Development of a hybrid THz camera using synchronized two-color laser radiation

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Abstract—**We demonstrate a hybrid system for THz raster scan imaging using frequency-stabilized DFB lasers for electro-optic detection. The system combines a 0.65-THz micro-electronic narrow-band emitter with two synchronized diode lasers, providing two-color laser radiation. The functional principle promises three-dimensional real-time imaging capabilities.**

I. Introduction And Background

Recently, we developed a hybrid system for active continuous-wave (CW) THz imaging using a micro-electronic radiation source and a laser operating in the near-infrared for optoelectronic THz detection[1-3]. The measurement of the THz radiation is achieved via electro-optic mixing[4], which readily enables multi-pixel THz detection and promises three-dimensional real-time imaging capabilities.

It proved convenient to employ an ultrashort-pulsed Ti:sapphire laser for this purpose. Its repetition rate was mixed with the frequency of the THz radiation to derive an intermediate frequency (IF) for data processing. The fact that the repetition rate is extremely stable enabled us to avoid active synchronization of the laser with the THz source. Ultra-short pulsed laser systems, however, are relatively large, cost- and maintenance-intensive. It is desirable to replace them by two synchronized diode lasers to achieve a THz beat signal.

We developed a three-dimensional THz imaging system based on electro-optic detection using a system of two temperature-stabilized DFB lasers (DFB: distributed feed-back) and a 0.65-THz micro-electronic narrow-band emitter. The fast laser control circuit for laser synchronization provides a stable difference frequency between the two lasers.

II. Experimental Approach

The setup is shown in Fig. 1. The microelectronic THz emitter is based on a highly frequency-stable W-band source from Radiometer Physics. Its radiation is first amplified, then frequency-multiplied by a factor of 6 to achieve 0.5 mW at 650 GHz. This radiation is emitted by a horn antenna, collimated with a Picarin lens, and guided to the reference detector, respectively the object from where some of the radiation returns and is focused onto the signal detector. Both detectors, acting as mixers, are read out by the linearly polarized light of the two diode lasers whose radiation is coupled with a 2x2 polarization-maintaining fiber combiner and guided to the detectors through optical fibers. Each laser emits on the order of 100 mW of which about half is available behind the fibers at the detectors.

The detectors consist of 1-mm-thick electro-optically active ZnTe crystals followed by pairs of photodiodes for balanced detection. The reference detector serves to determine the detuning (in the range of 10 MHz) of the difference frequency of the two lasers relative to the frequency of the THz radiation. The output signal of the reference detector is used as lock-in reference and for input to the laser synchronization electronics. The signal detector, receiving the THz radiation returning from the object, is used to measure both the amplitude of the signal and its relative phase with respect to the reference signal with a lock-in amplifier. By moving the object via an x-y-translation stage, a raster scan generates a two-dimensional reflected-amplitude image of the scanned object and provides the phase data encoding the depth information needed to reconstruct three-dimensional images.

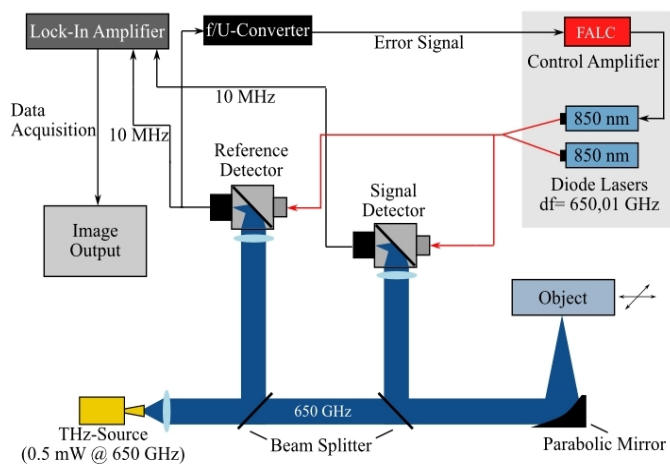

Fig.1: Scheme of the system setup

III. Results

The challenge in the development of this CW hybrid THz imaging system has been the need of an active stabilization of the laser difference frequency. Unstabilized, it varies by tens of MHz on a time scale of seconds. For phase-sensitive measurements with a lock-in amplifier, the signal of the reference detector must have a sufficiently high signal-to-noise ratio (SNR) and a linewidth well below 1 MHz.

By development and optimization of a fast laser control

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circuit, we achieve now a linewidth below 100 kHz and a satisfactory SNR. Fig. 2 shows that the two lasers can be stabilized with a residual linewidth of 61 kHz (difference frequency of 11.6 MHz in this example).

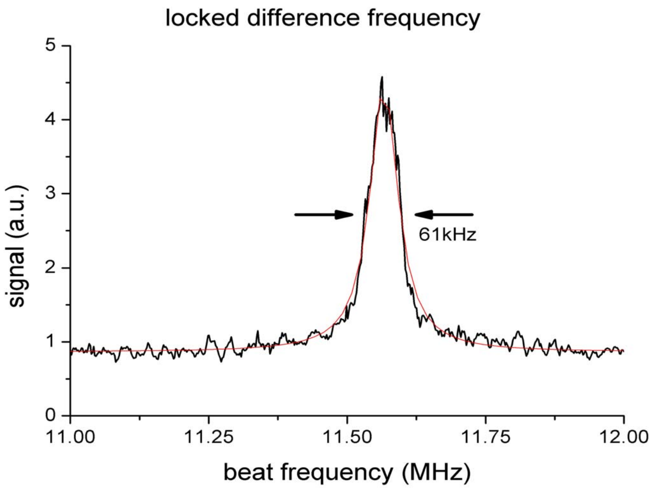

Fig.2: Frequency-locked two-color laser signal.

In order to synchronize the lasers with the THz emitter, the IF signal from the reference detector is directed to an f/U-converter (f/U: frequency to voltage) which provides an error signal for the laser stabilization electronics. The f/U-converter contains a voltage-controlled oscillator (VCO) whose frequency is compared with the IF of the input signal in a phase-locked loop (PLL). The circuit provides a voltage error signal for frequency offsets of several MHz.

This error signal is provided to a high-speed control amplifier (FALC 110, with the abbreviation standing for fast analog linewidth control). The amplifier, now commercially available from TOPTICA Photonics for diode laser stabilization, has a bandwidth of 10 MHz. It generates a control voltage signal which is fed to the fast laser driver electronics of one of the two diode lasers, and used there to adjust the drive current. The frequency of the laser radiation changes because of the slight current-induced temperature changes in the semiconductor material. This fast laser control circuit allows one to lock the lasers to a pre-defined difference frequency.

IV. Outlook

With this system, we explore single and multi-pixel phase-sensitive raster-scan imaging at 0.65 THz. In earlier studies, we have seen that the performance of multi-pixel electro-optic imaging is limited by the laser shot noise. In order to enhance the number of pixels which can be measured simultaneously, one can take advantage of the availability of tapered laser amplifiers which permit to achieve power levels of several hundred mW while maintaining fundamental-mode operation[5].

V. Acknowledgments

This work is funded by the LYNKEUS project of the Federal Ministry of Education and Research Germany (BMBF).

References

[1] T. Löffler, T. May, C. am Weg, A. Alcin, B. Hils, H.G. Roskos, “Continuous-wave terahertz imaging with a hybrid system,” *Appl. Phys. Lett.* **90**, 091111 (2007).

[2] T. May, C. am Weg, A. Alcin, B. Hils, T. Löffler, H.G. Roskos, “Towards an active real-time THz camera: first realization of a hybrid system,” in *Proc. of SPIE*, **6549**, 654907 (2007).

[3] C. am Weg, T. May, B. Hils, T. Löffler, H.G. Roskos, “On the way to an active terahertz camera: Optic design and its experimental verification,” in *Conf. Digest of IRMMW-THz 2007*, **Vol. 1**, 356, Cardiff, UK (2007).

[4] Q. Wu, M. Litz, and X.-C. Zhang, “Broadband detection capability of ZnTe electro-optic field detectors,” *Appl. Phys. Lett.* **68**, 2924 (1996).

[5] TOPTICA Photonics AG, http://www.toptica.com.

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