Cost-effective, CMOS-compatible, label-free biosensors using doped silicon detectors and a broadband source

Leanne Dias, Enxiao Luan, Hossam Shoman, Hasitha Jayatilleka, Sudip Shekhar, Lukas Chrostowski, and Nicolas A. F. Jaeger

Department of Electrical and Computer Engineering, University of British Columbia, 2332 Main Mall, Vancouver, BC, V6T 1Z4

diaslc2@ece.ubc.ca

Abstract: By replacing Ge-based photodetectors and tunable lasers with doped silicon photoconductive heater-detectors and broadband sources, we propose and demonstrate a cost-effective implementation of photonic sensors for biosensing applications.

OCIS codes: (130.6010) Sensors; (130.7408) Wavelength filtering devices; (230.5160) Photodetectors; (230.5750) Resonators.

Silicon photonics is an emerging solution to the currently growing demand for medical diagnostics. Compared to the modern gold-standard method, namely the ELISA, silicon photonic-based biosensors show the potential to achieve low-cost, complete lab-on-a-chip sensing systems [1] by leveraging mature CMOS fabs. In addition, silicon photonic-based devices excel at label-free detection. Current signal interrogation configurations for silicon photonic sensors require an expensive high-resolution tunable laser or optical spectrum analyzer, which inhibits their widespread use, especially for point-of-care diagnosis. To reduce the cost of biosensors and enable their proliferation, Song et al. [2] suggested a voltage scanning method using a tracking microring that electrically tracks the changes in the sensing microring. This method brings two advantages; first, the detection limit could be improved since lasers are not used in such technique, and wavelength shifts smaller than the laser linewidth can be tracked. Second, and most importantly, as the laser is the most expensive building block of a biosensor, replacing the laser with a broadband source provides a lower-cost solution. In [3] the authors implemented the same scheme with on-chip Ge photodetectors (PD). Here, we replace the on-chip Ge photodetectors with all-silicon, in-resonator

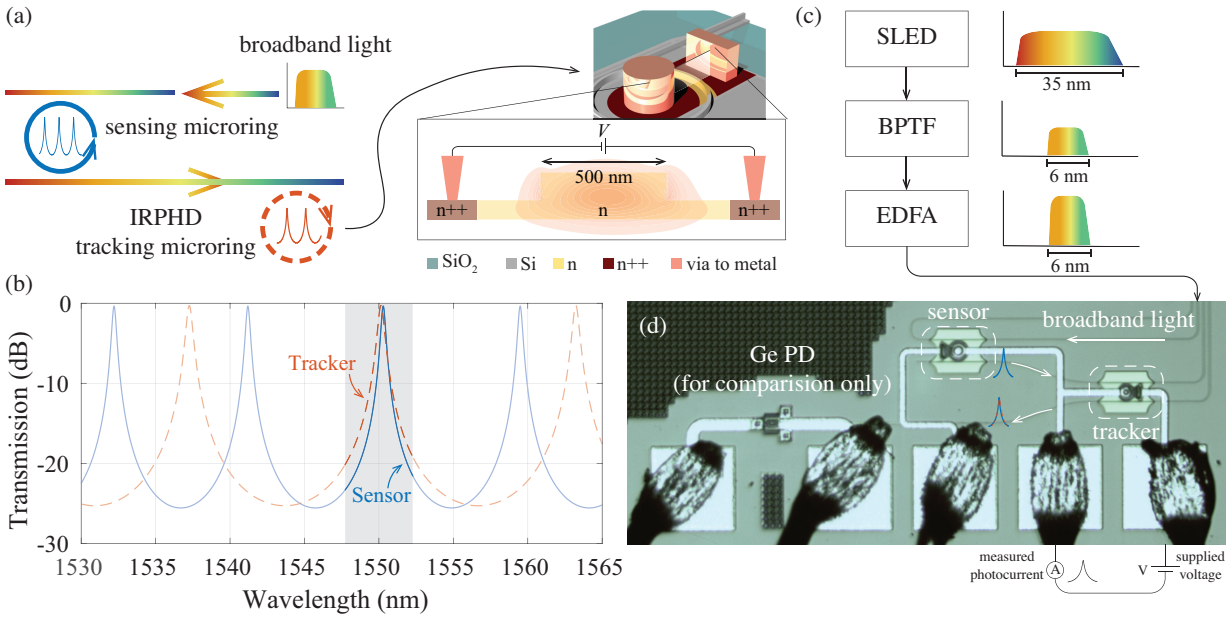

Fig. 1: (a) Layout of the photonic sensor consisting of two microrings, a sensor and a tracker, using a broadband source. (b) Frequency spectrum of each microring across the spectrum of the SLED shown in (c). The shaded region shows the resonance of each ring over a bandiwdth of 6 nm, as filtered by the BPTF in (c). (c) Block diagram of our experimental setup. (d) Optical microscope image of a test device.

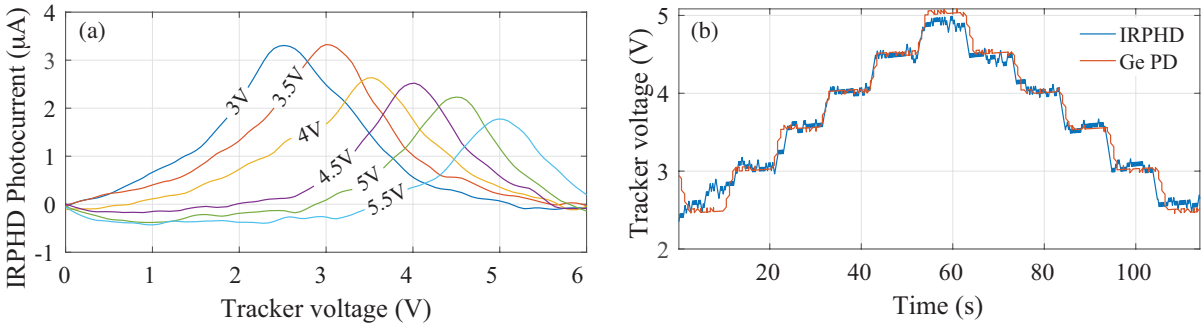

Fig. 2: (a) The IRPHD photocurrent as a function of the tracking ring voltage at various sensing ring voltages (indicated as legends on the line plots). (b) Tracker voltage to maximize the photocurrent (from the IRPHD and Ge PD) at various sensing ring voltage setpoints across time, implemented using a maximum search algorithm (the dither signal can be seen).

photoconductive heater-detectors (IRPHDs), which: (1) reduces the overall cost of photonic biosensors, since Ge PDs are not required; (2) reduces the number of pads by half for electrical I/O, thus reducing the on-chip real estate; (3) simplifies the control electronics by using a single element to detect light and tune the microring. While Ge PDs are preferable in some cases, for our application we show that similar performance can be attained using IRPHDs. Combining IRPHDs with a broadband source provides a low-cost photonic biosensor.

Our test devices were fabricated by IME A*STAR, Singapore. Fig. 1(a) shows a layout of the photonic sensor, which consists of two microrings, a sensor and a tracker, with radii of 10 and 8 μm, respectively. The microrings' rib waveguides are formed using a 500 nm core width with a 90 nm thick slab [4]. For the tracking microring, the waveguide core was N doped and the sides were N++ doped to form ohmic contacts, as shown in Fig. 1(a). For proof-of-concept, we simulate a biosensing experiment by replacing the sensing ring with an electrically tunable microring. The spectra of both microrings was simulated and is shown in Fig. 1(b). Since the IRPHD photocurrent is maximized when the sensing and tracking rings' resonances are aligned, the voltage supplied to the IRPHD tracking ring is proportional to the measurand perturbing the microring. Fig. 1(c) displays a block diagram of the experimental setup. As the FSRs of the sensing and tracking microrings are smaller than the bandwidth of the broadband source, other resonance mode overlaps are possible, which could cause false positives. To ensure only a single resonance mode overlap, we used a 6 nm bandpass tunable filter (BPTF). The broadband light was then passed through an erbium-doped fiber amplifier (EDFA) to compensate for the BPTF and on-chip grating coupler losses. In the future, an on-chip BPF can be implemented. Fig. 1(d) shows an optical microscope image of a test device. Fig. 2(a) shows the IRPHD photocurrent as a function of the tracking ring voltage for various sensing ring voltages. The high dynamic ranges of IRPHDs [4] suggest that low input powers (<-30 dBm) can be detected. By setting the voltage of the sensing ring, and scanning that of the tracking ring to align their resonances, a simulated bio-experiment is performed. The sensitivity was measured to be 174.5 mW/RIU. To compare and contrast the IRPHD performance to the Ge PD, we tuned the sensing ring in real-time and tracked the voltage change on the tracking microring, once by maximizing the IRPHD photocurrent, and once by maximizing an on-chip Ge PD (placed at the drop port of the tracking ring as shown in Fig. 1(d)). Fig. 2(b) shows the real-time tracking, for the Ge PD and IRPHD, using a maximum search algorithm; similar performance was obtained.

We have proposed and demonstrated that using photoconductive detectors as an alternative to Ge PDs reduces the fabrication costs, reduces the on-chip real estate, and simplifies the control electronics. These benefits are compounded by the fact that sensor systems typically require the use, and tracking of, multiple microrings on the same chip [3].

References

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