Micro-pin Photodiode-Antenna Chip Packaged for Sub-THz Applications

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***Abstract*—A Sub-THz transmitter module based on a micro-pin-antenna chip and a silicon lens for focusing RF radiation is presented. The radiated power of the module is up to -13.5 dBm and exhibits a power radiation of 1 µW at 200 GHz and higher.**

Keywords-waveguide integrated micro-pin photodiode; monolithic antenna; sub-THz; heterodyne signal generation and detection

I. Introduction

The THz-technology has been impressively developed in the last years due to great interest in applications of fiber-based radio and THz-spectroscopy. One of the great challenges in the THz technology is the realization of emitters and receivers. The advantage of using photodiodes (PD) for the generation of CW THz signals is the high output power. An UTC-PD with 148 µW and 25 µW output power at 457 and 914 GHz, respectively, has being reported in [1].

In one of our recent papers [2], we described the fabrication and the characteristics of the monolithically integrated pin photodiode and a planar antenna chip. In [3] a short report on a packaged sub-THz transmitter module was published. The main work of this paper is to present the detailed results of the module characteristics and its applications also to higher frequencies.

II. Micro-pin Photodiode and Module Packaging

To build widely tunable THz transmitters, not only the photodiode but also the antenna should have broadband characteristics. Therefore we designed a 5x7 µm^2 photodiode with more than 150 GHz bandwidth as shown in Fig. 1 and a frequency independent antenna, which comprises a logarithmic periodic circularly-toothed structure which is indicated in Fig. 1 (inset-lower). The micro-pin photodetector chip with optimized evanescent coupling scheme comprises a pin-mesa PD, an antenna and a spot size converter for effective fiber-chip coupling. All devices are integrated on a semi-insulating waveguide layer stack being composed of three quaternary optical guiding layers embedded within InP and an upper thicker waveguide layer (Fig.1, inset-top). A contact and matching layer with protrusion length L controls the optical intensity distribution in the device, it provides the refractive index match between the waveguide and the absorber and serves as n-contact layer with low resistance [4]. The intrinsic InGaAs absorption layer with 200 nm thickness provides a short transit time within the PD. The pin-mesa with a size of 5x7 µm^2 has a capacitance of about 21 fF and drives the antenna with approximately 70 Ω feedpoint impedance. The whole transmitter was fabricated on InP:Fe substrate employing metal organic vapor phase epitaxy (MOVPE) for the layer stack of the micro-pin PD.

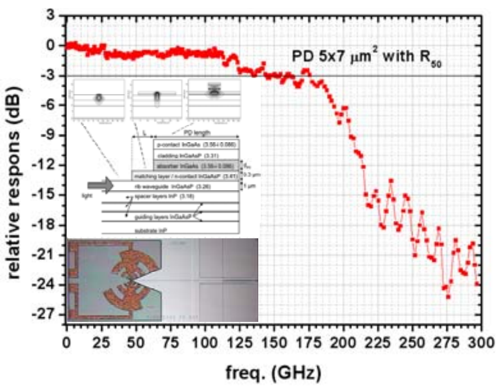

Figure 1. Frequency response of a micro-pin photodiode, inset-top: layer stack of the chip, fabricated micro-pin antenna chip (inset-lower).

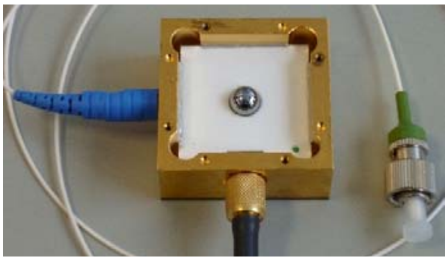

Figure 2. Packaged micro-pin antenna transmitter module with a Si-lens and a pig-tailed fiber.

The pin-antenna chip was packaged into a transmitter module with a fiber pigtail and a Si-lens located on the backside of the chip (Fig. 2). At (sub)mm-wavelengths Si-lenses are normally applied to eliminate the loss of the integrated circuit antennas due to substrate modes. The advantage of mounting the chip on such a Si-lens is that 97.8% [2] of the radiated power from the antenna is being directed to the lens side.

III. MEASUREMENTS

After module packaging, we have measured the transmitter with a heterodyne source and a power meter with a feed horn antenna as a receiver. The optical signal is monitored by an OSA. The measurement setup is shown in Fig. 3.

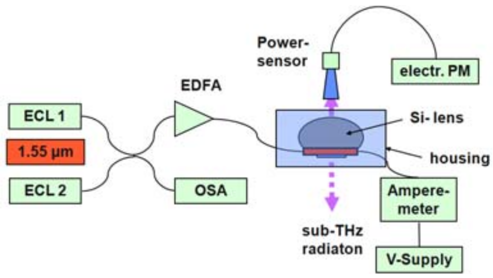

Figure 3. Heterodyne based measurement setup.

For the power measurement the horn antenna is mounted directly above the Si-lens, so that the emitted electrical power could be optimally received. The relation between the output electrical power and the input optical power is measured at 2 V reverse bias and 100 GHz beating frequency. The transmitter module exhibits a responsivity of 0.22 A/W and has a linear characteristic up to 15 dBm optical input power, as is shown in Fig. 4, which additionally indicates that the output power from the Si-lens is nearly 10 dB higher than that from the antenna side.

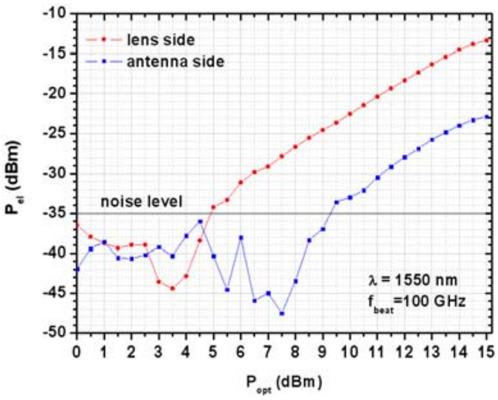

Figure 4. Output power vs. optical input power.

The heterodyne measurement was carried out in the frequency range of 50 to 300 GHz and at about 13.6 dBm optical power (corresponds to 5 mA photocurrent) for both sides. The results are illustrated in Fig. 5. The power meter is adjusted very carefully before the measurements. For the antenna side, the measurement was done only up to 200 GHz because of low power. The transmitter provides a maximal power of -13.5 dBm at about 65 GHz and 1 µW at 225 GHz. The resonance frequencies of the antenna lay approximately at 75 GHz, 110, 155 and 220 GHz. These are with some deviations well recognized in the smoothed curve of the lens side, whereas the original curve fluctuates strongly because of polarization mismatch between the radiated field and the receiver antenna. The tilting angle of the polarization plane is detected as ±35°. A good signal to noise ratio up to 1.6 THz of a coherent CW THz system with the same micro-pin PD in combination with a bow-tie antenna as the emitter and a photoconductor as the receiver has been reported in [5].

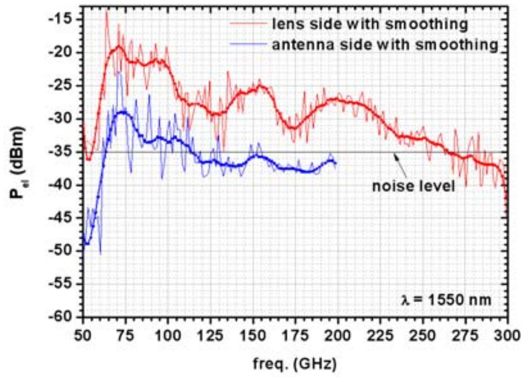

Figure 5. Frequency response of micro-pin antenna chip.

IV. CONCLUSION

A micro-pin antenna chip comprising a waveguide integrated pin PD and a logarithmic periodic circularly-toothed antenna was packaged into a fiber-fed transmitter module. The maximal radiated power of the device was -13.5 dBm and 1 µW output power at 225 GHz was obtained. The device could be optimized by applying DDR or UTC layer stacks for high power capability. Alternative antenna structures such as bow-tie antenna could be used to minimize the polarization tilting. Dipole antennas are suitable for resonant applications. An antenna array could be combined with some micro-pin PDs to control the THz far field pattern through changing the optical delay time or phases of the optical control signals.

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