Fixed Wavelength Interferometer Sensors for Low-Cost Chem-Bio Sensing Applications

Jianhao Shen[1, a], Juan Carlos Gauna[2], Arushi Rai[3], Liam McClimans[1], Roseanna Lawandi[1], Asela Perera[1], Madhuri Kango-Singh[3], Swapnajit Chakravarty[1,b]

[1]Department of Electro-Optics and Photonics, University of Dayton, OH, USA 45469; [2]St. Mary's University, San Antonio, TX, USA 78228; [3]Department of Biology, University of Dayton, OH, USA 45469

ABSTRACT

We experimentally demonstrated slow wave enhanced phase and spectral sensitivity in asymmetric Michelson interferometer sensors with a phase sensitivity 277,750 rad/RIU-cm and theoretical phase sensitivity as high as 461,810 rad/RIU-cm. In the context of low-cost chip integrated photonic packaged sensors, in this paper we will experimentally demonstrate a method for active tuning of interferometer fringes using phase change materials that will potentially overcome fabrication induced variation of interference fringe wavelengths, thus allowing sensor chip packaging with a fixed wavelength laser and available integrated photodetectors.

Keywords: Michelson interferometer, silicon photonics, photonic crystal waveguide, slow light

1. INTRODUCTION

Various chip-integrated biosensor platforms in silicon are being demonstrated using electrical and optical transduction methods to further the promise of label-free bioassays in point-of-care diagnostics without the need for fluorescent or radioactive tags. In the photonic on-chip domain, miniature sensors with high sensitivities have been experimentally demonstrated with microring resonators, photonic crystal microcavities [1,2], surface plasmon resonators [3,4] and Mach-Zehnder interferometers. Till date, interferometric techniques with the Mach-Zehnder Interferometer (MZI) [5] and Young's interferometer (YI) [6] have shown the lowest mass detection limits (in pg/mm^2). However, the lack of an appropriate on-chip low-cost light source in all above platforms has precluded the promise of highly multiplexed label-free lab-on-chip photonic sensors with most demonstrations either limited to the benchtop or modular systems with externally coupled light sources that need to be tediously aligned to grating or edge couplers. Recent demonstrations of bonded, transfer printed or direct epitaxy lasers on silicon chips promise to overcome this packaging limitation given that photodetector is already integrated. However, due to fabrication imperfections, resonator resonances and interferometer fringes are not likely to occur exactly at the designed absolute wavelength of the source laser which by itself is a variable parameter. A light emitting diode combined with an on-chip spectrometer is also a viable route, however at the present time, on-chip spectrometers required to measure the tens of picometer wavelength shifts still occupy a large area on a chip.

Active tuning of silicon microcavity resonances is currently achieved with thermal heaters that consume power continuously and can potentially affect the temperature of the analyte medium in the vicinity of the sensor. In recent years, phase change materials (PCMs) such as Sb_2Se_3 have shown the ability to achieve a large change in refractive index during an amorphous to crystalline phase transition and vice-versa and retaining the new material phase until a reset pulse is applied. When integrated on the reference arm in a silicon interferometer sensor, the PCM changes the relative phase difference between the interferometer arms, post-fabrication. As a result, the interference fringes can be conveniently aligned to the wavelength of the packaged source laser. As the interference fringe shifts with change in the analyte refractive index in chemical sensing, or the analyte biomarker attachment in biosensing, an integrated photodetector measures the change in output power at the fixed laser wavelength. In this paper, we show our experimental results of the slow wave enhanced Michelson interferometer sensor. Integration with microfluidic channels has been implemented for biosensing. Device fabrication towards PCM integration in slow light interferometers is in progress and will be presented.

2. DESIGN AND EXPERIMENT

Fig. 1(a) shows a schematic of the slow light Michelson interferometer chem-bio analyte sensor. Fig. 1(b) shows a top view microscope image of the fabricated slow wave Michelson interferometer (MI) sensor device. A two-dimensional

a shenj5@udayton.edu;
b schakravarty1@udayton.edu; phone 1 937 229-2747;

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photonic crystal waveguide (2D-PCW) with different lengths 5µm and 20µm are fabricated on the reference arm and the signal arm respectively. Fig. 1(c) shows the scanning electron microscope (SEM) image of the 2D-PCW structure. Fig. 2(a) and (b) show the experimental transmission spectrum measured for a single 2D PCW with the air holes filled with silicon dioxide, acetone (n=1.3586) and IPA (n=1.3772) respectively which show good agreement with the simulated transmission spectral fringes. Fig. 2(c) shows that for oxide clad reference and analyte clad signal arms of length 20µm and 5µm respectively in the MI versus MZI configuration, the phase sensitivity for the MI reaches ~461,810 rad/RIU-cm near the band edge. From experiments, phase sensitivity at the analyte transmission band edge is ~ 277,750 rad/RIU-cm.

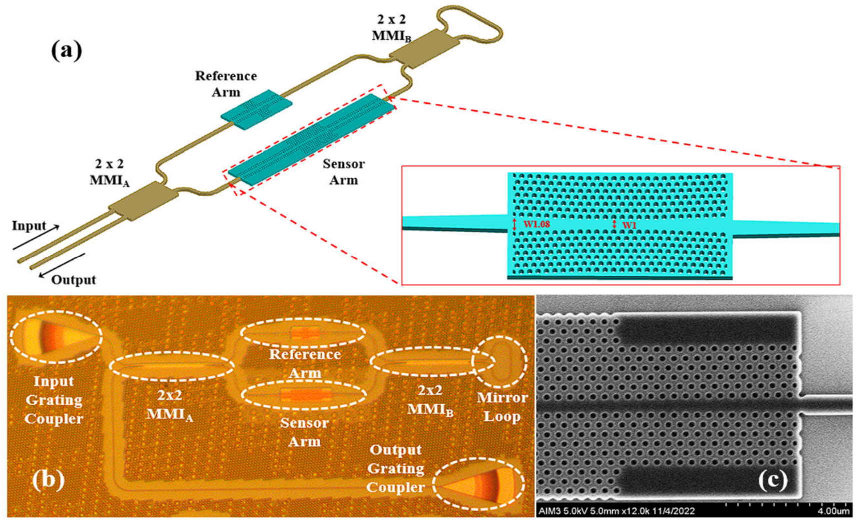

Fig. 1. (a) Schematic of unbalanced MI; (b) Microscope image of the MI fabricated on chip; (c) SEM image of the 2D-PCW structure;

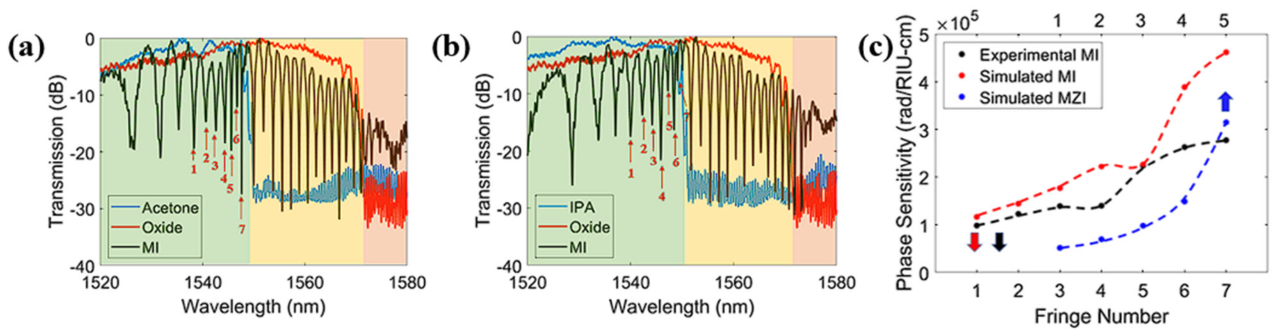

Fig. 2. Transmission spectrum of MI (a) with signal arm covered by acetone (black), single 2D-PCW device covered by acetone (blue) and oxide (red); (b) with signal arm covered by IPA (black), single 2D-PCW device covered by acetone (blue) and oxide (red); (c) Experimental phase sensitivity of asymmetric MI (black), simulated asymmetric MI (red), and simulated asymmetric MZI (blue).

PDMS sheets are cut by a CO_2 laser to form microfluidic channels and cleaned in an IPA ultrasonic bath. Following a 30-second O_2 plasma etch, the sheets are bonded using an in-house tool. The microchip is positioned under the channels as fluid flows over it. Light is coupled into and out of the interferometers via fiber-coupled grating couplers. Fig. 3(a) shows the schematic microfluidic integration with silicon photonic chip. The simulation of fluid flow trajectory done in SolidWorks is shown in Fig. 3(b). Fig. 3(c) is the microscope image of bonded PDMS sheets which exhibits the alignment tolerance. Fig. 3(d) shows the fluid flow through the 250µm×500µm channels.

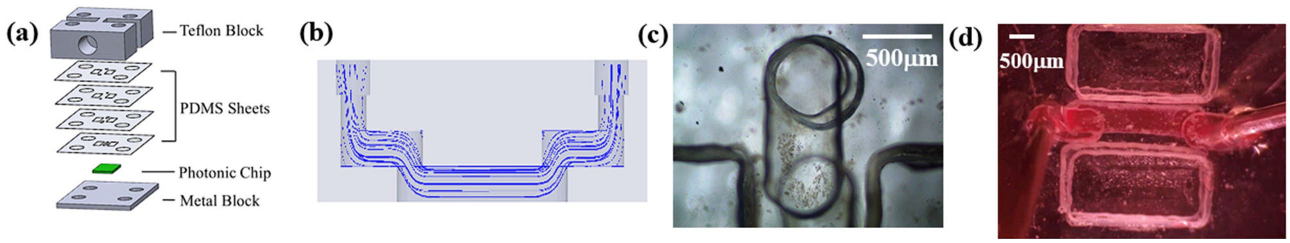

Fig. 3. (a) Schematic microfluidic integration with silicon chip (b) SolidWorks simulations of fluid flow trajectory (c) Microscope image of bonded PDMS sheets showing the alignment tolerance (d) and fluid flow through the 250μm×500μm channels.

Experiments are in progress to integrate PCMs on the reference arm and electrically bias the material phase transition appropriately to adjust the interference fringes to the fixed source wavelength laser. The devices will be tested to detect multiple biomarkers in protein samples derived from normal and cancer samples using protein lysates from *Drosophila* cancer models specifically, glioma models. The goal is to use this device to detect low levels of biomarkers in various types of samples including cell lysates from biopsy and liquid biopsy samples of cancer patients.

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