Supplemental Document

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Post-fabrication tuning of microring resonators using 3D-printed microfluidics: supplement

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Post-fabrication Tuning of Micro-ring Resonators Using 3D-printed Microfluidics: Supplemental Document

1. SOI CHIP FABRICATION

The chip that we use is fabricated by applied nanotools. Their silicon patterning process involves the definition of nano-scale features in SOI using electron beam lithography (EBL) and reactive ion etching (RIE) processes. The substrate is a 220 nm silicon device layer with a 2 µm buried oxide layer and 725 µm handle wafer. The patterning process begins by cleaning and spin-coating a material that is sensitive to electron beam exposure. A device pattern is defined into this material using 100 keV EBL. Once the material has been chemically developed, an anisotropic ICP-RIE etching process is performed on the substrate to transfer the pattern into the underlying silicon layer. The etch is performed until there is no remaining silicon and the underlying oxide layer is exposed. After the silicon devices have been deposited, silicon dioxide cladding is deposited using chemical vapour deposition (CVD). The oxide cladding thickness is 2.2 µm. They then do a Selective etching of the cladding oxide over silicon features to create windows in the oxide where the silicon devices are exposed to ambient conditions. The window is 175 µm x 210 µm. The waveguide is single modal. The waveguides are 500 nm wide x 220 nm thick.

2. EXPERIMENTAL SETUP

The experiemtnal setup is shown in the diagram in Fig. S1.

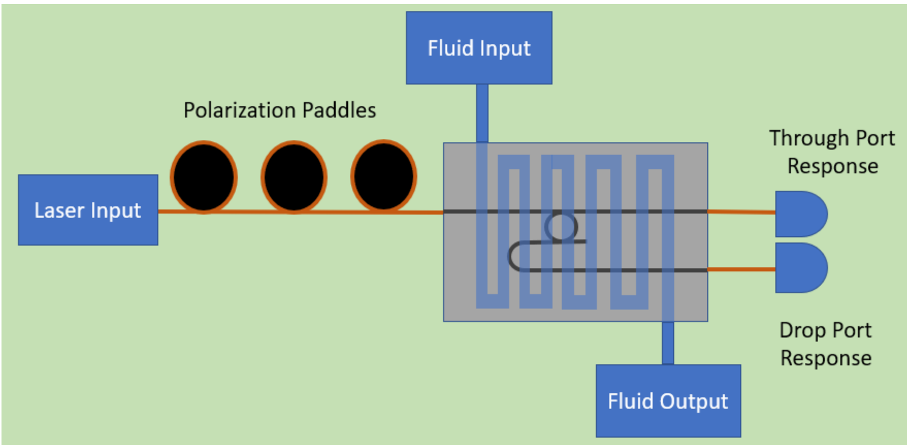

Fig. S1. The experimental setup used. The polarization of the light is adjusted using paddles. Light is then coupled to the SOI chip. We then measure both the through-port and drop-port response of the microring resonator. The NaCl solutions pass through the chip and when we change to a different solution, it is deposited in a final reservoir.

3. 3D PRINTING MICROFLUIDICS

To fabricate the 3D-printed microfluidic overlay, which has challenging dimensions including microgaskets that are 6 µm thick and facilitate a leak-free seal with the silicon chip, we used a custom digital light processor stereolithographic (DLP-SLA) printer with a 385 nm LED light source, a pixel pitch of 7.6 µm in the plane of the projected image, and capable of depositing layers that are 3 µm thick [1]. The resin consists of poly(ethylene glycol) diacrylate (PEGDA, MW 250) as a monomer, 1% (w/w) phenylbis(2,4,6- trimethylbenzoyl)phosphine oxide (Irgacure 819) as the photoinitiator, and 2% (w/w) 2-nitrophenyl phenyl sulfide (NPS) as the UV absorber. We used 1 mm thick, 25 mm square silanized glass slides as 3D printing substrates. The glass slides were first cleaned with acetone and isopropyl alcohol (IPA). Next, slides were immersed in a solution made of 10% 3- (trimethoxysilyl)propyl methacrylate and 90% toluene for 2 hours to facilitate better attachment of the 3D printed device to the substrate. After silane deposition, the glass slides were stored in fresh toluene in a closed container until use. The 3D printed microfluidic overlay chip was fabricated with a layer thickness of 10 µm. Each layer was printed with an exposure setting of 550 ms. This fabrication process takes 10 minutes to create the microfluidic overlay. The overlay is then cured with UV light for 20 minutes. The open channels of the 3D printed microfluidic overlay are clamped down onto the waveguide so that fluid is able to pass through the channels and make direct contact with the exposed ring resonators. The overlay is printed with micro-gaskets around the microfluidic channels that allow for a better seal between the microfluidic channels and the SOI chip [2].

4. SIMULATING TE AND TM MODES

Fig. 6 in the paper shows the simulated power at the drop port as a function of NaCl concentration for microring resonators of various radii using the TE modes. Fig S2 shows these same simulations but with the TM modes. In this simulation the values for r_1 and r_2 come from the S-parameters that were simulated using Lumerical MODE, they both have a value of 0.966. The loss factor a is 0.945. The value ϕ_{rt} is given by $\phi_{\mathrm{rt}} = kL$ where L is the length around the resonator and k is the wave vector, which is defined by $k = n_{eff}\frac{2\pi}{\lambda}$. The effective indices were found using an Finite Difference Eigenmode (FDE) solver. The results of these simulations are shown in Fig S3. Even though the TM modes are more sensitive, we chose to use the TE modes in our experiments instead of the TM modes because we had very high loss using edge coupling and since the percentage of light in the TM mode is significantly lower than that of the TE mode we could not detect the TM modes.

REFERENCES

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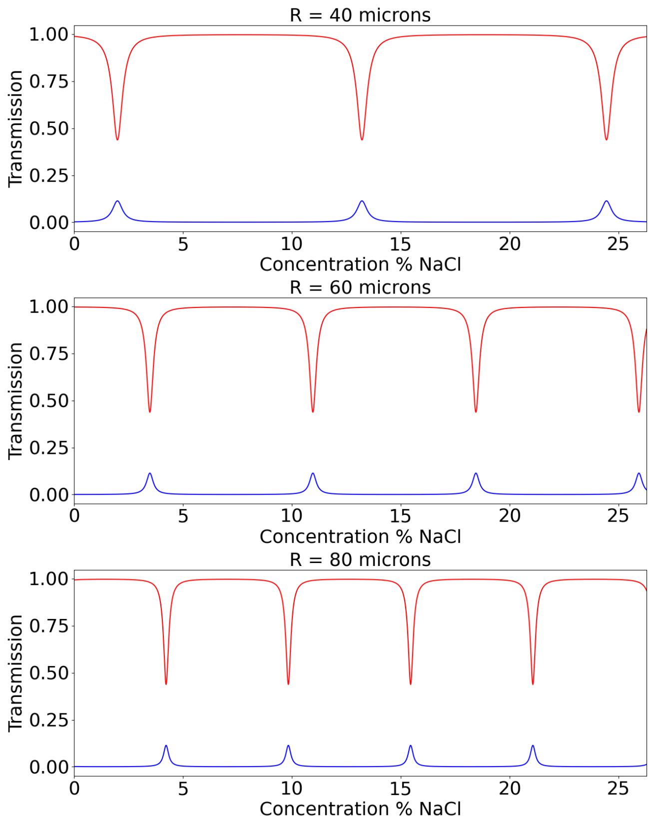

Fig. S2. Transmitted power through the drop port (Blue) and through port (Red) of ring resonators of different radii as a function of NaCl concentration at a wavelength of 1580 nm. This plot was simulated using the TM modes. Even though we never ran any experiments using the TM modes. This plot has been added for completeness

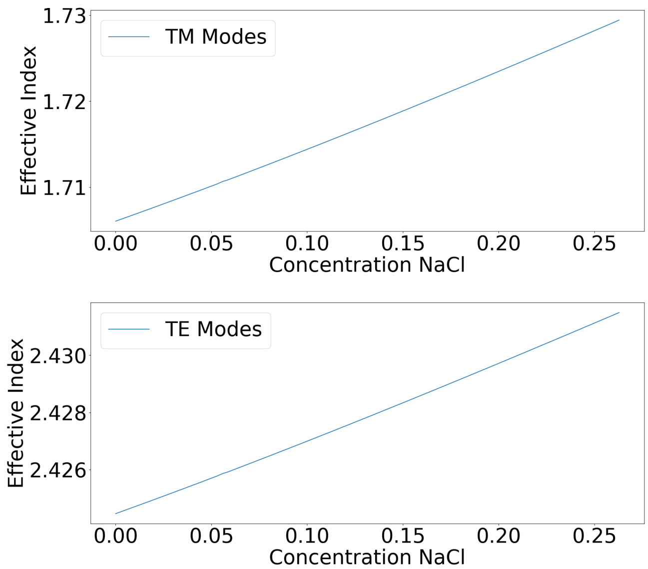

Fig. S3. The effective index of a silicon waveguide with a NaCl solution cladding as a function of the concentration of the NaCl solution. The top graph shows the TM modes and the bottom graph shows the TE modes.