All-polymer Microring Resonator Fabricated by UV Imprint Technique

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In recent years, polymer has been emerging as an ideal material option for integrated photonics devices. Combined with the novel nanoimprint lithography (NIL) technique, compact devices can be fabricated in a fast and efficient way, thus greatly reducing the total cost of the devices. In this paper, the good optical properties of a novel organic-inorganic hybrid polymer called PSQ-L are presented. The good UV (ultraviolet) curing property also makes it suitable for fabricating polymer based devices with a UV nanoimprint technique. Using this technique, a microring resonator consisting of ridge shaped waveguides is fabricated. The ring resonator shows good filtering characteristics, with Q factor above 5×10^4 *in air.*

Introduction

Recently, polymer has been emerging as an ideal material option for integrated photonics devices [1, 2]. First, the cost of the material itself is very low, which make it attractive where the economic factor needs to be taken into account. Second, many especial characteristics such as nonlinearity or amplification can be obtained with proper synthesizing. On the other hand, besides the traditional semiconductor method, polymer is also compatible with many novel fabrication techniques like soft lithography or nanoimprint lithography [3-5]. The latter methods have a huge potential for mass production, thus enabling further reduction of the total cost of critical optical components needed in the future optical network.

In this paper, the good properties of a novel polysiloxane liquid optical material named PSQ-L are shown. This kind of material not only has low optical loss but also high thermal stability. Combining its good UV curing property with a simple UV based soft imprint technique, a microring resonator consisting of ridge shaped waveguides is fabricated. The ring resonator exhibits good filtering characteristics, with Q factor above 5×10^4 in air.

Material

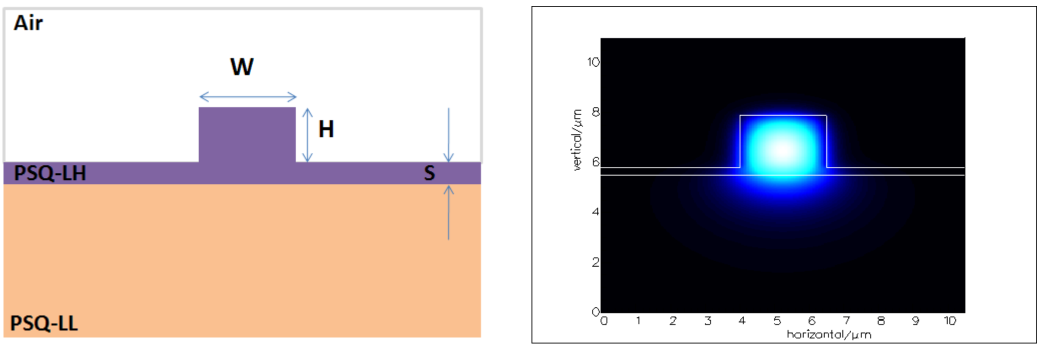
PSQ-L is a kind of silicate based inorganic-organic hybrid optical material [6, 7]. It has two components, PSQ-LH with high refractive index and PSQ-LL with low refractive index. By mixing them proportionally, the refractive index can be linearly adjusted between 1.454 and 1.515. The unique solvent free property and good UV curable property make it highly compatible with UV based soft imprint technique, which is adopted in this paper. Also, PSQ-L has low optical loss at 1550nm and high thermal stability. The main properties of PSQ-L are shown in Table 1.

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

Table 1 Main properties of polymer PSQ-L

Design and Fabrication

The waveguide is designed and fabricated in a ridge shaped structure (Fig. 1(a)). The width and height are designed to be W=2.5 µm and H=2.1 µm separately, in order to meet the single mode condition. Because of the relatively low index contrast, the radius of the microring resonator is chosen as R=300 µm to make the ring have low bending loss. It is important to note that the single mode condition and bending loss also have great relationship with the thickness of the residual layer (s in Fig. 1(a)), which should be decreased below 0.3 µm in our case. The simulated fundamental TE mode is shown in Fig. 1(b). The laterally coupled microring resonator is designed to work in low coupling regime. The coupling length between the straight waveguide and the ring is 110 µm and the gap between them is 1 µm.



(a) (b)

Fig. 1. (a) The schematic picture of the waveguide cross section. (b) The simulated fundamental TE mode of the waveguide.

In order to reduce the cost, both the cladding and core of the waveguide are made in polymer. The flow chart of the UV imprint process is shown in Fig.2. First, a layer of PSQ-LL is spin coated on the Silicon substrate. This layer serves as under cladding after UV and thermal curing. Secondly, a thin layer of PSQ-LH is spin coated on the first layer, followed by the imprinting of the mold. The soft PDMS mold is replicated from a master mould using the method of casting. When the PSQ-LH layer becomes solidified after UV exposure, the PDMS mold is peeled off. It can be seen that the waveguide structures have been successfully transferred from the PDMS mold to the PSQ-LH layer.

Finally, the sample is post baked at high temperature for 2h to make the polymer fully cured. The simple principle of UV nanoimprint method adopted in the paper provides a rather convenient way to form polymer waveguide structures compared with traditional standard CMOS technique, e.g. lithography and dry etching. The SEM image of the cross section of the fabricated waveguide is shown in Fig.3.

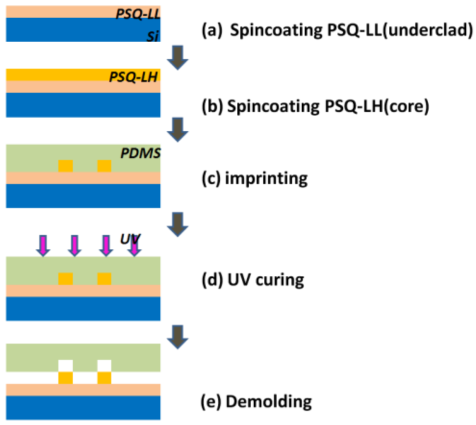


Fig.2 The fabrication process of UV nanoimprint lithography.

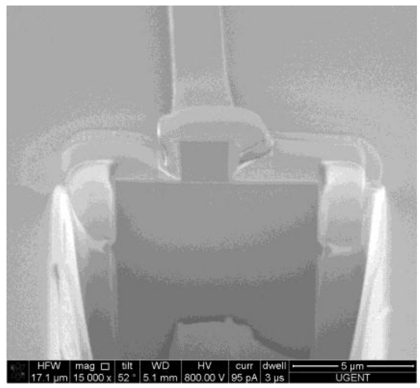
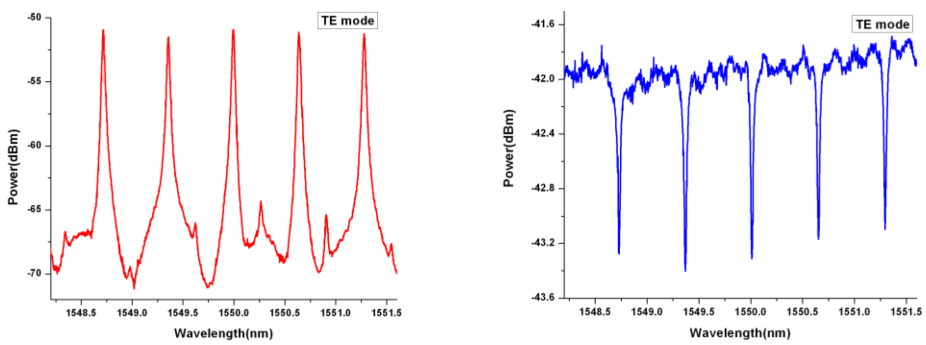


Fig.3 The SEM image of the fabricated waveguide

Measurement result

The transmission of the fabricated ring resonator is measured by a horizontal setup. The light from a tunable laser is coupled into the waveguide via a lensed fiber. The output light is collected by a single mode fiber, which is connected to a power meter. A polarization controller is used to control the polarization of the input light. The measured transmissions of the drop port and through port for the ring resonator are shown in Fig.4. Although the measurement was based on the TE mode, the TM mode has similar kind of characteristics.

From the measurement, the FWHM (Full Width of Half Maximum) of such kind of ring resonator is found to be around 0.03nm. By taking the ratio of resonant wavelength and FWHM, a Q value as high as 5×10^4 in air can be obtained. Low material's optical loss, low surface roughness loss and low coupling regime are the main reasons for the high Q value. The extinction ratio at the drop port and the through port are around 17dB and 1.5dB. The small FSR (Free Spectrum Range, ~0.64nm) is due to the relatively large ring radius, which could be improved in the future work.



(a) (b)

Fig. 4 The transmission of the microring resonator for TE mode.(a) Drop port; (b) Through port.

Conclusion

A novel inorganic-organic hybrid optical material called PSQ-L is introduced. In combination with the efficient UV nanoimprint technique, a microring resonator consisting of ridge shaped waveguides is fabricated. The ring resonator shows good filtering characteristics, with Q factor above 5×10^4 in air. This kind of device provides an ideal platform for label-free optical bio-sensing.

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