Polymer-based Two Dimensional Photonic Crystal for Biosensing Application

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Abstract— We experimentally demonstrate an ultra-sensitive and polymer-based two-dimensional photonic crystal (2D-PhC) cavity optical sensor. The device was fabricated with polymer on silicon substrate by using electron beam lithography (EBL) and operated near its resonance at 532 nm. Using 2D-PhC cavity optical sensor, reflection intensity was 60 times higher than without cavity. In addition, coating the sensor surface using layer-by-layer (LbL) assembly methodology by deposition of cationic (poly(sodium 4-styrenesulfonate)) and anionic (poly(allylamine hydrochloride)) layers for produces a different reflection intensity change. By deposition of LbL layers using 2D-PhC cavity optical sensor, reflection intensity was decreased systematically and high sensitively (at least 1 layer (thickness: 2 nm [1])). Furthermore, using this optical sensor, high sensitive detection of DNA hybridization could be achieved.

1. INTRODUCTION

PhCs are an attractive sensing platform because PhC provide strong light confinement which depend on the size and periodicity. In addition, optical response of PhCs are sensitive to surrounding refractive index changes. Hence, using PhCs, we have been developed polymer-based high sensitive biosensors that utilize the detection of surrounding refractive index change by the antigen-antibody reaction [2]. However, to develop the more sensitive PhC-based label-free biosensor, investigation on the PhC design is significant challenge.

PhCs can be designed to localize the electric field in the low refractive index region (e.g., air gap), which makes the sensors extremely sensitive to a small refractive index change. By introducing a point cavity into a PhC, defect states can be pulled down from the air band or up from the substrate band [3]. The corresponding optical spectrum shows narrow reflection peaks inside the photonic band gap (PBG), whose precise position is determined by the refractive index of the gap (Fig. 1). Thus, the presence of molecules inside the gaps can be detected by monitoring a large reflection intensity change. In this study, we designed a 2D-PhC cavity optical sensor that is capable of monitoring of surrounding refractive index change on the gap walls.

Based on these back grounds, we tried to design and fabricate the polymer-based two-dimensional photonic crystal (2D-PhC) cavity optical sensor for biosensing applications By using polymers for fabrication of 2D-PhC, biosensor will be realized by using more simplified fabrication techniques such as a nanoimprint lithography (NIL). In addition, based on the optical characteristics of polymers, PBG will be formed in the visible region. As a result, using this polymer-based 2D-PhC for biosensing application, sensor system can be established using cost effective optical set up.

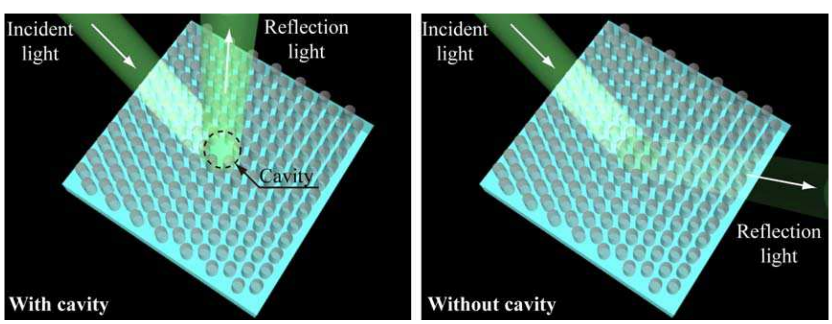

Figure 1: Schematic illustration of 2D-PhC cavity optical sensor. By introducing a point cavity into a PhC, reflection light will be drastically changed by the surrounding refractive index change.

2. EXPERIMENTS AND RESULTS

For the fabrication of the polymer-based 2D-PhC cavity optical sensor, negative tone electron beam resist (NEB22) was coated (thickness: 400 nm) onto the silicon substrate. The triangular configurated pillar array 2D-PhC cavity patterns (pillar diameter: 168 nm, pitch: 112 nm) were prepared on the electron beam resist-coated silicon substrate using EBL (Fig. 2). To investigate the sensing performance using EBL patterned 2D-PhC cavity, a LbL assembly methodology for deposition of cationic and anionic layers by electrostatic interaction for changing of the surrounding refractive index (Fig. 3), and the reflection intensity change by the irradiation of green laser (532 nm, 1 mW) was employed.

The 2D-PhC cavity was applied to evaluate the sensitivity, higher reflection intensity than similar design without cavity could be observed (Fig. 4). Using the 2D-PhC cavity, detection of LbL layers and the detectable number of layers was investigated. By deposition of LbL layers, reflection peak intensity was drastically decreased (Fig. 5). Result from the comparison of sensing performance using 2D-PhC which has reflection peak wavelength according to the Bragg reflection by calculating the changing ratio defined by reflection intensity (after deposition)/reflection intensity (bare 2D-PhC), 2D-PhC cavity could detect the extremely low number of LbL layer systematically.

In addition, 2D-PhC cavity was applied to detect the DNA hybridization. The probe DNA for tumor necrosis factor (TNF-α) was immobilized onto the 2D-PhC cavity surface. And the reflection intensity change due to the DNA hybridization-based refractive index change was monitored. As a result, the refractive index change with target DNA concentration could also be observed. From these results, this sensor has great potential for high sensitive detection of target molecules in visible region.

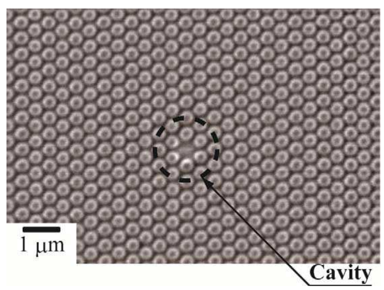

Figure 2: Scanning electron microscopy image of 2D-PhC cavity optical sensor.

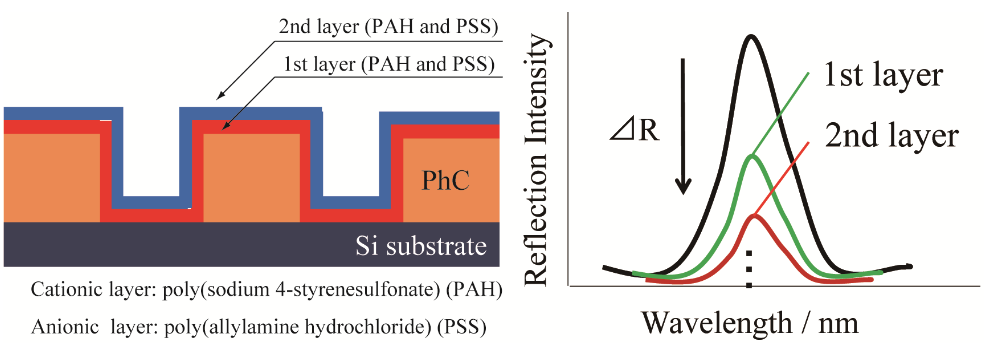

Figure 3: Schematic illustration of sensing performance evaluation using LbL assembly methodology.

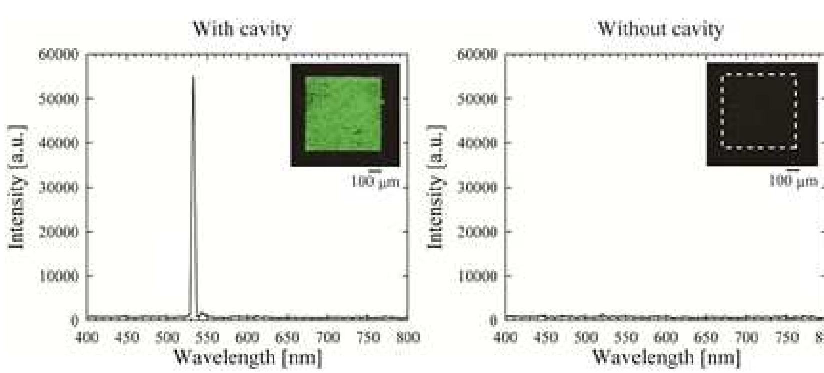

Figure 4: Reflection spectra and photograph of 2D-PhC cavity and without cavity.

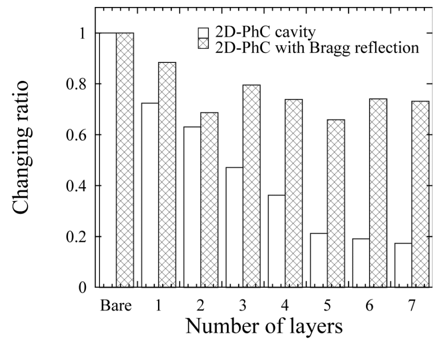

Figure 5: Reflection peak intensity change with number of LbL layers.

3. CONCLUSION

In this study, we succeeded to design and fabricate the polymer-based 2D-PhC cavity sensor for biosensing application. Using this sensor, high-sensitive detection of LbL layer deposition and DNA hybridization. From these results, this sensor has a great potentials for detection of biomolecular interactions such as an antigen-antibody for future medical diagnostics.

REFERENCES

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