High-Power and Ultra-Fast Photodiodes at THz Regime

(Invited Paper)

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Commanding the full electromagnetic (EM) spectrum (near 1 MHz to around 0.3 THz), which includes generation, modulation, wireless transmission, and detection by use of photonic approaches, plays an important role in modern electronic warfare, THz bandwidth measurement instruments (network analyzer), and the next-generation of wireless communication at the millimeter-wave or THz wave bands [1,2]. An ultra-fast photodiodes (PDs) serves as the key complements in this system. In this paper, we review our recent work about near-ballistic uni-traveling carrier photodiodes (NBUTC-PDs) [3,4] at THz regime. Figure 1 shows the conceptual band diagram of three kinds of device structure. Device A is the typical UTC-PD, B and C is the near-ballistic UTC-PD (NBUTC-PD) structure [3,4]. As compared to device A, we can clearly see that there is an additional n- and p-type charge layer in the collector layer of device B and C, respectively. The purpose of such two layers is for controlling the E-field distribution and suppressing the space-charge screening effect or inter-valley scattering effect of electrons [4]. In our previous works [3,4] the flip-chip bonding packages of NBUTC-PD has been adopted to enhance the efficiency and benefit optical alignment. In addition, the device heating can be minimized by bonding the active PD onto high thermal conductivity substrate (AlN). Figure 2 shows the measured optical-to-electrical (O-E) frequency response of NBUTC-PDs under 3mA output photocurrents. We can clearly see that > 300 GHz O-E bandwidth can be achieved under a 50 Ω load with high output photocurrent. In order to boost the photo-generated THz power, a femto-second optical pulse train system has been established [4]. Figure 3 shows the photo-generated THz power under short pulse train and sinusoidal excitations. Compared with optical sinusoidal signal excitation, a 3-dB enhancement in output power can be achieved. Furthermore, both devices can have strong and fast bias modulation characteristics [4]. It leads to their applications for THz radar [5] or wireless communication systems [6].

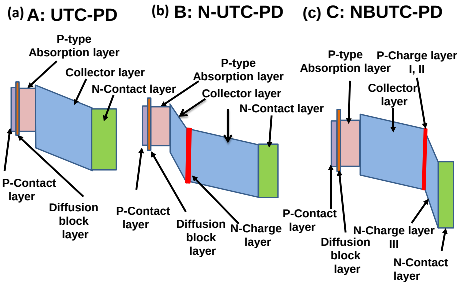

Figure 1. Conceptual band diagrams of (a) Device A: UTC-PD, (b) Device B: NBUTC-PD with n-charge and (c) Device C: NBUTC-PD with p-charge layers

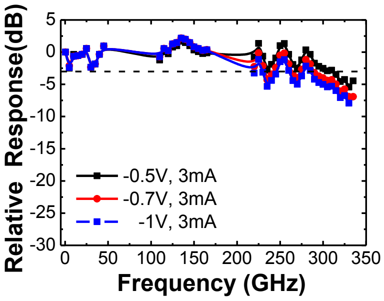

Figure 2. The bias dependent (-0.5, -0.7, and -1V) O-E frequency responses of NBUTC-PD (n-charge) with a 3 μm active diameter of PD measured at 3 mA output photocurrent.

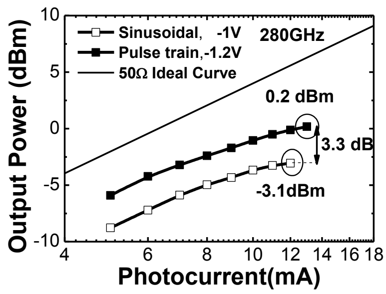

Figure 3. The measured photo-generated MMW power of NBUTC-PD (n-charge) with a 3 μm active diameter of PD versus photocurrent under sinusoidal (open symbol) and pulse train (close symbol) excitations at 280 GHz operation frequency. Solid line is ideal trace for 100% modulation depth and 50 Ω load.

[1] S. Koenig, D. Lopez-Diaz, J. Antes, F. Boes, R. Hennberger, A. Leuther, A. Tessmann, R. Schmogrow, D. Hillerkuss, R. Palmer, T. Zwick, C.Koss, W. Freude, O. Ambacher, J. Leuthold, and I. Kallfass, "Wireless sub-THz communication system with high data rate ," *Nature Photonics*, vol. 7, pp. 977-981, Dec., 2013.

[2] T. Nagatsuma, M. Shinagawa, N. Sahri, A. Sasaki, Y. Royter, and A. Hirata, "1.55-μm Photonic Systems for Microwave and Millimeter-Wave Measurement," *IEEE Trans. Microwave Theory Tech.*, vol. 49, pp. 1831-1839, Oct., 2001.

[3] Jhih-Min Wun, Cheng-Hung Lai, Nan-Wei Chen, John E. Bowers, and Jin-Wei Shi "Flip-Chip Bonding Packaged THz Photodiode With Broadband High-Power Performance," *IEEE Photon. Technol. Lett.*, vol. 26, no. 24, pp. 2462-2464, Dec., 2014.

[4] Jhih-Min Wun, Hao-Yun Liu, Yu-Lun Zeng, Shang-Da Yang, Ci-Ling Pan, Chen-Bin Huang, and Jin-Wei Shi, "Photonic High-Power CW THz-Wave Generation by Using Flip-Chip Packaged Uni-Traveling Carrier Photodiode and Femtosecond Optical Pulse Generator," *IEEE/OSA Journal of Lightwave Technology*, vol. 34, pp. 1387-1397, Feb., 2016.

[5] Tzu-Fang Tseng, Jhih-Min Wun, Wei Chen, Sui-Wei Peng, Jin-Wei Shi, and Chi-Kuang Sun,"High-depth-resolution 3-dimensional radar-imaging system based on a few-cycle W-band photonic millimeter-wave pulse generator," *Optics Express*, vol. 21, No. 12, pp. 14109-14119, June, 2013.

[6] Nan-Wei Chen, Jin-Wei Shi, Fong-Ming Kuo, Jeffery Hesler, Thomas W. Crowe, and John E. Bowers, "25 Gbits/sec Error-Free Wireless Link between Ultra-Fast W-Band Photonic Transmitter-Mixer and Envelop Detector," *Optics Express*, vol. 20, No. 19, pp. 21223-21234, Sep., 2012.