Terahertz Photomixing in InP/InGaAs UTC-PD Integrated with TEM Horn Antennas

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***Abstract*—Photomixers that consist in a uni-travelling-carrier photodiode (UTC-PD) integrated with a TEM horn antenna (TEM-HA) have been realized and characterized.**

I. Introduction And Background

ONE way to generate millimeter/sub-millimeter continuous waves up to the terahertz range is to use photonics, by mixing two optical signals in a fast photodetector lying at the feedpoint of a terahertz antenna. Most of photodetectors used in photomixing experiment are based on short lifetime photoconductive materials such as low-temperature grown gallium arsenide, ErAs:$In_{0.53}Ga_{0.47}As$ [1] or ion-irradiated $In_{0.53}Ga_{0.47}As$ [2]. The former operates at a wavelength of 0.8 µm while the latters are sensitive to a wavelength of 1.55 µm in order to benefit from the abundant optical components that exist at telecom wavelengths. An interesting alternative to these photodetectors is the uni-travelling-carrier photodiode (UTC-PD). The UTC-PD exhibits high cutoff frequency and also high saturation output power due to its operation mode and, also, operates at a wavelength of 1.55 µm. Contrary to conventionnal *pin* photodiode, absorption occurs in a *p*-doped layer, so only electrons are the active carrier travelling across the structure. A uni-travelling-carrier photodiode (UTC-PD) monolithically integrated with a wideband log-periodic toothed antenna have shown a record output power of 2.3 µW at 1.04 THz (photocurrent: 13 mA, incident optical power: 430 mW) [3]. Here, we present the photomixing results on a UTC-PD integrated with a new 3D antenna : the Transverse Electro-Magnetic Horn Antenna (TEM-HA)[4].

II. Device Fabrication

The InP/InGaAs UTC-PD epitaxial layers were grown on a semi-insulating InP substrate by gas-source molecular beam epitaxy. The absorption layer consist of a 100 nm-thick $In_xGa_{1-x}As$ compositional graded and 137 nm-thick collector layer. The double-mesa UTC-PD's were realized by conventional e-beam lithography and a combination of wet and dry etching. Photodiodes are monolithically integrated with a 50 Ω coplanar waveguide (CPW) that feed the TEM-HA. The TEM-HA shows a high efficiency and a large bandwidth. Furthermore, this antenna enables the illumination of the UTC-PD from the backside of the substrate because it does not require a silicon lens to collect the radiated waves. The TEM-HA is made up of a triangular conductive sheet inclined above the ground plane and supported by a PTFE cuboid, as shown in figure 1. The TEM-HA is fabricated on a sacrificial layer by standard optical lithography and chemical etching. The structures are then released by dissolving the sacrificial layer and dried in a supercritical CO_2 dryer. Once the structure is released, the triangular conductive sheet is lifted to an angle of 15° and bonded to a metallized PTFE cuboid as shown in figure 1. The bias voltage of the UTC-PD is achevied by gold wires, respectively brazed to the metallized PTFE cuboid and to the ground plane.

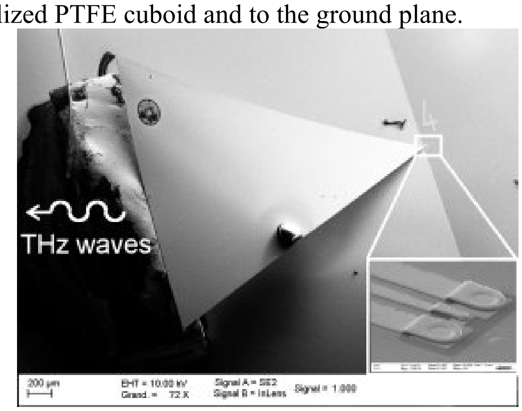

Figure 1 : SEM view of a UTC-PD integrated with a TEM-HA

III. Characterization

Figure 2 shows the experimental setup for the continuous-wave (CW) output-power measurement using the photomixing technique. The two optical signals are generated by two wavelength-tunable lasers (Agilent 81642A) and then coupled and injected in an erbium doped fiber amplifier (EDFA). Then, the optical beam is chopped and focused on the UTC-PD from the backside. The THz waves are radiated directly in the air by the horn, collimated by a parabolic mirror and detected by an liquid-helium-cooled silicon bolometer (QMC QSiB). The absolute THz power is estimated assuming a responsivity of 12 kV/W given by the manufacturer. Preliminary photomixing experiments were done using an Erickson PM4 calorimeter instead of silicon bolometer.

IV. Results

Two photodiodes, with different diameters (4 and 3 µm), have been characterized. As shown in figure 3, the THz power is a quasi quadratic function of the dc photocurrent. Due to variations of the photocurrent during the experiments, the points on P(f) curve on figure 4 are for a normalized photocurrent. The CR cutoff frequency of the 4 µm

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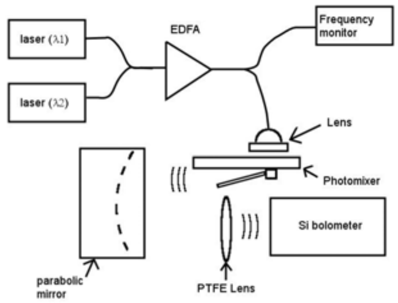

Figure 2 : Schematic drawing of the experimental setup for output power measurement

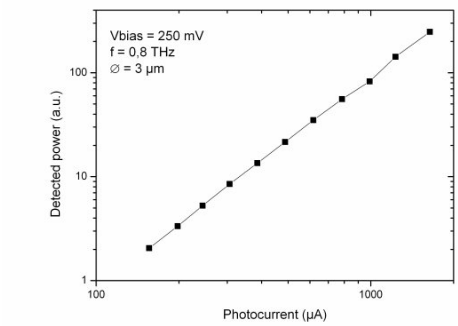

Figure 3 : Relationship between detected THz power and frequency for UTC-PD with diameter of 4 and 3 µm

diameter UTC-PD is, in first approximation, estimated to 220 GHz, while the 3 µm diameter one is about 400 GHz. Assuming that the two devices are from the same epitaxial growth, the bandwidth due to carriers travelling should be the same for both photodiode. Above 400 GHz, the CR cutoff frequency of the smallest UTC-PD, a ratio of about 4 should be found between the output powers. The theory seems to quite agree with experimental datas. The decrease of the junction capacitance can increase the output power of the photomixer at identical photocurrent.

V. Practical Application

An application of THz waves generation by photomixing is spectroscopy. One important need in spectroscopy experiments is spectral purity. In our setup the spectral purity of photomixer should be 20 MHz. The figure 5 shows the detected THz signal through about 15 cm of air at room pressure and temperature. We have demonstrated that at frequencies above 1 THz, the fabricated photomixer produces enough output power to detect some absorption lines of water vapor.

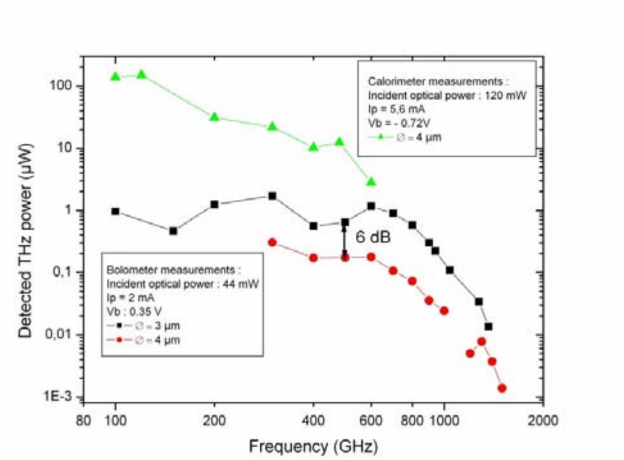

Figure 4 : Relationship between detected THz power and frequency for UTC-PD with diameter of 4 and 3 µm

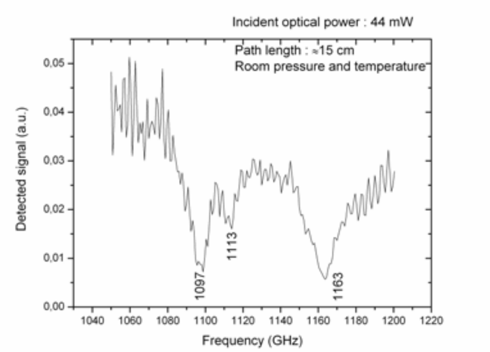

Figure 5 : Absorption lines of water vapor measured at room condition identified with the JPL database

VI. Conclusion

In this paper, we have presented our results achieved with two photomixers made up of UTC-PD, with a 4 and 3 µm diameter, and a TEM-HA. Our results show that a decrease of the junction capacitance is an interesting way to increase the THz power generated. The thermal tolerance of such devices has to be investigated.

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