

## Fabrication of an electro-optic polymer microring resonator

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*A laterally coupled electro-optic polymer microring resonator was designed and fabricated. The design consists of microrings of 200  $\mu\text{m}$  radius with racetrack structures to improve the coupling between the bus waveguide and the ring. Two different fabrication schemes namely reactive ion etching (RIE) and photodefinition are presented. Thermally grown siliconoxide on conducting silicon was used as the bottom cladding. Passive ring resonance behavior has been demonstrated around 1550 nm. The through port response of the ring showed a maximum extinction of about 12 dB and a finesse of 6.*

### 1. Introduction

Microring resonators are promising candidates for very large scale integration photonics. Polymer microring resonators are especially interesting for electro-optic (EO) modulator application in optical communication systems. Ring resonators made of EO polymers have certain advantages over inorganic materials such as  $\text{LiNbO}_3$ , most notably the low microwave/optical velocity mismatch allowing simple design of high speed modulation devices [1]. However, in traveling wave Mach-Zehnder high speed polymer modulators the bandwidth is limited by the loss of the several centimeter long micro-strip line [2]. On other hand in microring modulators, since the device is small the electrode size can be much smaller and as the microwave index of refraction of polymers is  $\sim 1.5$  the device's high speed behavior is mainly capacitive. Hence, electrode loss is not an issue and the bandwidth is set by the electrode capacitance. In the present work laterally coupled microring resonators have been fabricated in PMMA-DR1 (Polymethylmethacrylate-Disperse red) by RIE and in SU8 (a negative photoresist) by photodefinition. Lateral coupling offers the advantage of a single mask process and allows symmetric coupling avoiding the critical alignment step in the vertically coupled resonators. The coupling between the waveguide and the ring is an important factor which determines the quality factor of the rings. In most of the laterally coupled polymer microring resonators, submicron gaps between the bus waveguides and the ring are required for sufficient coupling. These submicron gap sizes can be achieved by imprinting involving expensive E-beam lithography. In the present work we demonstrate high coupling with the gap sizes of 1  $\mu\text{m}$  to 1.5  $\mu\text{m}$  (which can be easily achieved by contact mask lithography) by having racetrack structures. The coupling is varied by varying the racetrack length and the gap. PMMA-DR1 is used as a test material for the realization of the design. In the final devices PMMA-DR1 will be replaced by SU8-TCVDPA (tricyanovinylidenediphenylaminobenzene) polymer which

can be photodefined utilizing the low UV absorption window of the TCVDPA chromophore [3]. TCVDPA was chosen as it was reported to have the highest photochemical stability among a large number of EO chromophores [4].

## 2. Device design and fabrication

Microring resonator design was made using PMMA-DR1 as the core material with a refractive index of 1.6 at 1550 nm. Silicon oxide was used as the bottom cladding and the top cladding was VSC (an UV curable epoxy with a refractive index of 1.55 at 1550 nm). The bus waveguides were 2  $\mu\text{m}$  wide and 0.9  $\mu\text{m}$  thick to satisfy the monomodal condition. Because of single mask processing the thickness of the ring was also 0.9  $\mu\text{m}$ . For this configuration the minimum possible ring radius was 200  $\mu\text{m}$  in order that the bending losses in the ring is not more than 1dB/cm. Bending loss, scattering loss, transition losses between the straight and the bend sections of the ring and material loss are the main loss mechanisms in the microring resonator. In general scattering and material losses in microring resonator are much higher and the 1 dB/cm bending loss can be negligible. The simulated transition loss is 0.4 dB per round trip. The length of the racetrack is varied from 20  $\mu\text{m}$  to 240  $\mu\text{m}$  and the gap size is varied form 1  $\mu\text{m}$  to 1.5  $\mu\text{m}$ . In the first scheme inverted ridges were made by photolithography and RIE in thermally grown siliconoxide of 8  $\mu\text{m}$  thickness on conducting silicon. The conductive silicon will serve as the bottom electrode for electro-optic modulation. Silicon oxide was chosen as the bottom cladding instead of a polymer as the gaps of 1  $\mu\text{m}$  can be well defined than in a polymer. PMMA-DR1 was spin coated to fill the inverted ridges. The excess slab height of PMMA-DR1 was etched back to zero by RIE as even the presence of small slab height is detrimental for the bending losses of the ring. A top cladding of VSC was spin coated on top of it. A microscope picture of the fabricated device is shown in figure 1. In the second scheme the SU8 was spin coated on silicon oxide and the structures are made by direct photodefinition. The same mask used in the scheme 1 was used as the refractive index of SU8 is comparable with PMMA-DR1 [3]. Contact lithography was done in Karl süss mask aligner. A top cladding of VSC was applied on top of the SU8 core.

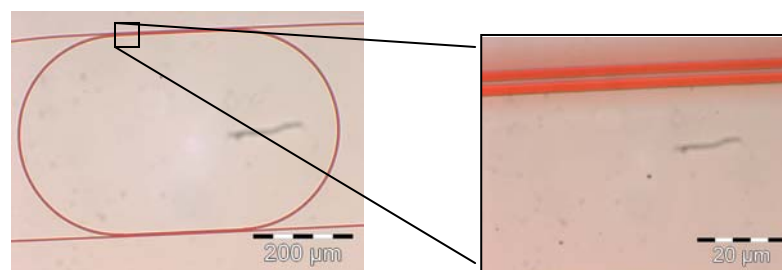


Figure 1: PMMA-DR1 microring resonator fabricated by RIE with a racetrack length of 240 $\mu\text{m}$  and a gap of 1  $\mu\text{m}$

## 3. Experiments and discussion

The microring devices were tested by coupling TE polarized light from a Erbium doped fiber amplifier (emission from 1530 nm to 1560 nm and 10 mW output power). The outcoupled light was analyzed with a spectrum analyzer. Figure 2 shows the through port response of the PMMA-DR1 microrings with a gap of 1 $\mu\text{m}$  for various racetrack

lengths. It can be seen from figure 2 that the extinction ratio increases with the racetrack length up to 160  $\mu\text{m}$ . The highest extinction ratio of 12 dB was seen at a racetrack length of 160 nm. With further increase in racetrack length the power couples back to the bus waveguide and the extinction ratio decreases. This decrease is very rapid with further increase in the racetrack length beyond 160 nm as the power couples back to the bus waveguide and also at very high racetrack lengths the roundtrip losses of the ring becomes a dominant factor.

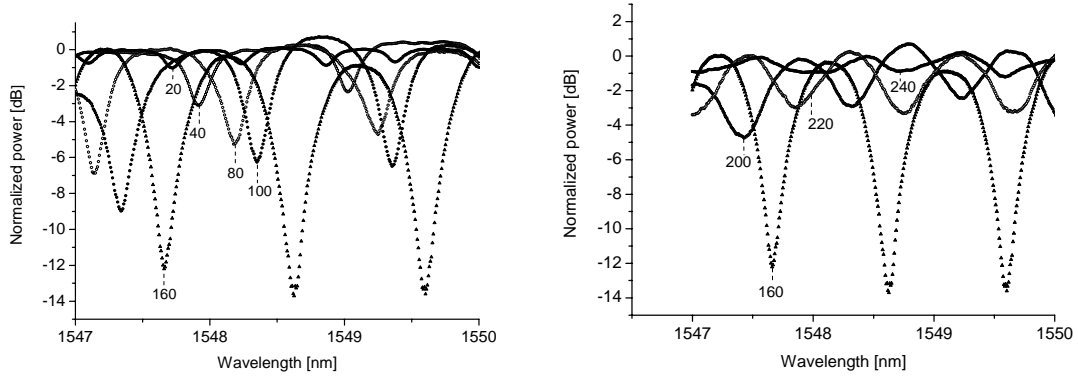


Figure 2: Through port response of PMMA-DR1 microrings of different racetrack lengths for TE polarization (Numbers shown in the graphs are the racetrack lengths in  $\mu\text{m}$ )

The quality factor of the resonance was measured for the device with 160 nm racetrack to be 8000 and the finesse was 6. The free spectral range (FSR) varies from 1.1 nm to 0.9 nm as the racetrack length varies from 20 nm to 240 nm. The coupling constants and the ring losses were extracted from the through port response by making a fit using Rfit software. The ring loss is 30 dB/cm. Figure 3 shows the extracted coupling constants as a function of racetrack length for different gap sizes.

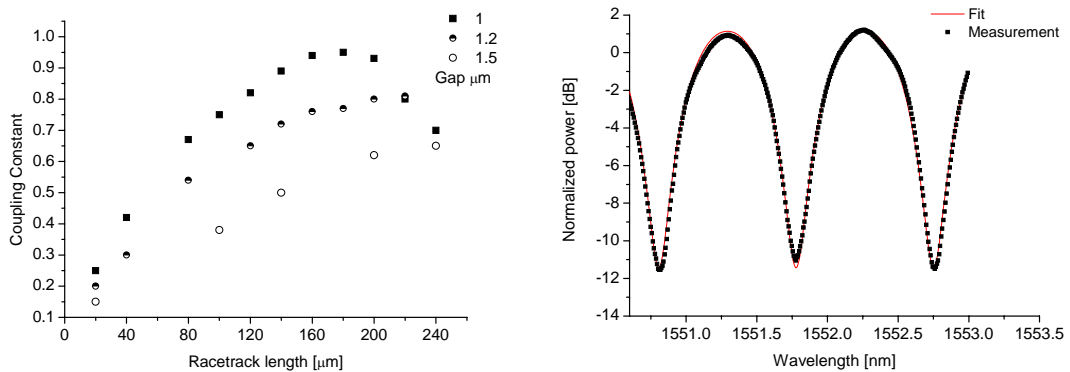


Figure 3: Coupling constants as a function of racetrack length for different gap sizes (left), Through port response of SU8 microring with a racetrack length of 180 nm and a gap of 1.5  $\mu\text{m}$  for TE polarization (right)

It can be seen from the figure 3 (left) that the maximum achievable coupling constant by increasing the racetrack length is limited by the gap size. By further reducing the gap size below 1  $\mu\text{m}$  coupling constant close to about 0.95 can be achieved at a much shorter racetrack length which will reduce the roundtrip losses of the ring and increase the FSR slightly.

Figure 3 (right) shows the through port response of the photodefined ring in SU8. The gap size was 1.5  $\mu\text{m}$  and the race track length was 180  $\mu\text{m}$ . With further optimization of the photodefinition process gaps of less than 1.5  $\mu\text{m}$  can be realized. The coupling constant was found from the fit to be 0.94 and the ring loss is 19 dB/cm. When compared with the PMMA-DR1 rings with 1.5  $\mu\text{m}$  gap high coupling constant is found in the SU8 rings. This is because the refractive index of SU8 is slightly less than that of PMMA-DR1 and hence the mode field expands more into the cladding. Also a reduction in the ring losses of about 10 dB/cm is seen in the photodefined rings possibly because of reduced side wall roughness together with low material absorption loss.

#### 4. Conclusion

Laterally coupled microring resonators were fabricated in an electro-optic polymer (PMMA-DR1) and a passive material (SU8). SU8 can be loaded with TCVDPA chromophore to make it electro-optically active and can be photodefined. The coupling constant was varied by changing the racetrack length and extinction ratio of 12 dB was measured in both the material systems. This looks promising for electro-optic modulator applications.

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#### 5. References

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