Advancing Silicon Photonics for Clinical Applications

D. Ratner[1]
[1]University of Washington, Seattle, WA

Introduction:

The global burden of chronic illness – including diabetes, cancer, and cardiovascular disease – is substantial and increasing, especially among aging populations. Early detection can dramatically improve outcomes and reduce overall treatment costs. However, current quantitative clinical diagnostics (e.g., enzyme-linked immunosorbent assay, ELISA) are largely confined to hospital and laboratory settings due to their cost and training requirements. High-performance point-of-care and home-health diagnostics could bring early detection to the masses, potentially revolutionizing healthcare. Silicon photonics is an emerging biosensing technology that leverages the economies-of-scale offered by today's microchip foundries while promising the same level of integration, miniaturization, and portability found in microelectronic-based devices. While silicon photonic biosensors appear to be poised to transform clinical diagnostics by accelerating the analysis of patient samples, a number of critical development challenges must still be overcome. First and foremost, silicon photonic devices must demonstrate sensitivities that match or improve upon laboratory medicine standards. In addition to optimizing the sensor's optical properties, improving sensitivity will require the integration of biocompatible surface chemistries onto the device to support real-time label-free performance in complex biological matrices (e.g. blood and plasma). In this study, we explore specific strategies to overcome these design challenges, and highlight clinical applications for emerging silicon photonic biosensing technologies.

Materials and Methods:

Custom photonic devices were designed using Lumerical's MODE, FDTD, and INTERCONNECT optical wave simulators. Designs were fabricated using the Washington Nanofabrication Facility's (WNF) silicon photonic process development kit (PDK) and written on a silicon-on-insulator substrate using a JEOL JBX-6300FS Direct Write E-Beam Lithography System (e-beam). The e-beam provides a low-cost, fast turn-around fabrication process that has been optimized to produce consistent, robust, low-loss silicon photonic components. To verify functionality, the fabricated sensors were tested using our custom optical test setup (Figure 1). To characterize performance in wet media, the sensors were be immersed in aqueous refractive index standards to determine each sensor's fabricated Q, S, and ILoD. Theoretical models and observed results were compared, and the models modified to optimize critical design parameters. Serologic and antigenic performance of the sensors was characterized using fresh whole blood provided by the Puget Sound Blood Center.

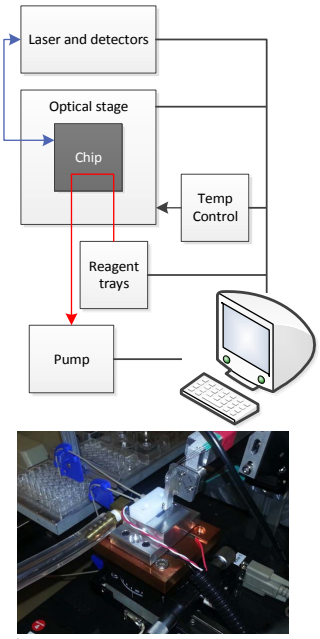

Figure 1.

Results and Discussion:

Employing the device development strategy outlined above, we have successfully demonstrated unparalleled slot-based biosensor performance of S=340 nm/RIU and Q = 1.5×10^4. Transverse electric vs. transverse magnetic mode device characterization has been used to establish the mode-dependent sensitivities of disk resonator architectures for use in bioanalytical applications in clinical samples (1.8×10^{-3} vs. 6.8×10^{-4} respectively). Employing these silicon photonic resonant devices, we performed real-time analysis of the serologic and antigenic profile of human blood as part of a rapid blood phenotyping clinical assay for use in transfusion and transplant medicine.

Conclusions:

Leveraging a custom silicon photonics optical characterization bio-bench, we have successfully designed, fabricated, and characterized a variety of novel silicon photonic biosensor architectures, including phase-shifted Bragg gratings, cascaded disk resonators, suspended waveguide gratings, and alternative silicon-on-insulator geometries to affect the evanescent field profile of our sensing devices. Through these efforts we have demonstrated sensitivities that match or exceed the highest reported sensitivities to date for similar photonic architectures. These sensor systems have been validated for their biological performance via serologic and antigenic profiling of human blood samples, and ongoing efforts are focused on increasing device sensitivity and adapting low-cost laser sources for biological sensing via silicon photonics.

Acknowledgements:

The authors would like to thank the Chrostowski Laboratory of the University of British Columbia for their collaboration and chip design expertise, CMC Microsystems for enabling the fabrication of the silicon chips via ePIXfab, and Lumerical Solutions, Inc. for providing the simulation software. This work was supported by the University of Washington (UW) Royalty Research Fund, The Wallace H. Coulter Translational Research Grant, NSF CBET (Award No. 1264174), and the Washington Research Foundation.