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# Towards lab-on-a-chip sensors with liquid-core optical ring resonators

**Xudong Fan, Ian M. White, Hongying Zhu, Jonathan D. Suter, and Hesam Oveys**

*A thin-walled glass microfluidic channel can incorporate multiple optical ring resonators around the capillary diameter to act as sensors on a high-throughput lab-on-a-chip platform.*

The vision of lab-on-a-chip technology involves integrating sensors with advanced microfluidic technology to construct devices that can rapidly and simultaneously perform an array of interrogations on a nanoliter or picoliter sample, resulting in lower cost and higher throughput analysis. Such a technique would find broad and numerous applications in genomics, proteomics, disease detection, chemical analysis, and drug discovery.

Optical microring resonators offer advantages over other photonic technologies for lab-on-a-chip integration of sensors. They are composed of a circular waveguide, such as a planar ring on a substrate,[1,2] or a micro-sized glass sphere.[3–5] When light couples into the waveguide, certain wavelengths will circulate in a resonating fashion. The high quality factor (Q-factor) of optical microrings results in an effective light/matter interaction on the order of centimeters, despite their sub-millimeter dimensions. This enables excellent detection from a highly compact sensor. Resonating wavelengths, also called whispering-gallery modes (WGMs), are dictated by the optical path-length of the circular waveguide. Changes in the environment near the surface of the sensor, or biochemical molecules interacting with it, impact the effective path-length, causing a shift in the wavelengths that define the WGMs. This observable shift is the sensing signal.

Thus, optical ring resonators form a simple detection mechanism without the need for fluorescent labels. Successful results have been obtained for detection of biomolecules, including proteins and DNA.[2–5]

Our concept of the liquid-core optical ring resonator (LCORR) is illustrated in Figure 1. This novel approach employs a glass capillary, which is a natural microfluidic channel, as a linear array of ring resonators.[6–8] If the capillary walls are sufficiently thin (about 2-4$\mu$m), an evanescent field interacts with the sample. The inner surface of the capillary can be treated with biorecognition elements to target specific analytes that, as they pass through, cause a wavelength shift that determines the WGMs. Dense multiplexing can be achieved by defining multiple ring resonators along a single capillary, and by integrating multiple capillaries into the lab-on-a-chip.

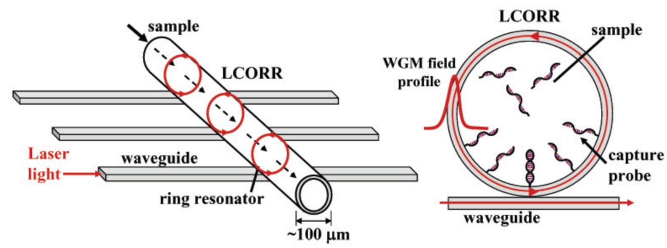


*Figure 1. Sensor based on liquid-core optical ring resonators (LCORRs). WGM: whispering-gallery mode.*

We manufacture LCORRs by drawing glass tubes (outer diameter = 1.2mm, inner diameter = 0.9mm) down to smaller dimensions. Hydrofluoric acid further reduces the wall-thickness. The resulting LCORR has a diameter of 100-150$\mu$m and walls 2-4$\mu$m thick, leading to a detection-volume for each ring that is less than 100 picoliters. The experimental setup is shown in Figure 2. The LCORR is in contact with an array of waveguides that carry the light from a tunable diode laser, which is periodically scanned.[8] When the wavelength of the light in the waveguide matches the resonant wavelength, it couples into the LCORR and causes the measured transmission power to drop, indicated by a spectral dip at the waveguide output. Thus, the relative position of the WGMs can be identified and their movement tracked.

We have proved the concept of the LCORR as a biomolecule detection device. After a silane solution was passed through the

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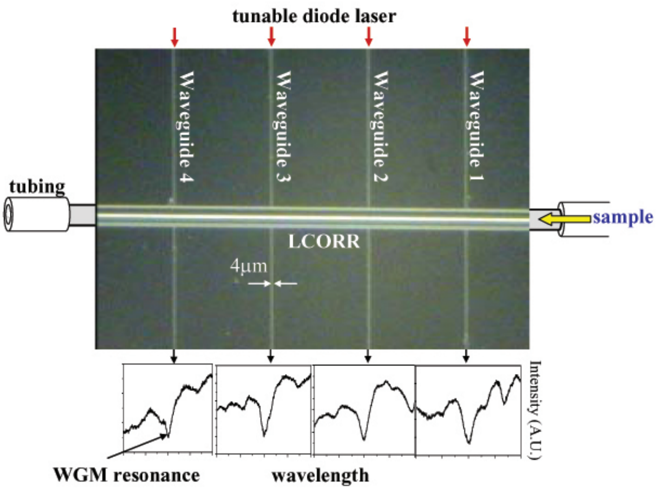


*Figure 2.* Light from a tunable laser is coupled into the LCORR ring resonators by a waveguide array. Resonating wavelengths are identified by dips in the measured optical power at the waveguide output.

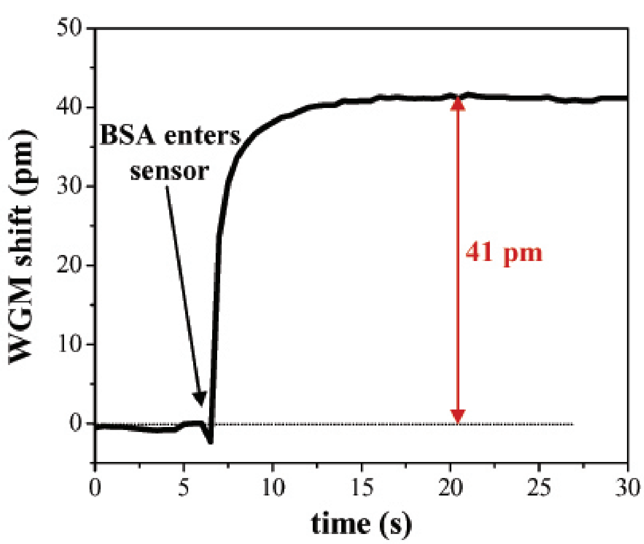


*Figure 3.* A saturating monolayer of bovine serum albumin (BSA) produced a shift of 41pm in the sensing signal.

LCORR to activate its inner surface, a 1mg/ml solution of bovine serum albumin (BSA) in phosphate-buffered saline was pumped through it. The sensing signal is plotted in Figure 4. The saturating characteristic of the curve verifies the Langmuir monolayer behavior of the BSA adsorption onto the silane layer. As detailed by our group,[7] the 41pm shift sets a detection-limit of approximately 10pg/$mm^2$. This value is comparable with label-free surface-plasmon-resonance sensing,[9] the most popular and commercially available label-free biosensing technology.

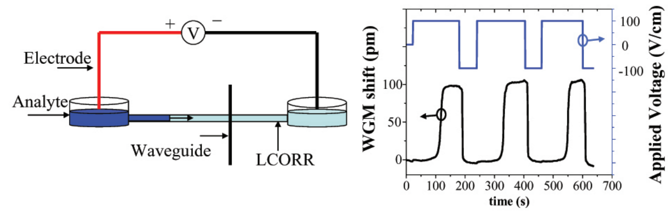


*Figure 4.* Sample movement through the LCORR has been demonstrated using electro-osmotic flow. The spectral shift in the signal indicates the analyte passing back and forth across the sensor head as the driving voltage is applied.

In addition, we have also shown that it is feasible to use LCORR for on-capillary detection of capillary electrophoresis. In this demonstration, an electrical field of 100V/cm is applied to generate an electro-osmotic flow. Figure 4 shows the WGM spectral shift when the analyte is driven across the detection-point defined as the waveguide in contact with the LCORR. The detection limit is estimated to be $10^{-6}$ refractive index units, corresponding to 5$\mu$g/mL in protein and DNA molecules.

Based on these preliminary results, we anticipate that the LCORR technology may find multiple roles in a variety of sensing applications. Our future work will include specific detection of disease biomarkers, extraction and separation of biomolecules, and further engineering advances towards a lab-on-a-chip implementation.

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