Self-aligned germanium fins in metallic slits as a platform for planar wavelength-selective photodetectors at telecommunications wavelengths

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Abstract: We demonstrate planar resonant photodetectors based on germanium fins self-aligned to metallic slits. By varying the fin widths, we engineer detectors with tunable and extended spectral response spanning the telecommunications C- and L-bands.

Germanium is a promising detector material for CMOS-compatible optoelectronic devices. However, the C (1530-1565 nm) and L (1565-1625 nm) bands commonly used in telecommunications include wavelengths beyond germanium's direct bandgap absorption edge at 1550 nm. As a result, thick or long Ge regions are required to absorb a significant fraction of the incident light, increasing detector size and response time or capacitance. Applying tensile strain to Ge moves the band edge to longer wavelengths [1], but the resulting device geometry can be non-planar and integrating other components with these detectors may be challenging. Here we show a novel alternative approach, extending the detector's absorption to longer wavelengths by using a metal/dielectric cavity to enhance the Ge indirect absorption tail. The resulting detector absorption spectrum can be tuned during manufacturing. In particular, the device can mimic a material with a longer wavelength absorption edge, all while enabling a compact nanoscale structure that promises low capacitances and high speeds.

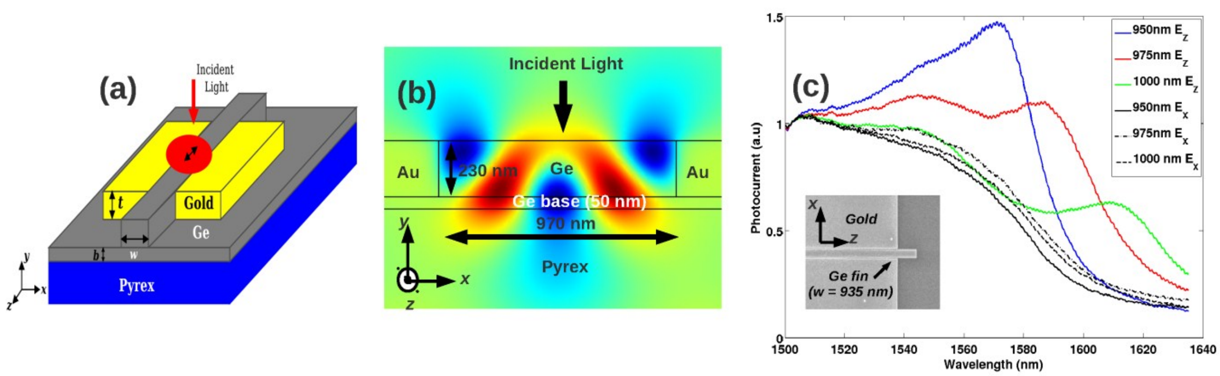

Fig. 1 (a) Device schematic **(b)** The electric field (E_z) profile in the device at resonance. **(c)** Measured absorption spectra for devices when excited with electric field polarization along the fin (E_z) clearly indicating redshifting of resonance with increasing width. Spectra in the orthogonal polarization (E_x) show no enhancement. An SEM image of a fabricated device is shown in the inset.

To fabricate the tunable detectors, epitaxial Ge was grown by reduced pressure chemical vapour deposition on a Si substrate. The Ge was then bonded to a Pyrex handle wafer using anodic bonding, and the silicon substrate was subsequently removed using an alkaline wet etch. Ge fins approximately 230 nm thick were etched, then surrounded by gold stripes using a self-aligned process [2]. An additional 50 nm Ge base layer was left to make electrical contact. Fig. 1(a) shows the device schematic and the inset of Fig. 1(c) shows an SEM image of a fabricated device. As discussed for Si detectors in [2], when the device is excited with electric field polarization along the fin (E_z), the structure supports strong absorption resonances, as shown in Fig. 1(b), that can be tuned lithographically by varying the width of the fin. The fin width w and the resonance peak λ_0 are related by $w \sim 5\lambda_0/2n_{Ge}$ where n_{Ge} is the refractive index of Ge. Fig. 1(c) shows measured absorption spectra for devices with widths of 950 nm (blue), 975 nm (red) and 1 μm (green) with polarization along the fin (E_z). The device with fin width 975 nm (red) has an effective band edge at 1590 nm, whereas the one with width 1 μm shows enhanced absorption in the L band, extending beyond 1610 nm. For comparison, in the orthogonal polarization (E_x) where this resonance is not active, the absorption spectra (black curves) of the devices with different fin widths are nearly identical and equivalent to bulk Ge, showing a band edge at 1550 nm.

By integrating a combination of these resonators with different widths, one can lithographically create different spectral responses in a single planar process. Simulations indicate that by improving fabrication and optimizing the Ge fin thickness, higher quality factors (Q) may be achievable, enabling use of these detectors for coarse wavelength division demultiplexing at telecommunications wavelengths.

1. D. Nam, D. Sukhdeo, A. Roy, K. Balram, S.-L. Cheng, K. C.-Y. Huang, Z. Yuan, M. Brongersma, Y. Nishi, D. Miller, and K. Saraswat, "Strained germanium thin film membrane on silicon substrate for optoelectronics," Opt. Express **19**, 25866-25872 (2011)
2. K. C. Balram and D. A. B. Miller, "Self-aligned silicon fins in metallic slits as a platform for planar wavelength-selective nanoscale resonant photodetectors," Optics Express **20**, 22735–22742 (2012).