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High Performance Long-Wavelength Velocity-Matched Distributed Photodetectors For RF Fiber Optic Links

T. Chau, S. Mathai, A. Rollinger, D. L. Sivco*, A. Y. Cho*, D. C. Scott+, T. A. Vang+, M. C. Wu, and T. Itoh
UCLA, Electrical Engineering Department,
66-147D Engineering IV, Box 951594
Los Angeles, CA 90095-1594
Tel: (310) 825-6859, Fax: (310) 825-6954, Email: wu@ee.ucla.edu
*Lucent Technologies, Bell Laboratories, Murray Hill, NJ 07974
+Photonics Technology Department, TRW, Redondo Beach, CA 90278

Abstract

Improved performance of InP-based long wavelength velocity-matched distributed photodetector (VMDP) with metal-semiconductor-metal photodiodes is experimentally demonstrated. A 3-dB bandwidth of 13 GHz and an external quantum efficiency of 0.57 A/W have been achieved.

I. Introduction

High power, high frequency photodetector is a key component for high performance microwave fiber optic links [1-3]. High optical power in externally modulated links can greatly enhance the link gain, signal-to-noise ratio, and spurious-free dynamic range [4]. In conventional photodetectors, there is a trade-off between the saturation photocurrent and the device bandwidth. High power device requires a large absorption volume, thus the device is usually large, resulting in large RC time or long carrier transit time that limits the device bandwidth. In contrast, conventional high-speed photodetectors with small RC time and small transit time usually have low saturation photocurrents. The velocity-matched distributed photodetectors (VMDP) is a novel type of travelling wave photodetector which can achieve both high bandwidth and high saturation power. It was first proposed in 1993 [6], and has been successfully demonstrated experimentally [1,5]. The successful fabrication of long-wavelength VMDP for use in 1.3 or 1.55 μm RF Photonics systems was first reported in [5]. In this paper, we report on the performance of improved long wavelength VMDP with new design and fabrication procedures. A 3-dB bandwidth of 13 GHz and an external quantum efficiency of 0.57 A/W have been achieved.

II. Device Structure and Fabrication

The schematic structure of the VMDP is illustrated in Figure 1. A passive (non-absorbing) optical waveguide is used to serially connect an array of periodically spaced metal-semiconductor-metal (MSM) photodiodes. Light in the optical waveguide is evanescently coupled to the MSM photodiodes. The photocurrents are added in phase and collected by a 50Ω coplanar strips (CPS) microwave transmission line. The active photodiodes are designed to have small optical confinement factor to keep them bellow saturation under high optical illumination. The bandwidth of the VMDP is limited by that of the individual photodiode, and the residual velocity mismatch. Since photocurrents are collected from many photodiodes along the transmission line, the individual photodiode does not need to have high quantum efficiency and therefore can be made small and fast. The MSM photodiodes serve two functions: generating photocurrents as well as providing the periodic capacitance loading needed for velocity matching. The VMDP design allows the passive waveguide, the active photodiodes, and the microwave coplanar strips to be independently optimized.

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The principle of the VMDP has been discussed in more detail in [1]. We have made three major changes: (1) mesa width reduction to reduce optical coupling loss from optical waveguide to active MSM photodiodes; (2) nitride passivation on mesa sidewall and underneath the large CPS electrodes to reduce dark current and improve device reliability; and (3) use of platinum in Schottky metal contacts to prevent gold diffusion at high power operation

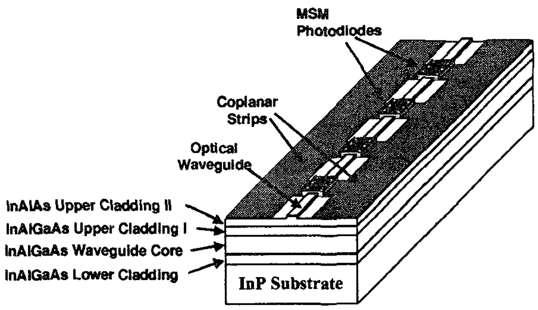

Figure 1. Schematic structure of long-wavelength velocity-matched distributed photodetector (VMDP)

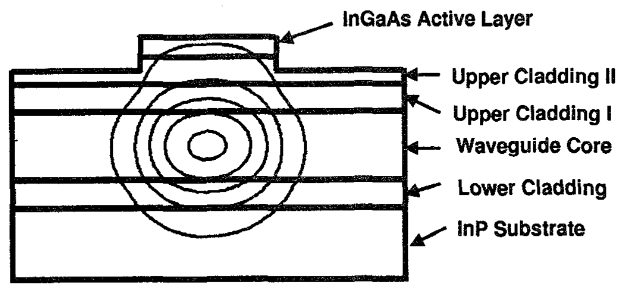

Figure 2. Contour plot of the fundamental mode profile in the photodiode region using BPM

Beam propagation method (BPM) is used to design and simulate the optical performance of the VMDP. Large-core optical waveguide is employed to reduce the coupling loss between the passive waveguide and the photodiode region as well as to reduce the optical power density in the absorption region. Only fundamental mode exists in both the passive waveguide and the photodiode regions. Figure 2 shows the optical field distribution of VMDP in the photodiode. Most of the optical energy concentrates in the waveguide core. The optical absorption and the coupling loss per photodiode for the VMDP shown in Fig. 1 are estimated to be 8.3% and 1.6%, respectively, by the BPM simulation.

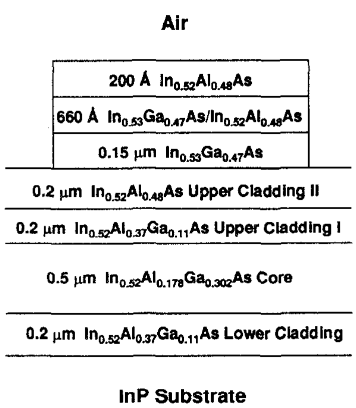

Figure 3. Cross section of VMDP wafer after mesa etching

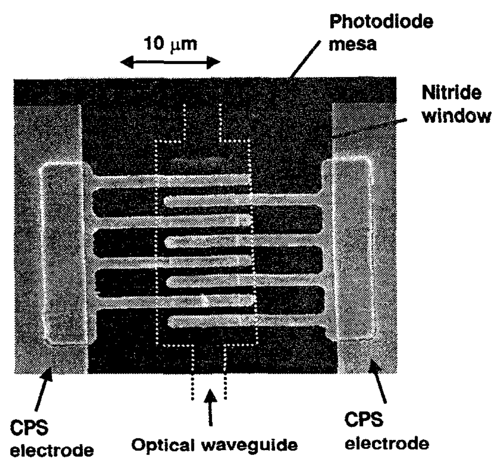

Figure 4. SEM picture of a single MSM photodiode of VMDP

The active MSM photodiodes consists of InGaAs absorption layer; InGaAs/InAlAs graded superlattice layers; InAlAs Schottky-barrier enhancement layer; and interdigitated fingers. The fabrication process is as followed: first, metal alignment markers are patterned on the substrate for subsequent process. Next, active mesas for photodiodes are defined by wet etching down to the InAlAs Upper Cladding II. Then optical ridge waveguide with ridge height of 0.1μm is formed by wet etching. After mesa and waveguide etching, a Si_3N_4 passivation layer is deposited to protect the mesa edges. The nitride directly on top of the active mesas are opened for Schottky contacts. Interdigitated Ti/Pt/Au fingers with 1μm finger width and 1μm finger spacing are patterned in the open windows using optical lithography. Finally, the CPS microwave transmission line is fabricated using standard liftoff technique. The cross section of VMDP wafer after mesa etching is shown in Figure 3. Figure 4 shows the scanning electron micrograph (SEM) of a single MSM photodiode in the VMDP.

III. Device Characteristics

All devices under test are mounted on copper heat sinks. The temperature is set at 19 °C using a temperature controller. The VMDP exhibits very low dark current: 8.3 nA at 10V bias for a 1-mm-long VMDP with 13 photodiodes. The dark current has been reduced by 10 times compared to the VMDP in [5]. It is attributed to the nitride passivation which prevents the leakage currents through the sidewalls and the CPS electrodes. The external quantum efficiency is measured to be 0.4 A/W. With anti-reflection (AR) coating, it could reach 0.57 A/W. The dominant loss comes from the coupling from optical fiber to the VMDP. Figure 5 shows the DC responsivity of the new device. The responsivity of the VMDP in [5] is also shown for comparison.

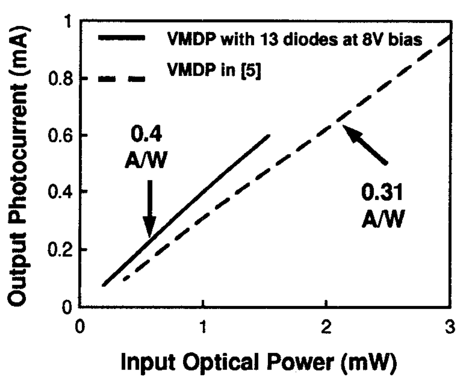

Figure 5. DC responsivity of VMDP (without AR coating)

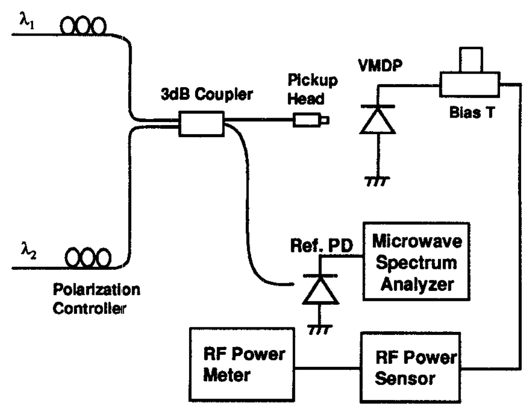

Figure 6. Schematic of optical heterodyne system setup for frequency response characterization of VMDP

The frequency response of the VMDP is characterized by optical heterodyne method [7,8]. The schematic of the experimental setup is shown in Figure 6. The system consists of two external cavity tunable lasers at 1.55μm, the frequency of each laser can be tuned in 1GHz step. The optical signals are combined by a 3dB coupler, and coupled to the VMDP using a fiber pickup head. The microwave signal generated by optical mixing in the VMDP is collected at the output end of the CPS by a 50GHz picoprobe (GGB Industries), which is connected to an RF power sensor and monitored by an RF power meter. The calibrated frequency response of long wavelength VMDP is shown in Figure 7. At 10 Volt bias, a 3dB bandwidth frequency of 13GHz is measured. By scaling down the MSM to deep sub-micron scale, much higher bandwidth (> 100 GHz) is expected.

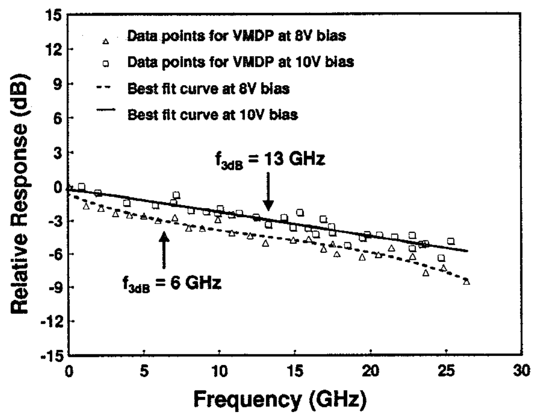

Figure 7. Measured frequency response of a long wavelength VMDP with 10 MSM photodiodes at different DC bias voltages

IV. Conclusion

In summary, we have experimentally demonstrated the improved performance of the long wavelength velocity-matched distributed photodetector (VMDP). A 3dB bandwidth of 13 GHz and a responsivity of 0.57 A/W have been achieved.

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