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Si Ring Optical Resonators for Integrated On-Chip Biosensing

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1. Introduction

Recently, optical micro-ring resonators have attracted much attention to sense biochemical materials [1, 2]. We are aiming to develop biosensors which are integrated on silicon chips. The Si micro-ring resonator is suitable for this application, because of its small size, and compatibility to silicon process. The feature of our study is employing Silicon Binding Protein (SBP) as the binder between antibodies and SiO_2 (Fig. 1). The SBP provide antibodies which orient in the same direction [3], resulting in high sensitivity to detection of antigens.

In this study, we have made Si micro-ring resonators, and evaluated their sensing capability for concentration of sucrose solution. And also the suitable wavelength and evaluation method for on-chip assay are discussed.

2. Experimental

The fabricated ring resonator on silicon-on-insulator (SOI) wafer is shown in Fig. 2. Resonance wavelength λ_{res} of the ring resonator with circumference l is given by

$$\lambda_{res} = n_{eq} l / m, \quad (1)$$

where n_{eq} is an equivalent index of the waveguide and m is an arbitrary integer. The Si micro-ring was fabricated using electron beam lithography and reactive ion etching. And a fluidic channel made of polydimethylsiloxane (PDMS) is attached to the wafer (see Fig. 3).

Measurement system for the ring resonator is shown in Fig. 4. To inject sucrose solution to the sample, we used syringes, and the flexible tube is connected to the PDMS fluidic channel. Wavelength dependence of the output signals of the ring resonator was measured by using tunable semiconductor laser and IR vidicon camera.

The resonance characteristics were also analyzed using two dimensional Finite Difference Time Domain (FDTD) method, and compared with the experimental results.

3. Results and Discussion

The shift of resonance wavelength $\Delta\lambda_{res}$ when ambient refractive index is changed is given by

$$\Delta\lambda_{res} = \lambda_{res} \Delta n_{eq} / n_{eq}, \quad (2)$$

from eq. (1), where Δn_{eq} is change in equivalent refractive index of the waveguide.

3.1 Resonance characteristics versus sucrose solution concentration

Figure 5 shows the wavelength dependence of the ring resonator output in purified water. Many resonance peaks are clearly observed. We have measured drop port output around the resonance wavelength with various sucrose solution concentrations as shown in Fig. 6. The resonance wavelength shifts were observed along with sucrose solution concentration. From Fig. 6, we have obtained 36.5 nm/refractive index unit (RIU) as a sensitivity of this ring resonator. We have compared the measured wavelength shift with the simulated one (see Fig. 7), which indicates good agreement. However, in the small sucrose concentration, the wavelength shift is very small.

In order to improve the detection sensitivity, the measurement wavelength was fixed at the sharpest point (λ = 1507.6 nm) in the resonance curve with purified water, and the output intensity versus sucrose concentration was measured. The result is shown in Fig. 8. The 1% sucrose solution can be clearly detected. In this method, the reproducibility of the measurement system restricts the detection resolution, and it is roughly estimated 0.15%.

3.2 Suitable measurement wavelength and required qualify-factor of resonator

We have investigated optimum wavelength for biosensor. In the wavelength region near 1500 nm, it could be difficult to detect the refractive-index change around the ring because the water absorbs the light at this wavelength. Figure 9 shows the simulated sensitivity of the resonator for various wavelengths. Si absorption and water absorption were also shown in Fig. 9. It is shown that the wavelength of 1300 nm is the best because both silicon and water absorption are low. The quality-factor (Q-factor) is calculated to be 2.5×10^5 at 1300 nm. Figure 10 shows the calculated behaviors of the intensity modulation for various Q-factors. The Q-factor of 2.5×10^5 can detect 0.01% sucrose solution. This is enough to apply biosensing.

4. Conclusions

We have developed ring resonator biosensors which detect 0.15% sucrose solution at wavelength of 1500 nm. Furthermore at wavelength of 1300 nm, it is estimated that the sensitivity will be improved more than one order of magnitude, which is better than the other report (0.05%) [1].

Acknowledgments

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References

[1] K. De Vos *et al*., Opt. Express. **15** (2007) 7610.
[2] A. Ramachandram *et al*., Biosens. Bioelectron. **23** (2008) 939.
[3] A. Kuroda *et al*.: Japan Patent 2006-005061 (2006).

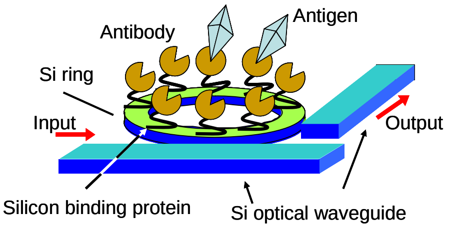

Fig. 1. Structure of a biosensor using micro-ring resonator with silicon binding protein.

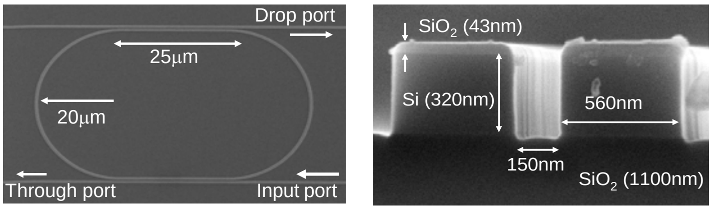

Fig. 2. SEM photograph of the fabricated ring resonator.

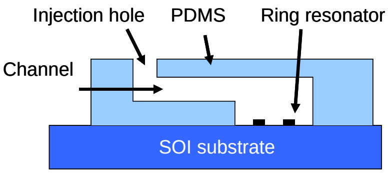

Fig. 3. Schematic structure of the fluidic channel using PDMS attached to the wafer.

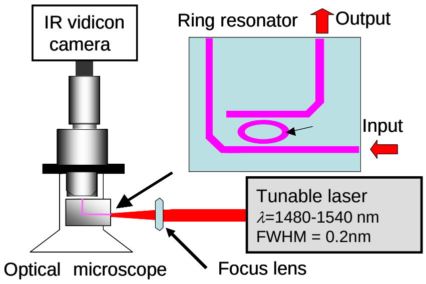

Fig. 4. Optical measurement system for characterization of ring resonator.

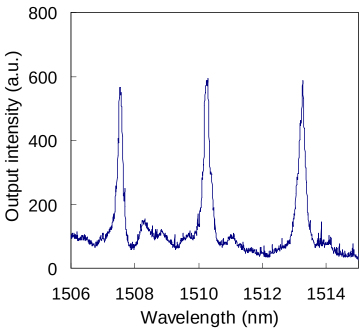

Fig. 5. Resonation characteristics of the fabricated ring resonator in purified water (through port).

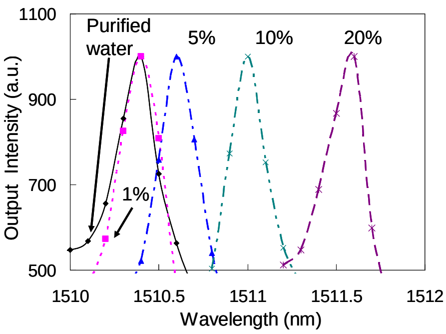

Fig. 6. Output of through port of the fabricated ring resonator. The resonation wavelength shifts were observed depending on the concentration of sucrose solution.

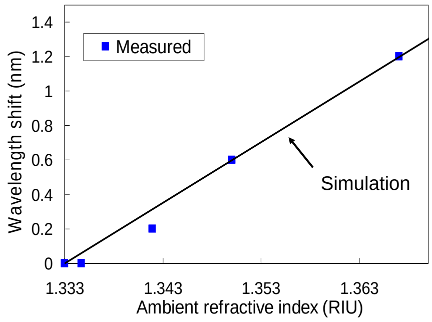

Fig. 7. Comparison between simulated and measured shifts of the resonation wavelength.

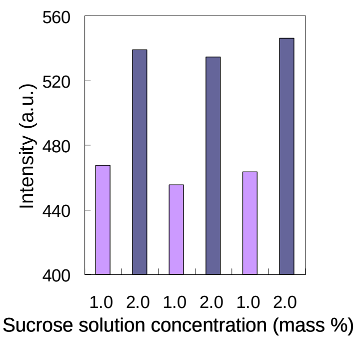

Fig. 8. Intensity modulation of output port at fixed wavelength (λ=1507.6 nm). 1% and 2% sucrose solution were injected alternately.

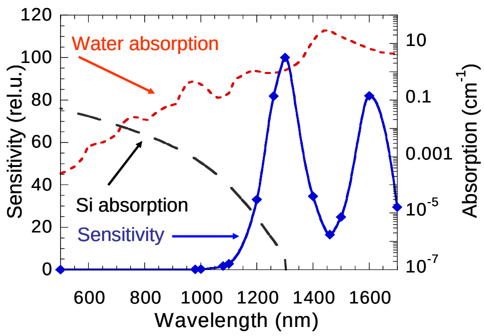

Fig. 9. Wavelength dependence of the sensitivity of the ring resonator, which is defined as the rate of the output change with respect to the refraction-index change of the circumstance. Also shown are the wavelength dependence of absorption of water and silicon.

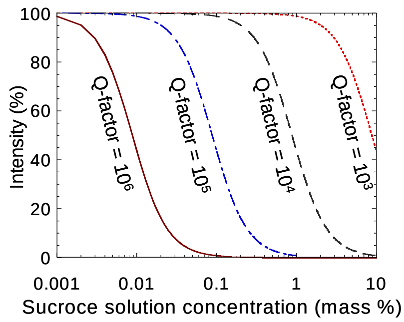

Fig. 10. Calculated intensity modulation for various Q-factors according to sucrose concentration. At least the Q-factor should be 10^5 for biosensing.