Terahertz-wave Emitter based on Antenna-Integrated MUTC-PD

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***Abstract*—The uni-traveling-carrier photodiode (UTC-PD) is a promising candidate for generating terahertz (THz) waves by photomixing since it utilizes only electrons as the active carriers and responded at very high frequency with relatively high output power. UTC-PD integrated with antenna makes THz generator compact and reduces the cost. In this paper, we fabricated an antenna integrated modified uni-traveling-carrier photodiode (MUTC-PD) with maximum operating frequency of 206 GHz and three resonance peaks (56 GHz, 106 GHz and 156 GHz) were found.**

Keywords—MUTC-PD, antenna, terahertz, integration

I. INTRODUCTION

Terahertz (THz) emitter attracts more attention for its wide applications such as high-bit-rate wireless communication, cancer diagnosis, imaging security, and spectroscopic analysis [1-3]. Photonics-based technology for millimeter- (mm) and sub-mm-waves generation has advantage of wide bandwidth, simple configuration and low cost than the electronics technology [4]. The uni-traveling-carrier photodiode (UTC-PD) adopting electrons as only carriers is a promising candidate for THz generation due to its high-frequency response and high-saturation output power [5]. As a widely used configuration, UTC-PD integrated with planar antenna is beneficial to enhance the radiation efficiency and reduces both the size of THz-wave generator and the cost [6]. Antenna such as bowtie [1], log-periodic [2], slot-like [6]and microstrip [7] have been reported to integrate with UTC-PD and enhance the output power.

In this paper, a THz-band antenna was designed and antenna integrated modified uni-traveling-carrier photodiodes (MUTC-PD) were fabricated. The integrated chip responded at 37.5-206 GHz. Output power enhancement was found in three peaks (56 GHz, 106 GHz and 156 GHz) and each of them indicates a narrow usable band.

II. DEVICE STRUCTURE AND FABRICATION

The epi-structure is designed to be grown by metal-organic chemical vapor deposition (MOCVD) on Semi-insulating (SI) InP substrate. The structure of MUTC-PD starts with 600 nm n+ doped InP n-contact layer and 20 nm n+ InGaAs etch-stop layer and then follows the 200 nm n- InP collector layer. The absorption layer consists of 80 nm p-doped InGaAs (p = 5×10^{17} cm^{-3}) and 86 nm undoped InGaAs. A heavy p-doped 5 nm InP cliff layer, a 4 nm undoped InP buffer layer and a thin undoped InGaAsP layer with grading bandgap are inserted between collector layer and absorption layer. The epi-structure completes with a 15 nm thick p-doped $In_{0.6}Ga_{0.4}As_{0.85}P_{0.15}$ block layer and a 60 nm p+ doped InP p contact layer.

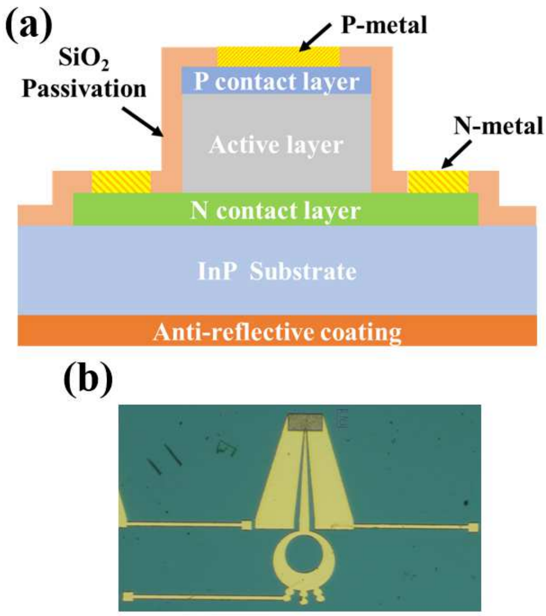

Fig. 1. (a) Schematic of cross profile of MUTC-PD. (b) Top view of the fabricated MUTC-PD integrated with antenna.

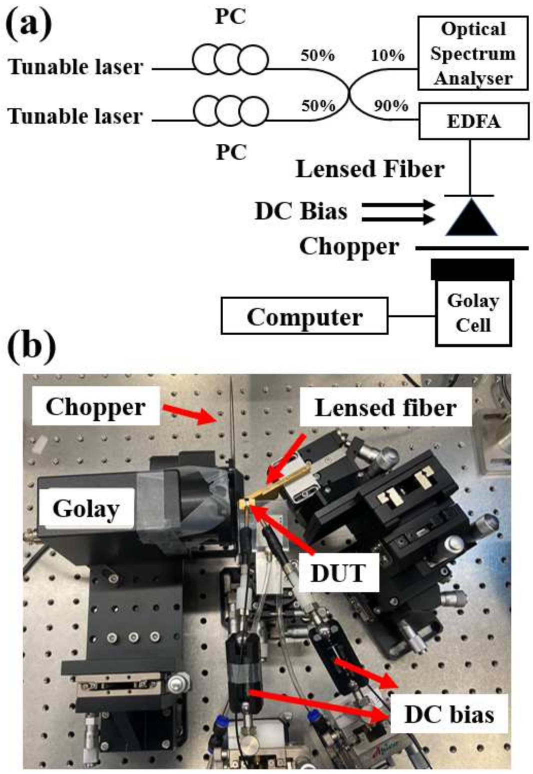

Fig. 2. (a) Schematic of experimental setup for output power measurement. (b) Picture of experimental setup.

Bottom-illuminated configuration is employed to increase the responsivity of MUTC-PD as the incident light power will be reflected by the top metal. Fig.1(a) shows the schematic diagram of the MUTC-PD designed to operate at 1550 nm. After the material growth, the epitaxial structures were processed into cylinder-shaped PDs by standard photolithography and inductively coupled plasma (ICP) dry etching. The surface of MUTC-PD was passivated by 500-nm-thick SiO_2 deposited by plasma enhanced chemical vapor deposition (PECVD) to suppress the dark current. After opening the electrode contact window by reactive ion etching (RIE), Ti/Pt/Au metal layers were evaporated on top InGaAs layer to form p contact, taper and antenna. Au/Ge/Ni metal layers were sputtered on n-contact layer to form n contact. Anti-reflective coating was deposited on the back of chip to increase the incident power absorbed into active region after lapping and polishing. Fig.1(b) shows the optical microscopic image of the fabricated MUTC-PD and the mesa diameter is 6 μm.

III. Characterization and Results Discussion

The schematic of experimental setup for output power measurement is plotted in Fig.2(a), and the picture of the measurement system is shown in Fig.2(b). The electromagnetic waves are generated by photomixing, an optical beat signal is prepared by a two-laser heterodyne beating system, both lasers are tunable and operating at around 1550 nm. Optical spectrum analyser is used to monitored the frequency. The optical beat signal is amplified by an Erbium-doped fiber amplifier (EDFA) and is coupled into MUTC-PD from the back by a lensed fiber. The frequency of the signal varies by adjusting the wavelength of the tunable laser, and the output power is detected by a Golay cell (TYDEX, GC-1P). The value of the output power is converted from the peak-to-peak voltage of the sinusoidal waveform.

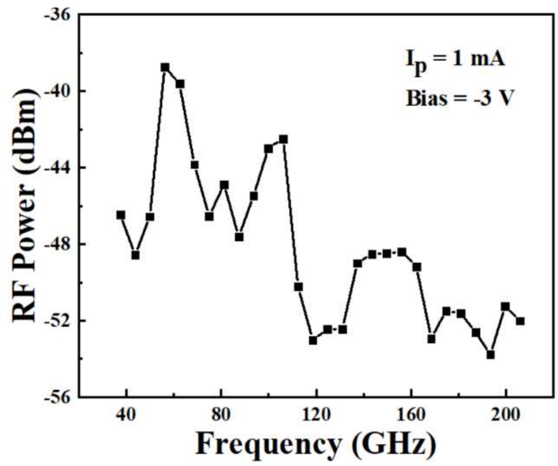

Fig. 3. Frequency dependence of output power from the fabricated 6-μm diameter MUTC-PD integrated with antenna at the reverse bias of 3 V.

Frequency dependence of output power from the fabricated antenna-integrated MUTC-PD at -3 V with 1 mA photocurrent is shown in Fig.3. We could detect output power at frequencies from 37.5 GHz to 206 GHz. The output power exhibited resonant characteristics where the output power sharply peaked at 56 GHz, 106 GHz and 156 GHz. The resonant characteristics mainly comes from the resonance of the antenna due to the size of antenna close to the wavelength in the SI InP substrate and indicates a narrow usable band. The output power of these peaks decrease with increasing frequency, which is mainly due to the decreased frequency response of MUTC-PD at high frequencies. This integrated chip realizes a compact photonic THz emitter, and the enhancement of resonance frequencies makes it a candidate for wireless communication. The future work includes improving the output power and employing the proposed module in a real-time wireless communication system.

IV. Conclusion

In this paper, we have designed and fabricated a back-illuminated MUTC-PD integrated with antenna. The maximum response frequency of the integrated chip is 206 GHz and three output power enhancement peaks (56 GHz, 106 GHz and 156 GHz) are found, mainly from the resonance of the antenna. The enhancement of resonance frequencies make the integrated chip possible for wireless communication.

Acknowledgment

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References

[1] T. Ishibashi, Y. Muramoto, T. Yoshimatsu, et al. Generation and detection of continuous THz-wave radiation by diode technologies[C]//2015 IEEE Photonics Conference (IPC). IEEE, 2015: 116-117.

[2] H. Ito, F. Nakajima, T. Furuta, et al. Photonic terahertz-wave generation using antenna-integrated uni-travelling-carrier photodiode[J]. Electronics Letters, 2003, 39(25): 1.

[3] E. Chao, B. Xiong, C. Sun, et al. D-band MUTC photodiodes with flat frequency response[J]. IEEE Journal of Selected Topics in Quantum Electronics, 2021, 28(2: Optical Detectors): 1-8.

[4] T. Ishibashi, T. Furuta, H. Fushimi, et al. InP/InGaAs uni-traveling-carrier photodiodes[J]. IEICE transactions on electronics, 2000, 83(6): 938-949.

[5] T. Ishibashi, Y. Muramoto, T. Yoshimatsu, and H. Ito, "Unitraveling-carrier photodiodes for terahertz applications," IEEE Journal of Selected Topics in Quantum Electronics, 2014, 20(6): 79-88.

[6] H. Ito, T. Ishibashi. Photonic terahertz-wave generation using slot-antenna-integrated uni-traveling-carrier photodiodes[J]. IEEE Journal of Selected Topics in Quantum Electronics, 2017, 23(4): 1-7.

[7] A. Hirata, T. Minotani, T. Nagatsuma. A 120-GHz microstrip antenna monolithically integrated with a photodiode on Si[J]. Japanese journal of applied physics, 2002, 41(3R): 1390.