Micro-fluid Channel Based on Ultralow-loss Silicon Crossing Waveguide for Various Sensing

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Abstract: We experimentally demonstrate a new type of micro-fluid channel design with crossing optical waveguides that not only block any gaps in the microfluidic channels in one fabrication step but also enable nearly lossless optical propagation in the primary waveguides on a chip. Such designs are critical for all sensing applications where the analyte must be flowed over the sensor.

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As micro-fluid channel systems have shown unique advantages in performing analytical functions such as controlled transportation, immobilization, and manipulation of biological molecules and cells, it has become an essential part of modern sensing research. Tremendous and various micro-fluid channel systems have been applied in different research areas like manipulation and analysis of biological cells [1] and accurate chemical analysis [2]. More importantly, micro-fluid channel system is a necessary technique for achieving integrated remote biosensors [3]. Our previous work has already demonstrated high sensitivity photonic crystal chemical sensor [4], enhanced sensitivity photonic crystal biosensors [5] and plasmonic-active surface enhanced Raman spectroscopy systems [6]. While sensing characteristics can in general be demonstrated by dispensing analytes of interest via pipettes, when binding kinetics needs to be measured for instance in the case of biosensors for drug discovery applications, a continuous flow of analyte must be reliably achieved.

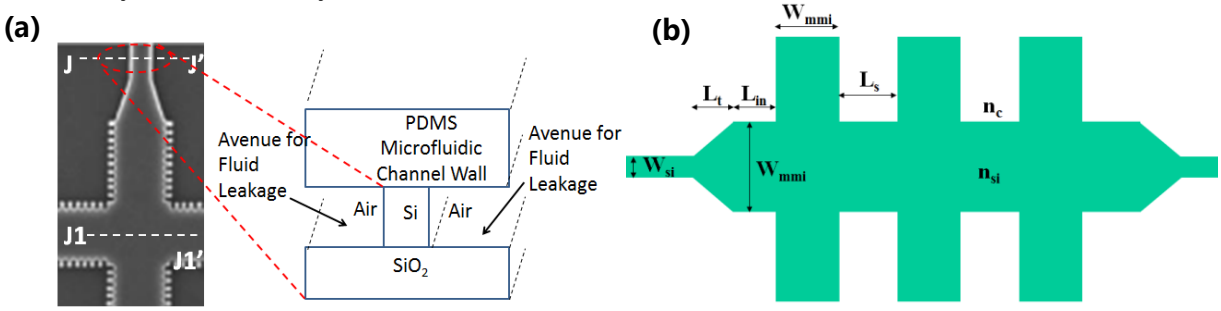

Fig. 1: (a) Cross-sectional view of the PDMS microfluidic channel when integrated with optical waveguides in silicon in a SOI substrate. Conventional waveguides are characterized by cross-sections J-J'. (b) Schematic of crossing waveguides that exist along J1-J1' in (a).

A conventional optical waveguide is characterized by cross-section such as J-J' shown in Fig. 1(a). Optical waveguides are in general layed out such that the fluids flow orthogonal to the direction of optical wave propagation. Thus, as noted in the right image in Fig. 1(a), an air gap would exist between the PDMS channel wall (PDMS being the material of choice for microfluidic channels) and the bottom silicon dioxide cladding in a silicon-on-insulator (SOI) substrate. One may introduce additional fabrication steps such as oxide deposition followed by planarization to close these gaps prior to microfluidic channel bonding. In the case of photonic crystal sensors, such post processing would necessitate removal of the oxide from the etched photonic crystal patterns which would result in additional etching of the bottom oxide unless the process is very strictly controlled. A poor tolerance on the oxide removal process post processing would lead to uncertain resonance wavelengths in photonic crystal biosensors. To achieve the integrated, remote and multiplicity sensing system, a reliable and efficient technique for making closed micro-fluid channel and integrating it with a dynamic measuring system is necessary.

In this paper, we demonstrate an approach which uses silicon crossing waveguide arrays with <0.025 dB insertion loss per crossing [7] to build up micro-fluid channel. The microfluidic channel would now instead go over the section J1-J1' which thus closes the gaps that would otherwise exist in the channel along J-J' in the absence of

waveguide crossing. This novel approach is extremely fabrication friendly, since the primary ridge waveguides, photonic crystals and crossing waveguides are fabricated in the same step, and also offers a smooth interface for microfluidic channel bonding.

Effective medium theory is utilized in order to calculate the cladding index around the crossing region which provides a minimal modal phase noise, thus lowering the loss at the crossing. Based on FIMMWAVE simulations, a cladding index (n_c) of ~2.5 is sufficient to provide 0.024dB loss/crossing. The schematic of design is shown in Fig. 1(b) with the optimized parameters: W_{si}= 0.6 μm, W_{mmi}= 1.2 μm, L_{in}= 2.16 μm, L_s= 1.58 μm, L_t= 1 μm.

The scanning electron microscope (SEM) image of a single silicon crossing waveguide is shown in Fig. 2(a). As shown by the cross-section J1-J1' in Fig. 1(a), a polymer mold will be attached onto it to offer a closed environment for measurement, where the ultralow silicon crossing waveguide will serve as a dam to prevent the liquid leaking form the trench (The dark part in Fig. 2(a) and (b), which is about 250 nm deep). Considering the possible detachment induced by liquid immersion, we increase the number of crossing wave guides. A SEM image of an array with 10 crossing waveguides is shown in Fig. 2(b).

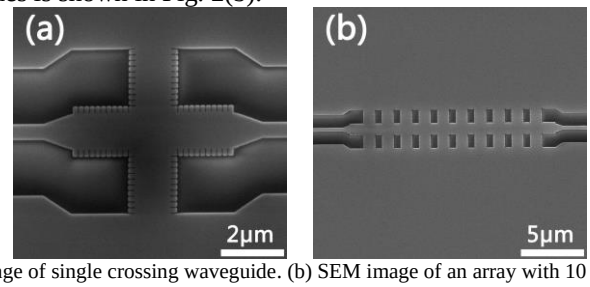

Fig. 2: (a) SEM image of single crossing waveguide. (b) SEM image of an array with 10 crossing waveguides

The crossing waveguides were integrated with photonic crystal waveguide (PCW), 1 x 4 multimode-interference (MMI) power splitter and subwavelength grating couplers (SWG) to become functional devices for bio-sensing . The layout of the full device is shown in Fig. 3(a). Fig. 3(b) shows spectra from L55 PC microcavities without crossing optical waveguides. Fig. 3(c) and 3(d) show spectra from L55 PC microcavities when the input and output strip waveguides in Fig. 3(a) are crossed by 1 and 10 waveguides respectively as in Figs. 2(a) and 2(b). The resonance characteristics of the L55 PC microcavities are unaltered by the crossing waveguides.

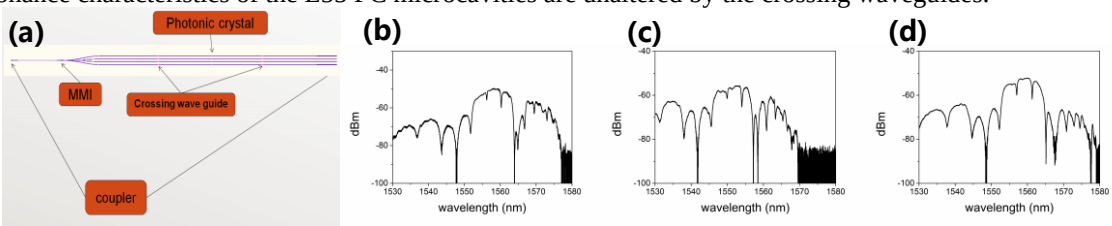

Fig. 3: (a) Layout of the device. Transmission spectra from a L55 PC microcavity coupled to a W1 PCW with (b) zero (c) one and (d) ten crossing waveguides.

In conclusion, we have developed a scheme to achieve micro-fluid channels for various sensing research. This process can be easily integrated with existing and reliable SOI micro-fabrication technique. The ultralow-loss crossing waveguides and the polymer mold will form a closed environment for testing, which will be demonstrated with respect to measurements of binding affinity.

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