High-Q Al_2O_3 Microring Resonator for Sensing Applications

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Waveguide based microring resonators (MRRs) are particularly suitable for on-chip integrated optical sensors. Their spectra contain resonance notches that shift due to the probing of the evanescent modal field of local dielectric variations. Sensors based on this shift have already been reported in the Si, Si_3N_4 and SiON technologies [1—3]. The Al_2O_3 technology has the prospect of very high quality (Q) factors due to its low propagation loss [4]. Furthermore, doping it with rare-earth ions enables the realization of on-chip laser based sensors for ease of detection [4]. Here, a high Q Al_2O_3 waveguide MRR sensor is presented as alternative to the traditional MRR technologies with the prospect of developing lasing-based Al_2O_3 MRR sensors.

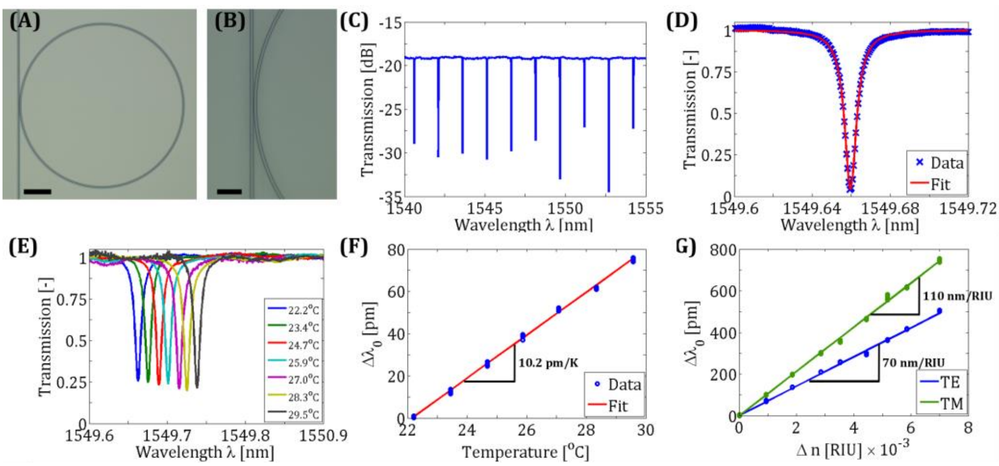

Fig. 1. (A), Optical microscope image of the MRR. Scale bar is 50 µm. (B), Close up of the MRR. Scale bar is 20 µm. (C), Transmission spectrum of the MRR. (D), Resonance with fit. (E), Spectral shift of resonance notch due to stage temperature. (F), Slope sensitivity of temperature sensing. (G), Slope sensitivity of refractive index sensing.

Geometrical parameters of the Al_2O_3 MRR were designed and then transferred to fabricated devices. The design was based on finite difference calculations of the modal field profiles of the bus and ring waveguides. For operation at 1550 nm optimized geometrical parameters are a radius of 150 µm, a coupling gap of 0.8 µm and a waveguide width and height of 2.4 µm and 0.7 µm respectively. The fabrication starts with the sputter deposition of Al_2O_3 onto a thermally oxidized (8 µm) silicon wafer. The waveguides are then defined by UV-lithography and reactive ion etching. A shadow mask is then used to locally deposit a PECVD-SiO_2 everywhere apart from the MRRs, leaving them exposed to the environment. The MRR is shown in Figures 1 A and B.

The MRR sensor was characterized by transmission measurements with a tunable laser in the C-band. Figure 1 C shows a typical spectrum containing the resonance notches. By fitting these resonances with a Lorentzian function their resonance wavelength λ_0 and Q factor can be determined. In the case of TE-polarized light a Q of 2.1e5 is obtained in the C-band. This corresponds with a finesse F=204 and a propagation loss α=0.9 dB/cm. By varying the temperature of the stage, a shift of the resonance wavelength is induced, as shown in Figure 1 E. For the case of variations in the stage temperature, T, a slope sensitivity of S_T=10.2 pm/K was achieved for TE-polarized light, as shown in Figure 1 F. With a standard deviation in the determination of λ_0 of 0.5 pm this corresponds to a limit of detection LOD= 0.15 K.

The transmission experiment was repeated by immersing the MRR in a water droplet. Higher propagation losses are now obtained due to the combined effect of absorption of light by the H_2O cladding together with a higher coupling loss due to the reduced refractive index contrast of the MRR and the cladding, both resulting in a reduced Q. For TE-polarized light the Q drops down to 51e3, corresponding with a F=50 and α=4.5 dB/cm. For TM-polarized the effect is even more dramatic due to the mode being less confined in the waveguide and results in a Q=33e3, F=32 and α=7.7 dB/cm. By dissolving NaCl in water the refractive index of the solution changes by 0.0018 RIU/%wt of NaCl, resulting in a resonance wavelength shift. Solutions were prepared with NaCl weight variations up to 4%, corresponding with a water refractive index variation of 0.007 RIU. The solutions were then placed on top of the MRR while monitoring λ_0 for both TE- and TM-polarization. Figure 1 G shows the slope sensitivity S_n for a variation of bulk cladding refractive index n. For TE-polarized light S_n=70 nm/RIU and for TM-polarized light S_n=110 nm/RIU. With a standard deviation in the determination of λ_0 of 0.5 pm this corresponds to a LOD of 2.2e-5 RIU and 1.4e-5 for TE and TM-polarized light respectively.

In conclusion, a high Q Al_2O_3 MRR bulk refractive index and temperature sensor was presented with S_n=110 nm/RIU together with a LOD=1.4e-5 for TM-polarized light.

References

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