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High-Speed Uni-Traveling-Carrier Photodiodes for Fiber-Optic Communications

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1. Introduction

The rapid growth of communication media, such as the Internet, requires a revolutionary expansion of throughput in fiber-optic communications systems. In addition to the full use of the wavelength, a high data rate in each channel is essential. The development of high-speed devices is the key to fulfilling this demand. Ultrafast photodetectors with high saturation power levels are important, because the combination of a high-saturation-power photodiode and an optical fiber amplifier (FA) can eliminate the post-amplification electronics, extend the bandwidth, and thus simplify the receiver configuration [1]. The uni-traveling-carrier photodiode (UTC-PD) [2], which has a unique mode of operation, is a promising candidate for such requirements. In this paper, we describe recent progress in our UTC-PD technologies.

2. Operation of UTC-PD

Figure 1 shows the band diagram of the UTC-PD. Because the p-type absorption layer is quasi-neutral, majority holes, by their collective motion, respond very fast, i.e., within the dielectric relaxation time. Therefore, only electrons are the active carriers, and their transport determines the total delay time. Since the electron velocity at overshoot is about one order of magnitude larger than the hole saturation velocity, both the carrier transit time in the depletion layer and the space charge effect are much smaller in a UTC-PD than in a conventional pin-PD. This feature results in both a higher 3dB bandwidth (f_{3dB}) and a higher output saturation current (I_s). We have already achieved a record f_{3dB} of 235 GHz for a PD operating at 1.55-μm wavelength [3] and a very high I_s of over 180 mA [4].

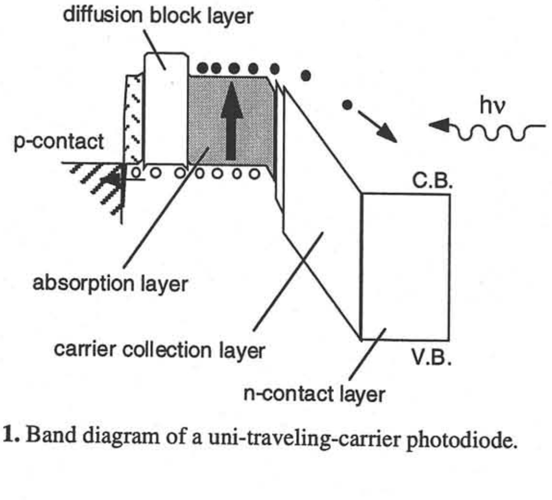

Fig. 1. Band diagram of a uni-traveling-carrier photodiode.

3. Device Characteristics

Figure 2 shows the pulse photoresponse of a back-illuminated InP/InGaAs UTC-PD [5] with a practical design, as measured by the electro-optic sampling technique [6]. The output peak voltage (V_p) increases linearly up to 2.0 V with increasing input power while the output pulse-width (FWHM) is maintained at less than 6 ps. The Fourier transform of the highest pulse response with a FWHM of 5.8 ps gives an f_{3dB} of 58 GHz. Figure 3 shows the relationship between V_p and f_{3dB} with bias voltage (V_b) as a parameter. Although a larger V_p is obtained with a larger V_b, a V_p of 1

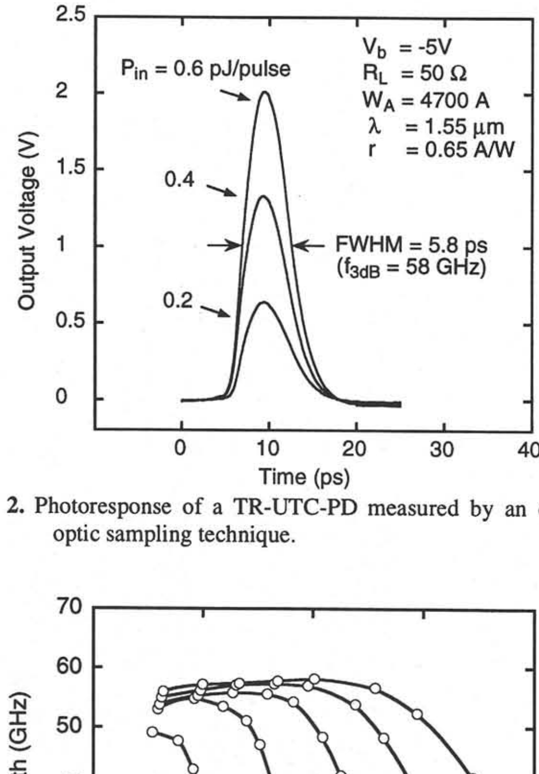

Fig. 2. Photoresponse of a TR-UTC-PD measured by an electro-optic sampling technique.

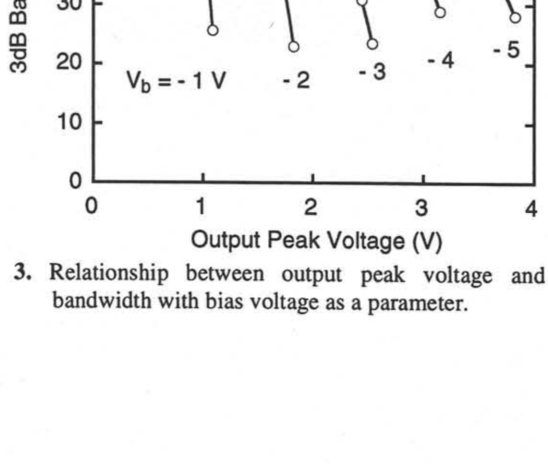

Fig. 3. Relationship between output peak voltage and 3-dB bandwidth with bias voltage as a parameter.

V (the value typically required for the direct drive of digital circuits) with an f_{3dB} of 40 GHz is obtained at V_b of only -1 V.

Efficiency is another important figure of merit. If we use a typical FA with maximum output power of 13 dBm (one having single pump laser diode), the required responsivity (r) for 1-V output is 0.5 A/W, assuming NRZ signals with a 50% mark ratio. Figure 4 shows the relationship between the 3dB bandwidth and efficiency in the conventional back-illuminated UTC-PDs we have fabricated. There is a trade-off between f_{3dB} and efficiency, and the efficiency of these UTC-PDs is still insufficient for applications requiring f_{3dB} of over 40 GHz. To overcome this, we have developed a novel back-illuminated UTC-PD (TR-UTC-PD) [5] that utilizes angled irradiation of the light reflected at a total reflection (TR) mirror formed adjacent to the PD. This device exhibits a sufficiently high efficiency of 0.65 A/W together with a high f_{3dB} of 50 GHz at a high V_p of 5 V.

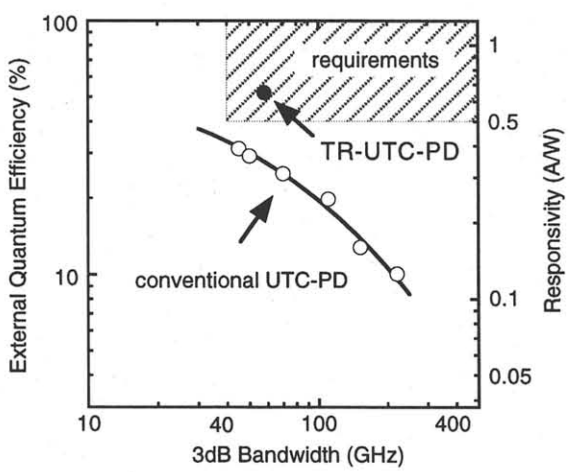

Fig. 4. Relationship between 3-dB bandwidth and efficiency. Hatched area represents the requirements (f_{3dB} > 40 GHz and r > 0.5 A/W).

4. Applications of High-Speed UTC-PDs

In high-bit-rate systems, such as those for 40 Gbit/s optical transmission, a UTC-PD acts as a photo-receiver that can drive the decision circuit directly without post amplifiers [1]. The operation of a UTC-PD at up to 80 Gbit/s with an output voltage of 0.8 V_{pp} has already been demonstrated [7]. A UTC-PD can also directly drive an electro-absorption modulator in order to realize an optical demultiplexer function [8]. Also promising is the monolithic integration of a UTC-PD with resonant tunneling diodes, which has been applied to a 80-Gbit/s optoelectronic demultiplexer [9, 10] and an optoelectronic clock recovery circuit [11].

UTC-PDs are also advantageous in analog applications, such as microwave/millimeter-wave fiber-radio wireless communications systems [4, 12-14]. The high linearity with the high output power of the UTC-PD can eliminate the power amplifier in the antenna station. High-power transmission of over +10 dBm at 60 GHz [14], and a 1-Gbit/s data transmission at 40 GHz [13] have already been demonstrated. Figure 5 shows the output power characteristics of a bias-circuit-integrated UTC-PD designed for 60-GHz millimeter-wave photonics applications [15]. A high saturation output (P_s) of +10 dBm at V_b of –3 V is obtained, and P_s is –6 dBm even at V_b of 0 V. This zero-biased operation capability is also important since it can further simplify the antenna station.

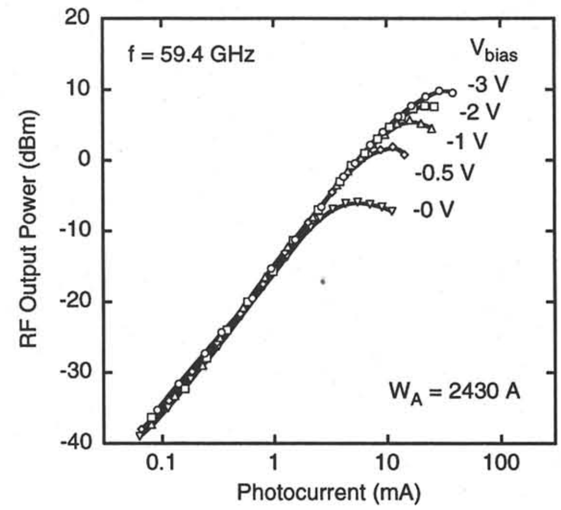

Fig. 5 Relationship between mm-wave output power and diode photocurrent.

5. Summary

The uni-traveling-carrier photodiode has excellent high-speed and high-saturation-output capabilities, which are promising for various high-speed and high-bit-rate fiber-optic communications systems.

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