Si-based Optical Receivers

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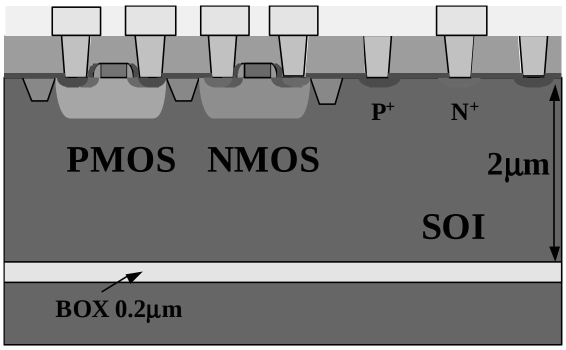
Several standards such as Gigabit Ethernet, Fibre Channel, and OC192VSR are specified for short distance data transmission. In addition, optical interconnects can provide the increased bandwidths that will be required on computer backplanes for board-to-board data transfer. For these applications, short-wavelength, inexpensive vertical cavity surface emitting lasers are commercially available. For receivers, large-volume, low-cost components are needed. Silicon technology offers an attractive choice for low-cost high-performance electronics. One solution for optical receivers consists of hybrid integration of III-V photodiodes with Si or GaAs electronics, but the cost can be reduced further by Si-based monolithically integrated circuits. At 850nm the absorption length in silicon is 20μm and a planar photodiode fabricated on a bulk substrate would have a low frequency component due to long transit times [1]. The challenge is to integrate high-speed, moderate quantum efficiency, low-voltage photodetectors into the CMOS/BiCMOS integration process. Low cost dictates that there be few or no modifications of the process flow.

In this paper we review work on a Si monolithic optical receiver using an unmodified 130nm silicide CMOS process flow on a 2μm-thick SOI substrate [2]. Figure 1 shows a cross section of the photodiode/transistor structure. The thickness of the SOI was chosen to achieve a compromise between quantum efficiency and bandwidth for the photodiodes. The photodetector was a lateral interdigitated P-I-N structure with 1μm-wide electrodes, 2μm electrode spacing, and total area of 2500μm^2 [1]. The amplifier used in this receiver was a three-stage transimpedance amplifier with active feedback. In order to achieve higher speeds NMOS transistors were used in the signal path. The transimpedance gain of the receivers was in the range 53.4dBΩ to 31dBΩ. The circuit dissipated total power between 10mW and 35mW depending on the design.

Figure 1. Schematic of PIN/transistor structure.

The bit error rate (BER) was measured on-chip using an 850nm vertical cavity surface emitting as the laser source [2].



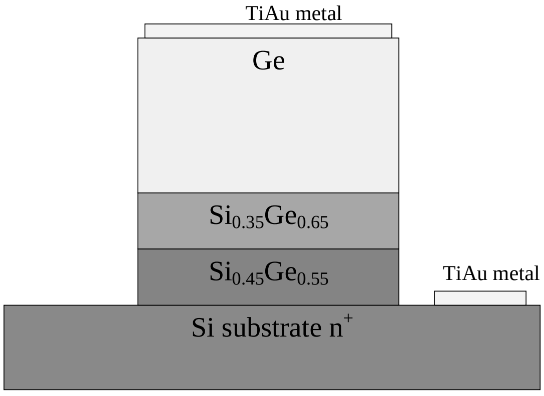
The maximum sensitivity for a BER of 10^{-9} was -19dBm at 1Gb/s and -16.5dBm at 2Gb/s. For a BER of 10^{-12} the sensitivities degraded by approximately 1dB at each bit rate. The dynamic range was 21dB and 18.5dB for 1Gb/s and 2Gb/s, respectively. Sensitivities of -15.4dBm, -10.9dBm, and 0.9dBm and 2dBm were measured for 3.125Gb/s, 5Gb/s, 6Gb/s and 8Gb/s, respectively.

In order to extend the operating wavelength to 1300nm, the Si photodiode can be replaced by a Ge photodetector. This has the advantage of compatability with much of Si process technology. In addition, Ge has high mobilities and a large absorption coefficient at 1300nm. The primary limitation associated with the direct growth of Ge on Si is that the high strain-related dislocation densities limit device performance. To improve the material quality of Ge on Si, many techniques have been investigated. Recently, a growth technique that utilizes thin buffer layers has been reported [3]. By optimizing the Ge concentration of two thin SiGe buffer layers, many threading dislocations can be "trapped" at the heterojunction interface, thereby reducing the dislocation density in the Ge layer.

We have utilized this approach to improve material quality and device performance. Prior to growth of the Ge layer, two different composition SiGe buffer layers, 0.6μm-thick $Si_{0.45}Ge_{0.55}$ and 0.4μm-thick $Si_{0.35}Ge_{0.65}$, were grown in a cold-wall ultra-high-vacuum chemical-vapor-deposition (UHV-CVD) system. Figure 2 shows a schematic of the device structure.

Figure 2. Schematic cross section of Si/SiGe/Ge heterojunction photodiodes.

As shown in Fig. 3, for 24μm-diameter devices, the dark current was 0.06μA, 0.27μA and 1.07μA at biases of 1V, 3V and 10V, respectively. The responsivity was measured by illuminating through the substrate with a 1.3μm laser source. After deposition of a 2000 Å SiO_2 anti-reflecting coating, 88% of the incident light is estimated to be transmitted into the device. The measured responsivity was 0.37A/W at 0V and 0.57A/W above 2V. RF response measurements were made using a network analyzer and a 1.3μm laser. The bandwidths are 4.0GHz at 3V, 6.0GHz at 5V, 7.8GHz at 7V and 8.1GHz at 10V for 24 μm-diameter devices. These bandwidths are much less than the RC bandwidths as determined by impedance measurements, which indicates that the device speed is limited by the carrier transit time.



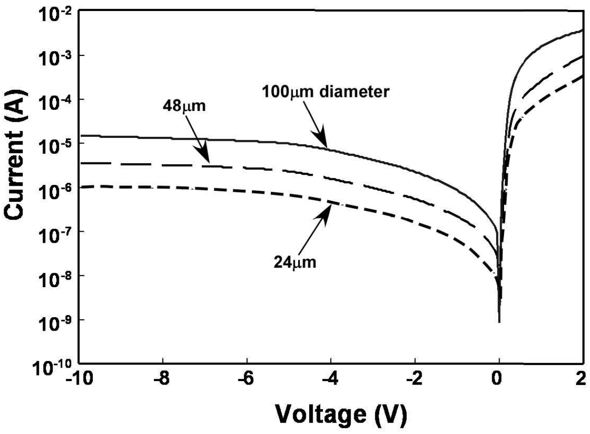


Figure 3. Current voltage for Si/SiGe/Ge heterojunction photodiodes.

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[3] Guangli Luo, Tsung-His Yang, Edward Yi Chang, Chun-Yen Chang and Koung-An Chao, *Jpn. J. Appl. Phys.* Vol. 42, pp. L512-L519, 2003.