A Low Cost Photonic Biosensor Built on a Polymer Platform

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ABSTRACT

Planar integrated optical biosensors are becoming more and more important as they facilitate label-free and real time monitoring biosensing with high sensitivity. In this paper, the systematic research on one kind of optical biosensor, based on a resonant principle in a polymer ring resonator, will be presented. Reduced footprint and high sensitivity are advantages of this kind of biosensor. Rather than expensive CMOS fabrication, the device with high performance is fabricated through a simple UV based soft imprint technique utilizing self-developed low loss polymer material. The measurement results for the bulk sensing of a NaCl solution and the surface sensing of a minimal amount of avidin molecules in a buffered solution will be presented.

Keywords: biosensor, label-free, polymer, ring resonator, ridge waveguide

INTRODUCTION

Recently, planar integrated label-free optical biosensors have received more and more attention because of the many benefits they can bring [1, 2]. Utilizing these biosensors, people don't need to resort to traditional fluorescent labeling methods, which are both time and labour consuming. Combined with microfluidic handling and surface chemistry modifications, they also enable real time monitoring and high specific target analysis. The "Lab-on-Chip" would be the ultimate goal.

Among the different materials, polymer has proved to be an ideal material option for integrated photonics devices [3, 4]. First, the cost of the material itself is very low, which makes it attractive where the economic factor needs to be taken into account. Secondly, many special characteristics such as nonlinearity or amplification can be obtained with proper synthesizing. Moreover, in addition to the traditional semiconductor process methods, polymer is also compatible with many novel fabrication techniques like soft lithography or nano imprint lithography [5, 6]. The latter methods have lots of merits such as minimal requirements for complicated equipments, simple fabrication processes involved, and a huge potential for high throughput. Based on the merits mentioned above, it provides us an opportunity to develop an extremely low cost thus disposable label-free optical biosensor built on a polymer platform, which would have huge cost advantage over their semiconductor counterparts, SOI for example [1].

In our research, a simple UV based soft imprint technique is developed with a novel polysiloxane liquid optical material named PSQ-L. Ring resonators can be fast patterned on to the silicon substrate to function as optical biosensors. Both the material and the imprint method will be introduced later in this paper. The ring resonators obtained by this method show good characteristics both in air and water environment, and it enables us to do the bulk sensing of a NaCl solution and the surface sensing of target molecules in a buffered solution. The measurement results will be presented in this paper.

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MATERIALS AND FABRICATION

1.1 Materials

Several kinds of polymer are available for optical waveguides and device fabrication, all of them with some advantages and drawbacks though. For example, negative photo resist SU-8 is a good choice for fast prototyping optical devices using standard lithography. However, its optical loss is high, which is detrimental for optical devices to achieve good characteristics. PMMA is also used as optical material but its thermal properties are poor. Polysiloxane, which is a kind of silicate-based inorganic-organic hybrid polymer, can meet both the optical and thermal requirements. The good properties of a novel polysiloxane liquid optical material named PSQ-L we synthesized for this work are shown in Table 1. Besides the good optical properties such as low optical loss, low birefringence and high thermal stability, it is to note that the good UV curing properties make it well compatible with a UV based soft imprint technique, which we use in our research.

Property	PSQ-LL	PSQ_LH
Refractive Index @1310nm	1.456	1.517
Refractive Index @1550nm	1.454	1.515
Birefringence (nTE-nTM)	<0.0005	<0.0005
Thermo-optic coefficient	-2.2×10-4	-2.4×10-4
Propagation Loss (slab waveguide)	not measured	<0.9 dB/cm@1550nm
	not measured	<0.3dB/cm@1310nm
Glass Transition Temp. (Tg)	not detectable	not detectable
Degradation Temp. (1 wt%)	322 ±10℃ (in air)	303 ±10℃ (in air)
	370 ±10℃ (in N_2)	343 ±10℃ (in N_2)
Film Surface Roughness (AFM)	<0.5nm	<0.5nm

Table 1: Properties of the PSQ-Ls series polymer.

1.2 Fabrication Process

We developed an ideal UV-based soft imprint technique which is compatible with PSQ-Ls series material. The fabrication process consists of two simple steps, one is mold fabrication and the other is waveguide patterning. The PDMS soft replicated mold is made from an SU-8 master mold by mold-castingprocess. Compared with the other kinds of molds made by dry etching or electroforming process [7, 8, 9], the mold obtained with this method shows much better sidewall roughness, which enables us to have good optical properties of the final fabricated devices. Then, depending on the application, the core material PSQ-LH with high refractive index or under cladding material PSQ-LL with low refractive index is imprinted by the PDMS mold. Around 3min. of UV curing with an intensity of 30mW/cm^2 in nitrogen atmosphere is needed before the mold is detached from the substrate. The whole fabrication process is fast and efficient. The fabrication process is shown in Fig. 1. Two types of waveguides, which we call inverted-rib waveguide and ridge waveguide, are fabricated utilizing this UV-based soft imprint technique and they were characterized using SEM, the results of which are shown in Fig. 2.

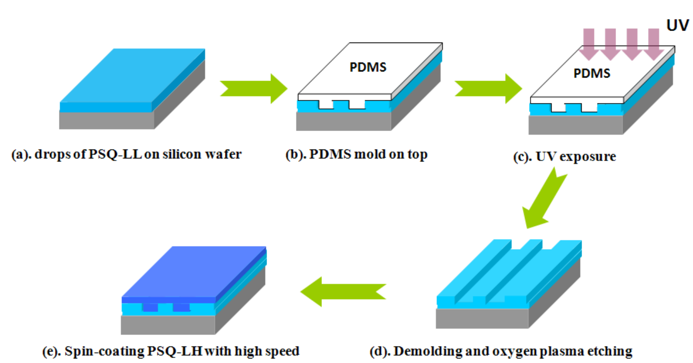
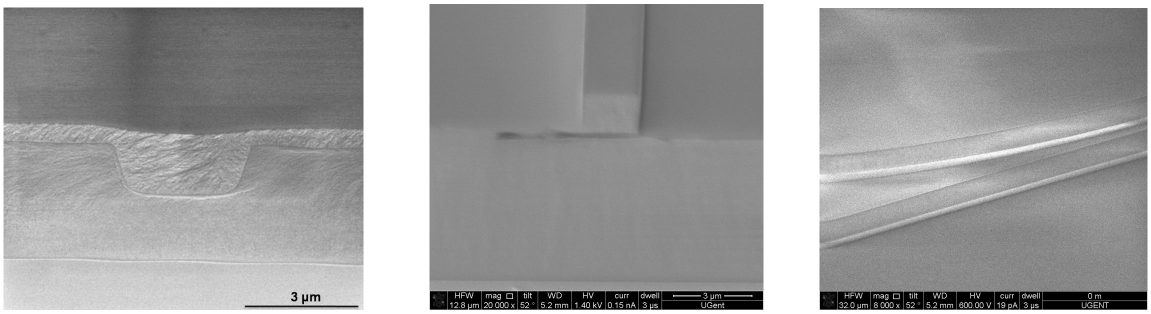


Fig. 1: The fabrication process of UV-based soft imprint lithography using PSQ-Ls.



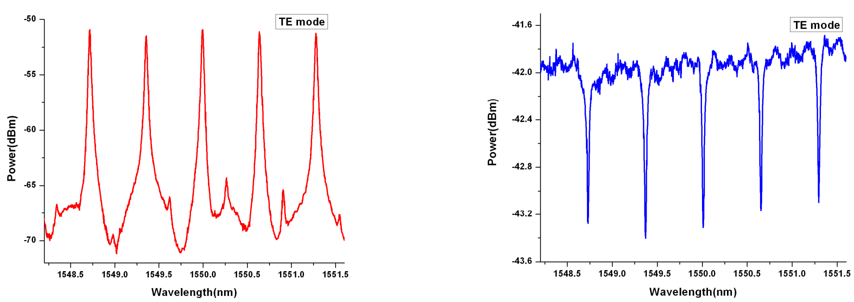
(a) (b) (c)

Fig. 2: Two types of polymer waveguide fabricated by UV soft imprint lithography using PSQ-Ls.

(a) inverted-rib waveguide. (b) ridge waveguide. (c) directional coupler formed by ridge waveguides

1.3 Measurements

For the application in label free bio-sensing, we choose a ring resonator as the transducer. Ring resonators have been demonstrated to be ideal devices for optical bio-sensing, and they have benefits such as small footprint, limited amount of analyte needed, kinetics monitoring and so on [10]. In order to enhance the sensitivity, the ridge waveguides are chosen to build the ring resonator. A lensed fiber is used to couple the light from a tunable laser into the input port of the ring. The transmitted light coming out of the through port and the drop port is collected by a cleaved single mode fiber or objective lens to the power meter. A polarization controller is used to control the polarization state of the input light. The measurement result for a ring resonator with the radius of 350µm and cross section dimension of $2.5\times2.1\mu m^2$ is shown in Fig. 3. The ring resonator exhibits good filtering characteristics, with a Q value as high as 5×10^4 in air, which is an important indication of the sensor's detection limit. Around 0.63µm FSR and 18dB extinction ratio are also obtained. It is to note that due to the Fabry-Perot interference, the through port possesses small oscillations in the spectrum. In order to increase the signal to noise ratio during the sensing measurements, the drop port is chosen.



(a) (b)

Fig. 3: The transmission of the microring resonator which consist of ridge waveguides for TE mode;

(a) Drop port; (b) Through port.

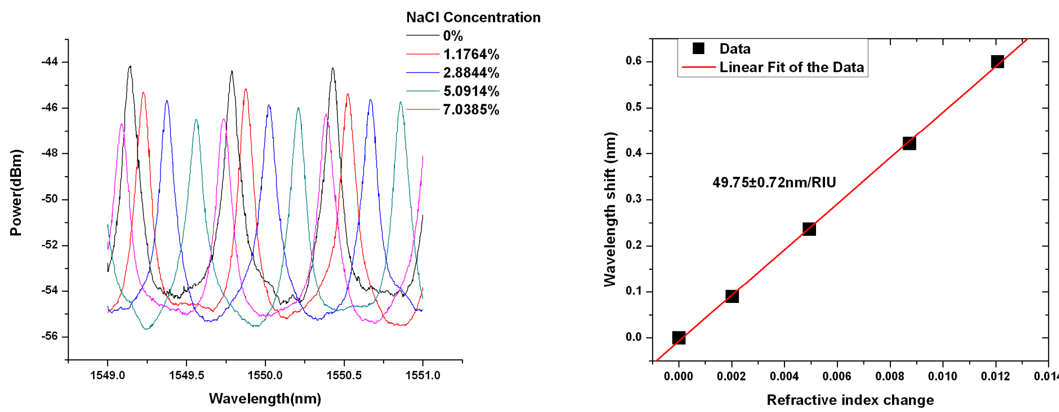
BULK SENSING AND SURFACE SENSING

1.4 Microfluidics channel

A promising way to bond the transducer chip with a fluidics channel is developed with the flip-chip equipment. With the "stamp-and-stick" method, the fluidics channel is mounted on top of the chip with ring resonators on it. The test solution can be delivered to the ring via inlet and outlet microtubes with a syringe and syringe pump. A reliability test is done to test the bonding property to prevent possible leakage.

1.5 Bulk sensing

To demonstrate bulk sensing, a NaCl solution is chosen as the analyte to flow over the ring resonator through the fluidics channel, which serves as upper cladding of the ring resonator. The refractive index of this upper cladding is modified in accordance with the NaCl solution's concentration, which in turn changes the effective refractive index of the guided mode of the ring resonator and thus its resonant wavelength. So by monitoring the wavelength shift, the minimal amount change of the analyte could be detected. The measurement result is shown in Fig. 4. The ideal resonant wavelength shifts are obtained for this ring resonator working in NaCl solutions with different concentrations. Around 50nm/RIU sensitivity is obtained. Due to the small resonant spectrum width, down to10^{-6}~10^{-5} refractive index change could be resolved.



(a) (b)

Fig. 4: The spectral shift of the microring resonances when flowed with sodium solutions with different concentration. (a) change of the spectrum at the drop port. (b) peak positions and their linear fit.

1.6 Surface sensing

In order to detect the specific target in the analyte, the waveguide surface needs to be treated to have receptors with binding sites immobilized on it. This is also referred as surface sensing. In order to do this, a route for grafting the biotin layer on the surface of the ring resonator has been developed. Fluorescence tests with labeled avidin confirm the successful coating of the biotin layer, which is shown in Fig.5. After that, an avidin solution with a concentration of 20µg/mL is pumped into the fluidics channel, with the flowing speed of 10mL/min. After around 50min, the PBS (Phosphate Buffer Solution) is flowed over to wash away the avidin molecules which are still unbound to the surface. The resonant peak position, which is determined by the Lorentzian fitting, is recorded with time during the process. A net wavelength shift of around 60pm is observed. The obvious resonant wavelength shift and the saturation phenomenon prove that the ring resonator is working under the surface sensing regime, where the affinity of biotin and avidin happens on the surface of ring resonator. The same principle can be applied to detect other targeted analytes, such as protein, DNA and so on.

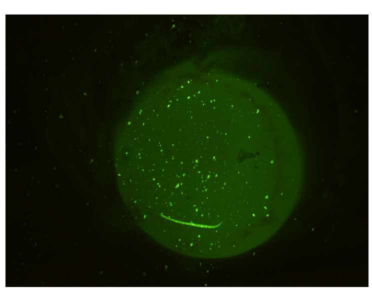


Fig.5: Fluorescence test of the sample coated with Biotin using Avidin-FITC.

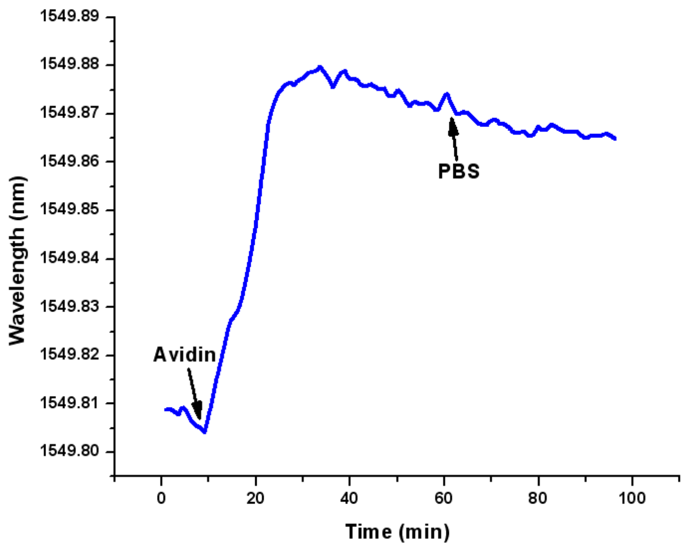


Fig. 6: Real-time monitoring of the resonance peak position at the drop port of the microring resonator which is coated with biotin layer when the fluidics channel is flowed with avidin solution.

CONCLUSION

We develop a a simple UV based soft imprint technique using a novel polysiloxane liquid optical material named PSQ-L. Based on this, a ring resonator with good filtering property is obtained, which is used as optical biosensor. The bulk sensing experiment with NaCl solutions shows a sensitivity of 49.75nm/RIU, and the surface sensing is demonstrated with a biotin-avidin system. Such a low cost optical biosensor built on a polymer platform would find vast applications in the fields of environmental monitoring, food safety, and diagnostic applications.

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