Label-free biosensing with a silicon-on-insulator ring resonator integrated on an optical fiber facet.

C. Lerma Arce*, K. Komorowska, D. Van Thourhout, P. Bienstman.
Photonics Research Group, Dept. of Information Technology, Gent University-imec
Sint-Pietersnieuwstraat 41, 9000-B Gent Belgium

ABSTRACT

This paper presents first sensing results for an optical fiber probe sensor based on silicon-on-insulator ring resonators. The proposed device combines the high quality of silicon-on-insulator ring resonator biosensors with the portability of optical fibers. The ring resonator is transferred from a silicon-on-insulator (SOI) chip to the tip of an optical fiber maintaining the sensor performance of the ring measured on a SOI sample.

Keywords: Ring resonator, Silicon-On-Insulator (SOI), biosensor.

1. INTRODUCTION

Optical fiber technology has undergone tremendous growth and advancement over the last years. The application of this technology for sensing is one that continues to expand and developed at a rate that could barely have been predicted few years ago[1]. Its use as a medical device for imaging hard-to-reach locations and its property to conduct light to a remote convenient location make of it a suitable tool for in vivo sensing applications. The most common and known is the endoscope.

Here, we propose an optical fiber probe sensor for label-free biosensing based on SOI ring resonator as transducer of the sensing device.

In [2], we described a SOI ring resonator, which has 70 nm/RIU sensitivity for bulk changes of the refractive index and showed a 625 pm saturation shift of the resonance wavelength for label-free sensing of proteins with the well-known strong affinity couple biotin/avidin.

In this paper, we present a fabrication method to transfer this ring resonator to a fiber facet, resulting in an optical fiber sensor with exactly the same characteristics that the sensor had on a SOI sample.

2. BIOSENSING WITH MICRORING RESONATORS

Biosensing with microring resonators is considered a promising technique for label-free biosensing thanks to its high sensitivity[3]. We designed a microring cavity in an add-drop filter configuration. The ring supports modes that resonate at a wavelength λ_{res} for which:

$$\lambda_{res} = \frac{L}{m} n_{eff} \tag{1}$$

L is the round trip length and *m* is the cavity mode order (=1,2...). The resonance results in a sharp dip in the transmission or a peak in the drop port.

*cristina.lermaarce@intec.ugent.be; phone +32 9 264 33 18; fax +32 9 264 35 93; photonics.intec.ugent.be

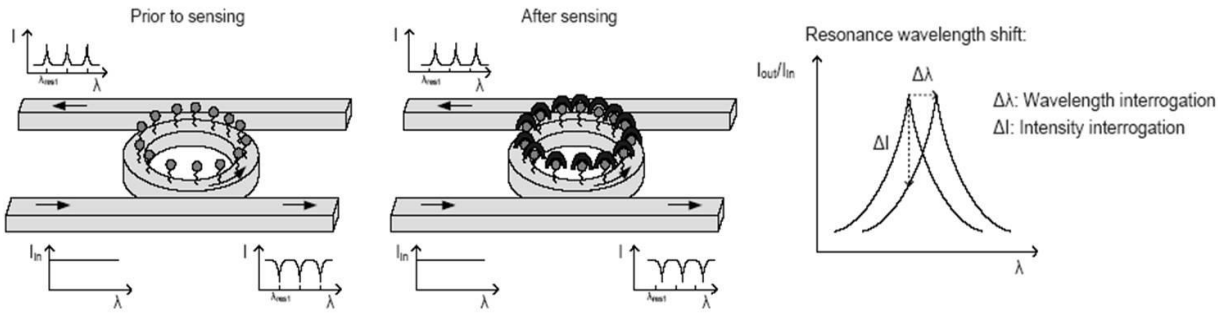


Figure 1. Basic principle of a ring resonator[4].

The resonance wavelength shift resulting from a changing local refractive index when biomolecular interaction takes place in the vicinity of the cavity is a quantitative measure for the number of binding events. Taking into account first order dispersion, this shift can be determined by means the following formula:

$$\Delta\lambda = \frac{\Delta_{env} n_{eff} \cdot \lambda_{res}}{n_g} \tag{2}$$

where $\lambda_{env} n_{eff}$ is the effective index shift caused by an environmental change and n_g is the group index.

3. DESIGN

The silicon waveguides in our design are 220nm high and 450nm wide, on top of 2 µm of silicon oxide and 750 µm Si substrate. The microring resonator for this experiment is a racetrack with 4 µm radius and 4 µm straight section. Smaller radii will increase bend losses but reduce scattering losses because of decreasing round trip length. In our design a racetrack shape is used in order to have more control over the coupling coefficient. An exhaustive study on the optimization of the resonator dimensions was previously performed by K. De Vos in [4].

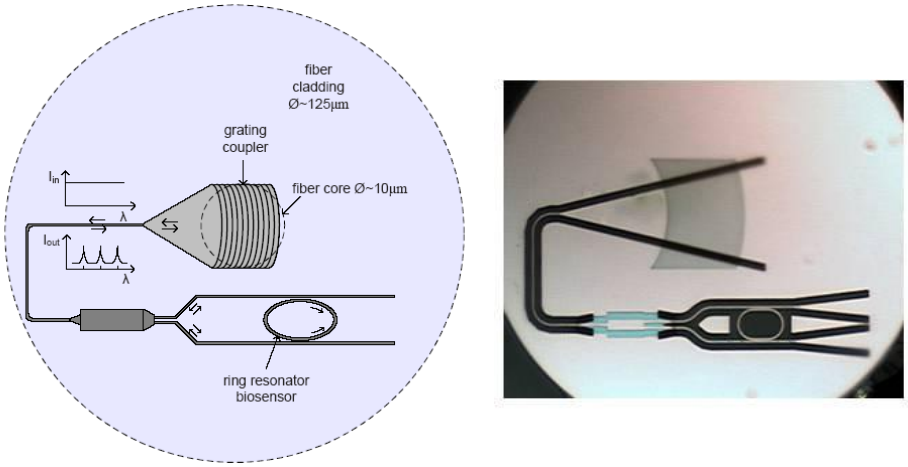


Figure 2. Top view of the optical fiber probe: photonic integrated circuit for biosensing aligned to the core of the optical fiber.[4]

The chip is designed to be 'retroreflective': using a dedicated light coupling scheme, light will couple into and out of the integrated circuit via the same grating coupler and under the same angle. The fiber core is aligned to a grating coupler. The cladding of the fiber carries the rest of the integrated circuit comprising a 3dB MMI splitter/combiner and a ring resonator biosensor. A curved grating focuses the light onto the SOI waveguide, which circumvents the need for space consuming waveguide tapers. A top view of the design is illustrated in Figure 2.

Biosensing based on semiconductor materials requires chemical modification of the silicon surface in order to provide a suitable biointerface. The surface modification provides the immobilization of the biomolecule in its most active conformation and prevents nonspecific protein adsorption, which can affect the sensitivity and specificity of the biosensor[5]. However, in this paper, we only concern ourselves with bulk sensing.

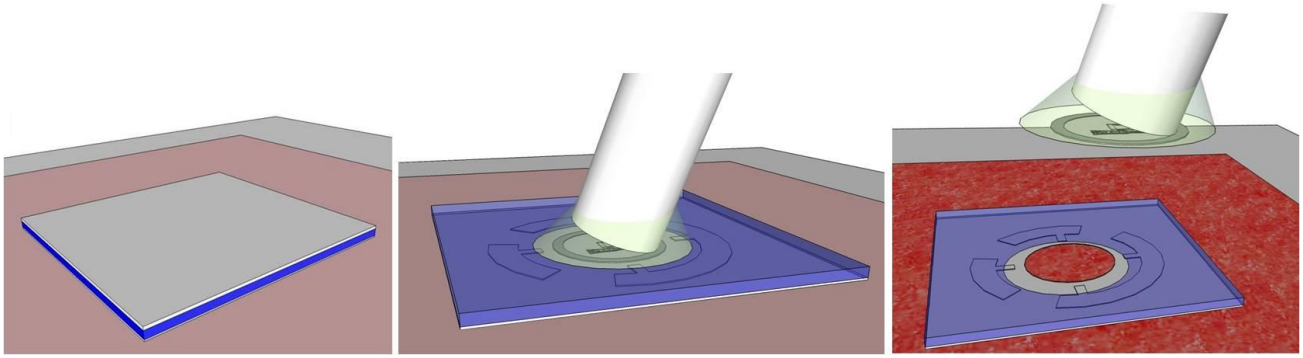
When the sensing device is immersed in sample solution, the resonance wavelength of the ring resonator will shift when analytes bind to the receptors. This shift is monitored by repeatedly scanning of the spectrum with a tunable laser and detection with a photodetector.

4. FABRICATION

The aim of the fabrication is to transfer the sensing circuit, previously described, from the SOI chip to the fiber facet.

First, the SiO_2 around the sensing structure is thinned down using dry etching. The sample is joined upside down to a silicon wafer that will be used as carrier by means of wax.

Next step is the removal of the silicon substrate. This step consists of two parts: First mechanical grinding of the substrate reducing its thickness up to 100 µm. Second, wet etching for the rest of the silicon. For this wet etching a mixture of acetic, nitric and hydrofluoric acid is used.



(a) (b) (c)

Figure 3. Fabrication process. (a) Sample fixed up side down by means of wax to a Si wafer. (b) Alignment of the fiber after the complete removal of the substrate. (c) Fiber pulled up with the sensing circuit attached to the tip.

At this moment in the process, the whole Si substrate has been completely removed. Only the Si waveguides and the SiO_2 are left at the sample. The alignment of the optical fiber above the grating couplers can then be carried out. A drop of a UV curable glue is used during the alignment, which is cured when the resonance detection is optimal. The sensing structure is now attached to the fiber.

The stage where the sample is held is a hot plate set at 120ºC after the previous step is preformed. The melting of the wax that joined the sample with the Si wafer allows the fiber to be pulled up breaking the thin layer of SiO_2 and getting on the tip of the fiber the previously glued sensing circuit.

Finally, the immersion of the fiber in boiling trichloroethylene, aceton and isopropanol cleans the residues of wax at the sensing surface.

5. BULK SENSING

The sensing device has been characterized by bulk sensing experiments. The sensor was introduced in watery NaCl-solutions with different concentrations. No surface chemistry was applied to the sensor surface for this experiment.

The change of the refractive index in those concentrations leads to a shift in the resonance wavelength. Figure. 4 shows a linear shift of the resonance wavelength with increasing salt concentration. Lorentzian fitting has been used to determine these shifts. The sensitivity of this device is 70 nm/RIU (Refractive Index Unit). It is the expected sensitivity for the same ring resonator that was simulated and measured on a SOI sample and demonstrated in [2]

Surface functionalization will be the next step to achieve the biomolecular detection using this fiber probe.

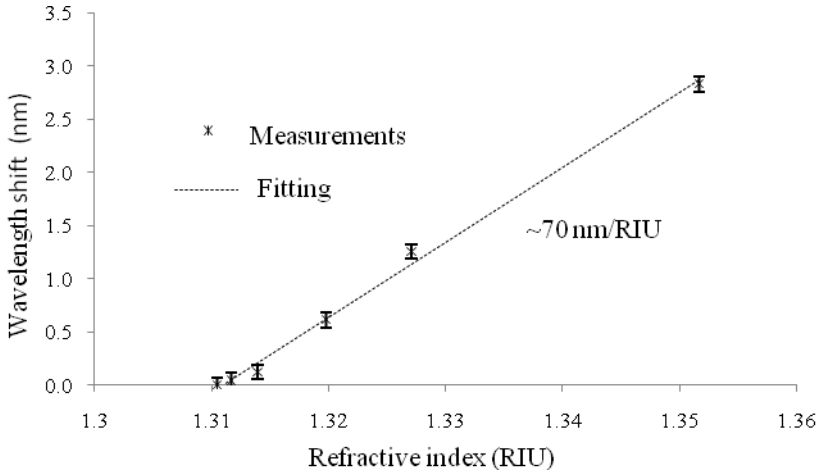


Figure 4. Resonance wavelength shift versus bulk refractive index change showing a sensitivity of 70nm/RIU.

6. CONCLUSIONS

This work deals with a novel implementation: an integrated SOI circuit is transferred to the facet of a single mode optical fiber. This can lead to a robust and portable device for in-vivo label-free biosensing. Its sensitivity is 70nm/RIU. The results for bulk sensing experiments achieve the same results of the same sensor on SOI chip. The characterization of the device for biomolecular sensing is the next challenge for this work.

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REFERENCES

1. Grattan, K. T. V and Meggitt B. T. [Optical fiber sensor technology] Chapman & Hall , London (1998).
2. De Vos, K. Bartolozzi, I. Schacht, E. Bienstman, E. Baets, R ”Silicon-on-Insulator microring resonator for sensitive and label-free biosensing”,Optics Express, 15(12), p.7610-7615 (2007).
3. Claes, T. Girones Molera, J. De Vos, K. Schacht, E. Baets,R. Bienstman, R. ”Label-Free Biosensing With a Slot-Waveguide-Based Ring Resonator in Silicon on Insulator” IEEE Photonics Journal, 1(3), p.197-204 (2009).
4. De Vos, K. ”Label-Free Silicon Photonics Biosensor Platform with Microring Resonators” PhD. Ghent University (2010).
5. De Vos, K, Girones Molera, J. Claes, T. De Koninck, Y. Popelka, S. Schacht, E. Baets, R. Bienstman, P. ”Multiplexed antibody detection with an array of silicon-on-insulator microring resonators,”IEEE Photonics Journal, 1(4), p.225-235 (2009).