Fabrication of All-polymer Microring Resonator by Using a Novel Polymer PSQ-L

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Polymer is emerging as a promising material to reduce the device cost in integrated optics. A novel inorganic-organic hybrid polymer PSQ-L has been introduced recently. This polymer film shows good optical properties and high thermal stability. An all polymer microring resonator is fabricated by using PSQ-LH as a core layer and PSQ-LL as a cladding layer. The waveguides are fabricated by a UV-based soft-lithography process consisting of two simple steps. The fabricated microring resonator has low scattering loss and a high Q factor of 2.8×10^4 is obtained.

Introduction

Polymer is emerging as a promising material in the field of integrated optics. The cost of devices can be lowered down due to the simple fabrication process. When applying polymer to fabricate waveguides, the optical properties and the thermal stability of the polymer have to meet the requirements for the optical applications [1]. One the other hand, the polymer should be compatible with advanced fabrication technology, like soft-lithography [2, 3] or nanoimprint lithography (NIL) [4].

In this paper we introduce a new polymer PSQ-L which has good optical properties and high thermal stability. This polymer is also compatible with soft-lithography fabrication process. A laterally coupled PSQ-L microring resonator is fabricated by UV-based soft-lithography. About 9dB extinction ratio from the through port and 16dB extinction ratio from the drop port is obtained. A high Q value of 2.8×10^4 is obtained. This easy fabrication process is compatible with other polymers.

Material

PSQ-L is a kind of inorganic-organic hybrid polymer[5], which is purely liquid (solvent free), UV curable and compatible with soft-lithography.

Polymer PSQ-L includes a high index polymer PSQ-LH and a low index polymer PSQ-LL. This polymer film shows good optical properties (Table 1) and high thermal stability (1% Td is above 300℃ in air and 340℃ in nitrogen). The optical loss of the film is less than 0.3 dB/cm at 1310nm and less than 0.9 dB/cm at 1550nm, which is quite low compared to commercially available polymers [1].

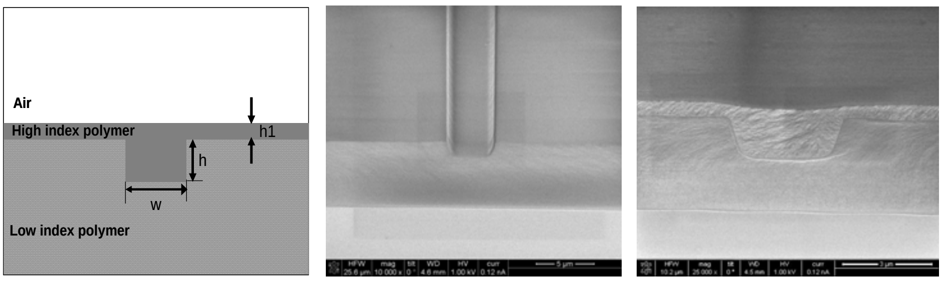
The optical properties of PSQ-L films are characterized by prism coupling (SPA-4000). The optical loss of the film (slab waveguide) is measured by immersion oil technology [6] and is a good approximation for the absorption loss of the material itself.

Table 1 Properties of Polymer PSQ-L

	PSQ_LL	PSQ_LH
Refractive Index @1310nm	1.456	1.517
Refractive Index @1550nm	1.454	1.515
Birefringence (n_{TE}-n_{TM})	<0.0005	<0.0005
Thermo-optic coefficient (/℃)	-2.2×10^{-4}	-2.4×10^{-4}
Propagation Loss (Measured from slab waveguide)	not measured	0.8~0.9 dB/cm@1550nm
	not measured	0.2~0.3dB/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

Design and Fabrication

The high index PSQ-LH is used as the core material of the waveguide and the low index PSQ-LL is used as the cladding material of the waveguide. The designed cross section of the waveguide is shown in Fig.1(a). To fulfill the single mode condition of the waveguide for the ring resonator, the waveguide has a width of 3 μm and a height of 2 μm (w=3 μm, h=2 μm in Fig.1(a)). Due to the high index contrast between the polymer core and air, most light is confined in the core of the lower cladding layer. This layer design gives good tolerance to the slab waveguide height (h1 in Fig.1(a)). As long as h1 is below 800nm, single mode condition can be achieved in the vertical direction.



(a) (b) (c)

Fig.1 (a) The cross-section of the waveguide (b) SEM picture of the imprinted low index layer (c) SEM picture of waveguide cross-section (after spin-coating the high index layer)

The imprint process is shown in Fig.2. The PDMS mold is made from an SU-8 master mold by cast-molding [3]. Unlike in conventional imprint processes, the imprint step is used to structure the cladding layer rather than the core layer and is followed by a spin-coating step to fill the imprinted features in the cladding layer to define the core of the waveguides. This process smartly avoids the difficulties related to controlling the thickness of the residual layer since the residual cladding layer thickness does not need to be controlled accurately as long as it is thick enough to eliminate the substrate leakage loss. The process is carried out as follows. First, a drop of pure PSQ-LL is deposited on the silicon wafer, and then the PDMS mold is put on top. After 20 minutes imprint time, it is exposed to the UV lamp for 3 minutes. After that, the PDMS mold is peeled off and the polymer is baked for 1h at 180℃ to allow for solidification after UV exposure. To improve the adhesion to the second layer, 5 minutes of oxygen plasma etching is done on the first layer. Then the core layer PSQ-LH is spin-coated on the first layer with high speed (9500rmp/s). Finally, the sample is post baked at 180℃ for 2h and 200℃ for another 2h to allow for full polymerization.

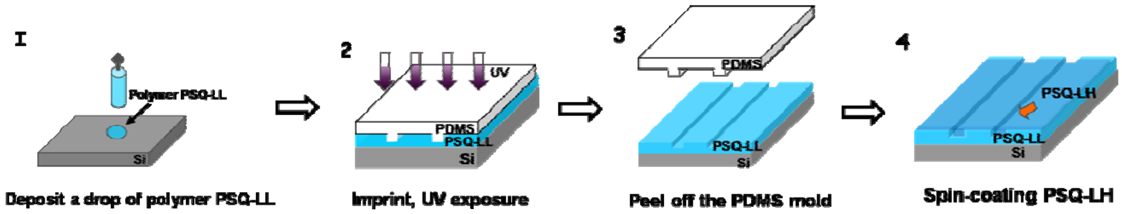


Fig.2 Fabrication process flow of the polymer waveguides

A SEM picture of the cross section of the waveguide is shown in Fig.1(b). The small roughness on the sidewalls originates from the SU-8 mold. A cross section SEM picture of the waveguide after spin-coating the second layer is shown in Fig.1(c). Due to the high spin-coating speed, the core layer forms a shallow trench on the waveguide surface.

In this paper the ring resonator is designed as a laterally coupled ring resonator. The waveguide cross-section is as described above. Due to the small index contrast between the core and cladding (about 0.061), the radius of the ring is chosen as 400 μm to eliminate the bending loss. The gap between the straight waveguide and the ring is designed as 1 μm to 1.8 μm. To ensure enough coupling between the ring and the straight waveguide, the ring is designed as a racetrack ring resonator with a coupling length of 150 μm.

Measurement Results

The transmission spectrum of the device is measured by coupling light from a tunable laser to the waveguide via a lensed fiber. The transmitted light is collected by a single mode fiber to the power meter. A polarization controller is used at the input port to select the polarization. Fig.3 shows the measured transmission spectrum of the ring resonator when excited with the TE mode. This ring has a gap of 1.2 μm. The waveguide is almost symmetric, so the TM mode shows similar response and similar results. The following analysis is therefore done for TE polarization only.

The FSR of the ring is about 0.57nm as expected due to the large ring radius. The FWHM (Full Width of Half Maximum) is about 0.056nm. By taking the ratio between the resonance wavelength and the FWHM, a Q factor about 2.8×10^4 is calculated. 9dB extinction ratio at the through port and 16dB extinction ratio at the drop port is obtained. By fitting the data, the per round trip power attenuation corresponds to a loss of 3.2 dB/cm of the ring waveguide. The material absorption loss is about 0.9 dB/cm and the loss due to mode mismatch between the straight waveguide and the bent ring waveguide is about 0.7 dB/cm, which follows from theoretical calculations. Assuming the bending loss and substrate leakage loss can be neglected, a scattering loss of the ring waveguide of 1.6 dB/cm is estimated. The improvement of the SU-8 mold roughness is expected to further reduce the scattering loss.

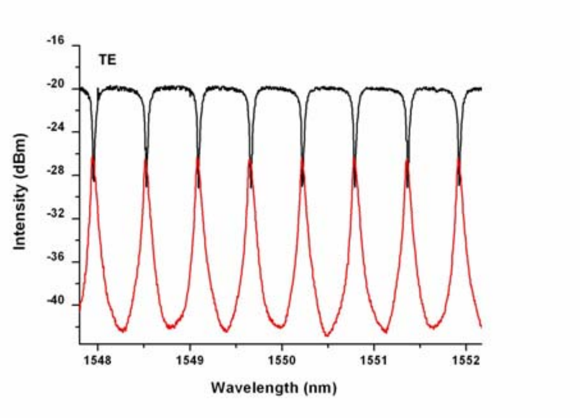


Fig.3 Measured transmission spectrum of microring resonator for TE polarized light

Conclusion

A novel polymer PSQ-L is introduced for optical applications. The polymer shows good optical properties and high thermal stability. A lateral coupled PSQ-L microring resonator is fabricated by UV-based soft-lithography. About 9dB extinction ratio from the through port and 16dB extinction ratio from the drop port is obtained. A high Q value of 2.8×10^4 is also obtained.

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