Experimental Comparison of Commercial PIN-PD and UTC-PD for THz Power and Transmission Performance in the 370GHz-430GHz

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***Abstract*—We compare device and transmission performance of 32G-Bd QPSK, 8QAM and 16QAM signals using a PIN and UTC photodiode from 370 to 430 GHz which error-free transmission can be achieved at 100Gb/s net rate.**

Keywords—PIN-PD, UTC-PD, power performance, transmission performance

I. INTRODUCTION

Terahertz (THz) communication is widely regarded as the key component of future 6G mobile communication systems, and new solutions with carrier frequencies in the THz range are being investigated for larger bandwidth and spectral availability [1]. Pure electric mode and photon-assisted mode are two main categories for THz up-conversion technology among these researches. Photonic heterodyne-based optoelectronic solutions are currently being widely studied due to the simple system architecture, tunable carrier frequency, and small harmonic interference, which can break the bottleneck of electronic devices and generate ultra-high-speed wireless THz-wave signals[2]. Furthermore, the photonics-assisted heterodyne beating technique can generate a higher carrier frequency and wider adjustable range comparing pure electric mode [1]. Uni-traveling-carrier photodiodes (UTC-PDs) and positive-intrinsic-negative photodiodes (PIN-PDs) have become standard components as photo mixers to carry out the up-conversion of the data signal into the THz range in the past few years [3]. Both photodiodes are commercially available and feature a similar package (fiber-pigtailed housings with a hyper-hemispherical silicon lens). PIN-PDs have been used to demonstrate wireless transmission of up to 128 Gb/s for 16QAM, and error-free transmission is achieved at 100 Gb/s net rates [4]. UTC-PDs have been used for the real-time demonstration of 100 GbE THz-wireless and fiber seamless integration networks [5]. A power experimental comparison study of UTC-PD and PIN-PD is carried out by using a THz power meter [6]. However, there are no simultaneous comparison of the power performance and transmission performance of UTC-PD and PIN-PD.

In this letter, we explore UTC-PDs and PIN-PDs as photonic emitters in communication systems and compare their device performance and simultaneously show high-speed data transmission up to 128Gb/s for the first time, respectively. We generate 32G-Bd QPSK, 8QAM and 16QAM signals ranging from 370 GHz to 430GHz frequency spacing to measure power and BER. We achieve error-free transmission at a net data rate of 100 Gb/s with the bit error ratio (BER) below the FEC threshold of 2.2×10^{-2} assuming soft-decision forward-error correction (SD-FEC) finally.

II. EXPERIMENT SETUP

At the Optical-THz conversion module, as shown in Figure 1, we employ two free-running tunable external cavity lasers (ECL-1 and ECL-2) with 100 kHz linewidth. A 92Gb/s arbitrary waveform generator (AWG, M8196A) produces the in-phase and quadrature components of 32G-Bd QPSK, 8QAM and 16QAM signal. The signal is delivered over 20 km standard single mode fiber (SSMF), and an erbium-doped fiber amplifier (EDFA) is used to compensate for the fiber transmission loss. Polarization controllers (PCs) are necessary to adjust the incident direction to maximize output power. Then the optical signal and ECL-2 are combined by an optical coupler (OC), and another EDFA is used to adjust the power entering UTC-PD and PIN-PD. PIN-PD (TOPITICA, PCA-FD-1550-100-TX-1) and UTC-PD (NTT Electronics Corp. IOD PMAN-13001) serve as a heterodyne optical mixer, translating the optical beat note to an electrical carrier with frequencies.

At the THz receiver, as shown in Figures 1(a) and (b), there are two modules for measuring power and BER, respectively. First, for the THz power measurement, we employ the absolute THz power-energy meters, which is made of Thomas Keating Terahertz (TK THz) RAM. The power meter head is placed at a distance of 10 cm from the THz emitter. The power

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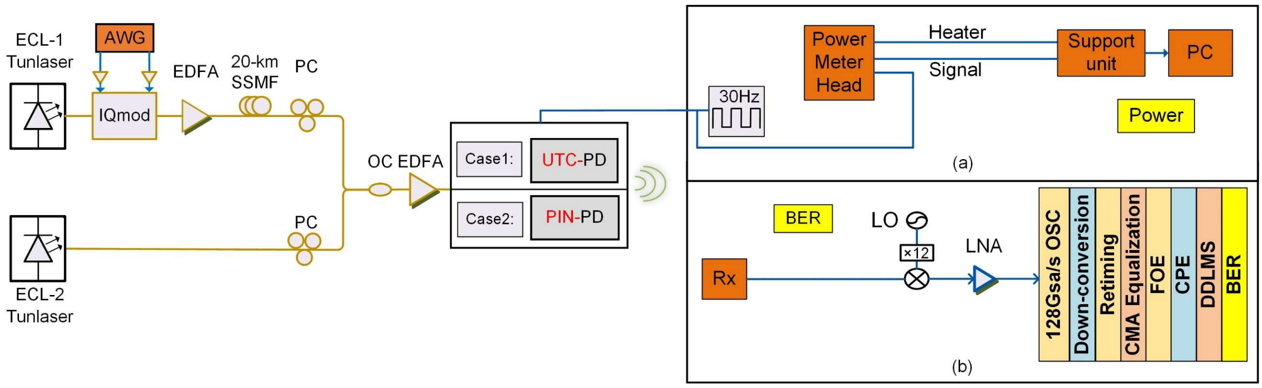

Fig. 1. Schematic setup of the experiment; (a)Schematic setup of the module for measuring power. (b) Schematic setup of the module for measuring BER.

meter head is connected to the support unit for signal transmission and heating. As shown in Figure 1(a), there are two cables to connect the pressure transducer BNC output on the top of the power meter head to the connector labelled SIGNAL and connect one of the two film heating connectors on the side of the power meter to the BNC cable labelled HEATER. The Square-wave signal of 30Hz is generated by a waveform generator (DG1022U) for reference and transmitted to PDs. Figure 2 shows the experimental setup and the picture of TK Power Meter.

In the module of BER, the transmitter and receiver are back-to-back. The received signal is driven by an electronic local oscillator (LO) source to implement analogue down-conversion and consists of a mixer, 12 frequencies multiplier chain, and captured by an oscilloscope (OSC) for decoding. The maximum bandwidth of down-conversion IF signal is 20 GHz and the LNAs (SHF S804B) have 60 GHz bandwidth and 16 dBm saturated output power with a gain of 27 dBm. Then the received signal is demodulated, equalized, and compensated by polarization demux, frequency offset estimation, carrier phase estimation and decision-drive least square mean (DDLMS) modules for calculating BER. Retiming has the functions of synchronizing signal for normal work of system receiver, making periodic judgment on received data signal, suppressing jitter and noise, restoring stable data signal for subsequent processing or transmission. CMA equalization algorithm can effectively suppress system noise and crosstalk, and has the function of polarization demultiplexing. The carrier frequency offset estimation is used to solve the problem that the local oscillator signal used for down conversion in the receiver is not synchronized with the carrier signal contained in the received signal. As the most important part of digital signal processing, carrier phase recovery algorithm compensates the phase noise caused by laser linewidth and mixer noise to make the received phase close to the initial phase.

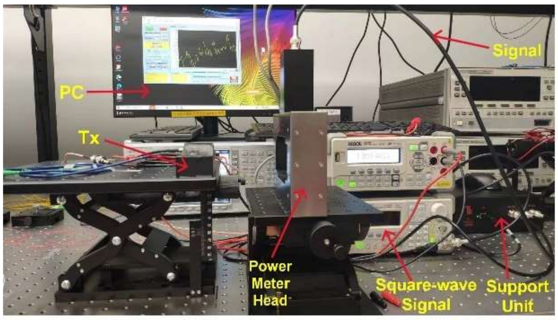

Fig. 2. The photo of the experiment setup.

III. EXPERIMENT RESULT

Figures 3 illustrates the divergence of power performance between UTC-PD and PIN-PD under the same optical power at 370 GHz, 390 GHz, 410 GHz and 430 GHz without adding signals. The experiment results in Figure 3 depicts the THz power of UTC-PD is higher than that of PIN-PD for all frequency points. What's more, at 370GHz, the THz power of UTC-PD is the highest and decreases with the increase of frequency. However, there is little effect on THz power of PIN-PD without adding signals when frequency changes. Moreover, UTC-PD and PIN-PD show no saturation of the THz power with the increase of input optical power and the linear inclination of UTC-PD curve is smaller than that of PIN-PD due to the difference of diodes' internal structure. The difference of the THz power can reach the smallest when the optical power is around 14 dBm. Especially, the THz power of UTC-PD is around 4 dBm higher than that of PIN-PD when the optical power is 12 dBm at 370 GHz.

Then, we compare the THz power of UTC-PD and PIN-PD under the same optical power at 370GHz and 430GHz by adding QPSK, 8QAM, and 16QAM signals in Figure 4. It can be seen that the THz power increases linearly with respect to the input optical power for two kinds of PDs at 370GHz and 430GHz. We can also see that the THz power of UTC-PD is always higher than PIN-PD under the same optical power for QPSK, 8QAM and 16QAM. What's more, it can also be seen

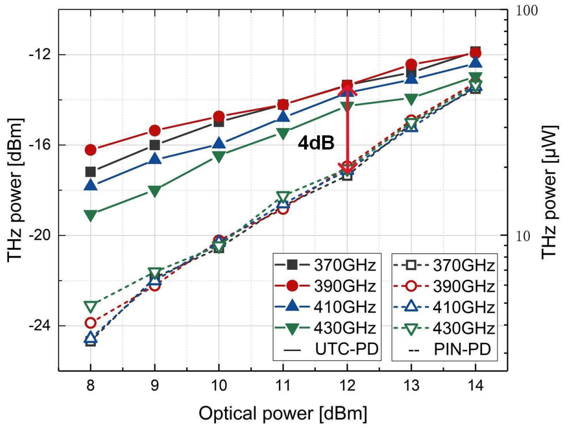

Fig. 3. Output THz power as a function of the UTC or PIN diode's input optical power at 370GHz, 390GHz, 410GHz and 430GHz.

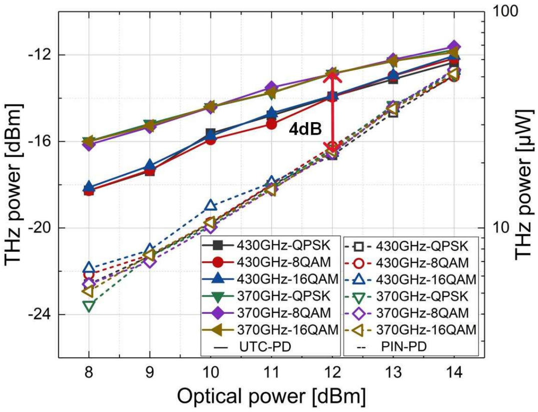

Fig.4. Output THz power as a function of the UTC or PIN diode's input optical power at 370GHz and 430GHz of 32G-Bd QPSK, 8QAM and 16QAM signals.

that under the three modulation formats of the same frequency, the THz power change of UTC-PD is larger than that of PIN-PD. The THz power of UTC-PD with adding signal is slightly higher than that without adding signal. The THz power of PIN-PD with adding signal has little change compared with that without adding signal yet. Like the previous one, the difference of the THz power of UTC-PD and PIN-PD is diminished little by little with the improve of optical power. The difference of the THz power of UTC-PD and PIN-PD is very closely when the optical power is nearly 14 dBm. The THz power of UTC-PD is also around 4 dBm higher than that of PIN-PD for 12dBm optical power with adding signal at 370GHz, especially. In addition, the THz power of UTC-PD at 370GHz is better than that at 430 GHz under the same optical power.

To better compare the performance of UTC-PD and PIN-PD, we measure the BER for comparing transmission performance in the case of BtB. Figures 5 and 6 show the BER performance of the system both for 32G-Bd QPSK, 8QAM and 16QAM at 370 GHz and 430 GHz as a function of the optical power into the PIN-PD and UTC-PD (lower x-axis), respectively. Note that the behavior of the BER curves is non-monotonic because of the existence of saturation phenomenon. Initially, the BER performance of the system improves as the received THz power for all situations (and including the signal-to-noise ratio) when the optical power is in the noise-limited case. However, the BER performance starts to degrade when the optical power is higher than 12dBm for the non-linear case. The THz power increases with the increase of optical input power, while the system performance decreases with the increase of THz power level. This effect is attributed to the nonlinear compression of the input signal at the receiving end at a higher receiving THz power. The BER performance of UTC-PD is significantly one or two magnitudes better than that of PIN-PD for three modulate formats at 370GHz. Especially when the input optical power of optimum case is 12dBm, the performance of three modulate formats is the best at 370GHz. Moreover, error-free transmission can be achieved when the optical power of QPSK is around 12dBm at 370GHz.

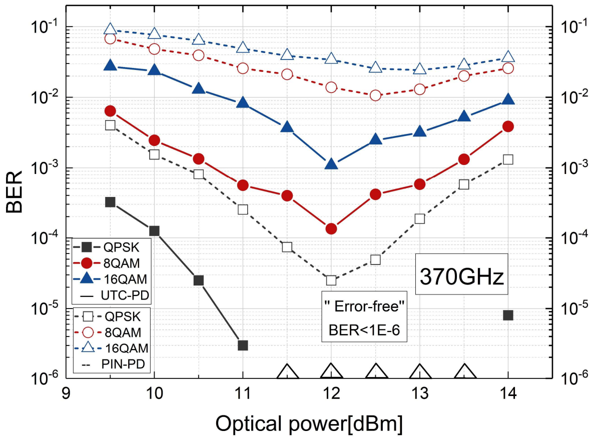

Fig. 5. BER performance curves of QPSK, 8QAM and 16QAM for the THz system at 370 GHz.

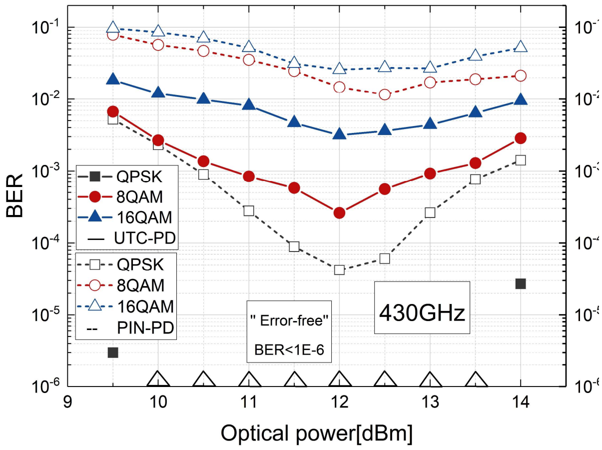

Fig.6. BER performance curves of QPSK, 8QAM and 16QAM for the THz system at 430 GHz.

The performance of the BER for three modulate formats at 430 GHz is similar to that at 370 GHz. The BER performance of UTC-PD becomes better than that of PIN-PD under the same modulate format at 370GHz and 430GHz. The best BER performance can also even reach the situation of error-free (<1E-6) when transmitting the QPSK signal using UTC-PD with the optical power of around 12dBm at 430GHz. Nevertheless, by comparing Fig.5 and Fig.6, we can discover that the performance of BER at 370GHz is better than that at 430GHz when transmitting three modulation signals by using UTC-PD and PIN-PD due to higher THz power at 370GHz. Similar to 370GHz, the performance of BER will initially improve with the increase of input optical power under the three modulate formats. But the performance will decline

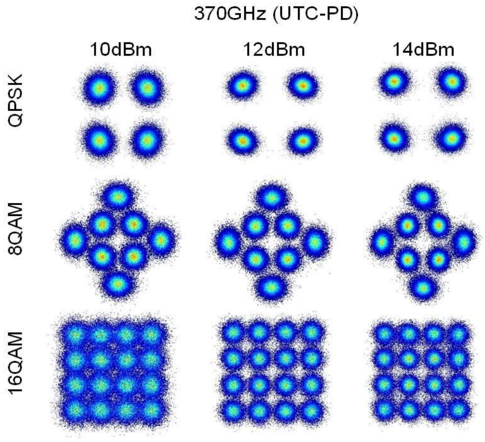

Fig.7. QPSK, 8QAM and 16-QAM constellation diagrams of UTC-PD for various optical power levels at the THz transmitter.

gradually due to the fact that the input optical power is saturated when the optical power is higher than 12dBm at last. The best performance of BER can be obtained at 12 dBm under the THz carrier frequency at 430GHz. Considering the BER of 2.2×10^{-2} threshold, error-free transmission can also be achieved for the 32G-Bd 16QAM signal at 430GHz.

Figure 7 shows the evolution of the signal distortion of the QPSK, 8QAM and 16QAM constellation diagrams for various optical power levels at the THz transmitter by using UTC-PD at 370GHz. We can easily find that the constellation diagrams of 12dBm are clearer and more effective than the others at 370 GHz under the three modulate formats. Furthermore, as shown in Figure 7, the constellation diagrams of 14 dBm optical power have obvious saturation phenomena comparing the other cases because of the enough input optical power.

IV. CONCLUSION

We have compared the device performance and the THz transmission of 32-GBd QPSK, 8QAM and 16QAM signals using PIN-PD and UTC-PD range from 370GHz to 430GHz. Compared with PIN-PD, we can achieve the significant BER performance when using UTC-PD for transmitting and we will compare the transmission performance at different transmission distances for UTC-PD and PIN-PD in the future. To the best of our knowledge, this is the first demonstration and comparison of transmission performance at a net data rate up to 100 Gb/s and power performance using a photonic UTC-PD and PIN-PD emitter. From the perspective of power, UTC-PD and PIN-PD also show no saturation of the THz power with the increase of input optical power. UTC-PD and PIN-PD have become the most mature economic and commercial tunable THz continuous wave emission source, and also have great application prospects in the future.

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