

Nano-Scale Fluidics for Ultra-Compact Lab-On-A-Chip Device Applications

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Abstract:

Ultra-high quality factor (Q) chip-scale silicon nitride (SiN) optical microresonators are very attractive for lab-on-a-chip biological sensing. Two key challenges in developing multiplexed sensor arrays are fluidic sample delivery and surface coating of the sensor surface. This project focused on designing, fabricating, and testing various SU8 microfluidic channels tightly integrated on the top of an array of SiN microresonators. Each resonator was functionalized with a specific surface coating for a particular analyte, using a large-angle surface patterning tool and the Nano eNabler™ System from BioForce Nanosciences, Inc. Fluidic channels were sealed by a polydimethylsiloxane (PDMS) or glass cover slip and inlet/outlet ports were provided for the sample injection through external syringe. Preliminary experimental results, obtained by flowing a set of Brix fluids in the microfluidic channel with different refractive index units (RIU), showed that the sensor bulk refractive index sensitivity was ~ 1 nm/RIU.

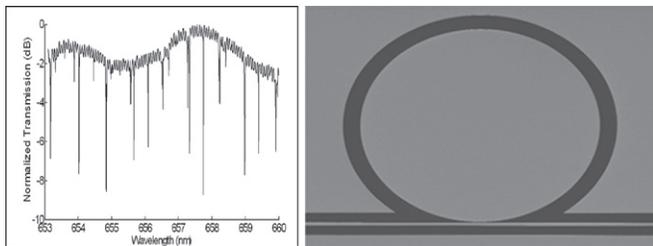


Figure 1: (a) Measured spectral response for an SiN resonator. (b) SEM picture of resonator. The resonator had a diameter of 40 μm .

Introduction:

Our goal is a compact, handheld, lab-on-a-chip device for rapid biomolecular assay. Today, such an assay takes anywhere from a few hours to a week. Using the proposed sensor, we anticipate a biomolecular assay for a multiplexed panel of analytes could be completed within a few minutes from raw serum samples and without cumbersome pre-processing steps such as fluorescent tagging and labeling.

The sensing mechanism relies on the shift in the resonance wavelength of a planar ultra-high Q SiN optical resonator induced by changes in the refractive index on the sensor cavity surface (see Figure 1), and is calculated using

$$\lambda_{\text{resonance}} = \frac{L}{m} n_{\text{eff}}$$

where λ is the resonance wavelength; L , the length of the cavity; m , the mode (1, 2...); and n_{eff} is the effective refractive index of the resonant mode.

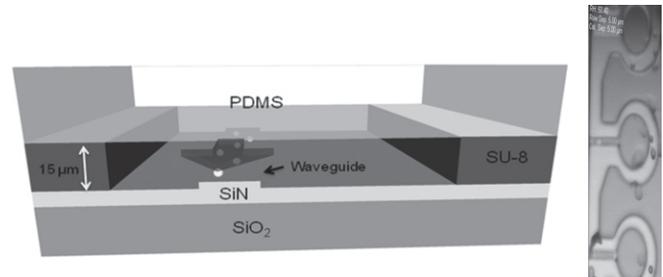


Figure 2: (a) Design of microfluidic channel. The dots on the surface of the SiN waveguide represent surface coatings that will target specific biomolecules that we would like to sense in the fluid. The arrow represents the light that couples to the waveguide. (b) In situ spotting technique was developed using angled 10 mm cantilever tips and a Nano eNabler™. We obtained < 1 μm spots on the active surface of the SiN resonator inside SU-8 microfluidic channels with good spatial overlap to the electromagnetic mode of the resonator.

In a multiplexed sensor array, each sensor surface has a unique surface coating for sensing a specific biomolecule. In this work, we have developed techniques to solve the two major challenges in developing such a multiplexed sensor. The first involves the development of optimal microfluidic channels fabricated directly on the top of the SiN resonators that enable dramatic reduction in the diffusion time for the biomolecules thereby enabling assay time to be dominated mostly by the binding kinetics on the sensor surface. The second task in this research involves the development of surface patterning techniques that could enable highly-specific surface coatings to be applied to the sensor surface following the fabrication of the fluidic channels.

Experimental Procedure:

SiN resonator chips were fabricated using electron beam lithography. They were operated in the visible wavelength range to overlap with the low optical absorption loss region for water. SU-8 (MicroChem) was spin-coated on the SiN resonators to a thickness of 15 μm and patterned to define microfluidic channels pre-aligned to the resonators (see Figure 2a).

A large-angle surface patterning tool and the Nano eNabler™ System was used to print sub-femtoliter volumes directly on the surface of the resonators within the microfluidic channels. We repeatedly approached $< 1 \mu\text{m}$ protein buffer spots on the top of the SiN resonator, by optimizing the approach velocity and dwell times for the surface patterning tool. We could also achieve a good alignment between the spot and the peak in the electromagnetic mode in the resonator (see Figure 2b).

Finally, we explored several different fluidic channel sealing techniques. One approach was to use a rectangular piece of PDMS (Sylgard 184), treated in oxygen plasma and then attached on the top of the SU-8 microfluidic channel. Another approach that we adopted was direct SU-8 to SU-8 bonding using a SU-8 coated glass cover slip. Prebaking conditions were optimized to enable good bonding. A blanket UV-exposure was used to cure and finally seal the cover slip to the fluidic channel. More optimization of this process is required in order to get a repeatable tight fluidic seal and to avoid fluid leaks.

A prototype sensor consisting of a SiN resonator with a SU-8 microfluidic channel and a PDMS lid was used to evaluate

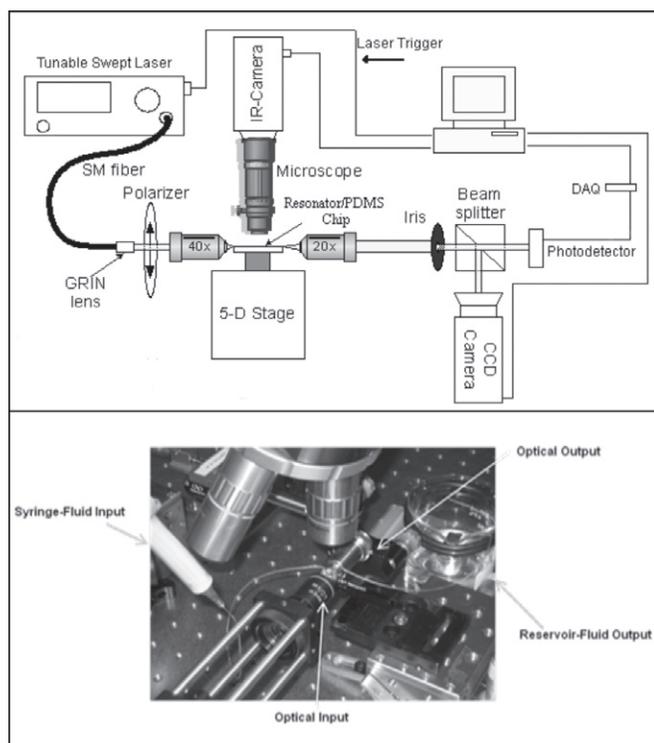


Figure 3: (a) Schematic of optical test setup. (b) Picture showing prototype sensor test using a syringe for fluid injection.

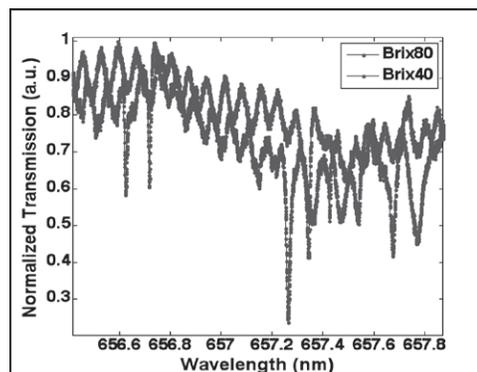


Figure 4: Spectral response of microdisk resonator. Bulk refractive index sensitivity of $\sim 1 \text{ nm/RIU}$ was experimentally obtained.

initial sensor bulk refractive index sensitivity using Brix fluids injected into the microfluidic channel (Figure 3b). Following fluid injection, the resonance wavelength was obtained by a swept-wavelength test using a tunable laser (New Focus Velocity 650-660 nm) (Figure 3a). We obtained a bulk refractive index sensitivity of $\sim 1 \text{ nm/RIU}$ (Figure 4). Leaking was observed from the PDMS fluidic seal with prolonged fluid flow and resulted in incomplete removal of fluid and even fluid mixing in the sensor. We anticipate that with a more stable fluidic sealing, fluidic mixing could be eliminated and the sensor sensitivity could be improved.

Results and Conclusions:

SU-8 microfluidic channels were fabricated directly overlapping SiN microresonators. A technique suitable for fabricating multiplex-sensor arrays was developed by depositing sub-femtoliter volumes of surface coating ligands directly onto the resonator surface within the microfluidic channel. Due to ease of fabrication, PDMS to SU-8 seal using oxygen plasma was adopted in this project for the first sensor prototypes. Bulk refractive index sensitivity of $\sim 1 \text{ nm/RIU}$ was experimentally obtained. Better fluidic sealing is required in order to prevent leaks and fluid mixing in the sensor.

Future Work:

One way to improve the fluidic seal would be to use a cover slip. An initial process for such a sealing has been developed by using SU-8 coated glass cover slip and exploiting the SU-8 to SU-8 bonding process to directly seal the SU-8 fluidic channel with the glass cover slip.

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