analyzed theoretically and experimentally the inter-element coupling behavior between the periodic structure's so-called "meta-atoms" by varying the number of meta-atoms arranged periodically in the array. For this reason a planar metamaterial consisting of ring-shaped subwavelength periodic structures on a thin metal film was developed to exhibits a resonant transparency at the frequency of about 0.35 THz. The cross-talk between the meta-atoms due to electromagnetic multipole interferences lead to a significant change in resonance bandwidth and the quality (Q) factor. We anticipate that found coupling behavior between inter-element with subwavelength dimensions can potentially be used for a variety of applications such as filters, multi-pixel emitter and detector arrays, etc. for broad THz frequencies.

Ultra-broadband Impedance-matched Terahertz Absorption Of Drude-Smith Type Thin-film Materials **Mo-P2-29**

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The complex light-matter interactions could be used to manipulate the properties of terahertz waves. Based on the intraband transition of single-layer graphene, which is presented as a typical Drude-type material, efficient broadband terahertz absorption will be induced. However, the mobility of high-quality graphene layer is quite large, which means long scattering times and limits the bandwidth of terahertz broadband absorption. In this work, we indicate this limitation could be solved by using the Drude-Smith type materials, which tend to possess a short carrier scattering time and lead to an ultra-broadband terahertz absorption. If the condition of impedance match is satisfied, the maximum absorption could achieve ~50%, in the case of suspension or free space.

Correcting Pixel Errors For Terahertz Spatial Light Modulation Via Binary Erasure Codes **Mo-P2-30**

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In general, if there are some damaged pixels in a terahertz spatial light modulation based on metasurface, then the metasurface can not image correctly. In this paper, our main contribution is to introduce error-correcting codes to correct erasure errors in the imaging system of the terahertz spatial light modulation. Firstly, we analysis the pixel error is equivalent to the erasure error in coding theory. Secondly, we shows that our binary erasure code with minimum distance d which can correct d-1 erasure errors in the imaging system. Then, by time division multiplexing, it helps to save resources and improve the error-correcting capability. Finally, Our simulation shows that a binary [27, 16, 6]-erasure code can correct 5 pixel errors for a 4× 4 array size terahertz spatial light modulation based on metasurface.

Infrared Photocurrent Imaging And Spectroscopy With An Atomic-force-microscopy Probe **Mo-P2-31**

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We demonstrate a new setup where the photocurrent excited in graphene by mid-infrared quantum cascade laser pulses is collected with an atomic force microscopy probe (PC-AFM). The setup can measure the infrared photoresponse of devices with nanometric spatial resolution, but it can also be used as a novel infrared nanospectroscopy technique. We have tested our setup on a single-layer graphene stripe deposited on a SiO2/Si substrate and contacted by a metal line. At zero DC voltage bias, we observe a photocurrent compatible with a photo-thermoelectric effect. Also, we used the setup to apply a DC electric field to a piezoelectric polymer film and perform electric-field dependent IR nanospectroscopy so to observe the vibrational Stark effect at the nanoscale.

Generalized Phase-extraction Of Amplitude And Phase Contrast In Coherent THz-s-SNOM Based On Laser Feedback Interferometry. **Mo-P2-32**

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We report the use of a generalized phase-extraction algorithm to extract amplitude and phase data in THz scattering-type scanning near-field optical microscopy (s-SNOM) employing laser feedback interferometry in a THz quantum cascade laser. Our approach allows for only a small number of measurements of the self-mixing voltage, thus greatly improving acquisition rates. We investigate the accuracy of this method experimentally and demonstrate its use for fully coherent imaging of the out-of-plane field supported by an individual micro-scale resonator. Furthermore we report a dual-modulation approach that allows direct electronic measurement of the complex scattered field without recourse to fringe fitting.

A Terahertz Absorption Modulator Based On GaAs Schottky Diodes **Mo-P2-33**

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This paper presents a terahertz absorption modulator based on GaAs diodes

with a multi-branch microstrip branch parallel design method. Experimental results show that the modulator has a minimum insertion loss of 7.8 dB with an isolation of 20 dB, and a bandwidth with a VSWR less than 1.5 of 60 GHz. The minimum VSWR between 200-210 GHz was 1.1, and a maximum single-tone modulation rate of 32 GHz was measured. The experimental results show that the designed absorption modulator performs good ON-OFF effect and excellent absorption characteristics, as well as a high modulation rate, with the possibility of realizing terahertz high-speed signal transmission modulation.

A Low Insertion Loss 140GHz Terahertz Modulator Based On GaAs-diodes **Mo-P2-34**

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An ultra low insertion loss 140GHz terahertz modulator based on GaAs-diodes is presented in this paper.In this modulator, two Schottky diodes are connected across a metal structure on the E-side of the waveguide. Terahertz amplitude modulation is achieved by applying a bias voltage to change the state of the diode, thereby affecting the propagation of terahertz waves in the waveguide.Through experimental testing, the modulator can achieve an ultra low insertion loss of 0.9 dB at 140 GHz, with a modulation depth of up to 99.9%.

A High Power Capacity Terahertz On-chip Modulator Based On SRR **Mo-P2-35**

Kesen Ding[1]; Shixiong Liang[2]; Jinlong You[3]; Hao Yi[3]; Wei Wang[2]; Sen Gong[3]; Yaxin Zhang[3]

[1]Huzhou, Huzhou; [2]Shijiazhuang; [3]Huzhou

A high power capacity terahertz modulator based on Split-Ring Resonator(SRR) is presented in this paper. A double-layer structure is proposed to improve the switching ratio. The meta-unit and the SRR are distributed on the upper and lower layers of quartz chip respectively. The SRR improves the switching ratio by increasing the electric field resonance strength. GaAs Schottky diodes with large anode diameter are used to increase the power capacity of the modulator.The experiment results show that the power capacity of modulator is increased to 50 mW, achieving 5 dB insertion loss and 11 dB switching ratio at 366 GHz.

Design Of A 220 GHz Terahertz Wide-Band Common Emitter Low Noise Amplifier Chip **Mo-P2-36**

Lian Hu[1]; Ziqiang Yang[1]; Qingfeng Li[2]; Qinwen Tong[2]; Yaxin Zhang[1]

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This paper presents an integrated low noise amplifier (LNA) based on an ac-coupled common-emitter topology. In order to improve the amplifier gain, a

seven stage cascade amplification structure was adopted. ADS software is used to simulate the LNA with operating frequencies ranging from 200 to 240 GHz. The results show that the small signal gain is 23 dB, the noise figure is 8.8 dB at 220 GHz, and the 3 dB bandwidth is 20 GHz (210-230 GHz), which validate of the design.

A 3-bit Terahertz Phase Shifter Based On GaAs Diodes **Mo-P2-37**

Huajie Liang[1]; Shaokang Gu[2]; Lin Zou[1]; Shixiong Liang[3]; Yaxin Zhang[2]; Ziqiang Yang[2]

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Terahertz 360-degree phase shifter is the key to high-speed communications, terahertz radar. Terahertz on-chip phase shifters possess low insertion loss, high accuracy, large phase shift range, and crucially, easy integration. We propose a 360-degree 3-bit terahertz on-chip phase shifter based on GaAs diodes, which consists of a 180-degree reflection phase shift structure and three 45-degree transmission phase shift units. We utilize a digital code to represent the states of the diode, the "1" indicates that the diode is on, and the "0" indicates that it is off. Under 8 coding states from "0,000", "0,001", "0,011", to "1,111", the phase shifter achieves a 360 degrees phase shift in 45 degrees steps with high linearity in the 215-225 GHz band. The insertion loss of all 8 states is below 10 dB at 220 GHz.

On-Chip Terahertz Circulator Based On Time-varying Coupled Resonators **Mo-P2-38**

Xuan Sheng[1]; Ziqiang Yang[1]; Huajie Liang[1]; Lin Zou[1]; Dan Liang[1]; Yaxin Zhang[2]

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In this study, a novel on-chip terahertz circulator using time-varying coupled resonators is designed. The circulator consists of three tunable microstrip resonators, which enable the control of terahertz signal input and output via a coupled microstrip structure. In addition, a pair of varactor diodes loaded in every branched resonator is controlled by a low-frequency sinusoidal signal, allowing resonance control of that particular branch. Using the principle of space-time modulation, the phase difference of each control signal is set to 120 degrees, allowing non-reciprocal transmission of the three ports. Simulation results show that the circulator achieves 8.2 dB insertion loss, 21.1 dB isolation and 20.3 dB return loss at 0.14 THz, with a bandwidth of 5 GHz for 20 dB isolation.

This Study Explores The Use Of Passive And Flexible Optics Elements To Achieve THz Beam Profile Engineering For Imaging Applications Via Mechanical Bending. **Mo-P2-39**

Linas Minkevičius[1]; Rusnė Ivaskevičiūtė-Povilauskienė[1]; Vladislovas Cizas[2]; Ernestas Nacius[2]; Ignas Grigelionis[2]; Karolis Redeckas[2]; Matas Bernatonis[2];

Sergej Orlov[2]; Gintaras Valusis[2]
[1]Savanorių ave. 231, Vilnius; [2]Savanoriu ave. 231, Vilnius

This study explores the use of passive and flexible optics elements to achieve THz beam profile engineering for imaging applications via mechanical bending. Specifically, a stainless steel-based C-shaped metasurface was designed and fabricated using laser ablation technology. The metasurface performance and polarisation manipulation were experimentally evaluated for different focal distances and geometrical metaatom parameters. Experimental data are well supported by simulations using the Finite Difference Time Domain method. The results obtained pave the way to achieve accurate beam profile engineering and resolved polarisation in THz imaging.

THz High-gain PTFE Low-profile Vortex Antenna **Mo-P2-40**

Wenbo Li[1]; Kai Huang[1]; Hongxin Zeng[1]; Wei Wang[2]; Yaxin Zhang[1]; Ziqiang Yang[1]
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This article presents a THz high-gain PTFE low-profile vortex antenna. The antenna consists of a feed horn antenna and a PTFE low-profile vortex lens. The former generates a spherical waves, and the latter is used for collimation and generating vortex beams. This antenna has a high gain of 29.3 dBi, a sidelobe level of -17.5 dB, and a high isolation of 35.7 dB when using OAM modes with l=±1. It also has the advantage of being lightweight and easy manufacturing, which has important potential value in areas such as terahertz wireless communication and mode multiplexing systems.

A Low-Profile CPW-Fed Wideband Terahertz Antenna Based On UC-PBG Structures For Wireless Applications **Mo-P2-41**

Mohammad Alibakhshikenari[1]; Mohammad M. Fakharian[2]
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In this paper, a low-profile coplanar waveguide (CPW) fed wideband terahertz microstrip antenna for wireless applications has been proposed. Uniplanar Photonic Band Gap (UC-PBG) structures as ground planes are combined by the zero-shaped antenna on the same plane as a radiator on the two sides. A microstrip line feed is used to excite the proposed antenna placed on a Rogers RT/Duroid 6010 substrate (dielectric constant Er= 10.2). The antenna is designed and simulated using the HFSS software. The simulation results show that the antenna mounted on the UC-PBG ground plane has over 30% bandwidth with good radiation characteristics.

Terahertz Super-Resolution Image Reconstruction By Frequency Mapping **Mo-P2-42**

Ting Zhu[1]; Guangyou Fang[1]; Emma Pickwell-MacPherson[2]; Xuequan Chen[1]
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Terahertz images of low frequencies suffer from a low spatial resolution due to the diffraction limit. Conventional near-field techniques have critical

requirements on sample types. Here, we propose a purely numerical super-resolution algorithm based on frequency mapping. It utilizes the ultra-broadband coherent characteristics of terahertz spectroscopic imaging and determines the mapping relationship through clustering and genetic algorithms. Super-resolution images of low frequencies can be reconstructed with a high accuracy, which is verified by the spectral transmission coefficients.

3-D Printed Dual-band Dual-polarized Metalens Antenna **Mo-P2-43**

Yilong Cai; Wenqiang Deng; Yuxuan Xie; Shuyan Zhu
Sun Yat-sen University Zhuhai Campus, Zhuhai

This conference paper presents a new all-dielectric dual-band dual-polarized metalens antenna working at E-band and D-band. Taking advantage of the flexibility of 3D-printing technology, a two-layer structure including a polarizer and a metalens antenna can be realized conveniently and cost effectively. The polarizer converts linearly polarized (LP) incident waves to circularly polarized (CP) waves at E-band, while converting LP incident waves to cross-polarized waves at D-band. The metalens antenna transforms the wavefront from spherical to plane at dual-band. Simulation results demonstrate that the proposed antenna achieves 3 dB axial ratio (AR) bandwidths of 64.28-87.85 GHz with peak gains of 27.13 dBi for CP waves and peak gains of 28.79 dBi for LP waves at 127.51-165 GHz.

Terahertz Reflection Vibrometry For Analyzing Metal Foil Displacement Induced By Single Cavitation Bubble Collapse **Mo-P2-44**

Vladyslav Cherniak[1]; Jan C. Balzer[1]; Bettar Ould El Mocta[2]; Hemant Sagar[2]
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Cavitation bubbles produced in lower pressure regions, causes erosion and vibration of ship propeller and other hydro-machinery. Therefore, a major interest lies in optimizing and designing hydro-machinery to reduce the caused damage. So far destructive mechanisms on ridged compounds by bubbles are well understood however, structural vibration of elastic nearby structures is still a quest. Therefore, fundamental understanding of the dynamics of cavitation bubbles and resulting structural response of elastic structures e.g. foil must be investigated. In this work, we present a terahertz reflection measurement setup to investigate in the effects of single cavitation expositions on metallic surfaces under water. We compare the measurements with those of a commercially available optical interferometer.

Emission Angle Of THz Beam From Nonlinear Quantum Cascade Laser And The Effect Of Imaging Result **Mo-P2-45**

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(THz) nonlinear quantum cascade laser (THz NL-QCL) is small size and easy to handle semiconductor source. THz NL-QCL is capable of ultra-broadband emission and can be operated at room temperature. In THz NL-QCL, when converting from mid-infrared to terahertz wave, a Cherenkov phase matching scheme is adopted. By adopting Cherenkov scheme, emission angle is slightly different depending on the terahertz frequency. We found the change of focus

point caused by the difference of emission angle in the imaging system is approximately within ±0.2 mm by simulation. We confirmed that the difference of focus point did not affect in spectroscopic imaging.

Evidence Of Capillary Action In Multilayered Fibrous Media Observed With THz Spectroscopy **Mo-P2-46**

Irina Nefedova[1]; Roman Grigoriev[2]; Aleksi Tamminen[2]; Helena Rodilla[3]; Emma MacPherson[4]; Zachary Taylor[2]
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Here we investigate the applicability of the stratified media model to complex, multilayered media. THz reflectivity spectra of drying cellulose-based material show pronounced, frequency-dependent reflectivity reduction below dry reflectivity. Analysis suggests the remaining water is distributed at the top surface of the paper thus consistent with a capillary in opposition to gravity.

Terahertz Radar And Deep Learning-Based Detection Of Soft Foreign Objects In Food Products: An Automatic Inspection Approach **Mo-P2-47**

Seungeon Song[1]; Donghoon Kwak[1]; Youngduk Kim[1]; Jonghun Lee[2]
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This study investigates the feasibility of an automatic detection system for foreign objects in food using terahertz radar and deep learning techniques. The experimental setup comprises a terahertz radar source, beam splitters and collimators, and a terahertz receiver with a 32 x 32, 1024-pixel area scanner. Received images representing signal strength transmitted through noodles serve as input for a deep learning model after pre-processing to eliminate noise. A binary decision is then made on whether the food contains foreign objects or not.

Qualitative Identification And Quantitative Detection Of ?-lactose Solutions Using High Power THz-ATR Spectroscopy **Mo-P2-48**

Wei Shi[1]; Haiqing Wang[1]; Lei Hou[2]; Lei Yang[1]; Cheng Ma[2]; Yusong Zhang[1]; Chunhui Li[1]; Hong Liu[1]
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We present the design and construction of a set of THz-ATR spectrometers for highly sensitive detection of liquid biological samples. High-power THz-ATR spectroscopy is effective for the qualitative identification and quantitative detection of ÃZÂ±-lactose aqueous solutions with a minimum concentration of 0.292 mol/L. This approach offers new perspectives for the refinement and in-depth detection of biomedical samples.

Concept Of A Near-field Antenna-scanner For Mm-wave Applications **Mo-P2-49**

David Ulm; Nora Meyne; Kai Baaske; Thomas Kleine-Ostmann
Bundesallee 100, Braunschweig

This contribution presents a concept of a volumetric antenna scanner for the

mm-wave frequency range. When being used as a near-field scanner, high mechanical and electrical accuracy is required due to the small wavelengths at mm-wave frequencies. Possible solutions to meet these requirements and their impact on the measurement uncertainty are discussed.

Simple And Affordable Spectrum Analyzer For The THz Radiation Range **Mo-P2-50**

Paweł Komorowski; Przemysław Zagrajek; Norbert Pałka
gen. Sylwestra Kaliskiego 2, Warsaw

A simple, compact, and cost-efficient setup for the spectral characterization of sub-THz and THz beams is proposed. It utilizes, the well-known property of the diffraction gratings to redirect the radiation at an angle dependent on the frequency. In the presented reflective configuration only a single moving element is necessary -- a rotary stage. A set of diffraction gratings with varying constants has been manufactured using laser-cutting and served for the experimental verification of the setup. The results are consistent with the theory and prove the feasibility of the THz spectrum analyzer.

Evaluation Of The Reliability Factors On Illicit Drugs On-Site Identification Based On Portable Terahertz Time Domain Spectroscopy **Mo-P2-51**

Zi Xi Josie Lim[1]; Nan Zhang[1]; Wei Ji Phua[1]; Angeline Tang[2]; Lijie Yu[2]; Jia Yi Kwang[2]; Angeline Tiong Whei Yap[2]; Lin Ke[3]
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Researchers have developed a portable Terahertz Time Domain spectrometer (THz-TDS) that can perform on-site analysis without requiring nitrogen purging. The device was tested on 19 different chemicals, including diluents and illicit drugs, to verify its capabilities. A database of these chemicals was also established and their characteristic absorption peaks were verified against literature reports. The study found that the THz-TDS was capable of identifying drugs and had good repeatability in various conditions. The researchers concluded that the THz-TDS has the potential to be a practical and valuable tool for fast drug detection in the future.

Demonstration Of A 245 GHz Real-Time Wireless Communication Link With 30 Gbps Data Rate **Mo-P2-52**

Ting Zhang[1]; Hao Zhang[2]; Xiaojing Huang[2]; Hajime Suzuki[3]; Joseph Pathikulangara[3]; Ken Smart[3]; Jia Du[1]; Jay Guo[2]
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A 245 GHz wireless communications system with a data rate of 30 gigabits per second (Gbps) at a 1.2 m distance is demonstrated. The system consists of low-complexity and real-time baseband modules to provide the high-speed wideband signal processing capability. Multi-channel base-band signals are combined and converted to 15.65 Ã‚Â± 6.25 GHz wideband intermediate frequency (IF) signals. The demonstration proves the potential for future high-speed communications beyond 5G technology, especially, for space applications, such as intersatellite communication where atmospheric attenuation is negligible.

Loss And Dispersion Limitations Of THz Surface Wave Links **Mo-P2-53**

Jie Qing[1]; Miguel Navarro-Cia[2]
[1]Chenghua District; [2]Edgbaston Campus

Terahertz surface wave links are proposed for highly integrated on-chip systems and for specific short-range applications. The metal grating-based THz surface wave link is analyzed in terms of attenuation and dispersion limitation. The energy efficiency of the link at a specific structure geometry and operating frequency is demonstrated, leading to effective guidance for the layout of terahertz surface wave links.

Blockage Prediction In Directional MmWave Links Using Liquid Time Constant Network **Mo-P2-54**

Martin Hedegaard Nielsen[1]; Chia-Yi Yeh[1]; Ming Shen[2]; Muriel Médard[1]
[1]50 Vassar St, Cambridge; [2]Selma Lagerløfs Vej 312, Aalborg

We propose to use a liquid time constant (LTC) network to predict the future blockage status of a millimeter wave (mmWave) link using only the received signal power as the input to the system. The LTC network is based on an ordinary differential equation (ODE) system inspired by biology and specialized for near-future prediction for time sequence observation as the input. Using an experimental dataset at 60 GHz, we show that our proposed use of LTC can reliably predict the occurrence of blockage and the length of the blockage without the need for scenario specific data. The results show that the proposed LTC can predict with upwards of 97.85% accuracy without prior knowledge of the outdoor scenario or retraining/tuning. These results highlight the promising gains of using LTC networks to predict time series-dependent signals, which can lead to more reliable and low-latency communication.

Millimeter-wave--Infrared Multi-wavelength Computed Tomography **Mo-P2-55**

Daiki Shikichi[1]; Raito Ota[1]; Kou Li[2]; Daiki Sakai[1]; Takeru Suyama[3]; Hiroki Okawa[4]; Satoshi Ikehata[3]; Imari Sato[3]; Yukio Kawano[1]
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Carbon nanotube (CNT) film-based sensors are attracting attention as a technology that enables ultra-broadband and multi-wavelength optical imaging. Here, we report on the achievement of nondestructive material identification and structural reconstruction of a three-dimensional object made of multilayered composite materials by combining wide-band multi-wavelength long-wavelength optical imaging using CNT film-type elements and computed tomography measurement, a typical example of computer vision technique.

System For Automatic Detection Of Defects In Composite Structures **Mo-P2-56**

Kamil Kaminski[1]; Norbert Palka[1]; Marcin Maciejewski[1]; Marcin Kowalski[1]; Elzbieta Czerwinska[1]; Przemyslaw Zagrajek[1]; Piotr Synaszko[2]; Krzysztof Dragan[2]
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This paper presents the concept of a system for the automatic detection of defects in composite structures using a time domain spectroscopy (TDS) scanner. The operation of the presented system can be divided into several stages, i.e. measurement with a high-speed terahertz scanner based on electronically controlled optical sampling (ECOPS), filtering of the obtained terahertz signals, peak to peak (P2P) in the slice parameterisation, generation and selection of the most representative signal features indicating the presence of a defect and classification of whether a given signal disturbance should be considered a defect. All elements beyond the measurement stage are realised in post-processing.

Encoder-Based Synchronization For ECOPS High-Speed Terahertz Raster Scanner **Mo-P2-57**

Marcin Maciejewski; Kamil Kaminski; Norbert Palka
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This article describes the encored based synchronization method for a terahertz time domain spectroscopy raster scanner build with the commercially available TeraFlash Smart platform. We used microcontroller with dedicated counter to combine synchronization signals from various devices included in the scanner. As a result, a fast scanning mode was obtained which is 25 times faster than classic step by step approach. The developed system is capable to scan a 500 x 500 mm sample with resolution of 1 mm in about 20 min.

High-resolution Visualization Of The Temperature Changes In A Tissue-equivalent Phantom For THz Frequencies Using Fluorescent Thermoprobe **Mo-P2-58**

Shota Yamazaki; Maya Mizuno; Tomoaki Nagaoka
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The water-rich biological tissues strongly absorb radio waves at THz frequencies, and then temperature rising occurs in a skin depth of several hundred micrometers. Therefore, temperature measurements at the skin surface with high- resolution are required to evaluate thermal effects induced by THz waves. In this study, we employed a fluorescent thermoprobe which is a macromolecular sensor for temperature measurement and visualized the temperature distribution in a tissue-equivalent phantom for THz frequencies with a high spatial resolution over 100 μm.

Terahertz Time-domain Spectroscopy For The Analysis Of Latex Film Formation **Mo-P2-59**

Gonçalo Costa[1]; Emily Brogden[1]; Jacob Young[1]; Arturo Hernandez-Serrano[1]; Rayko Stantchev[2]; Stefan Bon[1]; Emma MacPherson[1]
[1]University of Warwick, Coventry; [2]National Sun Yat-sen University, Department of Physics, Kaohsiung

THz Time Domain Spectroscopy was used to analyze the thin-latex film formation process, relevant to the paint industries. Latex solutions with different properties were analyzed (glass transition temperatures, particle size, etc.). The study was done under different environmental conditions and 2D water distribution maps as a function of their drying period were produced.

Advanced Experimental Investigations On Cooling Concepts Of Cavities For Megawatt-Class CW Gyrotrons **Mo-P2-60**

Sebastian Stanculovic[1]; Konstantinos Avramidis[2]; Rosa Difonzo[3]; Eleonora Gajetti[3]; Gerd Gantenbein[1]; Stefan Illy[1]; John Jelonnek[1]; Alberto Leggieri[4]; Tobias Ruess[1]; Tomasz Rzesnicki[1]; Laura Savoldi[3]
[1]Kaiserstr. 12, Karlsruhe; [2]Athens; [3]Corso Duca degli Abruzzi, 24,, Torino; [4]2 Rue Marcel Dassault, Vélizy-Villacoublay

The ongoing research and development of high-power fusion gyrotrons demands for an effective cavity cooling system for optimum gyrotron operation. In this work, the latest improvements in the test set-up for the thermal-hydraulic investigation of a cavity cooling is described. In order to increase the overall accuracy in the experiments and to eliminate potential uncertainties a set of improvements of the test set-up are considered: a new flowmeter with flow rates that range up to 12 l/min and with improved measurements accuracy; faster thermocouples, with reaction times < 0.1 s. Additionally, following modifications are introduced: a coating of the inner surface of the copper cavity with a Nickel layer of 100 Âμm thickness in order to increase the heat load using induction heating; 3D printing Additive Manufacturing (AM) of the mock-up in order to directly compare the cooling performances and to validate the 3D printing AM technique for this application; (3) installation and test of a new mock-up with mini-channels and with Raschig rings for a direct comparison between the two cooling techniques. The obtained experimental results provide input to validate numerical models used for the cavity cooling optimization.

Diamond Dielectric Characterization With Superconducting LC Micro-resonators **Mo-P2-61**

Francesco Mazzocchi; Dirk Strauß; Theo Scherer
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The development of high optical quality, ultra-low losses single crystal diamond windows is paramount for the realization of future nuclear fusion, given the foresaw increase in power of microwave ECRH systems. High Q, superconducting thin film resonators can be effectively used to determine dielectric characteristics of extremely low losses materials like single- and poly-crystalline diamond. In this work we present a study evaluating superconducting LC micro-resonators as potentially useful characterization tools for dielectric materials, with a particular focus on poly- and single crystalline diamond substrates.

Towards Fracture Toughness Measurements Of MPA CVD Diamond In Nuclear Fusion Devices **Mo-P2-62**

Gaetano Aiello[1]; Pablo Estebanez[2]; Bronislava Gorr[3]; Andreas Meier[3]; Sabine Schreck[3]; Theo Scherer[3]; Dirk Strauss[3]; Christoph Wild[4]; Eckhard Woerner[4]
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Optical quality polycrystalline diamond is the only window material allowing transmission of high-power microwave beams in nuclear fusion devices. Failure to fracture is the main failure mode for diamond, which is integrated in the shape of disks in the so-called window units. This paper reports on the path to measure the fracture toughness of this diamond for a later potential structural integrity assessment of the disks based on fracture mechanics.

Experimental And Theoretical Study Of Terahertz Spectrum On Luteolin **Mo-P2-63**

Ting Zeng[1]; Gan Zhang[2]; Qin Huang[2]; Jun Zhou[3]; Sen Gong[3]
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In this work, we measured the absorption spectrum of luteolin by terahertz time-domain spectroscopy (THz-TDS). The characteristic absorption peaks of luteolin was obtained in the frequency range from 0.85 to 1.3 THz. In parallel with the experimental study, density functional theory (DFT) calculation was performed to optimize the possible single-molecule structure of luteolin and simulate the corresponding experimental THz spectra. The theoretical result was in good agreement with the experimental data. Accordingly, THz-TDS is a promising method for identifying chemical constituents of natural products.

A Novel Local Symmetry Peak Finding Method For Terahertz Content Extraction Through Multilayer Structures **Mo-P2-64**

Yuqing Cui; Yafei Xu; Xingyu Wang; Liuyang Zhang
No 28 Xianning West Road, Beilin District, Xi'an

Terahertz (THz) time-domain spectroscopy emerges as a promising inspection technique for nonpolar materials that provides both fine resolution and broadband spectrum. However, its practical application on multilayer structure is limited by the rapid decrease of signal-to-noise ratio (SNR) along the vertical propagation direction resulting from various reasons such as absorption and scattering. Here we propose a non-iterative pulse extraction method along with an imaging method for content extraction through multilayer structures. The method exploits the local symmetrical characteristics of the reflected THz pulses in the time domain for stratigraphic reconstruction, and then obtains THz images based on the average time-domain amplitude around the peaks. To demonstrate, alphabetic characters written on each layer were successfully extracted from a sixteen-layer stack of paper. This technique offers opportunities for practical inspection of coatings, cultural artifacts, drugs, and especially layered composites with dozens of sub-millimeter layers.

High Frequency Signal Generation From Aliased Signals In A Direct Digital Synthesizer For Terahertz Applications **Mo-P2-65**

Eunsang Kwon
218, Gajeong-ro, Yuseong-gu, Daejeon, Republic of Korea, Daejeon

This paper presents a method for generating high-frequency signals up to the sampling frequency of a direct digital synthesizer (DDS) by utilizing aliased signals. The proposed technique can be used in terahertz (THz) systems that require fast frequency control. By utilizing the second image region of the DDS using a high-pass filter (HPF), a signal can be generated up to the system clock frequency. The results show that the developed system can be used as a signal source for THz scanning applications with fast frequency sweep capability

Nondestructive Structural Observation Of Paintings Using Infrared, Millimeter And THz Pulsed Waves **Mo-P2-66**

Kaori Fukunaga[1]; Yoshimi Ueno[2]
[1]Nukui-Kita 4-2-1, Koganei; [2]Tokyo

Nondestructive test techniques using electromagnetic waves from microwave to infrared are used for cultural heritage studies, with different frequency bands selected depending on the objectives. For example, since the 20th century, radar technology has been widely used for archaeological site exploration and structural investigations of buildings, and infrared region has been used since the 20th century mainly as a spectroscopic technique to identify pigments on the surface of paintings. A comparison of THz time domain scanning and infrared pulsed thermography has been made for the observation of the internal structure of a painting. From a practical point of view, photographic methods such as thermography are more suitable than scanning techniques for pre-treatment surveys where time and budget are limited. If the precise structure is required, then time domain scanning techniques should be used. It may be time to provide a good practice guide for conservators and art historians who are not experts in optics.

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19 September 2023

08:30 - 09:15 **Plenary Session 3** **Symposia Theatre**

Chairperson(s): Frank Hegmann,

08:30 **Plasmonic Terahertz Camera For Real-Time Terahertz Imaging** **Tu-PL1-1**

Mona Jarrahi
420 Westwood Plaza, 420 Westwood Plaza, Los Angeles

We present a terahertz camera based on a plasmonic focal-plane array that can generate ultrafast temporal and hyperspectral terahertz images with an imaging speed exceeding 16 fps. We demonstrate super-resolving both shape and depth information of imaged objects with a lateral/depth resolution as small as 60/10 ï□m and an effective number of pixels exceeding 1-kilo-pixels.

09:15 - 10:00 **Plenary Session 4** **Symposia Theatre**

Chairperson(s): Frank Hegmann,

09:15 **Terahertz Spintronics: New Insights Into Magnetic Phenomena and Their Application In Terahertz Photonics** **Tu-PL2-2-1**

Tobias Kampfrath
Arnimallee 14, Berlin

By applying terahertz time-domain techniques to spintronic nanostructures, new insights into the ultrafast dynamics of electron spins can be gained. Relevant applications such as the spintronic generation and detection of terahertz electromagnetic fields emerge.

10:30 - 12:00 **Laser Sources & Detectors II** **Symposia Theatre**

Chairperson(s): Hiroaki Minamide,

10:30 **Investigation Of RTD THz Oscillator With Wide Frequency Tuning Capability** **Tu-AM-1-1**

Enes Mutlu[1]; Wen Li[1]; Benedikt Sievert[2]; Robin Kress[1]; Simone Clochiatti[1]; Andreas Rennings[2]; Anton Grygoriev[1]; Werner Prost[1]; Daniel Erni[2]; Nils Weimann[1]

[1]Lotharstr. 55 (ZHO), Duisburg; [2]Bismarckstr. 81, Duisburg

Compact THz sources with a large VCO tunability are useful for a variety number of applications such as radar or communication. There are different approaches using transistor technology and smart circuit development to fulfill these requirements. A different approach is investigated in using single resonant tunneling diode oscillator with a large emitter spacer thickness topology to increase frequency tunability up to 7.6% in the WR2.2 band. Free-space spectrum measurements in the far field showing this observation are presented. Additional physical TCAD simulations are carried out using non-equilibrium Green's function formalism and a Poisson solver to investigate in the large capacitance change in this layer stack configuration.

10:45 **Resonant-Tunneling Diode With Spiral Bias Connections For Circularly Polarized Radiation** **Tu-AM-1-2**

Mingxiang Stephen Li[1]; Safumi Suzuki[2]; Christophe Fumeaux[1]; Withawat Withayachumnankul[1]

[1]The University of Adelaide, SA, 5005; [2]2-12-1 Ookayama, Meguro-ku, Tokyo 152-8552, Japan

Resonant-tunneling diodes (RTDs) are promising electronic sources for terahertz wireless communications. A recently proposed RTD with a series-fed patch array indicates that surface waves can propagate along the extended biasing structure. In this paper, we follow this concept and present a cavity-coupled RTD with a spiral bias configuration for circularly polarized (CP) radiation with high efficiency. Full-wave simulations suggest that the structure can radiate with an axial ratio generally lower than 2 dB and a radiation efficiency above Ã¢^'5 dB from 400-600 GHz. A broadside directivity of around 25 dBi can be achieved at 500 GHz when the spiral structure is used to feed a hyper-hemispherical silicon lens.

11:00 **On-wafer Characterisation Of Resonant-tunnelling Diodes Up To 1.1 THz** **Tu-AM-1-3**

Patrik Blomberg; Jan Stake; Josip Vukusic; Vladimir Drakinskiy

Chalmersplatsen 4, Gothenburg

This paper presents on-wafer S-parameter characterisation of resonant-tunnelling diodes between 0.5 THz and 1.1 THz. Diodes with a peak current density of 532 kA/cm2 and a clear negative differential region have been fabricated. An on-chip Multi-Thru-Reflect-Line calibration kit was developed

and utilised to achieve accurate S-parameter measurements up to 1.1 THz.

11:15 **A Simple View On Large-Signal Resonant-Tunneling-Diode Dynamics** **Tu-AM-1-4**

Petr Ourednik; Dinh Tuan Nguyen; Michael Feiginov
Gusshausstrasse 25/354, Vienna

We present a model for an accurate description of the large-signal resonant-tunneling-diode (RTD) dynamics, which allows for a simple and intuitive analysis in terms of dynamical trajectories in a phase space. We show that the RTD admittance can be accurately described by a simple RLRC equivalent circuit, which has a universal configuration, but with different circuit parameters in the large- and small-signal cases.

11:30 **Conventional Vs. Island THz Slot-Antenna Resonant-Tunneling-Diode Oscillators** **Tu-AM-1-5**

Dinh Tuan Nguyen[1]; Petr Ourednik[2]; Michael Feiginov[2]
[1]Karlsplatz 13, Vienna 1040, Austria, Vienna; [2]Karlsplatz 13, Vienna 1040, Austria

Island design of on-chip slot-antenna RTD oscillators allows one to strongly reduce the ohmic antenna losses. In this work, we report on operation of such island oscillators in the frequency range 1.2-1.74 THz with the radiated output power of 2.2 Ã‚Âµ W at the fundamental frequency of 1.74 THz. We also show, that the conventional, but otherwise identical, RTD oscillators would have been limited to the operation at frequencies below 1.55 THz.

11:45 **Nonlinear Optical Response In Resonant Tunneling Diode Terahertz Oscillators** **Tu-AM-1-6**

Takashi Arikawa[1]; Seiga Yamasaki[2]; Koichiro Tanaka[2]
[1]2167 Shosha, Himeji; [2]Oiwakecho, Kitashirakawa, Sakyo-ku, Kyoto
We studied nonlinear optical response of resonant tunneling diode (RTD) terahertz oscillators. We observed nonlinear frequency mixing processes such as four-wave mixing. These nonlinear optical responses should be responsible for the frequency comb generation in RTD oscillators.

10:30 - 12:00 **Ultrafast Phenomena & Spectroscopy** **Cartier I**
Chairperson(s): Dmitry Turchinovich,

10:30 **Terahertz Cavity Phonon Polaritons In The Deep-Strong Coupling Regime** **Tu-AM-2-1**

Andrey Baydin[1]; Manukumara Manjappa[2]; Sobhan Subhra Mishra[3]; Hongjing Xu[4]; Jacques Doumani[5]; Fuyang Tay[6]; Dasom Kim[5]; Felix Hernandez[7]; Paulo Rappl[8]; Eduardo Abramof[8]; Ranjan Singh[3]; Junichiro Kono[5]
[1]6100 Main St., Houston; [2]CV Raman Road, Bengaluru; [3]Singapore; [4]6100 Main St, Houston; [5]6100 Main St; [6]6100 Main St.; [7]Av. Prof. Luciano Gualberto 315; [8]Av. dos Astronautas, 1.758. Jd. Granja

We have studied the resonant and nonperturbative coupling of transverse

optical phonons in lead telluride with photons in small-mode-volume terahertz cavities, observing a giant vacuum Rabi splitting on the order of the uncoupled phonon and cavity frequencies. Our terahertz time-domain spectroscopy experimental data, systematically collected as a function of sample thickness, temperature, and cavity length, can be well reproduced by our electromagnetic simulations. These results demonstrate that this uniquely tunable platform is promising for realizing and understanding predicted cavity-vacuum-induced ferroelectric instabilities, as well as for exploring applications of light-matter coupling in the ultra- and deep-strong coupling regimes in quantum technology.

11:00 **A Novel Terahertz Line Array Detection Scheme Of Polarimeter-interferometer System On EAST** **Tu-AM-2-2**

Huihui Yan; Haiqing Liu; Shouxin Wang; Hui Lian; Weiming Li
No. 350 shushanhu Road, Hefei, Anhui, China, Hefei
A multi-channel POlarimeter-INTerferometer (POINT) system for plasma electron density and current distribution measurement has been installed on Experimental Advanced Superconducting Tokamak (EAST), with a spatial resolution of 8.5 cm. Different from the spatial resolution upgrade process in a conventional multi-channel system that increasing the number of spatial viewing channels by optical elements, a novel terahertz line array detection scheme is proposed to improve the spatial resolution to 4.5 mm by replacing the original single Schottky mixer with a line array HEMT detector based on the original system. Related optical design and components design as well as bench test of this new detection scheme has been carried out to verify the feasibility and the reliability. Bench test results obviously displayed the well performance of the cylindrical lens designed to convert the shape of laser beam. The coupling effect of cylindrical lens to line array HEMT detector in signal detection is optimized for high spatial resolution measurement.

11:15 **Research On The EAST Plasma Density Diagnostics By The Terahertz Spectroscopy Using Asynchronous Sampling And Single-shot Schemes** **Tu-AM-2-3**

Haitao Tao[1]; Ming Fang[1]; Haiqing Liu[2]; Cuizhen Wang[2]; Susu Hu[3]; Yinxian Jie[3]; Chun Zhou[3]
[1]Anhui University, Hefei; [2]Hefei Comprehensive National Science Center, Hefei; [3]Chinese Academy of Sciences, Hefei
In this paper, we propose to develop asynchronously locked, high stable, high-repetition-rate ultrafast fiber lasers to achieve the diagnostics of Experimental Advanced Superconducting Tokamak (EAST) plasma density by high-speed real-time terahertz spectroscopy with asynchronous sampling and single-shot measurement schemes.

11:30 **Terahertz Time Domain Spectroscopy For Characterizing Properties Of Carbon Nanotube Yarns** **Tu-AM-2-4**

Laura Londono[1]; Natalie Frey[2]; Andrew Fitzgerald[2]; Lyubov TITOVA[2]; Kateryna Kushnir[2]
[1]100 Institute Rd, 100 Institute Rd, Worcester; [2]Worcester Polytechnic Ins, 100 Institute Rd, Worcester

Carbon nanotube (CNT) yarns are made of aligned filaments of structured

carbon such as single or multi-walled carbon nanotubes. They are flexible, strong, thermally and electrically conductive in the axial direction. Here we report on using THz time-domain spectroscopy to characterize Miralon Â® yarn manufactured by Huntsman corporation. As CNTs strongly absorb and reflect THz radiation polarized along the CNT axis, THz TDS provides a rapid, non-destructive approach to characterize CNT fiber bundle alignment in the yarn materials. It can be used to study correlations between alignment and yarn tenacity and other properties.

11:45 **Terahertz Torsional Dynamics And Their Influence On Electron-Phonon Coupling In Organic Semiconductors** **Tu-AM-2-5**

Michael Ruggiero
82 University Place, Burlington

Terahertz vibrational dynamics are the primary cause of detrimental electron-phonon coupling in organic semiconducting crystals. This has made these materials prime candidates for study using terahertz vibrational spectroscopy. In this work, we highlight how terahertz torsional dynamics in thiophene-functionalized organic semiconductors play a major role on charge transport properties in these materials. Overall, this work highlights the ability to guide the rational design of new materials using crucial insight from terahertz time-domain spectroscopy studies.

10:30 - 12:00 **Semimetals** **Cartier II**

Chairperson(s): Jigang Wang,

10:30 **Terahertz And Multi-terahertz Spectroscopy Of Light-driven 3D Dirac Semimetal Cd3As2** **Tu-AM-3-1**

Yuta Murotani; Ryusuke Matsunaga
5-1-5 Kashiwanoha, Kashiwa, Chiba

We studied optical and electrical properties of the light-dressed Floquet states in a 3D Dirac semimetal, Cd3As2, using terahertz and multi-terahertz spectroscopy techniques. Combining a narrowband pump and a broadband probe in the multi-terahertz frequency region, we observed strong stimulated Rayleigh scattering originating from optical transitions between the Floquet states. The large group refractive index accompanying this phenomenon may be applicable to slow light generation with a bulk semimetal at room temperature. We also observed Faraday rotation of a terahertz probe transmitting a Cd3As2 sample under a circularly-polarized multi-terahertz pump, which had been expected as a manifestation of the light-induced Floquet-Weyl semimetal. We found, however, that the sign of the measured anomalous Hall conductivity contradicts the theoretical prediction for the Floquet-Weyl semimetal. Based on microscopic calculation, we revealed that the observed Faraday rotation mainly arises from direct photocurrent generation allowed by the electric field in the terahertz probe pulse. Polarization-resolved terahertz time-domain spectroscopy, which enabled non-contact and ultrafast detection of the transient anomalous Hall conductivity including the sign, paves the way for disentangling the competing mechanisms of light-induced anomalous Hall effect.

11:00 **Kerr Effect And Self-focusing In Nodal Semimetals In Terahertz Regime** **Tu-AM-3-2**

Chao Zhang
Northfield Avenue, Wollongong

We determine the Kerr index, associated critical Kerr power, and focal length of nodal semi metals. The focal lenth is directly relate the dynamical non-linear optical conductivity of the semimetal. In this framework, through the non-linear conductivity, one can directly observe how the Kerr index is altered by intrinsic parameters of the semimetal such as node separation and bandgap, which determine its topological phase. In THz and microwave regime, Kerr index is found to be around 10^15â^'10^20 m^2/W. Dependence of the Kerr index, critical power and focal length on temperature, chemical potential, band gap and node separation are obtained. Our result shows that the tunability of the non-linear response of a nodal semimetal persists in its focusing phenomenon.

11:15 **Terahertz Characterization Of Charge Carrier Dynamics In 3D Dirac Semi-metal Cd3As2 Nanowires** **Tu-AM-3-3**

Yahya Saboon[1]; Xinyn Liu[1]; Thorsten Hesjedal[2]; Michael Johnston[3]; Laura Herz[3]; Jessica Boland[4]
[1]Photon Science Institute, Department of EEE, Manchester; [2]Department of Physics, Clarendon Laboratory, room 149, Oxford; [3]Clarendon Laboratory; [4]Photon Science Institute

In summary, we have highlighted the potential of Cd3As2 nanowires in various innovative applications such as usages in high-speed optoelectronics and ultrafast optical switches, owning to high charge carrier mobility at room temperature for its nanowires.

11:30 **THz-induced Carrier Multiplication In TaAs Weyl Semimetal** **Tu-AM-3-4**

Sarah Houver[1]; Davide Soranzio[2]; Simone Biasco[2]; Chandra Shekhar[3]; Claudia Felser[3]; Elsa Abreu[2]; Matteo Savoini[2]; Steven Johnson[2]
[1]10 rue Alice Domon et Léonie Duquet, Paris; [2]Auguste-Piccard-Hof 1, 8093 Zürich; [3]Nöthnitzer Straße, 40 01187 Dresden

Topological Dirac and Weyl semimetals (D&W SM) have attracted a lot of attention due to their unusual electronic properties, which are strongly dependent on the symmetry of the system. By altering the symmetry of the lattice, using for example a pulse of light, one can expect to modify their topological nature and induce/suppress the related properties "on demand". High-field Terahertz (THz) radiation that interacts with vibrational states under near-resonant conditions is a promising pump candidate to induce structural changes in D&W SM compounds, possibly leading to topological transient or permanent changes. There are, however, some challenges to achieving such control. D&W SM have a specific band structure showing a 3D-linear dispersion around nodes, which makes them sensitive to THz-induced carrier multiplication. These carrier multiplication processes can compete with and ultimately screen the interaction of the THz light with vibrational modes. Here, we present recent results of 2D-THz spectroscopy of a bulk Weyl semimetal

TaAs in reflection. We highlight THz-induced carrier multiplication effects and study the field and temperature dependence of the number of carriers induced by the THz field. We examine possible carrier multiplication mechanisms which could be involved.

10:30 - 12:00 **Waveguide** **International I**

Chairperson(s): Vince Wallace,

10:30 **Research And Development Of Corporate-feed Waveguide Slot Array Antennas In 120GHz And 350GHz Bands** **Tu-AM-4-1**

Jiro Hirokawa
S3-20, 2-12-1 Ookayama, Meguro, Tokyo
This talk presents the research and development of the corporate-feed waveguide slot array antennas in 120GHz and 350GHz bands. The 120GHz-band antenna has fabricated by diffusion bonding of laminated thin metal plates. The antenna has a double-layer structure. The bottom layer is a corporate-feed circuit and the upper layer has cavities with radiating slots. Each end of the feeding waveguide has a coupling slot that excites 2x2 radiating slots. All the radiating slots are fed in equal amplitude and phase irrespective of frequency. The full corporate-feed gives wideband characteristics. Low-loss electrical contact is achieved by laminating several metal plates with different waveguide structures and bonding with mechanical pressure and high temperature in a vacuum. The 350GHz-band antenna introduces gold-coating silicon wafers for high precision in the fabrication. The perpendicular corporate-feed is introduced by removing the side walls of the cavities to simplify the radiating layer. A two-dimensional monopulse circuit is integrated with the antenna to achieve polarity orthogonal multiplexing in the rectangular coordinate system for non-far field region to increase the transmission capacity.

11:00 **Time-Domain Integration Of Broadband Terahertz Pulses Via Tapered Two-Wire Waveguide** **Tu-AM-4-2**

Giacomo Balistreri[1]; Alessandro Tomasino[2]; Junliang Dong[1]; Aycan Yurtsever[1]; Salvatore Stivala[3]; José Azaña[1]; Roberto Morandotti[1]
[1]1650, Boulevard Lionel Boulet, Varennes; [2]1650, Boulevard Lionel-Boulet, Varennes; [3]Viale delle Scienze, Palermo
In this work, we report on the implementation of a time-domain integrator device operating on arbitrary broadband Terahertz (THz) pulses. This analog signal-processing functionality is implemented by employing a two-wire waveguide (TWWG) variant, based on a tapered configuration. A conventional TWWG is made of two copper wires separated by an air gap between them. Here, we show here that, if the gap between the wires is much smaller than the THz wavelength and the wire radius, the propagating THz field undergoes a field enhancement factor that is inversely proportional to the THz frequency, thus matching with the spectral behavior of a time-domain integrator. Both simulation and experimental results here demonstrate that the tapered TWWG (briefly, TTWWG) is indeed able to perform the time-domain integration functionality.

11:15 **Low-loss, 1-m Long Length, Hollow-core THz Waveguide Operating At 1 THz, Based On Anti-resonant Guiding Mechanism** **Tu-AM-4-3**

Georges HUMBERT[1]; Jean-Louis AUGUSTE[1]; Guillaume DUCOURNAU[2]; Jean-Francois LAMPIN[2]

[1]123 av. A. Thomas, LIMOGES; [2]Cité Scientifique - Avenue Poincaré, Villeneuve d'Ascq

A hollow-core THz waveguide composed of 10 silica capillaries is designed and fabricated. The waveguide based on the anti-resonant guiding mechanism presents a large transmission window (~ > 600 GHz) centered at 1 THz, with measured propagation losses below 0.5 dB/m.

11:30 **Low-loss Coplanar Waveguide To WR-5 Waveguide E-plane Transition With Bias-Tee.** **Tu-AM-4-4**

Himanshu Gohil[1]; Hui Wang[1]; Diego Pardo[2]; James Seddon[3]; Cyril Renaud[3]; Peter Huggard[1]

[1]R25, RAL Space, Harwell Campus, Didcot; [2]Kings College London, London; [3]University College London, London

We present a grounded co-planar to WR-5 waveguide transition with a bias-tee designed for integration of photodiodes and similar biased devices. The planar waveguide circuit is based on a 75 um thick quartz substrate and allows the packaging of the device in a metallic split-block configuration. The transition has insertion loss of less than 0.3 dB from 140 to 170 GHz, and less than 0.6 dB over the lower half of the WR-5 band.

11:45 **Terahertz Integrated Polarization Rotator Based On Effective-Medium-Clad Waveguide** **Tu-AM-4-5**

Weijie Gao[1]; Withawat Withayachumnankul[2]; Masayuki Fujita[1]; Tadao Nagatsuma[1]

[1]1-3 Machikaneyamacho, Toyonaka, Osaka; [2]Adelaide, South Australia

We propose a terahertz planar polarization rotator monolithically implemented into the all-silicon effective-medium-clad dielectric waveguide platform operating over 260--400 GHz (WR-2.8 band). The proposed polarization rotator consists of a tapered solid and an effective-medium waveguide core surrounded by in-plane asymmetric air-silicon effective-medium claddings based on mode evolution theory. The effective medium plays a key role in significantly enhancing the polarization extinction ratio over a broad bandwidth, leading to an average extinction ratio of > 15 dB over the whole WR-2.8 band with a fractional bandwidth of 42% together with an average insertion loss of < 1 dB on a footprint of 1.36λc × 6.15λc. Such a low-loss and broadband polarization rotator is promising for beyond-5G communications with multi-dimensional multiplexing to increase channel capacities.

10:30 - 12:00 Antenna Imaging Techniques I **International II**

Chairperson(s): Peter Siegel,

10:30 **Complementary Harmonic Suppression Of Radiation At 300/600 GHz By A Pair Of Frequency-Selective Surfaces Fabricated On Polyimide Membranes** **Tu-AM-5-1**

Hui Yuan[1]; Meng Zhang[2]; Daniel Erni[3]; Hartmut G. Roskos[1]
[1]Max-Von-Laue Str.1, Frankfurt am Main; [2]Bismarckstr. 81 (BA), Duisburg; [3]Bismarckstr. 81 (BA)

A harmonic complementary band-stop filter pair for standing-wave suppression at both the signal and the local-oscillator (LO) frequency of a sub-harmonic heterodyne measurement and imaging system is presented. The design of the filters is based on complementary metamaterial structures for 300 GHz, respectively 600 GHz. The filters are implemented on ultra-thin polyimide (PI) membranes which helps to achieve a low insertion loss at the pass bands and gives the filters mechanical flexibility. Experimental results show that the filters provide a 30-dB isolation at the respective stop bands and that they have less than 0.1-dB insertion loss at the pass bands.

11:00 **A Tightly-Sampled Focal Plane Array In 22 Nm CMOS With Integrated Direct-Detectors For Terahertz Imaging Applications** **Tu-AM-5-2**

Martijn Hoogelander; Robbin van Dijk; Maria Alonso-delPino; Marco Spirito; Nuria Llombart
Mekelweg 4, Delft

The design of a focal plane array (FPA) for imaging at sub-mm wavelengths generally is a trade-off between resolution and sensitivity. For maximum angular resolution, minimal spacing between FPA elements is desired, which leads to increased losses due to spillover and mutual coupling and therefore deteriorates the imaging sensitivity. This work presents the characterization of an ultra-wideband (200 GHz - 600 GHz) FPA with integrated direct-detectors, achieving a tight sampling of the focal plane by implementing overlapping of the feed elements, hence alleviating the penalty in aperture efficiency. The overlapping of the feed elements in implemented using a combination of a dual-polarized connected array configuration resembling a chessboard, and leaky-wave propagation in the CMOS stratification. The measured radiation patterns and aperture efficiency show <1dB agreement with simulations. Moreover, a beam spacing corresponding to a near diffraction-limited resolution is combined with a minimum cross-over level below 2 dB over the entire band, making this design a promising candidate for high-resolution terahertz imaging systems. To demonstrate the imaging capabilities of the chessboard array, a quasi-optical imaging setup was developed.

11:15 **A Shaped Quartz Lens Antenna For Wide Scanning Sub-millimeter Imaging Systems** **Tu-AM-5-3**

Huasheng Zhang; Shahab Oddin Dabironezare; Nuria Llombart
Delft University of Technology, Delft

Lens based focal plane arrays (FPAs) with thousand elements are promising candidates for wide scanning sub-millimeter security imaging systems. To analyze such arrays, a coherent Fourier Optics approach is employed to design an FPA of quartz lenses coupled to a reflector. We consider quartz as the lens

material due to its lower cost with respect to silicon-based lens arrays and focus on the design of the lens element at the edge of the FPA. The reflector's scanning angle at the edge of its FPA is 20.3 degrees, and the lens surface is shaped to couple better to the reflector. The performance of the optimized shaped lens is validated by full-wave simulation with excellent agreement. The simulated scan loss of the system is 2.8 dB. A prototype was fabricated and will be measured to validate this performance.

11:30 **Near-field Characterization Of A GHz Branchline Coupler Using A THz Microscope** **Tu-AM-5-4**

Marius Neumann; Paul Julius Ritter; Julius Mumme; Meinhard Schilling; Benedikt Hampel
Hans-Sommer-Str. 66, Braunschweig

The design of microwave circuits is usually based on simulations, which can be supported by S-parameter measurements to evaluate the circuit's performance after fabrication. Some characteristics of complex designs cannot be investigated this way, but advanced measurement methods can improve the design process significantly. In this work, a THz microscope is used to characterize a microwave network consisting of a branchline coupler and multiple patch antennas in a frequency range of 20 to 40 GHz. The radiation intensity above the patch antennas is spectroscopically measured and compared to conventional S-parameter analyses. The near-field pattern of the circuit is spatially measured and compared to corresponding simulations. The THz microscope is a versatile tool that can be used to validate simulation results and improve the overall microwave circuit design process.

11:45 **Multi-Spectral Photonic THz Imaging Using MUTC-PDs And Dielectric Rod Waveguide Antennas** **Tu-AM-5-5**

Israa Mohammad; Thomas Haddad; Sumer Makhlouf; Andreas Stöhr
Lotharstraße 55, Duisburg

We present a photonic-assisted multi-spectral THz imaging approach employing ultra-broadband modified UTC photodiodes (MUTC-PDs), wideband dielectric rod waveguide (DRW) antennas, and THz Schottky barrier diode (SBD) envelope detectors. The MUTC-PDs connected to the DRW antennas enable multi-spectral imaging from 60 GHz to above 300 GHz. For experimental validation, a standard USAF resolution target is utilized as a device under test proving a resolution power of ?/2 is achieved at 300 GHz.

13:30 - 15:30 **Laser Sources & Detectors III** **Symposia Theatre**

Chairperson(s): Mona Jarrahi,

13:30 **High Sensitivity Spectroscopic Measurement With A Highly Nonlinear THz-PMT And An Is-TPG** **Tu-PM1-1-1**

Naoya Kawai[1]; Hisanari Takahashi[2]; Kota Katsuyama[1]; Yuma Takida[3]; Tobias Olaf Buchmann[4]; Matej Sebek[4]; Simon Jappe Lange[4]; Peter Uhd Jepsen[4]; Hiroaki Minamide[3]; Hiroshi Satozono[2]; Takayuki Ohmura[1]
[1]314-5,Shimokanzo, Iwata City; [2]5000,Hirakuchi, Hamamatsu City; [3]519-1399

Aramaki-aza Aoba, Sendai City; [4]2800 Kongens, Lyngby

High-speed and high-sensitivity detectors are required for applications such as spectroscopy and imaging using terahertz (THz) waves. So far, we have developed THz-Photomultiplier Tube (THz-PMT)/ THz-Image Intensifier (THz-I.I.), which is a combination of THz wave-to-electron conversion using a metasurface to enable THz-driven field emission, a PMT and an I.I.. In this report, we use an injection-seeded THz-wave Parametric Generator (is-TPG) as a narrowband and frequency-tunable pulsed THz-wave source with a THz-PMT detector to measure the water vapor concentration of air. The THz-PMT detector has a highly non-linear response to changes in the electric field strength from the is-TPG source, which allows for precise characterization of the water absorption spectrum and temporal changes herein. We perform a frequency sweep from 0.7 to 1.2 THz and show that our THz-PMT signal drops significantly at water absorption lines. This standard technique, operated on our novel THz instrumentation, is expected to enable highly sensitive spectroscopic measurements.

13:45 **Simultaneous Measurement Of Orthogonal Terahertz Fields Enabled Via A THz MODEM (modulator/demodulator) Scheme** **Tu-PM1-1-2**

Huiliang Ou[1]; Rayko Stantchev[2]; Mykhaylo Semtsiv[3]; William Masselink[3]; James Lloyd-Hughes[4]; Emma MacPherson[4]

[1]Gibbet Hill Rd, Coventry; [2]70 Lienhai Rd, Kaohsiung; [3]Unter den Linden 6; [4]Gibbet Hill Rd

A scheme is proposed and demonstrated that realizes the rapid simultaneous measurement of orthogonal terahertz fields. A fibre-coupled multi-pixel THz emitter on InGaAs generated orthogonal polarization states, with a dynamic range and bandwidth comparable to a commercial antenna. We developed a dual-frequency modulation/demodulation scheme that used a conventional photoconductive detector to record the orthogonal polarization states. This work has significant potential to improve the speed of polarization-resolved THz spectroscopy and imaging. We demonstrate its efficiency by characterizing birefringent crystalline materials and anisotropic metamaterial.

14:00 **Graphene Field-effect Transistors As THz Detectors: Distinguishing Between Resistive Self-mixing And The Hot-carrier Thermoelectric Effect** **Tu-PM1-1-3**

Florian Ludwig[1]; Andrey Generalov[2]; Jakob Holstein[1]; Anton Murros[2]; Klaara Viisanen[2]; Mika Prunnila[2]; Hartmut G. Roskos[1]

[1]Max-von-Laue-Strasse 1, Frankfurt am Main; [2]Tietotie 3, Espoo

Graphene-based detectors of THz radiation -- despite their improvement over the years -- continue to exhibit a lower sensitivity than detectors made from other materialsystems. In order to gain a deeper understanding of some of the detection processes and their constraints, we analyze here experimentally and by simulations the operation of graphene TeraFETs, detectors based on rectification in antenna-coupled field effect transistors, over the frequency range 0.1-1.2 THz. The devices were fabricated with an advanced wafer-scale process technology. It is well-known that two detection mechanisms contribute, resistive self-mixing and the photothermoelectric effect. We determine the

respective contributions to the responsivity and their frequency dependencies, put the results into perspective with competing technologies, and suggest ways to improve detector performance.

14:15 **A Novel Scattering-type THz Microprobe With Integrated Source And Detector For Contact-free, High-speed Surface Imaging At Sub-μm-resolution** **Tu-PM1-1-4**

Martin Priwisch[1]; Michael Nagel[2]; Alexander Michalski[2]; Denise Priwisch[1]; Yoonkyung Jang[1]; Ikseon Jeon[1]; Inkeun Baek[1]
[1]1-1 Samsungjeonja, Hwaseong-si; [2]Otto-Blumenthal-Strasse 25, Aachen

Terahertz (THz) Time Domain Spectroscopy (THz-TDS) provides an interesting set of possibilities for contactless wafer inspection as many used materials contain resonant features in their refractive indices within the THz-spectrum. It can be used to analyze electrical properties, such as sheet resistance. Even though there is a large set of advantages for THz-TDS, the wavelength of THz radiation is often in the same or higher range as geometric features of interest. The limits for the spatial resolution of THz measurements are therefore given by the THz waves while scattering effects are not limited by the wavelength. To make use of the THz scattering effect to achieve spatial resolutions in the nanometer scale scattering-type Scanning Near-field Optic Microscopy (s-SNOM) can be used. One major hurdle for implementing s-SNOM is the complex setup required for alignment and operation since the THz emitter, the scattering tip and the THz detector are separated. A method is presented where a new THz probe antenna design provides the possibility to measure THz scattering and allows high spatial resolutions by combining those components into a probe tip. As a result, a high spatial resolution can be achieved, and an oscillation tip can be omitted.

14:30 **The In-plane Photoelectric Effect For Terahertz Detection In Two- And Quasi-one-dimensional Electron Systems** **Tu-PM1-1-5**

Wladislaw Michailow[1]; Sergey Mikhailov[2]; Nikita Almond[1]; Harvey Beere[1]; David Ritchie[1]
[1]JJ Thomson Avenue, Cambridge; [2]Universitätsstraße 1, Augsburg

The in-plane photoelectric (IPPE) effect is a quantum phenomenon in 2D electron systems that can be used to efficiently detect THz radiation. In this effect, electrons absorb THz photons and jump onto an artificially created, electrically tunable potential step within the plane of a degenerate 2D electron gas. We show the experimental realization of this principle in photoelectric tunable-step (PETS) detectors, a new type of dual-gated antenna-coupled THz detectors exploiting the IPPE effect. The devices demonstrate a strong photoresponse, which can only be explained by the IPPE effect. We demonstrate key advantages that the 2D IPPE effect offers when compared to the conventional, 3D photoelectric effect. We also present our theoretical results on the IPPE effect in a 2D- and in a quasi-1D-electron system.

14:45 **On-Chip Direct Laser Writing Of Spectral Filter Structures For Terahertz Field-Effect Transistors** **Tu-PM1-1-6**

Michael Kocybik[1]; Jakob Holstein[2]; Erik Waller[1]; Alvydas Lisauskas[2]; Hartmut Roskos[2]; Maris Bauer[1]; Fabian Friederich[1]
[1]Fraunhofer-Platz 1, Kaiserslautern; [2]Max-von-Laue-Straße 1, Frankfurt am Main
We demonstrate first results of 3D direct laser writing (DLW) of metallic filter structures on narrow-band antenna-coupled field-effect transistors (TeraFET) directly on the detector chip. The chip itself contains a spectroscopic line array of resonant TeraFETs ranging from 0.53 to 1.98 THz. We apply a 3D laser metal writing (DLW) process directly on the die, printing filter structures made of silver particles for the narrowing of the frequency response and the suppression of spurious waves. In our first measurements, we investigate changes in the detection resonance frequency in comparison to bare TeraFET arrays from the chip foundry.

15:00 **Design And Characterization Of A Hairpin Filter At GHz Frequencies Using A THz Microscope For Near-Field Analysis** **Tu-PM1-1-7**

Paul Julius Ritter; Marius Neumann; Julius Mumme; Meinhard Schilling; Benedikt Hampel
Hans-Sommer-Str. 66, Braunschweig
Microwave filters are widely used for telecommunication applications and measurement systems. Hairpin filters are very compact edge couple bandpass filters, which typically exhibit low insertion loss and a narrow bandwidth. In this work, a hairpin filter with a designed center frequency of 34.38 GHz is investigated. The scattering parameters are measured with a network analyzer and the near-field distribution is measured spatially at multiple frequencies with a THz microscope, using a superconducting Josephson cantilever. The measured results of the hairpin filter agree well with the 3D electromagnetic simulations. The THz microscopy setup is capable of measuring three-dimensionally the intensity and frequency of field distributions from 1 GHz to 5 THz. This setup is a versatile tool for characterizing and optimizing microwave circuits and can be used to validate simulation results.

15:15 **Implementation Of A Multi-element Detector Consisting Of An 8×8 Network Of Patch-antenna-coupled TeraFETs For Gas Spectroscopy With THz-QCLs** **Tu-PM1-1-8**

Jakob Holstein[1]; Michael Horbury[2]; Nicholas North[2]; Harry Godden[2]; Lianhe Li[2]; Joshua Freeman[2]; Alexander Valavanis[2]; Edmund Linfield[2]; Alvydas Lisauskas[1]; Hartmut G. Roskos[1]; Anastasiya Krysl[1]
[1]Max-vonLaue Straße 1, Frankfurt am Main; [2]Woodhouse, Leeds LS2 9JT
Monolithically integrated, antenna-coupled field-effect transistors (TeraFETs) are known as sensitive detectors, which can be designed to work properly over the entire THz range (0.1-10 THz). In this work, we present a new multi-element THz detector design. It employs 8Ãf-8 monolithically integrated patch-antenna-coupled TeraFETs fabricated in a commercial 65-nm CMOS process. In contrast to conventional detector matrices, where each TeraFET represents a pixel, here the entire TeraFET network serves as a single pixel, combining the output signals of all elements in a parallel read-out circuit. The matrix approach offers two advantages: A larger effective detector area, which

makes beam alignment easier, and a significantly reduced electriÃ‚Â¬cal resistance down to approx. 300 ÃZÂ© at the working bias point, leading not only to a reduction in detector noise but also to an increase in modulation bandwidth, which improves the time resolution of measurements of dynamical processes. We demonstrate applicability of the detector for laboratory methanol gas spectroscopy at 3.4 THz with a quantum cascade laser (QCL) applied as a radiation source.

13:30 - 15:30 **Spectroscopy II** **Cartier I**

Chairperson(s): Masaya Nagai,

13:30 **Breath Analysis Of COPD Patients By Terahertz/Millimeter-Wave Gas Spectroscopy -- A Proof-of-Principle Study** **Tu-PM1-2-1**

Nick Rothbart[1]; Rembert Koczulla[2]; Olaf Holz[3]; Klaus Schmalz[4]; Heinz-Wilhelm Hübers[1]

[1]Rutherfordstr. 2, Berlin; [2]Malterhoeh 1; [3]Feodor-Lynen-Straße 15; [4]Im Technologiepark 25

We demonstrate the application of terahertz/millimeter-wave gas spectroscopy to the analysis of exhaled human breath from a clinical environment. 28 sets of samples from patients with the Chronic Obstructive Pulmonary Disease were measured and analyzed. Comparison with gas chromatography-mass spectrometry, a very well-established method, showed very good correlation of up to R=0.93. The variations between duplicate samples were also as small as in the reference measurements.

13:45 **Investigating The Rigidity Of Ortho-terphenyl** **Tu-PM1-2-2**

Johanna Koelbel[1]; Michael T. Ruggiero[2]; J. Axel Zeitler[3]; Daniel M. Mittleman[1]

[1]Department of Engineering, 184 Hope Street, Providence; [2]Department of Chemistry, 82 University Pl, Burlington; [3]Department of Chemical Engineering, Philippa Fawcett Drive, Cambridge

The molecular glass former ortho-terphenyl has traditionally been used as a model system for rigid molecular solids. This assumption has been questioned, and therefore its rigidity was investigated by experimental terahertz time-domain spectroscopy and low-frequency Raman spectroscopy and theoretical density functional theory. The results show that there are a number of coupled internal and external motions present in the terahertz regime that contradict the assumption that ortho-terphenyl is rigid.

14:00 **Analytical Terahertz Wave Absorption Spectroscopy Of Dimethyl Ether** **Tu-PM1-2-3**

Ingrid Wilke[1]; Megan N. Powers[2]; Timothy E. Rice[2]; Arshad Chowdhury[2]; Muhammad Waleed Mansha[3]; Mona M. Hella[3]; Matthew A. Oehlschlaeger[4]

[1]Department of Physics, 110 8th St., Troy; [2]Department of Mechanical Engineering, 110 8th Street, Troy; [3]Department of Electrical Engineering, 110 8th St., Troy; [4]Department of Mechanical Engineering, 110 8th St., Troy

Terahertz (THz) wave rotational absorption spectra of dimethyl ether (DME) are reported. Measurements have been performed at room temperature and pressures of 1 to 8 Torr (1.22 to 10.67 mbar) in the 220 to 330 GHz frequency band using an electronic THz wave spectrometer. Observed rotational transition frequencies and absorption strengths are in very good agreement with literature and extent prior work to conditions where considerable pressure broadening occurs. A room temperature collisional self-broadening coefficient of 12.1 GHz / bar for DME has been derived. The potential of THz wave absorption measurements for quantitative DME gas sensing in industry and the environment is demonstrated.

14:15 **Real-Time Terahertz Absorption Spectroscopy Of Methanol And Deuterated-Methanol Vapour, Using A TeraFET Detector Array** **Tu-PM1-2-4**

Michael Horbury[1]; Nicholas North[2]; Jakob Holstein[3]; Harry Godden[2]; Lianhe Li[2]; Joshua Freeman[2]; Edmund Linfield[2]; Hartmut Roskos[3]; Alvydas Lisauskas[3]; Alexander Valavanis[2]
[1]University of Leeds, Leeds; [2]University of Leeds; [3]D-60438 Frankfurt am Main

We have demonstrated the potential of terahertz (THz) spectroscopy using a THz-frequency quantum cascade lasers coupled with a THz field-effect-transistors detector as a tool for probing chemical reactions, by observing distinct transitions in methanol and deuterated methanol (CH3OD) in the 3.35, 3.4 and 3.45 THz region.

14:30 **Mapping Of Kidney Stone By Far-Infrared Spectroscopy** **Tu-PM1-2-5**

Verdad Agulto[1]; Wangxuan Zhao[1]; Mihoko Maruyama[1]; Masae Takahashi[2]; Kosaku Kato[1]; Valynn Katrine Mag-usara[1]; Masato Ota[1]; Yutaro Tanaka[1]; Yusuke Mori[1]; Masashi Yoshimura[1]; Makoto Nakajima[1]
[1]Suita, Osaka; [2]Sendai, Miyagi

Kidney stones are mainly composed of calcium oxalate (CaOx) minerals, and the understanding of the polymorphisms of CaOx is essential in establishing the pathogenesis of kidney stone formation. CaOx polymorphs are predominantly calcium oxalate monohydrate (COM) and calcium oxalate dihydrate (COD). In this study, we employ reflection-mode Fourier transform infrared spectroscopy in the far-infrared region to map the spatial distribution of the main CaOx phases in a thin section of kidney stone. A higher reflectance band is observed on the COD-rich areas of the kidney stone compared to COM-rich areas in the spectral region between 5-10 THz. The spatial distribution of COM and COD phases is demonstrated herein based on the reflectance map utilizing the selected frequency of 8 THz. Our results show that THz waves could be useful in kidney stone analysis without an invasive sample preparation, thereby preserving the spatial information of the stone which contains the history of the stone formation process.

14:45 **The Temperature Dependent Changes In The Terahertz Absorption Spectrum Due To The Self-assembly Of Quadruplexes In A Solution Of The Nucleoside Guanosine Monophosphate** **Tu-PM1-2-6**

Yu Heng Tao[1]; Simon Schulke[2]; Gerhard Schwaab[2]; Steffen Murke[2]; Simone Pezzotti[2]; Stuart Hodgetts[1]; Alan Harvey[1]; Vincent Wallace[1]; Martina Havenith[2]

[1]35 Stirling Highway, Crawley; [2]Universitätsstraße 150, Bochum

The self-assembly of the nucleoside guanosine monophosphate (GMP) into complex DNA secondary structures, in aqueous solution is concentration and temperature dependent. It is a unique phenomenon that provides a basis for studying more complicated structures related to DNA. In the present study, we show that distinct features in the terahertz spectrum (30 to 400 cm-1, 0.8 to 12 THz) are associated with the formation of GMP dimers and quadruplexes, and that these can be attributed to changes in the hydration water and intra-molecular modes of the aggregated structures. This finding establishes a basis for further investigation into secondary DNA structures using terahertz radiation, such as G-quadruplex and i-motif.

15:00 **Liquid-Liquid Phase Separation Of Protein By Trivalent Heavy Metal Ions: Ion-specific Alteration Of Water Structure Exposed By THz Study** **Tu-PM1-2-7**

Ria Saha[1]; Rajib Mitra[2]

[1]JD Block, Sector 3, Salt Lake City, Kolkata - 700106, India, Kolkata; [2]JD Block, Sector 3, Salt Lake City, Kolkata - 7001, Kolkata

We show that trivalent ions (specifically Lanthanide heavy metals) can induce microscopic liquid-liquid phase separation (LLPS) of globular protein (bovine serum albumin) in which protein rich phase co-exists with a dilute phase. The protein rich LLPS droplets are characterized by dynamic light scattering and optical microscopy measurements. We investigated the perturbation of hydration structure at protein surface using THz-FTIR spectroscopy technique. We found highly ion-specific protein hydration at RT and at temperature above melting temperature of protein where the existence of LLPS still observed.

15:15 **Sensing Alcohol Contamination In Water by THz Time Domain Ellipsometry** **Tu-PM1-2-8**

Zahra Mazaheri[1]; Gian Paolo Papari[2]; Antonello Andreone[2]

[1]Via Vicinale Cupa Cintia, 26, 80126 Naples NA, naples; [2]Via Vicinale Cupa Cintia, 26, 80126 Naples NA

We report on the use of a customized time-domain THz ellipsometer to monitor the effect of a contaminant on the dielectric response of water. The setup can detect in a very simple way small changes in the optical properties of aqueous mixtures due to the presence of low amount of isopropyl alcohol. We tested the dielectric response of different volume concentrations by directly measuring the ellipsometric parameters for each mixture. We observed a sharp, nonlinear decrease in the absorption coefficient by gradually adding alcohol in water. Significant deviations between experimental data and the theoretical expectations are interpreted as due to competing effects produced by the amphipathic nature of the contaminant.

13:30 - 15:30 Condensed Matter II **Cartier II**

Chairperson(s): Renee Sher,

13:30 **THz Spontaneous Magnon Fluctuations And Room-temperature Spin Switching In The Orthoferrite Sm0.7Er0.3FeO3** **Tu-PM1-3-1**

Takayuki Kurihara[1]; Marvin Weiss[2]; Andreas Herbst[2]; Julius Schlegel[2]; Tobias Dannegger[2]; Martin Evers[2]; Andreas Donges[2]; Makoto Nakajima[3]; Sebastian T.B. Goennenwein[2]; Ulrich Nowak[2]; Alfred Leitenstorfer[2]
[1]5-1-5 Kashiwanoha, Kashiwa; [2]Universitaetsstrasse 10, Konstanz; [3]2-6Yamadaoka, Suita

Ultrafast dynamics of correlated spins in the picosecond to femtosecond timescales have so far been pursued mainly with pump-probe schemes by perturbing the system and measuring the induced changes. Here, we reveal the femtosecond time-resolved autocorrelation function of the sub-THz spontaneous spin fluctuation dynamics in an orthoferrite, existent under the ambient condition due to thermal occupation. The correlation dynamics shows a significant enhancement of the amplitude and coherence time around the spin reorientation transition temperature, which is ascribed to the spontaneous switching of spin moment between the energetically degenerate states.

14:00 **Differentiation Of The Microstructures Of Agarose Hydrogels Using Terahertz Time Domain Spectroscopy (THz-TDS)** **Tu-PM1-3-2**

Mark Justine Zapanta; Annelies Postelmans; Wouter Saeys
Kasteelpark Arenberg 30, Heverlee

Agarose hydrogels are widely used analytical separation media in chemistry and tissue scaffold in biomedical engineering because of their highly tunable mechanical and rheological properties. The functional properties of these gels are attributed to its fibrillar mesh microstructure. However, a foil microstructure of the agarose hydrogel was recently observed and described. It is important to differentiate these two microstructure as they have different properties. In this work, the use of terahertz time domain spectroscopy (THz-TDS) to differentiate the two microstructure of agarose hydrogels was demonstrated. Using the global hydration number calculated from the THz permittivity, it was found that the two microstructures have different hydration environments, with the foil microstructure having a greater hydration number than the mesh microstructure. To validate the presence of the two distinct microstructures, scanning electron microcopy (SEM) was used to visualize the microstructures and rheometry was employed to demonstrate the difference in their chain flexibility.

14:15 **Low-Frequency Vibrational Spectroscopy And Crystal Structure Predictions For Fumaric Acid And Maleic Acid** **Tu-PM1-3-3**

Salvatore Zarrella; Timothy Korter
Department of Chemsitry, 111 College Place, Syracuse

Low-frequency vibrational spectroscopy of molecular crystals provides new benchmarks for validating crystal structure prediction methods based on fundamental computational chemistry simulations. The terahertz and Raman spectra of the lattice vibrations of crystalline maleic acid and fumaric acid have been measured and then successfully modeled using solid-state density functional theory to accurately account for the intermolecular forces in the crystals. This rigorous computational approach has been combined with a

faster-running molecular mechanics evaluation of numerous crystal packing variations to identify previously unknown polymorphs of both compounds.

14:30 **Probing Ultrafast Non-equilibrium Dynamics In An Organic-dimer Mott Insulator With Terahertz-infrared Continuum Probe Pulses** **Tu-PM1-3-4**

Konstantin Warawa[1]; Yassine Agarmani[1]; Harald Schubert[1]; Martin Dressel[2]; Michael Lang[1]; Hartmut G. Roskos[1]; Mark D. Thomson[1]
[1]Max-von-Laue-Str. 1, Frankfurt am Main; [2]Pfaffenwaldring 57, Stuttgart

We apply optical-pump terahertz-infrared-probe reflection spectroscopy to study the non-equilibrium dynamics in the Mott insulator κ-(BEDT-TTF)Cu[N(CN)2]Cl (κ-Cl), following intra-molecular electronic excitation of the organic dimers. The perturbation and subsequent relaxation of the correlated electronic system is treated with a global spectral analysis including a bleach of the inter-Hubbard-band transition and a photoinduced low-frequency contribution from the excitations above the Mott gap, providing a more complete picture of the nature of the excited states.

14:45 **Crystal Symmetry Effects On Protein Structural Vibrational Signatures** **Tu-PM1-3-5**

Andrea Markelz[1]; Alexander McNulty-Romaguera[2]; Jeffrey McKinney[3]; Deepu George[4]; Timothy Lafave[5]; Alex Davie[6]; Tod Romo[7]; Alan Grossfield[7]; Jason Benedict[8]; Xiaotong Zhang[8]
[1]239 Fronczak Hall, Buffalo; [2]239 Fronczak Hall; [3]45 Dan Rd, Canton; [4]Laurel Brook Road; [5]239 Fronczak; [6]West Henrietta, NY; [7]Rochester, NY; [8]Buffalo, NY

The method of terahertz anisotropic microspectroscopy (ATM) is robust method to fingerprint protein structural vibrations. Potentially ATM could address why there are evolutionarily dominant structural motifs as well as the development of allosteric drugs for protein function regulation. However, it is important to confront the possible pitfall that the structural vibrational bands measured by ATM do not reflect in vivo dynamics. In particular, it is well known that while many proteins can function in crystallo, proteins requiring large conformational change cannot, due the crystal contact forces preventing large-scale motions. Here we compare ATM measurements of hen egg white lysozyme (HEWL) crystallized in three different symmetry groups to spectra calculated using normal mode ensemble analysis (NMEA). The studies demonstrate that in fact, as the actual atomic displacements are vastly smaller than the crystal unit cell, there is little effect of the crystal contact forces on the spectra.

15:00 **Emission Of Coherent THz Magnons In An Antiferromagnetic Insulator Triggered By Ultrafast Spin--phonon Interactions** **Tu-PM1-3-6**

Enzo Rongione[1]; Oliver Gueckstock[2]; Maximilian Mattern[3]; Olena Gomonay[4]; Meer Hendrik[4]; Christian Schmitt[4]; Rafael Ramos[5]; Takashi Kikkawa[6]; Martin Micica[7]; Eiji Saitoh[5]; Jairo Sinova[4]; Henri Jaffrès[1]; Juliette Mangeney[7]; Sebastian Goennenwein[8]; Stephan Gerpraegs[9]; Tobias Kampfrath[2]; Mathias Kläui[4]; Matias Bargheer[3]; Tom Seifert[2]; Sukhdeep Dhillon[7]; Romain Lebrun[7]

[1]Université Paris-Saclay, Palaiseau; [2]Freie Universität Berlin; [3]Universität Potsdam; [4]Johannes Gutenberg-University Mainz; [5]Tohoku University; [6]The University of Tokyo; [7]24 rue Lhomond, Paris; [8]University of Konstanz; [9]Bayerische Akademie der Wissenschaften

Antiferromagnetic (AFM) materials have been proposed for new types of narrowband THz spintronic devices owing to their ultrafast spin dynamics. Although manipulating coherently their spin dynamics remains a key challenge, this can be potentially accomplished by spin-orbit torques or direct optical excitations. Here, we demonstrate the combined generation of broadband THz (incoherent) magnons and narrowband (coherent) magnons at 1 THz in ultra-thin films of AFM -- heavy metal (NiO/Pt). We show, experimentally and through modeling, two excitation processes of the spin dynamics in NiO, an off-resonant instantaneous optical spin torque in (111) oriented films and a strain-wave induced THz torque induced by ultrafast Pt excitation in (001) oriented films. These phenomena leads to broadband and narrow band THz emission, respectively, through the inverse spin Hall effect in the adjacent heavy metal layer, opening new routes towards the development of fast opto-spintronic devices based on AFM materials.

13:30 - 15:30 **Space, Environment, Communications and Spectroscopy** **International I**

Chairperson(s): Tsung-Tse Lin,

13:30 **Stratospheric Balloon Missions For High Resolution Submillimeter-FIR Astronomical Spectroscopy** **Tu-PM1-4-1**

Paul Goldsmith
4800 Oak Grove Dr., Pasadena

Many spectral lines that are key tracers of star formation lie in the submillimeter and far-infrared. This wavelength range is almost completely blocked for astronomical observations by terrestrial water vapor, and studies must be carried out from stratospheric or space platforms. Stratospheric balloons are currently the only platforms for carrying out observations throughout the 1000 -- 5000 GHz frequency range. I present the science goals of two NASA Antarctic balloon missions that are being developed to observe some of the most important fine structure lines. The Galactic/Extragalactic Ultra/Long Stratospheric Terahertz Observatory (GUSTO; C. Walker, [University of Arizona], PI), which will observe lines of N+, C+, and O0. Employing a 90cm diameter telescope, GUSTO will map the central portion of the Milky Way and the Large Magellanic Cloud. The s Astrophysics Stratospheric Telescope for High Spectral Resolution Observations at Submillimeter wavelengths (ASTHROS; J. Pineda, [JPL], PI), which will observe both fine structure lines of ionized nitrogen. With a 2.5m diameter telescope, ASTHROS will have high angular resolution and be able to make detailed measurements of the electron density in ionized regions. These missions both depend on advances in technology that allow sensitive submillimeter heterodyne focal plane arrays with modest power consumption.

14:00 **Silicon Meta-Optics For Compact Space-Based Optical Systems** **Tu-PM1-4-2**

Conner Ballew; Sven van Berkel; Subash Khanal; Cecilia Leung; Leslie Tamppari; Goutam Chattopadhyay
4800 Oak Grove Dr, Pasadena

Meta-optics made of low-loss dielectric material can simultaneously control spatial, spectral, and polarization properties of light with high efficiency, and in wavelength-scale volumes. By inverse-designing the shape of the Si layers using multi-objective optimization, complex multi-functionality can be realized offering an extraordinary path towards miniaturizing optical system. This talk will cover the fabrication, assembly, and characterization of meta-optics imaging systems being developed for space-based terahertz imaging. The concept of an extremely small instrument capable of high-resolution spectroscopy and high-gain beam steering enabled by meta-optics will be presented.

14:15 **Radiometric Calibration Of A Hyperspectral Microwave Sounder** **Tu-PM1-4-3**

Natalia Bliankinshtein[1]; Philip Gabriel[2]; Olivier Auriacombe[3]; Yi Huang[4]; Mengistu Wolde[5]; Shiqi Xu[5]; Lei Liu[4]; Jean-Christophe Angevain[6]
[1]1200 Montreal road U-61, Ottawa; [2]Wolfville; [3]Gothenburg; [4]Montreal; [5]Ottawa; [6]Noordwijk

Hyperspectral microwave sounding of atmospheric temperature and humidity profiles is a promising application for spaceborne weather observation. This approach extends the capabilities of more traditional infrared sounders to include in-cloud retrievals, significantly expanding the observational scope of the remote sensing technique. Calibration of microwave spectrometers is a vital step, ensuring the accuracy of observations and, consequently, retrieved profiles. Here, we study the calibration of HiSRAMS, a prototype tested on an airborne platform in Canada in 2021--2023. Due to design constraints, HiSRAMS is susceptible to errors arising from quasi-optical standing waves and environment-dependent biases. Cryogenic calibration results, standing wave corrections, and bias analysis are discussed.

14:30 **On The Design Of Wide Band Multi-lens Focal Plane Arrays For The TIFUUN Instrument** **Tu-PM1-4-4**

Alexandra Mavropoulou[1]; Shahab Oddin Dabironezare[1]; Jochem Baselmans[2]; Akira Endo[1]
[1]Mekelweg 4, Delft; [2]Niels Bohrweg 4, Leiden

Terahertz Integral Field Unit with Universal Nanotechnology (TIFUUN) is a wideband spectral mapper operating at (sub)-millimeter wavelengths. The instrument is under development for ground-based astronomy and will be deployed to the ASTE telescope in Chile. In this work, the building blocks for TIFUUN's wideband (2:1) mappers are discussed. These components are based on multi-lens focal plane arrays of leaky lens antennas coupled to filter banks based on Microwave Kinetic Inductance Detectors.

14:45 **Two-Dimensional Fixed-Frequency Terahertz Beam Steering Based On Displacement Controlled Leaky-Waveguides** **Tu-PM1-4-5**

Naoki Tanaka; Yasuaki Monnai
4-6-1, Komaba, Meguro-ku

Terahertz waves are expected to accommodate broad bandwidth required for

the Beyond 5G/6G. However, diffraction losses of terahertz waves become much severer than that of microwaves. To negate the diffraction losses, directional transmission with terahertz beam steering capability is strongly needed. Currently, practical phase shifters to implement beam steering in the terahertz band are not available. To address this challenge, we develop a novel method of two-dimensional beam steering based on a displacement-controlled leaky-waveguide composed of parallel metal plates, which is fed by a planar parabolic mirror. We demonstrate two-dimensional beam steering without sweeping the frequency. This method will be important for practical wireless communication.

15:00 **MmWave Vs FSO Propagation: First Results From An Experimental Testbed In Italy** **Tu-PM1-4-6**

Elizabeth Verdugo[1]; Lorenzo Luini[2]; Carlo Riva[2]; Gianluca Galzerano[1]; Laura Resteghini[3]; Christian Mazzucco[3]; Roberto Nebuloni[1]
[1]Piazza L. da Vinci, 32, Milan; [2]Via Ponzio 34/5, Milan; [3]Centro Direzionale Milano 2, Palazzo Verrocchio Se, Milan

Optical wireless links, namely Free-Space Optics (FSO), and mmWave links, appear to meet the high-capacity requirements for backhauling in the next-generation communications systems. However, wireless links at such high frequencies are susceptible to weather conditions. Specifically, FSO is severely affected by fog attenuation, while mmWaves struggle through the rain. Moreover, the theory predicts that the impact of rain on FSO is not as significant as on mmWaves, due to the forward scattering gain. Two mmWave links (at E- and D-band, respectively) and a near-IR FSO link have been deployed across an 800-m path in Milan, Italy, to study those effects. The experimental setup also includes weather sensors (disdrometers and visibilimeters) on either side of the path. Results collected during an 8-hour rainy event are presented here. FSO attenuation (in dB) is around 50% of mmWave attenuation at a peak rainfall rate of 20 mm/h

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13:30 - 15:30 Chemistry, Biology & Medicine I **International II**

Chairperson(s): Daniel Molter,

13:30 **Terahertz-driven Electron Field Emission And Ion Field Evaporation: Application To Atom Probe Tomography** **Tu-PM1-5-1**

Angela Vella[1]; Michella Karam[1]; Jonathan Houard[1]; Ganesh Damarla[1]; Said Idlahcen[2]; Anna Martinez[3]; Domenico Paparo[3]; Ammar Hideur[2]
[1]Avenue de l'Université BP 12, Saint Etienne du Rouvray; [2]Avenue de l'Université, Saint Etienne du Rouvray; [3]Monte S. Angelo, via Cintia, Napoli

Single-cycle terahertz (THz) pulses have been used to drive electron emission from biased and unbiased metallic nano-tips. The electron emission yield and the maximum electron energy are linked to the THz near-field. Recently, the development of similar approaches to drive ions emission was reported. Field

emission of positive ions from a nanometric tip (called field evaporation) is the basic principle of the Atom Probe Tomography, which is a 3D imaging technique based on controlled field evaporation of atoms from a nanometric needle shaped sample under a strong electric field. Here we report on the use of single-cycle THz pulses to emit electrons and ions from nanometric tips. The THz source used in our experiments is a homemade laser based on two-color plasma generation. By election emission, the temporal shape of the THz near-field signal is measured as a function of the relative time delay between the THz pulse (pump) and the near infrared pulse (probe). In the case of positively biased nanotips the enhancement of terahertz field allows to trigger the emission of positively charged ions from the nano-tip. Based on this effect, we demonstrate a high-chemical and spatial resolutions terahertz- assisted APT instrument.

14:00 **Detection Of Nucleocapsid Proteins Of COVID-19 Using A Terahertz Chemical Microscope** **Tu-PM1-5-2**

Xue Ding[1]; Sayaka Tsuji[2]; Mana Murakami[3]; Jin Wang[4]; Hirofumi Inoue Inoue[5]; Toshihiko Kiwa[5]

[1],3-1-1 Tsushimanaka kitaku, Okayama; [2]Okayama University, 3-1-1 Tsushima-naka,kita-ku; [3]Okayama University, 3-1-1 Tsushimanaka kitaku; [4]Okayama University, 3-1-1 Tsushimanaka kita-ku; [5]Okayama University

Since the first person infected with COVID-19 was diagnosed in December 2019, the infection has spread rapidly all over the world. PCR and antigen testing are commonly used to detect infection, but detection sensitivity and sample size can be improved. In our group, a terahertz chemical microscope (TCM) has been developed. In this study, we successfully detected the SARS-CoV-2 nucleocapsid proteins (N protein) in solutions by immobilizing the aptamer and N protein on a sensing plate using avidin-biotin reaction.

14:15 **Terahertz ATR Sensing Of Cell Membrane Permeabilization during Trypsin Proteolysis** **Tu-PM1-5-3**

Guilhem Gallot[1]; Blandine Lordon[2]

[1]Route De Saclay, Palaiseau; [2]route de Saclay, Palaiseau

Using both terahertz ATR sensing and fluorescence confocal microscopy, we were able to disentangle permeabilization and geometry effects and to provide quantitative dynamics during trypsinization. We observed that geometric effects are negligible at low concentrations of trypsin and become noticeable at high concentrations. Permeabilization is clearly observed by terahertz sensing even at the lower concentrations, with potentially harmful consequences for the treated cells.

14:30 **Out Of Focus Terahertz Reflection Measurements For The Determination Of The Porosity Of Pharmaceutical Tablets Based On The Refractive Index** **Tu-PM1-5-4**

Moritz Anuschek[1]; Thomas Kvistgaard Vilhelmsen[2]; J. Axel Zeitler[3]; Jukka Rantanen[4]

[1]Universitetsparken 2, København; [2]Novo Nordisk Park 1, Maalov; [3]Philippa Fawcett Dr, Cambridge; [4]Universitetsparken 2, Copenhagen

The refractive index of pharmaceutical tablets at terahertz frequencies has been known to correlate well with tablet porosity, making terahertz time-domain spectroscopy (THz-TDS) a promising approach to monitor the physical attributes of tablets. THz-TDS transmission measurements are commonly applied for this purpose; however, reflection measurements should be considered as it probably would be easier to implement in a production setting and does not rely on the sample thickness. In this study the applicability of out of focus THz-TDS reflection measurements for the refractive index of pharmaceutical tablets of different mass and porosity is demonstrated. A good correlation of the refractive index and tablet porosity was found. Further, the measurement of the sample surface without prior focus adjustment allowed for an additional height determination. The developed method was considered a promising approach to determine tablet porosity in a pharmaceutical manufacturing setting.

14:45 **Broadband Mm-wave Sealed-volume Liquid Bio-sensor Exploiting Tailored Delocalization Of Modal Fields In A Micro-scale Silicon Waveguide** **Tu-PM1-5-5**

Daniel Headland[1]; Daniel C. Gallego[2]; Muhsin Ali[2]; Ashish Kumar[1]; Marina Moreno Mayorga[3]; Horacio Lamela[1]; José M. Sánchez-Puelles[3]; Guillermo Carpintero[1]
[1]Av. de la Universidad 30, Leganés; [2]Parque Tecnológico, Av. Gregorio Peces Barba, Leganés; [3]C. Ramiro de Maeztu, 9, Madrid

We demonstrate mm-wave sensing of a sealed volume of bio-liquid via a dielectric waveguide's evanescent fields, which are enhanced by narrowing the guide core in order to reduce field confinement. This is exploited to investigate whether a culture of Gliboblastoma cells effects a measurable change in the composition of a nutrient solution. A small discernible decrease in absorption is observed, indicating potential for future safe and noninvasive mm-wave diagnostic tools.

15:00 **Evaluation Of Reflective Properties Of Meta-atoms Using Point Terahertz Sources And Its Application In Microfluidics** **Tu-PM1-5-6**

Luwei Zheng; Kazuki Hara; Masayoshi Tonouchi; Kazunori Serita
Suita, Osaka, Japan, Osaka, Japan

We present the evaluation of reflective properties of terahertz (THz) meta-atoms, an elementary unit of metamaterials, by using point THz sources in the near-field region and their application in microfluidics. The near-field THz emission is locally generated in the process of optical rectification in a non-linear optical crystal, GaAs at a femtosecond laser focusing irradiation spot and excites the meta-atoms, which results in a change in the resonance states. The reflected THz wave pulses are detected by using a typical THz Time-domain spectroscopy technique. The response of meta-atoms with various configurations has proved to be of great potential in interacting with each other in a very sensitive way due to the electric-field-coupling-effect, which leads to a higher spatial resolution and detecting sensitivity. These results promise to accelerate the development of industrial/medical applications with micro-scale

resolution and THz lab-on-chip devices with high sensitivity for bio-sensing and trace amount detection.

15:15 **Polarization-Sensitive THz Time-Domain Imaging Of 27 By 27 Mm2 Field Of View At About 0.5 Frames Per Second Using The PHASR Scanner 3.0** **Tu-PM1-5-7**

Zachery Harris; Kuangyi Xu; M. Hassan Arbab
Bioengineering, 100 Nicolls Rd., Stony Brook

We present the terahertz Portable HAndheld Spectral Reflection (PHASR) Scanner version 3.0, a polarization-sensitive imaging system, which can acquire a 1 inch-square full THz-TDS images in about 2 seconds. Here, we demonstrate three improvements made from the previous generation of PHASR Scanners: (1) changes to the beam steering, hardware and algorithms that allow faster scanning speed (2) a four-channel design featuring two emitters and two detectors to allow single-shot acquisition of multiple polarization states, and (3) the addition of an achromatic waveplate for control of the generated polarization states. We will present spectroscopic and polarimetric applications of this system.

16:00 - 18:00 **Laser Sources & Detectors IV** **Symposia Theatre**

Chairperson(s): Rebecca Milot,

16:00 **Terahertz Electrometry Via Infrared Spectroscopy Of Atomic Vapor** **Tu-PM2-1-1**

Shuying Chen; Dominic J. Reed; Andrew R. MacKellar; Lucy A. Downes; Nourah F. A. Almuhaw; Matthew J. Jamieson; Charles S. Adams; Kevin J. Weatherill
Durham University, Durham

Nowadays, the characterization of radiation falling within the so-called "terahertz (THz) gap" has become an prominent issue due to the increasing use of THz systems in applications such as non-destructive testing, security screening, telecommunications, and medical diagnostics. THz detection technologies have advanced rapidly, yet traceable calibration of THz radiation remains challenging. Here we demonstrate a system of electrometry in which a THz signal can be characterized using laser spectroscopy of highly excited (Rydberg) atomic states. We report on proof-of-principle measurements that reveal a minimum detectable THz electric field amplitude of 1.07 ± 0.06 V/m at 1.06 THz with 3 ms detection time, corresponding to a THz power at the atomic cell of approximately 3.4 nW. Due to the relative simplicity and cryogen-free nature of this system, it has the potential to provide a route to a SI traceable "atomic candle" for THz calibration across the THz frequency range and provide an alternative to calorimetric methods.

16:30 **Investigation Of Fast Frequency Selective Qualitative Terahertz Spectroscopy** **Tu-PM2-1-2**

Rejeena R Sebastian; Redwan Ahmad; Xavier Ropagnol; François Blanchard
100 Notre-Dame St W, Montreal, Quebec H3C 1K3, Montreal

We present a new method for ultrafast qualitative terahertz (THz) spectroscopy using a combination of broadband THz pulses and a Schottky energy sensor. By integrating a mechanical chopper composed of frequency-selective surfaces

in front of the detector, samples are identified by combining unique spectral signatures normalized to each filter transmission. This simple scheme will have a significant impact on the advanced detection of THz solutions for real-world applications and provide a new playground for predictive modelling of the THz signal.

16:45 **Rapid-Scan High-Resolution Frequency-Domain THz Spectroscopy With Dynamical Phase Control** **Tu-PM2-1-3**

Yuto Shoji; Eiji Ohmichi; Hideyuki Takahashi; Hitoshi Ohta
1-1 Rokkodai, Nada, Kobe

In this study, we developed a technique for rapid-scan high-resolution THz spectroscopy. By locking the photocurrent at its extremum using a feedback circuit, a high-speed data acquisition rate as fast as 18 points/s was achieved. This value corresponds to about hundredfold improvement from our previous setup. We compared transmission spectra between the present and previous techniques, and found that both gave identical results. The present technique was applied to THz spectroscopy of gas-phase acetonitrile, and the periodic absorption spectra with a spacing of 18.30 GHz, characteristic for gas-phase acetonitrile was successfully observed. The present technique will be useful for spectroscopic studies of sharp resonances in the THz region such as electron spin resonance, gas-phase spectroscopy, and whispering gallery mode resonance.

17:00 **10 THz Bandwidth With A Fiber-Coupled THz Time-Domain Spectrometer** **Tu-PM2-1-4**

Tina-Celine Hesselmann; Lars Liebermeister; Alexander Dohms; Steffen Breuer; Shahram Keyvaninia; Marko Gruner; Konstantin Wenzel; Martin Schell; Robert Kohlhaas
Einsteinufer 37, Berlin

Fiber-coupled terahertz (THz) time-domain spectrometers (TDS) are versatile tools that are used extensively in academia and industry. Here, we examine two different THz sources with the aim to reach the highest spectral bandwidth: A DSTMS crystal and a photoconductive membrane emitter. With both sources, we demonstrate record bandwidths around 10 THz. At the same time, the photoconductive emitter leads to a 30 dB-higher peak dynamic range of up to 100 dB at 1 THz.

17:15 **Single-shot Spectrometers And Realtime THz Digitizers, Using Diversity Electro-Optic Sampling (DEOS)** **Tu-PM2-1-5**

Eléonore Roussel[1]; Christophe Szwaj[1]; Clément Evain[1]; Bernd Steffen[2]; Christopher Gerth[2]; Marie Kristin Czwalinna[2]; Bahram Jalali[3]; Serge Bielawski[4]
[1]Bat. P5; [2]Notkestr. 85, Hamburg; [3]University of California Los Angeles; [4]Bat. P5, Villeneuve d'Ascq

Recording a THz waveform in single-shot is needed in Time-Domain Spectroscopy (TDS) and the study of accelerator physics. However, existing methods suffer from fundamental trade-offs in bandwidth, resolution, and

sensitivity, which have limited their applications so far. We present here a new method for single-shot Time-Domain Spectrometers -- or equivalently terahertz Analog to Digital Converters (ADC) -- that can be operated with unprecedented temporal resolution and bandwidths. The core of the method consists of a novel association of classical THz electro-optic detection, together with the theoretical concept known as diversity, borrowed from photonic time-stretch. We present prototypes and tests of two single-shot systems: a TDS system capable of single-shot THz spectroscopy with record spectral resolution, and a THz recorder that records the electric field created by 200 fs long relativistic electron bunches at European XFEL.

17:30 **Single-Shot Terahertz Waveform Detection By Chirped-Pulse Up-Conversion Spectroscopy With Dispersion Compensation** **Tu-PM2-1-6**

Ryo Tamaki[1]; Jun Takeda[2]; Ikufumi Katayama[2]
[1]705-1 Shimoimaizumi, Ebina; [2]79-5 Tokiwadai, Hodogaya, Yokohama

Chirped-pulse spectroscopy combined with single-shot electro-optic (EO) sampling enables to detect terahertz waveform in time-domain without scanning the relative time delay between the terahertz wave and the probe pulses. In this study, we demonstrate reduction of the waveform distortion appeared in the chirped-pulse spectroscopy by combining sum-frequency generation and dispersion compensation. In addition, by performing the phase offset EO sampling, the positive and negative phase offset signals were measured simultaneously to reduce the common mode noise. As the result, single-shot terahertz waveform detection with a ±50 V/cm accuracy was achieved.

17:45 **Comparative Study Of Terahertz Chemical Microscopy And Flexible ISFET Approaches For Calcium Ion Detection** **Tu-PM2-1-7**

Sota Yoshida[1]; Toshihiko Kiwa[1]; Jin Wang[1]; Kenji Sakai[2]
[1]Kita-ku, Tsushima-naka 1-1-1, Okayama city; [2]Tatara-Toya 1-3, Kyotanabe city

In this study, we conducted a comprehensive comparison of two advanced techniques, terahertz chemical microscopy (TCM) and ion-sensitive field-effect transistors (ISFET), for calcium ion detection. The results revealed the advantages and limitations of TCM and flexible ISFET, offering valuable insights into their applications and improvements.

16:00 - 18:00 **Ultrafast & Nonlinear Phenomena I** **Cartier I**
Chairperson(s): Andrey Baydin,

16:00 **Quantitative Terahertz Magnetometry** **Tu-PM2-2-1**

Dmitry Turchinovich[1]; Wentao Zhang[2]
[1]Universitätsstr. 25, Bielefeld; [2]Universitätsstr. 25

Here we present the adaptation of THz emission spectroscopy to precise measurements of ultrafast magnetization dynamics in materials [1]. Within our approach, the sub-picosecond and picosecond dynamics of a macroscopic magnetic moment in a material can be reconstructed from the observable - the

THz electrooptic signal detected in a far-field, in a fully calibrated manner. As an example, we present the measurement of ultrafast demagnetization in laser-excited iron nanofilm, and demonstrate two contributions to the process - direct laser-driven transient demagnetization via hot-magnon emission, and an additional process of transient demagnetization driven by a coherent acoustic phonon [2]. The challenges and requirements for successful implementation of ultrafast THz magnetometry will be discussed. The quantitative effect of spectrometer misalignment and the most optimal THz emission spectrometer configuration will be demonstrated. [1]. W. Zhang and D. Turchinovich, "Rigorous signal reconstruction in terahertz emission spectroscopy," Opt. Express 29, 2441 (2021). [2]. W. Zhang, P. Maldonado, Z. Jin, T. S. Seifert, J. Arabski, G. Schmerber, E. Beaurepaire, M. Bonn, T. Kampfrath, P. M. Oppeneer, and D. Turchinovich, "Ultrafast terahertz magnetometry," Nature Communications 11, 4247 (2020).

16:30 **Terahertz Field-Driven Nonlinear Magnonics In Antiferromagnets** **Tu-PM2-2-2**

Zhuquan Zhang[1]; Frank Gao[2]; Zi-Jie Liu[1]; Yu-Che Chien[1]; Alexander von Hoegen[1]; Jonathan Curtis[3]; Prineha Narang[3]; Edoardo Baldini[2]; Keith Nelson[1]
[1]77 Massachusetts Avenue, Cambridge; [2]Main Building (MAI) 110 Inner Campus Drive Austin, Austin; [3]405 Hilgard Avenue, Los Angeles

Coherent excitations of magnetically ordered materials, referred to as spin waves and their quanta, magnons, have emerged as prominent candidates for interference-based signal processing technologies. Despite growing interest in manipulating magnonic states beyond thermodynamic equilibrium, elucidating and inducing coherent couplings between distinct magnon modes remains a formidable challenge. By developing and employing a novel two-dimensional (2D) terahertz (THz) polarimetry technique facilitated by single-shot detection, we successfully uncover correlated magnonic states at the sum and difference frequencies of the two modes, as well as a second-order magnon upconversion response. These findings not only expand the domain of nonlinear magnonics by incorporating antiferromagnets but also lay the groundwork for further advancements in the ultrafast control of magnetism.

16:45 **Femtosecond Laser-induced Ultrafast Magnetization In Two-dimensional Magnetic Material-antiferromagnetic Heterostructures** **Tu-PM2-2-3**

Peiyan Li[1]; Sai Chen[1]; Shanshan Liu[2]; Faxian Xiu[2]; Wei He[3]; Xiaojun Wu[1]
[1]No. 37 Xueyuan Road, Haidian District, Beijing; [2]57 Wudong Road, Yangpu District, Shanghai; [3]55 Zhongguancun East Road,Haidian District,Beijing

Here, we demonstrate the ultrafast magnetization of the two-dimensional magnetic material Fe3GeTe2 (FGT) pumped by 80-MHz femtosecond laser pulses, which is discovered by the spintronic terahertz (THz) emission spectroscopy in (Fe3GeTe2/CrSb)3 superlattice. Measurements at room temperature reveal the emergence of light-tunable room-temperature ferromagnetism in FGT, as its intrinsic Curie temperature TC is 206 K. As verification for this wondering phenomenon, we also measured the ultrafast magnetization dynamics by tr-MOKE.

Hysteresis-induced Multistability In A Nonlinear Terahertz Split Ring

17:00 **Resonator** **Tu-PM2-2-4**

Gervais Dolvis Leutcho; Lyne Woodward; François Blanchard
1100 R. Notre Dame O, Montréal

The development of photonic memory devices will be a big issue in the future for applications such as communication. Multistability will therefore be a desired behavior for such devices. In this paper, the dynamical behavior of a nonlinear split-ring resonator (NSRR) under AC and DC excitation is investigated in two-parameter space diagram at terahertz (THz) frequency regime. The hysteresis effect induces multistability in the NSRR and some coexisting dynamic regions are revealed. The results obtained in this work not only demonstrate that multistable metasurfaces are feasible, but also provide some numerical leads to researchers who are already thinking about the development of multistable terahertz devices.

17:15 **High Field Terahertz Time-Domain Spectroscopy Of Lactose Monohydrate** **Tu-PM2-2-5**

Thomas Gill; Andrew Burnett; Connor Kidd; Aniela Dunn; Joshua Freeman; Edmund Linfield; Alexander Davies; Paul Dean; Calum Towler; Lianhe Li
University of Leeds, Woodhouse Lane, Leeds

High field terahertz spectroscopy measurements of lactose monohydrate are presented. It is found that the feature at 0.53 THz, relating to the translatory motion of the lactose molecules along the long axis of the unit cell, becomes saturated with an incident THz field strength of 26 kV/cm for a pure powdered lactose sample. We also obtain an estimate of the feature at 1.37 THz to become saturated with a THz field strength of 205 kV/cm. This nonlinear saturation indicates the potential of dynamically distorting the crystal structure at sufficiently high fields.

17:30 **Terahertz Nonlinear Photonics Based On The Ultrafast Thermodynamics Of Quantum Materials** **Tu-PM2-2-6**

Klaas-Jan Tielrooij
Den Dolech 2, Eindhoven

Quantum materials with massless Dirac fermions -- such as graphene and topological insulators -- exhibit extremely large terahertz nonlinearities. This is the result of their ultrafast thermodynamics: efficient electron heating-cooling dynamics taking place on femtosecond-picosecond timescales. We have recently developed a grating-graphene metamaterial with local field enhancement, giving rise to strongly enhanced THz nonlinearities in graphene. These grating-graphene metamaterials, however, suffer from saturation effects due to inefficient electronic heat dissipation, and therefore produce limited harmonic output power. Most recently, we have used a topological insulator system with surprisingly efficient surface-to-bulk electronic heat dissipation, which strongly reduces saturation effects. As a result, we demonstrated close to a milliwatt of generated third harmonic signal from a fundamental signal at 500 GHz. These results have interesting prospects for nonlinear terahertz photonic applications.

16:00 - 18:00 Topological & 2D Materials **Cartier II**

Chairperson(s): Taiichi Otsuji,

16:00 **Efficient Terahertz Harmonic Generation In Topological Metamaterials** **Tu-PM2-3-1**

Sergey Kovalev[1]; Klaas Tielrooij[2]; Igor Ilyakov[3]; Jan Deinert[3]; Thales Oliveira[3]; Alexej Ponomaryov[3]; Alessandro Principi[4]; Alexander Block[2]; Sabin Varghese[2]; Steffen Schreyeck[5]; Karl Brunner[5]; David Reig[2]; Grzegorz Karczewski[5]; Carmen Carbonell[2]; Sergio Valenzuela[2]; Laurens Molenkamp[5]; Tobias Kiessling[5]; Georgy Astakhov[3]
[1]Bautzner Landstrasse 400, Dresden; [2]Barcelona; [3]Bautzner Landstrasse 400; [4]Manchester; [5]Würzburg

Graphene, with its massless Dirac surface states, exhibits large THz nonlinear susceptibilities leading to efficient THz high harmonic generation (HHG). However, the THz HHG efficiency in graphene strongly saturates with increasing incident field strength, limiting the HHG field conversion efficiency to a level of 1%. Here, we show that the THz HHG efficiency can be significantly enhanced at high THz driving fields by mitigating the overheating problem, making use of the efficient heat exchange between surface and bulk states of topological insulators. By implementing topological-based metamaterials for field enhancement, THz third harmonic generation with ~10% field conversion efficiency is demonstrated. These results are of particular interest for efficient on-chip optoelectronic devices operating at ultrahigh frequencies.

16:30 **Observation Of Terahertz Emission From Topological Material Candidate SrCd2Sb2 Single Crystals** **Tu-PM2-3-2**

Po-Wei Gong[1]; Yi-Cheng Cheng[1]; Pei-Tsung Yang[1]; Xin-Yun Chang[1]; Jiun-Haw Chu[2]; Cheng-Chien Chen[3]; Jiunn-Yuan Lin[1]; Chih-Wei Luo[1]; Chien-Ming Tu[1]
[1]No. 1001, Daxue Rd. East Dist., Hsinchu; [2]Physics-Astronomy Building, Rm. C121, Box 351560, Seattle; [3]Campbell Hall, Rm.310, 1300 University Blvd., Birmingham

We report on terahertz emission from topological material candidate SrCd2Sb2 single crystals under ultrafast optical excitation with different polarization. Nonzero circular dichroism of the emitted THz radiation were observed as the polarization of optical pulses switch from right circular polarization to left circular polarization. The observed phenomena are coincident with circular photogalvanic effect. Our work demonstrates the potential applications of SrCd2Sb2 on opto-spintronics devices.

16:45 **Topological Materials For Helicity-dependent THz Emission** **Tu-PM2-3-3**

Abdul Mannan[1]; Yahya Saboon[1]; Chelsea Xia[2]; Djamshid Damry[1]; Piet Schoenherr[2]; Dharmalingam Prabhakaran[2]; Laura M Herz[2]; Thorsten Hesjedal[2]; Michael Johnston[2]; Jessica Louise Boland[1]
[1]University of Manchester, Oxford Rd, Manchester; [2]University of Oxford, Parks Rd, Oxford

Topological insulator (TI) materials are emerging as novel materials for spintronic applications. Here, we demonstrate helicity-dependent THz emission from Dirac semi-metal Cd3As2 nanowires and used scattering-type scanning optical microscopy (s-SNOM) to identify potential single nanowire candidates for device applications. The preliminary investigation data of a candidate nanowire shows a homogenous topography and constant dielectric function in the MIR range. Indicating high-quality crystalline growth ideal for topological characterization.

17:00 **Terahertz Surface Plasmon Resonance In Dirac Electron System Topological Insulator (Sb, Bi)2(Te, Se)3** **Tu-PM2-3-4**

Hinano Sugimoto[1]; Kana Nishimura[2]; Hitoshi Tabata[2]
[1]Engineering Building 5, 7-3-1 Hongo, Bunkyo-ku, Tokyo-to; [2]Engineering Building 5, 7-3-1 Hongo, Bunkyo-ku

Terahertz wave, corresponding to intermolecular binding energy, is the key to realize a non-labeling bio-medical sensor. We aim to enhance the sensitivity by a selective resonant excitation effect of the specific binding and surface plasmon at the THz band. Here, we report the THz-SPR of (Bi, Sb)2(Se, Te)3 in both experiments and calculations. We have revealed that bulk electron influence seen in band structure may not contribute much to SPR, and Bi2Se3 has the highest Q value among graphene or topological insulator below 1 THz. Furthermore, the sugar chain-lectin specific binding, which has weaker interactions than antigen-antibody binding, was also observed due to the enhancement of Bi2Se3 THz-SPR.

17:15 **Temperature Dependance Of Intrinsic Spin Orbit Coupling Gap In Graphene Probed By Terahertz Photoconductivity** **Tu-PM2-3-5**

Kenneth Maussang[1]; Khalid Dinar[1]; Cédric Bray[1]; Christophe Consejo[1]; Juan Antonio Delgado-Notario[2]; Sergey Krishtopenko[1]; Ivan Yahniuk[3]; Sebastian Gerbert[1]; Sandra Ruffenach[1]; Erwin Moench[4]; Kornelia Indykiewicz[5]; Benjamin Benhamou -- Bui[1]; Benoit Jouault[1]; Jérémie Torres[1]; Yahya Moubarak Meziani[2]; Wojciech Knap[1]; August Yurgens[6]; Sergey Ganichev[3]; Frédéric Teppe[1]
[1]Place Eugène Bataillon, Montpellier; [2]USAL-Nanolab, Salamanca; [3]Terahertz Centre, Regensburg; [4]Terahertz Center, Regensburg; [5], Wroclaw University of Science and Technology, Wroclaw; [6]Chalmers University of Technology, Göteborg

Graphene is a quantum spin Hall insulator, with a nontrivial topological gap induced by the spin-orbit coupling. Such splitting is weak (~45μeV) in the absence of external magnetic field. However, due to rather long spin-relaxation time, graphene is an attractive candidate for applications in quantum technologies. When it is encapsulated in hexagonal boron nitride, the coupling between graphene and the substrate compensates intrinsic spin-orbit coupling and decreases the nontrivial topological gap, which may lead to phase transition into a trivial band insulator state. In this work, we have measured

experimentally the zero-field splittings in monolayer and bilayer graphene by the means of subterahertz photoconductivity-based electron spin resonance technique. The dependance in temperature of such splittings have been also studied in the 2-12K range. We observed a decrease of the spin splittings with increasing temperature. Such behavior might be understood from several physical mechanisms that could induce a temperature dependence of the spin-orbit coupling. These includes the difference in the expansion coefficients between the graphene and the boron nitride substrate or the metal contacts, the electron-phonon interactions, and the presence of a magnetic order at low temperature.

17:30 **Tunable Plasmonic Graphene Antenna Array For Communications At THz Frequencies** **Tu-PM2-3-6**

Elana P. de Santana[1]; Daniel Stock[1]; Zhenxing Wang[2]; Kun-Ta Wang[2]; Sergi Abadal[3]; Max Lemme[2]; Peter Haring Bolívar[1]
[1]Hölderlinstr. 3, Siegen; [2]Otto-Blumenthal-Straße 25, Aachen; [3]Jordi Girona, 1-3, Mòdul D6, Barcelona

The existence of plasmonic waves at a graphene/dielectric interface at THz frequencies enables the use of graphene as the radiative element of antennas working at this frequency range, but with a smaller lateral dimension compared to a standard metallic antenna. Due to the low carrier mobility in large-area graphene, result of its manufacturing process, the emitted radiation of graphene antennas is still smaller than its metallic counterpart. In this work, we show that the low emission of a graphene antenna can be compensated by antenna arrays. The proposed 1x4 graphene antenna array presents a far-field radiated gain of 9.3 dBi with a resonance frequency at 269 GHz. The resonating frequency of the graphene antenna array can also be tuned by an electrostatic bias.

17:45 **Tuneable Terahertz Frequency-selective Absorber Based On A Graphene/gold Bilayer Metasurface** **Tu-PM2-3-7**

Andrew Squires[1]; Xiang Gao[2]; Jia Du[1]; Zhaojun Han[1]; Dong han Seo[3]; James Cooper[1]; Adrian Murdock[1]; Simon Lam[1]; Ting Zhang[1]; Tim van der Laan[1]
[1]36 Bradfield Road, Lindfield; [2]Haidan District; [3]Naju

In this work, a 0.2 THz electrically tuneable frequency-selective absorber is designed, fabricated, and experimentally tested. The tuneable absorber is achieved through a novel graphene/gold bilayer with a superimposed metamaterial structure. With this approach, a high-quality resonance is provided by the gold, with electrical tuneability from the graphene, in the bilayer. 16 dB of amplitude tuning at the designed 0.2 THz resonance is demonstrated, alongside 95% broadband modulation for only 6V applied bias. Terahertz time domain spectroscopy in reflection geometry is used to experimentally characterize the device, developed through an equivalent circuit model and three-dimensional full wave modelling and simulation in CST Microwave Studio. The design, fabrication and testing method are readily adaptable to other non-tuneable metal metasurfaces to produce a myriad of reconfigurable terahertz devices.

16:00 - 18:00 Passive Components **International I**

Chairperson(s): Hui Yuan,

16:00 **A Spiral Phase Plate Prepared Via High-resolution 3D Printing For THz Vortex Beam Generation** **Tu-PM2-4-1**

Andreea Aura Paraipan[1]; Innem V. A. K. Reddy[2]; Giacomo Balistreri[1]; Luca Zanotto[1]; Diana Gonzales-Hernandez[3]; Mostafa Shalaby[4]; Roberto Morandotti[1]; Carlo Liberale[3]; Luca Razzari[1]
[1]1650 Blvd. Lionel Boulet, Varennes; [2]Thuwal 23955-6900, Kingdom of Saudi Arabia; [3]Thuwal 23955-6900; [4]8005 Zürich

Three-dimensional (3D) printing technologies have recently been used for the fabrication of custom optical components in the terahertz (THz) range, with benefits related with flexible design, fast prototyping, and preparation of on-demand devices. However, standard 3D printing methods have a limited spatial resolution (~100 Âμm), typically allowing the fabrication of components with the necessary precision only for frequencies of a few hundred GHz. The advanced 3D printing method based on two-photon polymerization (TPP) can instead give access to nanoscale resolutions (< 100 nm). Here, we employ this technique to fabricate a spiral phase plate (SPP, i.e., a device that can convert a Gaussian beam into a vortex beam with a helical phase) operating at around 1 THz. Using our recently developed scanless THz time-domain imaging (TDI) method, we experimentally retrieve hyperspectral information about both the amplitude and phase of the generated vortex beam, which is found to agree with the results of our numerical simulations.

16:15 **Fabrication Of Freestanding THz Band-pass Filters** **Tu-PM2-4-2**

Erwin Hack; Ivan Shorubalko; Jil Graf; Peter Zolliker; Elena Mavrona
Uberlandstrasse 129, Dubendorf

We present a fabrication concept for freestanding THz filters and other photonic elements. It uses a polymer film substrate onto which a designed metamaterial is processed using standard clean-room processes. Elements are framed to custom dimensions and shapes using 3D printing. The resulting freestanding elements are robust, easy to handle, and mountable. We assessed the performance of the fabricated band-pass filters using THz time-domain spectroscopy. The process is adaptable to other wavelength ranges and has the potential for upscaling in manufacturing.

16:30 **A High Q-Factor 270 GHz 3D-printed Photonic Crystal Slot Resonator** **Tu-PM2-4-3**

Yixiong Zhao[1]; Masoud Sakaki[1]; Niels Benson[2]; Jan Balzer[1]
[1]Bismarckstrasse 81, Duisburg; [2]Bismarckstr. 81, Duisburg

In this paper, we fabricate a PhC slot resonator using LCM technique. The PhC with rectangular holes shows good performance and agrees with the simulation results. The LCM technique has high potential for fabricating 3-dimensional and complex structures for THz devices.

16:45 **A Combined 60/170 GHz Notch Filter For Collective Thomson Scattering At ITER** **Tu-PM2-4-4**

Dietmar Wagner[1]; Walter Kasparek[2]; Fritz Leuterer[1]; Harald Schütz[1]; Jörg Stober[1]; Manfred Thumm[3]
[1]Boltzmannstr. 2, Garching; [2]Pfaffenwaldring 31, Stuttgart; [3]Kaiserstr. 12, Karlsruhe

A Collective Thomson Scattering (CTS) diagnostic system is planned for the International Thermonuclear Experimental Reactor (ITER), which will be a primary diagnostic for measuring the dynamics of the confined fusion born alpha particles in the ITER plasma. The probe beam for this diagnostic comes from a 60 GHz 1 MW gyrotron. Since the measured signal close to the frequency of the probing beam is in the nW range, the receiver has to be protected with a narrow notch filter rejecting the gyrotron frequency. At the same time it also needs protection against stray radiation from the 20 MW ITER Electron Cyclotron Heating System (ECH), operating at 170 GHz.

17:00 **Monte Carlo Evaluation Of The Effects Of Higher Order Modes In High-power Millimeter-wave Systems** **Tu-PM2-4-5**

Burkhard Plaum
Pfaffenwaldring 31, Stuttgart

The effect of higher order modes on the performance of high-power millimeter wave systems is evaluated with a Monte Carlo method. It makes use of the superposition principle, which allows to simulate the system just for the pure modes resulting in fundamental solutions. For the Monte Carlo analysis, we generate linear combinations of these solutions for 1000s of mode mixtures. The results are histograms for important parameters like peak power densities, truncation losses and the overall heating efficiency. The results can be helpful for the design of high-power millimeter wave systems, especially the dimensioning of cooling systems or the definitions of safety margins in cases, where the expected field strength is close to the breakdown limit.

17:15 **Terahertz CPS-based Spoof Surface Plasmon Polariton Filter On Silicon Nitride Substrate** **Tu-PM2-4-6**

Mohsen Haghighat; Thomas Darcie; Levi Smith
3800 Finnerty Road, Victoria

In this research, we have experimentally verified the performance of a Terahertz (THz) spoof surface plasmon polariton (SSPP) device using a co-planar strip (CPS) transmission line. The CPS-SSPP structure investigated here was initially proposed in [Y. J. Guo, et al., "Spoof plasmonic waveguide developed from coplanar stripline for strongly confined terahertz propagation and its application in microwave filters," Opt. Express, 26, 8, 10589, 2018] [1], but the authors were unable to verify the performance in the THz region due to equipment limitations. We verify their work by using methods commonly used in our research laboratory by fabricating the CPS-SSPP structure on a thin (1 μm) Silicon Nitride membrane to minimize the radiation loss and dispersive effects. After noting inconsistencies incurred by the different substrate conditions via simulation, we find the experiment results agree. Also, for the first time, we demonstrate a guided wave SSPP stopband at a frequency greater than 1.0 THz.

17:30 **Lattice Type Dependence Of Transmittance Spectrum In Moth-eye Antireflective Structures** **Tu-PM2-4-7**

Rikuo Koike; Shotaro Kawano; Haruyuki Sakurai; Kuniaki Konishi; Norikatsu Mio
7-3-1, Hongo, Bunkyo-ku
Moth-eye structures fabricated by laser processing are attracting attention as a broadband antireflection technology in the terahertz band. While increasing the aspect ratio of the structure can broaden the antireflection bandwidth, there is a limit to high aspect ratio processing by laser. In this study, we investigate the dependence of moth-eye structure lattice types as an alternative solution to increase the bandwidth. We fabricated moth-eye structures on high-resistivity silicon with triangular, square, and hexagonal shapes using femtosecond laser processing, and measured their transmittance spectra by terahertz time-domain spectroscopy. In addition, numerical calculations of the transmission spectra were performed using the finite element method from a simple model based on the structural data of the sample. Both experimental and computational results show that the hexagonal lattice moth-eye structure exhibits the broadest antireflection bandwidth the cutoff frequency is 15% higher than that of the conventional square lattice moth-eye structure. This conclusion can be applied to laser-processed moth-eye structures in various frequency bands and is expected to have a wide range of applications.

17:45 **Masked Stereolithography 3D-printed Terahertz Diffractive Lens** **Tu-PM2-4-8**

Po-Jen Yu[1]; Tsung-Chieh Tseng[2]; Yu-Hang Wang[1]; You-Chia Chang[2]; Shang-Hua Yang[1]
[1]No. 101, Sec. 2, Guangfu Rd., East Dist., Hsinchu; [2]1001 University Road, Hsinchu

The design, fabrication, characterization of a 3D-printed terahertz diffractive lens operating at 300 GHz is presented. The designed diffraction lens is composed of connected rectangular pillars to enhance mechanical stability. The size of the square pixel is 500 μm, and the height of the prisms changed from 200 μm to 1800 μm to fully control 2π phase, based on the meta-atom library. Moreover, we use a commercial masked stereolithography (MSLA) 3D printer to fabricate the diffraction lens rapidly with precise structural accuracy and low cost. Here, we demonstrate that the terahertz focusing ability of 3D-printed diffraction lens and the new possibility of functional flat THz optics through additive manufacturing techniques.

16:00 - 18:00 **Chemistry, Biology & Medicine II** **International II**

Chairperson(s): Andrea Markelz,

16:00 **Retrieving The Dynamic Hydration Profile Of Skin In Vivo With A Handheld Terahertz Probe** **Tu-PM2-5-1**

Xuefei Ding; A. I. Hernandez-Serrano; Emma Pickwell-MacPherson
Department of Physics, Coventry

In this work, we measured human skin in vivo with a handheld terahertz probe and demonstrated a method to retrieve the dynamic hydration profile of skin from the raw THz data. We presented the hydration profiles of participants with skin of different Fitzpatrick skin types, and results reveal some correlations between the surface hydration of skin, the thickness of stratum corneum and the skin types.

16:30 **Slush-skin Thickness Measurements With Terahertz Time-Domain Spectroscopy** **Tu-PM2-5-2**

Daniel Molter; Stefan Duran; Jens Klier; Dmytro Kharik; Dominik Gundacker; Joachim Jonuscheit; Georg von Freymann
Fraunhofer-Platz 1, Kaiserslautern

Dashboards of modern vehicles are often covered with PVC skins, which are sometimes made of two layers. To ensure safe airbag deployment in case of a crash, their individual layer thicknesses must be measured non-destructively directly after manufacturing. For this purpose, we have developed a terahertz time-domain spectroscopy system with a hand-held reflective measurement head.

16:45 **Pulsed Terahertz Time Domain Spectroscopy For Evaluating Treatment Efficacy: Initial Validation In Monitoring Pancreatic Ductal Adenocarcinoma** **Tu-PM2-5-3**

Debamitra Chakraborty[1]; Bradley N. Mills[2]; Jing Cheng[1]; Ivan Komissarov[1]; Scott A Gerber[2]; Roman Sobolewski[1]
[1]University of Rochester, Rochester; [2]University of Rochester Medical Center, Rochester

Pancreatic Ductal Adenocarcinoma (PDAC) is a highly invasive malignancy with limited curative effectiveness. Here, we report the viability of using pulsed Terahertz (THz) time domain spectroscopy (THz TDS) to monitor the efficacy of Stereotactic Body Radiation Therapy (SBRT) in treating PDAC in murine models. Our study shows that THz imaging can provide reliable and reproducible results to differentiate the changes in untreated and SBRT-treated PDAC tissue using THz refractive index and absorption coefficient as mapping parameters with statistical significance. Hence the study highlights that pulsed THz-TDS can be used as a technique to monitor tumor responses to immunotherapy, providing a comprehensive assessment of the tumor's reaction to the treatment.

17:00 **Hyperbolic-elliptical Lenses For Rapid THz Reflection Imaging Of Curved Biological Surfaces** **Tu-PM2-5-4**

Arjun Virk; Zachery Harris; Hassan Arbab
100 Nicolls Road, Stony Brook

We describe a novel approach for designing a hyperbolic-elliptical lens pair system and associated normal- incidence beam steering for rapid single-pixel THz-TDS imaging of curved surfaces with a large field-of-view (FOV). The lenses are optimized in an iterative algorithm to ensure phase-front matching to spherical surfaces such as the human cornea. The lenses were fabricated using

HDPE and their optical performance was characterized. The new lenses provide a FOV which is 12% larger than previous methods using off-axis parabolic mirrors, while the beam steering approach reduces scanning time from several minutes to about 4 seconds or less. The scanner developed in this work will enable in vivo imaging of corneas in clinical settings.

17:15 **In-vivo Stratum Corneum Hydration Inspection Using A Non-invasive Terahertz Hand-held Scanner** **Tu-PM2-5-5**

Arturo Hernandez Serrano; Emma Pickwell-MacPherson
Gibbet Hill Road, Coventry

In this work, we successfully measured the hydration dynamics and thickness of the most external layer of skin; the stratum corneum (SC) of 95 healthy volunteers accurately using our own home-built hand-held THz scanner in reflection configuration. The water accumulation in this layer of skin has been monitored within one minute in a non-invasive fashion.

17:30 **Using THz-ATR Spectroscopy For Detecting Mimicked Interstitial Fluid Flow In Ex Vivo Skin** **Tu-PM2-5-6**

Lorenza Pia Foglia; Bjørn Hübschmann Mølvig; Mads Ehrhorn; Miriam Galbiati; Simon Jappe Lange; Peter Uhd Jepsen
Ørsteds Plads, Building 343, Kongens Lyngby

The skin's interstitial fluid (ISF) holds a plethora of biosensing applications due to its accessibility and its rich composition, similar to that of blood. THz-ATR spectroscopy provides the right tools for the development of a non-invasive biomolecular detection scheme in vivo, however, it also presents several challenges. The detection must rely on whole frequency spectra, as these are featureless for solvated biomolecules below 5 THz. The high data complexity invites for the use of machine learning (ML) approaches to process the data. ML approaches are very powerful yet they are very sensitive and require smart engineering of data collection and amplification in order to build good training datasets. We explore this by investigating how to build a dataset for biomolecular detection in ex vivo skin. We propose an experimental procedure for embedding a liquid solution in ex vivo pig skin samples that mimics the ISF's flow from the hypodermis to the viable epidermis. The contrast due to the absorbed solution is shown in the reflectivity and the reproducibility is assessed with respect to sources of variability in the experimental procedure. An optimized protocol represents a steppingstone to further studies towards in vivo THz biosensing.

17:45 **Wavefront Modified Spherical Vector Beams For THz Cornea Imaging** **Tu-PM2-5-7**

Joel Lamberg[1]; Faezeh Zarrinkhat[2]; Aleksi Tamminen[1]; Juha Ala-Laurinaho[1]; Zachary Taylor[1]
[1]Maarintie 8, Espoo; [2]Enterprise Cambridge Research Park, Cambridge

Ocular diseases can be detected in early-stage with non-destructive terahertz imaging by analyzing cornea thickness and water content changes. We propose wavefront-modified spherical vector beam imaging, which reduces nominal 4-5 % super-confocally focused Gaussian beam imaging errors to less than 0.1 %.

18:00 - 19:30 Poster Session 3 **Foyer (3rd**

Recent Advances In THz Clinotrons **Tu-P1-01**

Alexei Kuleshov[1]; Sergey Vlasenko[2]; Sergey Kishko[2]; Sergey Ponomarenko[3]; Eduard Khutoryan[2]
[1]12 ac. Proskura str., Kharkiv; [2]12 ac. Proskura str.; [3]Greifswald, 17491 Germany

Brief description of the clinotron operating parameters in millimeter and THz ranges is presented. The various schemes of the clinotron tubes have been considered and discussed, mainly focusing on the features like generation of intensive sheet electron beam and its transportation with a small inclination angle to the surface of the slow-wave circuit, thermal expansion of the slow-wave circuit elements during the clinotron operation and requirements for the water-cooling system, beam-wave interaction efficiency, both electronic and mechanical frequency tuning. The advantages of the operation of the THz clinotron with multi-period grating on the hybrid bulk-surface modes have been shown and discussed.

THz Detection Optimization Of Antenna Coupled AlGaN/GaN High Electron Mobility Transistors **Tu-P1-02**

Maxim Moscotin[1]; Justinas Jorudas[1]; Miroslav Saniuk[1]; Pawel Prystawko[2]; Sergey Rumyantsev[2]; Wojciech Knap[2]; Grzegorz Cywinski[2]; Irmantas Kasalynas[1]
[1]Sauletekio av. 3, Vilnius; [2]ul. Sokolowska 29/37, Warsaw

In this work we study the THz antenna coupled AlGaN/GaN high electron mobility transistors (HEMTs) in different configurations of the EdgeFET and FinFET designs to develop a sensitive TeraFET detector. The dependence of sensitivity on channel length is found experimentally studying two types of radiation coupling via ohmic and capacitive connection of THz antennas.

Amplified Mode Switching Effect In THz Field Effect Transistors With Grating Gate **Tu-P1-03**

Michael5184218830 Shur[1]; John Mikalopas[2]; Gregory Aizin[2]
[1]9433 van Arsdale Drive, 9433 van Arsdale Drive, Vienna; [2]Kingsborough College of the City University of NYC, 2001 Oriental Blvd, Brooklyn

Short-channel, high-mobility grating gate THz structures maintaining resonant oscillations of the electron density (i.e., plasma waves) in the device channels have the potential to generate high power THz radiation. In this paper, we report on a new effect of Amplified Mode Switching that involves intersecting plasmonic modes and explain recent intriguing experimental data of switching from attenuation to amplification in gated gate graphene structures.

Algorithm For Determination Of Cutoff Frequency Of Noise Floor Level For Terahertz Time-domain Signals. **Tu-P1-04**

Edgar Santiago Reyes Reyes[1]; Ramon Carriles Jaimes[1]; Enrique Castro Camus[2]
[1]Loma del Bosque 115, Leon; [2]Renthof 5, Marburg
The frequency-dependent signal-to-noise ratio of terahertz time-domain signals is a relevant source of uncertainty for parameters measured with it and limits the total usable bandwidth of such signals. Also, nowadays, the volume of data collected in a single data set, such as terahertz time-domain image, reaches tens, and even hundreds of thousands of waveforms, and the calculation of the usable bandwidth of these large datasets becomes a challenge, so this calculation must be automated. In this work we present a method to estimate the bandwidth of terahertz time-domain signals, which can be applied to signals from any terahertz time-domain system.

Coherent Emission From A Linear Array Of RTDs **Tu-P1-05**

Fanqi Meng[1]; Zhenling Tang[2]; Jahnabi Hazarika[3]; Safumi Suzuki[2]; Roskos Hartmut G.[3]
[1]Max von Laue street 1, Frankfurt am Main; [2]O-okayama 2-12-1-S9-3, Meguro-ku,, Tokyo; [3]Max von Laue street 1, Frankfurt

We report coherent emission from a linear array of resonant tunneling diodes (RTDs), each embedded in a slot antenna. The line array consists of 11 RTD elements. The RTD array shows single-frequency oscillation, which is an indication of coherent coupling of the RTDs. The emission frequency features two regimes: a low-frequency regime, where the odd mode will oscillate (the phase of neighboring RTDs are opposite); a high-frequency regime, where the even mode will oscillate (the phase of neighboring RTDs are the same). Which of the two regimes dominates is found to depend on the oscillation frequency of the RTDs.

Passive Compensation Method For Permanent Magnet Undulator Based On Temperature Compensation Alloy **Tu-P1-06**

Longgang Yan; Peng Li; Lijun Chen
Mianshan Road 64, Mianyang

The temperature has a negative impact on the magnetic field of permanent magnet undulator, which must be suppressed to avoid worsening the stability of light source. In this proceeding, a passive compensation method based on temperature compensation alloy is proposed. The compensation condition is derived and it is demonstrated that the method has an excellent temperature compensation effect by simulation. The result shows the impact of temperature on magnetic field is reduced remarkably. In addition, the method can be applied to various types undulators because it isn't related to a specific structure.

Fabrication And Characterization Of Low Barrier Height InAs/GaxIn1-xAs/InAs Heterostructure Diodes Toward Millimeter-wave Detection **Tu-P1-07**

Moto Inoue; Masatoshi Koyama; Toshihiko Maemoto; Shigehiko Sasa
5-16-1 Ohmiya, Asahi-ku, Osaka

This study presents the fabrication and characterization of new low barrier height heterostructure diodes with a GaInAs triangular barrier for zero-bias

millimeter-wave detection. The designed structure is composed of an n-InAs/GaxIn1-xAs/InAs/n-InAs heterostructure that has a low barrier of graded Ga composition GaxIn1-xAs layer. The heterostructure was grown, fabricated, and characterized to confirm the nonlinear rectification effects. The proposed low barrier diodes exhibit clear nonlinear current-voltage characteristics owing to the triangular energy band barrier of GaInAs. Moreover, the zero-bias DC current responsivity and differential resistance extracted from nonlinear I-V curves are discussed.

Design Of Rectangular Microstrip Patch Antenna For Early Breast Cancer Screens **Tu-P1-08**

Xuanxuan Zhang[1]; Lixia Yang[2]; Haiqing Liu[3]; Zhiyong Zou[4]; Weiming Li[4]; Cuizhen Wang[3]; Yuan Yao[4]

[1]Anhui University, 111 Jiulong Road, Shushan District, Hefei City, Anhui Province, China, hefei; [2]Anhui University, No.111, Jiulong Road, Shushan Di, hefei; [3]No.350, Shushan Lake Road, Luyang District, Hefei; [4]No.350, Shushan Lake Road, Luyang District, Hefei, hefei

In this paper, a microstrip rectangular patch antenna for breast tumor monitoring was designed. The antenna was designed h =1.6 mm, FR4 medium plate with relative dielectric constant ÃZÂμr = 4.4 F/m, working in the frequency ranges from 3.79 GHZ to 12.47 GHZ and can identify a radius of 5 mm mammary tumor. Simulation results show that the optimal return loss at 10.1 GHz is - 30.4 dB. Moreover, the large bandwidth obtained is 8.68 GHz when the return loss |S11| < 10 dB. VSWR < 2 for the entire frequency band range, indicating exactly matching the antenna.

A High-Order Mode Terahertz Extended Interaction Oscillator With Three Electron Beams **Tu-P1-09**

Youfeng Yang; Ping Zhang; Yuan Zheng; Yang Dong; Shaomeng Wang; Zhanliang Wang; Zhigang Lu; Yubin Gong
Qingshuihe Campus:No. 2006, Xiyuan Avenue, Chengdu, Chengdu

An effective high-order mode circuit is proposed for a terahertz extended interaction oscillator (EIO) with three electron beams. Compared to the conventional standard TM51 mode, the proposed quasi TM51 mode has five similar field spots distribution in the y-direction and higher characteristic impedance R/Q. The particle-in-cell (PIC) simulations showed that, working in quasi TM51-6?/54 mode with single electron beam, an output power of 2601 mW can be achieved at 612.15 GHz with a voltage of 28.3 kV and a current of 25 mA. When 3 electron beams are introduced, an enhanced output power of 3881 mW can be obtained at 612.51 GHz.

Concept Design Of Collective Thomson Scattering Applied To EAST **Tu-P1-10**

Jingshuo Zhang; Chengming Qu; Lifu Zhang; Zhengwei Wu; Ge Zhuang; Jinlin Xie
No. 96, Jinzhai Road, Hefei City, Anhui Province, Hefei

The Collective Thomson Scattering (CTS) is one of the important means to obtain the main ion temperature and fast ion velocity distribution functions in fusion devices. This paper mainly studies the feasibility of measuring the main ion temperature in EAST using CTS. The possibility of using a 60 GHz

gyrotron and a CO2 far infrared laser as a CTS diagnostic probe source was studied, and the advantages and disadvantages of each frequency were compared. The results show that the CTS based on a 60 GHz gyrotron has high feasibility and can be used to measure the main ion temperature with existing technologies. By adjusting the angle between the differential scattering vector and the magnetic field, the diagnosis can also complete the measurement of the deuterium to tritium fuel ratio.

A Design And Performance Of A Low-cost THz Imaging System Using InP Gunn Diode Emitter, Paraffin Wax Optics And Commercially Available GaAs HEMTs **Tu-P1-11**

Linas Minkevicius[1]; Vincas Tamosiunas[2]; Ignotas Bucius[2]; Domas Jokubauskis[1]; Karolis Redeckas[1]; Gintaras Valusis[1]
[1]Savanoriu ave. 231, Vilnius; [2]Sauletekio ave. 3, Vilnius

A design and performance of a low-cost THz imaging system using InP Gunn diode emitter, paraffin wax optics and commercially available GaAs HEMTs is reported. The system operates at 94 GHz with a spatial resolution of â^¼3 mm and exhibits contrast of nearly two orders of magnitude.

A Novel Broadband Port-Access Scheme To Interface Several Waveguide Bands To A Single Schottky Barrier Diode Detector **Tu-P1-12**

Muhsin Ali[1]; Daniel Headland[2]; Alejandro Rivera-Lavado[1]; Oleg Cojocari[3]; Andreas Stöhr[4]; Guillermo Carpintero[2]
[1]Avenida Gregorio Peces-Barba 1, Leganés; [2]Avenida de la Universidad 30, Leganés; [3]D-63457 Hanau; [4]Lotharstr. 55, Duisburg

Electronic terahertz receivers frequently utilize Schottky barrier diodes. However, the 40% single-mode bandwidth of the hollow metallic waveguides that interface the diode to the external world is a bottleneck to the broadband diode. Here, we demonstrate that LeapWave proprietary technology based on a dielectric rod waveguide-based interposer is capable of significantly widening this span to 125%, for a receiver with reasonable responsivity between ~2 and ~160 V/W in the frequency range from 75 to 320 GHz.

On The Experimental Characterization Of Generated And Received Pulses Of Photoconductive Antennas **Tu-P1-13**

Huasheng Zhang; Juan Bueno; Paolo Sberna; Nuria Llombart; Andrea Neto
Delft University of Technology, Delft

Photoconductive antennas (PCAs) are promising candidates for sensing and imaging systems. We have investigated their properties under pulsed laser illumination both in transmission and reception. First, a transmitting PCA has been characterized including power measurement. Then, a Quasi-Optical (QO) link between a transmitter and a receiver was modelled and analyzed. In this work, we characterize this link with measurement. We use bow-tie based PCAs as examples, and measure the radiated power of the transmitter and the detected current of the receiver. The measurement shows good agreement with the simulation.

Improved Large Area Photoconductive Antenna Design For High Field **Tu-P1-14**

THz Generation

Connor Kidd; Mark Rosamond; Thomas Gill; Lianhe Li; Edmund Linfield; Alexander Davies; Joshua Freeman
University of Leeds, Woodhouse Lane, Leeds

An improved large area design has been developed for LT-GaAs photoconductive antenna arrays fabricated on optically transparent sapphire substrates to generate high field terahertz (THz) radiation. By optimising a design to support larger biasing fields, a 1.5 times improvement in signal strength resulting in fields of up to 200 kV/cm is reported.

Improvement In The Detection Efficiency Of Terahertz (THz) Time-domain Spectroscopy (TDS) By Applying An Alternating Magnetic Field Bias In Spintronic Emitter **Tu-P1-15**

Hideaki Kitahara[1]; Katsuyuki Ishii[1]; Miezel Talara[1]; Takashi Furuya[1]; Mary Escaño[1]; Masahiko Tani[1]; Dmitry Bulgarevich[2]; Dongfeng He[2]; Makoto Watanabe[2]
[1]3-9-1 Bunkyo, Fukui; [2]1-2-1 Sengen, Tsukuba

In this study, we demonstrate the enhancement in the detection performance of spintronic THz - TDS system by employing an alternating-current (AC) magnetic field bias. The AC bias was provided by an antenna mount which we fabricated. Compared with the direct-current (DC) magnetic field bias, we have observed twice the emission amplitude from the AC-biased magnetic field based on the obtained temporal waveforms from a spintronic THz emitter.

Dimensioning Photoconductive Connected Array Sources To Maximize The Radiated Power. **Tu-P1-16**

Martijn Huiskes[1]; Juan Bueno[1]; Nuria Llombart[2]; Andrea Neto[2]
[1]Mekelweg 4, Delft; [2]Mekelweg 4

Photoconductive antennas (PCAs) are used for imaging and sensing applications because of their ability to radiate short pulses with large bandwidths in the THz regime. The characterization of PCAs has previously been done using a time-domain Norton equivalent circuit. Thanks to a recent contribution, the size of the excited photoconductive area of PCAs that results in an impedance match with the antenna can be determined analytically using only the available optical power and the material parameters of the photoconductor. Through the impedance matching, the radiated THz power is maximized. These insights are used for the dimensioning of a wide-band photoconductive connected array to be used in the low THz band, excited by a high power laser (~1W).

Impact Of Antenna Metal's Thicknesses And Structures On Terahertz (THz) Wave Generation Performance Of Spintronic Emitters **Tu-P1-17**

Miezel Talara[1]; Dmitry Bulgarevich[2]; Kana Kobayashi[1]; Hideaki Kitahara[1]; Takashi Furuya[1]; Mary Clare Escaño[1]; Makoto Watanabe[2]; Masahiko Tani[1]

[1]Bunkyo 3-9-1, Fukui; [2]1-2-1 Sengen, Tsukuba
We compare THz wave generation performance of diabolo-shaped spintronic antennas with 3 nm, 100 nm and 200 nm Pt thicknesses at the antenna flares. The center of these antennas where spin-to-charge current conversion occurs is composed of 2 nm Fe and 3 nm Pt metal layer. THz - time domain spectroscopy (THz - TDS) showed the most efficient emission, especially at frequencies <1.5 THz, from the diabolo antenna with 200 nm Pt layer. We also compare THz emission amplitude of diabolo and rectangular spintronic antennas composed of 200 nm Pt layer at the displacement current direction. Time-domain and frequency-domain waveforms showed higher emission amplitude from the rectangular antenna especially at frequencies >1.1 THz.

Recording THz Pulse Shapes At 88 MHz Repetition Rate Using Photonic Time-stretch, At Synchrotron SOLEIL **Tu-P1-18**

Christophe Szwaj[1]; Eléonore Roussel[1]; Clément Evain[1]; Marc Le Parquier[1]; Pascale Roy[2]; Laurent Manceron[2]; Jean-Blaise Brubach[2]; Marie-Agnès Tordeux[2]; Marie Labat[2]; Serge Bielawski[3]

[1]Bat. P5, Villeneuve d'Ascq; [2]Gif-sur-Yvette; [3]Lille University, Bat P5, Villeneuve d'Ascq

In order to record complex THz pulses at high repetition rate, a particularly efficient method consists of combining electro-optic detection with the so-called photonic time-stretch method. In this method, the THz signal modulates a laser pulse. Then the modulated laser pulse is stretched in time until it reaches the multi-nanosecond range, and is recorded using a single photodiode and oscilloscope. We present the current record in repetition rate, in the MHz range (up to 88 MHz), obtained at the AILES beamline of the SOLEIL facility. We also discuss the foreseen improvements of the THz time-stretch method, in order to reach long record durations and/or high bandwidth. The developed setups can also be used for developing fully table-top time-domain spectroscopy systems above 1 MHz acquisition rate.

Terahertz Detection Using A Ridge Waveguide **Tu-P1-19**

Sota Mine[1]; Gabriel Gandubert[2]; Xavier Ropagnol[2]; Kosuke Murate[1]; François Blanchard[2]

[1]Furo-cho, Chikusa-ku, Nagoya; [2]Montréal, QC
In this study, we demonstrate a terahertz detector for the future development of integrated optical components at these frequencies. The detection of terahertz-waves was achieved using a microstructured lithium niobate crystal in a ridge-waveguide configuration with a heterodyne electro-optics sampling method. The ridge waveguide also enabled broadband terahertz wave detection by reducing the diameter of probe beam.

The Measurement Of The Coating Uniformity Of Lithium Iron Phosphate Cathodes On Metal Substrates With Terahertz Time-domain Spectroscopy **Tu-P1-20**

Faezeh Zarrin Khat[1]; Alasdair Pentland[1]; Carl Reynolds[2]; Emma Kendrick[2]; Philip F. Taday[1]

[1]1, Enterprise Cambridge Research Park, Cambridge; [2]University of

Birmingham, Birmingham

For the first time, the thickness uniformity of lithium iron phosphate (LFP) cathodes are measured using terahertz time-domain spectroscopy. Cathodes are widely manufactured with cobalt, however providing cobalt material comes with supply and health issues. LFP cathodes are introduced as an alternative to tackle this challenge. The aim is to use terahertz pulses to generate an on-line tool to undertake manufacturing process control. Different thickness of cathodes compressed to different densities is measured and the uniformity of their coating is inspected.

Thermoelectric Effect In Carbon Nanotube Films For THz And IR Ultra-broadband Photodetectors **Tu-P1-21**

Yue Wang; Guangcheng Sun; Xiaoju Zhang; Zijian Cui; Xinmei Wang
No 5 Jinhua South Road, Xi'an

A carbon nanotube (CNT) films ultra-broadband photodetectors based photothermoelectric effect is investigated, and their excellent performance is attributed to p-n junctions formed by p- and n-type CNT films. The high Seebeck coefficient and low thermal conductivity of CNTs films are two key figures of merit for improving the performance of CNT-based photothermoelectric detectors, which can be achieved by tailoring the thermoelectric properties of the CNT films

LT-GaAs Metasurfaces As Continuous-wave THz Detectors Operating In The Telecommunications Band **Tu-P1-22**

James Seddon[1]; Lucy Hale[2]; Hyunseung Jung[3]; Sarah Norman[4]; Sadhvikas Addamane[5]; Igal Brener[5]; Cyril Renaud[6]; Oleg Mitrofanov[6]
[1]Department of Electronic & Electrical Engineering, Roberts Building,, University College London, Torrington Place,, London; [2]Roberts Building, University College London, Torrington Place, London; [3]Sandia National Laboratories,, Albuquerque; [4]Roberts Building Torrington Place, London; [5]Sandia National Laboratories, Albuquerque; [6]Roberts Building, Torrington Place, London

We present a novel approach for efficient continuous-wave (CW) detection of terahertz (THz) radiation using low-temperature-grown gallium arsenide (LT-GaAs) metasurfaces. While typical THz CW detectors require complex material growth, annealing, and device architectures, our approach demonstrates that LT-GaAs, despite its low absorption at infrared wavelengths, can be used for low-noise THz detection by nanostructuring it into a metasurface.

Experimental Investigations On Effects Of The Magnetic Field Taper On A Continuously Frequency-Tunable Gyrotron **Tu-P1-23**

Tao Song[1]; Wei Wang[1]; Diwei Liu[2]
[1]No.2006, Xiyuan Ave, West Hi-Tech Zone, Chengdu; [2]No.2006, Xiyuan Ave, West Hi-Tech Zone, 611731, Chengdu

In this abstract, experimental investigations on effect of the magnetic field taper on a continuously frequency-tunable gyrotron are carried out. In the

experiment, it is found that when the magnetic field taper becomes obvious, the operating frequency of the operating mode with higher axial index decreases and the frequency-tuning range becomes narrow. At the same time, the output power also decreases.

Study Of The Pill-box Window For The High-power Microwave Transmission Line **Tu-P1-24**

Shouqi Xiong; Zaojin Zen; Yi Jiang; Xinrui Hu; Guowu Ma; Hongbin Chen
No. 64 Mianshan Road, Mianyang

The pill-box window is the most window applied in the high-power microwave transmission line. In this paper, a simulation model of the pill-box window is built by the particle-in-cell (PIC) solver. The influence of the metal ring's thickness on the window's characteristics is studied. The window is optimized and adapted to the impact of the metal ring. The ghost mode oscillation caused by the asymmetry of the pill-box window is also analyzed. The analysis results indicate that there is no ghost mode in the working frequency band of the window. The pill-box window is designed for the high-power L-band transmission line. The working frequency band of the window is 1.25~1.35GHz. The maximum power capability of the window is intended to be 5MW. Up to now, the primary designing process of the pill has been accomplished. The pill-box window is being manufactured in the Institute of Applied Electronics (IAE) CAEP. The high-power tests of the pill-box window are also within the schedule.

Dependence Of Efficiency Degradation Caused By Beam Misalignment On The Azimuthal Index In Gyrotrons **Tu-P1-25**

Xianfei Chen; Houxiu Xiao; Xiaotao Han
Wuhan National High Magnetic Field Center, Huazhong University of Science and Technology, Hongshan District, Luoyu road, 1037, Wuhan
Gyrotron operating at short wavelengths (THz regimes) can be very sensitive to the misalignment between the electron-optical system and the resonator. This paper presents a generalized study on the effect of different cases of electron beam misalignment on the gyrotron operation. The dependence of such an effect on the azimuthal index is analyzed. The results show that a larger azimuthal index m will lead to higher sensitivity of the gyrotron operation to the electron beam misalignment. Besides, the dependences of the efficiency degradation of gyrotron operation on the tilt angles are varied for different types of electron beam tilt.

Temperature Control Of Irradiated Biological Samples With Pulse Repetition Frequency Modulation Of A Gyrotron **Tu-P1-26**

Yuusuke Yamaguchi; Masafumi Fukunari; Yoshinori Tatematsu
3-9-1 Bunkyo, Fukui
The biological effects of terahertz waves have been attracting attention, and high-frequency gyrotrons are being used as a wave source in recent years. In discussing the effects of terahertz waves, it is particularly important to separate them from thermal effects. Therefore, temperature control of the irradiated sample is essential. In this study, a Proportional-Integral-Differential (PID) controller that can adjust the temperature of the irradiated liquid sample by modulating the pulse repetition frequency of the gyrotron has been developed.

By optimizing the PID gains, it was found that the temperature could be maintained at the target value of approximately 35 deg. C with an error of less than 0.1 deg. C.

Experiments On Efficient Fifth-Harmonic Multiplication in A Conventional V-Band Gyrotron **Tu-P1-27**

Mikhail Glyavin[1]; Gregory Denisov[2]; Irina Zotova[2]; Andrey Malkin[2]; Alexander Sergeev[2]; Roman Rozental[2]; Andrey Fokin[2]; Vladimir Belousov[2]; Mikhail Shmelev[2]; Alexey Chirkov[2]; Alexander Tsvetkov[2]; Ilya Bandurkin[2]
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We propose a method of efficient frequency multiplication in conventional gyrotrons with excitation at ultrahigh (s = 5,9,13...) cyclotron harmonics. The method is based on a peculiarity of cylindrical waveguide mode spectrum, which follows from an obscure property of the Bessel derivative roots. We present the theoretical concept, the simulations and the results of the proof-of-principle experiment in which 0.22 THz/80-100 mW radiation at the 5th cyclotron harmonic has been detected in continuous-wave regime. Feasibility of the proposed method for providing powerful radiation in the terahertz gap is also discussed.

Advances In Terahertz Detection With Graphene Field-effect Transistors **Tu-P1-28**

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Sensitive low-noise passive terahertz detection relies on two basic elements: coupling of free-space electromagnetic wave to a rectifying element, and downconversion of alternating electric field into direct current. We present efficient approaches for both problems enabled by electronic properties of graphene and its bilayer. We experimentally demonstrate increased radiation coupling enabled by plasmon resonance in graphene field-effect transistor, which becomes possible due to relatively long plasmon lifetimes. We further show increased non-linear rectification in graphene bilayer with induced band gap, which is attributed to enhanced thermoelectric coefficient and emergence of tunneling rectification pathways. These factors enable very low noise equivalent powers down to ~40 fW/Hz1/2 at cryogenic temperatures T~20 K, which outperforms existing semiconductor and superconductor bolometers.

Modulation--doped Multiple CdTe Quantum Wells As THz Detectors, Filters And Emitters **Tu-P1-29**

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We studied quantum structures grown by a molecular beam epitaxy comprising CdTe quantum wells (QWs) modulation-doped with iodine donors in Cd1-xMgxTe barrier (x = 0.2 or 0.3). Experiments were carried out at liquid helium temperatures at magnetic fields up to 9 T. Samples studied differed by the number of and the distance between QWs, the thickness of spacer and the doping level. Magnetotransport measurements revealed electron concentrations of the order 10^11 cm^-2 per well and a one-carrier conductivity with only a slight admixture of a parallel transport in some samples. Transmission of THz radiation in the range 0.1 -- 1.0 THz showed a well-defined cyclotron resonance minimum in the case of single QWs which developed into Shubnikov -- de Haas -- like oscillations in samples with multiple QWs. Such oscillations were also observed in THz photocurrent and were interpreted as resulting from free-carrier absorption. The study carried out on a large number of samples with different technological parameters made it possible to select optimal structures based on CdTe/Cd1-xMgxTe modulation-doped quantum wells as THz detectors (resonant or non-resonant) for applications in magnetic fields at low temperatures. Multiple quantum wells were also shown to be magnetic-field-controlled emitters of THz radiation.

Status Of The Heterodyne Superconductor-Insulator-Superconductor Receivers For The LCT **Tu-P1-30**

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In summary, the status and experimental results of the heterodyne SIS receivers for the LCT are presented. The 345 GHz receiver was operated at a temperature of 4.2 K, and showed good pumped IV and heterodyne detection characteristics. A Y factor of 2.3 and receiver DSB noise temperature of 81 K were obtained. For all frequencies, best receiver bias occurs between 2.0-2.3 mV, and the optimal LO pump current is 80-120 μA.

Multilayer Vacuum Window Design For Submillimeter Telescope Receivers **Tu-P1-31**

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A broadband anti-reflection vacuum window based on PTFE, Zitex and HDPE multilayer is designed for the telescope receiver windows in the submillimeter bands (230/460, 345/650 GHz). HDPE is widely used in the preparation of lens, infrared filters and vacuum hot pressing windows due to its extremely high transmittance and low dielectric constant in the terahertz band, and is considered to be a vacuum window material that can replace silicon materials. Zitex is a kind of 50% porous Teflon, which can reduce the reflection of incident electromagnetic waves. Therefore, ALMA and CSO telescopes have developed different structures of vacuum windows based on quartz and HDPE, respectively. However, the dielectric constants between Zitex and HDPE are quite different, and the adhesive might enter the holes of Zitex during the hot pressing process, resulting in large reflection losses. In this paper, we design a multilayer vacuum window (Zitex/PTFE/HDPE/PTFE/Zitex), using PTFE as a

transition layer and LDPE as an adhesive.The film shows the opportunity to be implemented in the LCT receivers.

Real-Time Analysis Of THz Quantum-Cascade Laser Signals Using A Field Effect Transistor Array

Tu-P1-32

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We demonstrate real-time analysis of the emission from a 3.4 THz quantum-cascade laser (QCL) source, using an array of nanoscale field-effect transistor devices. We show that THz power can be detected directly up to a modulation bandwidth of 500 kHz, and indirectly via a change in the device threshold, up to a 100 MHz bandwidth.

Growth Response Of Escherichia Coli Bacterial Cells On Exposure To 1.25 Wm-2 Synchrotron-sourced Terahertz Radiation

Tu-P1-33

Zoltan Vilagosh[1]; The Hong Phong Peter Nguyen[1]; Palalle Tharushi Perera[1]; Denver Linklater[1]; Dominique Appaddo[2]; Jitraporn Vongsvivut[2]; Mark J. Tobin[2]; Rodney Croft[3]; Elena P. Ivanova[1]
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The growth of E. coli cells following low intensity 1.25 Wm-2 broadband synchrotron-sourced Terahertz (THz) radiation was monitored following serial exposures for 60 minutes with distinct samples at 10-minute intervals. After 20 minutes, E. coli cells showed a reduction to 53% compared to the control, and a minor fluctuation in colony forming units density followed by a major recovery to 80% at 60 minutes.

Compact Single-shot Electro-optic Detection System For THz Pulses With Femtosecond Time Resolution At MHz Repetition Rates

Tu-P1-34

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Electro-optical detection has proven to be a valuable technique to study temporal profiles of THz pulses with pulse durations down to femtoseconds. The Coulomb field of a relativistic electron bunch resembles the current profile, and therefore electro-optical detection can be exploited for non-invasive bunch length measurements at accelerators. Here we present a compact and robust electro-optical detection system based on spectral decoding to measure single-shot longitudinal bunch profiles of electron bunches down to 200 fs. Apart from the GaP crystal and the corresponding laser optics at the electron beamline all components are housed in 19-inch chassis for rack mount and remote operation inside the accelerator tunnel. The novel linear photo diode array KALYPSO [1] allows to acquire the modulated laser spectra at frame rates of up to 2.26 MHz. First longitudinal bunch profile measurements at the

European X-ray Free Electron Laser (XFEL) show bunch length of around 400 fs (rms) with an arrival-time jitter of 35 fs (rms).

Research On W-band Sheet-Electron-Beam Vacuum-Tube Power Amplifier And Oscillator **Tu-P1-35**

Ivan Chistyakov[1]; Vladimir Titov[2]; Roman Torgashov[2]; Andrey Starodubov[2]; Igor Navrotsky[1]; Dmitriy Zolotykh[1]; Nikita Ryskin[2]
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In this paper, we present the results of design, simulation and development of W-band traveling-wave tube (TWT) and backward-wave oscillator (BWO) with sheet electron beam. We consider grating and sine-waveguide slow-wave structures (SWS) designed to operate at 10-12 kV voltage of synchronism. Hot-test operation of the devices was simulated by using 3-D particle-in-cell (PIC) code. Electron gun providing a 0.1-A sheet electron beam was designed and fabricated. The results of fabrication and cold-test measurement of the SWSs are presented. Design, simulation, and fabrication of the other key components of the tubes, such as vacuum window, magnetic focusing system, and depressed collector, are also discussed.

Free Induction Decay Signals Stimulated And Detected By Photomixing **Tu-P1-36**

Francis Hindle[1]; François Parnet[2]; François Bondu[2]; Guillaume Ducournau[3]; Jean-François Lampin[3]; Gael Mouret[1]; Goulc'hen Loas[2]; Emilien Peytavit[4]
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A photoconductor device driven by a dual frequency Ti:Sa laser is electrically pulsed to provide a powerful pulse around 291 GHz. The pulsed radiation polarizes the OCS gas which emits a free induction decay signal that is observed after the end of the pulse by optical heterodyne detection using a second photoconductor driven by the same beatnote frequency shifted by ~1 GHz. This is the first step in the development of all photonic chirped pulsed spectrometer.

Low Temperature Permittivity And Loss Tangent Of Zirconia From 220 To 325 GHz **Tu-P1-37**

Guangjiang Li; Sudheer Jawla; Michael Shapiro; Richard Temkin
190 Albany Street, Cambridge

Zirconia rotors are used extensively as sample holders in present-day DNP NMR research. The samples are irradiated by a THz beam that must pass through the wall of the rotor. The design of these rotors thus depends critically on knowing the dielectric constants of the zirconia material. We present the first high-accuracy experimental measurements of the permittivity and loss tangent of YTZP Zirconia in the 220-325 GHz frequency range. The measurements were made from room temperature down to 79 K.

Terahertz ATR Sheds Light On Real-time Exchange Kinetics Occurring Through Plasma Membrane During Photodynamic Therapy **Tu-P1-38**

Xiujun Zheng[1]; Blandine Lordon[1]; Anne-Françoise Mingotaud[2]; Patricia Vicendo[2]; Rachel Brival[2]; Isabelle Fourquaux[2]; Laure Gibot[2]; Guilhem Gallot[1]
[1]Route De Saclay, Palaiseau; [2]Université de Toulouse, Toulouse

THz ATR spectroscopy provides, in a single measurement, the relative number of defects per membrane surface created by oxidative stress generated during photodynamic therapy (PDT), offering early, sensitive real-time information. THz spectroscopy is therefore a complementary technique to established (biological) assays and can be applied to any topic requiring the real-time examination of short-term plasma membrane permeabilization.

18:00 - 19:30 **Poster Session 4** **Foyer (4th floor)**

Modeling With TESLA-family Of 2.5D Large-signal Codes: Predicting Performance And Stability Of The Experimental Mm-wave TWTs **Tu-P2-01**

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We present an overview of the results and current status of the developed at NRL TESLA-family of 2.5D large-signal codes (including the circuit-model based code TESLA-FW and impedance matrix Z based code TESLA-Z), which are suitable for modeling of Serpentine/Folded-waveguide TWTs. These codes have been successfully applied to predict performance of the developed at NRL experimental single-stage G-band and 2-stage W-band TWTs. More recent progress in the code's development resulted in creation of the code TESLA-Z based stability analysis framework, which has successfully predicted band-edge instabilities, observed in both TWTs at the beam-voltages above their operational values.

Charge-transfer Dyes In A Polymer Matrix: an Avenue Towards Large Area THz Emitters? **Tu-P2-02**

Felix Gorka[1]; Goretti Guadalupe Hernandez Cardoso[1]; Enrique Castro-Camus[1]; Henning Menzel[2]; Tasja Schwenke[2]; Li Zhao[3]; Florens Kurth[3]; Wolfgang Kowalsky[3]; Hans-Hermann Johannes[3]; Martin Koch[1]
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Oriented, organic charge-transfer chromophores have been discussed as a scalable emitter for broadband THz radiation. We investigate the THz emission properties of several thin film host-guest system under resonant excitation in terms of dye loading, molecular structure modification as well as excitation parameters.

Output Coupling Optimization For An Optically Pumped CH3OH Gas Laser **Tu-P2-03**

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Lasers that emit THz light using CO2 laser-pumped gas molecules are widely used as a light source for polarimeter- interferometer diagnostic systems in plasma fusion devices because of their continuous, stable high-power output. This paper describes the basic structure of a laser we developed to generate 2.5 THz light by pumping CH3OH molecules using the 9P(36) branch of a CO2 laser. The design of the output coupler is optimized according to the indexes of laser transmittance, divergence angle and spot variation to make some guidance for further experimental investigation.

NanoMi: A Modular Platform For Terahertz-integrated UTEM **Tu-P2-04**

Samuel Ruttiman[1]; Makoto Schreiber[1]; Mark Salomons[2]; Darren Homeniuk[2]; Xuanhao Wang[3]; Olivier Adkin-Kaya[4]; Mohammad Kamal[4]; Jesus Alejandro Marin Calzada[1]; Patrick Price[2]; Martin Cloutier[2]; Misa Hayashida[2]; Ray Egerton[1]; Ken Harada[5]; Yoshio Takahashi[5]; Heiko Muller[6]; Marek Malac[2]; Frank Hegmann[1]
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Ultrafast electron microscopy techniques allow for the structural dynamics of materials to be studied, and are typically achieved by modifying a commercial electron microscope to grant optical access to both the cathode and sample regions. To enhance the temporal resolution of these techniques, the electron bunch probe can be compressed by intense terahertz pulses confined in a tapered waveguide structure. The necessary modifications for optical access and waveguide integration may not be viable on all commercial systems, and has the potential to compromise the column. NanoMi is an open-source, modular electron microscopy platform that is amenable to user customization and is ideal for electron-beam-based experimentation. Laser pulses for ultrafast electron microscopy applications can be integrated into the system without any modification to the column. Intense THz pulses can also be integrated and coupled into a TPPWG positioned along the electron-optic axis to provide electron-bunch compression along with additional acceleration, lensing, and deflection capabilities.

Terahertz-induced Influence On The Octanol-water Phase Separation **Tu-P2-05**

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In this study, we employed MD simulations to investigate the interference mechanism of THz electric fields in the phase separation process of octanol and water solution. We found that a 22 THz electric field resulted in a decrease in the SASA of octanol, indicating that THz waves affected the arrangement and aggregation of octanol molecules. THz electric fields may influence the aggregation behavior of octanol through various pathways, thus providing new

possibilities for its application in chemical analysis, drug research, and biomolecular studies.

Infrared Nanospectroscopy And Terahertz Irradiation Of Pathological Protein Aggregates **Tu-P2-06**

Antonia Intze[1]; Raffaella Polito[1]; Maria Eleonora Temperini[1]; Valeria Giliberti[2]; Michele Ortolani[1]
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ÃZÂ±-Synuclein (ÃZÂ±S) is of wide interest because its aggregation is a hallmark of many neurodegenerative disorders, including Parkinson's disease. Here, we are using the atomic force microscopy-assisted infrared nanospectroscopy to investigate its aggregation into nanoscale fibrils and describe the secondary structure change of the protein during aggregation. Perspective THz irradiation experiments have been designed and are being set up, with the aim of modifying the secondary structure of proteins and/or aggregates through prolonged THz irradiation with CW sources.

Study On Isoniazid-Succinic Acid Cocrystal Using Terahertz Spectroscopy And DFT Calculations **Tu-P2-07**

Jiale Zhang[1]; Mei Wan[2]; Jiyuan Fang[2]; Yaqi Jing[2]; Zhi Hong[2]; Yong Du[2]
[1]Hangzhou, Hangzhou; [2]Hangzhou

Isoniazid (INH), is a first-line anti-tuberculosis drug with high efficiency and low toxicity. And succinic acid (SA) is a basic organic chemical material which widely used during the cocrystal screening stage. In the present work, the cocrystal of INH and SA was prepared by solvent evaporation method. The cocrystal and its starting components were analyzed and identified using terahertz (THz) spectroscopy. In addition, to investigate the crystal structure of this cocrystal, the theoretical cocrystal form was simulated using density functional theory (DFT). By analyzing the calculated data and experimental results, it could be concluded that the hydrogen bonds in the INH-SA cocrystal are pyridine N-carboxylic acid heterosynthon. Furthermore, the vibrational modes of the cocrystal were attributed based on the simulation.

THz Spectroscopic Electron Paramagnetic Resonance Of The Fe3+ Defect In GaN **Tu-P2-08**

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We present a recently developed method for electron paramagnetic resonance (EPR) measurements in the THz spectral range. The method is based on spectroscopic ellipsometry and thus requires no cavity, unlike conventional EPR. This permits us to scan the frequency parameters in addition to the magnetic field parameters. To showcase this, both frequency and magnetic field scans are performed on Fe-doped GaN, and the results are compared to previous work that used conventional EPR to study the same defect.

Terahertz Response Of An Interacting Confined Electron-Hole Pair **Tu-P2-09**

Filip Klimovic; Tomás Ostatnický
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Terahertz conductivity spectra of semiconductor nanostructures contain valuable information relevant for the design of new electronic and optoelectronic devices. Contemporary models for interpretation of data usually treat charge carriers as independent. However, due to spatial confinement of charge carriers, Coulomb interaction plays an important role in nanostructures, inducing correlation between the carriers. We develop a quantum-mechanical model of a confined electron-hole pair, and we show a significant change in the predicted spectra when Coulomb interaction is accounted for. The impact of this effect is universal for all nanostructures.

Crystal Structure And Vibrational Analysis Of Pyrazinamide-Glutaric Acid Based On Terahertz Spectroscopy And DFT Calculation **Tu-P2-10**

Yaqi Jing; Mei Wan; Jiale Zhang; Jiyuan Fang; Zhi Hong; Yong Du
Hangzhou, Hangzhou

Cocrystal of pyrazinamide (PZA) and glutaric acid (GA) was prepared by solid-state grinding. The cocrystal and its starting components were detected using terahertz (THz) spectroscopy. The results showed that three absorption peaks appeared in the spectrum of the cocrystal which were distinct from those of the starting components, indicating the formation of cocrystal. Furthermore, the crystal structure was simulated using density functional theory (DFT). The THz spectra and simulated results revealed that the hydrogen bonds are composed of amide groups from the PZA and GA molecules respectively.

We Study The Atmospheric THz Transmission Properties Over A Wide Range Of Temperature And Humidity Conditions: From 6 To 45°C And Relative Humidity From 20 To 90%. **Tu-P2-11**

Martin Koch[1]; Enrique Castro-Camus[2]; Fatima Taleb[2]; Juan Viana[2]
[1]Renthof 5, Marburg; [2]Renthof 5

Telecommunications rely on the transmission properties of the atmosphere in real conditions. The transmission properties (absorption and refractivity) are studied over a broad bandwidth and a wide range of temperature and humidity conditions, ranging from 6 to 45Â°C and relative humidity from 20 to 90 %.

Temperature Dependence Of The Dielectric Function Of Dehydrated Biological Samples In The THz Band **Tu-P2-12**

Jan Helminiak[1]; Mariana Alfaro-Gomez[2]; Goretti Guadalupe Hernandez-Cardoso[1]; Martin Koch[1]; Enrique Castro-Camus[1]
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Based on its high sensitivity to the presence of water, terahertz radiation has introduced itself as a suitable source for the study of biological tissue and the diagnosis of some medical conditions. As shown in previous publications, the water content of a given system can be calculated by approximating the tissue with effective medium theories. Within these models, the optical behavior of water is a well-known temperature dependent parameter, whereas the behavior

of the dry tissue has been traditionally assumed to be temperature independent. In this study we show with the usage of a self-designed heat chamber that the dielectric functions of various biological tissues as porcine skin, oak leaf and brown mushroom show between 20°C and 36.5°C indeed some variations based on their respective temperatures, which might indicate that this parameter cannot always be neglected in the analysis models.

Signal Processing System For Solid Source Interferometer On EAST **Tu-P2-13**

Jiamin Zhang[1]; Yuan Yao[2]; Tianyi Ruan[3]; Yao Zhang[2]; Haiqing Liu[2]; Yinxian Jie[2]; Bili Ling[2]
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A signal processing system is designed for the terahertz solid-source interferometer (SSI) system on Experimental Advanced Superconducting Tokamak (EAST), which can be used for real-time electron density calculation. This system calculates the phase difference between the detection signal and reference signal which acquired by the solid source interferometer system and then unwraps the wrapped phase value to output the electron density value in real time. The system is architected on a hardware development board with high speed, high accuracy, strong anti-interference capability and wide adaptability, which is suitable for EAST laser interferometer system to obtain the real-time electron density data and provide valid density information to plasma feedback control system.

Sensitive Terahertz Photoresponse Of A Three-Dimensional Dirac Semimetal **Tu-P2-14**

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We observe the strong terahertz photoresponse of a bulk three-dimensional Dirac semimetal Cd3As2 contacted with two gold electrodes. When terahertz radiation illuminates the two contacts, the photovoltages exhibit symmetric amplitudes but opposite polarities at zero-bias, and the response time is on the millisecond level. These characteristics provide evidence that the photothermoelectric effect dominates the terahertz photoresponse of the Cd3As2 device. Due to the Dirac semimetal nature and good thermoelectric property of Cd3As2, our device shows a noise-equivalent-power as low as 5.3 nW Hz-1/2. This work demonstrates that Cd3As2 could be a promising candidate material for terahertz detection.

Effect Of The Degree Of Sulfation On The Hydration State Of Agarose Gels Investigated Using Terahertz Time Domain Spectroscopy (THz-TDS) **Tu-P2-15**

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Agarose is a biopolymer widely used as a separation medium in chemistry, as gelling agent in foods, and as scaffold in tissue-mimicking materials. The gel strength and the electroendoosmosis (EEO) value are important quality parameters of agarose which have direct impact on its functionality. These two attributes are correlated to the sulfate contents of agarose. In this work, the relationship between these parameters were investigated from the point of view of water dynamics. Terahertz time-domain spectroscopy (THz-TDS) was employed to study the hydration state of the hydrogels through an analysis of the THz dielectric parameters obtained from the Double-Debye model. It was found that an increase in the sulfate content of the agarose does not significantly change the relaxation time of water bound to the matrix, but it decreases the strength of the fast relaxation of water. This decrease in relaxation strength, attributed to a decrease in the amount of bound water, can affect the gel strength as bound water is thought to be responsible for stabilizing the junction zones of the gel network. The thinning of the hydration layer with increasing sulfate concentration can affect the EEO as more water becomes available for internal convection within the gel.

THz-near IR Hyper-Raman Surface Spectroscopy Of Silicon Wafer Surface **Tu-P2-16**

Laetitia Dalstein; Marc Tondusson; Jerome Degert; Eric Freysz
351 cours de la liberation, Talence

We recorded the hyper-Raman spectra resulting from the interaction of picosecond visible and ultrashort THz pulses at the surface of (100) silicon wafer. It reveals the signature of the Si lattice phonon and SiO2 mode centered at ~610 cm-1 and ~1100 cm-1, respectively. This technique also evidences the growing of the SiO2 layer at the surface of the silicon wafer exposed to ambient air.

Influence Of Substrate Temperature On Preparation Of High-Tc Superconducting NbN Thin Film For SIS Tunnel Junction **Tu-P2-17**

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NbN thin films were deposited on sapphire substrate by RF magnetron sputtering. The effect of substrate temperature on crystal structure, surface morphology, ion valence state and superconductivity of samples were investigated using X-ray diffraction, scanning electron microscope, atomic force microscope, X-ray photoelectron spectroscopy and physical property measurement system. The results show that all NbN thin films have a ÃfZÃ‚Â´-phase structure and grow preferentially along the (111) direction. The samples exhibit high crystallization quality, compact grains, and small surface roughness. With the increase of substrate temperature, the grain size is increased gradually and the binding rate and strength of Nb and N atoms are enhanced, leading to an increase in superconducting transition temperature. When the substrate temperature is as low as 150ÃfÂ¢"f, the superconducting transition temperature reaches 16.58 K. The obtained samples show a good application prospect in preparing superconducting SIS tunnel junctions and developing the corresponding mixers.

Terahertz Longitudinal Conductivity Of Epitaxial Mn3Sn Thin Films **Tu-P2-18**

Tinggui Yin; Tianyu Zhang; Dong Gao; Fu Tang; Zechuan Bin; Jun Qin;

Longjiang Deng; Shigao Zhao; Qingying Yi; Shenggang Liu; Lei Bi; Min Hu
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Abstract--Due to the response frequencies mostly located in the terahertz range, antiferromagnetic materials are currently the research focus of terahertz spintronics. Specifically, the terahertz properties of antiferromagnetic Weyl semimetal material Mn3Sn have attracted attention. In this work, based on a self-built terahertz polarized time-domain spectroscopy system, we preliminarily measured the terahertz conductivity of high-quality Mn3Sn films epitaxially grown using pulsed laser deposition. The experimental results show that the Mn3Sn films exhibits typical Drude-Smith characteristics. We believe that the reason for this difference may be due to the change in carrier transport properties caused by the stress on the films. The high absorption rate and magneto-optical effect of Mn3Sn in the terahertz frequency range make it a promising emerging material for developing terahertz devices.

Near-Perfect THz Absorber With Wide Range Tunability **Tu-P2-19**

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THz absorbers have wide applications ranging from sensors and monochromatic detectors for narrowband absorbers to shielding and energy harvesting for broadband absorbers. Designing a THz absorber with perfect absorption is a challenging topic. In this work, we present a broadband THz absorber with bandwidth ranging from 0.9 to 1.3 THz and a near-perfect absorption >90 %. The absorptance frequency can be tuned using low voltage application (0.2 - 5 V), from 1.3 to 10 THz while maintaining high absorptivity. In comparison with other structures, this absorber represents an ultra-thin (20 nm -- 160 nm) and simple structure based on 2D materials (graphene, MoS2, phosphorene) without including Au or other precious materials. It is easy to fabricate, cost-effective, and voltage-tunable through nearly the whole THz region. Although the structure is a broadband absorber its fractional bandwidth ranges from 20-45% which can be enhanced to a narrowband absorber in future works.

Terahertz Direct High-order Modulator Based On Coding Multi-subarray Metasurface **Tu-P2-20**

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In recent years, terahertz direct-modulated wireless communication systems with low complexity and power consumption have drawn a lot of interest as a result of the advancement of terahertz high-speed modulators. However, the terahertz direct modulator mainly achieves the on-off-keying (OOK) modulation format by changing the working frequency or resonance modes, while high-order modulation technology is limited by poor frequency band flatness and linearity. Here, we propose a terahertz direct high-order modulator based on coding multi-subarray metasurface. The whole metasurface is

composed of four sub-arrays, each sub-array contains an array of metal structures and active material two-dimensional electron gas (2DEGs). Higher-order PAM4 modulation is achieved by independently controlling 2DEGs in the subarrays to change the collective resonant mode. In addition, we exhibit satisfactory flatness across a 60GHz operational frequency range and achieve an 81% modulation depth when operating at 0.224 THz.

Frequency Spectrum Prediction Of Metamaterial Absorbers Based On Semi-Random Matrix Generation Method Combined With Deep Learning **Tu-P2-21**

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This presentation proposes a semi-random matrix generation method for growing meshes on the structure of a terahertz metamaterial absorber, the method results in a great variety of entirely new structures being obtained. With the input of matrix data of the metamaterial absorber models, the spectral prediction deep neural network constructed based on GoogLeNet architecture can quickly and effectively predict the absorption spectrum. Furthermore, Box-Cox transformation is used to map the uneven distributed spectral data to a normal distribution, which will help to smooth the output predicted curve with low oscillation. The results indicate that the proposed data processing method is favorable to the improvement the prediction capability and output stability of spectrum prediction network and can effectively facilitate related metamaterial design tasks by DNNs.

Ultrafast Non-equilibrium Carrier Dynamics In Vertical Graphene **Tu-P2-22**

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Vertical graphene (VG), a complex thin-film material with hierarchical microstructures, has been successfully implemented in various applications. In this work, we have measured the ultrafast dynamics of VG, which is grown vertically on SiO2 wafers, by optical-pump terahertz-probe (OPTP) spectroscopy. We have found the relaxation of non-equilibrium charge carriers with two decay times. Furthermore, we also measure the photoconductivity of VG in the different pump-probe delays, which indicates distinct Drude-Smith characteristics. This work investigates the light-matter interactions between VG and terahertz(THz) waves and paves the way for the development of high-speed THz optoelectronic devices.

Novel Cherenkov Threshold In Nonlocal Graphene Hyperbolic Metamaterials **Tu-P2-23**

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Although Cherenkov radiation (CR) has already been generated by slow electrons in some hyperbolic mediums, the nonlocality induced by these electrons is usually neglected before. In current work, besides the modifications of plasmonic modes in graphene hyperbolic metamaterials (GHMs), we

indicate a novel velocity threshold of CR which is induced by the (wavevector-dependent) nonlocalities of graphene. Specifically, this velocity threshold for CR is exactly the Fermi-velocity of graphene, which is roughly equal to 1/300 of the speed of light. Our results are significant for future studies of basic CR physics in complex material systems and CR-based integrated free-electron nano-photonics devices.

Infrared Attenuate Total Reflection Cell With A Functionalized Surface **Tu-P2-24**

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We discuss an ATR cell utilizing chips from silicon wafers. The cell can be used for wet-chemical analysis on functionalized surfaces. Here, silicon chips are exemplarily "functionalized" by silica layers to provide a hydrophilic or hydrophobic ATR surface in-situ.

Trace Detection Of Furazolidone Based On Terahertz Meta-surface Sensors **Tu-P2-25**

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In this article designs a terahertz meta-surface microstructure device based on a symmetrical open loop, there is a resonance peak f1 = 0.937 THz and the refractive index sensitivity reached 196 GHz/RIU and can be applied to high sensitivity sensing detection. The meta-surface sensor was used for trace experimental detection of concentrations of furazolidone solutions. The results showed that the minimum detection mass concentration of the meta-surface sensor for the drug reached 10 mg/dL, which is expected to be applied in the sensing detection of samples in biomedical and other fields.

THz Optical Characterization Of Novel Chalcogenide Phase Change Materials **Tu-P2-26**

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THz transmission characteristics of Ge3Sb2Te6 and Sb2Se3 thin films of phase change materials (PCMs) annealed at several temperatures have been investigated for the first time. The results are compared to the optical properties of the well-known Ge2Sb2Te5 PCM. The measured transmission spectra confirm interesting features such as the presence of non-volatile intermediate states in Ge3Sb2Te6 or the absence of losses for all Sb2Se3 states, which are particularly interesting for reconfigurable THz photonics applications such as dynamic THz absorption and beam steering.

Dual-band Tunable Absorber Of Terahertz Metamaterial Based On Gallium Arsenide **Tu-P2-27**

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Based on the fact that the conductivity of photosensitive semiconductors can be regulated by external pump light, a metamaterial absorber with single-band and dual-band switchable is designed by adding gallium arsenide (GaAs) to the nested cell ring structure in terahertz region. With the increase of external pump light power, the maximum absorptivity is 99.9% when the conductivity of GaAs is 5Ãf-10^5 S/m. which is expected to be applied in the fields of modulator, frequency selector, detector, and so on.

Terahertz Near-Field Imaging For Buried Structures **Tu-P2-28**

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We demonstrate terahertz imaging of deeply buried structures using the s-SNOM technique. Our approach successfully visualizes buried metallic lines at unprecedented depths, approximately 10 times larger than the probe diameter, opening up new possibilities for advanced quality control of semiconductors.

Microscopic Study On The Essence Of Enamel Demineralization By Terahertz Near-field Technique **Tu-P2-29**

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Abstract--Early demineralization of enamel has always been a concern for dentists, but revealing the essence of enamel demineralization from a microscopic perspective has been challenging due to the lack of appropriate detection methods. Terahertz technology, with its nondestructive and nonionizing properties, offers applications in biomedical imaging. In this study, we utilized continuous wave (CW) Terahertz near-field scanning microscope (THz-SNOM) technology to perform near-field imaging of enamel after demineralization. We examined the changes in surface structure and enamel permittivity during the demineralization process. The presented approach thus uncovers the mechanism of enamel demineralization from a microscopic perspective.

Temperature Dependent Dynamics Of Charge Carriers In Tellurium-Hyperdoped Silicon **Tu-P2-30**

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Tellurium-hyperdoped silicon shows significant promise as a candidate as an intermediate band material for highly efficient solar cells and photodetectors. We use Time- Resolved THz Spectroscopy to study excited carrier dynamics of

Si hyperdoped with 0.5, 1, and 2 % of Te. Normalized photoconductivity measurements reveal carrier lifetime trend across the sample between 100K and 310K. Consistent with the literature, charge carrier lifetime reduces with increasing dopant concentration. We found that the carrier lifetime becomes less temperature dependent as the dopant concentration increases. The peak photoconductivity changes with temperature which indicates temperature-dependent carrier mobility. In literature, the photodetection range of Te-hyperdoped silicon extends to 5.0 micro-m at 20K. Our temperature dependent carrier transport study in hyperdoped silicon reveals charge carrier trapping and carrier mobility at different Te dopant concentrations.

A Terahertz QPSK Phase Shifter Based On Insertion Micro-structure Chips **Tu-P2-31**

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Terahertz phase shifter is a key research direction of terahertz technology. In this paper, we design a terahertz phase shifter based on a 3 dB waveguide coupler as well as GaAs-diodes. The simulation results show that the phase shifter is capable of achieving the Quadrature Phase Shift Keying (QPSK) modulation function with phase error less than 3Â° and insertion loss better than 9dB at 220GHz.

Terahertz-capillary Electrophoresis (THz-CE) For Direct Detection Of Separated Substances In Solutions **Tu-P2-32**

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A novel detection technique for capillary electrophoresis (CE) is presented using THz waves, namely "THz-CE", which enables to detect separated substances in a solution flowing in a hollow of capillary whose inner diameter (ID) is 0.1 mm. We placed a narrow open-tubular capillary on the surface of a GaAs semiconductor substrate as a THz-emitter. By focusing femtosecond pulsed laser beams at the surface of GaAs closest to the capillary, THz waves were locally generated to pass through the capillary, so that THz absorbance spectra were obtained from the capillary which has narrower ID than the diffraction limit. We successfully achieved the CE separation between acetic acid and n-propionic acid around neutral pH and obtained the electropherograms with THz-time domain spectroscopy (TDS), which are similar to those obtained with conventional contactless conductivity detection. Our proposed THz-CE showed the potential for the systematic analysis of inter/intra-molecular weak interactions like hydrogen bonds, which are unable to obtain with conventional detectors. This technique will be able to be used for the analysis of biological samples containing many chemical components combined with various separation techniques.

Development Of Data Labeling Techniques For Terahertz Image-based AI **Tu-P2-33**

Cancer Diagnosis

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To develop an AI-based cancer diagnosis technology using terahertz medical imaging, it is imperative to obtain accurately labeled pathological tissue-stained images that serve as the ground truth. However, acquiring these reference images presents challenges such as the cooperation of pathology specialists, high-capacity Whole Slide Images (WSI), and accuracy issues. This study addresses these challenges by creating a brain tumor animal model to obtain tissue-stained images of brain tumor samples, and developing an algorithm using a U-Net neural network for automatic cancerous area segmentation. Through data preprocessing and AI training, high-accuracy labeled data can be provided for terahertz-medical imaging-based AI cancer diagnosis.

90~99 GHz Image-Rejection Mixer In 0.14-um MHEMT Technology **Tu-P2-34**

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We designed and fabricated a 90~99 GHz image-rejection mixer MMIC using 0.14-Î¼m MHEMT technology. The fabricated image-rejection mixer MMIC has a conversion loss of 6.8~9.6 dB, image-rejection ratios of 8.5~24.2 dB for RF input frequencies of 90~99 GHz, an LO power of 9 dBm, LO frequencies of 89.92~98.92 GHz and an IF output frequency of 80 MHz.

Analysis Methods Comparison On A W-Band Corrugated Horn Antenna **Tu-P2-35**

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We present a detailed modeling and characterization comparison of a corrugated antenna operating in the W band. The antenna's performance was predicted using 3D Commercial CST Studio Suite and 2D SRSR software. To compare the measurement results with the predicted simulation response, various methods were employed, including far-field characterization, near-field to far-field transformation, and far-field measurement using a compact test range. Detailed analysis was conducted to evaluate the antenna's return loss, insertion loss, directivity, cross-polarization, and co polarization radiation pattern. The results showed that the antenna's performance matched the expected characteristics predicted by CST and SRSR down to -70 dB. The antenna demonstrates low side lobe levels below the main lobe and low cross-polarization levels. For each type of characterization, the differences between the models and measurements were calculated.

Design Of 340 GHz High-Gain Monopulse Antenna For Terahertz Capture And Tracking System **Tu-P2-36**

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In this paper, a 340 GHz high gain monopulse antenna for terahertz capture tracking system is presented. The feed source is a four-feed horn antenna, and a waveguide with no tension angle at the terminal is used as the feed element to reduce the shielding of the feed source to the parabolic aperture. Four waveguide magic-Ts are used to sum and difference the input and output signals of the four horn feeds. In addition, the reflector is employed to enhance the antenna gain. The monopulse antenna is simulated and verified, and good performance is obtained. The simulated results demonstrate that in the 335-345 GHz band range, the antenna reflection coefficient is less than -10 dB, the maximum differential beam zero depth is -39 dB, and the antenna gain can reach 63 dBi and the 3 dB beamwidth is 0.048Ãf,Ã,Â°.

Design Of THz Low-Loss Flexible Waveguide Structure **Tu-P2-37**

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In this paper, a flexible waveguide structure in terahertz (THz) band is designed and optimized which selects the porous polymer fiber as the core of the structure. The simulation results show that the structure can achieve insertion loss of 0.08dB/cm and flat dispersion coefficient of about 1.5ps/(GHzÂ·m) in the range from 195 to 225GHz. In addition, the insertion loss of the structure with the bending radius of 31mm is also calculated and the results show that: the performance of the designed THz flexible waveguide structure has a little change with the bending radius, which will be well applied in THz communication system.

Design Of A 220 GHz Fourth-harmonic Mixer Based On Schottky Diode **Tu-P2-38**

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In this paper, a 220 GHz fourth-harmonic mixer was designed based on Schottky diode. The structure of multistage reduced height waveguide has been used to expand the bandwidth. On the basis of the common sub-harmonic mixer, this mixer further reduces the required frequency of the LO source. According to the simulation results, the frequency range of RF is 200-240 GHz. When the IF is 1GHz, the conversion loss of single sideband (SSB) is better than 13 dB. In the range of 202-237 GHz, the conversion loss is better than 11.5 dB, and the best value is 10.66 dB.

THz Topological Waveguides In 600 GHz Frequency Region. **Tu-P2-39**

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This work presents an experimental demonstration of a silicon-based valley photonic crystal (VPC) waveguide designed for the 590-620 GHz frequency range. The study measured the transmission and group delay for both normal silicon waveguides and VPC waveguides to investigate the effectiveness of topological valley kink states for THz communication applications. The results suggest that VPCs, known for their topological protection, hold great promise for high-performance photonic circuits, enabling cost and power-efficient data communication applications in the THz range. The design uses Silicon on Insulator (SOI) wafers with a 90 Âμm-thick high-resistivity silicon (HR-Si) and an 11.7 relative permittivity, offering a CMOS-compatible platform with low absorption loss and a non-dispersive refractive index. The experimental measurements were performed using a VNA-based measurement system, and the results were compared with non-topological silicon chips' transmission and group delay. The study concludes that the topological valley kink states in the VPC waveguides are promising for THz communication applications, enabling high-speed 6G data transfer systems. The findings of this study pave the way for further research into higher frequency bands, leading to Tbit/s systems and high-speed data communication applications.

Reconfigurable Terahertz Holograms With Cascaded Diffractive Optical Elements **Tu-P2-40**

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This work demonstrates cascaded diffractive optical elements (DOEs) designed through Machine Learning at terahertz frequencies. Machine learning in this application enables the realization of reconfigurable terahertz holograms through a tailored multi-degree-of-freedom variation; that is by either varying the spacing, number, order, and the rotational alignment of the elements it is possible to attain targeted holograms. The designed DOEs are fabricated by 3D printing technique and validated through experimental measurements. In all cases, the desired diffraction patterns are achieved. Such spatial terahertz light control can have a profound impact on terahertz signal multiplexing, displays, and imaging.

Iterative Design Of Multiple-Input Single-Output Structures For THz Signal Multiplexing **Tu-P2-41**

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Mulitple-input multiple-output technology plays an essential role in today's wireless telecommunication. Therefore, this paper tries to incorporate this method with an optical approach in the terahertz band. Two approaches to terahertz diffractive optical multiple-input single-output structures for 96 GHz

are compared. Both are based on scalar propagation with a modified convolution method. The first approach applies a modified iterative algorithm called Ping-pong. Two separated point sources are placed on the input plane, and single output is requested. The second method combines two separately iterated structures. Each elementary structure is divided into stripes. Stripes are then interlaced to obtain a combined structure. Two described methods are simulated, and resulting structures are manufactured by 3D printing for experimental evaluation. In both cases, experimental data show well-defined output peaks.

3D Printed Diffractive Optical Elements For THz Spatial Multiplexing **Tu-P2-42**

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This study presents the design, manufacturing, and examination of single-input multiple-output (SIMO) diffractive structures for spatial frequency-division (de)multiplexing of terahertz (THz) radiation. SIMO phase structures were designed as a combination of two different types of diffractive optical elements. Structures were examined in numerical simulations. Subsequently, SIMO structures were manufactured from cyclic olefin copolymer material using 3D printing fused deposition modeling technology and validated in the experimental setup. Compared to binary structures presented in our previous study, the novel design method of SIMO structures provides 40% higher effective efficiency.

Research On Multipath Artifacts For Typical Concave Objects In Millimeter Wave Security Imaging **Tu-P2-43**

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Millimeter wave (mmw) security imaging technology is a way to detect concealed objects by receiving the scattered field of targets and then processing the mmw data to form an image. In the actual process, due to the existence of the concave structure of targets, in which there are multiple reflections of electromagnetic waves, resulting in serious multipath artifacts in the reconstruction results. In this paper, based on the ray-tracing principle, the electromagnetic wave propagation principle of the typical concave structure under the scanning regime of a uniform linear antenna array is studied. The two-dimensional (2-D) scattering models of the typical concave structure is established, which provides a basis for solving the problem of accurate imaging of more complex cavities.

Fast Spectrometer Based On Software-defined Radio For Plasma Diagnostics **Tu-P2-44**

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During the operation of tokamak, various radiation signals are generated, which carry information about the energy and distribution of high-energy particles. In this paper, using software-defined radio (SDR) technology, a broadband fast spectrometer has been developed, and the electromagnetic spectrum with a bandwidth of 7 GHz during EAST discharge has been experimentally obtained. The ion cyclotron emission (ICE) has been observed by adjusting the receiving frequency band to 34-39 MHz.

A Novel Fresnel Elliptical Reflector For MMW And THz Near Field Imaging **Tu-P2-45**

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This article describes the design and simulation of a novel Fresnel elliptical reflector that can assist emerging technologies in the field of millimeter-wave and terahertz security imaging. The analytical expressions that satisfy the corresponding amplitude and phase of each section are presented in a general manner. Two different Fresnel reflectors are designed, and their performance is compared with conventional reflectors using numerical simulations based on the Comsol and Feko software packages. The simulation results confirm the proper focusing of the Fresnel reflector at the desired frequency. Furthermore, the frequency behavior of the designed reflectors has been thoroughly investigated. In conclusion, this study provides valuable insights into the design and simulation of Fresnel reflectors, which can significantly enhance the performance of emerging technologies in the field of millimeter-wave and terahertz security imaging.

Frequency-diverse Phase Holograms With Spatial Filtering For Submillimeter-wave Imaging **Tu-P2-46**

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A design technique for frequency-diverse phase holograms using spatial filtering to enhance submillimeter-wave imaging performance is presented. The frequency-diverse holograms are designed to create complex, spatially varying field patterns for an imaging system operating at 325-355 GHz. The proposed technique uses spatial filtering during the hologram synthesizing process to eliminate the wide-angle plane-wave components. This minimizes the field dispersion outside the region of interest, improving the signal-to-noise ratio and imaging performance.

VMD-based Methods For Denoising Terahertz Signals Obtained From Biological Tissue **Tu-P2-47**

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We examine methods for denoising THz signals. The main method is based on the variational mode decomposition (VMD) followed by one of several

thresholding techniques. We present some preliminary results for the denoising of a signal obtained from a biological tissue under low-noise condition and to which various amounts of synthetic noise are added. The study shows the potential of VMD-based methods in characterizing biological samples and, in particular, human breast cancer tissue.

Terahertz Spectra Study Of Quercetin And Quercitrin From Ecdysantherarosea **Tu-P2-48**

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In view of the potential application of terahertz technology in the identification and structure identification of organic small molecule compounds, the absorption spectra of the extract of Edysanthera rosea Hook.et Arn in terahertz band were analyzed by terahertz time-domain spectroscopy (THz-TDS). The spectral characteristics and absorption peaks of quercetin and quercitrin in 0.8 ~ 1.25THz band were obtained. The two compounds have the same absorption peaks at 1.10 and 1.16 THz, and they also have significantly different characteristic absorption peaks, which reflects the fingerprint characteristics of terahertz for small molecular compounds.

OSAS-B: A 4.7-THz Heterodyne Spectrometer For Atomic Oxygen In The Mesosphere And Lower Thermosphere **Tu-P2-49**

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We present the instrumental design and results of the first flight of the Oxygen Spectrometer for Atmospheric Science from a Balloon (OSAS-B). OSAS-B is a 4.7-THz heterodyne receiver for atomic oxygen based on a hot-electron bolometer mixer and a quantum-cascade laser as local oscillator.

An Improved Photonic Crystal Resonator For Sensing Applications At 100 GHz **Tu-P2-50**

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In this work, we compare two photonic crystal (PhC) resonators for biosensing applications at around 100 GHz. They are fabricated and characterized to study their sensing performances. Due to an introduced slot within the resonator and an optimized Q-factor of more than 6,000, the sensing capacity is greatly improved.

Standardizing Terahertz Time-domain Experimental Data And Processing **Tu-P2-51**

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From molecular vibration investigation to observing galaxies, terahertz technology has been advanced by countless research groups worldwide over the past three decades. Naturally, a considerable portion of the research resource would have been exploited for software development and modification. Without a standardized file format to store and exchange terahertz experimental data and the subsequent processing steps, it is challenging to utilize archived data, exchange data and use processing code shared by others. We, therefore, suggest a standardized data format, the .thz format, to store time-domain terahertz data and a set of compatible analysis tools to process the *.thz files. This short paper introduces the design considerations of the HDF5-based data format and a converter tool that can be used to convert and organize terahertz time-domain experimental data into the new format. We also introduce a compatible terahertz spectrum analysis tool, CaTSper. All software is released as the dotTHz project via GitHub under the MIT license to allow widespread adoption and modification. The terahertz community is invited to contribute to the project so that more tools of greater breadth and depth can be established and shared for the benefit of the community.

A 124.9 GHz Traveling Wave Switch Direct Modulator Using Different Switch Units **Tu-P2-52**

Tianchi Zhou
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Terahertz direct modulator is one of the most important devices in terahertz direct modulation communication systems. In this paper, a direct modulator based on traveling wave switching scheme is designed. Its working frequency is located at 140 GHz band, and it is a second-order traveling wave switch modulator with two different switch units. In the simulation, the traveling wave switch modulator reaches an overall insertion loss of 4 dB and the on-off ratio of 24.4 dB at 125 GHz. In experiment, a 4.7 dB insertion loss and a 28.9 dB switching ratio is realized in 214.9 GHz. With the frequency changes, the on-and-off states switched and another switching ratio peak is found at 147.2 GHz.

THz Communication System At 1.8 THz By Photonics-Based Transmitter And Electronics-based Receiver **Tu-P2-53**

Isao Morohashi; Yoshihisa Irimajiri; Akira Kawakami; Tadashi Kishimoto; Pham Tien Dat; Atsushi Kanno; Norihiko Sekine; Iwao Hosako
4-2-1 Nukui-Kitamachi, Koganei, Tokyo

We have demonstrated wireless transmission of quadrature phase shift keying (QPSK) signals at 1.8 THz and investigated usability of the frequency multiplier as a local oscillator (LO) source in the heterodyne receiver system for the wireless communication. For the transmitter, THz signals were converted from optical carriers extracted from a broadband optical comb. The receiver system was composed of a hot electron bolometer mixer and a frequency multiplier for the LO. In the transmission experiment, QPSK signals were successfully demodulated. The EVM of the demodulated signal was about 17 %, which was lower than that in the case of a phase-locked QCL for the LO

reported previously.

A Minimalist Terahertz Direct Modulator-based Real-time High-speed Communication System **Tu-P2-54**

Yi Hao; Ding Kesen; You Jinlong; Wang Wei; Liang Shixiong; Sen Gong; Zhang Yaxin
China,Chengdu,

This study describes a terahertz direct modulator-based direct modulation communication system. To achieve information loading, it uses a terahertz direct modulator as the core and a camera video signal as an intermediate frequency modulation signal. The terahertz detector also enables information demodulation[4]. The system satisfies the requirements for high transmission rate and long transmission distance under the constraints of simple architecture, no requirement for AD/DA, and low power consumption, which lays the groundwork for further realizing the minimal real-time communication of 100 meters and 100 Gbps required in the next generation of information technology.

Integratable 3D Printed Terahertz Horn Coupler **Tu-P2-55**

Qigejian Wang[1]; Haisu Li[2]; Syed Daniyal Ali Shah[3]; Boris Kuhlmey[4]; Shaghik Atakaramians[5]
[1]School of Electrical Engineering and Telecommunications (G17), UNSW Sydney, Kensington; [2]Institute of Lightwave Technology, Beijing Jiaotong University, Beijing; [3]School of EET, UNSW Sydney, Kensington; [4]School of Physics, The University of Sydney, Camperdown; [5]School of EET (G17), UNSW Sydney, Kensington

Frequencies above 100 GHz are envisaged to provide substantially higher capacity and lower latency in wireless telecommunications. Moving to higher frequencies comes with unique challenges to be addressed, including poor coupling efficiency from free space in and out of planar air-core waveguides. Here, we design, fabricate and demonstrate a 3D printed horn coupler which improves the normalized transmittance of a hybrid photonic crystal waveguide by 20 dB. This work provides a fast, convenient and economical way of customizing couplers for different waveguide ports and could be integrated in terahertz devices.

A Concept For The Efficient Integration Of Reconfigurable Intelligent Surfaces Into A Ray Tracing Framework **Tu-P2-56**

Christoph Herold; Thomas Kürner
Schleinitzstraße 22, Braunschweig

Reconfigurable intelligent surfaces are considered as a solution to shape difficult communication environments. In this contribution, a concept for the efficient integration of reconfigurable intelligent surfaces into an existing ray tracing framework is presented. By ray tracing a RIS-assisted communication scenario in two steps - between transmitter and reflective intelligent surface and between reflective intelligent surfaces and receiver - and by combining those two parts automatically, an efficient computation of this otherwise difficult communication link can be provided. The presented solution allows for a later

update of the RIS propagation models due to the ray-tracer's separation of path finding and computation of propagation effects.

Terahertz Sensor Based On Topological Photonic Waveguide **Tu-P2-57**

Xuejiao Xu; Zhijie Mei; Xudong Liu; Yiwen Sun
No.1066, Xueyuan Avenue, Nanshan District, Shenzhen

A terahertz (THz) sensor based on topological photonic crystal waveguide was designed to detect liquids with different refractive indices. Simulation analysis shows that the transmitted THz wave is sensitive to the refractive index of liquids near the waveguide surface with line defect structure, which indicates the proposed THz topological photonic crystal waveguide based sensor has the potential for micro detection, single cell analysis and sorting in the future.

Nondestructive Inspection Of Bridge Tendon Using A THz A-scanner **Tu-P2-58**

Dae-Su Yee; Ji Sang Yahng; Seung Hyun Cho
267 Gajeong-ro, Yuseong-gu, Daejeon

When manufacturing bridge tendons, voids may be formed between the sheath and the grout. We have developed a movable THz A-scanner for nondestructive inspection of bridge tendons, which can be used to measure THz A-scan data in real time. We present that the existence and size of the voids can be detected with the THz A-scanner.

Real-time On-line Thickness Measurement Of Supercapacitor Electrode Coating Using Terahertz Technology **Tu-P2-59**

Zhengxian Gao[1]; Chun Wang[1]; Xu Zheng[1]; Chen Li[1]; Xiaoqing Jia[2]; Xuecou Tu[2]; Lin Kang[2]; Jian Chen[2]; Peiheng Wu[2]
[1]Chentian Industrial Zone, Baotian 1st Road, Shenzhen; [2]Xianlin Ave 163, Nanjing

Terahertz nondestructive testing technology is a new testing method, which can accurately measure the complex refractive index, thickness and other parameters of samples. Electrode coating is widely used in the field of new energy, such as battery separator, supercapacitor electrode, etc. Here, combined with the integrated supercapacitor electrode production line, we propose a method to measure the carbon powder coating thickness of supercapacitor films online of using the terahertz reflection time-domain spectroscopy.

Coatings Thickness Detection On Anisotropic Materials With Sparse Decomposition Method **Tu-P2-60**

Yulei Huang[1]; Weixing Li[1]; Lin Ke[2]; Meiqiang Zhu[1]; Nan Zhang[3]
[1]No1 Daxue Road, Xuzhou; [2]2 Fusionopolis Way, Singapore; [3]Creative Industrial Park 22-404, Suzhou Industrial Park, Suzhou

Sparse decomposition method is used to locate the layer interface pulse with terahertz transmission signal as prior knowledge. Then take advantage of time of flight (TOF) method to realize multi thin layer coating thickness detection on anisotropic substrates without considering the complex properties of the anisotropic materials. This method is validated on the coated carbon-fiber reinforced polymers (CFRP) samples with two coating layers successfully.

Terahertz Nondestructive Characterization Of Tertiary Mill Scale On Commercial Hot-rolled Steel Strips **Tu-P2-61**

Min Zhai[1]; Alexandre Locquet[1]; Cyrielle Roquelet[2]; Jean-Luc Borean[2]; Philip Meilland[2]; David Citrin[1]
[1]2 Rue Marconi, Metz; [2]Voie Romaine, BP 30320, Maizières-lès-Metz

Terahertz time-of-flight tomography is employed to characterize tertiary mill-scale thickness down to ~ 10 μm on production steel strips. Overall agreement between terahertz measurements and scanning electron microscopy is found, validating the practical application of terahertz time-of-flight tomography for in-line nondestructive thickness characterization and quality control of optically thin mill-scale on commercial steel products, especially in a production environment.

Microprobe-based Terahertz Near-field Imaging Of Highly Scattering Pharmaceutical Coatings On Small Tablets **Tu-P2-62**

Michael Nagel[1]; Matthias Wolfgang[2]; Martin Spoerk[2]; Johannes G. Khinast[2]; Simon Sawallich[1]; Alexander Michalski[1]
[1]Otto-Blumenthal-Str. 25, Aachen; [2]Inffeldgasse 13, Graz

Pharmaceutical solid dosage forms can be inspected using terahertz time-domain spectroscopy systems. However, in many cases, the size, shape, and composition pose considerable challenges using classic far-field configurations. We demonstrate how these challenges can be overcome using microprobe-based THz near-field imaging in reflection-mode and a wavelet-based signal analysis algorithm. This technique reveals buried interface structures that were not resolvable before.

Sparse Synthetic Antenna Array For 3D Imaging And Spectroscopy In The Terahertz Range **Tu-P2-63**

Manal Ait Assou; Georges Humbert; Aurelian Crunteanu; Cyril Decroze
123 Albert Thomas Avenue, Limoges

We propose a terahertz (THz) 3D imaging and spectroscopy approach using planar synthetic arrays. In order to improve the acquisition time, the number of antenna elements needed in the synthetic array is reduced by employing a sparse synthetic array. The performances of the full synthetic array and the sparse array are compared experimentally in both imaging and material characterizations.

Assessment Of Anti-corrosion Coatings Adhesion Using Terahertz Time Domain Reflection Spectroscopy. **Tu-P2-64**

Vincent Wallace
35 Stirling Highway, Perth

Corrosion is a significant economic problem, accounting for up to 5% of the Global GDP. New coatings are being developed to prevent corrosion, but they must bond well with the metal surface, have a minimal thickness, and not delaminate over time. Coating adhesion is crucial for the coating system to attain its design lifetime. Coatings applied following the manufacturer's

recommendations generally offer good adhesion to the substrate and can resist the permeation of corrosive agents. Coating adhesion depends on the coating property and substrate cleanliness, surface roughness, and any pre-treatments before coating application. The study evaluated the effects of surface roughness profile morphology and height on the pull-off adhesion strength value of the coating and its correlation with interfacial adhesion at the coating and substrate. The results show that delamination of coatings on steel used to protect the material from corrosion can be detected using terahertz reflection spectroscopy. The THz data agree well with standard industry pull-off testing. The study provides evidence that THz reflection spectroscopy can be used for non-destructive testing of anticorrosion coatings and the aging process.

Defects Detection In Indian Timber Wood Using THz Imaging Technique **Tu-P2-65**

Mercy Latha A
Near to BITS, Pilani Campus, Pilani, Jhunjhunu

There is a demand for defect identification in timber wood, particularly by Indian timber industries. Present defect detection techniques, namely ultrasonic scanning, sound hammering, x-ray imaging, NIR imaging, and microwave imaging pose a series of problems such as poor accuracy, destructive approach, and cumbersome operation. To overcome the limitations of conventional techniques, terahertz (THz) imaging is emerging as a potential alternative capable of detecting various defects in wood non-destructively. In this study, the THz imaging technique has been employed for defect detection of various defects in three different types of Indian timber wood, namely neem (Azadirachta indica), babool (Acacia nilotica) and vetpalai (Wrightia tinctoria). THz continuous-wave imaging system with a photomixer as the source and a Schottky-based quasi-optical detector has been employed for phase insensitive imaging in the range of 0.1 to 0.4 THz. The acquired THz images demonstrate the capability of THz imaging system in detecting different sub-surface and bulk defects, namely knots, chip marks, insect infestations, etc., non-destructively. Further, since THz radiation has sufficient penetration depth, this technique can be used for identifying defects lying deeper inside the timber wood as well.

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20 September 2023

08:30 - 09:15 **Plenary Session 5** **Symposia Theatre**

Chairperson(s): François Blanchard,

08:30 **High Harmonic Spectroscopy For Many-body Dynamics In Solids** **We-PL-1-1**

Koichiro Tanaka[1]; Kento Uchida[2]
[1]Oiwake, Kitashirakawa, Sakyo, Kyoto-shi; [2]Oiwake, Kitashirakawa, Sakyo, Kyoto

We report our recent results on high harmonic generation in crystalline solids, and the effect of many-body correlations on extreme nonlinear optical process driven by intense infrared field. Our observations indicate that high harmonic

generation can be a new spectroscopic tool to investigate ultrafast non-equilibrium dynamics of the many-body system.

09:15 - 10:00 **Plenary Session 6** **Symposia Theatre**

Chairperson(s): François Blanchard,

09:15 **Terahertz Pump/X-ray Probe Experiments At LCLS** **We-PL-2-1**

Matthias Hoffmann
2575 Sand Hill Road, Menlo Park
I will give a summary of THz experiments using ultrafast x-ray pulses from free electron lasers as a probe. The first part will be a brief review of our past and current capabilities at SLAC and highlight results that we were able to achieve during the first ten years of operation of LCLS. The second part of the talk will focus at the the future capabilities of LCLS-II (which is coming on-line this year) and how we will scale to much higher repetition rates to enable new and exciting science.

10:30 - 12:00 **Laser Sources & Detectors V** **Symposia Theatre**

Chairperson(s): James Lloyd-Hughes,

10:30 **Broadband GaP Contact Grating Terahertz Source Pumped At 3.9 μM** **We-AM-1-1**

ABHISHEK GUPTA[1]; ROKAS JUTAS[2]; CLAUDIA GOLLNER[2]; AUDRIUS PUGZLYS[2]; ANDRIUS BALTUSKA[2]; JOZSEF FULOP[1]
[1]Wolfgang Sandner utca 3, SZEGED; [2]TU Wien, Vienna

A novel GaP semiconductor contact grating THz source with trapezoidal line profile, pumped at the mid-infrared wavelength of 3.9 μm, is demonstrated. The source can be scaled to high electric fields due to the plane-parallel geometry, the availability of good-quality large GaP crystals, and the large bandwidth of up to 6 THz.

11:00 **A New Screening Methodology For Terahertz Generation Crystals** **We-AM-1-2**

(Enoch) Sin-Hang Ho[1]; gabriel Valdivia Berroeta[2]; Zachary Zaccardi[3]; Sydney Pettit[3]; Bruce Palmer[3]; Matthew Lutz[3]; Claire Rader[3]; Brittan Hunter[3]; Natalie Green[3]; Connor Barlow[3]; Coriantumr Wayment[3]; Daisy Harmon[3]; Paige Petersen[3]; Stacey Smith[3]; David Michaelis[3]; Jeremy Johnson[3]
[1]Brigham Young University, Provo; [2]Connecticut, USA.; [3]C100 BNSN, Brigham Young University, Provo

Organic nonlinear optical (NLO) crystals are effective in light frequency conversion through nonlinear optical applications, such as optical rectification and second-harmonic generation, due to low dielectric constants and high molecular hyperpolarizabilities. Yet only a few organic NLO materials have

been identified. Combining data mining for structures from the Cambridge Structural Database and density functional theory calculations, we discover new organic nonlinear optical crystals that generate intense terahertz (THz) radiation. To confirm our combination approach, we recrystallized and tested the newly discovered organic nonlinear materials. The results of THz experiments showed the THz generation capabilities exceed state-to-art THz generation crystals (DAST, OH-1 and BNA).

11:15 **Intense Broadband THz Generation In The Organic Crystal BNA By Compression Of Ytterbium Laser Pulses Based On A Gas-filled Hollow-core Fiber** **We-AM-1-3**

Young-Gyun Jeong[1]; Luca Zanotto[1]; Dong-Jae Seo[2]; Yujin Nam[2]; Xin Jin[1]; Jisoo Kyoung[2]; Bruno E. Schmidt[1]; Mostafa Shalaby[3]; Luca Razzari[1]
[1]1650 Boul. Lionel-Boulet, Varennes; [2]119 Dandae-ro, Dongnam-gu, Cheonan; [3]Technoparkstrasse 1, Zürich

We investigate the enhanced THz generation characteristics of the organic crystal BNA when pumped by compressed ytterbium laser pulses. When the pump pulses are compressed down to 42 fs using a gas-filled hollow-core fiber and chirped mirrors, the THz conversion efficiency is increased by 75%, and the generated frequency spectrum extends up to 12 THz. These findings demonstrate the benefits of using compressed ytterbium laser pulses for enhancing THz generation in suitable nonlinear crystals for the development of intense and broadband THz sources.

11:30 **Characterization Of Organic Nonlinear Optical Crystals For THz Applications** **We-AM-1-4**

Hirohisa Uchida[1]; Chisa Koyama[2]; Kohei Hayase[3]; Kosuke Murate[3]; Kodo Kawase[3]; Kei Takeya[4]
[1]Yosuien-nai, 59 Gansuin-cho, Kamigyo-ku; [2]Yosuien-nai, 59 Gansuin-cho, Kamigyo-ku; [3]Chikusa-ku, Nagoya; [4]Okazaki

In this work, we evaluated the effects of humidity and temperature on organic nonlinear optical crystals. For the effect of humidity, we compared the THz wave generation before and after exposure tests at a temperature of 30 Ã‚Â°C and a humidity of 80 % for 10 weeks. As a result, terahertz wave output decreased for the DAST crystal, while terahertz wave output did not decrease for the DASC and OH1 crystals. For the effect of temperature, we evaluated the temperature dependence on the EO effect. As a result, when the EO signal was evaluated using one DAST crystal, the EO signal changed periodically with temperature fluctuations. On the other hand, when the a-axes of the two DAST crystals were orthogonal, the EO signal did not fluctuate. From these results, we have shown that the properties of organic nonlinear optical crystals need to be understood and their use optimized.

11:45 **Improved Terahertz Generation Through Heterogenous Multi-Layered Organic Crystal Structures** **We-AM-1-5**

Aldair Alejandro; Daisy Ludlow; Paige Petersen; Kayla Holland; Fatoumata N'diaye; Tanner Manwaring; David Michaelis; Jeremy Johnson

BNSN C100, Provo

Yellow organic crystals, like BNA, MNA and NMBA can be used to produce terahertz (THz) light via optical rectification of ultrafast laser pulses. In this work, we create new multi-layered "sandwich" structures with these yellow crystals by (1) fusing them to sapphire plates that allow the crystal to withstand higher laser fluences and (2) using MBBA liquid crystal to improve THz output efficiency through refractive-index matching in the layers of the structure. We show that the sapphire plates significantly increase the damage threshold of these yellow organic crystals by a factor of two or more. We also show that the THz output efficiency is further increased by using a multi-layered sandwich structure with an exit liquid crystal layer. In some cases, we show that the sandwich structure increases the THz intensity by more than a factor of two.

10:30 - 12:00 **Spectroscopy III** **Cartier I**

Chairperson(s): Shuying Chen,

10:30 **Terahertz Multispectral Sub-Wavelength Tomography Using A Solid-Immersion Lens** **We-AM-2-1**

Da-Hye Choi; Mugeon Kim; Dong Woo Park; Eui Su Lee; IL-Min Lee
218 Gajeong-ro, Yuseong-gu, Daejeon, Korea, Daejeon

We demonstrate a multispectral sub-wavelength 3D THz imaging system by combining a solid-immersion lens (SIL) with a typical THz time-domain spectrometer (TDS). The imaging resolution of the system is enhanced in a wide spectral range (from 0.3 to 2.0 THz) with the aid of the SIL. Experimentally achieved imaging resolution enhancement results are consistent with the numerical simulation results. To highlight the multispectral sub-wavelength THz imaging capability, the spectral response of the WR1.9 waveguide near the cutoff frequency, inaccessible with a conventional THz-TDS-based imaging system, is obtained. In addition, we construct the multispectral sub-wavelength 3D images using the system by selecting the appropriate measurement time window of the temporal THz signal. 3D images of a credit card show the sub-wavelength details of the card, including an IC chip, invisible due to the plastic cover. The experimental results demonstrate the capability of the imaging system in non-contact, non-destructive testing of objects with the sub-wavelength scale structures.

10:45 **Detecting Crystallization Of Norfloxacin In Paper Tablets After Wet Granulation By Terahertz Time-domain Spectroscopy** **We-AM-2-2**

Lara Heidrich[1]; Ayat Abdelkader[2]; Jan Ornik[1]; Enrique Castro-Camus[1]; Cornelia M. Keck[2]; Martin Koch[1]
[1]Renthof 5, Marburg; [2]Robert-Koch-Straße 4, Marburg

Granulated and non-granulated smartFilm tablets loaded with norfloxacin (NOR) were investigated using terahertz (THz) time-domain spectroscopy (TDS) and x-ray powder diffraction (XRD). THz TDS was more sensitive to crystalline NOR, as through THz TDS, partial crystallization of NOR after wet granulation can be observed, which was not detectable by XRD. The results

obtained by THz TDS were used for quantitative crystallinity assessment in the smartFilm tablets.

11:00 **Towards Single-pulse Terahertz Spectroscopy At MHz Rates** **We-AM-2-3**

Nicolas Couture[1]; Wei Cui[2]; Markus Lippl[3]; Rachel Ostic[2]; Défi Jubgang[2]; Aswin Vishnuradhan[2]; Eeswar Yalavarthi[2]; Angela Gamouras[4]; Nicolas Joly[5]; Jean-Michel Ménard[2]
[1]25 Templeton St., Ottawa; [2]25 Templeton St.; [3]Staudtstraße 2; [4]1200 Montreal Rd.; [5]Schloßplatz 4

Single-pulse time-resolved THz detection is performed at repetition rates up to 1.1 MHz with a table-top system. Our detection scheme combines electro-optic sampling of THz pulses with spectral encoding onto a chirped near-infrared pulse, followed by time-stretch spectroscopy to monitor the oscillating electric field of each THz pulse. We demonstrate the concept by monitoring cumulative carrier injection dynamics in silicon at 50 kHz until a saturation density is reached and investigate signal-to-noise ratio at higher repetition rates. This technique paves the way towards fundamental research on fast and non-reproducible phenomena requiring real-time monitoring as well as industrial applications requiring fast data acquisition for non-invasive quality control.

11:15 **The Effect Of Terahertz Scattering On Loss Coefficient In Granular Compacts** **We-AM-2-4**

Keir N Murphy[1]; Daniel Markl[1]; Alison Nordon[2]; Mira Naftaly[3]
[1]99 George St, Glasgow; [2]99 George St,, Glasgow; [3]Hampton Rd, Teddington

Terahertz (THz) scattering in compacts is of great interest due to its potential to quantify particle size changes in granular materials. In this study, we investigate the effect of both particle size and concentration on THz scattering. The scattering contributions to the loss coefficient are extracted and analysed using specially fabricated samples consisting of borosilicate microspheres suspended in either a polytetrafluoroethylene (PTFE) or paraffin oil matrix.

11:30 **Characterization Of Morphology-Dependent Transport In Lead-Halide Perovskite Printed Films Using Time-Resolved Terahertz Spectroscopy** **We-AM-2-5**

Nils Refvik[1]; Lennart Reb[2]; Christoph Lindenmeir[2]; Charles Jensen[1]; Howe Simpson[1]; Damini Vrushabendrakumar[3]; Karthik Shankar[3]; Peter Müller-Buschbaum[2]; Frank Hegmann[1]
[1]4-181 CCIS, Edmonton; [2]James-Franck-Str. 1 85748, Garching; [3]Donadeo Innovation Centre for Engineering, Edmonton

We report on position-dependent measurements of photocarrier transport using time-resolved terahertz spectroscopy (TRTS) across a slot-die printed perovskite film of varying morphology. Using the Drude-Smith model for the photoconductivity spectra we report maximum intrinsic mobilities of 540 ± 20 cm^2/Vs. In addition, we measure variation across the film in the extracted mobilities and the localization c-parameter, correlated with complementary measurements of the film morphology and optical properties. To the best of our knowledge this is the first TRTS study performed on perovskite films produced

using a slot-die printing technique.

11:45 **Enhanced Liquid Sensing With 3D Printed Terahertz Photonic Crystals** **We-AM-2-6**

Marcel Grzeslo; Jonas Tebart; Rihab Hamad; Andreas Stöhr; Andreas Klein
Lotharstr. 55, Duisburg

Liquid sensing at THz frequencies is attractive, as it allows not only for the identification of different substances, but due to large attenuation of aqueous solutions, even small changes in concentration are detectable, making it ideal for process monitoring. The sensitivity can be further enhanced, by introducing a cavity, which holds the liquid, which also simplified the measurement as now a peak shift, height and width can be quantified. Here we present 3D printed metallic photonic crystals with standard WR3 waveguide interfaces for experimental characterization. The design of 2D hexagonal and 3D wood pile photonic crystals to optimize the sensitivity is presented. Aqueous glucose and alcohol solutions are investigated.

10:30 - 12:00 **Superconductivity & Condensed Matter** **Cartier II**

Chairperson(s): Martin Dressel,

10:30 **Higgs Coherence Spectroscopy Of A Parametrically Driven Superconductor** **We-AM-3-1**

JIGANG WANG
Department of Physics and Astronomy, AMES

We present the discovery of parametrically driven superconductivity by light-induced order-parameter collective oscillations in iron-based superconductors. The time-periodic relative phase dynamics between the coupled electron and hole bands drives the transition to a distinct parametric superconducting state out-of-equalibrium. This light-induced emergent coherence is characterized by a unique phase--amplitude collective mode with Floquet-like sidebands at twice the Higgs frequency. We measure non-perturbative, high-order correlations of this parametrically driven superconductivity by separating the terahertz-frequency multidimensional coherent spectra into pump--probe, Higgs mode and bi-Higgs frequency sideband peaks. We find that the higher-order bi-Higgs sidebands dominate above the critical field, which indicates the breakdown of susceptibility perturbative expansion in this parametric quantum matter.

11:00 **Tunable THz Beam Splitter Based On Superconducting NbN** **We-AM-3-2**

Yan Teng; Yuhua Xiao; Shaochen Li; Chun Li; Ling Jiang
Nanjing Forestry University

In this paper, a novel terahertz (THz) beam splitter based on superconducting NbN is proposed to realize dynamic switching of the multi-beam. NbN has low ohmic loss at 4.5K temperatures and can avoid the loss of THz waves on metals to the maximum extent. Temperature-controlled beam splitters can reduce design complexity and increase application flexibility. We have designed and simulated the implementation of a superconducting beam splitter for five beams to three beams modulation. The proposed method provides a new approach to the design of THz beam modulation devices.

11:15 **THz And Mid-Infrared Linear Dichroism In The High Tc Superconductor La2-xSrxCuO4** **We-AM-3-3**

Deepu George[1]; Andrea Markelz[1]; John Cerne[1]; Xi He[2]; Ivan Bozovic[2]; Timothy LaFave Jr.[1]

[1]239 Fronczak Hall, Department of Physics, University at Buffalo, SUNY, Buffalo; [2]Condensed Matter Physics & Materials Science Dept., Bldg. 480 P.O. Box 5000, Upton

We measure the rotation of the linear polarization of light that is transmitted through a high Tc superconductor film as a function of sample orientation. We observe a linear dichroism signal over the entire probing range from 2 to 230 meV, which is consistent with anisotropic in-plane conductivity. The La2-xSrxCuO4 thin film sample is epitaxially constrained to be tetragonal, so the symmetry breaking is purely electronic.

11:30 **Status Of The Spurious Evidence For Photoinduced Superconductivity** **We-AM-3-4**

Steve Dodge; Leya Lopez; Derek Sahota
8888 University Drive, Burnaby

After more than a decade of research on photoinduced superconductivity, the experimental evidence for its existence remains controversial. Recently, we identified a fundamental flaw in the analysis of several influential results on K3C60 and showed that similar measurements on other compounds suffer from the same problem. We described how to account for this systematic error, and reanalyzed evidence that had previously been advanced for both photoinduced superconductivity and Higgs-mediated terahertz amplification. We found that both phenomena may be understood instead as a photoenhancement of the carrier mobility that saturates with fluence, with no need to appeal to a photoinduced phase transition to a superconducting state. We summarize this reinterpretation and describe how subsequent work on K3C60 provides quantitative support for it.

11:45 **Terahertz Excitation Of Chiral Phonons Probed Via The Faraday Effect** **We-AM-3-5**

Jeremy Johnson[1]; Megan Nielson[2]; Sin-Hang (Enoch) Ho[2]; Aldair Alejandro[2]; Matthew Lutz[2]; Clayton Moss[2]

[1]C312 BNSN BYU, Provo; [2]C371 BNSN BYU, Provo

By combining two variably delayed THz pulses with vertical and horizontal polarizations, we create one combined THz pump pulse with circular polarization. This circular polarized THz pulse is used to excite chiral phonon motion in non-magnetic LiNbO3, which in turn induces a transient magnetic moment that we probe via the ultrafast Faraday effect.

10:30 - 12:00 Antenna Imaging Techniques II **International I**

Chairperson(s): Zachary Taylor,

10:30 **Terahertz Single Pixel Imaging Via Spatial Polarization Modulating Masks** **We-AM-4-1**

Seth Lowry[1]; Matt Reid[2]; Christopher Collier[1]
[1]1137 Alumni Ave, Kelowna; [2]3333 University Way, Prince George

Terahertz single pixel imaging is rapidly evolving to meet innovations in spatial terahertz modulation. The work presented here demonstrates a novel modulation scheme for terahertz frequencies involving the direct spatial modulation of the imaging beam polarization. This is realized by the design of modulation masks that incorporate wire-grid polarizers as each modulating pixel to probe the polarization response of an object. The wire-grid polarizer masks are constructed by preparing parallel wires of aluminum film on polyethylene by laser ablation. In this work, five-by-five pixel polarization-sensitive images of an object are reconstructed by a compressive imaging method to demonstrate the feasibility of using spatial polarization modulation to conduct polarization-resolved terahertz single pixel imaging. This modality gives access to polarization-resolved images using terahertz detection configurations which are less complex with faster image acquisition relevant to terahertz material inspection via polarization-resolved imaging.

10:45 **Multi-color Terahertz Spatial Light Modulator For Single-pixel Imaging** **We-AM-4-2**

Chenyu Wang; Yu Liao; Xudong Liu; Yiwen Sun
No.1066 Xueyuan Avenue, Nanshan District, Shenzhen

A broadband THz single-pixel imaging system was built by a 10*10 broadband electrical SLM. The SLM shows modulation performance at various frequencies. A metal pattern with "box" shape was successfully constructed with our system at 3 frequencies. The imaging system in this paper outperforms the current single-pixel imaging systems based on metamaterials in terms of bandwidth and pixel numbers.

11:00 **Antenna For Free Space-coupled Third-order Sub-harmonic Coherent Detector Array In The 300 GHz Band** **We-AM-4-3**

Meng Zhang[1]; Zhenming Tian[2]; Benedikt Sievert[2]; Christian Preuss[2]; Nils Weimann[2]; Andreas Rennings[2]; Daniel Erni[2]
[1]Bismarckstrasse 81, Duisburg; [2]Bismarckstrasse 81

A third-order sub-harmonic transmitarray is proposed for a coherent detector array. The transmitarray operates in the 100 and 300 GHz bands, which correspond to the RF signal and LO signals in coherent detection. Considering the integration with an on-chip detector element, the transmitarray element is fabricated on a silicon wafer utilizing a multi-layer photolithography process. In the measurement, the element shows the capability of receiving signals from its opposite sides in the dual-band. At 100 GHz the antenna emits broadside whereas in the 300 GHz band the beam radiates in the opposite direction.

11:15 **Improved Phase Retrieval Techniques For Millimeter Wave Beams In Noisy Environments** **We-AM-4-4**

Alex Laut; Kyle Thackston; Lavanya Periasamy; James Anderson
PO Box 85608, San Diego

Characterizing a millimeter wave beam's propagation properties is critical for power coupling into an overmoded transmission line for applications such as

plasma heating in a fusion device. Techniques to process experimental beam data from millimeter wave sources will be discussed. A method to reliably estimate the second statistical moment of a noisy RF beam will be described as will an improved phase retrieval algorithm used to determine the complex field distribution at a source's aperture where experimental data cannot be directly acquired. The coupling quality can be indicated by a modal decomposition of the aperture field. These techniques were incorporated into an interactive code to assist in the commissioning of ECH gyrotrons

11:30 **Analysis Of Surface Roughness With 3D SAR Imaging At 1.5 THz** **We-AM-4-5**

Aman Batra[1]; Yevhen Ivanenko[2]; Viet T. Vu[2]; Michael Wiemeler[1]; Mats I. Pettersson[2]; Diana Goehringer[3]; Thomas Kaiser[1]
[1]Bismarckstr. 81, Duisburg; [2]Valhallavägen 1, Karlskrona; [3]Nöthnitzer Str. 46, Dresden

The expansion of the synthetic aperture radar (SAR) to the emerging THz spectrum has enabled a new era of applications in the areas of automobile, security, non-destructive testing, and material characterization. Thanks to the sub-mm wavelength, extraction of material surface properties is possible and of significant interest for the THz SAR applications. The properties define the surface scattering behavior, which is relational to the applied frequency. This study focuses on surface classification. We evaluate the scattering behavior of a rough surface and a smooth surface at 1.5 THz based on a SAR processing sequence that is introduced in this paper. First, we form the 3D SAR images of the metallic objects and then evaluate the surface properties based on the variation in the energy reflected by the object's surface.

10:30 - 12:00 **Chemistry, Biology & Medicine III** **International II**

Chairperson(s): Angela Vella,

10:30 **Towards The Detection Of Heavy Metals In Plants Using THz** **We-AM-5-1**

Lisa Kreuzer[1]; Fabian Brix[2]; Petra Düchting[2]; Sebastian Gassel[1]; Carsten Brenner[1]; Milan Deumer[3]; Robert Kohlhaas[3]; Ute Krämer[2]; Martin R. Hofmann[1]
[1]Universitaetsstraße 150, Bochum; [2]Universitätsstraße 150, Bochum; [3]Einsteinufer 37, Berlin

The pollution of soil and the resulting contamination of plants with heavy metals is a growing concern for, food safety and human health in industrialized countries. Until now, the exposure of plants is studied by means of complex procedures in the laboratory, in which a part of the plant is destroyed. In this study, we demonstrate a non-destructive method using Terahertz spectroscopy to detect heavy metal accumulation in leaves of A. halleri.

11:00 **Comprehensive Data Analysis And Machine Learning Models For Automatic Identification Of Chemical Compounds Based On Terahertz** **We-AM-5-2**

Spectra

Zi Xi Josie Lim[1]; Nan Zhang[1]; Wei Ji Phua[1]; Lijie Yu[2]; Jia Yi Kwang[2]; Angeline Tang[2]; Angeline Tiong Whei Yap[2]; Yee-Fun Lim[3]; Lin Ke[4]
[1]75 Ayer Rajah Crescent, #01-08, Singapore; [2]11 Outram Road, Singapore; [3]2 Fusionopolis Way, Singapore; [4]2 Fusionopolis Way, Singapore

The article describes a method for auto-identification of chemical compounds encountered in complicated real-world scenarios, with common issues such as complex spectra, mixtures, and masking of signals. This method comprised a sample treatment protocol, data processing technique, and machine learning algorithms. The data processing technique involved normalizing and filtering the chemical spectrum to isolate characteristic peaks. Principal Component Analysis and t-distributed Stochastic Neighbor Embedding were used to identify significant features and reduce data dimensionality. Machine learning models such as Support Vector Machine, Random Forest Classifier, Gradient Boosting Classifier, and Neural Network Classifier were implemented to classify the identified peaks. The accuracy of the models was tested using diluents, illicit drugs, and mixture chemicals, and all machine learning models showed over 90% accuracy. This concluded that the method can potentially be incorporated into software for on-site testing and automatic identification of chemical compounds in real-world scenarios.

11:15 **In-line Non-destructive Multi-wavelength Medicine Quality Inspection** **We-AM-5-3**

Yuya Kinoshita; Sayaka Hirokawa; Kou Li; Daiki Sakai; Yuto Matsuzaki; Yuto Aoshima; Raito Ota; Daiki Shikichi; Yukio Kawano
#1609, 1-13-27 Kasuga, Bunkyo-ku

We report on real-time in-line measurements of pharmaceuticals using carbon nanotube (CNT) sensors and multi-wavelength. In this study, we developed an in-line multi-wavelength optical system consisting of single photo-sources from IR to MMW to perform pharmaceutical imaging inspections. In these bands, CNT films are well known for their highly efficient absorption. As a result, based on different transmittances of medicines, we demonstrated in-line imaging identification of different types of medicine.

11:30 **Machine Learning Classification Of Breast And Oral Fresh Cancer Tissue Based On Terahertz Imaging** **We-AM-5-4**

Jyotirmayee Dash[1]; Arun Jana[2]; Lenin B[1]; Shyamsundar Mandyam[1]; Bala Pesala[1]
[1]Siruseri, Chennai; [2]Siruseri., Chennai

In this paper, a compact cost-effective continuous wave Terahertz (THz) system is utilized to differentiate between cancer and healthy tissue regions in fresh tissue samples. Both oral and breast cancer margin assessment has been analyzed using THz imaging. More than ten cancer and normal fresh tissues are imaged below 0.3 THz and the results are compared with the histopathology images (i.e. the gold standard technique). Advanced Machine Learning algorithms such as Support Vector Machine and Random Forest algorithm are incorporated based on the THz results to differentiate cancer and normal tissue.

Significant contrast at lower frequency region on the fresh tissue confirms the potential of THz imaging for intraoperative cancer margin detection.

13:30 - 15:30 **Laser Sources & Detectors VI** **Symposia Theatre**

Chairperson(s): Matthias Hoffmann,

13:30 **Terahertz Hot-Electron Bolometric Detectors Based On Metal/Black-AsP/Graphene FETs: Proposal And Evaluation** **We-PM1-1-1**

Taiichi Otsuji[1]; Victor Ryzhii[1]; Chao Tang[1]; Maxim Ryzhii[2]; Vladimir Mitin[3]; Michael Shur[4]
[1]2-1-1 Katahira, Aoba-ku, Sendai; [2]Ikkicho, Aizuwakamatsu; [3]12 Capen Hall, Buffalo; [4]110 8th Street, Troy

A novel terahertz (THz) hot-electron bolometric detector based on a graphene field effect transistor with the black-AsP gate barrier layer (BL) is proposed. The authors developed the device model, and evaluated its THz detection performances theoretically. By providing a relatively low energy barrier for the emitted electrons the b-AsP BL helps reinforce the THz radiation absorption and the intensification of the electron heating and thermionic emission associated with the resonant excitation of plasmonic oscillations in the graphene channel. The characteristic responsivity R for the structures with the Fermi energy ? = 120 to 140 meV (corresponding plasma frequencies in the range of 1 to 3 THz), the device feature size of 10 to 20 ?m, and the electron viscosity frequency of 0.1 /ps operating at room temperature was estimated to be R = 500 to 1,000 A/W. One remarkable feature is that higher harmonic resonant frequencies get larger responsivity than that at the fundamental frequency.

13:45 **Fast THz Detection By An Asymmetric-Dual-Grating-Gate Graphene-Channel FET Based On Plasmonic And Photothermoelectric Effects** **We-PM1-1-2**

Koichi Tamura[1]; Shinnosuke Uchigasaki[1]; Hironobu Seki[1]; Chao Tang[1]; Daichi Ogiura[1]; Kento Suwa[1]; Hirokazu Fukidome[1]; Yuma Takida[2]; Hiroaki Minamide[2]; Tetsuya Suemitsu[3]; Taiichi Otsuji[1]; Akira Satou[1]
[1]2-1-1 Katahira, Aoba-ku, Sendai; [2]519-1399 Aramakiaza-aoba, Aoba-ku, Sendai; [3]6-6-10 Aramakiaza-aoba, Aoba-ku, Sendai

We investigate the fast photoresponse of an asymmetric du-al-grating-gate graphene-channel FET THz detector and experimentally demonstrate a 10-ps-order fast response time to 0.95-THz radiation incidence at room temperature. Through the bias-voltage dependences of the photoresponse, we identify that both plasmonic and photothermoelectric rectification effect co-exist in a wide gate bias voltage range as the detection mechanisms.

14:00 **Influence Of Antenna Parameters On Terahertz Photoelectric Tunable-step Detector Operation** **We-PM1-1-3**

Ran Chen; Harvey Beere; David Ritchie; Wladislaw Michailow

Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge

A novel, quantum mechanism, the in-plane photoelectric effect, was recently demonstrated in two-dimensional electron gas (2DEG)-based dual-gated detectors yielding a large terahertz photoresponse. To develop the mechanism further, a systematic study is carried out in this work to investigate the parameter dependence of the THz photoresponse. The electric field distribution within the 2DEG channel is simulated and integrated to obtain the radiation-induced ac potential difference as a function of the gap size and the 2DEG depth. Based on the simulation results, we design, optimize, and fabricate a dipole-antenna photoelectric tunable-step (PETS) THz detector with gap size b = 190 nm and 2DEG depth d = 90 nm, which shows a strong photoresponse to 1.9 THz radiation.

14:15 **Integrated Ultra-Broadband THz Photodiode With Silicon Rod Waveguide Interface** **We-PM1-1-4**

Shuya Iwamatsu[1]; Muhsin Ali[2]; José Luis Fernandez-Estevez[1]; Marcel Grzeslo[1]; Sumer Makhlouf[3]; Guillermo Carpintero[4]; Andreas Stöhr[1]
[1]Lotharstr. 55, Duisburg; [2]Avenida Gregorio Peces-Barba 1, Leganés; [3]Essener Str. 5, Oberhausen; [4]Avenida de la Universidad 30, Leganés

Dielectric waveguides have shown great promise for THz integrated systems due to their ultra-low loss and broadband operation. This study reports an integration of ultra-broadband uni-traveling-carrier photodiode (UTC-PD) with high-resistivity silicon dielectric rod waveguides (DRW), which would fully exploit ultra-broadband performance of THz photomixers and play a vital role in developing practical on-chip THz spectroscopy systems.

14:30 **Ultra-Compact And Room-Temperature Focal Plane Assemblies For Lunar Advanced Filter Observing Radiometer For Geologic Exploration** **We-PM1-1-5**

Giacomo Mariani; Matt Kenyon; Byeongho Eom
4800 Oak Grove Dr, Pasadena

This work presents focal plane modules for Lunar Advanced Filter Observing Radiometer for Geologic Exploration, a multispectral imaging infrared radiometer which measures heat coming from the lunar surface to determine the temperature, thermal inertia and composition of geologic materials on the Moon's surface. The focal plane arrays are micromachined at JPL and integrated into sub-assembly modules to be mounted on the optical telescope of the instrument.

14:45 **BABAR-ERI: Black Array Of Broadband Absolute Radiometers -- Earth Radiation Imager** **We-PM1-1-6**

Christopher Yung[1]; Cameron Straatsma[2]; Nathan Tomlin[1]; David Harber[2]; Odele Coddington[2]; John Lehman[1]; Michelle Stephens[1]
[1]325 Broadway, Boulder; [2]1234 Innovation Dr, Boulder

BABAR-ERI is being developed for a CubeSat capable of imaging the Earth's

outgoing longwave radiation with a 1 km ground sample distance (GSD) using a push-broom imager. The detector is a silicon micromachined 32-pixel linear array of electrical substitution radiometers capable of broadband sensing from 0.3 Î¼m to 100 Î¼m using vertically aligned carbon nanotube absorbers located on each pixel. Our aim is to demonstrate data performance, with a CubeSat, against existing CERES instruments but at a smaller GSD. Electrical substitution radiometers are well suited to this task as they have heritage as ground calibration transfer standards and in space for total solar irradiance measurements.

15:00 **On Cold Operation Of An SiGe HBT As A Broadband Low-NEP THz Direct Detector** **We-PM1-1-7**

Janusz Grzyb[1]; Marcel Andree[1]; Bernd Heinemann[2]; Holger Ruecker[2]; Ullrich Pfeiffer[1]
[1]Rainer-Gruenter-Str. 21, Wuppertal; [2]Im Technologiepark 25, Frankfurt (Oder)

This paper reports on cold operation of a SiGe HBT in an experimental 0.13-μm technology as a broadband THz power detector and compares it against the classical forward-active operation range based on a frequency-dependent nonlinear device model. In the near-THz fractional bandwidth of 250-1000 GHz, a state-of-the-art optical NEP of 3.9-28 pW/√Hz and 2.1-16 pW/√Hz for cold and forward-active operation, respectively, was measured for the antenna-coupled THz detector comprising 2 devices in common-base (CB) configuration.

15:15 **A Broadband Dual-Polarized Low-NEP SiGe HBT Terahertz Direct Detector For Polarization-Sensitive Imaging** **We-PM1-1-8**

Marcel Andree[1]; Vishal Jagtap[2]; Janusz Grzyb[2]; Ullrich Pfeiffer[2]
[1]Rainer-Gruenter Str. 21, Adersstraße 48, Wuppertal; [2]Rainer-Gruenter Str. 21

A broadband silicon-integrated dual-polarized antenna-coupled THz direct detector with a minimum NEP of 2.7 pW/√Hz at 450 GHz and 16 pW/√Hz at 850 GHz is implemented in a 4-mirror focussed imaging setup, demonstrating polarization-sensitive imaging at 852 GHz. Polarization-sensitive images are computed through the Stokes vector formulation. Based on the degree of linear polarization, finer local physical fingerprints of an imprinted Teflon object are revealed.

13:30 - 15:30 **Nonlinear THz Phenomena** **Cartier I**
Chairperson(s): Guoqian Liao,

13:30 **Nonlinear THz Control Of Lead Halide Perovskite Lattices In 3, 2, And 1 Dimensions** **We-PM1-2-1**

Sebastian F. Maehrlein[1]; Joanna M. Urban[1]; Maximilian Frenzel[1]; Marie Cherasse[1]; Gaell Trippé-Allard[2]; Abdelaziz Jouaiti[3]; Sylvie Ferlay[3]; Emmanuelle Deleporte[2]
[1]Faradayweg 4-6, Berlin; [2]4 Av. des Sciences, Gif-sur-Yvette; [3]4 Rue Blaise

Pascal, Strasbourg

Lead halide perovskites (LHPs) have emerged as promising semiconductor materials for next-generation optoelectronic devices such as solar cells or LEDs. The origin of their surprising optoelectronic properties have been linked to a delicate interplay of their complex lattice structure and electronic degrees of freedom. Here, we demonstrate coherent THz control of lead halide's octahedral twist modes, being highly relevant for structural phase fluctuations and dynamic disorder. We discuss the different nonlinear driving mechanisms and give an outlook for lattice control of dimensionality-tailored LHPs in three, two, and one dimensions.

14:00 **Interplay Between Intervalley Scattering And Impact Ionization Induced By Intense Terahertz Pulse In InSb Thin Films** **We-PM1-2-2**

Carlos Miguel Garcia Rosas[1]; Xavier Ropagnol[1]; Leo Guiramand[2]; Francois Blanchard[2]; Tsuneyuki Ozaki[1]

[1]1650 boulevard Lionel Boulet, Varennes; [2]1100 rue Notre-Dame Ouest, Montreal

In this work, we reveal the intricate interplay between two major nonlinear THz effects: intervalley scattering and impact ionization, generated by an intense few-cycle THz pulse in an undoped (100) indium antimonide semiconductor at room temperature. Our results show an initial transmission enhancement when increasing the peak electric field up to 91 kV/cm, followed by increased absorption for higher fields. Our analytical model explains that this initial transmission enhancement occurs due to a balance between absorption bleaching (induced by intervalley scattering of electrons in the conduction band) and impact ionization. We show that for THz peak electric fields higher than 91 kV/cm, impact ionization starts to be the dominant energy loss mechanism. These experimental results match very well qualitatively and quantitatively with our developed theoretical model.

14:15 **High-harmonic Generation In P-doped Si By Band Non-parabolicity, Energy-dependent Relaxation And Dopant Photo-ionization** **We-PM1-2-3**

Fanqi Meng[1]; Frederik Walla[2]; Sergey Kovalev[3]; Jan-Christoph Deinert[3]; Igor Ilyakov[3]; Min Chen[3]; Alexey Ponomaryov[3]; Sergey G. Pavlov[4]; Heinz-Wilhelm Hübers[4]; Nikolay V. Abrosimov[5]; Christoph Jungemann[6]; Hartmut.G Roskos[2]; Mark D. Thomson[2]

[1]Max von Laue street 1, Frankfurt am Main; [2]Max von Laue street 1, Frankfurt; [3]Bautzner Landstr. 400, Dresden; [4]Rutherfordstr. 2, Berlin; [5]Max-Born Str. 2, Berlin; [6]Kackertstr 15, Aachen

We investigate ultrafast harmonic generation (HG) in Si:B, driven by intense 300-GHz pump pulses with fields up to 115 kV/cm, at 4~K and 300~K. We report several novel findings: (i) Harmonics of order up to n=9 are observed at room temperature, while at low temperature we can resolve harmonics reaching even n=13. (ii) For T=300 K, simulations by multi-valence-band Monte-Carlo

calculations combined with finite-difference time-domain propagation show that the HG process, upon increase of the radiation field, becomes more and more dominated by energy-dependent scattering rates over the contribution from band non-parabolicity. (iii) At T=4 K, we observe a drastic rise of the HG yield with the THz field strength, as one reaches the threshold for tunnel ionization at (internal) pump fields of 30 kV/cm. We disentangle the HG contributions in this case into contributions from the initial 'generational' and subsequent band-nonlinearities, and show that scattering severely degrades any coherent recollision during the subsequent oscillatory motion of the holes.

14:30 **Ultrafast Carrier Dynamics In Germanium Driven By Strong THz Field** **We-PM1-2-4**

ABHISHEK GUPTA[1]; VINEET GUPTA[2]; JANOS BOHUS[2]; KALYANI CHORDIYA[2]; MOUSUMI KAHALY[2]; ASHUTOSH SHARMA[2]; JOZSEF FULOP[2]

[1]Wolfgang Sandner utca 3, SZEGED; [2]WOLFGANG SANDNER UTCA 3, SZEGED

Strong THz field driven ultrafast carrier dynamics in n-doped Ge is studied by THz pump--THz probe measurements. Strong and distinctly different transient redistribution of free carriers at different pump field strengths (90 kV/cm, 450 kV/cm) and temperatures (300 K, 95 K) is revealed. Signatures of a large transient population of the Γ valley were observed especially at the low temperature, where impact ionization can also contribute to the observed dynamics.

14:45 **High-field Terahertz Carrier Dynamics In Ge And GaAs** **We-PM1-2-5**

Matthew Lutz; Clayton Moss; Josue Dominguez; Jeremy Johnson

Ezra Taft Benson Building, Campus Dr, Provo

We performed high-field terahertz transmission measurements on germanium (Ge) and gallium arsenide (GaAs). We observed a decrease in sample absorption as electric field strength increased in both cases. To understand the underlying processes, we modeled the change in carrier population as a function of time in Ge and applied a Drude model to calculate absorption. For GaAs, we ascribe the change in signal to carrier generation via impact ionization and Zener tunneling.

15:00 **Martensite Transformation Triggered With Intense THz Pulses** **We-PM1-2-6**

Masaya Nagai[1]; Yuhei Higashitani[1]; Masaaki Ashida[1]; Koichi Kusakabe[2]; Hirohiko Niioka[3]; Azusa Hattori[4]; Hidekazu Tanaka[4]; Goro Isoyama[4]; Norimasa Ozaki[5]

[1]Machikaneyama 1-3, Toyonaka; [2]3-2-1 Kouto, Kamigori; [3]2-8, Yamadaoka, Suita; [4]8-1 Mihogaoka, Ibaraki; [5]2-1 Yamadaoka, Ibaraki

We demonstrate THz-induced martensitic transformation. We irradiated the intense THz pulses resonant for the lowest optical phonon on the surface of the partially stabilized zirconia plate and found that the clear evidence of martensitic transformation from tetragonal to monoclinic phase. We calculated the phonon dispersion in tetragonal zirconia and found the effective channel for the trigger of the transformation. Since the THz pulse excitation allows specific

local shear deformation beyond thermal equilibrium, it will open new scheme of nonlinear phononics in condensed matters.

13:30 - 15:30 **Metasurfaces & Plasmonics I** **Cartier II**

Chairperson(s): Jean-Michel Ménard,

13:30 **Vectorial Currents And Broadband Terahertz Vector Beams With Optoelectronic Metasurfaces** **We-PM1-3-1**

Jacob Pettine[1]; Lauren Gingras[2]; Peter Adel[2]; Chun-Chieh Chang[3]; Rohit Prasankumar[4]; Ronald Holzwarth[5]; Antoinette Taylor[3]; Shizeng Lin[3]; Prashant Padmanabhan[3]; Hou-Tong Chen[3]
[1]PO Box 1663, Los Alamos; [2]Bunsenstraße 5; [3]PO Box 1663; [4]Bellevue; [5]Martinsried

While fundamental to many scientific and technological applications, capabilities for controlling charge currents remain highly restricted, particularly at modern limiting nanometer spatial and femtosecond temporal scales. Here, we demonstrate a novel method for versatile ultrafast light-based current control within new class of optoelectronic metasurfaces. Local directional charge flows in the graphene layer underlying each gold nanoantenna conspire to millimeter-scale currents, as characterized via terahertz (THz) emission. Implementing large-area vector arrays as efficient sources, we introduce readily frequency/polarization tunable broadband cylindrical vector beam generation in the THz range, toward applications in information science, charge acceleration, THz spectroscopies, and THz imaging.

14:00 **Continuous 3D Multimodal Buckling Modulated Chiral Responses In Reconfigurable Terahertz Metamaterials** **We-PM1-3-2**

Donghai Han; Liuyang Zhang
No. 28, West Xianning Road, Xi'an

Recent advances of metamaterials (MMs) have opened the door to giant chirality beyond natural levels of existing media. A variety of tunable chiral MMs are also proposed to realize dynamic chiral control and the morphologically reconfigurable MMs are widely constructed to modulate chiral responses owing to its simple structural composition. However, the existing reconfigurable MMs can only transform from non-chirality to one chirality under external loadings. Here, a reconfigurable terahertz MM is proposed to realize the multiple modulation of the chiral effect based on the 3D multimodal buckling deformation. The planar MM is initially transformed into a 3D symmetric morphology without chirality by releasing the biaxially pre-stretched substrate. Furtherly, the orthogonal uniaxial loading-path can facilitate two morphologies of MM with opposite chirality. In the above-mentioned continuous deformation process, the circular dichroism can be modulated from -0.18 to 0.18. Our proposed multimodal reconfiguration principle has provided a novel modulation principle of MMs and might extend the reconfigurable meta-devices toward more advanced functional applications.

14:15 **Sensitivity Enhancement Of THz Meta-Material By Decoupling Its Resonance From Substrate's Fabry-Pérot Oscillations** **We-PM1-3-3**

Heena Khand[1]; Rudrarup Sengupta[2]; Gabby Sarusi[2]

[1]Marcus Family Campus Ben-Gurion University of the Negev P.O.B. 653, Beer-Sheva; [2]Marcus Family Campus P.O.B 653

In this work, we introduce the issue of sensitivity-reduction due to the interaction/coupling of substrate's Fabry-PÃ©rot (FP) oscillations with the terahertz Meta-Materials (MM) LC-resonance. This coupling is more intense in thicker semiconductor substrates, due to high density of FP oscillations and thus probability of coupling with the single MM resonance increases, resulting in reduced sensitivity of resonant MM. We show sensitivity-restoration of the MM resonance red-shift, by decoupling it from the FP-oscillation after thinning down the substrate (using CMOS-only-process), giving 5-fold enhancement in dielectric-sensitivity compared to conventional substrates.

14:30 **1-bit Terahertz Time-space-coding Metasurfaces With Refined Wavefront Modulation For Harmonic Beam Scanning Enhancement** **We-PM1-3-4**

Munan Yang[1]; Feng Lan[1]; Yaxin Zhang[1]; Dongfang Shen[2]; Tianyang Song[1]; Luyang Wang[1]; Ziqiang Yang[1]

[1]404B, Research Institute Building, University of Electronic Science and Technology of China (Qingshu, Chengdu; [2]404B, Research Institute Building, University of E, Chengdu

Considering state of the art, coding-metasurface-based terahertz beam steering confronts issues of narrow angular range and low precision limited by nonideal space-encoded methodology. The emerging time-space coding metasurfaces open a new dimension to improve electromagnetic wave modulation accuracy and range under time-varying signal manipulation. Herein, based on the high electron mobility transistors (HEMTs), we propose a terahertz time-space coding metasurfaces (TTSCM) with refined wavefront modulation for harmonic beam scanning enhancement. Combining cyclic time modulations on the bias feeding signal and HEMT-switched phase coding, the TTSCM compensates the 1-bit quantization error with the joint coding for refined wavefront modulations. Numerical prediction verifies that the symmetrical Ãff‚Ãf‚Ã‚±1st harmonic beam scanning within Ãff‚Ãf‚Ã‚±80Ãff‚Ãf‚Ã‚° angular range and a scanning accuracy of 1Ãff‚Ãf‚Ã‚° has a larger field of view and higher precision. The proposed terahertz time-space-coding metasurfaces offers a feasible approach for various scenarios, such as super-resolution imaging and wireless communications.

14:45 **High-efficiency And Wideband Five-order Geometric-Phase Coding Metasurfaces For Sub-terahertz RCS Reduction** **We-PM1-3-5**

Haobin Sun[1]; Feng Lan[2]; Munan Yang[3]; Tianyang Song[3]; Luyang Wang[4]; Yaxin Zhang[4]; Ziqiang Yang[4]

[1]NO.2006, XIyuan Ave, West Hi-Tech Zone, Chengdu, Chengdu; [2]NO. 2006, XIyuan Ave, West Hi-Tech Zone, Chengdu; [3]NO. 2006, XIyuan Ave, West Hi-Tech Zone, Chengdu, The Yangtze Delta Region Institute (Huzhou), University

of Electronic Science and Technology of Chin, Chengdu; [4]NO. 2006, XIyuan Ave, West Hi-Tech Zone, Chengdu, Chengdu

Pancharatnam-Berry principled high-order geometric-phase metasurfaces have drawn considerable interest for their unique ability to regulate electromagnetic waves exquisitely. However, the efficiency and bandwidth of high-order geometric-phase metasurfaces remain to grapple with for practical applications. Herein, we propose a high-efficiency and wideband five-order geometric-phase coding metasurface consisting of 5-fold rotationally symmetric structures. Rotating the proposed meta-atoms can effectively realize LCP-RCP conversion over 90% efficiency in 105-120 GHz or vice versa and 2-bit coding with smooth Ï?/2 phase-shift interval. As a proof of concept, a 2-bit high-order geometric-phase coding sequence convoluted from the cross-coding and orthogonal coding sequences attains enhanced RCS reduction on the proposed metasurface. Corroborated by rigorous full-wave simulations and numerical calculations, the novel phase-coding metasurfaces are promising in terahertz holograms, computational imaging, vortex beam generations, flat lenses, etc.

15:00 **Coherent Thermal Emission From Circular N-GaN Surface Relief Gratings** **We-PM1-3-6**

Vytautas Janonis[1]; Evaldas Valasevicius[1]; Pawel Prystawko[2]; Irmantas Kasalynas[1]
[1]Saulėtekio ave. 3., Vilnius; [2]Ul Sokolowska 29 37, Warsaw

Coherent thermal emission of surface plasmon phonon polaritons from circular shaped n-GaN surface relief gratings with different filling factors was investigated theoretically and experimentally. Emission spectra were obtained experimentally without collection optics and compared with theoretical modelling providing insight into the polariton dispersion characteristics.

15:15 **Absorptive Infrared Metasurface On 100 Nm-Thick Dielectric Membrane** **We-PM1-3-7**

Harumi Asada; Takehito Suzuki
#405 Building 5, 2-24-16 Naka-cho, Koganei-shi, Tokyo

Terahertz flat optics based on metasurfaces that control both the dielectric and magnetic properties can offer two-dimensional planar optical components substituted for conventional three-dimensional bulky optical components. However, it has yet to be shown whether metasurfaces with an ultrathin dielectric membrane can open the doors to a wide range of optical components based on terahertz flat optics. Here, we demonstrate an absorptive infrared metasurface on a 100 nm-thick SiNx membrane with double-sided metal structures. The metasurface consists of square Au patches with a side length of 1200 nm periodically placed at a spacing of 200 nm on the front and an Au layer covering the back. Measurements by Fourier transform infrared spectroscopy (FT-IR) verify a reflectance of 2.2%, transmittance of 0.7%, and the high absorptance of 97.1% at 50 THz. Metasurfaces with an ultrathin dielectric membrane based on the unprecedented fabrication method presented here would lead to attractive applications such as absorbers for laser detection and ranging (LiDAR), directivity control of thermal radiation, and generation of vacuum ultraviolet coherent light.

13:30 - 15:30 THz Microscopy **International I**

Chairperson(s): Masayoshi Tonouchi,

13:30 **Continuous Carrier-Envelope Phase Control For Terahertz-Driven Scanning Probe Microscopy Of 2D Semiconductors** **We-PM1-4-1**

Bruno Schuler[1]; Jonas Allerbeck[1]; Joel Kuttruff[2]; Laric Bobzien[1]; Lysander Huberich[1]; Maxim Tsarev[2]
[1]Ueberlandstrasse 129, Duebendorf; [2]Universitaetsstrasse 10, Konstanz

Defects in 2D semiconductors present an exciting materials platform to engineer atomic quantum states in a robust, yet tunable solid-state system. In this contribution, we will present our efforts to probe the dynamics of point defects in transition metal dichalcogenides (TMDs) at picosecond time and atomic spatial resolution by means of an ultrafast THz pulse driven scanning tunneling microscope (THz-STM). We demonstrate an efficient, continuous carrier-envelope phase control, which enables state-selective tunneling into specific defect orbitals in our multi-MHz repetition rate system.

13:45 **Surface Oxidisation Layer Identification Of Indium Nitride Nanoparticles Via S-SNOM** **We-PM1-4-2**

Xinyun Liu[1]; Rajiv Prinja[2]; Tom Vincent[3]; Baset Gholizadeh[3]; Daniel Johnson[3]; Nazir Kherani[4]; Jessica Boland[3]
[1]2.323 Photon Science Institute, University of Manchester, Manchester; [2]Department of Electrical & Computer Engineering,; [3]Photon Science Institute, University of Manchester, Manchester; [4]Department of Electrical & Computer Engineering, U

InN materials have been widely used in optoelectronic devices, namely red LEDs. However, the surface oxidization introduced during growth and by air exposure can change their bandgap and mobility drastically, affecting device performance. In this study, we employed a surface-sensitive technique, scattering-type scanning near-field optical microscopy (s-SNOM) to investigate the oxidization level of InN nanoparticles and demonstrate how tapping amplitude and demodulation order affect the near-field response.

14:00 **Scattering-type Near-Field Optical Microscopy Characterization Of Topological Insulator Bi2Te3 Nanowires** **We-PM1-4-3**

Daniel Johnson[1]; Tom Vincent[1]; Xinyun Liu[1]; Baset Gholizadeh[1]; P. Schöenherr[2]; Thorsten Hesjedal[2]; Olga Kazakova[3]; Nathaniel Huáng[3]; Jessica Boland[1]
[1]Photon Science Institute, Alan Turing Building, Manchester; [2]Clarendon Laboratory, Parks Road, Oxford; [3]Hampton Road, Teddington

Topological Insulator (TI) devices have potential applications in spintronic and low-loss communication devices. However, they are difficult to characterize

with standard far-field spectroscopy due to contributions from both the surface and the bulk. Utilizing the surface-sensitive scattering type Scanning Nearfield Optical Microscopy (s-SNOM) technique coupled with high surface-to-volume ratio structures such as nanowires, the local dielectric function and electro-optical properties of the metallic surface states of TI candidate Bi2Te3 are investigated. We demonstrate spectral resonant features at 1250 cm-1 , which are imaged with nanoscale resolution.

14:15 **Nanoscale Charge Motion In GaAs Nanobars Studied By Terahertz Spectroscopy** **We-PM1-4-4**

Hynek Nemec[1]; Vova Pushkarev[2]; Tomas Ostatnicky[3]; Petr Kuzel[2]
[1]Na Slovance 2, Praha; [2]Na Slovance 2; [3]Ke Karlovu 3, Praha

Terahertz photoconductivity spectra and dynamics of electrons in GaAs nanobars were investigated using time-domain terahertz far-field and near-field spectroscopy. The photoconductivity spectra demonstrate that at low temperatures, band-bending leads to confinement of electrons to a volume smaller than the geometrical dimensions of the nanobars. Furthermore, scanning near-field THz microscopy reveals a that band bending leads to a rapid escape of photogenerated charges away from the photoexcited surface.

14:30 **Charge Carrier Profiling With MIR And THz S-SNOM** **We-PM1-4-5**

Cristiane N. Santos[1]; Édouard Lebouvier[1]; Benjamin Walter[1]; Sophie Eliet[1]; Nicolas Chevalier[2]; Jean-Michel Hartmann[2]; Romain Peretti[1]; Marc Faucher[1]; Jean-François Lampin[1]
[1]Avenue Henri Poincaré, Villeneuve d'Ascq; [2]F-38000 Grenoble, MINATEC Campus, F-38054 Grenoble

In the past years, it has been shown that s-SNOM (scattering-type scanning near-field optical microscopy) is a powerful technique to probe different light-matter interactions. Among them, charge carriers present different optical responses in the mid-infrared (MIR) and terahertz (THz) regions. Here we show that THz s-SNOM is highly sensitive to small changes in charge carrier concentration in a semiconductor, with spatial resolution at the nanometer scale.

14:45 **Investigating WTe2 Atomic-Scale Defects In K-space Using THz Scanning Tunneling Microscopy** **We-PM1-4-6**

Vedran Jelic; Stefanie Adams; Mohamed Hassan; Trevor Hickle; Tyler L. Cocker
567 Wilson Rd, East Lansing

Tungsten ditelluride (WTe2) is a candidate type-II Weyl semimetal. Its electronic states have been investigated with atomic spatial resolution in conventional STM, with ultrafast temporal resolution in spectroscopy experiments, and in momentum space using angle-resolved photoemission spectroscopy. Here, we demonstrate that our experimental setup can combine all three. We show that terahertz scanning tunneling microscopy (THz-STM) can capture the electronic structure of the surface down to single atomic defects

and has the stability and resolution to investigate impurity scattering in Fourier space.

15:00 **Multilayer Permittivity And Thickness Extraction In Infrared Scanning Near-field Optical Microscopy Using Deep Learning** **We-PM1-4-7**

Dario Siebenkotten; Clemens Elster; Bernd Kästner
Abbestraße 2-12, Berlin

Scattering-type scanning near-field optical microscopy combined with Fourier-transform infrared spectroscopy allows for material identification and characterization more than two orders of magnitude below the diffraction limit. This resolution is achieved by positioning an AFM-tip in close proximity to the sample. However, owing to the complex interaction between incident wave, tip and sample, extensive modelling is needed for the quantitative extraction of material parameters defining the optical response, particularly for layered samples. Due to the strong non-linearity between the optical parameters and the scattered light, fitting of the model is generally necessary, but it is often unstable and time-consuming, requiring human expert supervision. Deep learning algorithms offer a fast alternative but have so far only been applied to bulk samples. Here, we extend those approaches to samples consisting of one and two layers of polar crystals, which exhibit a strongly non-linear scattering response, on top of a Silicon substrate, by training convolutional neural networks with model data. We present the network architectures and resulting optical parameter extraction efficiencies and discuss extensions to other sample systems.

15:15 **A General Approach To THz Near-Field Waveform Sampling in A Lightwave-Driven Scanning Tunneling Microscope Junction** **We-PM1-4-8**

Vedran Jelic[1]; Mohamed Hassan[1]; Stefanie Adams[1]; Kaedon Cleland-Host[1]; Spencer E. Ammerman[2]; Tyler L. Cocker[1]
[1]567 Wilson Rd, East Lansing; [2]Ueberlandstrasse 129, 8600, Dubendorf

We develop a new technique for capturing the THz near-field waveform within the atomic-scale tunnel junction of a lightwave-driven scanning tunneling microscope.

13:30 - 15:30 **Novel Imaging Techniques II** **International II**

Chairperson(s): Gintaras Valusis,

13:30 **Depth Reconstruction For Reference-Free THz Holography Based On Physics-Informed Deep Learning** **We-PM1-5-1**

Mingjun Xiang; Hui Yuan; Lingxiao Wang; Kai Zhou; Hartmut Roskos
Ruth-Moufang-Straße 1, Frankfurt am Main

Recently, supervised and unsupervised deep learning (DL) methods for amplitude and phase recovery in reference-free THz holographic imaging have found increased attention in the terahertz (THz) frequency range. However, three-dimensional (3D) scene reconstruction at THz bands still faces challenges

due to the unknown object's depth in this system. This paper demonstrates a depth reconstruction method for THz holography based on DL algorithm. We incorporate Fresnel diffraction as the physical prior knowledge to obtain a sequence of different intensities with the corresponding depths to train the neural network (NN). The depth reconstruction tasks are achieved based on the dataset transplanted from MNIST. With this approach, we avoid the prohibitively time-consuming collection of a large number of THz-frequency images. Both simulated and experimental results illustrate the accuracy of the method, representing the first steps towards fast THz 3D imaging with reference-beam-free low-cost power detection.

14:00 **Subsurface Defect Detection And Classification In 3D THz Images Of Glass Fiber Reinforced Thermoplastic Based On 3D Convolutional Neural Network** **We-PM1-5-2**

Aya Souliman; Yashkumar Darji; Matthias Kahl; Michael Möller; Peter Haring Bolívar
Hölderlinstr. 3, Siegen

This research proposes a 3D convolutional neural network (3D CNN) to classify subsurface defects in a glass fiber reinforced thermoplastic (GFRT) composite material inspected by a 3D THz imaging system. The 3D THz inspection system generates 3D volumetric data based on frequency modulated continuous wave (FMCW) technique operating in a frequency range of 499 GHz to 733 GHz. A set of 89 non-defective and defective GFRT samples is measured and data augmentation is performed to create a database for 3D CNN training. The results demonstrate that the 3D CNN achieves a mean test accuracy of 98.9%.

14:15 **Ultra-Wideband Terahertz 3D Imaging With Aspherical Telecentric F-θ Optics** **We-PM1-5-3**

Shiva Mohammadzadeh[1]; Jens Klier[1]; Jörg Seewig[2]; Georg von Freymann[1]; Fabian Friederich[1]
[1]Fraunhofer-Platz 1, Kaiserslautern; [2]Gottlieb-Daimler-Straße, Gebäude 44, Kaiserslautern

In this contribution we report on the development of a mobile ultra-wideband frequency-modulated continuous-wave (FMCW) terahertz imaging device with an integrated scanning f-θ lens for 3D image acquisition. The objective lens is designed to operate with the broad bandwidth of 1.65 THz of the mobile 3D scanning system. For the design of the f-Theta lens, the optical properties of three different materials for lens fabrication were investigated using the realized optoelectronic FMCW radar. In addition to the optical system design, the overall integration of the mobile system is the focus of our work in this paper.

14:30 **Digital Holographic Diffraction Tomography Based On Physics-enhanced Deep Neural Network Using Continuous-wave Terahertz** **We-PM1-5-4**

Jie Zhao[1]; Xiaoyu Jin[2]; Dayong Wang[2]; Lu Rong[2]; Yunxin Wang[2]; Shufeng Lin[2]

[1]Ping Leyuan No. 100, Chaoyang District, Beijing; [2]Ping Leyuan No. 100, Chaoyang District

In this paper, a terahertz (THz) in-line digital holographic diffraction tomography (THz-IDHDT) is proposed and implemented. However, the inherent twin-image problem of the in-line digital holography seriously degrade the quality of the reconstruction results. Here, a learning-based phase retrieval algorithm by combining the physical model and the convolution neural networks is applied and named as physics-enhanced deep neural network (PhysenNet). It allows us to recovery the complex amplitude distribution of the sample with high fidelity from a single in-line digital hologram, without any constraints or labeled data for pre-training. In the experiments, the feasibility of the PhysenNet and its superiority in terms of imaging quality are demonstrated using a single foam sphere. Then the 3D refractive index distributions of the foam sphere sample are successfully reconstructed by the THz-IDHDT. Compared to the ground-truth value, the relative error of the average refractive index value reconstructed by the proposed method is only 0.17%.

14:45 **Automatic Analysis Of Images From The THz TDS Reflection Scanner** **We-PM1-5-5**

Norbert Pałka[1]; Kamil Kaminski[1]; Marcin Maciejewski[1]; Piotr Synaszko[2]; Krzysztof Dragan[3]

[1]2 Kaliski Str., Warsaw; [2]6 Książe Bolesław Str., Warsaw; [3]6 Książe Bolesław Str.

We present a method for automatic detection of defects in glass fibre reinforced polymer (GFRP) based on a terahertz time-domain spectroscopy (TDS) system. A GFRP sample with round inclusions of different sizes were measured by means of a TDS reflective scanner. The algorithm acquired a series of C-scans, which were then pre-selected to identify only those images with features potentially associated with defects. A thresholding method based on Gaussian fit to histogram was developed. The results showed that 87% of defects were detected.

15:00 **Two- And Four-step Phase Shifting Methods For Terahertz Holography** **We-PM1-5-6**

Rusnė Ivaskevičiūtė-Povilauskienė[1]; Linas Minkevičius[1]; Domas Jokubauskis[1]; Agnieszka Semion[2]; Gintaras Valusis[3]

[1]Saulėtekio Ave. 3, Vilnius; [2]75 Koszykowa, Warsaw; [3]Sauletekio Ave. 3, Vilnius

It has been shown that implementation of the two-step and four-step phase-shifting techniques in Fresnel holography can improve background subtraction by up to five times. Utilization of this technique enables the enhancement in quality of the captured holographic images, especially in cases where objects introduce phase alterations. It has been demonstrated that by recording holograms of an object with two distinct planes, it is possible to achieve high-quality 3D image reconstruction.

15:15 **SiGe MIMO In-line Imager With 12x64 Elements For Real-time 3D Image Acquisition** **We-PM1-5-7**

Matthias Kahl[1]; Raphael Hussung[2]; Andreas Keil[2]; Esref Turkmen[3]; Diego Moro-Melgar[4]; Oleg Cojocari[4]; Wojciech Debski[3]; Fabian Friederich[2]; Peter Haring Bolivar[1]
[1]Hoelderlinstrasse 3, Siegen; [2]Fraunhofer-Platz 1, Kaiserslautern; [3]Im Technologiepark 1, Frankfurt (Oder); [4]Josef-Bautz-Straße 15, Hanau

We demonstrate a 3D imaging system operating at 235-270 GHz based on a multiple-input multiple-output (MIMO) sparse array with 64 receivers realized in low-cost silicon germanium hetero-bipolar semiconductor technology. The parallel acquisition with a high number of receivers, combined with 12 time-multiplexed high-power transmitters, high-frequency switching and fast data acquisition electronics, enables high image acquisition rates compatible with in-line imaging in an industrial production environment. The system is designed for defect detection in composite thermoplastic parts after their forming process. Such parts are interesting for lightweight automotives given their excellent mechanical properties in combination with a mass manufacturing compatible processing technology. In this contribution we concentrate on the system realization aspects, and present exemplary 3D reconstruction images.

16:00 - 18:00 **High Field THz Generation II** **Symposia Theatre**

Chairperson(s): Luc Bergé,

16:00 **500 GHz Field-Resolved Detection In Thin-film Lithium Niobate Devices** **We-PM2-1-1**

Alessandro Tomasino[1]; Amirhassan Shams-Ansari[2]; Marko Loncar[2]; Ileana-Cristina Benea-Chelmus[1]
[1]STI IEM HYLAB, Lausanne; [2]Harvard University, Cambridge

In this work, we show the coherent reconstruction of terahertz (THz) transients in thin-film lithium niobate integrated photonics circuits. Our devices modulate the intensity of a probe beam guided through a Mach-Zehnder interferometer (MZI) structure, under the illumination of an impinging THz wave. Golden bow-tie antennas fabricated along the waveguides, collect and tightly squeeze the THz radiation across their gap, greatly enhancing the THz-probe nonlinear interaction. We show that the probe intensity modulation reproduces the oscillations of the THz electric field established across the gaps of the metallic antennas

16:30 **Spatiotemporal Imaging Of Near-Fields From A Tilted Pulse Front THz Source** **We-PM2-1-2**

Annika Gabriel; Mohamed Othman; Matthias Hoffmann; Emilio Nanni
2575 Sand Hill Rd., Menlo Park

A better understanding of the THz near-field properties is necessary for the optimization of THz generation efficiency, transport, and coupling. We demonstrate a fast and efficient technique for spatial and temporal characterization of single cycle strong field THz pulses in the near-field of a lithium niobate source using electro-optic sampling. In this technique an

enlarged probe beam and CCD camera are used to image the entire THz field in one shot. Using this technique, we have reconstructed the full temporal 3D THz near-field close to the lithium niobate emission face.

16:45 **High-intensity THz Pulses Generation In Lithium Niobate Using A Reflective Echelon Scheme** **We-PM2-1-3**

Ammar Hideur[1]; Anna Martinez[2]; Rezki Becheker[1]; Léo Guiramand[3]; François Blanchard[3]; Xavier Ropagnol[3]; Said Idlahcen[1]; Thomas Godin[1]; Jonathan Houard[4]; Domenico Paparo[5]; Angela Vella[4]
[1]675, Avenue de l'Université, Saint Etienne du Rouvray; [2]Monte S. Angelo, via Cintia; [3]Québec H3C 1K3, Montréal; [4]Avenue de l'Université, Saint Etienne du Rouvray; [5]Monte S. Angelo, via Cintia, Napoli

This work analyzes how the beam size and the repetition rate affect the THz generation efficiency in lithium niobate (LiNbO3) using the RES (Refractive Echelon Mirror) configuration. Our THz source is driven by an ytterbium-fibre-based chirped-pulse amplifier system. The system delivers ultrashort pulses of 300 fs duration with a maximum energy of 240 μJ at 330 kHz. It is found that by optimizing the pump beam size on the LiNbO3 crystal, we measure a THz power of 114 mW for 44.5 W pump power at 205 MHz repetition rate, corresponding to a total optical-to-THz efficiency of 0.25%.

17:00 **Scaling Tilted-pulse-front Based THz Setups By Control Of The Spatio-temporally Coupled Pump Pulse Parameters** **We-PM2-1-4**

Tobias Kroh; Nicholas Matlis; Franz Kaertner
Notkestr. 85, Hamburg

We investigate both by experiments and simulations on how spatio-temporal coupling of pump pulse parameters in tilted-pulse-front based terahertz (THz) setups can be used to control the position of the "temporal focus", which is where minimum pump pulse duration is reached. This concept opens a pathway to pump tilted-pulse-front setups with arbitrarily stretched pump pulses which significantly simplifies pump pulse transport at high pulse energies. This concept is experimentally demonstrated by efficient operation of a tilted-pulse-front THz source with pump pulses stretched by a factor of x25 to 10 ps and extraction of a THz energy of 0.4 mJ while operating well-below damage threshold. Our findings are not only relevant for THz based particle acceleration and strong-field physics but any application that requires control over the temporal focus of beams with a tilted-pulse-front such as direct laser-based particle acceleration.

17:15 **Generation Of 208 KV/cm Peak Field At 2.6 THz In GaP** **We-PM2-1-5**

Wei Cui[1]; Eeswar Yalavarthi[1]; Aswin Vishnu Radhan[1]; Mohammad Bashirpour[1]; Angela Gamouras[2]; Jean-Michel Ménard[1]
[1]25 Templeton Street, Ottawa; [2]1200 Montreal Road, Ottawa
We present a high-field THz source with a spectral peak centered at 2.6 THz. The setup relies on optical rectification of 0.57 mJ near-infrared pulses to generate THz peak fields up to 208 kV/cm. A phase grating directly etched at

the surface of the crystal enables a tilted-pulse-front configuration that optimizes phase-matching conditions. Even when saturation effects are considered, a 5 mJ generation pulse is expected to yield a THz peak field approaching 600 kV/cm. This high-field THz source allows new research opportunities relying on the ability to drive coherent phenomena and nonlinear effects in the region between 2 and 4 THz.

17:30 **Lithium Niobate Based Single-Cycle THz Source With 643mW Of Average Power** **We-PM2-1-6**

Tim Vogel; Clara J. Saraceno
Universitaetsstr. 150, Postbox 17, ID 2, Bochum

We demonstrate power scaling of a THz source based on the tilted-pulse front method in cryogenically cooled lithium niobate to a record-high average power of 643 mW, obtained at 40 kHz repetition rate.

16:00 - 18:00 **Spintronics** **Cartier I**

Chairperson(s): Melanie Müller,

16:00 **Spin-momentum Locking And Ultrafast Spin-charge Conversion In Ultrathin Epitaxial Bi1-xSbx Topological Insulator** **We-PM2-2-1**

Jean-Marie GEORGE[1]; Enzo RONGIONE[1]; Laetitia BARINGTHON[1]; Diana SHE[1]; Gilles PATRIARCHE[2]; Romain LEBRUN[3]; Aristide LEMAITRE[2]; Martina MORASSI[2]; Nicolas REYREN[1]; Francois BERTRAN[4]; Sukhdeep DHILLON[5]; Patrick LE FEVRE[4]; Henri JAFFRES[1]
[1]1 Av Augustin Fresnel, Unite mixte de Physique CNRS Thales, Palaiseau; [2]Université Paris-Saclay, CNRS, C2N, Centre de Nanosciences et de Nanotechnologies, Palaiseau; [3]1 Av Augustin Fresnel; [4]Synchrotron SOLEIL, L'Orme des Merisiers, Départementale 128, St Aubin; [5]ENS, Université PSL, CNRS, Sorbonne Université, Un, 2Laboratoire de Physique de l'Ecole Normale Supérieure, Paris

We combine spin- and angle-resolved photo-emission spectroscopy, and time-resolved THz emission spectroscopy to evidence that spin-charge conversion arises mainly from the surface state in Bi1-xSbx ultrathin films, down to few nanometers where confinement effects emerge. We correlate this large conversion efficiency, typically at the level of the bulk spin Hall effect from heavy metals, to the complex Fermi surface obtained from theoretical calculations of the inverse Rashba-Edelstein response. Both surface state robustness and sizeable conversion efficiency in epitaxial Bi1-xSbx thin films bring new perspectives for ultra-low power magnetic random-access memories and broadband THz generation

16:30 **Enhancement Effect Of A Neodymium Magnet Mount On Terahertz Electromagnetic Waves From The Ultrafast Photocurrent And From Coherent LO Phonon In A GaAs-based Epilayer** **We-PM2-2-2**

Hideo Takeuchi; Yusuke Sengi; Shungo Matsuoka; Kai Matsunaga

3-3-138 Sugimoto, Sumiyoshi, Osaka
We succeeded in enhancing terahertz electromagnetic wave emitted from GaAs-based epitaxial layers by simply mounting a wafer chip on a neodymium permanent magnetic. The terahertz waves, which originate from the ultrafast photocurrent and the coherent longitudinal optical phonon, were simultaneously enhanced. The present finding provides a simple method for enhancing terahertz wave emitted from the compound semiconductor surface illuminated by the femtosecond laser pulse.

16:45 **Coated Spintronic Emitters For Improved THz Time-domain Spectroscopy** **We-PM2-2-3**

Ford Wagner[1]; Simas Melnikas[2]; Joel Cramer[3]; Djamshid Damry[1]; Chelsea Xia[1]; Kun Peng[1]; Gerhard Jakob[3]; Mathias Klaeui[3]; Simonas Kicas[2]; Michael Johnston[1]
[1]Clarendon Laboratory, Parks Road, Oxford; [2]Savanoriu ave.231, Vilnius; [3]Institute of Physics, Mainz

Spintronic metal thin films excited by femtosecond laser pulses have proven to be excellent sources of broadband THz radiation, making these emitters increasingly popular for THz spectroscopy. Unfortunately, a significant proportion of the incident excitation laser is transmitted through the spintronic emitters, which can inadvertently photoexcite samples or cause damage to elements of the spectrometer. Here, we demonstrate a high-reflectivity coating made from alternating layers of SiO2 and Ta2O5 that effectively blocks the incident excitation pulse and enhances the peak THz electric field by roughly 35%. We further improve the emitter performance with an anti-reflective coating. We find spintronic emitters with both coatings exhibit over 40% improvement in peak THz electric field compared to an uncoated emitter and transmit less than 0.1% of the excitation laser pulse.

17:00 **Spintronic Terahertz Emitter On A Fiber Tip** **We-PM2-2-4**

Felix Paries[1]; Nicolas Tiercelin[2]; Geoffrey Lezier[2]; Matthias Vanwolleghem[2]; Maria-Andromachi Systaki[3]; Gerhard Jakob[3]; Martin Jourdan[3]; Mathias Kläui[3]; Zdenek Kaspar[4]; Tom Seifert[4]; Tobias Kampfrath[4]; Georg von Freymann[5]; Daniel Molter[1]
[1]Fraunhofer-Platz 1, Kaiserslautern; [2]Av. Henri Poincaré, Lille; [3]Staudingerweg 7, Mainz; [4]Physikinstitut der FU, Arnimallee 14, Berlin; [5]Erwin-Schroedinger-Str. 46, Kaiserslautern

Spintronic terahertz emitters have attracted considerable interest within the last decade. They promise terahertz sources with unmatched broad frequency bandwidth which are easy to manufacture and operate, and therefore easy to scale at low cost. However, the experiments and proofs-of-concept rely on free-space ultrashort-pulsed pump lasers and rather complex benchtop setups. This contrasts with the requirements of widespread industrial applications, where robust, compact, and safe footprints are needed. To meet these requirements,

we present a novel fiber-tip spintronic terahertz emitter solution that allows spintronic terahertz systems to become fully fiber-coupled. The pump fiber can be connected seamlessly via a standard FC/PC connection and emitters can be exchanged easily within a couple of minutes. Our recorded terahertz signals prove the full functionality of the newly developed concept. To demonstrate a possible application, we used our new fiber-tip spintronic emitters to build a simple terahertz near-field imaging setup that does not require the complexity of modern terahertz scanning near-field optical microscopy (THz-SNOM) technologies.

17:15 **Spintronic Coding Surface For THz Generation And Manipulation** **We-PM2-2-5**

Sai Chen[1]; Hanchen Wang[2]; Jingyu Liu[3]; Peng Chen[4]; Mingxuan Zhang[2]; Xiufeng Han[4]; Caihua Wan[4]; Haiming Yu[1]; Yan Zhang[3]; Xiaojun Wu[2]
[1]Beijing, Beijing; [2]No.38 Xueyuan Road, Beijing; [3]105 West Third Ring North Road, Haidian District, Beijing; [4]No. 8, South Third Street, Zhongguancun, Haidian District, Beijing

The utilization of spintronic terahertz (THz) emitters has a significant influence on broadband coherent spectroscopy and imaging at THz frequencies. By using femtosecond light to irradiate the spintronic heterostructures, spin currents from the ultrafast demagnetization effect can be transformed into charge currents through the inverse spin Hall effect, leading to the emission of THz waves. In this work, through the incorporation of sequential and inverse deposition of W-Co20Fe60B20-Pt heterostructure nanofilms, we have gained control over the spin current and THz waveform, enabling us to achieve a 180Â° phase difference across a broad frequency spectrum while efficiently radiating THz waves. This, in turn, allows us to control the spatial phase of THz wave radiation. To test the device's capabilities, we manufactured lithography-based instruments capable of focusing, producing vortexes, and dividing beams. Our investigation aims to advance the development of THz pulse sources while providing essential support for cutting-edge technologies such as THz spectroscopy, high-resolution imaging, and high-speed communications.

17:30 **Spintronic Inverse Spin Hall Photomixing Beyond 1THz** **We-PM2-2-6**

Pierre Kolejak[1]; Geoffrey Lezier[1]; Guillaume Ducournau[1]; Jean-François Lampin[1]; Tiercelin Nicolas[1]; Mathias Vanwolleghem[2]
[1]Faculté des Sciences et Technologies - Université de LILLE, Avenue Poincaré, Villeneuve d'Ascq; [2]Faculté des Sciences et Technologies - Université de LILLE, Avenue Poincaré, Villeneuve d'Ascq

We have demonstrated experimentally how ultrabroadband inverse spin Hall emitters present an unprecedented new scheme for room temperature THz CW and frequency comb generation. Building on previous proof-of-principle demonstrations, we demonstrate here by improved experimental developments how this photomixing effectively does not present any frequency rolloff at least up to 1,05THz, contrary to standard photoswitches. A theoretical and numerical model implementing spin Hall dynamics in nanometric FM/HM stacks predict photomixing bandwidths up to 10THz.

17:45 **THz Emission From Exchange-Coupled Fe/Ru/Ni Spintronic Emitters** **We-PM2-2-7**

Roman Adam[1]; Christian Greb[2]; Daniel Bürgler[3]; Derang Cao[4]; Sarah Heidtfeld[2]; Fangzhou Wang[2]; Jing Cheng[5]; Debamitra Chakraborty[5]; Ivan Komissarov[5]; Hilde Hardtdegen[2]; Martin Mikulics[2]; Markus Buscher[2]; Claus Michael Schneider[2]; Roman Sobolewski[5]
[1]Wilhelm-Johnen-Straße, Juelich; [2]Wilhelm-Johnen-Straße; [3]Wilhelm-Johnen-Straße, Julich; [4]Qingdao; [5]Rochester

We explored THz emission from Si/SiO2//Ta/Fe/Ru/ Ni/Al2O3 spintronic emitters. We tuned magnetization alignment of Fe and Ni layers by varying the interlayer exchange coupling (IEC) strength using a range of Ru layer thickness t. Depending on IEC strength, magnetization hysteresis shows either ferromagnetic (t = 1.1 nm, 1.5 nm), antiferromagnetic (t = 1.3 nm) or canted (t = 1.7 nm, 1.9 nm) relative alignment. Competition between IEC and an external magnetic field results in a dramatic difference in THz emission from the ferromagnetically (FM) and anti-ferromagnetically (AFM) coupled structures. The resulting THz emission from IEC structures is a result of an interference of THz transiens generated by the individual Fe/Ru and Ru/Ni emitters.

16:00 - 18:00 **Metasurfaces & Plasmonics II** **Cartier II**

Chairperson(s): Jacob Pettine,

16:00 **Light-matter Coupling Between Organic Molecules And A THz Metasurface** **We-PM2-3-1**

Ahmed Jaber[1]; Michael Reitz[2]; Avinash Singh[3]; Ali Maleki[1]; Yongbao Xin[4]; Brian Sullivan[4]; Ksenia Dolgaleva[1]; Robert Boyd[1]; Claudiu Genes[2]; Jean-Michel Ménard[1]
[1]75 Laurier Ave E, Ottawa; [2]Staudtstraße 2, 91058, Erlangen; [3]75 Laurier Ave E; [4]2700 Swansea Crescent, Ottawa

Strong light-matter interactions between confined vacuum fields and matter can lead to the formation of hybridized states called polaritons. In the terahertz region, these interactions can involve the coupling of vibrational molecular bonds with the resonant mode of a planar optical cavity. We demonstrate an alternative architecture to explore the strong light-matter regime by coupling the plasmonic mode of a metasurface with the sharp vibrational resonance of glucose. More specifically, we gradually increase the number of glucose molecules covering the metasurface and observe a red shift of the plasmonic resonance with a Rabi splitting of 90 GHz at zero detuning. This work is a first step towards the investigation of more complex hybrid cavity architectures combining planar mirrors and metasurfaces to explore multiple polaritonic interactions.

16:30 **Simultaneous Terahertz Generation-manipulation By Nonlinear Metasurfaces** **We-PM2-3-2**

Yongchang Lu[1]; Qingwei Wang[1]; Xi Feng[1]; Li Niu[1]; Xueqian Zhang[1]; Quan

Xu[1]; Yanfeng Li[1]; Jianqiang Gu[1]; Chunmei Ouyang[1]; Zhen Tian[1]; Weili Zhang[2]; Jiaguang Han[3]
[1]Weijin Road 92#; [2]Stillwater 74078; [3]Weijin Road 92#, Tianjin

Terahertz linear metasurfaces offer unique methods for terahertz manipulations in a linear interaction way. The emergence of nonlinear metasurfaces, however, provides a promising approach for simultaneous terahertz generation and manipulation in a single compact device. Here we report on our recent advances in this topic.

16:45 **Generating Terahertz Perfect Vortex Beam Via All-dielectric Metasurface** **We-PM2-3-3**

Fan Huang[1]; Wanying Liu[1]; Jianqiang Gu[1]; Quan Xu[1]; Quanlong Yang[2]
[1]No.92 Weijin Road, Nankai District, Tianjin, China, Tianjin; [2]South Lushan Road, Changsha, Hunan, Changsha

Perfect vortex beam (PVB), characterized as the ring radius-independence to topological charge (TC), enables applications in particle manipulation, quantum optics and optical communication. Generating PVBs with novel structure in terahertz regime is conductive to develop OAM related terahertz research such as terahertz communication. Here, two sorts of all-dielectric metasurface are proposed to generate two special PVBs, multichannel and divergence controllable terahertz PVBs and spin-distinguished superposed terahertz PVBs, respectively. By arranging the subwavelength meta-atoms and meta-molecules, the metasurface can endow the anticipated wavefront to the incident polarization states. These two novel PVBs generation devices are compact and easy to integration, providing promising opportunities in tailoring complex structured light and terahertz communication.

17:00 **Broadband THz Bandpass Filters Based On Multi-layered Metasurfaces** **We-PM2-3-4**

Ali Maleki[1]; Avinash Singh[2]; Ahmed Jaber[2]; Wei Cui[2]; Yongbao Xin[2]; Brian Sullivan[2]; Robert W. Boyd[2]; Jean-Michel Menard[1]
[1]25 Templeton St, Ottawa; [2]25 Templeton St

We present a terahertz (THz) bandpass filter design based on four superimposed metasurfaces. The devices feature a spectral transmission with a flat passband region at T = 0.65 and a stopband rejection larger than 40 dB. The two regions are separated by steep roll-offs with a slope of 85 dB/octave. Because of their unique filtering properties, these devices enable new applications for weak signal detection in THz research and industry.

17:15 **Polarization Selective Dual Frequency Metasurface-based Resonant Thermal Terahertz Emitters On N-GaAs/GaAs** **We-PM2-3-5**

Ignas Grigelionis; Vladislovas Cizas; Kestutis Ikamas; Vytautas Jakstas; Barbora Skelaite; Domas Jokubauskis; Andrius Biciunas; Andrzej Urbanowicz; Marius Treideris; Renata Butkute; Linas Minkevicius
Sauletekio ave. 3, Vilnius

Thermal metamaterial-based emitter on GaAs with rectangular metacell shape emitting dual frequencies in THz range is demonstrated. Structure was epitaxially grown and top metallic metasurface was formed by ultraviolet laser

lithography. The dual frequency resonant emission was experimentally revealed with the possibility to resolve different frequencies at different polarization in THz range. Such emitter could be used in THz imaging applications where polarization resolve is needed.

17:30 **Electrically Tunable THz Metasurfaces Enabling Near-Unity Modulation Depth** **We-PM2-3-6**

Hou-Tong Chen[1]; Chun-Chieh Chang[1]; Hichem Guerboukha[2]; Daniel Mittleman[2]; John Reno[3]; Michael Lilly[3]; Sadhvikas Addamane[3]
[1]PO Box 1663, MS K771, Los Alamos; [2]School of Engineering, Providence; [3]Center for Integrated Nanotechnologies, Albuquerque

We report active THz metasurfaces with reflection approaching zero when incident from the substrate side and applied with an appropriate voltage bias. This finding provides a new route to accomplish near-unity modulation depth of THz waves, which is promising particularly for THz wireless communications.

17:45 **Manipulation Of Terahertz Waves With A Right- Or Left-handed Metasurface For Directivity Enhancement** **We-PM2-3-7**

Keita Mochizuki; Harumi Asada; Takehito Suzuki
#405 Building 5, 2-24-16, Naka-cho, Koganei-shi, Tokyo
The manipulation of terahertz waves based on flat optics with metasurfaces is being employed in terahertz continuous-wave (CW) sources, such as resonant tunneling diodes (RTD) and quantum cascade lasers (QCL) for 6G wireless communications and terahertz imaging. However, two-dimensional optical components in terahertz flat optics are strongly subject to the distance from CW sources because meta-atoms with different dimensions optimize the gradient distribution of the refractive indices, such as in gradient-refractive-index (GRIN) metalenses. Here we demonstrate that an original terahertz metasurface with identical double-sided meta-atoms on a dielectric substrate enhances the directivity of terahertz waves. Terahertz time-domain spectroscopy (THz-TDS) measures that the metasurface has right- or left-handed dispersion characteristics, resulting in transmittance enhancement with 177% at 0.47 THz. The metasurface could be mounted on terahertz CW sources without considering the design of the distance between the metasurafce and sources to enhance the directivity. Our findings suggest that the manipulation of terahertz waves has the potential to significantly accelerate the growth of terahertz industrial applications.

16:00 - 18:00 **Integrated Technologies 1** **International I**

Chairperson(s): Hongxin Zeng,

16:00 **Single-Mode Rib Waveguide For The Terahertz Range Using 3D Printed Alumina** **We-PM2-4-1**

Harrison Lees[1]; Masoud Sakaki[2]; Daniel Headland[3]; Niels Benson[4]; Jan

Balzer[4]; Withawat Withayachumnankul[1]
[1]The University of Adelaide, Adelaide; [2]University of Duisburg-Essen, Duisburg; [3]Universidad Carlos III de Madrid; [4]University of Duisburg-Essen
In recent years, all-dielectric waveguides have emerged as a promising candidate platform for future integrated terahertz technologies. Inspired by optical photonics, many of these technologies are limited to planar waveguides and are reliant upon advanced mask-based etching techniques for fabrication, which incur significant costs. Instead, we propose a non-planar platform based upon an all-dielectric single mode rib waveguide constituted from 3D printed alumina. With an experimentally verified fractional bandwidth exceeding 40% and acceptable loss, we believe this is a practical alternative waveguide platform for sensing and communications applications.

16:30 **Characterization Of Flexible Micro Coaxial Cables In The WR03 Band** **We-PM2-4-2**

Benedikt Sievert; Daniel Erni; Andreas Rennings
Bismarckstraße 81, Duisburg

Abstract--This paper evaluates the applicability of commercial transition from a WR03 waveguide band towards a mono-mode operating coaxial cable is designed, fabricated, and evaluated. The losses within the coaxial cable are estimated by full-wave FEM simulations and agree well with the measurements of the fabricated prototypes. Although the significant losses of approximateely 0.6 dB/mm inherently limit the applicability of these cables compared to moderate-lossy rectangular or dielectric waveguides, the cables offer outstanding flexibility, enabling eased assembly (compared to mechanically fixed waveguides) or vibration decoupling.

16:45 **0.75—1.1THz Waveguide-Integrated Amplitude Modulator Based On InAs Photo-excitation** **We-PM2-4-3**

Julien Guise[1]; Hajasoa Ratovo[1]; Monique Thual[2]; Jeffrey Hesler[3]; Theodore Reck[3]; Emmanuel Centeno[4]; Jean-Baptiste Rodriguez[1]; Laurent Cerutti[1]; Fernando Gonzalez-Posada[1]; Thierry Taliercio[1]; Stéphane Blin[1]
[1]860 rue St Priest, CC 05005, Montpellier; [2]6 rue Kerampont, Lannion; [3]979 Second street, S.E. Suite 309, Charlottesville; [4]Campus Universitaire des Cézeaux, Aubière

We present an integrated amplitude modulator operating in the 0.75—1.1-THz frequency range. This component offers typically a modulation depth of 10 dB, a modulation bandwidth of 40 MHz and insertion losses of 6 dB. The modulator is based on the optical pumping of an InAs layer deposited on a semiconductor substrate, using moderate pumping optical power of less than 600 mW at a wavelength of 1 Âμm. Such performances are possible thanks to its integration within a WR1.0 waveguide.

17:00 **Frequency-dependent Resolution Using Asymmetric Terajet Microscopy** **We-PM2-4-4**

Alesia Paddubskaya[1]; Nadzeya Valynets[1]; Andrey Novitsky[2]; Yanfeng Li[3]; Jiaguang Han[3]; Oleg Minin[4]; Igor Minin[4]
[1]Bobruiskaya str. 11, 220006 Minsk; [2]Nezavisimosti av.4, 220030 Minsk; [3]Weijin Road 92, Nankai District, Tianjin; [4]Lenina Ave. 30, 634050 Tomsk

In this paper, we propose a concept of resolution enhancement for sub-terahertz (THz) images by employing the coupling between a dielectric sphere and a time-domain THz spectrometer. The terajet effect is used as a simple approach to overcome the diffraction limit. Correlation between the resolutions in the x- and y-directions and the frequency of the incident THz beam is analyzed both analytically and experimentally.

17:15 **Photonic Integrated Phase Control For Continuous Wave Terahertz Spectroscopy** **We-PM2-4-5**

Lauri Schwenson; Simon Nellen; Lars Liebermeister; Milan Deumer; Sebastian Lauck; Martin Schell; Robert Kohlhaas
Einsteinufer 37, Berlin

We present the first photonic integrated phase control for continuous wave (cw) terahertz (THz) spectroscopy. The dedicated photonic integrated circuit (PIC) allows for amplitude and phase detection without the need of any moving parts like fiber stretchers or free space optics. Our experimental evaluation shows equal performance of the PIC compared to a state-of-the-art fiber-based system. Furthermore, we present a phase control subsystem consisting of the PIC and a printed circuit board (PCB) with commercial driving and acquisition electronics, allowing for easy integration of the phase control into a cw THz spectrometer. With this subsystem, we demonstrate fast measurement rates, e.g. 2.8 THz bandwidth acquired within 0.5 s, and high performance with 3.6 THz bandwidth and >80 dB dynamic range in less than 3 min. This approach is an important step towards photonic integrated, compact and economic THz systems for cost-sensitive sectors in research and industry.

17:30 **Improving The Performance Of THz Delivery From A Quantum Cascade Laser Within A Dry 3He Dilution Refrigerator** **We-PM2-4-6**

Matthew Vaughan[1]; Wladislaw Michailow[2]; Matthew Tan[2]; Mohammed Salih[1]; Lianhe Li[1]; Harvey Beere[2]; David Ritchie[2]; Edmund Linfield[1]; Giles Davies[1]; John Cunningham[1]
[1]Woodhouse, Leeds; [2]Cavendish Laboratory, Cambridge

We demonstrate a substantial enhancement to the integration of a quantum cascade laser into a dilution refrigerator via hollow metal waveguides (HMWG) by the inclusion of a multi-mesh 6THz low pass filter to block IR radiation, and a Winston cone to focus light output from the waveguide. These alterations allow us to lower the base temperatures to ~114mK, and the sample temperature to ~160mK while detecting a cyclotron resonance (CR) response in a two dimensional electron gas (2DEG) illuminated within the dilution refrigerator. For comparison, before these changes we achieve a base temperature of 206mK and an effective sample temperature of 430mK while detecting CR.

17:45 **Thickness And Refractive Index Calculation Of Contact Lenses Over Time Using Terahertz Imaging And Optical Coherence Tomography** **We-PM2-4-7**

Stephy Vijaya Kumar Jayasree; Antony J. Fiitzgerald; Barry Cense; Gavin

Swartz; Vincent Wallace
35 Stirling Hwy,, Crawley, Perth

Contact lenses are widely used for correcting refractive errors and treating various ocular disorders. However, their thickness and refractive index can change over time due to dehydration and mechanical stress, which can impact their optical performance and safety. In this study, we introduce a new method to measure these parameters using a combined terahertz and optical coherence tomography system. An iterative algorithm that combines information from multiple locations within the sample can provide the depth information and refractive index measurements for both THz and OCT frequencies. We applied this method to contact lenses and measured their thickness and refractive index at different time intervals. The results revealed significant changes in these parameters over time, highlighting the importance of proper monitoring. Overall, this novel method provides accurate and reliable measurements of contact lens thickness and refractive index over time, providing essential insights into their behavior in vivo.

16:00 - 18:00 **Non-Destructive Testing I** **International II**

Chairperson(s): Shunichi Futatsumori,

16:00 **Ancient Enamel Plate Characterized By Time Domain Spectro Imaging** **We-PM2-5-1**

Patrick Patrick Mounaix[1]; Philip Taday[2]; Frederic Fauquet[3]; Rémy Chapoulie[4]; Aurélie Mounier[5]; Ayed Ben Amara[6]
[1]351 cours de la Libération cedex, Talence; [2]Cambridge, CB4 0DS, UK; [3]2Laboratoire IMS- UMR 5218 CNRS, Université Bordea; [4]3Archéosciences Bordeaux : Matériaux, Temps, Image; [5]Archéosciences Bordeaux : Matériaux, Temps, Image; [6]archéosciences Bordeaux : Matériaux, Temps, Image

We report on further development of terahertz systems for measuring the thicknesses and the detection of fracture in art science. Analysis of time-domain data is described and the results of measurements made on ancient enamel plate are presented. We also show X-Ray images and hyperspectral visible and infrared images to identify the pigments used. We also test the Z tracker developed by Teraview Ltd and demonstrate the possibility to perform THz imaging on non-flat samples.

16:15 **Terahertz FMCW Synthetic Aperture Imaging Based On RSMA For Nondestructive Testing** **We-PM2-5-2**

Zhen Ding; Jiajia Qian; Jun Zhou; Luyang Liu; Xiuxiu Yang; Qianfei Wang; Yaxin Zhang
No. 819, Xisaishan Road, Huzhou, Huzhou

In this paper, we proposed a nondestructive testing (NDT) technique based on terahertz frequency modulated continuous wave (FMCW) synthetic aperture imaging in the frequency range from 0.26 THz to 0.4 THz for the inspection of honeycomb composites commonly used in the aerospace applications, and use a range shift migration algorithm (RSMA) to image different distance planes.

The results show that the method can successfully observe the internal structure and surface defects of the material and can achieve imaging of thicker samples with high resolution in both distance and azimuthal directions. This demonstrates that the system is capable of being applied to the nondestructive detection of the shape and location of defects such as debonding, inclusions or pores in materials.

16:30 **Free-space Terahertz Spectrum Analysis With An Optoelectronic Hybrid System** **We-PM2-5-3**

Alexander Theis; Michael Kocybik; Georg von Freymann; Fabian Friederich
Fraunhofer-Platz 1, Kaiserslautern

Motivated by the recent advances in 5G and 6G technologies, we developed an optoelectronic hybrid system capable of high-resolution spectrum analysis in the terahertz range. The concept involves the phase-locking of three continuous-wave (CW) distributed-feedback diode lasers by mixing the laser light with the radiation of a high-power, electronic narrow-band emitter. To synchronize the laser beat signals with the reference source, two heterodyne optical phase-locked loops consisting of a photoconductive antenna and a PID controller are implemented in the setup. This approach eliminates the need for frequency extenders currently required in state-of-the art spectrum analyzers, resulting in a simpler and more cost-effective architecture. Using our hybrid system, we are able to generate laser difference frequencies ranging from 0 to over 1 THz, with precision in the range of several Hz. Moreover, the frequency can be easily extended to higher frequencies by incorporating suitable electronic emitters or by cascading even more lasers with our concept. To demonstrate the system's resolution and stability, we measure various spurious harmonics of electronic emitters, by implementing the laser frequency synchronization setup in a CW free-space terahertz spectrum analyzer.

16:45 **Sub-Diffraction-Limit Mm-Wave Near-Field Imaging Using Truncated Silicon Rod** **We-PM2-5-4**

Yuma Kawamoto[1]; Daniel Gallego[2]; Alejandro Rivera-Lavado[2]; Tadao Nagatsuma[1]; Daniel Headland[3]; Guillermo Carpintero[3]
[1]1-3 Machikaneyama, Toyonaka; [2]Parque Tecnológico, Av. Gregorio Peces Barba, 1, Leganes; [3]Av. de la Universidad, 30, Leganes

We propose a straightforward truncated silicon rod as a near-field imaging probe for the mm-wave and terahertz (THz) frequency ranges, with potential for applications in semiconductor wafer inspection. Semiconductor wafers have high refractive index, which is well matched to the fundamental mode of the truncated rod, leading to low reflection. In contrast, a more-conductive surface will generate stronger reflections. We take advantage of the difference in these reflections and generate an image of a chromium-on-silicon test target. The resolution is 0.75 mm, which is less than one quarter of the free-space wavelength at the center of the operation frequencies, and is below the diffraction limit.

17:00 **THz Signal Identification For Intelligent Characterization Under High-resolution Mode Based On The Pelee-ECA Network** **We-PM2-5-5**

Xingyu Wang; Yafei Xu; Yuqing Cui; Liuyang Zhang
No. 28 Xianning West Rd, Xi'an, Xi'an, ShaanXi, China

Recently, artificial intelligence (AI) technology has shown great potential in the automatic and intelligent identification of internal defects in composites based on terahertz (THz) spectroscopy. Based on the powerful feature extraction capability of deep learning, a Pelee-ECA framework-based three-dimensional intelligent characterization system is proposed to detect the glass fiber reinforced polymer (GFRP) debonding defects in terahertz nondestructive testing (THz NDT), in which the defect datasets are firstly established by the THz time domain spectroscopy (THz-TDS), and then the Pelee-ECA framework is adopted to realize the automatic and intelligent defect location and imaging by accurately classifying different THz signals. A series of experiments have been performed to validate the effectiveness of proposed system, which will provide a new solution for intelligent and automatic THz characterization of internal debonding defects of composites.

17:15 **Electric Potential Mapping Measurement For All-Solid-State Lithium-Ion Batteries Using A Terahertz Chemical Microscope** **We-PM2-5-6**

Taketo Yamaguchi; Yusei Hosokawa; Ryota Tomie; Takumi Higuchi; Takashi Teranishi; Jin Wang; Kenji Sakai; Toshihiko Kiwa
3-1-1 Tsushimanaka Kitaku, Okayama

Terahertz Chemical Microscope (TCM) has been developed to measure the electric potential distribution of batteries during charging and discharging. The battery is mounted on a sensing plate with SiO2 and Si films on a sapphire substrate and irradiate with a femtosecond laser to generate THz pulses. THz amplitude is proportional to the electric potential on the sensing plate, so the electric potential distribution of the battery on the sensing plate can be measured. In this study, a method was developed to measure the cathode surface of an all-solid-state lithium ion battery by the TCM and visualized the electric potential distribution of the battery. This result shows that the TCM could be a useful tool for measuring of all-solid-state batteries.

17:30 **Carbon Nanotube-based Transparent Stretchable Millimeter-wave--infrared Imager** **We-PM2-5-7**

HONGHAO LI; Norika Takahashi; Yoshiaki Togami; Masayuki Hamanaka; Kou LI; Yukio Kawano
1-13-27, Kasuga, Bunkyo-ku

This work develops a multi-functional imager sheet for the potential use in non-destructive inspection techniques. The presenting imager collectively satisfies optical transparency in the visible light band and stretchable broadband detector operations in millimeter-wave (MMW)--infrared (IR) regions. The device comprises different properties of carbon nanotube thin-films: single-walled metallic for photo-absorption and single-walled semiconducting for thermoelectric conversion, to demonstrate the above transparent MMW--IR imager configuration. By synergizing such characteristics with human vison sense, employing the device potentially enriches non-destructive inspection techniques as wearable modules.

17:45 **THz-TDS With A GHz Single-cavity Dual-comb Laser** **We-PM2-5-8**

Justinas Pupeikis[1]; Benjamin Willenberg[2]; Christopher Phillips[2]; Sandro Camenzind[2]; Ursula Keller[2]; Robert Kohlhaas[3]; Lars Liebermeister[3]; Bjorn Globisch[3]

[1]Auguste-Piccard-Hof 1, Zurich; [2]Auguste-Piccard-Hof 1; [3]Einsteinufer 37

We demonstrate THz time-domain spectroscopy (TDS) with a single-cavity dual-comb laser operated at 1 GHz repetition rate. The compact single laser emits two pulse trains with slightly different repetition rates. Due to this condition very rapid and precise optical delay sweeps between two pulse trains are obtained. We show THz-TDS measurements with 1 kHz and 22 kHz delay-sweep rates. Further data processing allows to perform triggerless signal averaging leading to 55 dB dynamic range in the THz spectrum with 2 GHz spectral resolution for a total measurement time of 2 seconds.

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21 September 2023

08:30 - 09:15 **Plenary Session 7** **Symposia Theatre**

Chairperson(s): Chiko Otani,

08:30 **Electrodynamics Of Solids: Low-Energy Spectroscopy Of Correlated Electrons** **Th-PL-1-1**

Martin Dressel
1. Physikalisches Institut, Pfaffenwaldring 57, Stuttgart

Electronic correlations in solids, though often neglected for simple materials, can become decisive effects leading to novel states of matter. Spectroscopic investigations have to adjust to the small energy scales of relevance here, μeV or meV. Hence, the crucial optical experiments are conducted in the far-infrared range, at THz and microwave frequencies or even below. In recent years, significant advances in methods, materials and understanding allowed us to shed new light on the electrodynamic properties of correlated electron systems, answer pertinent questions and reveal unexpected properties.

09:15 - 10:00 **Plenary Session 8** **Symposia Theatre**

Chairperson(s): Chiko Otani,

09:15 **THz Communications On The Way Towards Its Application On 6G** **Th-PL-2-1**

Thomas Kuerner
Schleinitzsr. 22, Braunschweig

Already a couple of years ago THz communications have not only become an attractive new research area on channel modeling but also triggered a couple of

projects heading to develop appropriate technological solutions to enable the set-up of hardware demonstrators. In parallel discussions and activities in standardization and regulation already took off. In October 2017, IEEE published Std. IEEE 802.15.3d-2017 the worldwide first wireless communications standard operating in the 300 GHz frequency band. At the World Radio Conference 2019 (WRC-2019) 160 GHz of spectrum has been identified for the use of THz communications and ETSI has recently kicked-off an ETSI ISG THz targeting future standardization in 3GPP. The speaker has been actively involved in all those areas. The contribution will provide a brief overview on the current status of the development of THz Communication systems focusing on past and ongoing large research projects in Europe, recent results on advanced channel characterization at 300 GHz, current activities at IEEE 802 and ETSI and at hardware demonstrators operating in this frequency range.

10:30 - 12:00 **Advanced THz Sources II** **Symposia Theatre**

Chairperson(s): Sukhdeep Dhillon,

10:30 **Fundamental Balanced Mixer Module For 300-GHz Band Based On Fermi-Level Managed Barrier Diode On SiC Platform** **Th-AM-1-1**

Hiroshi Ito[1]; Yuma Kawamoto[2]; Takahiro Ohara[2]; Tadao Nagatsuma[2]; Tadao Ishibashi[3]
[1]7-3-1 Hongo, Bunkyo-ku, Tokyo; [2]Toyonaka, Osaka; [3]Naka-gun, Kanagawa

A fundamental balanced mixer module for operation in the 300-GHz band was developed using an epi-layer-transferred Fermi-level managed barrier diode on a SiC substrate. The fabricated module exhibited an intermediate frequency bandwidth of about 26 GHz for a local oscillator signal at 280 GHz with a good port isolation of more than 13 dB.

10:45 **Power Combined Amplifiers For Terahertz Varactor Sources** **Th-AM-1-2**

Theodore Reck; Eric Bryerton; Jeffrey Hesler
979 Second Street, Charlottesville

The development of broad-band power amplifier MMICs from 120 GHz and above is enabling a new generation of varactor sources. Power combining is an essential technique to maximize the amount of power available from these devices. Two, four and eight-way combining of three different power amplifier MMICs is demonstrated, resulting in over 1 W of power at 140 GHz and 160 GHz, and over 400 mW at 195 GHz. A 260 GHz doubler driven by a 130 GHz 2-way combined amplifier is presented producing 100mW of power with less than 10 W DC power consumption.

11:00 **Design And Optimization Of A High-Power Terahertz Doubler Based On Dual-Chip GaAs Monolithic Technology.** **Th-AM-1-3**

Hongji Zhou[1]; Shixiong Liang[2]; Yazhou Dong[3]; Hailong Guo[3]; Jianghua Yu[3]; Jun Zhou[3]; Jingrui Liang[3]; Yaxin Zhang[3]
[1]Yangtze Delta Region Institute (Huzhou), University of Electronic Science and Technology of China, H, Qingshuihe Campus of UESTC, No.2006, Xiyuan Avenue, West Hi-tech Zone, Chengdu, Sichuan, P.R.China, Huzhou; [2]National Key Laboratory of Solid-State Microwave D, National Key Laboratory of Solid-State Microwave Devices and Circuits, Hebei Semiconductor Research, Shijiazhuang; [3]Huzhou Key Laboratory of Terahertz Integrated Circ, Huzhou
This paper presents a novel design and optimization methodology for a high-power terahertz doubler. Terahertz frequency multipliers have widespread applications in wireless communication, medical imaging, and security detection, but face challenges of low power output and conversion efficiency. To address these issues, this study utilizes a dual-chip GaAs monolithic technology to achieve higher power capacity and conversion efficiency, resulting in improved power output. A full-wave simulation approach is employed to optimize the doubler's performance, followed by a series of experimental verifications. The experimental results demonstrate a continuous wave power output of 130mW and a peak efficiency of 32.8%. The proposed design and optimization approach offer valuable guidance and inspiration for the development and advancement of high-power terahertz frequency multipliers.

11:15 **Monolithically Integrated Optically Pumped InP-based THz-Mixer** **Th-AM-1-4**

Marcel Grzeslo[1]; Andrej Lavrič[2]; Tim Brüning[1]; Jonas Tebart[1]; Shuya Iwamatsu[1]; Jose Luis Fernández Estévez[1]; Andreas Stöhr[1]
[1]Lotharstraße 55, Duisburg; [2]Trzaska cesta 25, Ljubljana

This work successfully demonstrates the first monolithic integration of an optically pumped THz-mixer using InP-based modified unitraveling-carrier photoidodes (MUTC-PDs) and fermi-level managed barrier diodes (FMBDs). In comparison to schottky barrier diodes (SBDs), FMBDs feature a tunability of the barrier height by adjusting the doping concentration. The barrier height is designed to be 70 meV in order to provide low power levels for switching and low noise equivalent power (NEP). Ultra-broadband mixing from 30 GHz to 300 GHz is achieved by providing sufficient LO-power to the FMBD mixer from the integrated waveguide-type MUTC-PD, making this technology suitable for compact and efficient PICs. A low conversion loss of 16.5 dB and a small NEP of 3.8 pW/sqrt(Hz) are obtained at 30 GHz. Both, providing a compact powerful LO source and low switching power requirements enables a compact and cost-effective realization for on-chip THz-mixer systems.

11:30 **Terahertz Wave Generated By Photomixing Of Dual-wavelength Laser Lights Injection-locked To A 560-GHz-spacing Soliton Microcomb For THz Wireless Communication** **Th-AM-1-5**

Yu Tokizane[1]; Shota Okada[2]; Kenji Nishimoto[2]; Hiroki Kishikawa[2]; Yasuhiro Okamura[2]; Naoya Kuse[2]; Atsushi Kanno[3]; Shintaro Hisatake[4]; Takeshi Yasui[2]
[1]2-1, Minami-Josanjima-cho, Tokushima; [2]Tokushima; [3]Aichi; [4]Gifu
Photomixing of internal mode beat in optical comb is a potential method to

generate low phase noise CW-THz wave for next-generation wireless communication. Here, we generated a 560-GHz THz wave by photomixing of dual-wavelength near-infrared laser lights injection-locked to a 560-GHz-spacing soliton microcomb with a uni-traveling-carrier photodiode. Then, we apply the generated THz waves for THz wireless communication.

11:45 **Fiber-coupled THz Transceiver Based On Rhodium-doped InGaAs With 6.5 THz Bandwidth And Up To 106 μW Emitted THz Power** **Th-AM-1-6**

Alexander Dohms; Steffen Breuer; Shahram Keyvaninia; Marko Gruner; Lars Liebermeister; Martin Schell; Robert Kohlhaas
Einsteinufer 37, Berlin

We present a fiber-coupled transceiver for terahertz (THz) time-domain spectroscopy in reflection geometry. The monolithically integrated transceiver is based on rhodium (Rh) doped In0.53Ga0.47As (InGaAs:Rh) grown by molecular beam epitaxy, combining emitter and receiver on the same photoconductive chip. A record THz power for transceivers of 106 μW, a maximum spectral bandwidth of 6.5 THz and a peak spectral power of 79 dB are achieved.

10:30 - 12:00 **Ultrafast & Nonlinear Phenomena II** **Cartier I**
Chairperson(s): Klaas-Jan Tielrooij,

10:30 **Bloch Wavefunction Interferometry Of Driven Electron-Hole States** **Th-AM-2-1**

Seamus O'Hara[1]; Joseph Costello[2]; Qile Wu[3]; Kenneth West[4]; Loren Pfeiffer[4]; Mark S. Sherwin[2]
[1]717 Gayley Walk Apt 101, Goleta; [2]Broida Hall, Santa Barbara; [3]Broida Hall; [4]B404 Engineering Quad

High Order Sideband Generation (HSG) occurs when a semiconductor is driven by a strong sub-THz field while probed with a weak near-infrared laser. We show the spectrum of sideband polarizations emitted from bulk GaAs can be viewed as the interferogram from a Michelson-like interferometer between the Bloch waves associated with two species of electron-hole pairs. A simple analytical model is used to calculate the dynamical phase accumulated by Bloch waves associated with E-HH and E-LH pairs. The measured and calculated interferograms are in good quantitative agreement, including scaling with THz field strength. The success of the analytical model makes it possible to probe the interferogram's dependence on other material parameters.

11:00 **Ultrafast Expansion Of Electron-hole Plasma In GaAs Probed By THz Radiation** **Th-AM-2-2**

Tomas Ostatnický[1]; Filip Klimovič[1]; Tinkara Troha[2]; Filip Kadlec[2]; Petr Kuzel[2]; Hynek Němec[2]
[1]Ke Karlovu 3, Praha 2; [2]Na Slovance 2, Praha 8

Ultrafast and long-distance expansion of electron-hole plasma in bulk GaAs crystal at temperatures ranging from 20 K to 300 K is observed by means of the optical pump -- THz probe experimental technique. The expansion speed ~c/50

at 300 K notably exceeds values reported earlier in the literature but it also exceeds the values permitted by the GaAs band structure for a bare electron. This observation is interpreted in terms of a stimulated emission, fast transport and reabsorption of photons by creation of electron-hole pairs. Theoretical quantitative model, based on the above interpretation, shows a very good agreement with the experimental data, gives a valuable insight into the system dynamics and predicts conditions at which the effect should be observable. At temperatures below 100 K, further increase of the propagation speed of electron-hole plasma surface (up to ~c/10) is observed. This effect is interpreted as the direct observation of the optical soliton propagation in the crystal.

11:15 **Ultrafast Optical Pump-probe Of Magnetic Kagome Metals** **Th-AM-2-3**

Marcos Vinicius Goncalves Faria; Ece Uykur; Stephan Winnerl; Oleksiy Pashkin; Manfred Helm
Bautzner Landstraße 400, Dresden

The Kagome lattice is a two-dimensional network of corner-sharing triangles that is known to combine linear bands hosting massless Dirac fermions and dispersionless flat bands featuring massive localized electrons, both arising due to its geometry. FeSn binary compounds and the RMn6Sn6 (R = Tb, Gd and Y) series are commonly studied magnetic Kagome metals, which possess different magnetic ground states and interlayer Kagome coupling. Several steady-state experimental techniques have been used to study the magnetic and electronic structure of these materials and the effects of magnetism on the band structure. However, the ultrafast dynamics and the interplay of these unusual features have not yet been widely explored in the scope of time-domain spectroscopy. Here we present temperature- and fluence-dependent carrier dynamics of various magnetic Kagome metals studied using the optical pump-probe technique. Distinct carrier relaxations have been observed, and they can be partially attributed to the simple two-temperature model, as these are highly metallic compounds.

11:30 **Attoclocking Delocalized Bloch Electrons With Multi-terahertz Fields** **Th-AM-2-4**

Josef Freudenstein[1]; Markus Borsch[2]; Manuel Meierhofer[1]; Dmytro Afanasiev[1]; Christoph Peter Schmid[1]; Fabian Sandner[1]; Marlene Liebich[1]; Anna Girnghuber[1]; Matthias Knorr[1]; Mackillo Kira[2]; Rupert Huber[1]
[1]Universitätsstraße 31, Regensburg; [2]1301 Beal Avenue, Ann Arbor

We use multi-terahertz light fields to force electron-hole pairs in crystalline semiconductors onto closed trajectories and clock the delay between separation and recollision with a 300 as precision. This value corresponds to 0.7% of the driving field's oscillation period. The strong Coulomb correlations emergent in atomically thin tungsten diselenide are found to shift the optimal timing of recollisions by up to 1.2 ± 0.3 fs compared to the bulk material. A quantitative analysis with quantum-dynamic many-body computations yields a direct and intuitive view on how the Coulomb interaction, non-classical aspects, the strength of the driving field, and the valley polarization influence the dynamics, opening unprecedented views of quantum many-body correlations and phase

transitions.

11:45 **Ultrafast Dynamics Of Coulomb Electric Field Contraction by Relativistic Electron Bunch** **Th-AM-2-5**

MAKOTO NAKAJIMA[1]; Masato Ota[1]; Koichi Kan[2]; Youwei Wang[1]; Verdad C Agulto[1]; Kosaku Kato[1]; Yasunobu Arikawa[1]; Tatsunosuke Matsui[3]; Makoto Asakawa[4]
[1]2-6 Yamadaoka, Suita; [2]Ibaraki, Ibaraki; [3]Mie; [4]Suita

In special relativity, the Lorentz transformation of electromagnetic potentials has never been directly demonstrated in experiments. Here, we show the spatiotemporal electric field profiles around a highly energetic electron beam with a sub-picosecond temporal resolution obtained by electro-optic sampling. We observe the Coulomb field contraction in the propagation direction of the beam under the Lorentz transformation. We investigated the dynamical behavior of the Coulomb field after passing the beam through a metallic plate. The contraction of the electric field around a beam of highly energetic electrons predicted by the special relativity is experimentally visualized for the first time.

10:30 - 12:00 **Condensed Matter & Semimetals** **Cartier II**
Chairperson(s): Sarah Houver,

10:30 **Investigation Of Terahertz Tunable High Q-factor BIC Resonance** **Th-AM-3-1**

Xiaoyong He
, No. 100 Guilin Road, Shanghai, China, Shanghai

Based on the 3D Dirac semimetals (DSM) supported tilted double elliptical resonators, the tunable propagation properties of quasi-bound in continuum (BIC) resonance have been investigated in the THz regime. The results show that by altering the rotation angle, an obvious sharp BIC transmission dip is observed with a Q-factor of more than 60. The Fermi level affects the BIC resonance significantly, and the amplitude modulation depths is 92.8%. Additionally, with the modified configurations of elliptical resonators, another transmission dip resonance is excited and indicates a red shift with the increase of the permittivity of the filling material. The results are very helpful to develop novel tunable THz devices, e.g. modulators, filters, and sensors.

10:45 **Electrical Properties Of Thin Layers Of III/V Semiconductors Obtained By Terahertz Reflectometry And Transmissometry** **Th-AM-3-2**

Konstantin Wenzel[1]; Steffen Breuer[1]; Robert B. Kohlhaas[1]; Martin Schell[2]; Lars Liebermeister[2]
[1]Einsteinufer 37, Berlin; [2]Einsteinufer 37, Hardenbergstraße 36, 10623 Berlin, Berlin

We investigate indium gallium arsenide samples with various doping levels using terahertz (THz) time-domain reflectometry and transmissometry in the near- and far-field. The samples have been grown on indium phosphide substrates by molecular beam epitaxy under different growth conditions yielding a wide range of electrical properties including resistances from 10^1 to 10^6 Ohm/sq. We compare THz measurements on these samples to a model

based on the Tinkham Equation and standard 4-point measurements. The presented method allows non-contact and spatially resolved characterization of a broad spectrum of thin semiconductors, paving the way towards a new fast and contactless measurement technique for full-wafer characterization.

11:00 **Strong Proton-Phonon Coupling In Perovskite-type Electrolyte Of Proton-Conducting Fuel Cell** **Th-AM-3-3**

Masaya Nagai[1]; Hikaru Takehara[1]; Masaaki Ashida[1]; Yuji Okuyama[2]; Yukimune Kani[3]
[1]Machikaneyama 1-3, Toyonaka; [2]1-1 Gakuenkibanadai-nishi, Miyazaki; [3]3-1-1 Yagumo-nakamachi, Moriguchi

We performed THz spectroscopy of solid electrolytes with controlled water vapor partial pressure and temperature to reveal picosecond proton motions. We also performed the IR reflection spectroscopy, and showed that the protonic motions in protonated BaZrO3 are strongly influenced by lattice vibrations. Such a dynamical long-range proton--lattice correlation will enable new approaches to improve proton conduction in solid-state ionics.

11:15 **Terahertz Spectroscopic Study Of Vibrational Density Of States In LiCl-6H2O** **Th-AM-3-4**

Soo Han Oh[1]; Dan Kyotani[1]; Yasuhiro Fujii[2]; Suguru Kitani[3]; Yohei Yamamoto[1]; Tatsuya Mori[1]
[1]University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki; [2]Ritsumeikan University, 1-1-1 Noji-higashi, Kusatsu, Shiga; [3]Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku,, Yokohama, Kanagawa

We have investigated two characteristic behaviors in the terahertz-band vibrational density of states of LiCl-6H2O in the glassy state: a boson peak (BP) at 1 THz and a broad peak around 2 THz. We succeeded in reproducing the behavior of the BP using heterogeneous elasticity theory, and extracted the nanomechanical properties. In addition, the broad peak at 2 THz is attributed to the bending mode between hydrogen-bonded water molecules, and the interaction between the bending mode and terahertz light was investigated.

11:30 **Charge-Carrier Dynamics In Mixed Lead-Tin 2D/3D Metal Halide Perovskites** **Th-AM-3-5**

Jake Hutchinson[1]; Edoardo Ruggeri[2]; Samuel Stranks[2]; Rebecca Milot[3]
[1]Department of Physics, Gibbet Hill Road; [2]Cambridge; [3]Department of Physics, Gibbet Hill Road, Coventry

Halide perovskite thin films with mixtures of both standard 3D perovskites and quasi-2D or layered perovskites are promising materials for devices due to their increased stability. Optical-pump/THz probe studies combined with visible transient absorption measurements reveal the complex charge-carrier dynamics in these mixed materials.

11:45 **Tailoring Ultrafast Carrier Dynamics In GeS And GeSe Via Cu** **Th-AM-3-6**

Intercalation

Sepideh Khanmohammadi[1]; Kateryna Kushnir Friedman[1]; Catherine Tran[2]; Srihari Kastuar[3]; Erika Colin-Ulloa[1]; Chinedu Ekuma[3]; Kristie Koski[2]; Lyubov Titova[1]
[1]100 Institute Rd, Worcester; [2]1 Shields Ave, Davis; [3]27 Memorial Dr W, Bethlehem

Germanium sulfide (GeS) and germanium selenide (GeSe) are layered 2D van der Waals materials that belong to a family of group-IV monochalcogenides. These semiconductors have high carrier mobilities and moderate band gaps in the near infrared. Additionally, we have demonstrated that above gap photoexcitation results in ultrafast surface photocurrents and emission of THz pulses due to a spontaneous ferroelectric polarization that breaks inversion symmetry in the monolayer. Beyond the sub-picosecond time scales of shift currents, photoexcited carriers in both materials result in long-lived transient conductivity. We find that 800 nm excitation results in longer lived free photocarriers, persisting for hundreds of picoseconds to several nanoseconds, compared to tens to hundreds of picoseconds lifetimes for 400 nm excitation. Here, we report on tailoring the free photoexcited carrier lifetimes by intercalation of zero-valent Cu into the van der Waals gaps of GeS and GeSe. Density functional theory calculations predict that Cu atoms introduce mid-gap states. We demonstrate that intercalating only ~ 3 atomic % of zero-valent Cu reduces the carrier lifetime by as much as two-to-four-fold, raising the prospects of these materials being used for high-speed optoelectronics.

10:30 - 12:00 **Integrated Technologies 2** **International I**

Chairperson(s): Withawat Withayachumnankul,

10:30 **Terahertz Meta-chips And High-speed Communication Systems** **Th-AM-4-1**

Hongxin Zeng; Yaxin Zhang; Sen Gong; Lin Huang; Ziqiang Yang
UESTC: University of Electronic Science and Technology of China, No. 2006, Xiyuan Avenue, High-tech Zone (West Zone), Chengdu, Chengdu

Terahertz high-speed and efficient modulation technology is a key component in the development of a new generation of integrated, low-complexity, high-rate terahertz communications. Despite recent breakthroughs and advances, achieving high-speed, low insertion loss, and high modulation depth of terahertz waves simultaneously remains a scientific challenge in the field. This report introduces a meta-chip concept that combines conventional transmission lines with active semiconductor artificial microstructures to create a new terahertz modulation chip. This effectively addresses the issue of slow modulation rate and low modulation efficiency caused by large parasitic capacitance and low coupling efficiency in conventional chips. This meets the development needs of low-power, low-complexity direct modulation terahertz high-speed communication systems. Building on this foundation, we have also established a series of miniaturized or ultra-high-speed terahertz communication systems. This work not only provides new ideas for the development of terahertz high-speed modulation technology but also opens up

a new design approach for the development of high-performance terahertz integrated chips.

11:00 **Quasi-Optical LO Coupling Validation For A Planarly Integrated 2x2 Pixel Heterodyne Array At 1.95 THz** **Th-AM-4-2**

Sven van Berkel[1]; Alain Maestrini[1]; Cecile Jung-Kubiak[1]; Sjoerd Bosma[2]; Maria Alonso-delPino[2]; Darren Hayton[1]; Jacob Kooi[1]; Jose Siles[1]; Nuria Llombart[2]; Imran Mehdi[1]; Goutam Chattopadhyay[1]
[1]4800 Oak Grove Drive, Pasadena; [2]Mekelweg 4, Delft

Terahertz heterodyne spectrometer instruments have been traditionally limited to a single pixel or a handful of pixels due to integration and assembly constraints and a limited availability of local oscillator (LO) power. As a solution we propose a novel silicon-micromachined planar and modular packaging strategy, that will allow for a dense integration of a large number of pixels. Moreover, the RF- and LO signals will be quasi-optically coupled via two identical but opposite lens arrays, such that a single LO-source can efficiently pump all HEB-mixers of the 2x2 pixel demonstrator array simultaneously. This work reports on an intermediate step, where we validate the lens array performance and LO power coupling efficiency, by slightly modifying the silicon package into a transmit array configuration. In this way, the LO power coupled into the stack is directly re-radiated on the other side, which is then measured using a liquid helium cooled bolometer.

11:15 **Full-Duplex Beamforming In The Sub-Terahertz Regime** **Th-AM-4-3**

Subhajit Karmakar[1]; Atsutse Kludze[2]; Jacques Doumani[3]; Andrey Baydin[3]; Junichiro Kono[4]; Yasaman Ghasempour[5]
[1]Department of Electrical and Computer Engineering, Princeton University, Princeton NJ 08544, USA, Princeton; [2]Department of Electrical and Computer Engineering,, Princeton; [3]Department of Electrical and Computer Engineering, Houston; [4]Department of Electrical and Computer Engineering, Department of Physics and Astronomy, Houston; [5]Department of Electrical and Computer Engineering, Princeton

We propose a novel architecture that realizes full-duplex directional beamforming in the sub-terahertz regime. Our architecture leverages the frequency-controlled beam steering of leaky-wave antenna together with the polarization-dependent response of aligned single-wall carbon nanotubes. We evaluate the performance of this architecture via preliminary experiments.

11:30 **Packaging Technology For The Realization Of Tx And Rx Modules Based On RTD Devices** **Th-AM-4-4**

Christian Preuss[1]; Simone Clochiatti[1]; Robin Kress[1]; Enes Mutlu[1]; Florian Vogelsang[2]; Werner Prost[1]; Nils Pohl[2]; Nils Weimann[1]
[1]Lotharstrasse 55, Duisburg; [2]Universitätsstraße 150, Bochum

This paper presents an integration concept for a single device resonant

tunneling diode (RTD) broadband detector onto a low coast FR4 board. The assembly utilizes a flip-chip connection of the detector chip via a thermocompression bonding method. For broadband detection, an RTD detector with a logarithmic spiral antenna topology is chosen. To increase the stability of the interconnection against mechanical vibration, an additional underfill process employing an adhesive is performed. To enhance radiation coupling into the detector chip, a lens is mounted on the chip backside. With this arrangement a detector module is realized and characterized in the WR2.2 (330 GHz - 500 GHz) band.

11:45 **Modeling, Fabrication And RF Performance Of A W-Band Breadboard Optical Model For LiteBIRD MHFT** **Th-AM-4-5**

Abdallah Chahadih[1]; Cristian Franceschet[2]; Bruno Maffei[3]; Marco De Petris[4]; Luca Lamagna[4]; Jon Gudmundsson[5]; Marco Bersanelli[2]
[1]121 Rue Jean Teillac, Bures sur Yvette; [2]Via Giovanni Celoria 16 - 20133 Milano (Lombardia); [3]121 Rue Jean Teillac, 91440 Bures-sur-Yvette; [4]Piazzale Aldo Moro, 2 - 00185 Roma; [5]SE-106 91 Stockholm, Sweden

This paper presents a study performed on a breadboard model operating in the W band, designed for the LiteBIRD project. It consists of a dielectric lens that is fed by a corrugated horn. The accurate knowledge of the beam shape is crucial for LiteBIRD, and the main purpose of this breadboard is to verify the level of accuracy that can be reached by experimental measurements by comparing them to simulations. This breadboard was modeled, fabricated, and characterized. Measurement results show a very good agreement with simulations down to a level of about -70 dB.

10:30 - 12:00 **Non-Destructive Testing II** **International II**

Chairperson(s): Patrick Mounaix,

10:30 **Scattering Measurements With A Moving Human At 60 And 300 GHz** **Th-AM-5-1**

Tobias Doeker[1]; Daniel Mittleman[2]; Thomas Kürner[1]
[1]Schleinitzstr. 22, Braunschweig; [2]Box D, Providence

In this paper, a measurement campaign for investigating the influence of a human body and especially a moving human with respect to eavesdropping at 60 and 300 GHz is introduced and first results related to the evaluation of the orientation of the human are presented.

10:45 **Evaluation Of Small Bolt And Nut Detection Performance Using Airport Runway Foreign Object Debris Detection System Based On A 96-GHz Millimeter-Wave Radar System** **Th-AM-5-2**

Shunichi Futatsumori[1]; Naruto Yonemoto[1]; Noriaki Hiraga[1]; Nobuhiko Shibagaki[2]; Yosuke Sato[2]; Kenichi Kashima[2]
[1]7-42-23, Jindaiji-higashi, Chofu, Chofu; [2]Minato-ku, Tokyo

The automatic airport foreign object debris (FOD) detection system enables the safety and security operations of airport runways. In this regard, we developed an FOD detection system based on an optically connected 96-GHz distributed-type millimeter-wave radar sensor. In this paper, the small bolt and nut detection performance of the developed FOD detection system is obtained at an airport runway. The detection probabilities of six different bolt and nut samples, which included an M10 bolt and nuts with different lengths (2, 4, 6, and 8 cm), an M10 nut, and an M4 bolt and nut (length: 2 cm), are evaluated. Almost all samples, except for the M10 bolt with an 8-cm length, are smaller than the objects described in a standard document. From the measurement results, we confirm that the detection rate exceeded 95% for all sizes of M10 bolts and nuts.

11:00 **CW-THz System For High Scan Rate Inline Thickness Measurements** **Th-AM-5-3**

Niklas Schulz; Carsten Brenner; Lisa C. Kreuzer; Nils Surkamp; Martin R. Hofmann
Universitätsstr. 150, Bochum

We present a cw-THz system operating at 1 THz without moving components and with a high potential for integration. A high scan rate of the system is enabled by a single, fiber coupled monolithic Y-DFB laser, in which one of the emission modes is modulated in wavelength by gain current modulation.

11:15 **Influence Of Surface Roughness On Material Classification For Reflective THz-TDS Measurements** **Th-AM-5-4**

Sebastian Gassel; Martin R. Hofmann; Carsten Brenner
Universitätsstrasse 150, Bochum

THz spectroscopy is a useful tool for identification of materials. However, for its reliable use, the effects of surface roughness must be taken into account. Scattering, diffraction and interference can hinder reliable detection. In our experiments, we measure samples with defined roughness parameters at varying angles of incidence and reflection. To determine the effect on material classification, we train a machine learning algorithm with samples of low roughness and test it with samples of higher surface roughness.

11:30 **Bound States In The Continuum Enabled THz Dielectric Metasurface For High Sensitivity Refractive-Index Sensing** **Th-AM-5-5**

Marie Georgiades[1]; James Seddon[2]; Cyril Renaud[1]
[1]Torrington Place, London; [2]Torrington Place, Torrington Place, London

In this work we present a highly sensitive all-dielectric terahertz (THz) metasurface sensor consisting of an array of hollow cuboids made of silicon on top of a quartz substrate. The proposed design exploits the phenomenon of bound states in the continuum (BIC) to achieve a Q-factor of 10260 which corresponds to a sensitivity of 18.8 GHz/ RIU. This sensor is to be integrated in a continuous wave (CW) spectroscopy setup for the detection of chemical and biological substances based on refractive index sensing. The performance of the sensor offers a promising approach towards label-free, cost-effective and room temperature operable sensing solutions.

11:45 **Probing Live PN Junctions With Terahertz Waves** **Th-AM-5-6**

Bryce Chung[1]; Harrison Lees[1]; Chitchanok Chuengsatiansup[2]; Withawat Withayachumnankul[1]
[1]North Terrace, Adelaide; [2]Parkville, Melbourne

It is known that the reflectivity of semiconductor materials at terahertz frequencies is sensitive to changes in free carriers. This phenomenon has been rigorously studied with semiconductor wafers and offline semiconductor devices. Despite this capability for sensing free carriers, terahertz probing of semiconductor devices in operation is nearly non-existent. Here we observe a PN-junction diode in operation, using terahertz waves in reflection. The Shockley diode equation and Drude model are leveraged to explain the observation. We anticipate that this work will be fundamental in establishing the capability to monitor semiconductor devices in operation, potentially unlocking a new wave of terahertz applications in the semiconductor industry and beyond.

13:30 - 15:30 **High Field THz Generation III** **Symposia Theatre**

Chairperson(s): Alessandro Tomasino,

13:30 **GW-TW Terahertz Radiation From Ultraintense Laser-plasma Interactions** **Th-PM1-1-1**

Guoqian Liao; Hongyi Lei; Fangzheng Sun; Yutong Li
P.O. Box 603, Beijing

Our recent progress on the ultraintense laser-driven terahertz (THz) radiation from plasmas is presented. THz properties are fully characterized with the newly-developed single-shot ultrabroadband detection methods. Multi-gigawatt (GW) and even terawatt (TW)-scale THz bursts have been demonstrated experimentally by optimizing laser-plasma parameters. Such an extreme THz source enables a versatile pump-probe experimental platform particularly for the study of extreme THz wave-matter interactions.

14:00 **Measuring The Electro-optic Response Of Quartz For Accurate Sampling Of Intense THz Fields** **Th-PM1-1-2**

Maximilian Frenzel; Leona Nest; Joanna M. Urban; Michael S. Spencer; Sebastian F. Maehrlein
Faradayweg 4-6, Berlin

The advancement of THz sources with peak fields exceeding 1 MV/cm poses the challenge to accurately measure these electric field transients without distortions in the electro-optic detection. Z-cut alpha-quartz has been recently found as a suitable electro-optic sampling (EOS) crystal, but its accurate response function, which allows the THz electric field to be exactly determined from the measured EOS signal, was still elusive. Here, we employ intense THz fields (0.5 - 4 THz) generated via optical rectification in LiNbO3 to measure EOS in quartz. By comparison with a traditional EOS crystal, we determine the quartz response function in both experiment and theory, and apply it to extract the exact THz field waveform. Our work therefore establishes a new standard

for accurate measurement of intense THz electric fields using quartz, wherever conventional EOS materials face saturation effects or nonlinear distortions.

14:15 **Frequency-resolved Measurement Of Two-color Air Plasma Terahertz Emission** **Th-PM1-1-3**

Emmanuel Abraham[1]; Eiji Hase[2]; Jérôme Degert[1]; Eric Freysz[1]; Takeshi Yasui[2]
[1]351 cours de la Libération, Talence; [2]2-1 Minami-Josanjima, Tokushima

We investigated the far-field THz beam profile generated from two-color air plasma induced by bichromatic femtosecond laser pulses. Under our experimental conditions, using electro-optic sampling in both ZnTe and GaP crystals, along with ultra-broadband ABCD technique (0.2-30 THz), we were able to show that the THz beam exhibited an unimodal beam pattern below 4 THz and a conical beam pattern above 6 THz. This experimental result agrees with other theoretical studies based on the unidirectional pulse propagation equation, which have shown the transition of the THz emission from flat-top profile to a conical one due to the destructive interference of THz waves emitted from the plasma filament.

14:30 **Evaluation Of Methods For Measuring The Field Of An Intense THz Pulse** **Th-PM1-1-4**

xavier ropagnol[1]; Carlos Miguel Garcia Rosas[2]; Hirohisa Uchida[3]; François Blanchard[4]; Tsuneyuki Ozaki[2]
[1]1650 boulevard lionel boulet, Montreal; [2]1650 boulevard lionel boulet, 1650 boulevard lionel boulet, Varennes; [3]Kamigyo-Ku,, Kyoto; [4]1100 rue notre dame, Montreal

We compare two methods, that are commonly used, for measuring the peak field of intense terahertz (THz) pulses generated from organic crystals pumped by energetic, femtosecond near-infrared optical pulses. The first method evaluates the peak field directly from the intensity modulation of the probe pulse measured using electro-optic (EO) sampling. The second method calculates the peak field from the measured experimental parameters, such as the duration and the energy of the THz pulse with its spot size. We find that the latter method gives a peak field strength that is almost an order of magnitude higher than that obtained from the probe modulation. We mainly attribute this difference to the sensitivity of the devices used for this measurement, which is highly THz wavelength dependent.

14:45 **DC Electric Field Assisted Precise Control Of THz Radiation From Femtosecond Laser Plasma Filament In Air** **Th-PM1-1-5**

Tie-Jun Wang[1]; Juan Long[2]; Yuxin Leng[2]; Ruxin Li[2]; See Leang Chin[3]
[1]No. 390 Qinghe Road, Jiading District, Shanghai; [2]No. 390 Qinghe Road, Jiading District; [3]2375 rue de la Terrasse

Femtosecond laser ionized plasma filament in air has shown the capability to generate broadband THz even at remote distance. External DC electric field has been applied on the filament entirely and locally to enhance the THz intensity,

manipulate its phase, even control the spatial jitter of the THz pulse.

15:00 **Single-shot Waveform Detection Of Air-plasma Based THz Sources** **Th-PM1-1-6**

Alexander Ohrt; Siyan Zhou; Long Cheng; Yunhong Ding; Peter Uhd Jepsen; Binbin Zhou
Ørsteds Plads, Building 343, Kgs. Lyngby

We present the first ultra-broadband single-shot detection capable of capturing THz waveform generated through a two-color air-plasma THz source by using a spatially resolved detection scheme. Single-shot THz detection up to 20 THz is realized. Live acquisition of ultra-broadband THz waveform is possible, and the detection time window can be tuned by varying the angle between the THz and optical probe beam.

15:15 **High-repetition-rate, High-average-power Mid-infrared Optical Parametric Oscillator Based On BaGa4Se7 Pumped By A 1064 Nm Master-oscillator Power-amplifier Laser System** **Th-PM1-1-7**

Yue Sun[1]; Kai Chen[1]; Kai Zhong[1]; Degang Xu[1]; Chao Yan[1]; Shuai Liu[1]; Yuye Wang[1]; Jining Li[1]; Jiyong Yao[2]; Jianquan Yao[1]
[1]Tianjin University, Tianjin, China, Tianjin; [2]Chinese Academy of Sciences, Beijing

In this work, we reported a high-repetition-rate and high-average-power BGSe-OPO system pumped by a 1064 nm MOPA system. Under the repetition rate of 1 kHz and the average pump power of 6.08 W, the idler power of 139.1 mW and pulse width of 5.45 ns was achieved, corresponding to the optical-to-optical conversion efficiency of 2.29%. Due to the strong Fresnel reflection phenomenon of BGSe crystal surfaces without AR coating to reinforce OPO cavity loss, the conversion efficiency of OPO was low. However, saturation phenomenon and damage of the BGSe crystal were not found, so that the pump power can be improved to obtain excellent output characteristics of idler wave in future studies.

13:30 - 15:30 Gyro-Oscillators and Amplifiers I **Cartier I**
Chairperson(s): Stefano Alberti,

13:30 **Progress In High Power Gyrotron Development Projects At KIT** **Th-PM1-2-1**

Gerd Gantenbein[1]; Konstantinos Avramidis[2]; Benjamin Ell[1]; Lena Delpech[3]; Lukas Feuerstein[1]; Stefan Illy[1]; John Jelonnek[1]; Jianbo Jin[1]; Laurent Krier[1]; Heinrich Laqua[4]; Tobias Ruess[1]; Tomasz Rzesnicki[1]; Sebastian Stanculovic[1]; Manfred Thumm[1]
[1]Kaiserstrasse 12, Karlsruhe; [2]Zografou GR-15784, Athens; [3]Cedex, Saint-Paul-lez-Durance; [4]Wendelsteinstrasse 1, Greifswald

KIT is actively developing high power gyrotrons for application in fusion machines with magnetic confinement of the plasma. These projects are realized in tight cooperations with European partners and include conventional (hollow

cavity) gyrotrons as well as coaxial-cavity gyrotrons with increased power capabilities. For future applications in fusion devices with multi-MW ECRH systems the efficiency of gyrotron operation becomes very important. KIT is following the multi-staged depressed collector concept to maximize the efficiency. Preparations are ongoing to commission the FULGOR gyrotron teststand and operate it with full performance.

13:45 **Study Of 136/170 GHz Dual-Frequency Operation Based On The KIT 2 MW 170 GHz Coaxial-Cavity Pre-Prototype Gyrotron** **Th-PM1-2-2**

Tobias Ruess; Gerd Gantenbein; Stefan Illy; Jianbo Jin; Tomasz Rzesnicki; Sebastian Stanculovic; Manfred Thumm; John Jelonnek
Hermann-von-Helmholtz-Platz 1, Eggenstein-Leopoldshafen

Theoretical validation of a dual-frequency operation at 136 GHz and 170 GHz is carried out on the basis of the 2 MW 170 GHz coaxial-cavity pre-prototype gyrotron that has been built at Karlsruhe Institute of Technology (KIT). The key components such as the Magnetron Injection Gun (MIG), the coaxial cavity and the quasi-optical output coupler are investigated for the operation at 136 GHz and 170 GHz. The TE28,15 mode is selected as operating mode at 136 GHz. It is shown that the characteristic parameters fit best to those of the TE34,19 mode at 170 GHz. The coaxial triode MIG (cMIG) is intended for the first experiments. The simulated electron beam parameters of the cMIG are taken into account in the interaction simulations. An output power of 2.42 MW with an interaction efficiency of 41.9 % is achieved at 136 GHz in simulations, while the output power at 170 GHz is above 2 MW. The pre-prototype is currently being prepared for initial experimental verification. Measurement results are expected in mid of 2023 and will be presented.

14:00 **Progress In The Design Of Megawatt-Class Fusion Gyrotrons Operating At The Second Harmonic Of The Cyclotron Frequency** **Th-PM1-2-3**

Stefan Illy[1]; Konstantinos Avramidis[2]; Ioannis Chelis[2]; Benjamin Ell[1]; Lukas Feuerstein[1]; Gerd Gantenbein[1]; Zisis Ioannidis[3]; John Jelonnek[1]; Jianbo Jin[1]; George Latsas[2]; Alexander Marek[1]; Dimitrios Peponis[2]; Tomasz Rzesnicki[1]; Manfred Thumm[1]; Ioannis Tigelis[2]; Chuanren Wu[1]
[1]Kaiserstr. 12, Karlsruhe; [2]University Campus, Athens; [3]Euripou Campus, Psachna

In the frame of a EUROfusion Enabling Research Project (ENR) KIT and NKUA are working on new concepts for highly efficient, megawatt-class fusion gyrotron systems that will operate at the 2nd-harmonic of the electron cyclotron frequency. This will reduce the required magnetic flux density by a factor of two and therefore will lead to more compact and cost-efficient gyrotron systems at DEMO relevant and sub-THz frequencies.

14:15 **Parasitic-modes Free, High-performance Operation Of The European 1 MW, 170 GHz Short-Pulse Prototype Gyrotron For ITER** **Th-PM1-2-4**

Tomasz Rzesnicki[1]; Konstantinos Avramidis[2]; Ioannis Chelis[2]; Gerd Gantenbein[1]; Lukas Feuerstein[1]; Stefan Illy[1]; John Jelonnek[1]; Jianbo Jin[1]; Alberto Leggieri[3]; Francois Legrand[3]; Christophe Lievin[3]; Alexander Marek[1];

Tobias Ruess[1]; Sebastian Stanculovic[1]; Manfred Thumm[1]
[1]Kaiserstr. 12, Karlsruhe; [2]University Campus, Athens; [3]Vélizy-Villacoublay

The short-pulse (SP) prototype tube has been initially manufactured at KIT in 2015 to support the development of the European 1 MW, 170 GHz, CW gyrotron for ITER [1]. The SP gyrotron is in operation and used for testing and experimental validation of new gyrotron subcomponents for further improvements of the gyrotron performance. The very recent experiments were dedicated to the investigations of further enhancement of the gyrotron stability by the suppression of parasitic oscillations, observed during the previous gyrotron experimental campaigns. With recent modifications on the gyrotron setup, encouraging results have been achieved. In particular, for the first time a parasitic-modes free operation, in a very broad range of parameters, stable operation has been observed, leading to a significant improvement of the gyrotron overall performance. Achieved results will be presented in this paper.

14:30 **Resonant Ring With A Gain Of 32 For Use With A 1 MW 110 GHz Gyrotron** **Th-PM1-2-5**

Elliot Claveau; Michael Shapiro; Richard Temkin
77 Massachusetts Avenue, NW17, Cambridge

A 110 GHz quasi-optical ring resonator, designed for use with a 1 MW pulsed gyrotron, has been built and successfully tested using a 100 mW solid-state source. A high transparency (97%) input coupler is placed in the beam path, enabling a compression ratio of 32. The 6.7 ns output pulses are generated from the 2 m length ring using a Silicon laser driven semiconductor switch to produce the output pulse. The quasi-optical ring resonator is designed with large waist sizes so that input pulses of up to 1 MW will stay under the 35 kV/cm electric field limit for ionization in ambient air. In the next step, 1 MW, microsecond pulses will be compressed to 32 MW, 6.7 ns pulses with this ring resonator, permitting the operation of novel, 110 GHz linear particle accelerators.

14:45 **Nonlinear Theory Of Beam-wave Interaction In Gyrotron Cavities With Gradual And Abrupt Transitions** **Th-PM1-2-6**

Oleksandr Maksymenko[1]; Vitalii Shcherbinin[1]; Manfred Thumm[2]; John Jelonnek[2]
[1]Kaiserstr. 12, 76131 Karlsruhe, Germany, Akademicheskaya St. 1, 61108, Kharkiv, Ukraine, Eggenstein-Leopoldshafen; [2]Kaiserstr. 12, 76131 Karlsruhe, Germany, Eggenstein-Leopoldshafen

Self-consistent nonlinear theory of beam-wave interaction in complex-shaped gyrotron cavities is developed. The theory combines the generalized telegrapher's equations and mode-matching technique for gradual and abrupt transitions, respectively. As an example, a complex cavity of a second-harmonic 0.4-THz gyrotron is considered. For this gyrotron, the results of beam-wave interaction modeling are utilized as a check on accuracy of the simplified approach used in previous research

15:00 **Enhanced Performance Of 264 GHz EIO Subsystem** **Th-PM1-2-7**

Albert Roitman; Doug Yake; Parth Gandhi; Dave Berry; Tom Sertic
45 River Drive, Georgetown

This paper summarizes the performance improvements of a 264 GHz EIO subsystem achieved over the last decade. Every characteristic, practical, and reliability aspects were considered and addressed. Newer mechanical tuning provides operation with 5 W output power across a 1 GHz frequency range. Reduced voltage ripple of the Gen-IV power supply provides RF signal with linewidth of less than 4 MHz. Available LifeExtender option has the capability to extend a cathode's lifetime beyond three years of continuous operation. A modified water-cooling design prevents electro-etching of the miniature RF circuit, while the collector has a depression capability of up to 77 %

15:15 **A High-gain MMIC Power Amplifier Covering 55-115 GHz Based On 50-nm GaN HEMTs** **Th-PM1-2-8**

Bingfei Dou[1]; Qin Ge[2]; Jing Liu[3]; Xiaojiang Yao[4]
[1]5089, Wangjiang West Road, Hefei, China, Hefei; [2]Fuzhong 3rd Road, Futian, Shenzhen, Shenzhen; [3]Hefei, 230000, China, Hefei; [4]Nanjing, 210000, China

A 4-stage E-W ultra-wide-band MMIC power amplifier (PA) was designed and implemented, based on 50-nm gallium nitride (GaN) technology. A balanced-amplifier topology was utilized in this MMIC PA design, and high-low impedance microstrip lines were employed for broadband matching between power stages. By selecting a suitable output impedance, the amplifier can obtain a higher gain and output power. The measured gain and saturated output power (Psat) of fabricated MMIC PA is above 18 dB and 25 dBm, respectively, across over 55-115 GHz range. To the authors' best knowledge, this is the widest band that GaN MMIC PA operates with such high gain. And a peak Psat of 27.6 dBm with power-added-efficiency (PAE) of 13.4% was obtained at 83 GHz.

13:30 - 15:30 **Spintronics, Plasmonics & Valleytronics** **Cartier II**
Chairperson(s): Jean-Marie George,

13:30 **High-power Operation Of Spintronic Terahertz Emitters For THz-field-driven Scanning Probe Microscopy At MHz Repetition Rates** **Th-PM1-3-1**

Alkisti Vaitsi[1]; Vivien Sleziona[1]; Luis E. Parra Lopéz[1]; Tom S. Seifert[2]; Fabian Schulz[3]; Natalia Martín Sabanés[4]; Martin Wolf[1]; Tobias Kampfrath[2]; Melanie Müller[1]
[1]Faradayweg 4-6, Berlin; [2]Arnimallee 14, Berlin; [3]Tolosa Hiribidea 76, San Sebastian; [4]Faraday 9, Madrid

We discuss the successful and reliable operation of spintronic Terahertz (THz) emitters at high pump powers up to ~18 Watt and MHz repetition rates for THz-field-driven scanning tunneling microscopy (THz-STM). A rotating design of the spintronic emitter (STE) allows us to operate the STE at fluences close to ~1 mJ/cm^2 using 10's μJ pulse energies at MHz repetition rates. This

enables STE operation at average power densities of ~1 kW/cm$_2$, well above the laser damage threshold of thin metal films, with minimized thermal heating and no material degradation. With this new STE design, we reach incident THz field strength of several kV/cm at the tip-sample junction of the STM, resulting in THz bias voltages of more than 10 Volts using standard tungsten tips with THz field enhancement of ~10^5-10^6. We discuss the importance of well-optimized THz beam propagation, which due to limited mirror size and long beam paths is a crucial aspect for STE-driven THz-STM operation. The scalability of the rotating STE design opens up new possibilities for the integration of broadband STE sources in applications that require high THz fields or THz power at high repetition rates.

14:00 **Terahertz Time Domain Spectroscopy Of A Single Split Ring Resonator Coupled To An Amino Acid Crystal** **Th-PM1-3-2**

Théo Hannotte; Adrien Pillet; Jean-François Lampin; Romain Peretti
Cité Scientifique Avenue Henri Poincaré CS 60069, Villeneuve d'Ascq

Split Ring Resonators (SRRs) have been used in large arrays to interact with objects much smaller than the wavelength in the terahertz range. Using arrays of SRRs facilitates the measurement, but prevents one from extracting accurate information regarding the object properties in this frequency range. Here, we demonstrate that the experiment is possible with a single SRR. We measured the transmission spectrum of a single SRR coupled with less than 1Âμm of glutamic acid (GA) crystals, and extracted information on the 1.2THz vibration mode of GA crystals.

14:15 **Terahertz Plasmons In Periodic Structures Of Epitaxial Graphene** **Th-PM1-3-3**

Arvind Singh[1]; Hynek Nemec[1]; Jan Kunc[2]; Petr Kuzel[1]
[1]Na Slovance 2, 18200 Prague 8, Czech Republic, Prague; [2]Ke Karlovu 3, Prague 2 12116, Czech Republic

THz surface plasmon excitation and the ultrafast-light induced plasmon dynamics have been studied in lithographically prepared nanoribbons of epitaxial graphene via combined near-and far-field THz spectroscopic probes. The measured nonlinear dynamics of plasmons are entirely controlled by the chemical potential of laser-excited hot carriers through their temperature. Indeed, the transient spectra on sub-picosecond(ps) to hundred ps timescale are described by a two-temperature Drude-Lorentz model revealing the ultrafast evolution of the chemical potential.

14:30 **Different Terahertz Phases Of AlGaN/GaN Grating-Gate Plasmonic Crystals** **Th-PM1-3-4**

Pavlo Sai[1]; M. Dub[1]; V. Korotyeyev[2]; M. Filipiak[1]; M. Słowikowski[1]; Yu. Ivonyak[1]; D. But[1]; G. Cywinski[1]; W. Knap[1]
[1]ul. Sokolowska 29/37, Warsaw; [2]41 pr. Nauki, Kyiv

We present a comprehensive study of resonant 2D plasmon excitations in the grating-gate plasmonic crystals based on AlGaN/GaN heterostructures. We show that plasmonic crystals are formed and their different phases are electrically controlled by tuning the charge carrier density profile. We conducted both experimental and theoretical investigations of THz 2D plasmon

resonances and identified two distinct phases of such plasmonic crystals - the delocalized phase and the localized phase. A continuous transition between these phases of the plasmonic crystal is demonstrated by controlling the gate voltage. Additionally, it was found that the resonant frequency of plasmonic crystal in the localized phase is mainly determined by parameters of the ungated region and unexpectedly depends on the gate voltage. This effect is explained by the specific shrinking of the conductive profile of the 2DEG in the ungated region -- edge gate effect. This work represents the first demonstration of an electrically tunable transition between different phases of THz plasmonic crystals, which is a crucial step towards a deeper understanding of THz plasma physics and the development of all-electrically tunable devices for THz optoelectronics.

14:45 **Spintronic THz Emitters Based On Transition Metals And Semi-metals/Pt Multilayers** **Th-PM1-3-5**

Sylvain Massabeau[1]; Jacques Hawecker[2]; Enzo Rongione[1]; Anastasios Markou[3]; Sachin Krishnia[1]; Florian Godel[1]; Sophie Collin[1]; Romain Lebrun[1]; Jérôme Tignon[2]; Juliette Mangeney[2]; Thomas Boulier[2]; Jean-Marie George[1]; Claudia Felser[3]; Henri Jaffrès[1]; Sukhdeep Dhillon[2]
[1]1 Avenue Augustin Fresnel, Palaiseau; [2]24 Rue Lhomond, Paris; [3]Nöthnitzer Straße 40, Dresden

Heterostructures made of nanometer thick ferromagnetic/heavy metal junctions have become reliable materials in order to achieve broadband and gap-less THz sources, key elements for the development of THz technologies. Whereas the performances of these ultrathin spintronic THz emitters already surpass some usual THz sources, a better understanding of the fundamental emission/absorption mechanisms at play is crucial for reaching higher THz field. Starting from standard bilayer ferromagnetic/transition metal junctions, we present here how THz emission can be significantly enhanced by tailoring the stacking of such structures, adding a spin-sink layer and with the use of semi-metals as spin-injectors. Furthermore, our results allows to extract THz and spin properties of the materials, paving the way towards further enhancement.

15:00 **Layer-controlled Nonlinear Terahertz Valleytronics In Two-dimensional Semi-metal And Semiconductor PtSe2** **Th-PM1-3-6**

Minoosh Hemmat[1]; Sabrine Ayari[1]; Martin Micica[1]; Hadrien Vergnet[1]; Guo Shasha[2]; Mehdi Arfaoui[3]; Xuechao Yu[2]; Daniel Vala[4]; Adrien Wright[1]; Kamil Postava[4]; Juliette Mangeney[1]; Francesca Carosella[1]; Sihem Jaziri[3]; Qi Jie Wang[2]; Liu Zheng[2]; Jerome Tignon[1]; Robson Ferreira[1]; Emmanuel Baudin[1]; Sukhdeep Dhillon[1]
[1]24 rue Lhomond; [2]50 Nanyang Avenue; [3]Campus Universitaire 10; [4]Technical University of Ostrava, 17. listopadu 217

As a two-dimensional material for terahertz (THz) applications, platinum diselenide (PtSe2) can be uniquely tuned from a semiconductor in the near-

infrared to a semimetal with the number of atomic layers, unlike other transition metal dichalcogenides (TMDs). Therefore, atomic layer engineering can enhance the material's photonic properties at THz frequencies. By producing ultrafast photocurrents and engineering the bandstructure valleys, we demonstrate that a controlled THz nonlinearity - tuned from monolayer to bulk PtSe2 - can be achieved in wafer-size PtSe2. The sign of the ultrafast currents and hence the phase of the THz pulse can also be controlled through the excitation of different bandstructure valleys in layer-dependent circular dichroism. A semimetal has a strong dichroism that is absent in monolayers and few layers semiconducting. Through detailed DFT simulations, we demonstrate that circular dichroism can be controlled when PtSe2 becomes a semimetal and K-valleys are excited, highlighting the microscopic origins of this TMD bandstructure engineering. As well as showing that PtSe2 is a promising material for THz generation through layer-controlled optical nonlinearities, this work opens up a new class of circular dichroism materials beyond the monolayer limit of traditional TMDs, and impacts a range of domains from THz valleytronics to harmonic generation.

15:15 **Spintronic Terahertz Emission From Metal/PtSe2 Heterostructures** **Th-PM1-3-7**

Martin Micica[1]; Khasan Abdukayumov[2]; Fatima Ibrahim[3]; Celine Vergnaud[3]; Alain Marty[3]; Jean-Yves Veuillen[2]; Pierre Mallet[2]; Isabelle Gomes de Moraes[3]; Djordje Dosenovic[2]; Abdelkarim Ouerghi[4]; Vincent Renard[2]; Florie Mesple[2]; Frederic Bonell[3]; Hanako Okuno[2]; Mair Chshiev[3]; Jean-Marie George[5]; Henri Jaffres[5]; Sukhdeep Dhillon[1]; Matthieu Jamet[2]
[1]24 rue Lhomond, Paris; [2]38000, Grenoble; [3]17 avenue des Martyrs, Grenoble; [4]91120, Palaiseau; [5]F-91767, Palaiseau

Spintronic emitters have become an important THz source with gapless broadband THz emission and the ability to magnetically control the emitted polarization through ultrafast spin-to-charge conversion (SCC). This work has recently driven investigations of two-dimensional (2D) materials for new types of spintronic THz sources. Indeed 2D materials are ideal platforms for spin-to-charge conversion (SCC) as a result of their strong spin-orbit coupling and low crystal symmetries. One of such 2D materials is the transition-metal dichalcogenide PtSe2. In this work we present THz spintronic sources based on high quality epitaxially grown CoFeB/PtSe2/graphene heterostructures, with PtSe2 thicknesses ranging from 1 to 15 monolayers. The unique thickness dependent electronic structure of PtSe2 permits to demonstrate the different origins of the THz emission - from the inverse Rashba-Edelstein effect in monolayer PtSe2 to the inverse spin Hall effect for multilayers through the strength of the THz emission. This unique bandstructure flexibility makes PtSe2 an ideal candidate as a THz spintronic 2D material and to further study and explore the underlying mechanisms and engineering of the SCC for THz emission.

13:30 - 15:30 Active Sensing 1 **International I**

Chairperson(s): Luca Zanotto,

13:30 **Nonlinear Ghost Imaging For Scattering-Assisted Terahertz Waveform Synthesis.** **Th-PM1-4-1**

Vittorio Cecconi[1]; Vivek Kumar[2]; Juan Sebastian Totero gongora[1]; Luke Peters[1]; Luana Olivieri[1]; Jacopo Bertolotti[3]; Alessia Pasquazi[1]; Marco Peccianti[1]
[1]Sir David Davies Building, Loughborough; [2]Falmer, Brighton; [3]Dept. of Physics and Astronomy, Exeter

Terahertz Nonlinear Ghost Imaging is a novel approach that allows for the spatial-temporal sampling of objects with a resolution beyond the diffraction limit. We present our experimental campaign that aims to exploit Nonlinear Ghost Imaging to harness field-level waveform control via complex propagation in scattering media. Agile waveform control is possible at a fundamental level and it is enabled by near-field coupling between a distribution of terahertz source and a scattering medium.

14:00 **3D Tensor Compressive Sensing THz Single-Pixel Imaging For Refractive Index Estimation** **Th-PM1-4-2**

Szu-Hsi Chen[1]; Chia-Ming Mai[2]; Yi-Chun Hung[3]; Shang-Hua Yang[4]; Yuan-Hao Huang[5]
[1]No, 101, Section Ii, Kuang-Fu Road, Electrical Eng, Hsinchu City; [2]No, 101, Section Ii, Kuang-Fu Road, Electrical En, Hsinchu City; [3]No, 101, Section Ii, Kuang-Fu Road, Electrical Eng, Hsinchu; [4]No, 101, Section Ii, Kuang-Fu Road, Electrical En, Hsinchu; [5]No, 101, Section Ii, Kuang-Fu Road, Electrical Engineering Depart. National Tsing Hua University, Hsinchu

Time-resolved terahertz spectroscopic imaging has become a powerful tool for material identification and non-invasive imaging in recent years. However, this technique is generally suffered from the long data acquisition time. This study proposes a novel 3-D tensor-based compressive sensing model for terahertz single-pixel imaging systems. Unlike traditional systems that only use peak values for image pattern analysis, the proposed system can be used to derive the complete terahertz pulse information for refraction index analysis. Because this 3-D model can compress the terahertz response in both spatial and time domains in a tensor compressive sensing format, it can significantly reduce signal reconstruction time and facilitate rapid material identification.

14:15 **Learning-Based THz Multi-Layer Imaging With Model-Based Masks** **Th-PM1-4-3**

PU WANG[1]; Toshiak Koike-Akino[2]; Petros Boufounos[2]; Wataru Tsujita[2]; Genki Yamashita[3]; Tomonori Fukuta[3]; Makoto Nakajima[4]
[1]201 Broadway, Cambridge; [2]201 Broadway; [3]Amagasaki City, 661-8661; [4]Osaka 565–0871

This paper demonstrates a learning-based THz multi-layer pixel identification for non-destructive inspection. Specifically, we introduce a recurrent neural

network that sequentially learns features from THz spectrogram segments with masks from model-based sparse deconvolution. Initial performance evaluation on a three-layer sample with contents on all surfaces confirms the effectiveness of the proposed method.

14:30 **Far-field Terahertz Electric-field Imaging Using A Polarization Image Sensor** **Th-PM1-4-4**

Léo Guiramand; Xavier Ropagnol; François Blanchard
1100 R. Notre Dame O, Montréal

This work focuses on a far-field terahertz (THz) imaging technic. This one is based on two-dimensional electro-optical sampling (2D-EOS) where the temporal and spatial distribution of the THz electric can be reconstructed using a polarization image sensor. As we demonstrate in this work, compared to previous 2D-EOS demonstrations, the introduction of the polarization image sensor (PIS) greatly simplifies the imaging configuration. This is advantageous for the development of THz electric field imaging as well as for far-field hyperspectral THz imaging.

14:45 **An Optoelectronic M-Sequence Radar For The Terahertz Range** **Th-PM1-4-5**

Kevin Kolpatzeck; Sinan Akdas; Jan C. Balzer; Andreas Czylwik
Bismarckstr. 81, Duisburg

The M-sequence radar technique is a promising candidate for ranging applications at terahertz frequencies because of its comparatively simple implementation and relaxed hardware requirements. In this paper, we propose a novel concept for an M-sequence terahertz radar that is highly scalable in terms of carrier frequency, range resolution, and unambiguous range. The concept is based on modulating the intensity of the infrared signals in the transmit and receive branches of a terahertz frequency-domain spectroscopy (THz-FDS) system with delayed M-sequences. We exploit the time-averaging characteristic of the photoconductive terahertz detector to determine the cross-correlation between the transmit and the receive signal. First experimental results demonstrate ranging up to a distance of 4 m at a carrier frequency of 100 GHz.

15:00 **Frequency-multiplexing For Imaging At Submillimeter Waves** **Th-PM1-4-6**

Aleksi Tamminen[1]; Samu-Ville Pälli[2]; Juha Ala-Laurinaho[2]; Sazan Rexhepi[2]; Zachary Taylor[2]
[1]Maarintie 8, Espoo; [2]Aalto University, Maarintie 8, Espoo

We present simulation results on transmission-type element with optimized local transmission function at submillimeter waves. The element can be considered as a part of illuminating quasioptics for single-pixel imaging. The planar element is based on stacked layers of 497-μm silicon wafers. The wide-band transmission function is achieved with perforations in each layer, which realize the desired effective permittivity in the volume of the stacked layers. We have optimized the element for 220-330 GHz, with the transmission function producing frequency-multiplexed Hadamard-basis patterns.

15:15 **Imaging Of Large-Area Graphene Using Terahertz Cross-Correlation Spectroscopy** **Th-PM1-4-7**

Bjørn Mølvig[1]; Thorsten Bæk[2]; Jie Ji[3]; Peter Bøggild[3]; Simon Lange[2]; Peter Jepsen[2]
[1]Ørsteds Plads 343, Kongens Lyngby; [2]Ørsteds Plads 343; [3]Fysikvej 311

A novel THz Cross-Correlation system is presented and used for spectroscopy on few-layer graphene in the 0.1-1.4 THz range. The system utilizes photomixing of a telecom wavelength amplified spontaneous emission light source in a photoconductive antenna for THz generation and coherent cross-correlation sampling in a photoconductive antenna for detection. In addition to extracting the electrical properties of graphene using a spectroscopic model, we propose to extract the electrical properties by correlation to the time-domain peak-to-peak values of the obtained THz pulses, allowing for extraction at much higher rates.

13:30 - 15:30 **Metrology II** **International II**

Chairperson(s): Inkeun Baek,

13:30 **Characterization Of Photonic-Assisted Free-Space Sub-THz Data Transmission** **Th-PM1-5-1**

Mohanad Dawood AlDabbagh[1]; Jess Smith[2]; Thomas Kleine-Ostmann[1]; Mira Naftaly[2]; Irshaad Fatadin[2]
[1]Bundesallee 100, Braunschweig; [2]Hampton Rd, Teddington

In this work we discuss the characterization of a 220-330 GHz transmission setup based on a photonic-assisted free-space THz OTA link operating over 6 meters without THz amplifiers. We present the characterization results of different key components used in the transmission testbed and the DSP stages employed to demodulate the QPSK signals at 25.6 Gbit/s.

13:45 **High Precision Molecular Laser Frequency Measurements Using A THz Frequency Comb** **Th-PM1-5-2**

Alexandra Khabbaz[1]; Jean-François Lampin[1]; Luan Juppet[2]; Olivier Pirali[2]; Gael Mouret[3]; Francis Hindle[3]
[1]Avenue Poincaré, Villeneuve d´Ascq; [2]Rue André Rivière; [3]Avenue Schumann

Molecular lasers are a powerful source of continuous-wave THz waves that can be used as local oscillators in heterodyne receivers. In this work we show that it is possible to measure precisely their emission frequency using a simple setup based on a THz frequency comb referenced to a microwave synthesizer. We show two examples: the first one is the measurement of the frequency of a NH3 laser line around 2.029 THz and the second is the measurement of a D2O laser line around 2.450 THz

14:00 **Imaging The Stokes Vector Of Backscattered THz Speckle Fields Using The Two-Channel PHASR Scanner** **Th-PM1-5-3**

Kuangyi Xu; Zachery B. Harris; M. Hassan Arbab
100 Nicolls Road, Stony Brook
We present the polarimetric version of our Portable Handheld Spectral Reflection (PHASR) Scanner to directly capture terahertz speckles in the normal incidence back-scattering geometry. The images of the Stokes vector of terahertz fields are constructed with the signals collected in two orthogonal detector channels. We show that the distribution of the polarization states is strongly dependent upon the surface roughness and the illumination frequency. We investigate full polarimetric imaging by incorporating an achromatic THz quarter waveplate. This scanner can be used for rapid broadband polarimetric imaging of biomedical and industrial targets in the field.

14:15 **THz Dielectric Properties Of 3D Printable Silica Nanoparticle-based Photoresin** **Th-PM1-5-4**

Emil John Magaway[1]; Yeganeh Farahi[1]; Stephen Hanham[2]; Zhenyu Zhang[3]; Adriana Guaidía-Moreno[4]; Miguel Navarro-Cía[1]
[1]School of Physics and Astronomy, Birmingham; [2]School of Engineering, Birmingham; [3]School of Chemical Engineering, Birmingham; [4]Eggenstein-Leopoldshafen

GP-Silica, a newly developed photoresin embedded with silica nanoparticles useable with two-photon polymerization, aims to address the lack of low-loss material in the THz range. To determine its suitability for THz device fabrication, its dielectric properties were extracted over the range of 0.5 - 1.5 THz. Its refractive index was found to outperform other 3D printable materials by 1.2 - 1.4 times while its absorption coefficient was almost 5 times lower at 1 THz. The data shared cements the potential of not only GP-Silica but also two-photon polymerization for THz device manufacturing.

14:30 **Fast Scanning Terahertz Computed Tomography With A Telecentric F-θ Lens** **Th-PM1-5-5**

Lu Rong[1]; Ran Ning[2]; Shufeng Lin[2]; Jie Zhao[2]; Yunxin Wang[2]; Dayong Wang[1]; Min Wan[3]
[1]100 Ping Le Yuan, Beijing; [2]100 Ping Le Yuan; [3]Belfield

Terahertz computed tomography can be used to obtain 3D spatial distribution of absorption coefficient of a sample. In this study, a telecentric f-θ lens is designed to match with a 2D galvanometer, which achieves a parallel illumination field at the object plane. The intensity is incoherently accumulated and recorded by a THz camera. The data acquisition efficiency is enhanced by 500 times than the tedious raster scanning mode. This work can promote terahertz 3D imaging in the applications of non-destructive testing and quality control.

14:45 **On-wafer RF High-power Measurement With An LSMO Load At 40 GHz** **Th-PM1-5-6**

Thomas Quinten[1]; Lampin Jean-François[2]; Etienne Okada[2]; Victor Pierron[1]; Chantal Gunther[1]; Laurence Méchin[1]; Benjamin Walter[3]; Bruno Guillet[1]

[1]6 Bd Maréchal Juin, Caen; [2]Cité scientifique, avenue Poincaré, VILLENEUVE D'ASCQ; [3]Avenue Poincaré, VILLENEUVE D'ASCQ

We present a novel technique to measure RF power directly in the plane of a DUT using a CPW (CoPlanar Waveguide) test-pattern as an on-wafer power meter. Preliminary results show that we have been able to measure 24 dBm at 40 GHz. In the future, they will be fabricated to operate at 94 GHz and an electronic circuit will be set to maintain automatically the thermal equilibrium of the sample.

15:00 **How Accurate Are Reflection Measurements With TDS Systems?** **Th-PM1-5-7**

Andreas STEIGER[1]; Benjamin Röben[2]
[1]ABBESTR., 2-12, Berlin; [2]ABBESTR. 2-12, Berlin

A method for determining the accuracy of reflectance measurements with time-domain spectroscopy (TDS) systems was realized - to our knowledge for the first time - after a goniometric measurement setup was constructively improved. Thus, the reference pulse necessary for the evaluation of reflection measurements can now be determined with known precision. This allows the evaluation of the quality of non-destructive testing (NDT) results obtained by THz-TDS reflection measurements.

15:15 **Optical Alignment For Non-contact In Vivo THz Sensing** **Th-PM1-5-8**

Jacob Young[1]; Emma pickwell-macpherson[2]; Rakyo Stantchev[3]
[1]University of Warwick, department of physics, Coventry; [2]University of Warwick, department of physics, coventry; [3]National Sun Yat-sen University, department of physics, Kaohsiung City

The misalignment of THz optics is a key obstacle to the reflection geometry, non-contact measurement of in vivo skin samples. We have devised a protocol for performing these measurements, and an algorithm to correct THz pulses recorded with misaligned optic. The algorithm does not require precise knowledge of the sample position, but rather the sample is allowed to move throughout the measurements. The most probable properties of the sample are then determined. We have verified the performance of this process by measuring samples of known properties.

16:00 - 18:00 **Laser Sources & Detectors VII** **Symposia Theatre**

Chairperson(s): Jozsef Fülop,

16:00 **Multi-pixel Addressable Photoconductive Arrays For THz Beam Shaping And Polarization Control** **Th-PM2-1-1**

James Lloyd-Hughes
Department of Physics, Gibbet Hill Road, Coventry

Photoconductive sources of pulses of THz radiation enable the reliable,

compact, broadband and high dynamic range THz spectrometers most often used in academia and industry. In this Keynote Talk I will describe our recent work on photoconductive arrays that allows exquisite control of the spatial profile or polarization state of a THz beam. High purity linear, circular, radial or azimuthal THz beams were created using photoconductive pixel arrays with orthogonally-oriented elements. Multi-pixel devices with parallel elements were used to dynamically steer the position of a THz beam, or to adjust its profile from Gaussian to flat top. Photoconductive arrays are thus attractive for high-speed beam modulation in THz spectroscopy and imaging applications.

16:30 **Active Multipixel Photoconductive Emitter Technology For THz Beam Shaping And Steering** **Th-PM2-1-2**

Nishtha Chopra[1]; Justas Deveikis[2]; James Lloyd-Hughes[3]
[1]University of Warwick, Gibbet Hill Road, 3.06 (MAS Building), Coventry;
[2]University of Warwick, University of Warwick, Gibbet Hill Road, Coventry;
[3]University of Warwick, Gibbet Hill Road, Coventry

A multipixel photoconductive emitter which consisted of an array of interdigitated electrodes was used to electrically control the spatial profile of a THz beam. We demonstrated that by varying the applied voltage levels, it is possible to spatially modulate the THz beam, with shapes tunable from gaussian to arbitrary non-gaussian shapes, such as a top hat. We characterized the THz beam profile at different off-axis transverse positions to validate the beam steering capability of our device. The spatial resolution of the approach was determined for different THz frequencies and the diffraction-limited performance of the system was established by comparison with the Abbé and Sparrow criteria.

16:45 **97% Throughput Hollow-Core Fibers For Pulse Compression Of High Power Yb Lasers** **Th-PM2-1-3**

Young-Gyun Jeong; Ivanov Maksym; Pedram Ghaderi; Etienne Doiron; Riccardo Piccoli; Luca Zanotto; Gabriel Tempea; Roberto Morandotti; Francois Legare; Luca Razzari; Bruno Schmidt
1650 Blvd. Lionel Boulet, Varennes

We demonstrate Yb laser (170fs) propagation in large a core hollow-core fiber (HCF) with 97.4% transmission and subsequent pulse compression down to 25fs. The tunable pulse duration between 25fs to 100fs can be used to enhance THz emission of BNA organic crystals for instance. We also demonstrate average power scaling of this approach to the 250W paired with pulse compression of 1.3ps Yb lasers down to 100fs. A particular setup feature is its ability to tune the input energy and repetition rate, respectively, over an order of magnitude. Pulse compression is possible for input pulses energies ranging from 1mJ to 10mJ with the same setup.

17:00 **Terahertz Generation From Water Under Long Wavelength Excitation** **Th-PM2-1-4**

Yiwen E; X.-C. Zhang
480 Intercampus Dr, Rochester

Here, we present our preliminary experimental findings on the generation of broadband terahertz waves from liquid water when subjected to long-

wavelength excitation in the range of 1.2 - 1.5 μm. Our results demonstrate that the THz emission characteristics differ significantly from those observed under 800 nm excitation, as we observe a higher central wavelength and a broader bandwidth of the THz wave emission. Furthermore, a positive correlation between the wavelength for excitation and the THz pulse is measured.

17:15 **Enhanced Terahertz Emission From Gallium Arsenide Nano-Hole Array Under Low Power Optical Pump** **Th-PM2-1-5**

Yangfan Gu[1]; Kemeng Wang[2]; Yongchang Lu[2]; Jianqiang Gu[2]
[1]Tianjin University, No.92, Weijin road, Nankai district, Tianjin, Tianjin;
[2]No.92, Weijin road, Nankai district, Tianjin

The surface built-in field in wide bandgap semiconductors can be used to accelerate photocarriers to generate broadband terahertz pulses. Such a method is simple yet relatively inefficient, struggling to integrate with compact systems with low power supply. Here, we report a nano-hole array on <100> semi-insulating gallium arsenide (GaAs) substrate, which boosts terahertz emission power up to 5.75 folds of bare GaAs with a 32 mW pump under 780nm excitation. The nanostructure reduces the reflection of the optical pump and localizes the photocarriers near the semiconductor surface, leading to stronger transient photocurrents and thus greater THz power. The enhancement is demonstrated experimentally to depend weakly on the radiation frequency, and the power difference of the emitted THz wave under the TE and TM pump is greatly smoothed. In addition, the THz emission enhancement is found to favor a low-power pump. The nano-hole array provides a viable route for advancing the poor efficiency of surface emission, which will promote the application of THz surface emission source in the practical THz systems employing compact femtosecond lasers.

17:30 **Tunable Pump Compression And Fast Modulation For Pulsed THz Generation** **Th-PM2-1-6**

Yazan Lampert; Alessandro Tomasino; Shima Rajabali; Ileana-Cristina Benea-Chelmus
BM 3136, Station 17

We demonstrate tunable dispersion compensation of femtosecond pulses at telecom wavelengths for broadband Terahertz generation in 7.5-meter fiber link using a Silicon prism pair. The prism pair enhances the amplitude of the THz E-field in InGaAs photoconductive antenna by up-to factor 5. As part of the fiber system, we employ a Mach-Zehnder modulator for pump intensity modulation at MHz frequencies and determine the dynamic range in electro-optic sampling. The performance is compared to direct modulation of the InGaAs antenna at the same frequencies. Our work establishes high compatibility between fiber and broadband THz systems.

17:45 **Optimization Of Multicycle THz Generation Using Versatile Optical Pulse Trains** **Th-PM2-1-7**

Christian Rentschler; Umit Demirbas; Zhelin Zhang; Mikhail Pergament; Nicholas H. Matlis; Franz X. Kaertner
Notkestrasse 85, Hamburg

Low efficiencies for narrowband optical-to-terahertz down-conversion remain a primary limiting factor for many applications of intense, laser-driven terahertz (THz) sources, highly sought after in material science and THz acceleration. Although simulations predict improvements in efficiency by using tailored trains of laser pulses as a driver, few studies have targeted this configuration. Here, we report on an experimental campaign using a flexible pulse-train driver to study THz generation in periodically-poled lithium niobate focusing on the effects of pulse train number, as well as crystal length and temperature. We also investigate the role of parasitic second harmonic generation.

16:00 - 18:00 **Nano & Quantum Devices** **Cartier I**

Chairperson(s): Hannah Joyce,

16:00 **Mid-infrared Quantum Well Photodetectors With 100GHz 3dB-bandwidth At Room Temperature** **Th-PM2-2-1**

Stefano Barbieri[1]; Quyang Lin[1]; Michael Hakl[1]; Jean-Francois Lampin[1]; Wenjian Wan[2]; J. C. Cao[2]; Hua Li[2]; Emilien Paytavit[3]
[1]Avenue Henri Poincaré, Villeneuve d'Ascq; [2]Shanghai, Shanghai; [3]Avenue Henri Poincaré, Villeneuve d'Ascq
Ultra-fast, GaAs-based multi-quantum well photodetectors operating in the 9.5-11.5um range are demonstrated, with a 3dB-cutoff bandwidth of 100GHz at room temperature. The multi quantum-well active region is sandwiched between a bottom metallic ground-plane and a top two-dimensional array of patch antennas connected in parallel. We study arrays of different dimensions and measure their frequency response in the range 0-220GHz. Beyond 100GHz we find a roll-off dominated by the 2.5ps-long, intrinsic capture time of the photo-excited electrons. To demonstrate the potential of these detectors for fast sensing applications, we show that they can be used to measure electronically and in real-time the time-dependent emission frequency of a quantum cascade laser operated in pulsed mode over a frequency range >60GHz. By exploiting broadband electronics, and thanks to its high signal-to-noise ratio, this technique allows the acquisition, in a single-shot, of frequency-calibrated, high resolution heterodyne mid-infrared spectra spanning up to 100GHz and beyond.

16:30 **Tunable Terahertz Cyclotron Emission From Two-dimensional Dirac Fermions** **Th-PM2-2-2**

Benjamin Benhamou--Bui[1]; Sebastian Gebert[2]; Maria Szola[3]; Christophe Consejo[3]; Sergey Krishtopenko[3]; Sandra Ruffenach[3]; Jérémie Torres[3]; Cédric Bray[3]; Benoit Jouault[3]; Kenneth Maussang[3]; Milan Orlita[4]; Xavier Baudry[5]; Philippe Ballet[5]; Sergey Morozov[6]; Vladimir Gavrilenko[6]; Nikolay Mikhailov[7]; Sergey Dvoretskii[7]; Frederic Teppe[3]
[1]163 rue Auguste Broussonnet, Campus Triolet Place Eugène Bataillon, Montpellier; [2]Am Hubland 97074 Würzburg; [3]163 rue Auguste Broussonnet;

[4]25 Martyrs Avenue, 38042 Grenoble Cedex 9; [5]17 avenue de Martyrs 38054 Grenoble; [6]Academicheskaya Str., 7, Afonino, Nizhny Novgorod; [7]ISP SB RAS, 13 Lavrentiev aven., Novosibirsk, 6300

In this work, we observed a sizable cyclotron emission from Landau quantized massive and massless Dirac electrons in HgTe QWs. This emission is tunable both by the magnetic field and the electron concentration in the range 0.5 to 2.5 THz. The results are in good agreement with a low energy model taking into account the relativistic nature of the electrons under magnetic field. Our results pave the way towards magnetic field and gate voltage tunable THz Landau lasers.

16:45 **Graphene-Coupled Highly Efficient THz Photomixer** **Th-PM2-2-3**

Alaa Jabbar Jumaah[1]; Masoumeh Goudarzi[2]; Maira Beatriz Perez Sosa[2]; Jaime Gómez Rivas[2]; Hartmut G. Roskos[3]; Shihab Al-Daffaie[2]
[1]Groene Loper19, Eindhoven; [2]Groene Loper 19, Eindhoven; [3]Max-von-Laue-Straße 1, Frankfurt am Main

A novel THz photomixer detector based on interdigitated multilayer graphene (MLG) on low-temperature-grown (LTG) GaAs is demonstrated. It exhibits an enhanced performance as compared with conventional LTG GaAs photomixers with metallic finger contacts. The obtained responsivity and the dynamic range are about 30$\times$ higher and the bandwidth is twice as large. The reason for this enormous improvement lies in the transparency of the graphene electrodes to VIS/NIR radiation which permits to optically excite mobile charge carriers in the LTG GaAs not only between the electrode fingers, but also below them. The measured enhancement of the detected photocurrent is explained by model calculations and simulations.

17:00 **Tunable Antenna-Coupled Intersubband Terahertz (TACIT) Mixer: Frequency-agile THz Heterodyne Detector Based On Intersubband Transitions In Single GaAs/AlGaAs Quantum Well** **Th-PM2-2-4**

Changyun Yoo[1]; Kenneth West[2]; Loren Pfeiffer[2]; Jonathan Kawamura[1]; Mark Sherwin[3]; Boris Karasik[1]
[1]4800 Oak Grove Drive, Pasadena; [2]Princeton University, Princeton; [3]UCSB, Santa Barbara

The Tunable Antenna-Coupled Intersubband Terahertz (TACIT) mixer is a novel THz heterodyne detector based on intersubband transitions in single GaAs/AlGaAs quantum-well heterostructures. With the ability to operate at higher temperatures (up to 60 K) and wide in-situ frequency tunability (2 - 5 THz), TACIT mixers have potential for a low-noise (with TSSB ~ 2,000 K) operation with a low (~ 1 ÂμW) required local-oscillator power. These properties offer both flexibility in detection frequency and multi-pixel array capability, making TACIT mixers an attractive THz heterodyne mixer technology for high-resolution spectroscopy in space applications. Here, we report on the recent development of 2.52 THz TACIT mixers fabricated from single, modulation-doped, 40-nm wide, rectangular GaAs/AlGaAs quantum

wells for 2.52 THz operation. Direct detection results at 20 K show that the detection frequency of a single TACIT device is widely tunable from 2.52 THz to 4.25 THz. We also present the heterodyne detection results at 2.52 THz at 10 K.

17:15 **THz Detection By Photomixing In Graphene** **Th-PM2-2-5**

Mark D. Thomson[1]; Florian Ludwig[1]; Jakob Holstein[1]; Reiam Al-Mudhafar[2]; Shihab Al-Daffaie[3]; Hartmut G. Roskos[1]
[1]Max-von-Laue-Str. 1, Frankfurt am Main; [2]Baghdad, Baghdad; [3]Groene Loper 5,, Eindhoven

Graphene has recently been shown to exhibit a strong nonlinear response in frequency multiplication experiments with sub-1-THz radiation. This nonlinearity arises from the ultrafast heating and cooling of its charge carriers during each oscillation cycle of the radiation. Here, we experimentally and by simulations investigate the applicability of this "relaxational" nonlinearity for the detection of continuous-wave (cw) THz radiation by photomixing. The charge carriers of antenna-coupled graphene stripes are heated by the beat note of two cw near-infrared (NIR) laser beams. This leads to a periodic modulation of the conductance of the graphene stripes, which is employed for the coherent detection of the THz radiation generated in an optoelectronic THz emitter excited by a portion of the NIR beat-note.

17:30 **Superconducting Nanowire Single-Photon Detector Arrays For The Near- To Mid-Infrared** **Th-PM2-2-6**

Benedikt Hampel; Richard P. Mirin; Sae Woo Nam; Varun B. Verma
325 Broadway, Boulder

Superconducting Nanowire Single-Photon Detectors (SNSPDs) are excellent devices for the analysis of faint light from the ultraviolet to the mid-infrared. Recent developments push their broad wavelength bandwidth further into the mid-infrared towards 20 μm and enable new areas of application such as astronomy and chemistry. SNSPDs could play a major role in the field of exoplanet spectroscopy where absorption lines of atmospheric components in the mid-infrared contain a wealth of information. In this work, we present current progress towards optimized detectors for mid-infrared wavelengths and their integration in arrays with the ultimate goal of demonstrating a large scale, single-photon-sensitive mid-infrared camera.

17:45 **Topological Quantum Materials For Ultra-Sensitive Terahertz Detection** **Th-PM2-2-7**

Lin Wang
500 Yu-tian Road

Terahertz is an attractive electromagnetic spectrum, which has excellent application potential in many fields including broadband communication, medical imaging, deep space exploration, non-destructive testing, and many more. However, the bottleneck of terahertz detection lies in the intractable contradiction between cryogenic cooling and device performance, which greatly limits its development. The emergence of natural 2D material systems provide new opportunities for terahertz detectors. In particular, the unique advantages of topological quantum materials, such as strong terahertz

absorption, high mobility, and nonlinear rectification, have brought the dawn of new terahertz detection. Therefore, we have carried out extensive research on terahertz detection based on topological quantum systems.

16:00 - 18:00 **Nanoscopy & Near-Field Effects** **Cartier II**
Chairperson(s): Daniel Mittleman,

16:00 **Mid-Infrared Nanospectroscopy To Probe Protein Conformation at The Nanoscale** **Th-PM2-3-1**

Antonia Intze[1]; Maria Eleonora Temperini[1]; Raffaella Polito[2]; Michele Ortolani[2]; Valeria Giliberti[1]
[1]viale Regina Elena 291, Rome; [2]Piazzale A. Moro 2

Photothermal atomic force microscopy-assisted infrared nanospectroscopy is applied to investigate protein conformation at the nanoscale. In the framework of protein aggregation, the possibility to probe protein conformation on nanometr-sized structures, enabled us to identify structural differences among fibrils formed under different conditions. By adopting a difference IR nanospectroscopy approach (visible light ON-visible light OFF), we then probed, for the first time, subtle transient conformational changes of light-sensitive protein receptors embedded in individual native cell membrane patches.

16:30 **Detector Development For Far-Infrared Near-Field Nanospectroscopy*** **Th-PM2-3-2**
G. Lawrence Carr
bldg. 741, Brookhaven Nat' Lab, Upton
A facility for performing infrared nanospectroscopy over the spectral range from ~2 microns to 55 microns (5000 1/cm down to about 180 1/cm) has been developed at the 22IR2/MET infrared beamline at NSLS-II. The facility is based on Neaspec/Attocube SNOM that uses the apertureless scattering from an atomic force microscope (AFM) tip. The broad spectral range, including the unprecedented reach into the far-IR beyond 30 microns, is due to the high spectral radiance synchrotron infrared source combined with custom detectors operating at 4.2K.

16:45 **Time-resolved THz-TDS Nanoscopy For Probing Carrier Dynamics With Femtosecond Temporal And Nanometer Spatial Resolution** **Th-PM2-3-3**
Tobias Gokus; Jonas Albert; Artem Danilov; Suman Paul; Andreas Huber
Eglfinger Weg 2, Haar

By combining THz-TDS based scattering near-field optical microscopy (s-SNOM) with ultrafast pump-probe spectroscopy we enable probing of dynamic material properties with femtosecond temporal and 20nm spatial resolution. We demonstrate s-SNOM based ultra-fast pump-probe THz-TDS imaging and spectroscopy as well as time-resolved THz near-field transient measurements of extreme sub-wavelength scale sample structures. As a representative material system, we study the spatial heterogeneity of photoexcited carriers in a silicon based semiconductor device and a micron-sized MoS2 crystal. For the latter, near-field THz transients reveal layer dependent carrier decay dynamics and

lifetimes in the picosecond range.

17:00 **THz-pump / MIR-probe Nanospectroscopy On Si-doped GaAs-InGaAs Core-shell Nanowires** **Th-PM2-3-4**

Andrei Luferau[1]; Stephan Winnerl[1]; Susanne Kehr[2]; Maximilian Obst[2]; Felix Kaps[2]; Emmanouil Dimakis[1]; Alexej Pashkin[1]; Lukas Eng[2]; Manfred Helm[1]
[1]Bautzner Landstraße 400, Dresden; [2]Nöthnitzer Str. 61, Dresden

We report on first THz-pump / MIR-probe SNOM studies on Si-doped GaAs-InGaAs core-shell NWs utilizing THz radiation from the free-electron laser FELBE. Upon intraband THz-pump we observe a red shift of the NW plasma resonance in both amplitude and phase spectra, while a controlled interband optical pumping induces a blue shift of the resonance. In both cases, the signal exponentially decays with a time constant of 4-5 ps. We attribute the blue shift to the contribution of photogenerated charge carriers, while the red shift is assigned to the heating of electrons in the conduction band accelerated by the THz electric field of the pump pulses and the subsequent increase of their effective mass due to the nonparabolic Γ-valley dispersion.

17:15 **Revealing Near-field Mode Distribution In Terahertz Asymmetric Split-ring-resonators** **Th-PM2-3-5**

Xingxing Xu; Min Hu; Xiaoqiuyan Zhang; Fu Tang; Shigao Zhao; Shenggang Liu
pidu distribute, No. 2006 xiyuan avenue, Chengdu

Terahertz metamaterials have emerged as a powerful tool for modulating terahertz waves in recent years. However, due to the subwavelength unit cell of metamaterials, prior studies have mainly focused on the far field. In this work, we present a novel approach that utilizes scattering-type scanning near-field optical microscopy based on terahertz time domain spectrometer (TDS s-SNOM) to investigate the surface field distribution of asymmetric metal split rings. Our aim is to provide a microscopic understanding of the mechanism underlying terahertz wave modulation. By revealing the underlying physics of Terahertz metamaterials at a microscopic level, our study will contribute to the development of more sophisticated and effective Terahertz metamaterials.

17:30 **Thermal Near-field Spectroscopic Analysis On Dielectrics** **Th-PM2-3-6**

Yusuke Kajihara[1]; Kuan-Ting Lin[2]; Ryoko Sakuma[2]
[1]Komaba 4-6-1, Meguro-ku, Tokyo; [2]Komaba 4-6-1, Meguro-ku

Material surface is covered with thermally evanescent waves (wavelength: 8 - 20 Î¼m at room temperature) because any material contains positive/negative charges due mainly to their electron movement and lattice vibration. Probing such thermal evanescent waves with nanoscale spatial resolution can visualize local dynamics of thermal equilibrium and non-equilibrium phenomena. Recently we have developed a thermal near-field optical microscope (SNOM), which probes thermal evanescent waves without any external illumination. In this study, we focus on the spectroscopic analysis of thermally excited evanescent waves on dielectrics. First, we developed a passive spectroscopic SNOM based on gratings and then probed spontaneous evanescent waves on

GaN and AlN at the wavelength of around 11 and 14 micrometers. Finally, we found that the thermally excited evanescent waves inside Reststrahlen band should be generated mainly by phonon polaritons.

17:45 **Near Field Analysis Of Individual High Quality Factor THz Resonators** **Th-PM2-3-7**

Lucy Hale[1]; Yuezhen Lu[2]; Abdullah Zaman[2]; Sadhvikas Addamane[3]; Igal Brener[3]; Oleg Mitrofanov[1]; Riccardo Degl'Innocenti[2]
[1]Electrical and Electronic Engineering, London; [2]New Engineering Building, Gillow Ave, Bailrigg, Lancaster; [3]Sandia National Laboratories, Albuquerque

Asymmetric split ring resonators supporting high quality factor modes are investigated using aperture near-field microscopy. Modes of varying q-factor are measured, and a novel cross-polarization measurement technique is used to resolve high spatial resolution near-field images of individual resonators.

16:00 - 18:00 **Active Sensing 2** **International I**

Chairperson(s): Kevin Kolpatzeck,

16:00 **THz 3D Imaging Based On An Inverse Spherical Synthetic Aperture** **Th-PM2-4-1**

Tobias Kubiczek; Efe Satiroglu; Thorsten Schultze; Jan C. Balzer
Bismarckstr. 81, Duisburg

This paper presents to our knowledge the first highresolution 3D reconstruction in the terahertz frequency range using an inverse spherical synthetic aperture. A wide-bandwidth terahertz time-domain spectroscopy system with antennas operating in divergent reflection geometry is used together with a low-cost 3D-printed device to rotate an object in azimuth and elevation. The method is evaluated by performing a 3D reconstruction of a 20-sided metal dice. The obtained resolution is 50 ?m in all directions.

16:15 **Low-Loss And High-Speed Generalized Terahertz Time-Domain Spectroscopic Ellipsometry** **Th-PM2-4-2**

Hao Chen; Kaijie Wang; Guangyou Fang; Xuequan Chen
Room 501, Building B7, Kai Yuan Da Dao No. 11, Huangpu District, Guangzhou, Guangzhou

Terahertz generalized spectroscopic ellipsometry has been accomplished using frequency-domain instrumentation, which is limited in bandwidth and complicated in polarization manipulation. In this study, we propose a low-loss and high-speed terahertz time-domain generalized ellipsometry system that can obtain four independent complex spectrums without any mechanical movement. We present its accurate characterization of an in-plane birefringent sapphire crystal wafer over a broad bandwidth of 0.2-3.5 THz.

16:30 **Characterization Of Active Liquid Crystal: Comparison Using Continuous And Time Domain Terahertz Techniques** **Th-PM2-4-3**

Audrey Le Bourlout[1]; Anastasiia Pusenkova[2]; Mariia Zhuldybina[1]; Xavier

Ropagnol[3]; Thomas Gisder[4]; Marc-Michael Meinecke[4]; Heiko Schroeder[4]; Heiko Gustav Kurz[4]; Tigran Galstian[2]; François Blanchard[1]
[1]1100 Notre Dame Ouest, Montréal; [2]2325 Rue de l'Université, Québec; [3]1650, boul. Lionel-Boulet, Varennes; [4]Berliner Ring 2, Wolfsburg

We have fabricated and characterized an active liquid crystal (LC) device operating in the terahertz (THz) frequency range. The device consists of LCs placed between glass plates with electrodes. Liquid crystals (LCs) are good materials for active phase and bias devices. Using both compact continuous wave (CW) and THz time-domain spectroscopy (TDS) system, our experimental results confirmed the phase variation due to mechanical rotation of the LC or to the bias voltage varying from 0 to 30 V applied between the electrodes at different frequencies. This work opens a simple path towards the development of active THz liquid crystal devices to serve as low-cost phase plates.

16:45 **Optical Properties Of Wood Biomass Material obtained By Terahertz Ellipsometry** **Th-PM2-4-4**

Atsushi Nakanishi[1]; Verdad Agulto[2]; Kosaku Kato[2]; Toshiyuki Iwamoto[3]; Hiroshi Satozono[1]; Makoto Nakajima[2]
[1]5000, Hirakuchi, Hamakita-ku, Hamamatsu; [2]2-6 Yamadaoka, Suita; [3]734 Miyakubo, Hosakamachi, Nirasaki

Recently, terahertz optical properties of biomass materials have been reported. However, for matrices or fillers with high terahertz wave absorption coefficients, obtaining the terahertz optical properties with conventional transmission measurements is challenging. Therefore, herein, terahertz time-domain ellipsometry in reflection configuration is used to measure high terahertz absorption biomass material. The terahertz optical properties of high absorption biomass material are investigated using terahertz ellipsometry.

17:00 **Terahertz Radar Sensing For Real-time Monitoring Of Powder Streams** **Th-PM2-4-5**

Anis Moradikouchi[1]; Marlene Bonmann[2]; Tomas Bryllert[2]; Anders Sparén[3]; Jonas Johansson[3]; Staffan Folestad[2]; Jan Stake[2]; Helena Rodilla[2]
[1]Chalmersplatsen 4, Gothenburg; [2]Chalmersplatsen 4; [3]Pepparedsleden 1, Mölndal

In pharmaceutical manufacturing processes, the flow properties of powder streams moving in the manufacturing pipes directly impact the properties of the final drug product, and there is a need for real-time non-invasive monitoring of the powder flow properties with process analytical tools. In this study, we propose a frequency-modulated continuous wave (FMCW) Doppler radar system with a center frequency of 340 GHz to measure the flow properties of falling powder streams in a vertical transparent tube. We successfully measured the velocity profile and powder flow density variation along the height of the tube with a spatial resolution of about 5 mm. In conclusion, the terahertz FMCW Doppler radar system was shown to be highly promising for real-time sensing of flow properties of powder streams in the pharmaceutical

manufacturing processes.

17:15 **Flexible Terahertz Gas Sensing Platform: Combining Hollow Waveguide Gas Cells With An Opto-Electronic Light Source** **Th-PM2-4-6**

Dominik Theiner[1]; Benedikt Limbacher[1]; Michael Jaidl[1]; Marie Ertl[1]; Karl Unterrainer[1]; Juraj Darmo[1]; Michael Hlavatsch[2]; Boris Mizaikoff[2]
[1]Gusshausstrasse 27-29, Vienna; [2]Albert-Einstein-Allee 11, Ulm

We present a robust platform for molecular gas sensing in the terahertz (THz) range. It combines near-infrared electro-optic modulation and photomixing to create a spectrally adaptable terahertz source, with a new generation of substrate-integrated hollow waveguides (iHWGs) providing freedom in the optical absorption path design. Results show low propagation losses qualifying iHWGs for proper THz waveguiding and flexible sensing. The latter is demonstrated by the measurement of various rotational transitions of nitrous oxide (N2O). A fast frequency sideband modulation technique leads to reduced measurement times and increased photometric accuracy compared to a standard wavelength tuning method.

17:30 **Photoconductive THz Near-field Detectors Operated With A 1550 Nm Cw-laser System For High Spatial- And Spectral-resolution Measurements** **Th-PM2-4-7**

Simon Sawallich[1]; Anselm Deninger[2]; Alexander Michalski[1]; Max C. Lemme[1]; Michael Nagel[1]
[1]Otto-Blumenthal-Str. 25, Aachen; [2]Lochhamer Schlag 19, Graefelfing

We combine terahertz (THz) near-field detectors with a continuous-wave frequency-domain THz-system operating at 1550 nm. This configuration enables high spatial-resolution near-field imaging in conjugation with a high spectral-resolution and more than 1.3 THz bandwidth.

17:45 **A Scanless Method For Terahertz Time-domain Imaging** **Th-PM2-4-8**

Luca Zanotto[1]; Giacomo Balistreri[1]; Andrea Rovere[1]; O-Pil Kwon[2]; Roberto Morandotti[1]; Riccardo Piccoli[3]; Luca Razzari[1]
[1]1650 boulevard Lionel-Boulet, Varennes; [2]Suwon, 443-749; [3]Piazza Leonardo Da Vinci, 32, Milano

Terahertz (THz) time-domain imaging can uncover the spectral fingerprints of materials, detect changes in both refractive index and absorption, and reveal the inner structure of complex objects through time-of-flight measurements. Despite its potential, the lengthy acquisition typically required to spatially raster-scan the object and record the terahertz temporal waveforms for each spatial point limits practical applications. Our scanless imaging method sets the path for an unprecedented reduction of both system complexity and acquisition time, by addressing this crucial bottleneck. By judiciously exploiting natural wave diffraction, time-to-space encoding is applied to THz point detection and enables a nearly instantaneous capture of the terahertz waveforms. Multidimensional images are then reconstructed through a computational method. This approach opens the route for next-generation fast and compact

THz imagers that are well-suited for high-repetition-rate laser sources.

16:00 - 18:00 **THz Quantum Optics & Near-Field Microscopy** **International II**

Chairperson(s): Marco Rahm,

16:00 **Landau Polaritons In The Ultrastrong And Superstrong Coupling Regime In A Multimode Terahertz Photonic-Crystal Cavity** **Th-PM2-5-1**

Fuyang Tay[1]; Ali Mojibpour[1]; Stephen Sanders[1]; Shuang Liang[2]; Hongjing Xu[1]; Geoff Gardner[2]; Andrey Baydin[1]; Michael Manfra[2]; Alessandro Alabastri[1]; David Hagenmüller[3]; Junichiro Kono[1]
[1]6100 Main St, Houston; [2]525 Northwestern Ave, West Lafayette; [3]8 All. Gaspard Monge, Strasbourg

We have demonstrated ultrastrong and superstrong coupling of a Landau-quantized two-dimensional electron gas in GaAs with a multiple-mode three-dimensional terahertz photonic-crystal cavity. The cavity had an asymmetric design such that the real-space profiles of photonic modes depended on the electric field polarization. Terahertz magnetospectroscopy experiments with polarized radiation clearly showed that the degree of hybridization of multiple cavity modes is a function of the spatial overlap of the photonic modes. These findings can be utilized for the dynamical tuning of multimode light--matter interactions, which can lead to the development of novel terahertz devices.

16:30 **Direct Measurement Of The THz Local Density Of Optical States** **Th-PM2-5-2**

Jaime Gomez Rivas[1]; Stan ter Huurne[2]; Djero Peeters[2]
[1]PO BOX 513, Eindhoven; [2]P.O. Box 513, Eindhoven

We introduce a double near-field THz probe microscope using micro-structured photoconductive antennas that allows the local excitation and detection of THz transients. When the THz probes for emission and detection are at distances much shorter than THz wavelengths, this setup effectively detects the complex THz field at the position of the source. The imaginary component of this field corresponds to the partial local density of optical states (partial LDOS), which defines the strength of interaction of the local source with its surrounding photonic medium. We use this novel technique to perform the first direct measurement of the partial LDOS of a dipole source close to a planar interface, the so-called Drexhage configuration, achieving an excellent agreement with theory. Our direct determination of the partial LDOS by measuring the complex field at the position of the source illustrates the potential of THz near-field microscopy for the precise investigation of photonic media and can be easily applied to more complex resonant media.

16:45 **Superconducting Josephson Probe Microscope** **Th-PM2-5-3**

Ping Zhang[1]; Shoucheng Hou[1]; Zixi Wang[1]; Zihan Wei[1]; Hongmei Du[1]; Dingding Li[1]; Yangyang Lv[1]; Hancong Sun[2]; Yonglei Wang[1]; Huabing Wang[1]; Peiheng Wu[1]

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Superconducting Josephson junctions are well suited for detecting electromagnetic waves in microwave (MW) and terahertz (THz) bands. To achieve ultra-high resolution, we prepare a pair of junctions directly on a quartz nanotip with a diameter from 100 nm to 200 nm. The size of the junctions can be less than 50 nmï¼Othus a nanoscale spatial resolution can be achieved. Then we use this superconducting Josephson probe to construct a scanning microscope to observe the near-field electromagnetic distribution of high-frequency integrated circuits, superconducting quantum chips, THz solid devices, etc. The best spatial resolution can be better than 50 nm.

17:00 **Strong Light-matter Coupling In SiGe Quantum Wells Embedded In Terahertz Patch Antenna Cavities** **Th-PM2-5-4**

Michele Ortolani[1]; Leonetta Baldassarre[1]; Tommaso Venanzi[1]; Fritz Berkmann[1]; Enrico Talamas Simola[2]; Michele Montanari[2]; Elena Campagna[2]; Luciana Di Gaspare[2]; Sara Cibella[3]; Andrea Notargiacomo[3]; Ennio Giovine[3]; Cedric Corley-Wiciak[4]; Giovanni Capellini[4]; Michele Virgilio[5]; Giacomo Scalari[6]; Monica De Seta[7]
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We aim at the demonstration of the strong-coupling limit of radiation-matter interaction in terahertz cavities containing SiGe heterostructures that realize parabolic quantum wells. We show by FTIR spectroscopy that SiGe parabolic quantum wells display high-quality intersubband transition lineshapes at 2.7 THz. We have fabricated terahertz cavity arrays with a plasmonic heavily-doped Ge ground plane and we have measured patch antenna resonances in the 3 to 5 THz range. Patch-antenna cavity arrays have been fabricated by an e-beam lithography lift-off process using Ti/Au evaporation, followed by deep reactive ion etching to form the cavities, also using e-beam lithography. The patch antenna cavity is formed through the addition of a 2-μm-thick N++ Si0.10Ge0.90 plasmonic-conductor ground plane below the quantum well stack. The square patch length L is chosen between 9 and 12 μm for different cavity arrays. Resonaces with quality factor around 8 have been observed between 3 and 5 THz in an undoped heterostructure, both at room temperatuire and at cryogenic temperatures. Strong-coupling experiments are ongoing.

17:15 **Quantum Algorithm Emulator For Implementation Of Deutsch-Jozsa Algorithm In The THz Region** **Th-PM2-5-5**

Zizwe Chase[1]; Ashley Blackwell[2]; Riad Yahiaoui[2]; Yi-Huan Chen[2]; Zhixiang Huang[3]; Xi Wang[3]; Thomas Searles[2]; Pai-Yen Chen[2]
[1]851 S. Morgan St., MC 154, Chicago; [2]851 S. Morgan St., MC 154; [3]210 South College Ave.

A quantum algorithm emulator (QAE) consisting of a photonic metastructure is investigated in the terahertz regime to show the implementation of the Deutsch-Josza algorithm. The QAE design consists of silicon as the oracle subblock and a polyimide gradient-index (GRIN) lens as the Fourier Transform subblock. Through a machine learning approach using inverse design the geometry of the GRIN lens was optimized to enhance the interaction of incident light with the metamaterial.

17:30 **Terahertz Landau Polaritons In Nano-slots: Ultrastrong Coupling Under Extreme Spatial Confinement** **Th-PM2-5-6**

Dasom Kim[1]; Sunghwan Kim[2]; Dukhyung Lee[2]; Shuang Liang[3]; Fuyang Tay[1]; Michael Manfra[3]; Dai-Sik Kim[2]; Junichiro Kono[1]
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We report ultrastrong coupling of the cyclotron resonance of a two-dimensional electron gas in a GaAs quantum well to terahertz cavity photons under extreme confinement to the nanometer scale. This was realized by an array of nano-slots fabricated close to the quantum well layer on the GaAs substrate. Our terahertz magnetospectroscopic measurements revealed two polariton branches as a function of applied magnetic field. While the photon-like part of the two polariton branches was clearly observed, the matter-like part was generally elusive. Our electromagnetic simulations quantitatively reproduce our observation for the upper-polariton branch. However, for the lower-polariton branch, our simulations predict a pronounced resonance, which was absent in experimental spectra. This discrepancy may be a consequence of the breakdown of the dipole approximation in this extreme confinement situation.

17:45 **Twin Beams Probe Pulses For Subcycle Sampling Of THz-MIR Fields** **Th-PM2-5-7**

Patrick Cusson; Stéphane Virally; Denis Seletskiy
2500, chemin de Polytechnique, Montréal

In a parametric down-conversion process pumped by chirped femtosecond pulses, we produce high-intensity near-infrared twin beams with a sub-4-cycle pulse duration, high occupancy of the fundamental temporal mode and strong photon-number correlations. These pulses are well-positioned for the implementation of bright squeezed states as the probe in electro-optic sampling, toward the accurate detection of non-Gaussian quantum fields in the terahertz-to-mid-infrared spectral range.

18:00 - 19:30 **Poster Session 5** **Foyer (3rd floor)**

Nanostructured THz Gunn Diode Using A Patch Antenna Combined With Side-contact And Field-plate Technologies **Th-P1-01**

Ahid S. Hajo; Deniz Cicek; Yunus Celik; Armin Dadgar; Oktay Yilmazoglu; Sascha Preu
Merckstr. 25, Darmstadt

We present a nanostructured THz Gunn diode with a patch antenna. The patch antenna uses the concepts of the side-contact and field-plate technologies to simplify the construction for a small effective diode height of few 100 nm with uniform field distribution for high voltage oscillation instead of an external RLC resonator. A stable negative differential resistance was measured.

Design And Simulation Of Electron Optics System For 340 GHz Extended Interaction Klystron **Th-P1-02**

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In this paper, the electron optics system of 340 GHz extended interaction klystron (EIK) is designed, and the design process of electron gun and permanent magnetic focusing system are described. Firstly, the design and debugging of the electron gun is carried out according to the initial design value, and the electron gun with the beam range and beam radius meets the requirements. Secondly, through theoretical calculation, it is known that the uniform region magnetic field is 0.7 Tesla, and the uniform magnetic field that meets the focus is designed. The simulation results show that the EOS has good laminarity, the passing rate of electron beam is 100%, and the filling ratio is about 60% under the voltage of 24kV and the beam current of 210mA.

Introduction Of Inverted-HEMT Structure In A Grating-Gate Plasmonic THz Detector For Drastic Improvement Of The Pulse Response **Th-P1-03**

Kenichi Narita[1]; Takumi Negoro[1]; Yuma Takida[2]; Hiroaki Minamide[2]; Taiichi Otuji[1]; Tetsuya Suemitsu[3]; Akira Satou[1]
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The gate readout of photovoltage from a grating-gate (GG) plasmonic terahertz (THz) detector based on an InGaAs-channel high-electron-mobility transistor (HEMT), instead of the conventional drain readout, enables both the scaling of photovoltage with the active area size and the impedance matching with 50-ÃZÂ© high-speed interconnection systems. Moreover, the so-called 3D rectification effect occurring in the gate-readout configuration at a positive gate bias voltage results in a significant enhancement of photoresponsivity. The temporal photovoltaic output waveform in the THz pulse detection measurement, however, exhibited an undesired very long tail following the main pulse whose width of ~180 ps. This tail must be avoided for use in high-speed THz wireless communication systems that require fast detector response. In this work, we fabricated GG plasmonic THz detectors based on normal-HEMT and inverted-HEMT epitaxial wafers and conducted THz pulse detection measurements on those detectors to compare their pulse photoresponses. we succeed in complete elimination of the long-tail response by the introduction of the inverted-HEMT structure, identifying its cause as the long electron trapping at donor levels in the InAlAs carrier-supply layer in the

normal-HEMT structure. It paves the way for the application of the plasmonic THz detectors to beyond-5G THz wireless communication systems.

Ion-Implanted GeSn Terahertz Photoconductive Antenna On Silicon **Th-P1-04**

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In this work, we demonstrated a phosphorus implanted GeSn photoconductive antenna (PCA) on Silicon for terahertz (THz) generation. The GeSn layer processed by mature ion implantation was grown on an 8-inch Si wafer through commercially available reduced-pressure chemical vapor deposition (RPCVD), demonstrating a low-cost, mass-producible, and complementary metal oxide semiconductor (CMOS) compatible THz PCA prototype. As a result, the GeSn PCA achieved a bandwidth over 1.5 THz with 60 dB of signal-to-noise ratio (SNR) under a bias voltage of 25 V and optical pump of 155 mW. This work demonstrates that mature ion implantation can be a feasible approach to efficiently modulate the carrier lifetime of group IV photoconductive material to ps level, which indicates that phosphorus implanted GeSn THz PCA can potentially operate as a detector, paving the way toward the THz system integration on Si platform.

Terahertz Absorbance Of Sputtered Nanocrystalline TiO2 Thin Film **Th-P1-05**

GURUVANDRA SINGH[1]; Subhash Nimanpure[2]; Amit Haldar[3]; Debankit Priyadarshi[3]; Amit Kumar Gangwar[4]; Preetam Singh[5]; SHOVON PAL[6]; Mukesh Jewariya[5]

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A high-quality nanocrystalline TiO2 thin film is fabricated on p-type silicon by an in-house developed DC magnetron sputtering system. The fabricated sample are characterized using Terahertz-time domain spectroscopy in transmission mode at room temperature. Our results demonstrated that nanocrystalline TiO2 thin films are extremely sensitive with respect to frequency. At the lower frequency (<1 THz) side, the absorption coefficient is higher, while at the higher frequency (>1 THz) side, the absorption coefficient value is certainly down with increase in the frequency. It may be possible due to the optical density of TiO2 is higher at the lower frequency side.

Optimization Of Substrate-lens-coupled CMOS Field-effect Transistor Detectors For 250 GHz By Pixel Binning Technique **Th-P1-06**

Kestutis Ikamas[1]; Dmytro B. But[2]; Domantas Vizbaras[1]; Cezary Kolacinski[2]; Alvydas Lisauskas[1]

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This paper reports on the optimization of the response characteristics of a

substrate lens-coupled detector for 250 GHz. The 3x3 array of detectors has been implemented using 180-nm CMOS technology. Each pixel comprises a circular-slot-antenna-coupled MOSFET detector that can be individually controlled and monitored. Such implementation allows monitoring the power distribution among detectors as well as applying a pixel-binning technique. Our experiments demonstrate that the binned detector exhibits a minimum optical noise equivalent power as low as 25 pW/√Hz at the central frequency. This performance is comparable with that of a individual detector; however, the binned detector has wider angular characteristics and improved modulation bandwidth. Furthermore, the detector array provides information on the focus spot size and can be used for beam monitoring.

Reduction Of Spectral Linewidth Of Resonant-Tunneling-Diode THz Oscillators Due To External Feedback **Th-P1-07**

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We theoretically show reduction of the spectral linewidth of resonant-tunneling-diode THz oscillators by the external feedback of output power. A simple relation between the frequency change due to the feedback and the spectral linewidth is found. The linewidth has minimum values at the feedback distance equal to integral multiple of half wavelength. The linewidth at the minimum points is narrower for larger amount of the feedback. Reduction of the linewidth becomes ~1/10 even with relatively small amount of the feedback. However, as the feedback amount increases, multimode oscillation due to the external cavity occurs in the middle between the minimum points of the linewidth and spread out.

0.34THz Longitudinal Double-Beams Staggered Double-Blade Backward Wave Oscillator **Th-P1-08**

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This paper proposes a staggered double-blade slow-wave structure (SDB-SWS) with two longitudinal circular electron beams. At the same time, a slow-wave structure with the working frequency of 340GHz is designed. The particle in cell (PIC) simulation of the proposed slow-wave structure was carried out, and the output power of 22.5W was obtained at the operating voltage of 23.8kV and the single electron beam current of 35mA.

A Tunable Narrow-band THz Radiation Using Subwavelength Hole Array Layer **Th-P1-09**

Ping Zhang[1]; Yin Dong[2]; Youfeng Yang[2]; Bingyang Liang[2]; Shengpeng Yang[2]; Yuan Zheng[3]; Shaomeng Wang[2]; Zhanliang Wang[2]; Yubin Gong[2]
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Subwavelength hole array (SHA) structures have attracted significant attentions because of their extraordinary optical transmission characteristic. In this study, we investigate a SHA layer that can control the Smith-Purcell radiation. The results show that the transmission characteristic can narrow the radiation spectrum and make the radiation tunable. Therefore, it can be concluded that the radiation from this kind of composited structure can be simplified by the radiation controlled by a SHA layer, and it provides a fast way to reshape the radiation spectrum by designing the SHA. With the development of micro-nano processing technologies, this structure is expected to develop into an efficient way to produce terahertz radiation.

Terahertz Resonant-Tunneling-Diode Oscillator With Coupled OffsetFed Slot-Ring Antenna Pairs **Th-P1-10**

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We proposed and fabricated a high-power high-directivity terahertz (THz) oscillator, which consists of two coupled offset-fed slot-ring antennas based on resonant tunneling diodes (RTDs). From an electromagnetic simulation, the two-slot-ring antenna geometry enables a high directivity over 11dBi downwards. The simulation results also suggested a high output power of over 1 mW at around 500 GHz with the offset-fed structure by increment in radiation conductance. We obtained ~500 GHz radiation with the fabricated device, but the output power (~100 μW) was lower than expected, because of the unexpected series resistance around the RTD mesa. This undesired series resistance can be avoided by fabrication optimization, thus higher output power can be anticipated in future works.

Research On Ripple Suppression Of High-voltage Power Supply For Gyrotron cathode Based On Series Linear Filtering **Th-P1-11**

Yang ChunHui
华中科技大学, 中国湖北省武汉市华中科技□, 武汉

The gyrotron is a compact high-power terahertz source. The high stability of the gyrotron output frequency enables a variety of applications, such as Dynamic Nuclear Polarization□Nuclear Magnetic Resonance, which requires maintaining a frequency stability of at least 10 ppm. One of the main factors affecting the gyrotron output frequency is the cathode voltage, which has an inverse relationship with the frequency. Therefore, a high-precision and fast-response cathode high-voltage power supply is essential to achieve closed-loop regulation of the gyrotron output frequency. Wuhan National High Magnetic Field Center has built an 800GHz gyrotron system, in which a cathode high voltage power supply of 20kV/1A is utilized. However, the power supply exhibits a 2% ripple and a response time of 40us, which results in a frequency shift and consequently impacts the experimental outcomes. In this paper, a

linear filter circuit topology is proposed, in which semiconductor devices in the amplification region are connected in series with the existing switched high-voltage power supply to improve ripple level without affecting response speed.

Design And Analysis Of Electron Optics System For 0.67 THz Traveling Wave Tube **Th-P1-12**

Jianliang Wang[1]; wenxin Liu[2]; Zhiqiang Zhang[1]; Fan Deng[3]
[1]BeiJing; [2]BeiJing, BeiJing, ??; [3]BeiJing, BeiJing

The electron optics system (EOS), including the electron gun and focusing system, is the core of traveling wave tube (TWT). The EOS of 0.67THz TWT is simulated and analyzed in this paper. The design process of the electron gun and the uniform permanent magnetic (UPM) focusing system is introduced. First, the initial parameters of the electron gun were obtained by the Tiwary method and MATLAB. After further simulation and optimization, the circular electron beam electron gun with operating voltage of 23.8kV and current emitted of 23.5mA was designed. Secondly, in order to ensure the stable transmission of the electron beam, the UPM focusing magnetic field structure matching the electron gun is used to obtain a good laminar flow electron beam, and the stable transmission distance is greater than 30mm.

Theoretical Investigation On Detecting Terahertz Waves By Rydberg Atoms **Th-P1-13**

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A five level Rydberg atomic system was proposed to detect the THz waves with the frequency of 0.17 THz. The calculation results show that the Aulter-Townes splitting distance is in direct proportion to the applied THz electric field intensity in the electromagnetically induced transparency (EIT) spectrum.

Limit Of Oscillation Frequency In Two-element Slot-ring Type RTD Oscillator Array **Th-P1-14**

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Resonance-tunneling-diode (RTD) oscillators are promising candidate for terahertz (THz) sources due to their compact size and ability to operate at room temperature. The conventional RTD oscillators use MIM capacitor to separate the DC bias and THz circuit, which complicates fabrication process. Therefore, to simplify the process, we proposed a structure-simplified oscillator without MIM capacitors. However, this approach resulted in degraded device characteristics in oscillation frequency and output power due to additional conduction loss for the two stabilization resistors at the edge of the slot antenna. Therefore, we proposed a two-element RTD oscillator array with a simplified structure. The device comprises two RTD mesas integrated with a slot-ring antenna and coupled by a resistor. Our analysis shows that the limit of oscillation frequency is equivalent to that of conventional oscillators because of reduction of conduction loss at the coupling resistor with the unique operation mode of the array. Furthermore, we successfully fabricated the RTD oscillator array and achieved an oscillation frequency of up to 1.36 THz.

Power Detection Of Solid-state Terahertz Transmitters: Terahertz Induced **Th-P1-15**

Thermoacoustic Signal And Its Characteristics

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Using a self-made terahertz (THz) transmitter (center frequency = 0.17THz, maximum output power = 92.8 mW), We propose a real-time THz power detection method based on terahertz-thermoacoustic (THz-TA) effect. The test results show that a linear relationship between the amplitude of THz-TA signals and the output power of THz transmitter is founded in the range of 2.8 - 92.8 mW (Pearson correlation coefficient R = 0.99571). We also noticed for the first time that the time interval of TA signal evoked by THz was consistent with the pulse width of THz signal (0.5,1,2 and 5 microseconds). Therefore, the THz-TA technology can not only realize the real-time detection of THz power, but also measure the pulse width of amplitude modulated terahertz signal to some extent.

Two-dimensional Effects In Multicycle THz Generation With Tunable Pump Pulse Trains In Lithium Niobate **Th-P1-16**

Umit Demirbas; Christian Rentschler; Zhelin Zhang; Mikhail Pergament; Nicholas H. Matlis; Franz X. Kaertner
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A main limitation for many applications of laser-driven sources of narrowband terahertz (THz) radiation in spectroscopy and particle acceleration is the low optical-to-THz conversion efficiency. Due to power limitations, it is often necessary to use small sizes of the optical pump beam in the range of the THz wavelength to achieve sufficient intensity to effectively drive the nonlinear process. However, diffraction of the THz radiation can then adversely affect the conversion efficiency. Here, we report on an experimental study of the role of self-focusing and the beam size of the pump beam on the down-conversion of lasers in periodically poled lithium niobate using tunable pulse trains. We identify self-focusing as a limiting factor of the conversion efficiency, demonstrate the potential of the pulse-train approach to mitigate this effect and investigate the dependence of the efficiency on the pump beam size.

Time-domain Measurements Of A ~300 GHz Split-ring Resonator Coupled To THz Goubau Line Waveguide By Evanescent Electric Field **Th-P1-17**

Robyn Tucker[1]; SaeJune Park[2]; Said Ergoktas[3]; Lianhe Li[3]; Edmund Linfield[3]; Giles Davies[3]; John Cunningham[3]

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We report on the development and measurement of an on-chip ~300 GHz split-ring resonator coupled by evanescent field to Goubau-line waveguide with integrated photoconductive switches for signal excitation and detection. Time-domain measurements of the device show that the resonant response well-matches simulations performed using HFSS. The device has potential to be useful in a range of low-THz sensing applications.

Manipulating The Refractive Index Of THz Generation Crystals **Th-P1-18**

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BNA and MNA are yellow organic crystals that can efficiently generate terahertz (THz) frequency light when pumped with infrared or 800 nm wavelengths. However, THz generation across a broad range of frequencies could be increased if the phase matching could be improved. In an effort to alter the material refractive index at pump and THz frequencies, we modify the structures of BNA and MNA aiming to improve phase matching ability.

Adapting Terahertz Spintronic Emitters Towards Maximum Performance **Th-P1-19**

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The boom in terahertz technologies of the last few decades is now not limited to the use of electric charge, but also fully exploits spin. Revolutionary spintronic terahertz emitters (STEs) offer versatile usage under a wide range of visible and infrared excitation wavelengths, arbitrary reflection/transmission excitation geometries, and utilization with most femtosecond oscillators and amplifiers. STE emission results in a 30THz-broad and gapless spectrum with easily controllable polarization. However, the optical-to-terahertz conversion efficiency is lower than traditional THz sources. Here, we demonstrate experimentally the enhancement of factor 6 in STEs power, which is the highest improvement nowadays. We integrate STEs with our optimized photonic cavities and provide procedures on how to dramatically increase efficiency.

Self-referencing Reflection Sensor For Industrial Applications **Th-P1-20**

Faezeh Zarrin Khat; Bryan Cole; Alasdair Pentland; Philip F. Taday
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Terahertz sensors have found their way into many industrial applications, though undertaking regular reference measurements could be inconvenient on some occasions. A sensor with a self-referencing (SR) mechanism (in a linear configuration) is designed and manufactured to tackle the challenge. The sensor head is used on Lithium Iron Phosphate (LFP) cathodes to report the thickness and refractive index of the material.

Monolithic Compact Terahertz Emitter And Detector **Th-P1-21**

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In this work, we present our recent development of a new ultra-compact

terahertz (THz) transceiver aimed at performing reflective near-field THz time-domain spectroscopy. This emitter/receiver is composed of a trilayer spintronic material deposited directly on a thin LiNbO3 (LN) electro-optic (EO) crystal. Our results demonstrate the generation and detection of a THz pulse by the LN crystal with, respectively, a pump beam at 1,040 Âμm and a probe beam at 800 nm detected in the near field. We also compare the performance of the LN detector for the emission from a spintronic emitter and that of a 1 mm thick cadmium telluride (CdTe) crystal.

Shot-noise Limited Detection Of Terahertz Transients From Spintronic Emitters **Th-P1-22**

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We show polarization switching of THz radiation from spintronic emitters by modulation of an external magnetic field at 787 kHz. Thereby, shot-noise limited sensitivity is achieved in an electro-optic sampling detection.

Highly Efficient THz Waves Using Laser Chaos **Th-P1-23**

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Efficiency of optical beats in a chaotically oscillating laser is confirmed comparing that of free running CW laser diode using a highly efficient plasmonic photomixer. The great potential of chaotically oscillating lasers is verified for THz systems.

Temperature-dependent THz Transients Emitted By Optically Excited FeNi/Pt Spintronic Emitters **Th-P1-24**

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We conducted a study on the temperature dependence of THz transients emitted from FeNi/Pt spintronic emitters excited by femtosecond optical pulses. The results indicate that the emitted THz radiation strength is governed by the temperature-dependent magnetization changes within the FeNi layer system. We observed a very good agreement between the magnetization and THz amplitude temperature dependences below the 0.8 T/Tc ratio. Our findings highlight the importance of considering temperature effects in THz spintronic emitters for improving their signal strength and efficiency.

Efficient Terahertz Generation Via Optical Rectification In Halide Perovskites **Th-P1-25**

Nathaniel Gallop[1]; Dumitru Sirbu[2]; David Walker[1]; James Lloyd-Hughes[1]; Pablo Docampo[3]; Rebecca Milot[4]
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THz emission from the all-organic, halide perovskite N-methyl-1,4-diazabicyclo[2.2.2]octan-1-ium (methyl-DABCO) ammonium iodide (MDNI) has been demonstrated for the first time. The generation mechanism was shown to be optical rectification, and a peak field strength of up to 12 kV/cm was achieved, demonstrating the promise of this class of materials as efficient THz emitters.

Conceptual Study And Design Of A Compact, Ultra-short Pulse Infrared/Terahertz Free Electron Laser **Th-P1-26**

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Free electron laser (FEL) is a powerful radiation source working at a wide range of wavelength. A compact free electron laser is proposed to simultaneously laser in the infrared (IR) and terahertz (THz) regimes with picosecond pulse and high peak power. The radiation source utilizes one photo-injector fully based on C-band RF acceleration technology to generate a train of short electron bunches at several tens of MeV energy. The electron bunches are then separated into two FEL lines by an S-band transverse deflecting cavity. It is possible to produce high power IR and THz radiation with the same electron injector. Two-regime operation provides multipole solutions for pump-and--probe experiment. In this report, we focus on the design of the injector.

High-Power, Ultra-Broadband THz Generation In Organic Crystal MNA **Th-P1-27**

Samira Mansourzadeh[1]; Megan F. Nielson[2]; Alan Omar[1]; Tim Vogel[1]; David J. Michaelis[2]; Jeremy A. Johnson[2]; Clara J. Saraceno[1]
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We present a THz-TDS operating with a high source average power of 4.4 mW at 400 kHz repetition rate, with a broad bandwidth of more than 10 THz, detected using the organic crystal 2-amino-5-nitrotoluene MNA as generation and detection crystals. The pump laser is an industrial Yb-based laser system, temporally compressed to a pulse duration of 35 fs. An optical-to-THz conversion efficiency of 0.08% is achieved.

Spectral Range Broadening Of Multimode-Laser-Driven Terahertz Spectroscopy System Using Two Laser Diodes **Th-P1-28**

Yuanhao Zeng[1]; Valynn Katrine Mag-usara[2]; Verdad C. Agulto[2]; Kosaku Kato[2]; Masato Ota[2]; Fumiyoshi Kuwashima[3]; Masashi Yoshimura[2]; Makoto Nakajima[2]
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We built a terahertz time-domain spectroscopy system that utilizes two continuous-wave multimode laser diodes with slightly different central wavelengths. We obtained intensified continuous terahertz waves using two multimode laser diodes compared with the case of only one laser diode. The spectral bandwidth of the generated THz wave extended up to 0.5Ã‚Â THz, which was broader than the 0.2Ã‚Â THz bandwidth obtained by 1 laser diode.

Vibration Analysis Of A 0.34THz Traveling Wave Tube **Th-P1-29**

Jianwei Zhong[1]; Wenxin Liu[2]; Fengyuan Zhang[1]; Peng He[1]; Zhaochuan Zhang[1]
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In order to improve the reliability of the traveling wave tube (TWT), this paper analyzes the vibration of the entire 340GHz TWT. The acceleration power spectral density is applied in the X, Y, and Z directions to calculate the stress distribution and deformation of the TWT under vibration conditions. The results show that the fundamental frequency of the traveling wave tube meets the requirements, the structural strength meets the safety margin requirements, and the design meets the overall requirements.

High-power And Pulse Test Of The 105/140 GHz Dual-Frequency MW-level Gyrotron **Th-P1-30**

Linlin Hu; Dimin Sun; Qili Huang; Tingting Zhuo; Peng Hu; Yi Jiang; Guowu Ma; Hongbin Chen; Hongge Ma
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The 105/140 GHz dual-frequency MW-level gyrotron for fusion application has been developing and updating at IAE since 2018. The gyrotron has used a triode MIG, a TE18, 7 mode for 105 GHz and a TE24, 9 mode for 140 GHz, a built-in quasi-optical mode converter, a single-stage depressed collector and a boron nitride single-disk window. In recent test, a great progress has been made, achieving a power of 1.0 MW at 105 GHz under ms short-pulse operations. The pulse-width extension results of 300 kW/2 s, 400 kW/1 s at 105 GHz and 400 kW/1 s at 140 GHz have been obtained.

A Dual-Frequency Mode Converter For A 70/105 GHz Gyrotron **Th-P1-31**

Stephen Cauffman; Monica Blank; Philipp Borchard; Kevin Felch
811 Hansen Way, Palo Alto

The VGE-8071A gyrotron, currently in fabrication, is designed to produce 600 kW of continuous RF output power in a Gaussian output beam at either 70 GHz or 105 GHz. The gyrotron circuit employs the TE11,3 interaction mode at 70 GHz, or the TE14,5 interaction mode at 105 GHz. To facilitate conversion of either operating mode into a Gaussian output beam, a dual-frequency internal converter is employed, consisting of a numerically optimized dimpled-wall launcher, two phase correcting mirrors, and a final toroidal mirror to direct the RF beam through the gyrotron output window. An external 2 mirror matching optics unit couples either output beam to an external transmission line system,

using frequency-specific swappable mirrors for precise alignment and optimal coupling of the beam to the transmission line.

Graphene Quantum Dot Bolometer Camera: Practical Approaches And Preliminary Results **Th-P1-32**

abdelouahad el fatimy
Mohammed VI Polytechnic University Lot 660, Hay Moulay Rachid Ben Guerir, 43150, Mohammed VI Polytechnic University Lot 660, Hay Moulay Rachid Ben Guerir, 43150, Benguerir

Graphene is an exciting candidate for the detection of high-frequency electromagnetic radiation. Here, we have studied the bolometric performance of epitaxial graphene quantum dots (Q.D.s) on the silicon carbide (SiC) substrate in the terahertz (THz) range. The graphene Q.D. having a diameter in the 200 nm range, exhibited an extremely high resistance variation with temperature up to 4.7 MÎ© K-1, a crucial parameter for the hot electron bolometers. The graphene Q.D.s bolometers have been fabricated in different geometrical configurations, such as variations in electrode spacing (2.5 and 5.0 Î¼m) and parallelly connected arrays of 4 and 8 Q.D.s. It is demonstrated that the absorbed power can be improved by tuning the bolometer geometrical configuration and the active graphene area, and the electrical responsivity is still very high for an extensive range of absorbed power. Additionally, we report that the photo response of graphene Q.D. bolometer devices is meagerly affected by the presence of a magnetic field as high as 15 T. The results presented here open ways to continue to optimize and realize the chip-scale matrix of the graphene Q.D.s bolometers for THz imaging and magneto-optical spectroscopy applications.

Printed Terahertz Metasurfaces For Multispectral Imaging By Thermo-conversion **Th-P1-33**

Cyprien Brulon; baptiste fix; Clément Verlhac; Patrick Bouchon
6 chemin de la vauve aux granges, Palaiseau

In this work, we investigate the fabrication and the application of ultra-thin terahertz metasurfaces as thermal converters for indirect terahertz imaging. The microstructures fabricated by an ultrasonically driven printing process (Microplotter) are used to improve the THz to IR conversion efficiency and tune the spectral or polarisation selectivity. The resulting conversion membranes show optical and thermal responses which are consistent with numerical simulations down to the first time of heating, establishing both reliable rules to design such membrane and an innovative method for easy and instantaneous near field imagine of the electromagnetic losses. This work paves the way for a low-cost solution of multispectral terahertz imaging with a standard infrared camera.

CW Laser Emission Up To 5 THz Using Optically Pumped Water Molecules **Th-P1-34**

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André Rivière

In this work we discuss the use of a new molecule (deuterated water, D2O) to produce THz radiation using a mid-infrared quantum cascade laser (MIR-QCL) pumped molecular laser. The molecular gain factor was used to determine the most favorable laser lines and several laser lines were measured up to 5 THz with an output power ranging from tens to hundreds of microwatts.

Development Of Multiple-Tunnel Slow-Wave Structures For Miniature W-band Traveling-Wave Tubes With Multiple Sheet Electron Beams **Th-P1-35**

Alena Rostuntsova[1]; Roman Torgashov[1]; Dmitriy Nozhkin[2]; Andrey Rozhnev[1]; Andrey Starodubov[1]; Nikita Ryskin[1]
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In this paper, we present the results of development of slow-wave structures (SWSs) for miniature W-band traveling-wave tube (TWT) amplifiers with multiple sheet electron beams. Two types of SWS are proposed: a ladder-type SWS with dumbbell-shaped slots and a meander-line SWS with metal supports. High-frequency parameters of the proposed structures are simulated. The analytical model is presented to predict dispersion of the SWS with dumbbell-shaped slots. This SWS exhibits the properties of a double-negative metamaterial. The results of particle-in-cell (PIC) simulation of beam-wave interaction in the TWT with meander-line SWS and double sheet electron beam are presented. Sample of this SWS is fabricated from a copper foil by high-precision laser micromachining with nanosecond pulse duration.

Monte Carlo Simulations Of Signal Contrast Mechanisms In Broadband Terahertz Polarimetric Imaging Of Biological Tissues **Th-P1-36**

Kuangyi Xu; M. Hassan Arbab
100 Nicolls Road, Stony Brook

Terahertz techniques have promising applications in biological and medical diagnosis. Polarimetric imaging systems are useful for enhancing imaging contrasts, yet the interplay between THz polarization changes and the random discrete structures in biological samples are not well understood. We perform Monte Carlo and Mie scattering simulations of the propagation of the THz waves in skin tissue with embedded structures, such as hair follicles and sweat glands. We show that the polarimetric contrasts are distinctly affected by the sizes and dielectric constants of the scatterers, as well as the frequency and polarization of incident waves. We describe the experimental requirements for extracting these polarimetric signal contrasts due to the low energy and small angular spread of the back-scattered THz radiations.

Investigation Of THz Absorption Spectra Of α-lactose Aqueous Solution **Th-P1-37**

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A method for direct detection of THz absorption spectra of the α-lactose

aqueous solution was proposed by using a strong field terahertz (THz) source combined with a horn shaped tapered parallel plate waveguide in a THz-TDS. And the THz absorption spectrum of α-lactose solution was simulated by the DFT and the simulation result is in good agreement with the experimental results. Finally, the types of chemical bond interaction that cause the absorption peak and the intramolecular interactions are investigated based on the experimental and simulation results.

Theoretical Study Of THz- Optoacoustic Signal Generation **Th-P1-38**

Lianghao Guo[1]; Bingyang Liang[2]; Kaicheng Wang[2]; Qin Zhang[2]; Yuankun Sun[2]; Hui Ning[2]; Shaomeng Wang[2]; Yubin Gong[2]
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Due to the unique sensitivity of the THz wave to water molecules, the excitation of the THz optoacoustic (THz-OA) wave is different from that of the photoacoustic wave. In this paper, we mainly studied the physical mechanism of ultrasonic wave generated by THz pulse irradiation on the surface of biological tissue. The study showed that the maximum acoustic pressure and maximum temperature rise caused by the difference of polarization loss in different biological tissues were significantly different at the THz frequency band, which provides theoretical support for THz optoacoustic imaging of biological tissues.

18:00 - 19:30 Poster Session 6 **Foyer (4th floor)**

The Reflectance Of Hydrated Melanin At 2.0 THz To 18.0 THz **Th-P2-01**

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Although the availability of data for the dielectric properties of biological materials in the 0.2 THz to 2.0 THz, region has improved over the past two decades, the 2.0 THz to 18.0 THz frequency rage date remains sparse in literature. We present a study of the reflectance of diluted sepia melanin (squid ink) and high melanin content porcine iris for the 2.0 THz to 18 THz range. Both sepia and porcine iris show a decrease in the reflectance at all frequencies when compared to water, 0.3M NaCl and non-melanin containing porcine cornea respectively in the 2.0 THz to 18.0 THz region. This suggests that both the absorption coefficient and refractive index are increased in the presence of melanin.

Far-Infrared Absorption Properties Of Bone-Related Calcium Phosphates **Th-P2-02**

Verdad Agulto; Wangxuan Zhao; Mihoko Maruyama; Yuga Ono; Kosaku Kato; Yutaro Tanaka; Hiroshi Yoshikawa; Yusuke Mori; Masashi Yoshimura; Makoto Nakajima
Suita, Osaka

Phase identification in bones is necessary in understanding the complex bone mineralization process. One technique that is employed in bone classification is infrared spectroscopy. However, most previous reports have focused on the mid-infrared region. It is then interesting to investigate bone components at far-infrared frequencies to find possible unique characteristics that could be useful in bone classification. In this study, we present the far-infrared/terahertz absorption properties of synthetic forms of the principal compounds involved in bone mineralization--hydroxyapatite (HAp) and octacalcium phosphate (OCP)--measured by Fourier transform infrared spectroscopy. We found unique absorption peaks of HAp and OCP at 2.9 and 3.3 THz, respectively. These findings could be useful in bone composition analysis using far-infrared/terahertz spectroscopy that can complement other methods.

Non-contact Millimeter Wave Dielectric Spectroscopy On Aqueous Solution **Th-P2-03**

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Inter-molecule and intra-molecule interaction in aqueous solution has important role on functionality of biomolecules such as proteins. These interactions can be probe with dielectric spectroscopic. Millimeter and THz range contains a rich amount of information of dielectric interactions in aqueous solution. In this work, we setup a millimeter wave quasi-optic dielectric spectroscopy system with high sensitivity and frequency resolution, and measured the complex dielectric spectrum of water and PBS+DTT buffer, which is two of most common background environments of biological sample.

Discussion On Appropriate Evaluation Methods For Low Absorbers In The Case Of Terahertz Spectroscopy **Th-P2-04**

Kei Takeya; HIdeki Ishizuki; Takunori Taira
38 Nishigonaka, Myodaiji, Okazaki

We have investigated methods for the correct evaluation of low absorbers in the terahertz frequency. We theoretically and experimentally optimized sample conditions, measurement methods, and optical systems necessary to correctly evaluate the low absorption coefficients of quartz crystal and polymers. Experiments using a narrow terahertz collimated beam with a Gaussian-type intensity distribution allowed us to estimate absorption coefficients for each sample that were lower than the previous literature values. This method can serve as a guideline for the correct measurement using THz-TDS.

Characterization Of Melanin Suspended In Alginate Biofilms At The THz Band Using FTIR And TDS Spectroscopy **Th-P2-05**

Mariana Alfaro[1]; Lidia Verduzco-Grajeda[1]; Monica Ortiz-Martinez[2]; Elodie Strupiechonski[3]; Diego Gonzalez-Quijano[1]; Nayeli Solis-Delgadillo[1]

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Melanin is an important biomolecule that plays a photo-protective role in our bodies. The characterization of melanin has always been challenging due to its unique chemical and physical characteristics, in particular its non-solubility in organic solvents and water. Here, the THz spectra of alginate biofilms with different melanin concentrations were analyzed using FTIR and TDS spectroscopies. The FTIR spectra show changes with respect to melanin content possibly attributed to the formation of new bonds as amines, hydrogen bonds, and crosslinking between melanin and alginate groups. The optical properties of the films, measured with TDS signals, also presented modifications for different melanin concentrations

Terahertz Generation In AlxGa1-xAs/GaAs Heterostructured P-i-n Diodes **Th-P2-06**

Valerii Trukhin[1]; Il'ya Mustafin[1]; Xiangyi Fan[2]; Vitalii Kalinovsky[3]; Evgenii Kontrash[3]; Kseniya Prudchenko[3]; Ivan Tolkachev[3]
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Experimentally studied the process of terahertz radiation generation in AlxGa1-xAs/GaAs heterostructured p-i-n diodes when excited by femtosecond optical pulses, which is associated with the ballistic motion of electrons: acceleration in the electric field to a speed significantly higher than the saturation speed at times of hundreds of femtoseconds ("velocity overshoot") and the subsequent sharp decline associated with the inter-doline transition of electrons from the Đ"-valley

Multiphysics Simulation Of Low Frequency Terahertz Induced Thermoacoustic Signal Characteristics **Th-P2-07**

Luyang Liu; Lin Huang; Jun Zhou; Zheng Liang; Zhen Ding; Yaxin Zhang
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Terahertz technology is rapidly developing and playing an important role in the fields of material identification, biomedicine, and communication. However, the strong absorption of terahertz energy in water has limited the development of terahertz technology to some extent. In fact, the strong absorption of terahertz energy in water causes the generation of terahertz photoacoustic (THz-OA) signal, and the propagation depth of THz-OA signal is much longer than the propagation depth of terahertz waves in water. In this paper, we construct the geometric model and use the finite element method to simulate and study the multi-physics effect of low frequency terahertz wave pulse width on the time interval of THz-OA signal. The results show that the time interval of the THz-OA signal changes synchronously with the terahertz pulse width, and the time interval of the two peaks of the THz-OA signal is always equal to the terahertz pulse width.

Complex Third Order Nonlinear Optical Susceptibility In The Terahertz Region Evaluated By Free-Electron Laser **Th-P2-08**

Youwei Wang[1]; T.N.K. Phan[1]; Tomoki Shimizu[1]; Masato Ota[1]; Kosaku Kato[1]; Koichi Kan[2]; Kosaku Kato[1]; Valynn Katrine Mag-usara[1]; Goro Isoyama[2]; Makoto Nakajima[1]
[1]2-6 Yamadaoka, Suita; [2]8-1, MIHOGAOKA, IBARAKI

We investigated the third harmonic generation from InAs(100) induced by THz-FEL. We evaluated the ratio of Ï?(3) components from the results of AAD. The highly efficient THG signals can provide fruitful information on the nonlinear optical susceptibility.

Femtosecond Circular Photogalvanic Effect In FeCo/graphene Nanobilayers **Th-P2-09**

Ivan Komissarov[1]; Jing Cheng[1]; Debamitra Chakraborty[1]; Genyu Chen[1]; Leszek Gładczuk[2]; Piotr Przysłupski[2]; Iraida Demchenko[3]; Kostiantyn Nikiforov[4]; Serghej Prischepa[5]; Kiryl Niherysh[6]; Floriana Lombardi[6]; Adam Łaszcz[2]; Daniel Bürgler[7]; Roman Adam[7]; Roman Sobolewski[1]
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We demonstrate the generation of THz transients from FeCo/graphene heterostructure triggered by circular polarized fs pulsed laser emission originated from circular photgalvanic effect

Study Of Real-time Frequency Stabilization System Based On ZYNQ System For Dual Lasers **Th-P2-10**

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Polarimeter/interferometer(POINT) diagnostic system on EAST is built based on the three-wave method, which requires the difference frequency between every two lasers to be stable. In this paper, a digital Proportion Integration Differentiation (PID) algorithm implemented in a ZYNQ system is adopted. First, the sine wave signal with frequency information is filtered by the acm2108 high-speed AD data acquisition board with a filter module consisting of FIR digital filter. The sinusoidal signal obtained from the data acquisition filter module is also shaped into a co-channel square wave signal and fed into the ZYNQ system for digital signal processing according to the incremental digital PID control algorithm, and the PID parameters calculated by the digital PID algorithm are subsequently passed to the laser's PZT driver. The ideal stability of the frequency difference is determined by the variation of the laser's cavity length, and the PZT driver allows precise adjustment of the cavity length to counteract the effects of intermediate frequency variations caused by other

causes, thus changing the frequency difference in a dual-laser diagnostic system. The experiment results show that the system achieves a relatively ideal effect and meets the requirements of the diagnosis system for intermediate frequency stability.

Quantitative Analysis Of Boson Peak Dynamics Of Glass Formers Based On Heterogeneous Elasticity Theory **Th-P2-11**

Dan Kyotani[1]; Soo-Han Oh[1]; Yasuhiro Fujii[2]; Suguru Kitani[3]; Yohei Yamamoto[1]; Tatsuya Mori[1]
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We have quantitatively evaluated the behavior of the boson peak (BP), which is the universal excitation in the terahertz region of glass-forming materials, using the heterogeneous elasticity theory. By solving the coherent potential approximation equation for the shear modulus, we extracted the nanoscale mechanical properties of glasses and investigated the physical origin of the determinants of BP. Furthermore, terahertz spectroscopy could become a new application for evaluating nanoscale elastic heterogeneity in glasses when the interaction between the BP and terahertz light is fully understood.

Room Temperature Photoluminescence In CdTe Grown By Liquinert-Processed Vertical Bridgman Method **Th-P2-12**

Hiroyasu Nakata[1]; Akira Fujimoto[2]; Yoshiyuki Harada[2]; Takeshi Hirai[3]; Shirou Sakuragi[4]; Yasuo Kanemtsu[5]
[1]1-21-18, Sakurai, Minoh; [2]Asahiku, Osaka; [3]Kusatsu, Kusatsu; [4]Kitasomagun; [5]Machikaneyama, Toyonaka

Bulk CdTe samples were grown by a liquinert-processed vertical Bridgman method to reduce the influence of a crucible wall. We observed near-band-gap photoluminescence in the samples at 300K. The peak around 1.5eV whose origin has been controversial for three decades is assigned to the recombination between a free electron and an acceptor-bound hole. We estimate the ionization energy of the acceptor to be 26meV. High concentrations of the acceptors are responsible for the reason why shallow acceptors are not ionized at room temperature.

Time-Domain Spectroscopy For Space Exploration At Terahertz Energy Scales **Th-P2-13**

Yookyung Ha[1]; Jonas Woeste[1]; Oliver Gueckstock[2]; Georgios Kourkafas[3]; Jovana Petrovic[4]; Mihailo Rabasovic[5]; Aleksandar Krmpot[5]; Tom S. Seifert[2]; Andrea Denker[3]; Tobias Kampfrath[2]; Nikola Stojanovic[6]; Michael Gensch[6]
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In recent years, short pulse lasers have made massive progress and space-ready

femtosecond laser systems are under development. Moreover, employing time-domain spectroscopy techniques to identify planetary minerals by their spectroscopic fingerprints in the infrared and terahertz frequency range can have technological advantages over conventional spectroscopic techniques such as Fourier-Transform Infrared or Raman spectroscopy. The advantages are compactness, the possibility to replace bulky optical components by electro-optic/acousto-optic photonic techniques and the potential to be chip-integrable. We focus on one particular time-domain technique, coherent phonon spectroscopy (CPS), which is sensitive to Raman-active modes. Here, CPS is demonstrated in single-color operation and thus the simplicity and its insensitivity to fluorescence background add to the advantages of this technique.

Temperature Dependence Of The Anisotropic Dielectric Properties Of Semi-insulating B-Ga2O3 In The Terahertz Region **Th-P2-14**

Shuang Liu[1]; Verdad C. Agulto[1]; Toshiyuki Iwamoto[2]; Kosaku Kato[1]; Masato Ota[1]; Ken Goto[3]; Hisashi Murakami[3]; Yoshinao Kumagai[3]; Masashi Yoshimura[1]; Makoto Nakajima[1]
[1]2-6 Yamadaoka, Suita, Osaka; [2]Nirasaki; [3]Koganei, Tokyo

We conducted measurements using terahertz time-domain spectroscopy on a semi-insulating bulk sample of (001)-oriented beta gallium oxide (β-Ga2O3) in the temperature range of 90 K to 400 K. We analyzed the complex dielectric function parallel to the a-axis [100] and b-axis [010] in the frequency range from 0.2 to 3 THz using the Lorentz model. Our analysis enabled us to investigate the temperature dependence of the static dielectric constants and phonon absorption, as well as the anisotropy of β-Ga2O3.

Chiral Nonlocal Terahertz Photoconductivity In Heterostructures Based On Topological Hg1-xCdxTe Films **Th-P2-15**

Aleksei Kazakov[1]; Alexandra Galeeva[1]; Alexey Artamkin[1]; Anton Ikonnikov[1]; Sergey Dvoretsky[2]; Nikolay Mikhailov[2]; Mikhail Bannikov[3]; Sergey Danilov[4]; Ludmila Ryabova[1]; Dmitry Khokhlov[1]
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We report on observation of strong non-local photoconducitivity induced by terahertz laser pulses in non-zero magnetic field in heterostructures based on Hg1-xCdxTe films being in the topological phase. While the zero-field non-local photoconductivity is negligible, it is strongly enhanced in magnetic fields ~ 0.05 T resulting in appearance of an edge photocurrent that exceeds the respective dark signal by orders of magnitude. This photocurrent is chiral, and the chirality changes every time the magnetic field or the electric bias is reversed. Appearance of the non-local terahertz photoconductivity is attributed to features of the interface between the topological film and the trivial buffer.

On-Chip THz Time-Domain Spectroscopy Sensor With Adjustable Sample Interaction By A Daughterboard **Th-P2-16**

Jimin Lee; Simon Sawallich; Max Lemme; Michael Nagel
Otto-Blumenthal Strasse 25, Aachen

In this study, we use a low-loss on-chip Terahertz (THz) sensor to measure conductance properties of metal thin-films and two-dimensional (2D) materials. The sensor has a coplanar strip (CPS) transmission line that creates a highly confined THz field in a transversal direction. The field interacts longer with the sample as it travels along the CPS line. We also use a detachable sample carrier film (a daughterboard) that can be easily replaced. This makes the sensor reusable and adjustable. The length of the daughterboard can change the interaction of the THz signal with the sample. Our low-loss on-chip THz sensor platform can analyze 2D materials sensitively and compactly which is important for future application in small cryostat chambers.

Thermal Transport Of Defect Graphene By Raman Spectroscopy. **Th-P2-17**

Sidi Abdelmajid AIT ABDELKADER[1]; Abdelouahed EL FATIMY[2]
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Understanding the effect of disorder on the relaxation dynamics of charge carriers is crucial for the operation of most graphene devices. Defect engineering is a useful technique to modulate the materials properties. This requires a comprehensive understanding of the influence of the defects on graphene device proprieties. In this work, to obtain the Raman signatures of the distance between vacancies and their sizes, we calculate the non-resonant Raman spectra of graphene with randomly distributed vacancies. Several vacancies with different geometries were treated for different concentrations. The calculated Raman spectra shows a G-band at 1588cm-1 and a D-band around 1340cm-1 as a characteristic band of defective and disordered graphene. The spectra also show other modes whose frequencies depend significantly on the concentration of vacancies. These modes can be a useful index to estimate the average distance between the vacancies. Based on these findings, we may extract information about the average vacancy diameter on our systems as well as their average inter-distances.

Catching A Terahertz Pulse In A Photonic Crystal Net Triggers Dynamic Frequency Conversion **Th-P2-18**

Aidan Schiff-Kearn; David Cooke
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We utilize the ultrafast imposition of two-dimensional metallic photonic band structure on a terahertz pulse to demonstrate dynamic frequency conversion. Greater-than-unity transmittance is demonstrated which indicates the redistribution of spectral content within the bandwidth of the pulse. This result is made possible by our platform for spatio-temporal modulation of a terahertz pulse in a silicon-filled parallel plate waveguide using patterned femtosecond optical excitation.

Strong Coupling Of An EIT-like Metamaterial With Photons In A Photonic Crystal Cavity **Th-P2-19**

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We report strong coupling between a plasmonic dark mode of an EIT-like metamaterial (EIT: electromagnetically induced transparency) with the photons of a 1D photonic crystal cavity in the terahertz frequency range. The coupling between the dark mode and the cavity photons is mediated by a plasmonic bright mode, which is proven by the observation of a frequency splitting which depends on the strength of the inductive interaction between the plasmon bright and dark modes of the EIT metamaterial. In addition, since the plasmonic dark mode strongly couples with the cavity dark mode, we observed four polariton modes. The frequency splitting by interaction of the four modes (plasmonic bright and dark mode and the two eigenmodes of the photonic cavity) can be reproduced in the framework of a model of four coupled harmonic oscillators.

Free-electron Infrared Nonlinearities In Heavily Doped InGaAs Nanoantennas **Th-P2-20**

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Free electrons in heavily doped semiconductors operate in the hydrodynamic regime, where oscillating velocity, current and electromagnetic field terms can mix and produce relatively strong nonlinear effects in the mid-infrared and terahertz ranges. We fabricate n-InGaAs nanoantennas with the aim of measuring the efficiency of third harmonic generation. We are exploring free electron nonlinearities in the hydrodynamic regime in heavily doped InGaAs epitaxial layers with small electron effective mass, to be used in future integrated photonics applications. Hydrodynamic effects are expected to provide relatively high and tunable nonlinear efficiency if compared to crystal nonlinearities. Nonlinear THG efficiency measurement with ultrashort-pulse mid-IR laser sources is ongoing, with measurements techniques based on difference-frequency generation in nonlinear crystals to produce very high-power ultrashort mid-infrared pulses.

Planar Chiral Metasurface With Maximal Chirality Empowered By Toroidal Dipole Resonances **Th-P2-21**

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Here, we demonstrate an all-dielectric chiral metasurface which exhibit giant chiroptical effects driven by toroidal dipole (TD) resonances. By introducing structural perturbations in the symmetric structure and only breaking the in-plane mirror symmetry, the proposed chiral metasurface can offer high-Q factor (~3230) chiroptical resonance with nearly maximal circular dichroism (CD) (~-0.98) at terahertz frequencies. Interestingly, the magnitude of CD signals can be freely modulated via tuning the geometrical asymmetry, while the value of Q factor almost remains unchanged. These results confirm that the proposed chiral metasurface are potential for applications which require high Q factors and strong CDs concurrently.

Terahertz Wave Absorbing Properties Of Double-coils Randomly Distributed In Cellulose Nanofibers **Th-P2-22**

Kosaku Kato[1]; Shiyu Feng[1]; Zixi Zhao[1]; Verdad Agulto[1]; Masato Ota[1]; Ami Mizui[2]; Takaaki Kasuga[2]; Hirotaka Koga[2]; Masaya Nogi[2]; Motoharu Haga[3]; Minoru Ueshima[4]; Makoto Nakajima[1]
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For 6G application, we fabricated a broadband sub-terahertz (THz) and THz wave absorber made of micrometer-sized metallic double coils randomly dispersed in cellulose nanofiber (CNF) foam. Double coils can work as "3D metamaterial," and exhibit resonance with electromagnetic waves in various orientations. Therefore, they can effectively absorb waves even when they are randomly distributed. Eco-friendly CNF was found to be a suitable material to uniformly disperse double coil particles in its foam. A shielding efficiency < -20 dB and absorbance >98% at 150—1000 GHz were observed by THz-time domain spectroscopy. Our absorber has a cost advantage because double coils can be mass-produced through machine processing and are usable in random distribution configuration without alignment.

Highly Sensitive Terahertz Metamaterial Sensor With Enhanced Spatial Distribution Of Strong Electric Field **Th-P2-23**

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A highly sensitive asymmetric double C-shaped THz metamaterial sensor is proposed and compared with a traditional aDSRR structure. The sensitivity is improved by extending the spatial distribution volume of the high electric field at resonance. This concept can also be utilized as an optimization method to significantly improve the sensing performances of other metallic metamaterial sensors, such as electric SRR structure. It has potential applications in trace substance detection and biosensing.

Efficient And Broadband Terahertz Polarization Convertor Enabled By An All-metal Stereo Reflective Metasurface **Th-P2-24**

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The pursuit of novel concepts and design schemes for metasurfaces to develop Terahertz (THz) polarization-related devices with exceptional performance is an ongoing and highly demanding project. Here, A new all-metal stereo U-shaped meta-atom based design scheme for manipulating terahertz polarization is proposed. The design functions as an efficient and broadband THz waveplate with tailorable birefringence by controlling sunken depth. The polarization conversion ratio (PCR) is >90% with 69% relative bandwidth and 85Ã‚Â° angle tolerance. The proposed meta-grating based on Pancharatnam-Berry (PB) phase method is also demonstrated, enriching design degrees of freedom for metasurfaces and offering potential for various functional devices. This design allows for flexible polarization control by simply adjusting the U-pillar's sunken depth and can be applied to design versatile polarization converters.

Photo-Curing Resin With Carbon Nanotube/Cellulose Nanofiber Composite Flakes As Electromagnetic Shielding Material **Th-P2-25**

Zixi Zhao[1]; Shiyu Feng[2]; Verdad C. Agulto[2]; Kosaku Kato[2]; Masato Ota[2]; Ami Mizui[3]; Takaaki Kasuga[3]; Hirotaka Koga[3]; Masaya Nogi[3]; Motoharu Haga[4]; Minoru Ueshima[5]; Nobuhiko Sarukura[2]; Masashi Yoshimura[2]; Makoto Nakajima[2]
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Abstract-In order to address the problem of electromagnetic interference in the next-generation communication, we propose a photo-curing resin with conductive fillers of carbon nanotube (CNT) and cellulose nanofiber (CNF) composite flakes as a new kind of shielding material. The characteristics were obtained using terahertz time-domain spectroscopy.

Terahertz Surface Plasmon Resonance Microscopy In The Otto Configuration **Th-P2-26**

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For the first time, wide-field amplitude terahertz (THz) surface plasmon resonance (SPR) microscopy utilizing coherent laser radiation has been demonstrated. An experimental setup has been designed that allows wavelength selection and enables scanning of both the angle and size of the air gap. This design aids in the optimization of parameters for efficient SPR excitation. The Otto configuration has been utilized for non-destructive testing of semiconductor surfaces. Additionally, the application of III-V semiconductors, specifically indium antimonide (InSb), as substrates has been investigated, potentially enhancing the resolution of SPR microscopy in the THz range.

Investigation Of Dual Frequency Terahertz Band-stop Filter Based On 3D Printed all-dielectric Metamaterials **Th-P2-27**

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A band-stop filter is a commonly used filter in electronic systems, typically used to suppress noise signals in wireless communication systems and to filter out fundamental or harmonic waves in electromagnetic compatibility measurements of electronic devices. Currently most of the study focused on metallic metamaterials devices to realize the function. In this study, a 3D printed polymer-based metamaterial band-stop filter was proposed. By designing a cylindrical-substrate structure using a polymer composite with dielectric constant of 3.5, transmittance coefficient of -22.20 dB and -24.79 dB can be obtained at the frequencies of 98.23 GHz and 109.25 GHz, respectively. Furthermore, the simulation results indicate that the filtering frequency can be regulated by adjusting the dielectric constant of the polymer composite. This results provide significant insights for the development of polymer-based terahertz metamaterials.

Exciting Extended Bound States In The Continuum In Symmetry-Broken Scalable All Dielectric THz Metasurface **Th-P2-28**

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A scalable all dielectric silicon metasurface support symmetry-protected (SP) and accidental bound state in the continuum (BIC) is investigated, which can excite new multiple extended BIC by introducing perturbation to the metasurface. For these extended BICs at Î" point but are not part of the SP-BIC, theoretical analysis and mode profiles reveals that one extended BIC is Friedrich--Wintgen BIC (F-W BIC) and the other extended BIC is a single resonance parameter BIC. Although the resonance frequency of proposed metasurface falls in the terahertz (THz) region, which can operate in the entire wavelength range from microwave to infrared by scaling the lattice constant.

Development Of A 3D Printed Dual-Band MmWave And THz Near-Field Microscope For Skin Cancer Detection **Th-P2-29**

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Material contrasts of millimeter and Terahertz waves can reveal information not accessible to other parts of the electromagnetic spectrum, such as the discrimination between healthy and cancerous tissue. The longer wavelengths,

as compared to optical frequencies, limit the resolution for many applications, which can be circumvented by using near-field microscopy. Here we present a dual-band scattering near-field microscope operating at 50-75 GHz (WR15) and 220-330 GHz (WR3), as these are two regions known to show a contrast between cancerous and healthy tissue. The microscope is based on a 3D printed metallic measurement head, with a compact and sturdy design, as the design is intended for in-vivo measurement and hence requires a certain degree of mobility. Here we present the development process, resolution and permittivity calibration and measurements of ex-vivo skin cancer samples.

Terahertz Near-Field Response Of Graphene Devices **Th-P2-30**

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Abstract - In recent years, due to their unique electromagnetic properties, novel two-dimensional materials have attracted increasing attention in the field of high-performance terahertz optoelectronic devices. With the progressive miniaturization and integration of devices, there is an urgent need for a method to study the terahertz properties of two-dimensional materials at subwavelength scales. In this work, we performed preliminary characterization of graphene layers within terahertz devices using a custom-built continuous-wave near-field system and a commercial time-domain spectroscopy near-field system. The study found that in stacked graphene with wrinkles, its terahertz near-field response is almost independent of wrinkle stacking. However, different substrates do have an impact on the near-field response of graphene.

Towards A Versatile And Cost-Effective Lock-In Amplifier **Th-P2-31**

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We present the development of a custom, cost-effective lock-in amplifier (LIA) for use in common laboratory settings. The LIA is built around the widely available and low cost STM32 microcontroller and off-the-shelf parts. It is designed and built with online tools, a process that enables iterating on the hardware and software quickly, which inspires regular improvements. The resulting amplifier provides high performance at a low cost in a small, low-power package, and we believe this will enable new use-cases. We benchmark our device against a widely used commercial digital lock-in amplifier, with results demonstrating the potential of combining software, hardware, and tools to create efficient and cost-effective custom laboratory solutions, not solely limited to lock-in amplifiers.

Deep Learning To Accelerate Terahertz Metamaterials Design For Biosensing Application **Th-P2-32**

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The Terahertz (THz) sensing technology has attracted tremendous research

interests in various fields of imaging, communication, spectroscopy and noninvasive detection. In line with this, THz Metamaterials (MM) which exhibit unique electromagnetic properties has prompted significant advances in THz biosensing. The properties of MM are dependent on the orientation, geometry or shape of the material's components which have been traditionally designed using intuitive reasoning and knowledge of the researcher. The growing interest in MM requires more sophisticated and advanced functionalities which implies high computational costs and efforts. The application of deep learning for MM design enable more efficient, accurate, faster and more convenient modelling of the relationship between design and response spectra of MM even in complex cases. This paper explores the deep learning based modelling of MM using inverse design models for the biosensing application.

Metallic 3D Printed Double-Ridged WR3.4 Interface for THz Power Combining **Th-P2-33**

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A metallic double-ridged rectangular waveguide (DRWG) to conventional WR3.4 (220-320 GHz) waveguide interface is designed and fabricated for photonic THz power combining. The DRWG is 3D printed as single metallic block using laser melting fusion (LMF) and stainless steel SS316L powder with a particle size of <50 ÃZÂ¼m. The fabricated waveguide has a cross-section of 860Ãf-430 ÃZÂ¼m. Simulations and experiments were conducted to examine the impact of the surface roughness and imperfect apertures' shape on the THz transmission loss. The measured average surface roughness for the top and bottom flange surfaces after printing were 4220 nm and 5050 nm, respectively. By manually polishing the surfaces, the average surface roughness was decreased to 190 nm for the top flange surface and 3008 nm for the bottom surface. The measured average loss associated to the non-perfect roughness, shape and material conductivity range from 4.2 dB to 3 dB for 220 GHz to 320 GHz.

Optimizing High-Performance Terahertz Sub-Harmonic Mixers With Customized Sparrow Search Algorithm **Th-P2-34**

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The fast, accurate, and effective design of high-performance terahertz devices is very significant for the advancement of terahertz communication systems. However, the traditional methodologies encounter big challenges, such as numerous parameters and complex nonlinearity in device design. In this work,

an innovative, AI-assisted approach harnessing refined swarm intelligence (SI) optimization algorithms were introduced for the design of a 220 GHz wideband subharmonic mixer. Simulation results confirm that, with a local oscillator frequency of 110 GHz maintained, the operating frequency range is 200-240 GHz, a 40 GHz RF bandwidth has been achieved, displaying a single-sideband conversion loss (CL) superior to 7 dB and the best CL of 6.15 dB. This accelerates the development of cutting-edge terahertz devices and catalyzes significant progress within the terahertz research fields.

A Shared-focus, Multi-pass Sample Cell (SFSC) Useful For THz And Optical Spectroscopy **Th-P2-35**

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A low-cost, multi-pass sample cell in which all of the optical beams are focused through the center of the chamber was developed for THz spectroscopy. The cell employs twenty toroidal mirrors directed towards the center of the chamber and arranged such that as each beam is reflected it "walks" around the chamber. The shared-focus sample cell (SFSC) was then employed to measure various molecular transitions of water.

Broadband Terahertz Plasmonic Multiplexers **Th-P2-36**

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In this work, we demonstrate a metal-wire-based plasmonic signal processor, which can simultaneously act as a broadband terahertz polarization-division multiplexer and as a novel platform to realize the independent manipulation of polarization-division multiplexed terahertz signals. Such a device opens up new exciting perspectives for exploiting the polarization degree of freedom and ultimately boosting the capacity and spectral efficiency of future terahertz networks.

THz Dielectric Directional Coupler Based On Effective Medium Cladding **Th-P2-37**

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In this paper, we present a 3-dB evanescent wave directional coupler at 300 GHz based on silicon waveguides surrounded by effective-medium with subwavelength perforations. This technique offers very low losses due to the absence of metals, allows fabrication in a single etching step and provides a method for engineering the permittivity of the cladding, thus allowing wave manipulation in all-dielectric platforms, extending the concepts of photonics to the THz region.

Design Of A Terahertz Waveguide Diplexer With High Isolation **Th-P2-38**

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A terahertz waveguide diplexer with high isolation was designed and verified based on network analysis. The diplexer is composed of two Chebyshev filters and an E-plane waveguide T-junction. By analyzing the equivalent network of the directly coupled iris filter, we designed two channel filters. The proposed diplexer was fabricated by high-precision computer numerical control milling technology. The experimental results show that the insertion loss is less than 1.51dB and the return loss is better than 15dB in the passband range, and the lowest in-band insertion loss is 0.7/0.61 dB for both two channels, the isolation between the two channels is greater than 63.9dB.

Typical Solutions Of Antenna On Chip (AoC) In Terahertz Band And Improved Structure For THz Applications **Th-P2-39**

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Antenna on Chip (AoC) provides a promising solution to the interconnection loss between the System on Chip (SoC) circuits and the antennas off the chip in the terahertz (THz) band. Owing to the AoC, the integration performance of the SoC can be greatly improved. In this paper, typical AoC designs in the last two decades have been summarized and compared. The solutions mainly include micromachining, silicon lens, artificial magnetic conductor (AMC), dielectric resonator (DR), etc. With respect to the practical problems of the AoC design, some typical case studies will be presented in the conference. Aiming at the low fabrication complexity and high integration, two types of AoC solutions are introduced to achieve broadband and high gain, respectively. The proposed antennas are quite suitable for the THz integrated SoC applications.

Terahertz Side Arm Orthomode Transducer With High Isolation And High Cross-polarization Discrimination **Th-P2-40**

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This paper presents a terahertz side arm orthomode transducer (OMT) with high isolation and cross-polarization discrimination (XPD). The structure of the OMT is based on the simplest orthogonal side arm design, but with the introduction of a mirror waveguide structure, which breaks the single symmetry limitation of the traditional orthogonal side arm structure, the OMT gains double symmetry and thus achieves superior isolation and XPD. At the same time, by using a simple matching waveguide, the OMT achieves a wider bandwidth without increasing the complexity of the structure. The proposed OMT has a working bandwidth of 190-230 GHz, with a return loss of less than -15 dB, an isolation of less than -85 dB, and an XPD of less than -77 dB across the entire bandwidth. Compared with other OMT structures with double symmetry, such as turnstile junction and double-ridged waveguide, the

proposed OMT structure is more compact and simpler, greatly reducing the difficulty of processing and manufacturing and having better tolerance capability.

Design Analysis Of Microwave Ablation Using Minimally Invasive Antenna In Human Liver

Th-P2-41

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Microwave ablation (MWA) is a minimally invasive technique used to treat liver tumors by heating and destroying cancerous cells. In this work, we designed and analyzed a novel externally-tapped intertwined helical antenna for MWA. The antenna was tested on a tissue model using the High-Frequency Structure Simulator (HFSS), and the results showed a reflection coefficient S11 of -17.91dB and a gain of -0.86dB. T-rings were added to the outer conductors to reduce back current and increase the near spherical ablation zone. The proposed antenna has resonant mode at 5GHz and can provide transversal heating for tumor ablation. The results demonstrate the potential of the intertwined helical antenna for MWA applications.

60 Lines Measurement In A Single Experiment Using Super-Resolution TDS

Th-P2-42

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Terahertz time domain spectroscopy (THz-TDS) has emerged as a versatile tool for investigating the physical properties of materials. However, its potential for gas-phase studies has remained largely unexplored, and it gained attention recently. We present here an extended application of the Constrained Reconstruction Super-Resolution (CRSR) algorithm for NH3. Leveraging an improved experimental setup, we were able to enhance the sensitivity of the spectrometer and test the algorithm with more rotational transitions. Moreover, we introduce a novel approach for quantifying the uncertainty of THz-TDS measurements, thus establishing a framework to evaluate the sensing capabilities of this technique.

A Terahertz Wave Frequency Measurement System Based On Fabry-Pérot Resonator

Th-P2-43

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In this paper, we present a terahertz (THz) wave frequency measurement system based on the Fabry-Perot (FP) resonator principle, employed for the assessment of a 263 GHz gyrotron's output frequency. The system comprises two components: hardware and software. The hardware incorporates a precision displacement stage and a highly sensitive power detector to enhance measurement accuracy, while the software utilizes various frequency domain transformation techniques and multiple filtering algorithms to mitigate spectral noise. Experimental comparisons between solid-state mixers and the proposed

system demonstrate its reliability. Furthermore, we examine the primary factors contributing to measurement errors.

Lens Absorber Coupled MKIDs For Far Infrared Imaging Spectroscopy **Th-P2-44**

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Future generation of astronomical imaging spectrometers are targeting the far infrared wavelengths to close the THz astronomy gap. Similar to lens antenna coupled Microwave Kinetic Inductance Detectors (MKIDs), lens absorber coupled MKIDs are a candidate for highly sensitive large format detector arrays. However, the latter is more robust to misalignment and assembly issues at THz frequencies due to its incoherent detection mechanism while requiring a less complex fabrication process. In this work, the performance of such detectors is investigated. The fabrication and sensitivity measurement of several lens absorber coupled MKID array prototypes operating at 7.8 and 12 THz central frequencies is on-going.

Distinguish Proliferative And Apoptotic Glioma Cells With Terahertz Metamaterials **Th-P2-45**

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A label-free approach to distinguish the proliferative and apoptotic features of glioma cells by using terahertz metamaterials with large effective area is proposed. Various frequency-shift responses are observed for the live and apoptotic glioma cells under therapeutic treatments, respectively. The relation between frequency shift â^?f and the numbers of live and apoptotic cells is fitted, which consequently reveals the relation of â^?f with respect to both proliferation and apoptosis rates unprecedentedly. This work paves a new way to study the proliferative and apoptotic responses of tumor cells, showing promising potential to guide individualized tumor treatments fast and label-free.

Progress In Process Development Of La0.7Sr0.3MnO3 Thin Films For Uncooled THz Bolometers **Th-P2-46**

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We present preliminary results of uncooled THz bolometers based on

La0.7Sr0.3MnO3 thin films on SrTiO3 buffered high resistivity silicon substrates. Fabrication improvements enable to obtain low contact resistance and the impedance measurements show that it is possible to minimize the impedance mismatch with an antenna.

Absolute Security With Digital Beamforming For High-Frequency Links **Th-P2-47**

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Absolute security relies on radiation patterns with diverse radiation minima across a wideband transmission. While radiation minima naturally shift with frequency, the change is minimal within typical communication bandwidth. In this paper, we propose to achieve high diversity in radiation minima with digital beamforming. With our proposed zero-forcing-based minimum steering, we demonstrate a significant secure region using 802.11ay parameters, indicating a promising direction to realize absolute security using digital beamformers.

High-speed THz Imaging Using A HCN Laser And A HEMT THz Detector **Th-P2-48**

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Terahertz (THz) radiation is poised to play a crucial role in a wide range of imaging applications, from security checks to medical diagnoses. In this study, we developed a high-speed THz imaging system for practical applications. The system utilizes a continuous wave (CW) discharge-pumped hydrogen cyanide (HCN) laser and an array detector with a resolution of 128Ã-32 to perform THz imaging. We successfully measured an image with a spatial resolution of 2 mm within 2 seconds. Experimental results demonstrate that this THz imaging system has the potential to be utilized for security checks.

Spectrally Efficient Optoelectronic Wireless Terahertz Communication System **Th-P2-49**

Bashar Husain; Kevin Kolpatzeck; Alexander Frömming; Lars Häring; Andreas Czylwik
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In this paper, we demonstrate a spectrally-efficient optoelectronic wireless terahertz (THz) communication system operating at a carrier frequency of 300 GHz. A Complex baseband-over-fiber transmission is achieved by utilizing an optical I/Q modulator on the transmitter side. The THz signal is generated by optical heterodyning in an antenna-integrated photodiode. On the receiver side, an electronic harmonic mixer is used to down-convert the received signal to an intermediate frequency (IF) of 3 GHz, which is then received by a digital storage oscilloscope (DSO) and saved for further offline signal processing. Experimental results of transmission and reception of an orthogonal frequency division multiplexing (OFDM) signal are presented in this work.

Metasurface Enabled THz Multi User Communications **Th-P2-50**

Fahid Hassan[1]; Jeffrey Lei[2]; Hichem Guerboukha[2]; Hou-Tong Chen[3]; Chun-

Chieh Chang[3]; Sadhvikas Addamane[4]; Michael Lilly[4]; Edward Knightly[1]; Daniel M. Mittleman[2]
[1]Rice University; [2]184 Hope St, Providence; [3]Los Alamos National Laboratory; [4]Sandia National Laboratories

We report THz multi-user communication enabled with an electrically-controlled metasurface. By applying different voltage profiles on the metasurface, we show that we can achieve simultaneous 2-user communication with QPSK symbols.

Electrically Small High Permittivity Lens Antenna Using Artificially Loaded Thermoplastics At 170 GHz **Th-P2-51**

Nick van Rooijen; Maria Alonso-delPino; Juan Bueno; Marco Spirito; Nuria Llombart
Mekelweg 4

This contribution presents the development of an electrically small lens antenna using an artificially loaded thermoplastic at 140-170GHz. We will present the on-going development of the Fly's Eye front end antenna concept that was presented in [1]. The antenna is composed on a dual plastic lens, a core lens and a shell lens, fed by a double slot. The core-lens, being presented in this contribution, is a spherical lens made from an artificially loaded plastic of permittivity 9.5. To the best of our knowledge, this thermoplastic material has not been used for lens antennas in this frequency range before. A 4mm lens prototype has been developed using this material, which includes an anti-reflective layer synthesized by drilling sub-wavelength holes on the lens contour. Full-wave simulations show a negligible degradation of the performance of the anti-reflection layer compared to an ideal homogeneous matching layer. Physical measurements and antenna measurements confirm that the antenna's performance matches the design specifications.

Broad Angle Receiver For The THz Band **Th-P2-52**

Yasith Amarasinghe[1]; Hichem Guerboukha[2]; Yaseman Shiri[2]; Rabi Shrestha[2]; Pernille Klarskov[1]; Daniel Mittleman[2]
[1]Department of Electrical and Computer Engineering, Aarhus University, Finlandsgade 22, Aarhus N; [2]School of Engineering, Brown University, 184 Hope, Providence

We designed a broad angle receiver using a leaky parallel plate waveguide by manipulating the plate separation. The device operates at 200 GHz and has an angle of acceptance of 27 degrees.

Analysis Of Water Thin Films Terahertz Spectra As A Function Of Polarization Using A Modified Total Reflectance Accessory **Th-P2-53**

Manuel Alejandro Justo Guerrero[1]; Arturo Mendoza-Galván[1]; Elodie Strupiechonski[2]
[1]Lib. Norponiente #2000; [2]Av. pie de la cuesta, Queretaro

In this work, we explore an important aspect of studying biological and

chemical samples in the terahertz range by exploiting the distinct properties of p- and s-polarized terahertz radiation in water bulk and thin films, which is made possible by water's high absorption. We present experimental data from THz-ATR spectroscopy of water and provide an interpretation of the observed optical phenomenon, supported by finite elements method simulations and an analytical model based on the Fresnel equations. Our findings reveal that the presence of a refracted beam in water can significantly increase the time-averaged electric and magnetic energy densities within the water domain by creating a thin micrometer-sized film with a top mirror to modify the accessory. These results suggest that this polarimetric technique could pave the way for highly sensitive terahertz microfluidic systems for detecting chemicals and biomolecules.

Extracting Error Bars On Refractive Index Retrieved In THz-TDS **Th-P2-55**

Noureddin Osseiran[1]; Jeyan Bichon[2]; Aditya Raj[2]; Sophie Eliet[2]; Romain PERETTI[3]

[1]Univ. Lille, CNRS, Centrale Lille, Univ. Polytechn, Villeneuve d'ascq; [2]Avenue Poincarré; [3]Avenue Poincarré, Villeneuve d'ascq

We present a new methodology for computing error bars in THz-TDS experiments and distribute open source software for this purpose. Pursuing our efforts in noise analysis and data processing of THz-TDS experiments, we followed a standard approach to derive the error bars from the simplest quantities coming from the experiments (transmission, absorbance) and a Bayesian approach when using an optimization fitting methodology to retrieve the plotted magnitude (refractive indices).

Burning Depth Determination In Wood With THz 3D Imaging Based On An Inverse Linear Synthetic Aperture **Th-P2-56**

Tobias Kubiczek; Thorsten Schultze; Jan C. Balzer
Bismarckstr. 81, Duisburg

This paper presents the measurement of burn depth in burned wood using an inverse linear synthetic 2D aperture. A terahertz time-domain spectroscopy system with wide-bandwidth and antennas operating in divergent reflection geometry is used together with two linear stages to move a piece of burned wood in two dimensions. This allows, in principle, the determination of the structural integrity of the burned wood and opens a new field of application for terahertz technology.

Measurement Of The THz Stokes Vectors Using The PHASR Scanner: Precise Determination Of The Jones Matrix Of The Scanning System **Th-P2-57**

Zachery Harris; Kuangyi Xu; M. Hassan Arbab
Bioengineering, 100 Nicolls Rd., Stony Brook

We present a polarization-sensitive version of our PHASR Scanner and a calibration method that allows for accurate measurement of the Stokes vector of the reflected light from sample surfaces. We have tested the performance of the polarimetric scanner by comparing the broadband measurements of the birefringent crystal sapphire to simulations after our Jones matrix calibration approach. The new scanner will enable future polarimetric imaging of biological samples and NDT applications.

Biological Response Of Human Skin Cells To 300 GHz Radiation **Th-P2-58**

Seung Jae Oh[1]; Inhee Maeng[2]; Hye Young Son[3]; Eui su Lee[4]; Ilmin Lee[4]; Kyung Hyun Park[4]

[1]50-1 Yonsei-ro, Seoul; [2]50-1 Yonsei-ro; [3]College of Medicine Yonsei University, Seoul; [4]Daejeon

This paper describes the biological effects of 300 GHz terahertz radiation on skin cells, specifically human newborn foreskin fibroblasts. The study analyzed the cells' viability, cancer-inducing biological signals, and aging under terahertz wave irradiation.

Evaluation Of Potential Risks Associated With Cancel Cell Motility And Utilisation Of MMW Radiation In Anticancer Applications **Th-P2-59**

Sergii Romanenko[1]; Anabel Sorolla[2]; Vincent Wallace[3]

[1]Bogomoletz str., Kyiv; [2]6 Verdun St, Perth; [3]35 Stirling Highway, Perth

Millimeter wave (MMW) radiation does not have enough energy to ionize atoms or molecules and therefore does not have the potential to cause DNA damage. This radiation is expected to deteriorate the viability of cancer cells in the tumor while healthy tissue remains unaffected. However, considering the aggressiveness of cancer cells in terms of their motility and invasiveness, MMW radiation-related thermal alterations in the exposed tumor and its environment may trigger cancer cell detachment and further spread. In this study, we looked into changes in cell adhesion and motility of a triple-negative breast cancer cell exposed to MMW radiation and compared it to an epithelial cell subjected to the same treatment.

Cryogenic Ultrafast Scattering-type Terahertz-probe Optical-Pump Microscopy (CUSTOM Facility) Capabilities At The University Of Manchester **Th-P2-60**

Baset Gholizadeh[1]; Richard Curry[2]; Jessica Boland[2]

[1]Office Number 2.319, Alan Turing Building, The University of Manchester, Manchester; [2]The Photon Science Institute, Oxford rd, Manchester

Characterizing the optoelectronic properties of low-dimensional materials at the micro and nanoscale requires advanced material characterization techniques. Scattering-type Scanning Near-field Optical Microscopy (s-SNOM) as a non-contact and non-destructive technique that enables high-resolution imaging and spectroscopy of nanoscale materials. The CUSTOM facility at the University of Manchester as a unique UK national facility that provides unprecedented capabilities for advanced nanoscale material characterization. The paper outlines the technical challenges of s-SNOM at the CUSTOM facility and their future framework for addressing these challenges.

Porosity Inversion Of Multilayer Medium At THz Frequency **Th-P2-61**

Bingyang Liang[1]; Lixia Yang[2]; Ping Zhang[2]; Yuanguo Zhou[1]; Shengpeng Yang[2]; Shaomeng Wang[2]; Yubin Gong[2]

[1]No. 58 Yanta Middle Road, Beilin District, Xi'an; [2]No. 2006, Xiyuan Avenue, High-tech Zone, Chengdu

The porosity of ceramic materials and composites is a key determinant of their overall characteristics. Material porosity might represent material preparation quality and performance. In this paper, we present an inversion approach for porosity in layered media based on the dyadic Green's function method in multilayer layered media. This study presents a layered media porosity inversion method based on dyadic Green's function. The multilayer dyadic Green function approach is used to calculate electromagnetic dispersion in space. Subsequently, the DBIM inversion method was used to achieve the inversion of the relative dielectric constant of multi-layer ceramic layers. Finally, we utilized the Maxwell-Garnett effective medium theory model to analyze the porosity of the medium. The method proposed in this article can be used to analyze material properties in non-destructive testing of layered media.

Real-time Inspection Of Food Products Using Terahertz Imaging System **Th-P2-62**

Mercy Latha A
near to BITS, Pilani campus, Pilani

Identification of foreign materials (namely metal, glass, plastic, or rubber), which are unintentionally dropped in food products, is extremely crucial from the food safety point of view. Hence, there is a demand for a simple and nondestructive system that can serve the purpose. In this study, efforts have been taken to identify the foreign materials in chocolates during the making process itself, when the chocolates are moving in the conveyor belts. To achieve this aim, a compact and real-time portable active terahertz imaging setup has been employed. The system is equipped with a 100GHz terahertz source with an output power of 80mW and a linear GaAs-based detector array with an unprecedented imaging speed of 5000 frames per second. A chocolate sample of dimension 39 mm x 39 mm x 10 mm, with artificially incorporated foreign particles, has been imaged. Due to the variation in the material properties of the chocolate and foreign material, the terahertz absorption and transmission changes attributing to the prominent contrast arising in the terahertz image. The imaging resolution of the terahertz imaging system is sufficient for most of the requirements of food industries. The results suggest that the terahertz imaging technique is a potential candidate for quality control/assurance in food industries, particularly in chocolate industries, due to their compact size and real-time imaging capabilities.

Dual-wavelength CW Lasers Injection-locked To Optical Comb Modes For Carrier Conversion From THz Wave To Near-infrared Light Via Electro-optical Polymer Modulator **Th-P2-63**

Yudai Matsumura[1]; Eiji Hase[1]; Yu Tokizane[1]; Naoya Kuse[1]; Takeo Minamikawa[1]; Junichi Hujikata[1]; Hiroki Kishikawa[1]; Masanobu Haraguchi[1]; Yasuhiro Okamura[1]; Takahiro Kaji[2]; Akira Otomo[2]; Atsushi Kanno[2]; Shintaro Hisatake[3]; Takeshi Yasui[1]
[1]2-1, Minamijosanjima-cho,, Tokushima; [2]4-2-1, Nukuikitamachi, Koganei; [3]1-1, Yanagito, Gifu

Photonic THz detection is a key in next-generation wireless communication (6G) to go beyond the upper frequency limit of existing wireless electronics. We present THz-to-optical carrier conversion based on a combination of two-

wavelength optical carrier and electro-optic polymer modulator.

22 September 2023

08:30 - 09:00 Closing Ceremonies **Symposia Theatre**

Chairperson(s): David Cooke,

09:00 - 09:45 Plenary Session 9 **Symposia Theatre**

Chairperson(s): Joo-Hiuk Son,

09:00 **Nanowires In Terahertz Photonics: Harder, Better, Stronger, Faster** **Fr-PL-1-1**

Hannah Joyce[1]; Stephanie Adeyemo[2]; Srabani Kar[2]; Jamie Lake[2]; Chawit Uswachoke[2]; Chennupati Jagadish[3]; Hoe Tan[3]; Yunyan Zhang[4]; Huiyun Liu[5]; Jessica Boland[6]; Djamshid Damry[7]; Michael Johnston[7]
[1]9 JJ Thomson Ave, Cambridge; [2]9 JJ Thomson Ave; [3]Research School of Physics; [4]School of Micro-Nano Electronics; [5]Department of Electronic and Electrical Engineerin; [6]Photon Science Institute; [7]Clarendon Laboratory

By virtue of their quasi one-dimensional geometries, III-V semiconductor nanowires present unique capabilities for terahertz photonic devices. Ultrafast terahertz polarisation modulators and miniature terahertz photoconductive detectors are two examples of such nanowire-based devices. By the same token, terahertz methods such as terahertz conductivity spectroscopy offer unparalleled insight into the electronic processes that dictate the performance of nanowire-based devices.

09:45 - 10:30 Plenary Session 10 **Symposia Theatre**

Chairperson(s): Joo-Hiuk Son,

09:45 **Quantum Vacuum Dressed Materials In Terahertz Cavities** **Fr-PL-2-1**

Junichiro Kono
6100 Main St, MS-378, Houston

This talk is about studying solids placed in terahertz cavities to uncover exotic new phases and phenomena in "ultrastrongly driven" materials in the complete absence of any external fields -- other than the fluctuating vacuum, or zero-

point, electromagnetic fields. Judicious engineering of such fluctuating quantum vacuum fields surrounding condensed matter inside high-Q and small-mode-volume terahertz cavities can lead to nonintuitive and ulrastrong modifications of electronic states, producing a quantum-vacuum-dressed material with novel properties. Recent theoretical predictions include cavity-enhanced, cavity-induced, and/or cavity-mediated electron-phonon coupling and superconductivity, electron pairing, anomalous Hall effect, ferroelectric phase transitions, quantum spin liquids, and photon condensation. This talk will describe our recent studies of various solid-state systems in terahertz cavities in search of such vacuum-induced phases of matter.

11:00 - 12:30 **tbd** **Symposia Theatre**

Chairperson(s): Tsuneyuki Ozaki,

11:00 - 12:30 **Laser Sources & Detectors VIII** **Cartier I**

Chairperson(s): Sergey Kovalev,

11:00 **High-performance Terahertz Optoelectronic Receivers Enabled By Monolithic Integration Of SBDs And UTC-PDs: Modelling And Design** **Fr-AM-2-1**

Iñigo Belio-Apaolaza[1]; James Seddon[2]; José M. Pérez-Escudero[3]; Iñigo Ederra[3]; Cyril C. Renaud[1]
[1]8TH floor Roberts Building, Torrington Place, London; [2]8TH floor Roberts Building, Torrington Place,, LONDON; [3]Av. Cataluña, s/n

In this work, we propose the monolithic integration of Schottky barrier diodes (SBDs) and uni-traveling-carrier photodiodes (UTC-PDs) to implement optoelectronic terahertz heterodyne receivers. By performing efficient frequency-mixing with SBDs and generating the local oscillator (LO) signal by optical means in UTC-PDs the virtues of both electronic and photonic domains are incorporated into the same receiver. A complete modelling process including semiconductor, electromagnetic, and non-linear harmonic domains is implemented to design a subharmonic mixer (SHM) at 220-330 GHz using antiparallel SBDs within the UTC-PD epitaxial structure. This is done in co-planar waveguide (CPW) on a silicon oxynitride film and semi-insulating indium phosphide substrate. Simulations show remarkable performance featuring a dual-side-band (DSB) conversion loss as low as 8.2 dB, a noise temperature of 2500 K, and an intermediate-frequency (IF) 3dB-bandwidth of 25 GHz, which is achieved with a driving photocurrent of 5-15 mA.

11:15 **Photoconductive, Continuous Wave THz Detectors Based On Rhodium** **Fr-AM-2-2**

Doped InGaAs With 125 DB Peak Dynamic Range

Milan Deumer; Shaffi Berrios; Steffen Breuer; Shahram Keyvaninia; Simon Nellen; Chris Phong Van Nguyen; Lars Liebermeister; Martin Schell; Robert Kohlhaas
Einsteinufer 37, Berlin

We present continuous-wave terahertz (cw THz) detectors with record high dynamic range of up to 125 dB at 0.12 THz, for the first time. These outstanding detectors are based on rhodium-doped InGaAs. In addition, the rhodium-doped detectors are compared with iron-doped detectors in terms of their electronic, dynamic and THz properties. Overall, the rhodium-doped devices show superior performance, which allows for a bandwidth of 4.5 THz with a 13 dB higher peak dynamic range than the previous record in a coherent setup.

11:30 **RF Waveform Noise Measurement By Electro-optic Sampling** **Fr-AM-2-3**

Filip Sosnicki; Ali Golestani; Michal Karpinski
Pasteura 5, Warszawa

The quickly increasing bandwidths of high-speed RF electronics, reaching already hundreds of GHz, create a need to characterize the wideband RF waveforms, as well as assess their noise. In particular, one of the challenges is to synchronize the wideband RF waveforms to optical clock signals by minimizing the time-interval-error jitter between the two signals. This way the RF waveforms may be used to modulate optical pulses for high-speed classical or quantum optical telecommunication. Here we show the experimental demonstration of electro-optic-sampling-inspired measurement of the repetitive RF waveform and its noise. We used commercially available traveling-wave electro-optic phase modulator in the Mach-Zehnder interferometer and a pulsed probing laser to measure the applied phase waveform on the pulse-by-pulse basis. provides the RF signal's amplitude noise and timing jitter by exploiting their different natures. We employed our method to high-frequency single-tone signals, as well as, to photonically generated high-speed pulses from a photodiode, measuring timing jitters of 240 fs and sub-8 fs, respectively. Our technique does not require any wideband RF measurement devices such as oscilloscopes or VNAs and can be employed in most telecom laboratories.

11:45 **2 THz Receiver For Thermospheric Science With 7000K DSB Noise Temperature At Room Temperature** **Fr-AM-2-4**

Alain Maestrini[1]; José Siles[2]; Choonsup Lee[1]; Robert Lin[1]; Liju Philip[1]; Imran Mehdi[1]
[1]4800 Oak Grove Drive, Pasadena; [2]4800 Oak Grove Driver, Pasadena

We report on the design, fabrication and preliminary characterization of the first fully solid-state room- temperature heterodyne receiver working around 2 THz. The receiver is based on a state-of-the-art subharmonically-pumped GaAs Schottky mixer and a state-of-the-art Schottky frequency multiplier chain at 1.0 THz that produces ~2mW of power. The receiver demonstrates a double-side-band (DSB) noise temperature of less than 7000 K at room temperature. This result enables the construction of a space-borne heterodyne instrument to

measure the wind velocities in the Earth's thermosphere by observing the emission of the atomic oxygen at 2.06THz.

12:00 **Adaptive THz Beam Steering At UTC-PD Array By Genetic Algorithm** **Fr-AM-2-5**

Ming Che[1]; Kazuya Kondo[2]; Ryo Doi[1]; Kazutoshi Kato[1]
[1]Kyushu University, 744 Motooka Nishi-ku, Fukuoka; [2]Kyushu University, 744 Motooka Nishi-ku

We developed a fiber-coupled uni-traveling-carrier photodiode (UTC-PD) array chip for the purpose of combining the generated THz waves, and the feasibility of 300 GHz beam steering with the aid of a genetic algorithm is demonstrated in this work. Not only is this algorithm capable of automatically compensating for the optical path difference arising from the inconsistent lengths of coupled fibers, but it can also calculate the optimal phase shift in each channel for deflecting the THz beam to a predetermined angle. The implementation of this optimization algorithm in THz beam steering provides an attractive solution for efficient THz wireless communication or imaging applications in a large-scale UTC-PD array.

12:15 **Purely Photonic Wireless Link At 120 GHz With A Photoconductive Antenna As Heterodyne Receiver** **Fr-AM-2-6**

Milan Deumer; Lars Liebermeister; Oliver Stiewe; Simon Nellen; Robert B. Kohlhaas; Robert Elschner; Colja Schubert; Ronald Freund; Martin Schell
Einsteinufer 37, Berlin
Optoelectronic generation and detection of THz signals are well-established in THz-sensing. Beyond sensing, there is great potential for using these photonic devices for wireless communication at (sub-)terahertz carrier frequencies. While photodiode-based emitters are often used in broadband wireless links, receivers based on photoconductive antennas are rarely found due to their limited electrical bandwidth of the intermediate frequency (IF). To demonstrate the potential of fully photonic wireless links, we have developed an efficient photoconductive antenna (PCA) that is integrated with a passive radio frequency (RF) circuit to support high IFs. The PCA is based on iron-doped indium gallium arsenide (InGaAs:Fe) and is packaged in a compact fiber-pigtail module. The RF transition from the antenna to coaxial output provides an IF bandwidth of 11 GHz enabling wide data channels. With this receiver, we report on a purely photonic wireless communication link over a distance of 1 m using a PIN photodiode as the transmitter. Using quaternary quadrature amplitude modulation (4-QAM), we achieved error-free data transmission at net data rates of up to 10 Gbps. This successful demonstration is an important step towards realizing the full potential of photonic technology in (sub-)THz communications.

11:00 - 12:30 **Metasurfaces & Plasmonics III** **Cartier II**

Chairperson(s): Yushan Zeng,

11:00 **Broadband Achromatic Terahertz Metalens Based On All-dielectric Sandwich-Shaped Meta-atoms** **Fr-AM-3-1**

Yi Xu[1]; Jianqiang Gu[1]; Quanlong Yang[2]; Jiaguang Han[3]
[1]92 Weijin Road, Nankai District, 605, Block C, Teaching Building No. 26, Tianjin; [2]932 Lushan South Road; [3]1 Jinji Road

We introduced a neoteric hybrid sandwich-shaped meta-atom paradigm made up of silicon-silica-silicon and experimentally demonstrated an achromatic terahertz metalens by leveraging these hybrid all-dielectric meta-atoms which can fundamentally expand and enrich the propagation phase and dispersion range while maintain high transmittance and linear dispersion relation over the target bandwidth. As a result, this metalens achieved a prominent achromatic and polarization-independent focusing performance from 0.5 to 1.1 THz with a numerical aperture of 0.47 and an average efficiency as high as 43.1%. Our work not only provides an outstanding achromatic metalens for the terahertz band but also offers a meta-atom regime that may further trigger the R&D of achromatic metasurfaces yet not limited to THz bands.

11:15 **Dielectric Interference Metasurface For Five-Channel Terahertz Field Control** **Fr-AM-3-2**

Tong Wu[1]; Xueqian Zhang[2]; Quan Xu[2]; Jiaguang Han[2]
[1]Tianjin University No. 92, Weijin Road, Nankai District, Tianjin ,China, Tianjin; [2]Tianjin University No. 92, Weijin Road, Nankai Dis

Metasurfaces have attracted growing attention due to their ability in tailoring the complex vectorial field (CVF) of the electromagnetic wave, which can be characterized by its amplitude, phase, and polarization. Here, a new metasurface paradigm is proposed, which can analytically achieve complete CVF control by designing polarization-dependent interference effect. Based on this, a five-channel imaging meta-hologram is experimentally demonstrated in the terahertz (THz) regime. Our method provides a new avenue toward novel and multi-functional THz devices for broad applications.

11:30 **Solid-state Intensity Modulator Based On A Single-layer Graphene-loaded Metasurface Operating At 2.4 THz** **Fr-AM-3-3**

Ruqiao Xia; Nikita Almond; Harvey Beere; David Ritchie; Wladislaw Michailow
Cavendish Laboratory, 19 J J Thomson Avenue, Cambridge

We demonstrate a free-standing solid-state terahertz intensity modulator operating at 2.4 THz that achieves a modulation depth greater than 59% of the intensity of the transmitted radiation using a single-layer graphene-metal metasurface. We employ a brickwork antenna structure because of its potential for high modulation speed and large modulation depth. An equivalent circuit model for the brickwork antenna structure has been developed to optimize the geometric antenna parameters for the desired frequency response. The device has been fabricated and characterized using terahertz time-domain spectroscopy. By gating the graphene, the optical response of the device is modulated electronically. This results in a large change in the measured transmittance.

11:45 **Nonlinear Metasurfaces For Amplitude-controllable And Pump-handedness-selective THz Generation** **Fr-AM-3-4**

Qingwei Wang[1]; Xi Feng[1]; Yongchang Lu[1]; Li Niu[2]; Quan Xu[2]; Xueqian Zhang[2]; Jiaguang Han[3]
[1]92 Weijin Road, Nankai District, Tianjin, China, Tianjin; [2]92 Weijin Road, Nankai District, Tianjin, China; [3]92 Weijin Road, Nankai District, Tianjin, China, No. 1, Jinji Road, Guilin, Guangxi, 541004, China

Integrating generation and manipulation processes of terahertz (THz) waves into a single device is crucial for miniaturizing THz systems. Nonlinear metasurfaces have recently emerged as a flexible platform to accomplish this task. However, such existing THz devices have limitations in achieving more controlling freedoms while being multi-functional. In this study, we introduce the coupling effect between different meta-atoms into the unit-cell design and experimentally validate its powerfulness in controlling nonlinear THz generation. Two types of meta-molecules are experimentally demonstrated, where the meta-molecule with achiral coupling allows full control over the THz amplitude, while the meta-molecule with chiral coupling makes the THz generation sensitive to the pump handedness. Moreover, the meta-molecule with giant chiral coupling further enables a multiplexing-based handedness-selective nonlinear metasurface, which generates THz beams with different orbital angular momentums (OAMs). This approach holds great promise for developing various integrated nonlinear THz devices.

12:00 **Enhanced THz Field Detection Using A Bull's-eye Plasmonic Antenna** **Fr-AM-3-5**

Hesam Heydarian[1]; Xitong Xie[2]; Aswin Vishnuradhan[1]; Eeswar Kumar Yalavarthi[1]; Arnaud Weck[2]; Angela Gamouras[1]; Jean-Michel Ménard[1]
[1]Department of Physics, Ottawa; [2]Department of Mechanical Engineering, Ottawa

We present a bull's-eye plasmonic antenna for enhanced terahertz (THz) field detection in an electro-optic sampling (EOS) scheme. We use numerical simulation to optimize the antenna's geometrical parameters to achieve a long nonlinear interaction length between a near-infrared gating pulse and locally enhanced THz field at the center of the plasmonic structure. The direct laser writing method is then employed to fabricate the gold eye-antenna on a 110-oriented gallium phosphide (GaP) substrate. The performance of the proposed nonlinear plasmonic detector is characterized with a time-resolved THz setup. Preliminary results show an improvement of the EOS detection sensitivity by 2.5 times at the plasmonic resonance frequency of around 2.5 THz.

12:15 **A Planar Plasmonic Reflector For Polaritons** **Fr-AM-3-6**

Shima Rajabali[1]; Josefine Enkner[1]; Erika Cortese[2]; Mattias Beck[1]; Simone De Liberato[2]; Jerome Faist[1]; Giacomo Scalari[1]
[1]Auguste-Piccard-Hof 1, Zürich; [2]Southampton

The coupling between propagating plasmons in two-dimensional electron gases

and deeply subwavelength resonators with submicron gaps can lead to energy leakage and limit the achievable coupling strength. To overcome this physical limit, a "plasmonic reflector" structure, based on periodic one-dimensional structures on both sides of the resonator gap, is proposed to optically reflect and re-confine this leakage back in the cavity.

11:00 - 12:30 **Active Sensing 3** **International I**

Chairperson(s): Marco Peccianti,

11:00 **Terahertz Circular Dichroism Imaging Of Twisted-layered Moiré Metasurfaces** **Fr-AM-4-1**

Katsuhiko Miyamoto[1]; Seigo Ohno[2]; Souma Makihara[1]; Takumi Yoichi[1]; Takeo Minari[3]; Takashige Omatsu[1]; Shota Tsuji[1]

[1]1-33, Yayoi-cho, Inage-ku, Chiba; [2]6-3, Aza-Aoba, Aoba-ku, Sendai; [3]1-1 Namiki, Tsukuba

We demonstrate a terahertz circular dichroism imaging to identify the structural chirality of twisted-layered moiré metasurfaces fabricated by nanoimprinting technology.

11:15 **A High Pump Power Commercial THz TDS System For The Hyperspectral Imaging Of New Classes Of Metasurfaces** **Fr-AM-4-2**

Lauren Gingras[1]; Jacob Pettine[2]; Peter Adel[1]; Ronald Holzwarth[1]; Hou-Tong Chen[2]

[1]Bunsenstr. 5, Martinsried; [2]Los Alamos National Laboratory

We demonstrate the ability to image a new class of metamaterials using a newly developed 1 W output power module at 780 nm. The symmetry-broken optoelectronic metasurfaces generate THz electric pulses with spatially patterned polarization maps. The unique hybrid 780 nm pump - 1560 nm probe system leverages state-of-the-art fiber-coupled photoconductive antennas to image the far field components in a single-pixel raster-scan fashion without compromising on sensitivity or rapidity of execution. We observe a spatially patterned THz electric field distribution in the far field as direct evidence of the direct THz vector beam generation capabilities of the optoelectronic metasurfaces.

11:30 **High Q Tunable THz Plasmonic Metasurface Based On InSb Particles** **Fr-AM-4-3**

Sina Aghili[1]; Rasoul Alaee[2]; Aydin Amini[3]; Ksenia Dolgaleva[2]

[1]75 Laurier Ave E, Ottawa, ON K1N 6N5, Ottawa; [2]75 Laurier Ave E, Ottawa, ON K1N 6N5; [3]1280 Main St W, Hamilton, ON L8S 4L8

We present a novel InSb-based metasurface design for THz plasmonic devices capable of realizing an ultra-narrow linewidth response, dynamically tunable via external stimulation. The metasurface comprises an ordered periodic array of InSb antennas embedded in a homogeneous medium, specifically designed to support a surface lattice resonance (SLR) with an ultra-high Q factor of 2500. This is achieved through the constructive interaction of localized surface

plasmon resonances (LSPRs) of individual elements at the Rayleigh anomaly (RA) diffraction frequency. When a weak static magnetic field is applied, the metasurface gives rise to magneto-plasmonic modes due to Zeeman-splitting effects, facilitating a multiband response. The spectral position and magnitude of these modes are highly dependent on the magnetic field strength, offering a versatile approach for controlling the metasurface's multi-band response. This tunable behavior makes this ultra-high Q InSb-based metasurface highly promising for various THz applications, including imaging, sensing, and lasing systems at the sub-wavelength scale.

11:45 **Phase-Correcting Millimeter-Wave Miter Bend Mirrors To Reduce Mode Conversion** **Fr-AM-4-4**

Kyle Thackston[1]; Alex Laut[2]; James Anderson[2]
[1]3550 General Atomics Ct, G13-502, San Diego; [2]3550 General Atomics Ct, San Diego

High power, low loss mm-wave transmission line systems such as those used in electron cyclotron heating in fusion energy experiments require waveguide miter bends for practical transmission line systems. For overmoded systems, these flat mirror miter bends result in inevitable mode conversion, reducing transmission line efficiency and imposing further system integration constraints. Previous attempts at designing phase correcting mirrors have relied on symmetric gap models of miter bends which ignore the inherent asymmetry of the component. This work discusses progress on using more advanced modeling to generate phase correcting mirrors and reduce mode conversion in miter bends.

12:00 **Electron Cyclotron Emission Diagnostics For Next Generation Nuclear Fusion Experiments, Such As DEMO** **Fr-AM-4-5**

Marco Zerbini; Massimo Alonzo; Giuliano Rocchi
via E. Fermi, 45, Frascati

The extreme conditions of fusion plasmas pose major challenges to the realization of the diagnostics, both for physics measurements and on the engineering side. The implementation of ECE diagnostics requires antennas placed in front of the plasma, an arrangement shared with microwave reflectometry, which makes the task even more challenging. Given the expected high thermal load and neutron flux in a fusion reactor a serious issue of antennas alteration (hence calibration reliability) exists. In addition plasma contamination arising from the material stripped from the antennae by the plasma erosion can seriously affect plasma operations. A specifically tailored ECE diagnostic system is being developed to operate with the perspective demonstration tokamak fusion reactor (DEMO).

12:15 **Optimized Terahertz Hyperspectral Analysis In The Frequency- And Time- Domains** **Fr-AM-4-6**

Margaret Granger; Alexa Urrea; Jeremy Johnson
BNSN C100, Provo

We optimize a fully automated method to differentiate unique sample components via hyperspectral imaging using terahertz time-domain spectroscopy (THz-TDS). Standard methods for THz hyperspectral image analysis rely on extracting amplitude data from the frequency-domain THz

transmission spectra. We show benefits in analysis made possible by the simultaneous use of both amplitude and phase components of the THz transmission data. Incorporating full-field THz information improves the integrity of sample component differentiation with respect to sample composition. Furthermore, we present on the ability to achieve comparable sample component separation by performing analysis on the time-domain THz data. Forgoing the Fourier transformation reduces computational time and costs while maintaining high quality data interpretability. As a demonstration of methods, we automatically distinguish the structure of a split-ring resonator metamaterial sample.

11:00 - 12:30 **Metamaterials, plasmonics and nanomaterials** **International II**

Chairperson(s): Junichiro Kono,

11:00 **Dynamic Transmission Of Terahertz Waves Through Bifeo3 Film Under Out Of Plane Applied Bias** **Fr-AM-5-3**

Shreeya Rane; Arun Jana; Palash Roy Choudhury; Dibakar Roy Chowdhury
Mahindra University Bahadurpally, Mahindra University Bahadurpally, Hyderabad

We have experimentally studied the multiferroic BiFeO3 (BFO) film by engaging Terahertz Time Domain Spectroscopy (THz-TDS) under externally provided longitudinal bias. Through our experiments, we have observed that the amplitude of THz radiation is dynamically modulated in the frequency range of 0.2-1 THz. This modulation can be attributed to the alignment of ferro-electric domains under the applied bias (0 to 600 kV/cm), resulting in an amplitude modulation of around 10%.

11:15 **Femtosecond Laser Induced Emission Of Coherent Terahertz Pulses From Ruthenium Thin Films** **Fr-AM-5-1**

Lorenzo Cruciani[1]; Stefan van Vliet[1]; Alessandro Troglia[2]; Roland Bliem[2]; Klaasjan van Druten[3]; Paul Planken[2]
[1]Science Park 106, Amsterdam; [2]Science Park 106; [3]Science Park 904

We demonstrate emission of terahertz pulses from Ru thin films through a second-order non-linear optical process. Ru deposited on different substrates showed different emission properties. For Ru on glass, a strong laser-induced increase in THz emission amplitude is observed when exposing the sample to optical powers above a certain threshold. We show that at these powers laser-induced oxidation occurs, resulting in an increased slope of the linear dependence of the THz-electric-field amplitude on pump power. The THz-electric-field, in this case, is mainly polarized along the sample surface, pointing in the same direction everywhere on the surface. In contrast to Ru on glass, the electric-field amplitude of the THz pulses emitted by Ru on sapphire

and on CaF2 shows a simple single linear dependence on pump power. Surprisingly, it is polarized orthogonal to the sample surface. However, in this case thermal oxidation enhances the emission and introduces an additional polarization component along the sample surface, similar to as-deposited Ru on glass. Our results show a strong correlation between emission strength and the degree of oxidation. Furthermore, they demonstrate that the knowledge of the state of the sample surface is crucial for the interpretation of THz emission experiments from (non-magnetic) metal surfaces.

11:30 **All-dielectric Tunable Q-factor Guided-mode Resonance Using Quasi-bound States In The Continuum** **Fr-AM-5-2**

Hyeon Sang Bark
123 Cheomdan-gwagiro(Oryung-dong), Advanced Photonics Research Institute 317, Gwangju

we designed tunable guided-mode resonance filter (GMRF). To control the Q-factor, we propose a dual ridge GMRF structure with ridges on both sides of the core waveguide. all-dielectric GMR can adjust the Q-factor at a fixed frequency by using quasi-bound state in the continuum (BIC). By changing the structural symmetry and asymmetry of the two ridges, the Q-factor can be maximized and minimized at a fixed resonant frequency, enabling a tunable filter. The proposed filter design was simulated using rigorous coupled wave analysis (RCWA) methods and finite-difference frequency-domain (FDFD) in the THz region

11:45 **Printed Terahertz Spiral Zone Plate For Vortex Beam Generation** **Fr-AM-5-4**

Redwan Ahmad[1]; Léo Guiramand[2]; Mariia Zhuldybina[2]; Xavier Ropagnol[2]; Ngoc Duc Trinh[3]; Chloé Bois[3]; Francois Blanchard[2]
[1]Apt 12, 4665 Avenue Bourret, Montreal; [2]1100 Notre-Dame St W, Montreal; [3]999 Av. Émile-Journault, Montreal

In this work, we fabricated and characterized printed terahertz (THz) spiral zone plates (THz-SZPs). Fabrication has been done using industrial roll-to-roll (R2R) continuous press with a flexography printing unit. From both simulation and experiment results it is seen that, printed spiral zone plates with topological charges, l = 1, 2, and 3, can convert the Gaussian THz beam into vortex THz beam accordingly with a focal length of 2.0 cm at the operating frequency of 0.36 THz.

12:00 **Photonic Crystal THz Leaky-Wave Antenna 3D-Printed In Alumina** **Fr-AM-5-5**

Hichem Guerboukha[1]; Masoud Sakaki[2]; Rabi Shrestha[1]; Jingwen Li[3]; Niels Benson[4]; Daniel Mittleman[5]
[1]184 Hope St, Providence, RI 02912, Providence; [2]Universitat Duisburg-Essen; [3]Jiangnan University; [4]Universität Duisburg-Essen; [5]184 Hope St, Providence, RI 02912, United States, Providence

We report a photonic crystal-based THz leaky-wave antenna 3D printed in alumina. Our design can support the transmission of hundreds of Mbit/s through the leakage of an engineered defect mode.

12:15 **Microscope For Electromagnetic Field Distribution Imaging With Intrinsic Josephson Junctions** **Fr-AM-5-6**

Zihan Wei[1]; Ping Zhang[1]; Yangyang Lv[1]; Hancong Sun[2]; Yonglei Wang[1]; Huabing Wang[1]; Peiheng Wu[1]

[1]Nanjing University Xianlin Campus, Nanjing; [2]Jiangning District, Nanjing

Bi2Sr2CaCu2O8+x (BSCCO) single crystals have been intensively studied in the context of terahertz (THz) sources and detectors, etc. This work presents a microscope setup utilizing a high-temperature superconducting intrinsic Josephson probe for spatial electromagnetic field distributions. While keeping the BSCCO probes in superconducting states and regular operation, both room-temperature samples and cryogenic-temperature samples can be characterized. This microscope not only realizes a new practical application for high-temperature superconductors, but also provides an essential probe for high-frequency electronic devices.