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High Sensitive Biosensor using Si Photonic Crystal Cavity Resonators

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Abstract

We report the fabrication and characterization of a 2D silicon photonic crystal (PhC) biosensor consisting of a cavity/defect type resonator and waveguides for enhancing the interactions between light and matter. Sensitivity was measured using sucrose solution and has shown highest sensitivity 1785nm/RIU (Refractive Index Unit) ever reported. We also investigated how cavity size effects on resonance wavelength shift, where we observed that large cavity exhibits more resonance wavelength shift.

1. Introduction

Early detection of biomaterials is very important for many applications in medical diagnostics. The mostly used two basic sensing methods are: fluorescent based sensing and label free based sensing. In the fluorescent sensing method, target molecules are labeled by fluorescence and finally the fluorescence intensity is used to represent the existence of biomolecules [1]. On the other hand the, label free detection method in which biomaterials are unlabeled and detection is done in their natural forms [2,3]. In the cavity type photonic crystal (PhC) resonator, light are confined in the cavity which makes the device extremely sensitive to a small refractive index change produced by biomolecules in the cavity. We investigated two types of structure: cavity type and defect type. Cavity type is formed by increasing the diameter of center hole. On the other hand defect type is the missing of one hole. The presence of biomaterial inside the center hole or in the defect region causes a local refractive index change, which can be monitored as the spectral shift of resonant wavelength. A schematic illustrating an example of cavity and point defect type photonic crystal resonator is given in Fig. 1 (a) and 1 (b). Fabricated device performance is listed in table I.

2. Principle of PhC Cavity Biosensor

The working principle of cavity type PhC biosensor is shown in Fig. 2, its principle is explained by the following equation:

$$\lambda_{res} = n_{eff}\left(\frac{L}{m}\right)$$

where, λ_{res} is the resonance wavelength, n_{eff}, is the effictve index, L is the cavity length and m is integer. When biomaterial is adsorbed in cavity as well as surroundings PhC holes also, then the effective index changes. As a results resonance wavelength shift occurs.

3. Simulation and Experiment

A numerical analysis based on the finite difference time domain (FDTD) method has been used to investigate the refractive index dependence of resonant wavelength shift. The simulations have been performed in water and sucrose environment by changing the radius of the holes and the periodicity as well as changing the radius of the center cavity aiming to obtain sharp resonance characteristics. Once the geometrical parameters were defined, the proposed device was fabricated using silicon-on-insulator wafer with the SiO_2-hardmask. Patterns of waveguides and photonic crystal as well as resonators were made by electron beam lithography (EB), reactive ion etching (RIE) of hard-mask with CF_4 and inductive couple plasma (ICP) etching of Si with Cl_2 gas. Measurements were carried out using an infrared tunable semiconductor laser (1280~1320 nm) and an InGaAs photodetector. The fabrication steps are shown in Fig. 4.

4. Results and Discussion

In this work, we studied both cavity and defect type resonators for biosensor. A comparison between two EB machines (Hitachi, HL-700:variable shape beam and Elionix, ELS-G100:point beam) is shown in Fig. 5 (a) and (b), where scattering of hole size are taken into account. Scanning electron micrograph image of fabricated device is shown in Figs. 6 (a) and (b). Figure 3 is showing the simulation results by varying the cavity diameter. In the cavity type structure light is confine in the cavity and light-biomolecule interaction more strongly occurs. When the cavity is large and connected with surroundings holes, the wavelength shift is much larger than normal cavity type. However, in the defect type structure only the evanescent light in the resonator region interacts with biomolecules then the resonant wavelength shift is very small. The sensing ability of both structures has been measured using sucrose solution at different concentration. The experimental results are shown in Figs. 7 (a) and (b). The resonance wavelength has shifted linearly with changing the sucrose concentration and device has shown very high sensitivity of 1785 nm/RIU. Sucrose concentration of 0.01% corresponds to prostate specific antigen (PSA) of 1ng/ml [4] which is in the practical sensitivity level.

5. Conclusion

In conclusion, we have fabricated 2D PhC cavity and single defect based biosensors of hexagonal lattice structure. We confirmed 8 times highest sensitivity in the cavity type structure than defect type.

References

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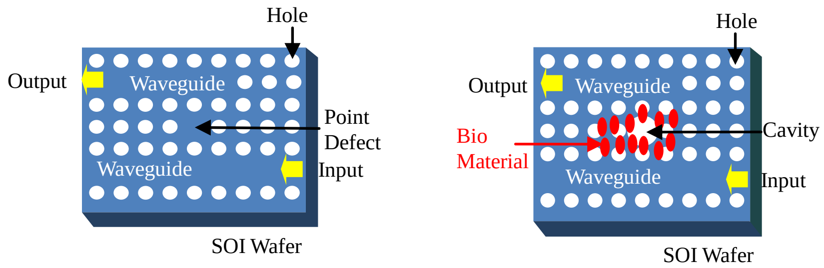


(a) (b)

Fig. 1 Schematic structure of the proposed photonic crystal based biosensor (a) defect type and (b) cavity type.

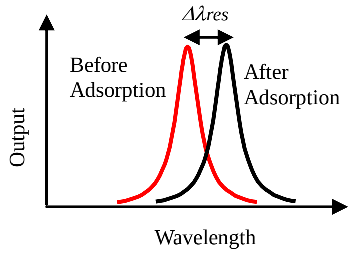


Fig. 2 Operation principle of the proposed device.

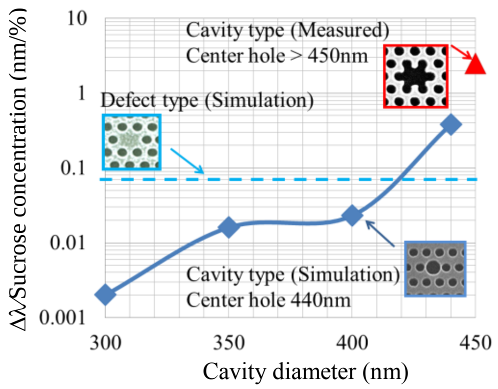


Fig. 3 Comparison of simulation and measured results at different cavity diameters. Defect type simulation results also include in this graph

Table I. Performance comparison of our device with other researcher`s work.

	Wavelength shift
D.Yang *et.al.* [5]	451 nm/RIU
W. Lai *et.al.*[6]	60 nm/RIU
B. Wang *et.al.*[7]	900 nm/RIU
This work	1785 nm/RIU

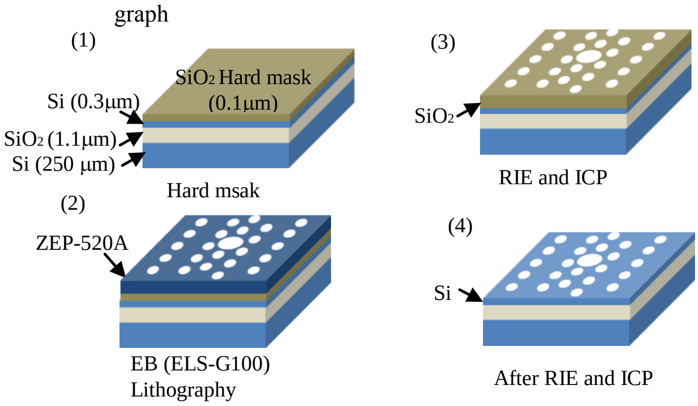


Fig. 4 Fabrication process.

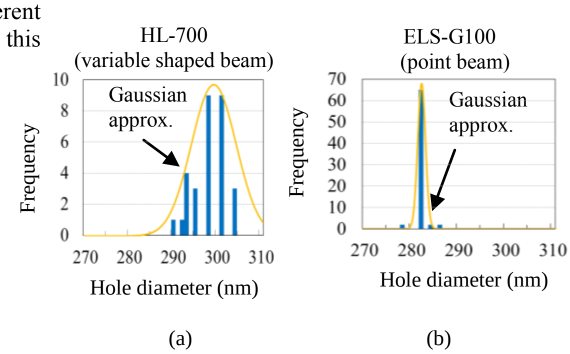
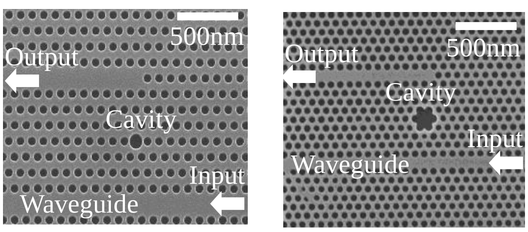
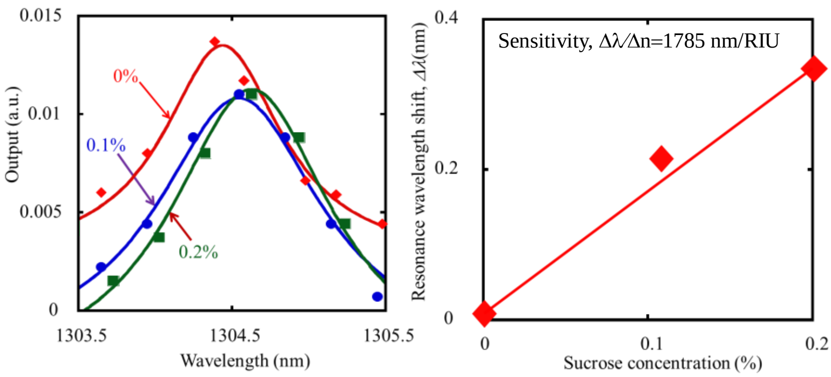


Fig. 5 Comparison of scattering of hole size fabricated by (a) HL-700 and (b) ELS-G100 lithography machines.



(a) (b)

Fig. 6 Scanning electron micrograph of the fabricated device (a) normal cavity type and (b) abnormal cavity type (with larger diameter).



(a) (b)

Fig. 7 Measured results of fabricated device (a) resonance peak shift with respect to sucrose concentration and (b) sucrose concentration versus resonance wavelength shift.