

# Hybrid-Polymer Photonic Microring Resonators for Biosensing Applications by Nanoimprint Lithography

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*The motivation of our work was to fabricate large areas of polymer microring resonators operating in the very-near infrared region (900 nm) using a new low-cost method, with a minimum number of process steps. Our optimized fabrication method results in the generation of high-quality devices with  $Q$  factors up to  $4 \times 10^4$  and finesses up to  $F \sim 14$ . The developed structures will be further used in biosensing applications. First investigations have been done to evaluate the response of the sensor to a change of the bulk refractive index.*

## Introduction

With the increasing demand for simple, low cost, user friendly and real-time monitoring devices in biosensing technologies, polymer materials have become important in the fabrication of the integrated optical devices. Polymers possess extraordinary properties, with most importantly high optical transmittance, but also an easier fabrication process, flexibility and their potential for low-cost production [1]. Moreover, compared to semiconductor materials, it is possible to tune more easily their refractive index and furthermore different active dopants can be added to the polymeric material to fabricate devices for a wide range of applications. Considering their potential for bio-applications including sensing, their biocompatibility and surface functionalization, polymers play an important and crucial role in the material selection. Moreover they can be easily integrated within microfluidic systems. For the fabrication of polymer devices, different methods have been described in the literature so far. Among them, the conventional UV lithography technique has been extensively used to pattern the polymers. Briefly, by exposing a photoresist to UV light through a mask, waveguides are generated after developing the unexposed areas. However the resolution obtained with this technique is limited by the diffraction of light as well as by scattering and interference. Therefore a big effort was done by researchers in this field to surmount this issue. As a result many novel fabrication techniques including nanoimprint lithography (NIL) have been developed in order to overcome the drawback of the limited resolution. It has been reported that NIL with low-cost equipment can fabricate high-resolution nanopatterns down to sub-25 nm resolution on a large scale. This replication technology is either thermal or UV based and uses a master mold that is pressed onto a polymer previously spun on a substrate. Consequently after the UV or thermal curing and the demolding, the patterns of the mold are imprinted on the desired polymer.

The motivation of our contribution was to fabricate large areas of microring resonators (MRRs) with a very good optical performance operating in the very-near infrared region (around 900 nm). Our optimized fabrication method results in the generation of patterns with a minimum residual layer of 40 nm without an etching step. The bend loss

decreases significantly with decreasing thickness of the residual layer and consequently this increases the Q-factor [2]. Considerable work on polymer optical devices at infrared wavelengths has been reported. However, there is an urgent challenge and demand for the development of polymer photonic based devices operating closer to/ or at visible wavelengths where the absorption of water is about 2000 times lower than in near infrared regions and lower cost light sources are available. In this work, we are exploring the perfluoropolyether-based (PFPE) materials, i.e., Fluorolink MD 700 (Solvay Solexis) for the fabrication of a soft mold on a flexible polystyrene substrate. A simple room temperature UV-imprinting process using the soft and flexible molds was used for the MRRs patterning. Finally preliminary results will be reported on the Ormocore MRRs sensor performance.

## Microrings Fabrication and Characterization

Initially, a negative photoresist (SU8-2 from MicroChemicals) was patterned by photolithography (see Fig. 1(a)). After SU8-2 was spun on fused silica at 5600 rpm for 40 seconds it was exposed using the contact mask aligner Süss MA6 to UV light through a chromium mask. After the development of the resist, in which the unexposed part of SU8-2 was removed, the substrates were hardbaked at 180 °C for 3 minutes in order to decrease the surface roughness. The exposure, the development time, as well as the baking and the flood exposure time have been optimized in order to generate structures with a very good quality. This quality of the master mold, including its surface roughness, is essential in the replication process where all the patterns are imprinted in the desired polymer, including the defects. After the master mold fabrication, the PFPE acrylate composite molds were prepared by thoroughly mixing 3% Irgacure 2022 photoinitiator (BASF) to Fluorolink MD 700 (Solvay Solexis), respectively. Afterwards, these mixtures were cast on top of the SU8 master mold. Polystyrene foils were placed on the top of the soft mold. UV-light was used to cure the PFPE material for 1 min with an intensity of 30 mW/cm<sup>2</sup>. As depicted in Fig. 1(b) peeling off the composite PFPE mold from the SU8-2 master mold completed the soft mold formation. One of the advantages of the proposed method is that there is no need to treat the master mold with an antiadhesive coating.

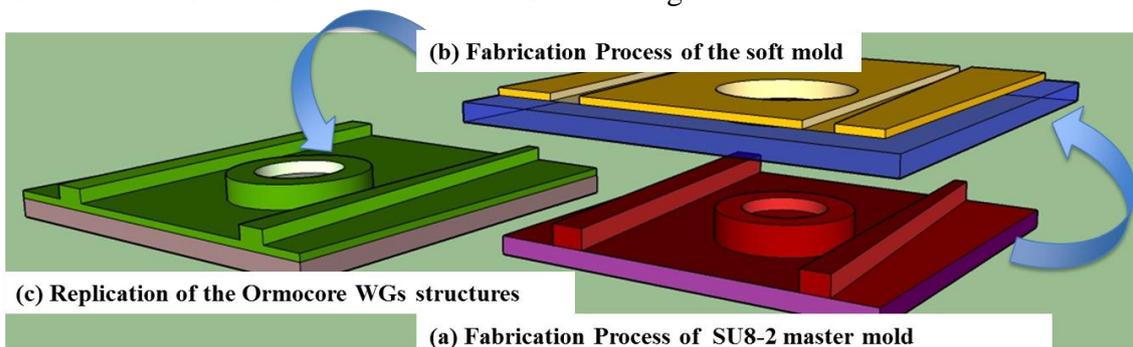


Figure 1: Schematic illustration of the fabrication process of microring resonators. (a) SU8 master mold has been prepared by photolithography. (b) Formation of the soft mold: initially PFPE was casting on the top of master mold; after the UV exposure the soft mould was peeled off from the master mold. (c) Generation of the Ormocore WGs by UV-NPL.

The final imprinting processes started with the preparation of thin Ormocore films on a

SiO<sub>2</sub> insulator on Si substrate. Afterwards, diluted Ormocore (Ormocore: thinner maT, 1:2) was spin-coated at 3000 rpm for 40 seconds. The imprinting was done manually by carefully bringing the PFPE composite molds in contact with the Ormocore films at room temperature.

After fabrication, the polymer MRRs were characterized by using scanning electron microscopy (SEM) and by optical investigation in transmission measurements. Figure 2(a) shows an SEM image of the fabricated structures with only 40 nm residual layer. On the left, in a focused ion beam (FIB) cross section, one sees that the waveguide's width and height are around 1 μm and the gap is 900 nm.

Optical spectra were recorded using a tunable laser as a light source (Newport, with a wavelength range: 890–910 nm and 20 pm resolution) and the output signal was measured with a power meter.

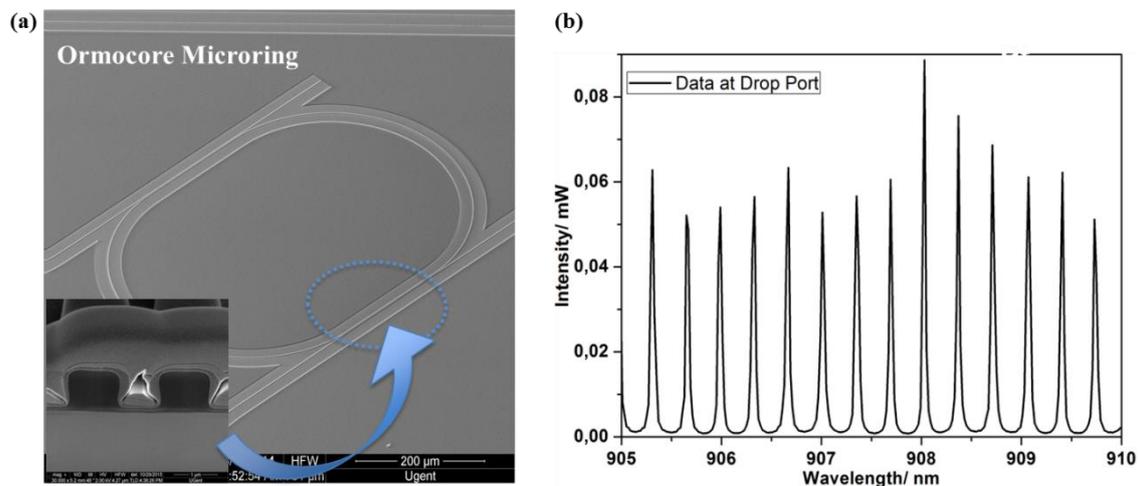


Figure 2: (a) SEM image of the fabricated microring resonator (MR) including a FIB cross-section in the gap region of the imprinted Ormocore MR. (b) The optical transmission spectrum of this structure measured at the drop port.

Figure 2(b) shows the optical transmission spectrum of the MRRs prepared using MD 700 soft molds on the drop port. The MRR has a radius of 180 μm and a coupling length of 190 μm. The calculated  $n_{\text{eff}} = 1.48$  and  $n_g = 1.58$  lead to a FSR of 0.34 nm. A high Q-factor of 39 000 corresponding to a linewidth of 23 pm was observed.

## Sensor Investigation

Before testing the sensor response to a change of the bulk refractive index, the effect of water absorption was investigated. As known, the refractive index and volume of polymers may change due to water absorption.

After the plasma treatment, the samples containing the MRRs were bonded on the Polydimethylsiloxane (PDMS) microfluidic channel using a Flip-Chip Bonder. The PDMS mold is made from an SU-8 50 master mold by cast-method. Prior to bonding the PDMS to the chip, inlet and outlet holes for microfluidic channels were punched in the PDMS using a 0.5 mm coring tool. After bonding the PDMS to the chip, the channels were linked to tygon micro-bore tubing using 21 gauge blunt needles. These tubes were used as the fluidic inlet and outlets and were connected to a syringe. Figure 3(a) shows the microfluidic system used in the measurement. Because the resonance of

the MRRs has high temperature dependence, a home-made temperature stabilized chunk, utilizing the Peltier effect is built and mounted onto the sample stage.

In the beginning when water was introduced in the sensing window, a big shift of the MRRs was triggered by an immediate change of refractive index from air to water. The exact shift could not be defined exactly due to our small FSR of 0.34 nm. Figure 3(b) depicts the sensor response after applying water as a function of time. After 18 minutes a 0.24 nm blue shift of the MRR resonance was detected. The system became stable after 3 hours. It was observed that the Q factor of MRRs decreases significantly to 6000 in air. This is most probably because of the increase in roughness after plasma treatment of the MRRs before bonding to PDMS. Currently another bonding method is tested in order to maintain the high Q factor of the MRRs also after bonding.

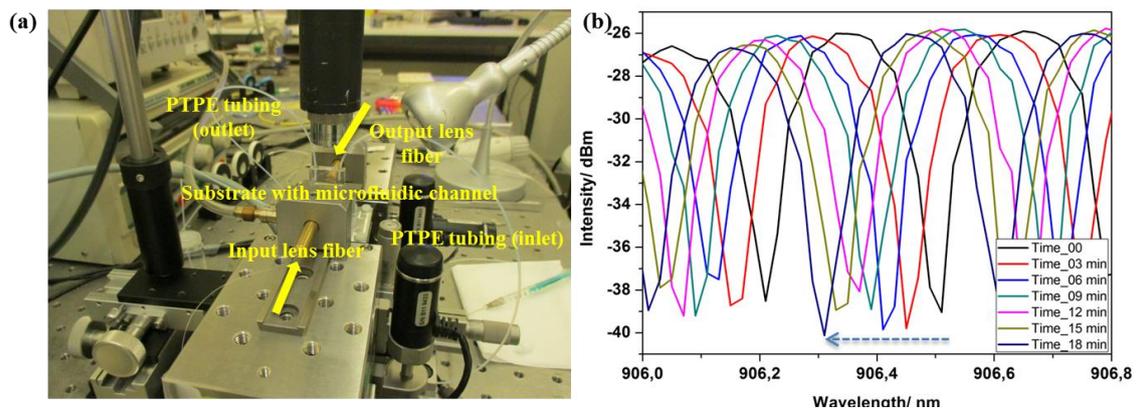


Figure 3: (a) Microfluidic system. The platform includes a PDMS microfluidic channel delivering fluids and the sample with the MRRs. Light from tunable laser sources is coupled into and out of the chip using lensed fibers. (b) Sensor response after applying water to the sensing window.

## Conclusion

In this contribution, we demonstrate a new fabrication process successfully producing large areas of hybrid polymer MRRs with very good optical performance at around 890 nm. In the nanoimprint process flow we take advantage of using PFPE composite molds. These molds provide the benefits of both a hard rigid material for high resolution and a soft flexible material for conformable contact without applying pressure. Finally the first investigation of sensor performance and stability were done. However these studies are still under investigation in order to obtain improved results and evaluate the response against change bulk refractive index using different concentration of glucose solutions.

## References

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