Double Slot Micro Ring Resonators with Inner Wall Angular Gratings as Ultra Highly Sensitive Biochemical Sensors

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***Abstract*—An ultra-compact double slot micro ring resonator with inner wall angular gratings is simulated and fabricated. This structure boosts the sensitivity to 749.033 nm/RIU with a Limit of Detection value of 8.010×10^{-5} RIU and a large measurement range of 72.62 nm.**

Keywords—Micro ring resonator, inner wall angular grating, high sensitive, biochemical sensor

I. INTRODUCTION

Label-free optical sensors on silicon-on-insulator (SOI) platforms have been widely investigated for applications such as medical diagnostics, food security, and environmental monitoring due to their compatibility with well-established complementary metal-oxide-semiconductor (CMOS) manufacturing technology. Many optical sensing structures based on the SOI platform such as Mach–Zehnder interferometer sensors [1], surface plasmon sensors [2], and microring/microdisk resonator sensors [3] have been widely studied. Microring resonator (MRR) structures provide the equivalent of a long light-matter interaction distance, therefore offering a combination of high sensitivity and ultra-small footprint. The slot microring resonator (SMRR) structure can enhance the light–analyte interaction and provide much higher sensitivity than traditional strip waveguide MRR sensors [4]. Also, some schemes, such as serially coupled double MRRs, grating-coupled silicon MRRs [5], and angular grating MRRs [6] have been investigated to expand the free spectral range (FSR) and enlarge the detection range. In this paper, a compact optical label-free sensor based on an inner wall grating double slot MRR (IG-DSMRR) is simulated and fabricated offering an ultra-large detection range and ultra-high sensitivity at the same time. The sensor utilizes an all-pass filter SMRR and inner wall gratings based on the SOI platform. Lumerical FDTD solutions are utilized to simulate and optimize the structural parameters to enhance the sensing performance of the device. Taking D-glucose solution as the top cladding medium, the sensing characteristics of the optical label-free sensor are demonstrated. The measured sensitivity can reach 749.033 nm/RIU with a Limit of Detection (LOD) value of 8.010×10^{-5} RIU and a large measurement range of 72.62 nm. This is the highest sensitivity reported so far for SOI-based MRR sensors.

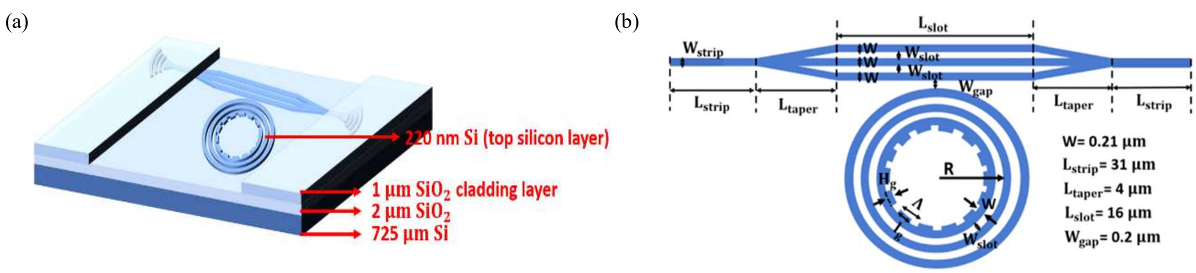

Fig. 1. (a) Schematic structure of the IG-DSMRR, (b) Detailed design parameters of the IG-DSMRR structure.

II. DEVICE STRUCTURE AND FABRICATION

The three-dimensional structure of the device and the SOI epilayer are illustrated in Fig. 1(a) and the detailed design parameters of the IG-DSMRR are shown in Fig. 1(b). The designed radius R of IG-DSMRR is 6.68 μm, the azimuthal period Λ and duty cycle of the inner wall gratings are 1.199 μm and 96% respectively, and the corrugation depth of the grating H_g is 24 nm. Also, the vertical grating coupler was optimized to give a maximum coupling efficiency of 41% to a single mode fibre (SMF) at 1555 nm and the designed grating period and duty cycle are 671.39 nm and 39.92% respectively. An optimized "W" shaped branch tapered coupler structure was used to couple the light between the strip waveguide and slot waveguide. The IG-DSMRR waveguide parts were fabricated using Hydrogen Silsesquioxane (HSQ) photoresist, e-beam lithography (EBL), and a SF_6/C_4F_8 dry etching recipe. The input and output grating couplers with a 110 nm groove height were created using PMMA resist, EBL, and SF_6/C_4F_8 dry etch gas mixture, then, the 1 μm thick top cladding layer of SiO_2 was deposited by PECVD. Finally, dry etching was used to remove the 1 μm thick SiO_2 layer on the top of the ring resonator area for sensing applications.

III. DEVICE PERFORMANCES

A scanning electron microscope (SEM) picture of the fabricated IG-DSMRR device is shown in Fig. 2(a) and a zoomed SEM picture of the slots and the rings is shown in Fig. 2(b), where the inner wall gratings are clearly seen. An SEM picture of the grating coupler is shown in Fig. 2(c). The period and the duty cycle of the fabricated grating coupler are 673.72 nm and 39.76% respectively, which are close to the designed values. The measurement setup is shown in Fig. 2(d), with the super luminescent diode (SLD) as a light source, an optical spectrum analyzer (OSA, 0.06 nm resolution) for measuring the transmission spectrum, and the two SMFs to connect the SLD with the input grating coupler, and output grating coupler with the OSA, respectively. A comparison of the simulated and experiment transmission spectra for water cover medium is shown in Fig. 2(e), where a large measurement range (Quasi-FSR=72.62 nm) could be achieved, >3× FSR of the MRR (23.74 nm) with the same structure but without the inner gratings. The wavelength difference between the simulated (1543 nm) and measured (1534 nm) transmission spectra may be because the grating height of the fabricated inner wall is around 210 nm, less than the 220 nm design value. Also, the simulated and measured wavelength shifts of the transmission spectrum with different concentrations of glucose solutions at 20 ˚C room temperature are shown in Fig. 2(f) and Fig. 2(g) respectively. The simulated and measured wavelength shifts versus different reflective indexes (corresponding to different concentrations of glucose) are shown in Fig. 2(h), where the simulated sensitivity was as good as 559.345 nm/RIU and the corresponding experimental sensitivity was 749.033 nm/RIU with a LOD value of 8.010×10^{-5} RIU. The relatively higher sensitivity for the experimental results may be due to the resolution limit of OSA.

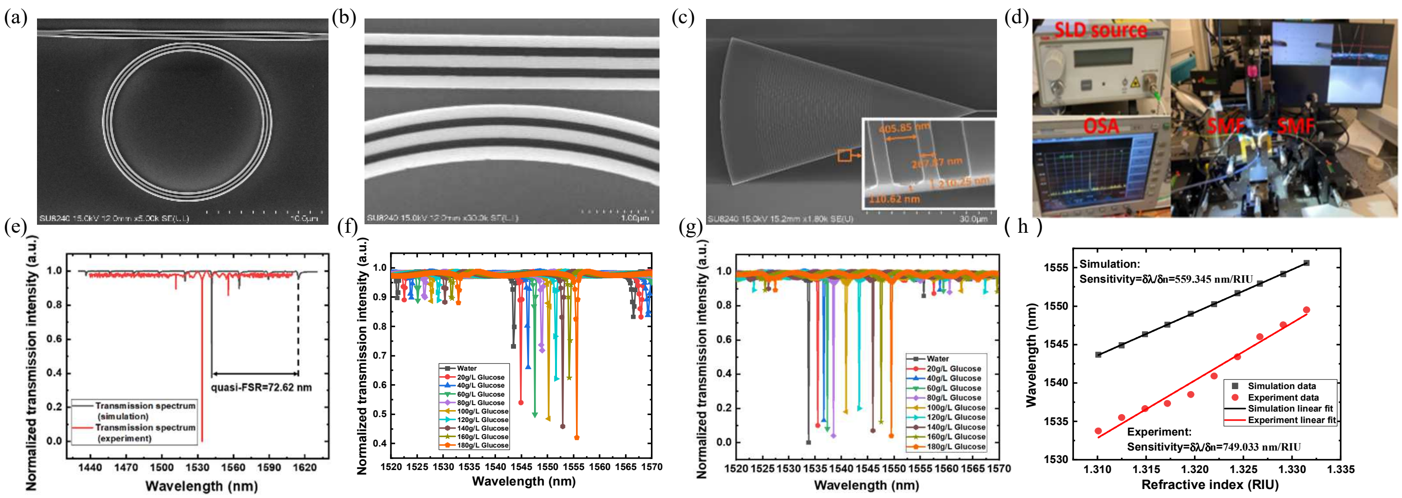

Fig. 2. (a)-(b) SEM images of the fabricated IG-DSMRR device, (c) SEM image of the fabricated grating coupler, (d) Measurement setup, (e) Transmission spectrum of simulated and fabricated IG-DSMRR for water cover medium, (f) Simulated and measured (g) transmission wavelength shifts with different concentration of glucose solution, (h) Sensitivity comparison of simulation and measurement of the IG-DSMRR device.

IV. CONCLUSION

In summary, a double slot micro ring resonator with inner wall angular gratings is modelled, fabricated, and measured. The experimental sensitivity can reach 749.033 nm/RIU with a LOD value of 8.010×10^{-5} RIU and an ultrawide quasi-FSR of 72.62 nm.

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