Recent Progresses in High Frequency, High Power Photodetectors

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High power, high frequency photodetectors play a key role in determining the performance of analog and microwave fiber optic links. The high power photodetectors allows the use of high power laser sources in externally modulated links. This can significantly reduce the RF insertion loss, and increase the spurious free dynamic range and signal-to-noise ratio of the link [1]. High power photodetectors are particularly important for high frequency links because the electro-optic modulators with low V_π (half-wave voltage) become more difficult to achieve. They are also useful for optoelectronic generation of millimeter-waves and submillimeter waves for local oscillators in radio astronomy [2,3]. Though significant progress has been made in high speed photodetectors, the conventional photodetectors tend to saturate at very low optical powers because they employ small absorption volume (typically on the order of 1 μm^3) to reduce transit time and parasitic capacitance. Recently, large-core waveguide photodetectors have been proposed to increase the saturation power [4]. Traveling-wave photodetectors can further extend the absorption volume and achieve even higher saturation power [5-7].

In this paper, we will review the recent progress in high speed, high power photodetectors. The design trade-offs among the saturation power, 3-dB bandwidth, and quantum efficiency will be described. The fundamental limit of saturation powers for various types of photodetectors, including surface-illuminated p-i-n photodetectors, waveguide photodetectors, traveling-wave photodetectors, and velocity-matched distributed photodetectors, will be derived and compared. In particular, the figure-of-merit (FOM) for high power, high frequency photodetector will be defined [5]. We will also present the recent experimental results of the long-wavelength velocity-matched distributed photodetectors (VMDP) fabricated at UCLA.

The VMDP consists of an array of localized photodiodes serially connected by a passive optical waveguide, and the photocurrents are collected in phase by a separate output microwave transmission line. The microwave transmission line has an impedance of 50 Ω and is velocity-matched to the optical waveguide, which allows the VMDP to extend its absorption length to several hundred micrometers without penalizing its bandwidth. Therefore, the saturation power is greatly enhanced while the bandwidth is essentially the same as that of a single photodiode. Another unique advantage of the VMDP is that the optical waveguide, active photodiodes, and the microwave transmission line can be independently optimized. A VMDP with nanoscale metal-semiconductor-metal photodiodes and coplanar strips transmission line has been designed and fabricated at UCLA. Long-wavelength photodetectors are also being developed at UCLA and other laboratories [7].

Another important development is high power balanced photodetectors. At high photocurrent, the receiver noise of externally modulated links is dominated by the relative intensity noise

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(RIN). Since balanced photodetectors can cancel out the RIN and the amplified spontaneous emission (ASE) noise from erbium doped fiber amplifiers (EDFA), there are great interests to develop high power balanced photodetectors. Recently, NRL has demonstrated the shot noise-limited performance by using balanced receivers with discrete photodiodes [8]. However, monolithic devices will be required for higher frequency links. UCLA is currently developing a high power balanced photodetectors based on the VMDP structures [9]. The experimental results and their implications on systems will be discussed in the conference.

Another important issue of high power photodetectors is their reliability. Because of the large power consumption and the resulting heat generated in the device, the reliability of high power photodetectors is worse than the conventional photodetectors. In RF photonic links, the photodetectors are often biased at high voltage to reduce their nonlinearity. This further increases the electrical power consumption in the devices. Theoretical study shows that thermal run-away and catastrophic damage could occur for high power photodetectors. Detailed results will be presented in the conference, and their implication on the design of high power photodetectors will also be addressed.

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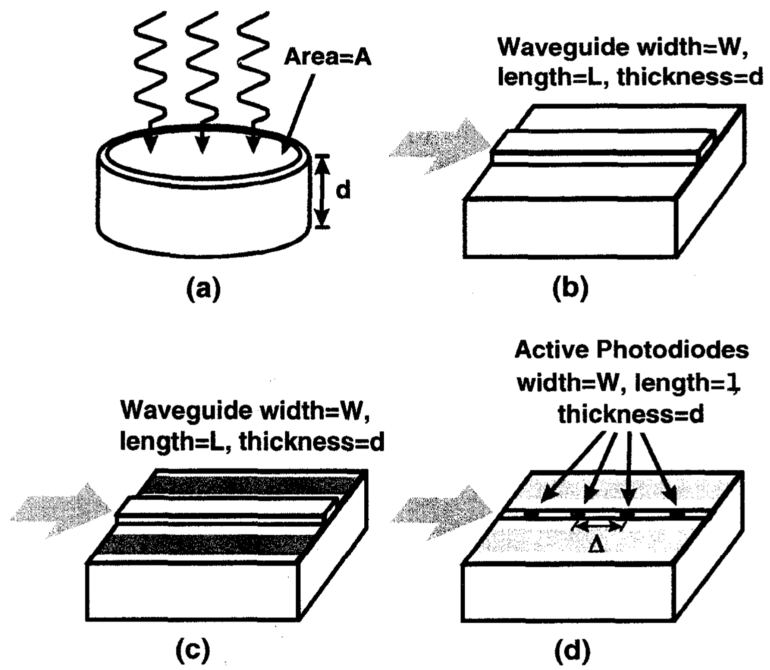

Figure 1. Various structures of high power photodetectors: (a) surface-illuminated photodetectors, (b) waveguide photodetectors, (c) traveling wave photodetectors, and (d) velocity-matched distributed photodetectors. (a) and (b) are lumped photodetectors, while (c) and (d) are traveling wave devices.

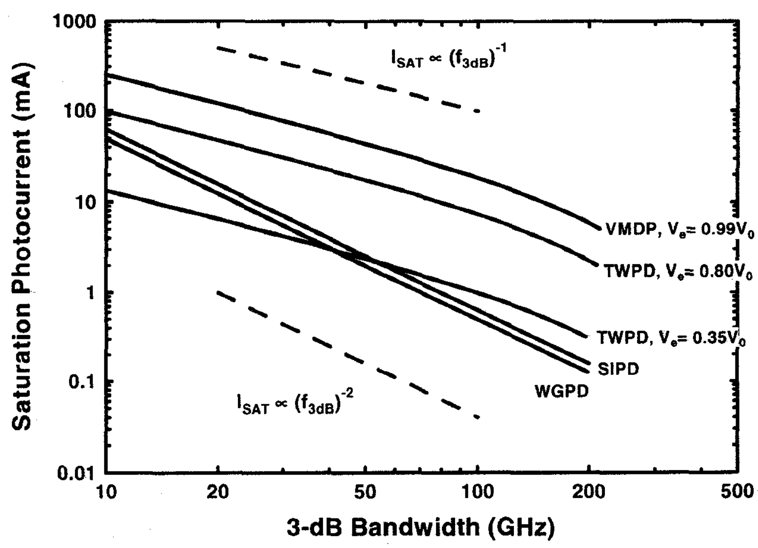

Figure 2. The calculated maximum saturation photocurrent versus the 3-dB bandwidth for the photodetectors shown in Fig. 1.