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Proceeding Paper

Photonic Biosensor for Label-Free Detection Based on Photonic Nanostructures on Si-Waveguide Ring Resonator †

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Abstract: A new structure of a micro-ring resonator for label-free biosensing is proposed. The structure includes sidewall-grating Si waveguide and periodical side-blocks that can enhance the light–matter interaction. From the electromagnetic simulations, the proposed structure exhibits a four-fold improvement in terms of sensitivity compared with the conventional structure. Moreover, the quality factor of the proposed structure is not degraded from that of the conventional structure. The improved sensitivity is promising for the detection of nanoparticles that can be applied to the environmental field and clinical diagnostics.

Keywords: ring resonator; photonic biosensor; Bragg grating

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1. Introduction

Silicon photonic biosensors are promising label-free biosensors due to the possibility of all-in-one-chip detection and low-cost fabrication [1,2]. The light confined within silicon waveguides of a photonic biosensor allows optical spectral responses to sense the biomolecules on the surface of waveguides.

Silicon based micro-ring resonator biosensors utilize resonant structures to detect the concentration of biomolecules. The waveguide effective index of the micro-ring resonator biosensor changes depending on the change in the refractive index (RI) of the materials surrounding the surface of the micro-ring resonator due to an interaction of biomolecules and an evanescent field, formed by an electric field travelling outside the waveguide. The effective index change (Δn_{eff}) can be defined by monitoring the resonant wavelength shifts ($\Delta\lambda$);

$$\Delta\lambda = \frac{\Delta n_{\text{eff}}\lambda_0}{n_{\text{g}}} \quad (1)$$

where λ_0 is the resonance wavelength and n_{g} is the group index in the Si waveguide. Nevertheless, the sensitivity, defined by the change in resonance wavelength per refractive index unit, has still been a research issue for detecting small refractive index changes. In a conventional structure for the waveguide of the micro-ring, most of the light is confined within the core of the silicon waveguide. This limits the interaction of the electric field and biomolecules. A structure of subwavelength waveguides could increase the sensitivity by modification of the effective sensing region [3]. In this report, we propose a unique structure for a micro-ring resonator that can improve the sensitivity by enhancing the sensing surface.

2. Results

We propose a Bragg grating micro-ring structure with a combination of the sidewall grating waveguide and periodical side-blocks as shown in Figure 1. The micro-ring has a radius of 7 μm and a width of 500 nm. In this structure, the waveguide with a sidewall corrugation structure defines regions where Si waveguide width becomes thinned (w_w = 200 nm). In addition, a pair of Si blocks is placed on both sides in the thinned waveguide region. The angle of the grating period (Λ) is 5 degrees and the number of the pair of side-blocks is 72. The angle of a couple of side-blocks (ΔΛ) is 2 degrees. The radii of the outer and inner blocks are defined by distance from the center point of the micro-ring to the center lines of the outer side-block and inner side-block, respectively. The distance from the center of the waveguide to the center of the outer block and inner block (Δr) is 150 nm. The total sidewall area of the proposed structure is 1.5 times larger than that of the conventional structure with the same ring radius and waveguide width.

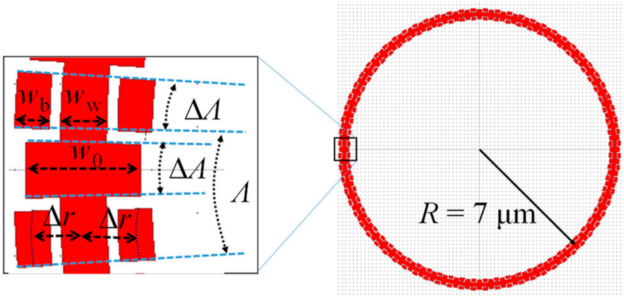

Figure 1. Design of the proposed Bragg grating structure for a micro-ring. Δr = 150 nm, w_b = 150 nm, w_w = 200 nm, w_0 = 500 nm, Λ = 5 degree, ΔΛ = 2 degree.

2.1. Characteristics of Micro-Ring Resonator

The 3D model of the structure of a Si micro-ring resonator is composed of three layers, which are a background layer of SiO_2 (n = 1.44), Si (n = 3.47), and a cladding layer (n_{clad}). The thickness of the Si waveguide was 220 nm. By the calculation of an electromagnetic field using the finite element method (FEM), the electric field of the proposed structure is in the region of 200-nm-width waveguide and congregates in the gap between the waveguide and side-blocks [4], as presented in Figure 2 (n_{clad} = 1.0). These results indicate that the use of the proposed structure enhances the sensing surface, which enables it to achieve a higher sensitivity.

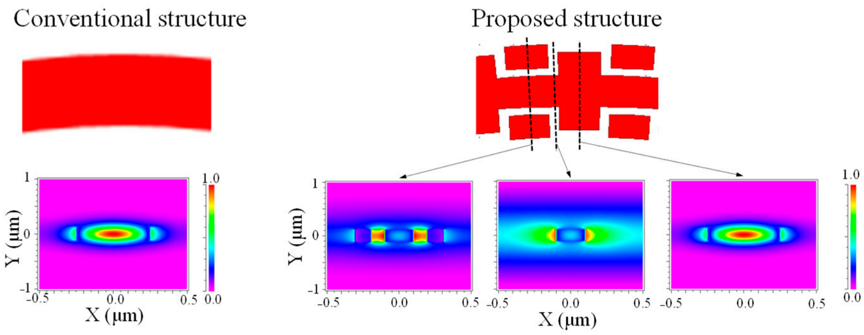

Figure 2. Electric field intensity distribution E_x of the conventional structure and the proposed structure.

Simulated sensitivities and quality factor were used to evaluate the effect of the proposed Bragg grating on the biomolecule sensing. These factors were calculated from the spectral responses to a wavelength of 1550 nm using the 3D finite difference time-domain (FDTD) method by FullWAVE (Rsoft). Sensitivity was calculated from the resonance wavelength shifts per refractive index change. Figure 3 shows the calculated results of the sensitivity and quality factor of different structures. The sensitivity of the proposed Bragg grating structure was 105.2 nm/RIU, which is 4 times larger than the sensitivity of the conventional structure. This might be the result of the increase of the sidewall field and high light confinement in the gaps between side-blocks and the waveguide. The quality factor of the proposed structure did not change significantly with the quality factor of the conventional structure. Furthermore, a degraded quality factor, caused by the absence of side blocks in the Bragg grating II structure, indicated the effect of side blocks on quality factor performance.

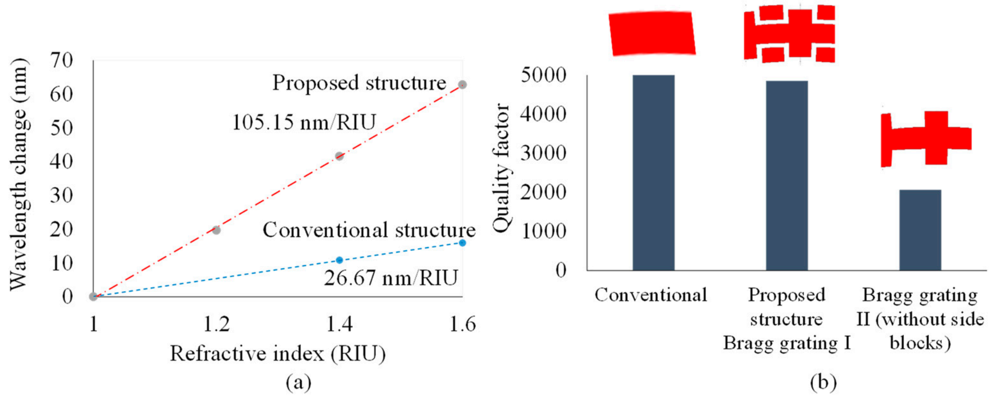

Figure 3. (**a**) Resonance wavelength changes due to different refractive index of the top cladding layer of the proposed structure and conventional structure. (**b**) Quality factor of three different structures of the conventional structure, the proposed structure (Bragg grating I), and Bragg grating II (without side blocks).

2.2. Ring Resonator with Bus Waveguide

After the characteristics of the micro-ring resonator were clarified, bus waveguides were designed next to the micro-ring resonators for the light coupling from the light source as depicted in Figure 4a. Here, the gap between the bus waveguide and the micro-ring was 200 nm. Figure 4b shows the magnetic field distribution H_y when the input light was 1550-nm wavelength CW light. Hence, almost the entire field was propagating the output waveguide.

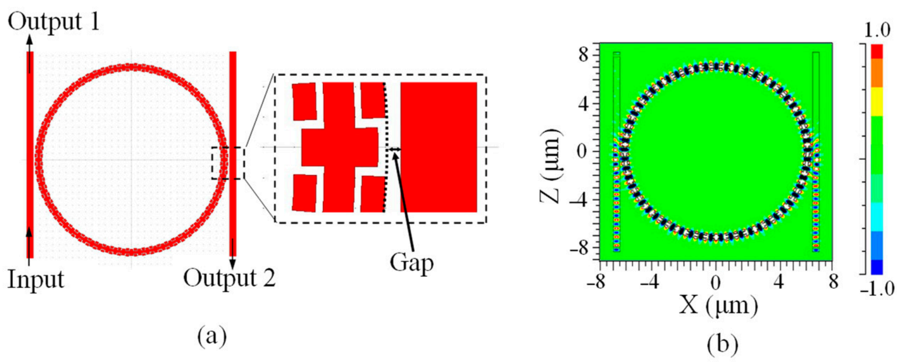

Figure 4. (**a**) Structure of proposed micro-ring resonator biosensor. (**b**) Magnetic field distribution H_y.

3. Conclusions

We proposed a Bragg grating micro-ring structure for a photonic biosensor. The simulated results of the micro-ring resonator with Bragg grating structure and nanostructures of side-blocks showed a four-fold improvement on the sensitivity compared to the conventional structure, while the quality factor did not change. The improved sensitivity is promising for label-free detection of nanoparticles in applications involving environmental monitoring or clinical diagnostics. Furthermore, the device fabrication and experimental demonstration will be reported in the future.

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Conflicts of Interest: The authors declare no conflict of interest.

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