

High Speed Resonant Cavity Enhanced Ge Photodetectors on Reflecting Si Substrates for 1550 nm Operation

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Abstract: We have fabricated high-speed resonant cavity enhanced Ge-on-SOI photodetectors, demonstrating 3dB bandwidths of more than 12 GHz at 3V reverse bias and a peak quantum efficiency of 59% at the resonant wavelength of ~1540 nm.

The monolithic integration of photodetectors designed for operation around the long-haul communication wavelengths (1300, 1550 nm) with silicon-based IC technologies has been a long-standing goal within the optical communications industry. One attractive solution involves direct monolithic integration, given the relative ease of fabrication and potential cost advantage associated with this approach. Si-based photodetectors would be ideal for monolithic integration with Si-based electronics; however, such detectors would not be viable for operation around the long-haul communication wavelengths, given the lack of sensitivity Si exhibits at wavelengths beyond 1100 nm.

Germanium is a good candidate, given its wavelength sensitivity in the NIR, as well as its compatibility with IC technologies. However, the relatively small absorption coefficient ($\alpha \approx 460\text{cm}^{-1}$) of bulk Ge at 1550 nm would necessitate a thick active region in order to achieve high efficiency, resulting in a slow device. One way to effectively enhance the response of a weakly absorbing medium, without sacrificing the device bandwidth, involves placing the absorbing region within a Fabry-Perot, or resonant, cavity [1]. To that end, we report on high-speed and high-efficiency resonant cavity enhanced (RCE) Ge photodetectors fabricated directly on an SOI substrate.

Illustrated in Fig. 1 is the basic structure of our Ge/SOI RCE photodetector, which consists of a Ge layer heteroepitaxially grown on a double-side polished SOI substrate. The thicknesses of the Si (340 nm) and SiO₂ (200 nm) layers provide a back reflectivity of 55% around the 1550 nm wavelength range. The heteroepitaxial growth of Ge on the SOI substrate was performed through a two-step UHV/CVD growth process [2], while the threading dislocation density within the Ge film was reduced by cyclic annealing. Coplanar waveguide Ti/Au metal contact pads to the Ge photodetectors were patterned for high-speed characterization. These vertical Schottky photodetectors were designed for bottom-illumination, and range in size from 10 μm to 78 μm in diameter.

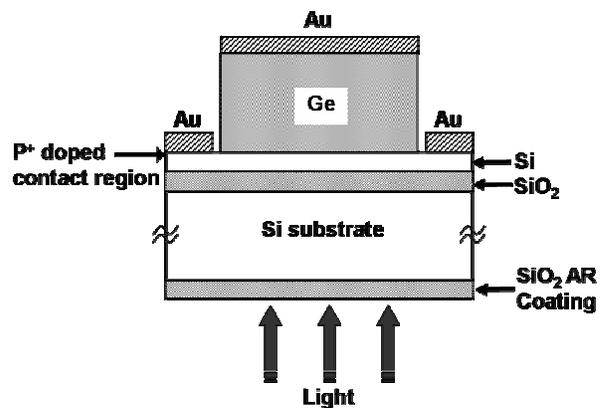


Fig. 1: Cross-sectional view of the back-illuminated Ge/SOI photodetector.

Current-voltage characterization of our 10 μm diameter Ge/SOI detectors reveal dark currents as low as 380 nA at -5V reverse bias. Quantum efficiency simulations of our back-illuminated Ge/SOI detectors optimized for 1550 nm operation reveal an η of 75% at 1550 nm, which is over 11 times that obtainable with bulk Ge on an ordinary Si substrate, assuming a Ge layer thickness of 1430 nm in both cases. Such a high η is due both to the resonant cavity effect, as well as the tensile strain-induced bandgap narrowing within the Ge film. The strain within the Ge film of the Ge/SOI structure stems from the difference between the thermal expansion coefficients of Si and Ge [3]. This strain-induced bandgap narrowing has been shown to increase the Ge absorption coefficient at 1550 nm by almost an order of magnitude, to around 3410cm^{-1} [4]. Illustrated in Fig. 2 is the measured bottom-illuminated η of a 78 μm diameter detector, along with its simulated response. Here, the photodetector is resonant at 1538 nm with a measured η of 59%, while the η at 1550 nm is 39%. Both η values were measured at a reverse bias of only 0.5V. Although short of the expected η of 75% and 67% at 1538 nm

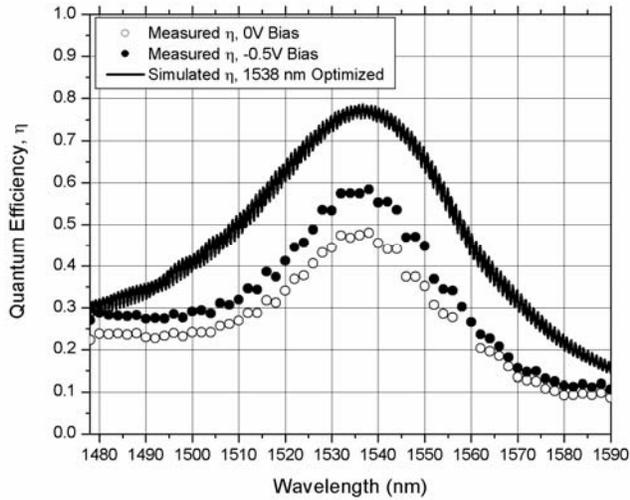


Fig. 2: Simulated vs. measured η of a 78 μm diameter Ge/SOI photodetector, resonant at 1538 nm. The measured η at 0 V (open circles) and -0.5 V bias (filled circles) are illustrated.

and 1550 nm, respectively, the measured η greatly exceed that obtainable in a single-pass configuration.

The temporal response of these Ge photodetectors was obtained through back-illumination with 1.2 ps FWHM laser pulses, wavelength centered at 1550 nm. Figure 3 shows the temporal response of a 10 μm diameter Ge/SOI detector at 1550 nm, with the FFT of the pulse shown in the inset. Here, the measured FWHM of the response pulse is 20 ps at -3V bias. The FFT of this pulse yields a 3dB bandwidth of 12.1 GHz, which is close to the theoretical value of 15.6 GHz simulated for the same detector structure. Figure 4 shows the 3dB bandwidths versus detector biasing for several detectors of sizes 10 μm , 28 μm , 48 μm and 78 μm in diameter. As can be seen in this figure, the detector bandwidths generally saturate around -2V biasing, making these detectors attractive for Si IC integration.

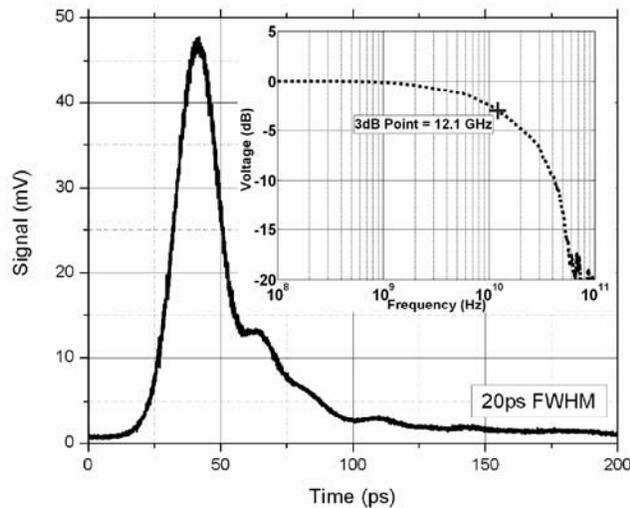


Fig. 3: Temporal response of a 10 μm diameter detector at -3 V bias. Measured pulse FWHM is 20 ps. The FFT of this pulse is shown in the inset.

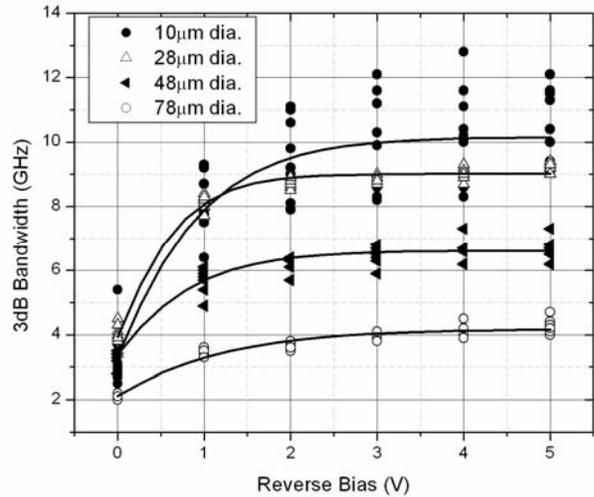


Fig. 4: 3dB bandwidth at 1550 nm vs. reverse bias for Ge/SOI detectors of sizes 10, 28, 48, and 78 μm in diameter. 2nd order polynomial fit curves for each detector size group are included.

To the authors' knowledge, we have demonstrated the fastest Ge photodetectors fabricated directly on Si for 1550 nm operation. These detectors exhibit quantum efficiencies of nearly 60% at 1540 nm, and have the potential of demonstrating quantum efficiencies of 75% at 1550 nm, with bandwidths approaching 13 GHz, making these photodetectors highly attractive for monolithic integration with Si ICs for 10 Gbps data communication systems.

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