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Polarization dependence of SU-8 micro ring resonator

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ABSTRACT

This work describes the polarization study in the optical micro ring resonator systems. The use of polymeric materials for micro ring resonator structures recently has gained major interests due to many advantages such as enabling a rapid and straightforward fabrication process. Here we report a demonstration of an optical micro ring resonators comprised of polymer material, namely SU-8. We have shown the effects of the polarizations induced by the micro ring resonator waveguide on the spectral frequency response experimentally with respect to the changes of the polarization states as ellipticity and azimuth states. The effects can be detrimental, or these can be exploited for new devices. For both throughput and drop ports of the micro ring resonator, the highest variation of Q_{factor} occurs in azimuth polarization state. The variation of the free spectral range induced by changing the polarization state at the drop and throughput ports is in the range of 0.2–0.65 nm and 0.2–0.75 nm respectively. Furthermore, the throughput port has experienced the highest finesse at the ellipticity polarization state. The significant wavelength shift has occurred in the drop port at the wavelength 1600 nm with azimuth polarization state. Besides, the throughput port has experienced a wavelength shift incurred by both azimuth and ellipticity states. Our results have demonstrated that low-cost photonics devices made from polymers are possible alternatives for next-generation photonics.

Introduction

SU-8 (may stands for Substrate with 8 epoxy) photoresist series are negative tones, epoxy-type photoresists based on EPON™ SU-8 (also called EPIKOTE™ 157) epoxy resins from Hexion Specialty Chemicals, Inc. (Columbus, OH 43215), and originally developed and patented by IBM. It is commercially available from MicroChem Corp. (Newton, Massachusetts) [1].

Sensing technology optimizations have been challenged by tradeoffs such as compactness, reliability, low cost, device reliability, and fabrication easy [2,3]. Regarding the latest researches, the ease of using established micro- and nanofabrication materials such as polymers or photoresists provide an avenue towards low-cost integrated photonic devices for sensing applications [4,5]. For instance, the polymer SU-8 is transparent between wavelength 400 nm and 1620 nm, with a transmission coefficient which is greater than 95%. Thus, this optical property can make the SU-8 a suitable material for the optical waveguides. As a factor of device performance, the polarization could have major contribution for the sensing applications [6–8]. However, it is rather difficult to fabricate a polarization-dependent photonic integrated circuit with polymer structures. One trivial tunability of a micro ring resonator occurs by changing its diameter or coupling coefficient, thus shifting the resonance which causes the wavelength filtering and or tuning the free spectral range (FSR) [9–13]. In the case if an unpolarized light is utilized, the polarization plane fluctuates arbitrarily around the propagation direction, therefore no direction is realized. The polarized light has the fixed phases for its field components which differ from each other. Two orthogonal states can be defined for a state of polarization (SOP), where the Poincaré sphere shown in Fig. 1, is the appropriate way to indicate the SOPs.

The Cartesian coordinate is in the center of the Poincaré sphere as shown in Fig. 1, where it represents 3 normalized Stokes Parameters as s_1, s_2, and s_3 at any point on the Poincaré sphere. The parameters are presented in Table 1.

Polarization diversity is used to enable polarization insensitive optical devices. Such designs can be achieved by splitting light into two orthogonal SOPs, such as those available in polarization splitters and rotators [14–18]. Fig. 2 shows the double side coupled micro ring resonator [19]. Here, we select a radius of the micro ring resonator in which the response to the polarization changes is maximized. In

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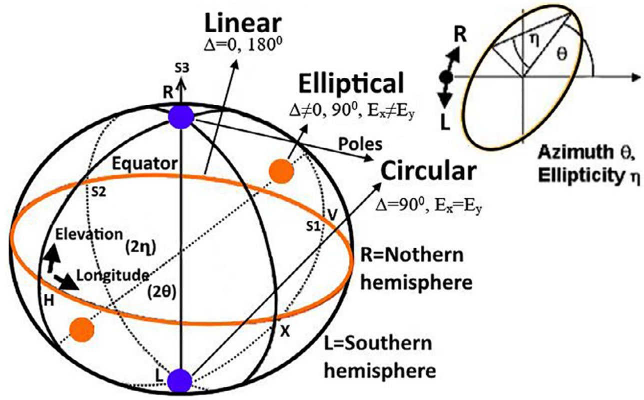

Fig. 1. Poincaré Sphere describing optical polarization directions.

Table 1
Short polarization and their values.

Short Polarization	θ	η	SOP	Angle
H linear, horizontal	0°	0°	H_{0°	Zero
+ Linear + 45°	45°	0°	R_{45°	Ellipticity
V Linear, Vertical	± 90°	0°	L_{-45°	Ellipticity
−Linear + 45°	−45°	0°	$\backslash_{-45^\circ}$	Azimuth
R right Circular	–	+45°	$/_{45^\circ}$	Azimuth
L left Circular	–	−45°	V_{90°	Azimuth

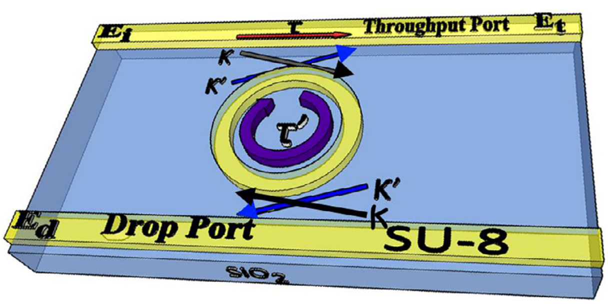

Fig. 2. Double side coupled micro ring resonator.

racetrack micro ring resonators, due to the mismatch losses in the straight-bend transition, the excess bend losses will contribute to the total losses. This causes additional sidewall roughness which affects the intensity distributions. This effect can occur for the mismatch in waveguide width [20,21]. In this research a broadband light source is used as an input. Extinction resonated wavelength has obtained from the injection straight waveguide (input bus waveguide), whereas the extracted resonant wavelengths have obtained at second straight waveguide (output bus waveguide). At the coupling region, the τcan be defined as the amplitude self-coupling coefficient in the ring waveguide [22–24]. κ is the amplitude cross-coupling coefficient for the straight-ring waveguide. With the assumption of symmetrical coupling,

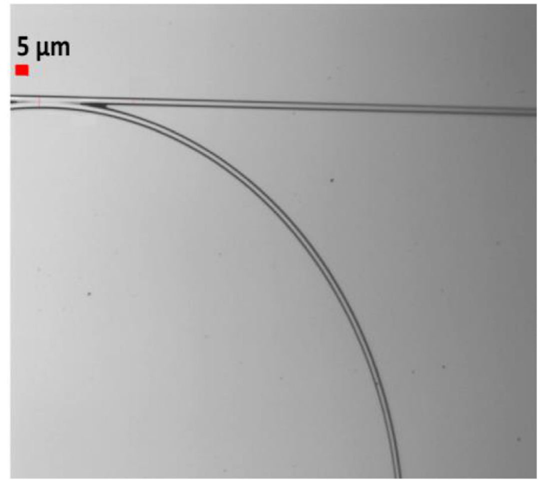

Fig. 3. Fabricated micro ring resonator structure with the SU-8 polymer.

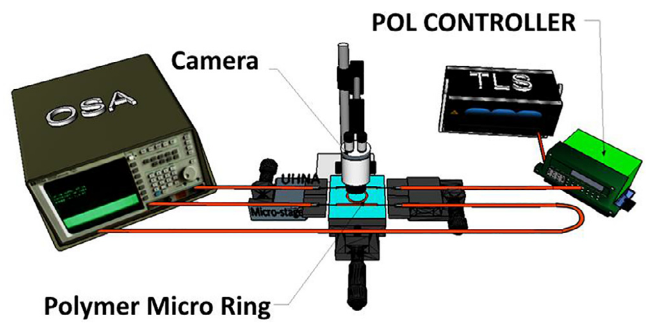

Fig. 4. Experiment setup used to investigate the dependency of the resonance wavelength upon the polarization changes of the input light. A tunable laser source (TLS) is synchronized with the optical spectrum analyzer (OSA) and it is used as a coupling light source.

therefore $\tau = \tau'$, $\kappa = \kappa'$.

Based on the notation in Fig. 1, as well as the assumption of symmetrical coupling, we can express the normalized transmitted and dropped intensities as follow:

$$T(\lambda) = \left|\frac{E_t}{E_i}\right|^2 = \eta^2 \left|\frac{\tau - \eta^2 M\tau \exp(j\varphi)}{1 - \eta^2 M\tau^2 \exp(j\varphi)}\right|^2 \quad (1)$$

and

$$D(\lambda) = \left|\frac{E_d}{E_i}\right|^2 = \eta^2 \left|\frac{\sqrt{M}\kappa^2 \exp(j\varphi/2)}{1 - \eta^2 M\tau^2 \exp(j\varphi)}\right|^2 \quad (2)$$

where E_i, E_t, and E_d are the amplitudes of the incident, transmitted and dropped fields, respectively. Here, ϕ is the single-pass phase shift of the propagated wave in the micro ring, and $\varphi = 2\pi R n_{eff}\beta$, where β is the propagation constant, n_{eff} refers to the effective refractive index of the micro ring waveguide and R is the micro ring radius. The field

Table 2
Parameters have been used in micro ring resonator design.

Variable	Value	Comment
The total circumference of the device	10,000 µm	The total length of the waveguide
Radius (r)	800 µm	Radius curvature of arc
Length of bend	$2\pi r \times angle(°)/360$	Length of the arc segments and the factor of is present because of the variable angle in degree
SiO_2 thickness	7 µm	Under cladding
Si thickness	500 µm	Handle wafer thickness
Index of under cladding SiO2	1.46	Refractive index of under cladding is 1.46
Index of substrate Si	3.47	Refractive index of substrate silicon oxide is 1.46
Coupling gap size	1 µm	Distance between $2\pi r \times angle(°)/360$ ring and waveguide