Velocity-Matched Distributed Photodetectors with High Saturation Power and Large Bandwidth

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High power, high frequency photodetectors are the key components for high performance RF fiber optic links and coherent receivers with high LO power. Conventional high speed photodetectors have poor saturation power because of their small absorption volume. High bandwidth and high efficiency have been demonstrated by the traveling-wave photodetector [1], however, its absorption volume remains very small (~ 1.1 μm^3). Attempt has been made to increase the saturation power by employing large-core waveguide photodetectors [2]. Previously, we have proposed a velocity-matched distributed photodetector (VMDP) which consists of an array of high speed photodiodes serially connected by a passive optical waveguide, and a separate microwave output transmission line [3]. By matching the velocities of the microwave transmission line and the optical waveguide, very large absorption volume, and hence high saturation power, can be achieved without sacrificing the bandwidth. In this paper, we report on the first demonstration of the VMDP. High peak saturation photocurrent (56 mA at 1-dB compression) and high bandwidth of 49 GHz are demonstrated.

Figure 1 shows the schematic structure and the SEM micrograph of the VMDP. Nanometer MSM photodiodes are distributed along a passive optical waveguide. The MSM photodiode has a finger width and spacing of 0.3 μm and 0.2 μm, respectively, and a length of 15 μm. Velocity matching is achieved by properly designing the spacing between the photodiodes (150 μm in current VMDP). In order to achieve high saturation power, the confinement factor of the MSM absorbing layer is designed to be very low (= 1.5%). The impulse response of the VMDP is measured by a femtosecond Ti:Sapphire laser and a 50GHz HP digitizing oscilloscope. The electrical frequency response is obtained from the Fourier transform of the impulse response, as shown in Fig. 2 for the VMDP with three photodiodes. The measured bandwidth is mainly limited by the loss of the microwave connections between VMDP and sampling scope (including microwave cable, splitter, bias-T, and probe), which are separately characterized by HP8510C network analyzer. The calibrated frequency response is shown in Fig. 2. The 3-dB bandwidth of 49 GHz appears to be limited by the digitizing oscilloscope.

To investigate the AC saturation effect, the impulse response of the VMDP is measured with increasing optical powers. Figure 3 shows the normalized AC quantum efficiency and the peak photocurrent versus the input optical pulse energy. At low optical power, the AC quantum efficiency is equal to the DC quantum efficiency (12.3% for VMDP with three photodiodes). As the optical power increases, the AC quantum efficiency starts to decrease. At 1dB compression, the measured peak photocurrents are 28, 56, and 66 mA for the VMDP's with 1, 3, and 5 photodiodes, respectively. These results agree well with the theoretical simulation which takes into account the distributed effect, as shown in Fig. 4. The peak saturation photocurrent can be further increased to > 100 mA by improving the coupling efficiency between passive and active waveguides from 82% to 96% (by employing selective etching to remove absorbing layer) and increasing the number of photodiodes to ten. The quantum efficiency of the device can be improved by optimizing the coupling efficiency of the lensed fiber (~ 45%) and AR-coating the VMDP facet (30% Fresnel loss).

In summary, we have demonstrated a novel velocity-matched distributed photodetectors with high saturation power and large bandwidth. The experimental results show that the VMDP structures are very attractive for high performance RF fiber optic links and high-power optical-microwave applications.

[1] K. S. Giboney, R. L. Nagarajan, T. E. Reynolds, S. T. Allen, R. P. Mirin, M. J. W. Rodwell, and J. E. Bowers, *IEEE Photonics Tech. Lett.*, Vol. 7, no. 4, pp. 412-414, 1995

[2] A. R. Williams, A. L. Kellner, and P. K. L. Yu, *Elec. Lett.*, 1993, **29**, pp. 1298-1299

[3] M.C. Wu and T. Itoh, *Proc. IEEE LEOS Summer Topical Meeting on Optical Microwave Interactions*, p.63, 1993

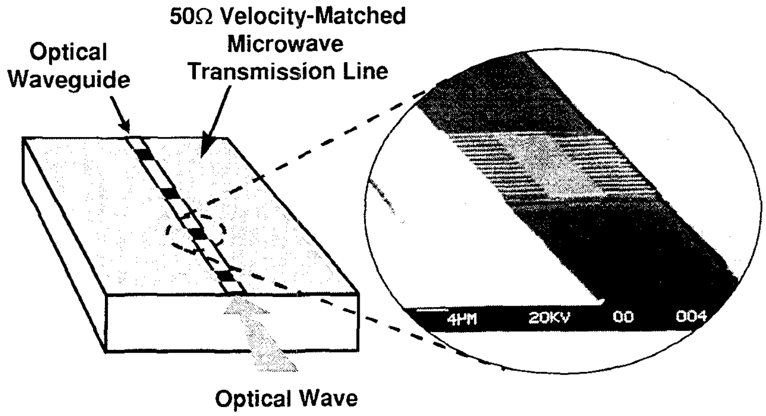

Figure 1 Schematic structure and SEM of the velocity-matched distributed photodetector (VMDP).

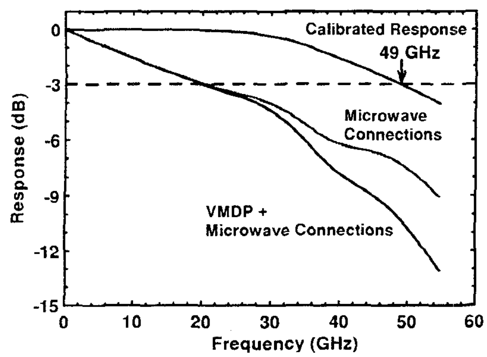

Fig. 2 Frequency response of the VMDP.

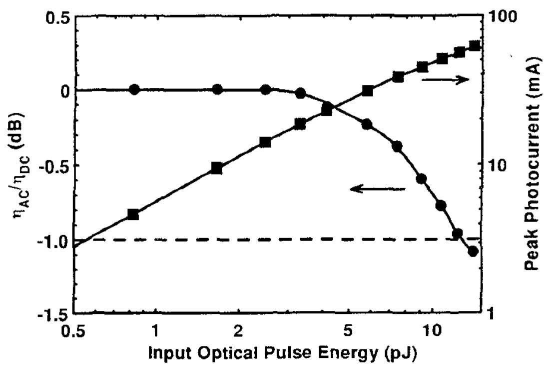

Fig. 3 AC saturation effect in the VMDP

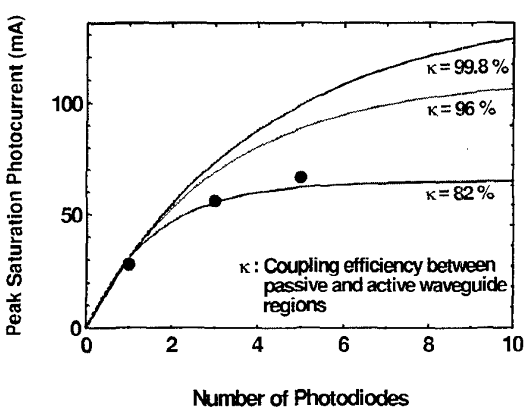

Fig. 4 Saturation photocurrent vs the number of photodiodes in VMDP.