Fiber Coupled Optically Tunable Polymer/Glass Microring Resonators

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Abstract: Polymer/glass microring resonators were fabricated coating cylindrical glass elements with different polymer doped materials and coupled to a tapered fiber. Resonance wavelengths are optically tuned with an external 975 nm laser signal.
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1. Introduction

During the last few years, microring resonators (MRRs) technology has become more popular for sensor application owing to their excellent sensitivity to changes in the surrounding media. Another attractive feature is their reduced dimensions, making them suitable for integration with other technologies and/or components such as fiber optics [1]. Mainly the dimensions of the cavity itself and the refractive index of the materials used for their fabrication define the spectral response generated by these resonating devices. When MRRs structures are subjected to an external perturbation or when the properties of the materials change, the resonance conditions are modified thereby yielding modifications in the transmission spectrum. The use of materials activated by external sources could therefore be useful to adjust the response of microring resonators, and this has been explored with both, acusto- and electro-optic materials [2, 3]. In addition, the use of polymers allows further functionalization with biological agents for biosensing applications [4].

Typical fabrication methods for MRRs are based on photolithographic processes or etching. These yield high quality surfaces, with proper smoothness to generate disks or racetrack waveguides [5]. Mold-replica and 3D printing techniques are also of common use based on polymeric materials showing a lower performance compared to photolithographic approaches, but providing ease of fabrication [6, 7]. An alternative to these techniques is the use of cylindrical elements in which the light is coupled only to a small cross section acting as the resonator. In this work we present the fabrication and characterization of MRRs fabricated with thin layers of polymeric materials used as coatings for cylindrical elements. The polymers include photoluminiscent and birefringent materials in order to achieve an optically tunable response. We further explore the use of multilayer resonators in order to improve the induced tuning effect in the MRRs.

2. Experiments

Microring resonators were fabricated with standard single-mode optical fibers (SMFs) with 125 μm cladding diameter (SMF-28e, Corning). Thin films of different polymers were used as coatings for the fibers; hence, the MRRs are based on a composite polymer/glass structure whose optical features depend on the thickness and refractive index of the corresponding polymer, and glass fiber used for their fabrication. For the polymers, we used polydimethylsiloxane (PDMS, Dow Corning 184) as a host material, and different dopants were added to obtain different functionalities. In particular, we evaluated the performance of the MRRs with coatings based on pure PDMS, PDMS doped with ytterbium and erbium-doped sodium yttrium fluoride (NaYYbErF, Sigma-Aldrich, CAS: 753489-02-0, henceforth referred to as PDMS+Yb), and PDMS doped with an azobencene (disperse Red 1, DR1, Sigma-Aldrich, CAS: 2872-52-8, referred to as PDMS+DR1). The doping concentrations for the mixtures were 1 wt% and 0.1 wt% for the DPMS+Yb and PDMS+DR1, respectively. Each of the base mixtures were mixed with a crosslinking agent in a weight ratio of 9:1. Thin coatings of approximately 1.6 μm of thickness were deposited over the fibers by means of a custom system working under the wire technique, and then heated at 85°C during a period of time of 2 hours for solidifying [8]. Using the same procedure, a multilayer resonator was fabricated with a first a layer of the PDMS+Yb mixture, and a second layer with the PDMS+DR1 material; both layers were estimated to be 1.6 μm thick.

Light was coupled to the MRRs using a SMF previously tapered down to a waist of 10 μm. Each of the tested resonators was positioned in minimal contact with the tapered fiber located in a perpendicular orientation. A broadband probe signal centered at a wavelength of 1550 nm was launched into the tapered fiber to monitor the transmission spectrum and observe the resonance effect in an Optical Spectrum Analyzer (OSA). To generate

changes in the materials of the resonators, a 975 nm laser diode was used as an excitation source at different optical powers. This "pump" beam was combined with the probe signal by means of a 980/1550 nm fiber wavelength multiplexer. The experimental setup and is shown in Figure 1. The excess of excitation light not coupled to the resonator was filtered with a 980/1550 nm fiber wavelength splitter.

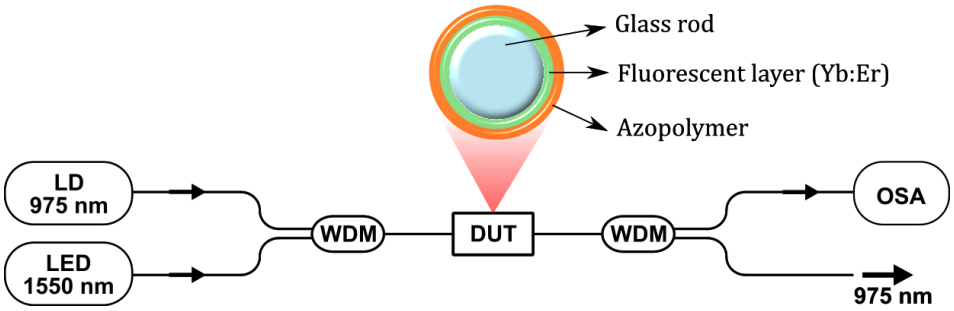


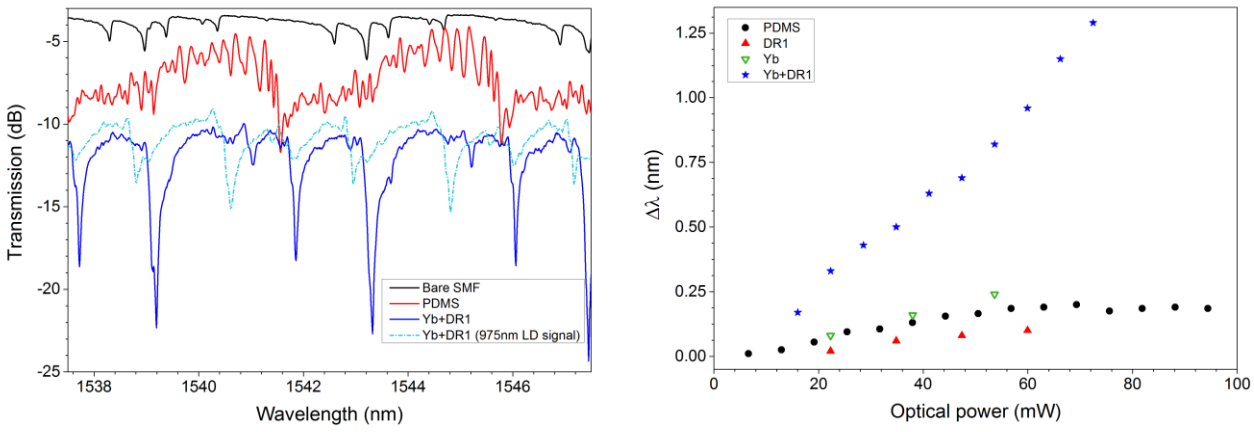
Fig. 1. Experimental setup for characterization of the polymer/glass microring resonators.

3. Results

We first obtained the transmission spectrum of a MRR constructed with a bare SMF-28 fiber. Upon placing the bare fiber in close contact with the tapered fiber, we observed a transmission spectrum with periodic attenuation features at specific wavelengths. The resonator free spectral range (FSR) was 4.26 nm, indicating a group refractive index of 1.4361 for the 125 μm diameter fiber. In subsequent experiments, the transmission spectra for the polymer resonators where obtained following the same procedure. Figure 2a illustrates the spectra obtained for the different resonators used in our experiment. As typically observed with this kind of resonant structure, the registered spectra show multiple peaks within each periodic lobe, indicating multimodal resonance conditions within the cylindrical structures. Another feature of the resonance response when using polymeric coatings was an enhancement of the contrast generated at the resonant wavelengths, reaching up to 10 dB attenuation.

In order to induce changes in the coating materials, the 975 nm laser signal was launched thru the tapered fiber. We first evaluated the effect of irradiating a MRR formed only with a PDMS layer; for this case, a displacement on the resonances towards shorter wavelengths was registered in the OSA. This shift in wavelength was observed to increase as the power of the 975 nm signal was increased. We then performed similar measurements for resonators formed with PDMS, PDMS+Yb, PDMS+DR1, as well as a multilayer arrangement (i.e., a layer of PDMS+Yb and a second layer of PDMS+DR1 on top). The wavelength shifts for each MRR as a function of the optical power is shown in Figure 2b. When using only PDMS as coating material, a slight displacement is gradually induced until a saturation point is reached. A similar response is generated when DR1 is added into the PDMS matrix, indicating no interaction of infrared light with the azobencene. In contrast, for the PDMS+Yb resonators, absorption of the 975 nm laser signal induces a larger modification in the refractive index. However, this leads to a distortion in the transmission spectra and the resonance peaks are lost.

Enhanced resonance tuning is achieved with the multilayer resonator. As seen in Fig. 3b, when the multilayer resonator is excited, larger wavelength shifts are obtained upon increasing the power of the 975 nm pump laser. For this arrangement the pump light is mostly absorbed by the PDMS+Yb layer, avoiding the distortion in the resonance peaks of the resonator. Notice that in this case, resonance occurs at outermost polymer layer, which incorporate the azobencene. Excitation of the PDMS+DR1 layer is achieved by the green luminescence generated in the PDMS+Yb layer. This is produced through upconversion effects when this polymer layer is pumped with the 975 nm signal. The green fluorescence signal is thus absorbed by the DR1 molecules, adding an additional change in the refractive index. Notice that for this multilayer arrangement, no saturation point was observed and a maximum wavelength shift of 1.6 nm was registered. The addition of a second layer (PDMS+DR1) thus contributes to an enhanced tuning response, without distorting the resonance effect.



a) b)

Fig. 2. a) Transmission spectra for different microring resonators. b) Wavelength peak shift upon 975 nm laser signal in different microring resonators.

4. Conclusions

Fabrication of the microring resonators was performed using optical fibers coated with thin films of photoactive materials as the resonators and then coupled to tapered fibers, obtaining contrasts of up to 10 dB at the resonance wavelengths. The use of different materials embedded within a PDMS polymeric matrix, resulted in a variety of materials with diverse absorptions. Resonance effects were tuned via an additional infrared laser pump signal transmitted thru the same optical fiber coupled to the resonators, generating a change in the effective refractive index by absorption of this light source; hence, the resonance wavelengths are shifted. Enhancement of the resonators was accomplished by using a multilayer approach for a where the bottom layer with particles of Yb:Er absorbed the pump signal generating green luminescence, which was likewise absorbed by the top layer containing azobencene molecules. Maximum wavelength shift of 1.6 nm was observed for a multilayered coated resonator.

5. References

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