Germanium on Double-SOI Photodetectors for 1550 nm Operation

Olufemi Dosunmu, Matthew K. Emsley, [1]Douglas D. Cannon, [2]Bruno Ghyselen, [1]Lionel C. Kimerling, and M. Selim Ünlü

Boston University, Department of Electrical and Computer Engineering, 8 Saint Mary's Street, Boston, MA 02215
[1] Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139
[2] SOITEC SA, Parc Technologique des Fontaines, 38190 Bernin, France

The drive for less expensive photodetectors for operation at near-infrared (NIR) communication wavelengths that can be easily integrated into other silicon-based technologies has led to serious investigations into the heteroepitaxy of lower bandgap materials on Si, one of which is germanium. However, the lattice mismatch which exists between Ge and Si (~4%) would ordinarily make such a combination unsuited for high-quality photodetectors [1]. The misfit and threading dislocations resulting from such a lattice mismatch are detrimental to the overall performance of photodetectors designed for optical communications.

We have fabricated a resonant cavity enhanced (RCE) Ge-on-double-SOI photodetector for operation around the 1550 nm communication wavelength. The Ge layer is grown through a novel Ge-on-Si direct epitaxial growth technique [2]. These Ge photodetectors are fabricated on a silicon wafer with a buried distributed Bragg reflector (DBR) which serves as a bottom mirror, while the air/Ge interface serves as the top mirror, forming a Fabry-Perot cavity. The buried DBR consists of only 2 periods of Si/SiO_2, fabricated – in collaboration with SOITEC – through a process called SmartCut®, and is designed for maximum reflectivity (>90%) over a broad wavelength range in the near IR, including 1300 and 1550 nm [3].

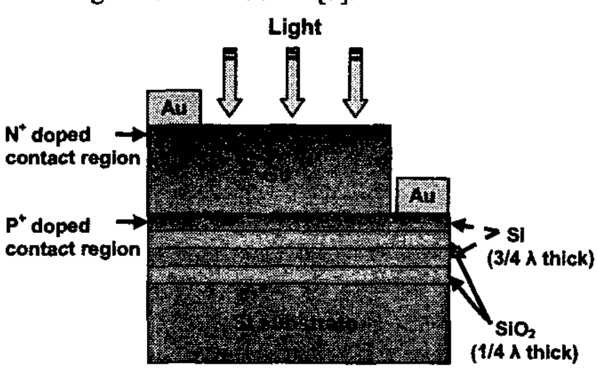

Fig. 1. Cross-sectional view of top-illuminated Ge/DSOI vertical PIN photodetector.

Our Ge/DSOI photodetector is a vertical PIN-type structure, as illustrated in Fig. 1. Here, the ion-implanted doped regions were performed in collaboration with Axcelis Technologies.

In using the Ge layer as the active region, it is necessary to position this region within a resonant cavity in order to enhance its normally low absorption around the 1550 nm wavelength range. The total absorption within this active region would depend more on the resonant behavior of the cavity than on the absorption length of Ge itself, as a result. However, in examining the absorption characteristics of our Ge/DSOI structure, we observed even further absorption enhancement beyond that obtainable with ordinary Ge within a resonant cavity.

This extra enhancement can be attributed to strain-induced bandgap narrowing within the Ge layer, resulting from the difference in the thermal expansion coefficients of Ge and Si [4]. Transmission and reflectivity measurements of this structure provided the Ge layer's absorption characteristic above 1150 nm, and as can be seen in figure 2, this extra enhancement is clearly noticeable at wavelengths above 1450 nm.

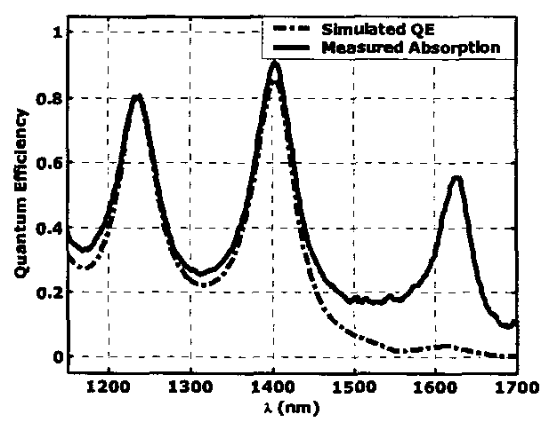

Fig. 2. Simulated QE vs. measured absorption of Ge/DSOI sample; Ge thickness: 755 nm.

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With the enhanced effective absorption coefficient of Ge extracted from this absorption data, the response of such a structure optimized for 1550 nm operation can be simulated. Given a Ge layer thickness of about 1.22 μm, for example, a quantum efficiency of 85% is attainable, and a capacitance and transit-time limited bandwidth of about 20 GHz is estimated.

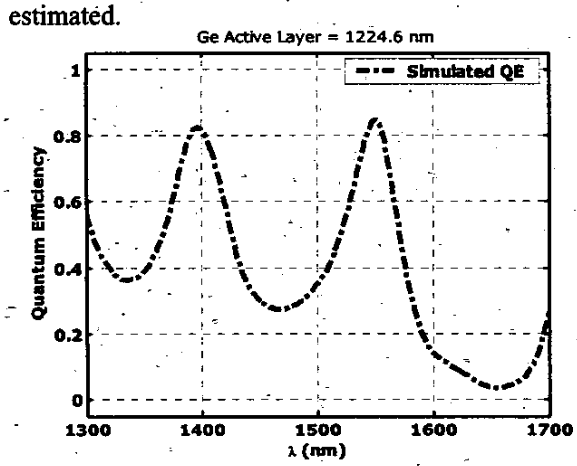

Fig. 3: Simulation of Ge/DSOI photodetector optimized for 1550 nm operation; Ge thickness: 1225 nm.

Figure 4 illustrates the response of one of our fabricated Ge/DSOI photodetectors, compared with the simulated response. Here, both the simulated and measured quantum efficiencies of this detector are lower than that anticipated for the optimized detector simply because the Ge layer thickness (737 nm) is not optimized for 1550 nm operation. At 1550 nm, the photodetector was measured having a quantum efficiency of about 15% at 2 V reverse bias, which is about half the simulated QE of 31%. The main reason for this discrepancy stems from the photogenerated carriers not being collected efficiently at the contacts. To improve the collection efficiency, this detector was reverse biased, while the tunable laser source was chopped and the detector signal measured via a lock-in amplifier. The improvement in the detector collection efficiency can be clearly seen when compared to the detector response at zero bias, which falls to about 9%.

We have simulated and fabricated Ge-on-DSOI photodetectors which are suitable for operation at 1550 nm. When optimized, our detectors should exhibit quantum efficiencies exceeding 85% at 1550 nm, with a bandwidth approaching 20GHz. The enhanced response of these detectors is attributed to both the resonant cavity effect as well as the strain-induced bandgap narrowing of the Ge layer.

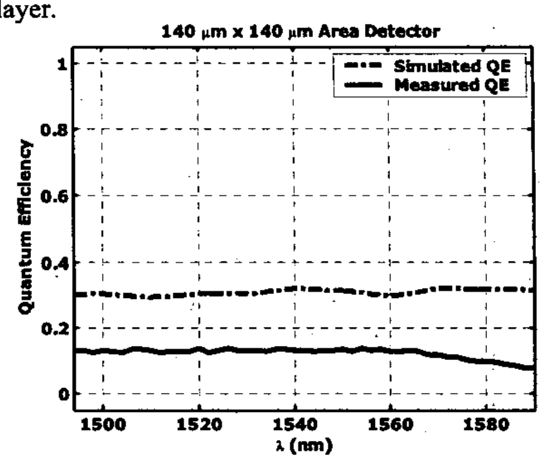

Fig. 4. Measured Ge/DSOI vs. simulated QE. Ge thickness: 737 nm. A 300 nm SiO_2 AR coating was used.

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