Whispering-Gallery-Mode Microdisk Optical Biosensor: Fabrication and Characterization

Abbie Tippie, Electrical Engineering, Colorado State University
NNIN REU Site: Center for Nanoscale Systems, Harvard University

NNIN REU Principal Investigator: Erli Chen, Center for Nanoscale Science, Harvard University
NNIN REU Mentor: Jiangdong Deng, Center for Nanoscale Science, Harvard University
Contact: abbie@tippietoes.com, erlichen@cims.harvard.edu, jdeng@cims.harvard.edu

Abstract:

The need for sensitive yet miniaturized instruments for bio-detecting has accelerated the development of micrometer-scale optical biosensors. Microsphere biosensors based on the resonant shifting of whispering-gallery mode (WGM) have been demonstrated previously. Despite its high sensitivity (high Q-factor), microspheres face challenges such as large mode volume (size is uncontrollable during fabrication) and difficulty in integration with other optical components. In this work, the fabrication of microdisk WGM resonators using photolithography and wet etching is studied. SiO_2 microdisks with diameters ranged from 400-1200 μm and thicknesses of 1 and 15 μm were fabricated on Si substrates. Preliminary spectroscopic tests showed that the as-fabricated disks have a Q-factor better than 10^4, indicating that microdisks are viable alternatives to microsphere sensors. Since the fabrication process used in the study is compatible with that in standard microfabrication, the sensors can be easily integrated with other electronic and optical components on a semiconductor chip. Further improvement in sensor fabrication and performance is also investigated.

Introduction:

Developing biosensor technology is a major development being pursued for medical, food or environmental testing. The detection of particles of proteins or DNA is key to successful biosensor advances. The biosensor developed in this paper uses whispering-gallery-mode optical resonances with high-Q factors to implement a high sensitive, robust system.

Whispering-gallery-modes (WGM) are generated when light is confined near the surface of a disk or spherical object by total internal reflection and is returned in phase after revolution about the perimeter [1]. If an eroded optical fiber is placed in close proximity to a resonant disk, the evanescent wave from the light in the fiber will excite the WGM modes of the disk. Resonant disks with high Q values will result in high sensitivity, as displayed by sharp dips transmission as observed at the output of the optical fiber.

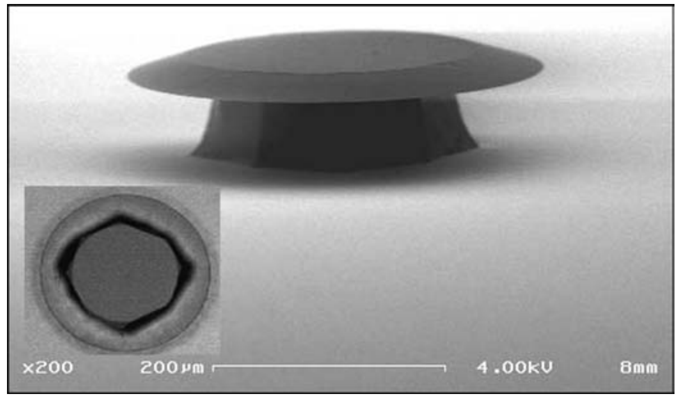

Figure 1: SEM image of 400 µm disk; inset: top down view taken with optical microscope.

Previous biosensor work has already been developed by Vollmer et al [2] to identify DNA using microsphere resonant cavities. The drawback to the current microsphere approach is the lack of control over the fabrication process and exact size of the microsphere. In this paper, we show how the controlled fabrication of disk-shaped WGM resonators offers a new form of optical biosensors.

Experimental Procedure:

The fabrication of the microdisks involved three steps: Mask generation, HF wet etching and KOH wet etching. The initial substrate consisted of a 15 μm layer of SiO_2 thermally grown on a 1 mm thick Si <100> wafer. Disks of photoresist were created following the photolithography process. To reduce the roughness of the disks' sidewall, the samples were then postbaked at 200°C for 10 min. The photoresist acted as a mask for the SiO_2 during the HF wet etching process. The silicon surface was then etched in KOH solution at a temperature of 100°C until the silicon base was ~ 30 μm narrower than the undercut edge of the SiO_2 disk. Figure 1 shows the final microdisk structure, composed of a 15 μm thick undercut disk of SiO_2 sitting upon a Si support base.

Evanescent coupling was used to excite the whispering modes of the microdisk structure. To expose the evanescent field, the outer polymer of a 125 μm diameter optical fiber was first dissolved using dichloromethane. A butane/nitrous oxide flame was then used to melt and stretch the fiber to a diameter of ~ 5 μm. The fiber was then positioned into a loop for easier alignment with the microdisk. A 1310 nm wavelength laser was coupled into the fiber. The eroded portion of the fiber was aligned under an optical microscope to contact the edge of the microdisk and thereby introduce coupling between the two objects. The transmission intensity was then measured using a photodiode interfaced with LABview.

To observe sensing properties, the microdisk was placed on a temperature-controlled surface. The surface of the plate was varied in temperature from 18°C to 25°C. A specific dip in transmission was then used to observe changes in the wavelength as the temperature varied with time.

Results:

As a means of determining the sensitivity and feasibility of the microdisk structure as a sensing device, Q-factor was calculated and sensing performance was observed. The optical resonances of the WGM modes in the disks were evidenced by dips in the intensity, as shown in Figure 2. For a 15 μm SiO_2 microdisk, a Q-factor of 4.5 x 10^4 was obtained. In Figure 3, we see how an increase in the temperature resulted in longer resonant wavelengths. Our data shows this effect is reversible; a decrease in temperature results in shorter resonant wavelengths.

Conclusions:

In conclusion, the microdisk structure is a viable alternative to the microsphere for sensing capabilities. The controlled fabrication and ease of integration provided by the microdisk are more advantageous to further development of WGM optical biosensors. These new microdisk optical biosensors will be easier to integrate on a semiconductor chip, thus resulting in a more robust design.

Future Work:

Further improvements to the fabrication and sensing will be implemented upon future experimentation. In order to achieve a higher Q-factor, some edge treatment techniques, such as CO_2 laser melting [2] and focused ion beam drilling are proposed. Other variations of substrate materials may also be explored. We hope to design and integrate a waveguide with the microdisk on the same surface in order to develop a fully integrated chip, sensitive and robust enough for the applications of biosensing.

Acknowledgments:

Erli Chen; Jiangdong Deng; Frank Vollmer; Dr. Kathryn Hollar; Chris Stokes; Jim Reynolds; James Houlahan; Rowland Institute at Harvard; Harvard University; NNIN; NSF.

References:

[1] Quan, H. and Z. Guo, "Simulation of whispering-gallery-mode resonance shifts for optical miniature biosensors," Journal of Quantitative Spectroscopy and Radiative Transfer 93, 231-243 (2005).

[2] Vollmer, F., D. Braun, A. Libchaber, M. Khoshsima, I. Teraoka, S. Arnold, 'Protein detection by optical shift of a resonant microcavity'. Appl. Phys. Lett. 80, 4057-4059 (2002).

[3] Armani, D.K., T.J. Kippenberg, S.M. Spillane, and K.J. Vahala, 'Ultra-high-Q toroid microcavity on a chip'. Nature (London) 422, 925 (2003).

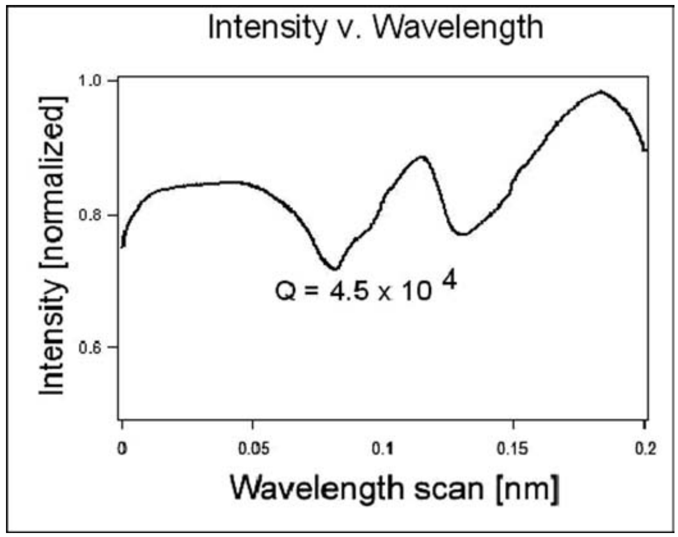

Figure 2, above: Microdisk/tapered fiber coupling.

Figure 3, below: Changes in wavelength and temperature v. time.