On-chip Integrated Differential Optical Microring Biosensing Platform Based on a Dual Laminar Flow Scheme

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Abstract: We propose an on-chip integrated differential optical silicon nitride microring biosensing platform which uses a dual laminar flow scheme. This platform reduces the fabrication complexity involved in the fabrication of the reference resonator.

OCIS codes: (280.4788) Optical sensing and sensors; (140.4780) Optical resonators

1. Introduction

Microfabricated optical resonator biosensors, compatible with CMOS technologies and easily incorporated with microfluidics, are good candidates for integration into portable electronic devices and commercial bench-top systems [1, 2]. However, practical instruments for assay and molecular binding measurements must be robust and external environmental changes must be accounted for. Traditionally, differential measurements, utilizing a reference resonator covered by either a SU-8 polymer or a silicon oxide (SiO_2) cladding layer, have been used to correct for temperature-induced signal drift and laser drift [3, 4]. In this paper, we present an optical resonator biosensing platform leveraging laminar flow conditions between the two non-mixing solutions to realize a reliable and sensitive differential measurement. In this platform, two resonators, one for sensing and the other for reference, are exposed to the aqueous environment. Then, two solutions, one containing the sample of interest and the other acting as a reference, are flown in one common microfluidic channel, with no disruption between the two fluid layers by laminar flow conditions, and delivered to the sensing and the reference resonator, respectively (Fig. 1(a)). This platform reduces the fabrication complexity involved in fabricating the top cladding layer and opening of the sensing window over the sensing resonator. We demonstrate the sensing capability of this platform by presenting the real-time resonance peak shifts due to the refractive index changes in a sodium chloride (NaCl) solution flown in bulk over the sensor.

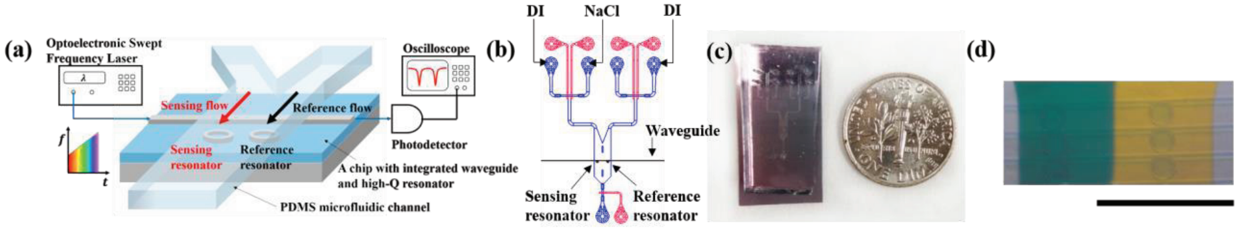

Fig. 1. (a) Schematic of the high-Q optical resonator biosensor using a dual laminar flow and the experimental setup. The reference flow and sensing flow in one common microfluidic channel are kept apart due to laminar flow conditions. (b) Schematic of the waveguide-resonator chip drawn together with the microfluidic device structure. In blue is the flow channel network and in red are the control valves. The two left inlets are used to deliver either the reference (deionized (DI) water, in this experiment) or sensing solution (NaCl) to the sensing resonator. One of the two right inlets is used to deliver the reference solution (DI water) for the reference resonator. (c) Photograph of (left) the fabricated device where the waveguide-integrated Si_3N_4 microring resonator chip is bonded to the PDMS microfluidic device, (right) dime shown to provide scale. (d) Photograph showing the two different dye solutions flowing onto three pairs of resonators with no disruption between the two fluid layers. Scale bar, 1 mm.

2. Fabrications and experimental setups

Two optical microring resonators with 70 μm radius, 4 μm width, and center to center spacing of 800 μm are realized on a 250 nm thick silicon nitride (Si_3N_4) layer on top of 6 μm thick SiO_2 on a silicon handle. The 900 nm wide waveguides and the microrings with the 400 nm coupling gap between them were patterned using electron beam lithography on electron beam resist, ZEP520A. The patterns were transferred to the Si_3N_4 layer using low DC-

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bias, inductively-coupled plasma reactive-ion etch (ICP-RIE) with SF_6/C_4F_8 chemistry. For the liquid delivery, a microfluidic polydimethylsiloxane (PDMS) device is bonded on top of the Si_3N_4 layer (Fig. 1(c)). The two-layer microfluidic structure consists of a bottom flow layer and a top control layer, and includes four inlets and one outlet, each with a corresponding control valve (Fig. 1(b)). The reference (deionized (DI) water, in this experiment) and sensing solutions (NaCl) are delivered to the sensing resonator using the two left inlets, while the reference solution (DI water) is delivered to the reference resonator using one of the two right inlets. The switching of the flow between the different inlets is controlled by the microfluidic valves, which are actuated by computer-controlled pressurized solenoid valves [6]. To illustrate the laminar flow achieved on this device, we introduce two different dye solutions from two inlets into one common flow channel. Figure 1(d) shows the established dual laminar flow for a successful delivery of the different solutions to the sensing and reference resonators. The microring resonators are characterized using a 1064 nm optoelectronic fast linearly swept VCSEL frequency laser with an optical frequency excursion of 300 GHz in 2 ms [5] that is coupled into the waveguide from free space optics. The transparency of silicon nitride and low water absorption at 1064 nm allows the microring resonators to maintain high Q-factors in aqueous environments, measured to be 1.4×10^5 and 2.0×10^5 (Fig. 2(a)). Using a Peltier thermoelectric cooler (TEC), the temperature of the resonator chip is fixed at 26 ºC (+/- 0.01 ºC).

3. Sensing methods and results

In order to demonstrate the actual sensing ability of this platform, sequentially diluted NaCl solutions of 2.5 mM, 5 mM, 10 mM, and 40 mM were flown over the resonators. First, the baseline was established by the continuous flow of the DI water from two inlets to both the sensing and reference resonator, followed by switching of the sensing flow to the NaCl solution while maintaining the reference flow of DI water. The sensing flow was then switched back to DI water. The difference in the resonance frequency between the sensing resonator and the reference resonator which was monitored in real-time is shown in Fig. 2(b). Concentrations of NaCl as low as 2.5 mM, equivalent to 2.64×10^{-5} refractive index units (RIU) with a sensitivity of -20.62 THz/RIU (77.81 nm/RIU), have been measured (Fig. 2(c)). The on-chip valve switching and low dead volume in the two-layer microfluidic structure result in a steady-state signal in about 20 seconds.

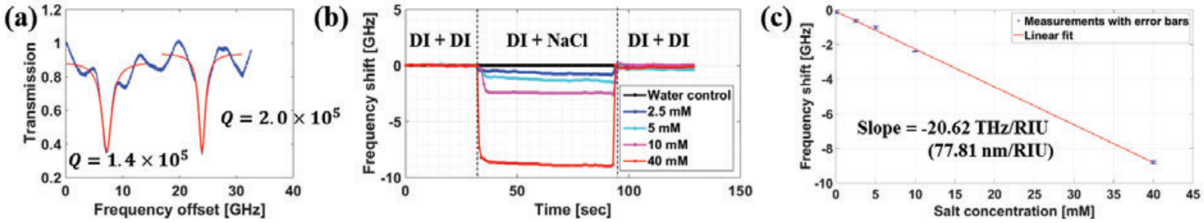

Fig. 2. (a) Transmission spectrum of the two high-Q microring resonators submerged in water measured with a 1064 nm linearly swept VCSEL (blue). The Lorentzian fits are shown in red. (b) Differential frequency shift versus time as NaCl sensing solution is flown over the sensing resonator while maintaining DI water over the reference resonator. (c) Resonance frequency shift versus concentrations of NaCl solutions.

4. Conclusions

We demonstrate an on-chip integrated optical silicon nitride microring resonator biosensing platform which uses a dual laminar flow scheme removing the need for additional fabrication steps. The bulk sensing capability is demonstrated using NaCl solutions of various concentrations. Effort to enable specific binding sensing for biological molecules using this platform is underway.

5. References

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