Two-dimensional Photonic Crystal Sensor for Detection of Biomaterial

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Received: February 2019 Revised: May 2019 Accepted: July 2019

ABSTRACT:
Biological components including cells, proteins, and nucleic acids have been studied by using biological sensors. All compounds in the organisms have sensors with identical mechanical sensors. Most of these sensors are specific cells which are sensitive to physical characteristics of outside environment including light, motion, temperature, magnetic-field, gravity, moisture, vibration, pressure, electrical fields, and sound. Since biosensors could be fabricated by using photonic crystals, these structures are used in designing the sensor due to the unique characteristics of photonic crystals. Refractive index around the sensing hole was changed and output transmission spectrum was studied. By changing refractive index, transmission spectrum undergoes measurable change and biomolecule could be measured by sensor in mentioned conditions. Results have shown that this sensor has good sensitivity for measuring small dimensions. In addition, high speed, high quality, simple structure, as well as higher sensitivity are other characteristics of photonic crystal sensors compared to other sensors.

KEYWORDS: Biomaterial, Sensitivity, Sensor, Two-dimensional Photonic Crystal.

1. INTRODUCTION

Sensors have widespread applications in biomedical research, production and testing medicines, environmental analysis, preservation of food and chemical industry [1], [2]. Medical sensors have significant development in bioassay and environmental safety [3]. Biosensors observe and analyze biological components like cells, proteins and nucleic acids [4]. Biosensor is made of bioreceptor and a transducer that bioreceptor detects target biomolecule and transducer transforms the biomolecule to a measurable signal. These two parts are embedded in an integrated form in biosensors [5]. Surface Plasmon Resonance (SPR), interference, optical waveguide, optical fibers, resonator based bio-ring and photonic crystals have been used in designing biosensors [6, 7]. Photonic crystal biosensors with structures consisted of alternative material layers have attracted many attentions in recent years [8, 9]. Photonic crystal [10-12] is fabricated by alternative materials with different refractive index in wavelength scale. Photon strongly scatters in these structures and redistributes in the energy level as separate energy bands. These conditions in a photonic crystal lead to the emergence of interesting characteristics like stop band, photon amplification, strong non-linear optic effects and photon confinement. Light emission features can be changed by inducing defect in the photonic crystals. Photonic crystals have widespread application in communication and sensory applications [13], [14].

They have considerable optical limitations compared to conventional optical devices. Optical limitation in the photonic band gap and flexibility of regulating wavelength with suitable regulation of structural parameters are among the causes of paying attention to photonic crystal biosensors. Various structures have been designed as sensor by considering the unique characteristics of photonic crystals. Photonic crystal resonator nano-ring biosensor [15, 16], photonic crystal fiber sensors [17], nano and micro photonic crystal resonators' biosensor and glucose detection biosensors are examples of these applications [18-21].

A photonic crystal based biosensor is presented in this study. The structure is obtained by creating defect in three sections. Simulation has been used to achieve the optimal structure and the structure has been improved by adding some bars.

2. DESIGN AND NUMERICAL RESULTS

Fig. 1 shows the sensor cross-section. Two-dimensional photonic crystals were used for designing sensor. This structure is an array consisted of silicon bars which are filled with air. The circular bars reduce the dispersion losses and control effectively the emission of electrical field mode. The radius of bars is $R_1 = 0.7 * a$, where, a is lattice constant and the distance between center of two bars ($a = 1\mu m$). Photonic crystal is in X-

Z plane with triangle arrangement.

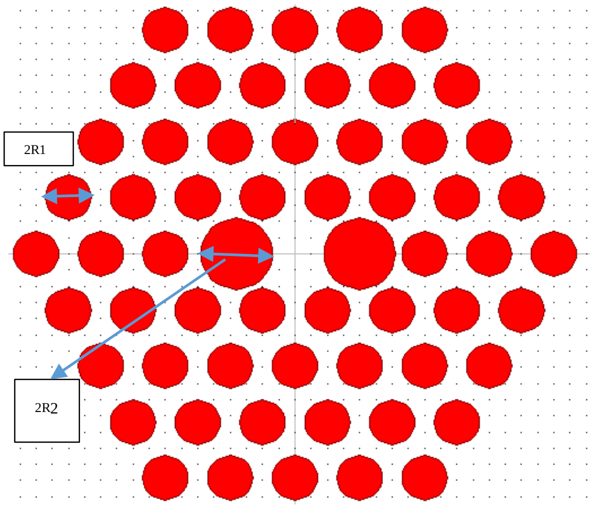

Fig. 1. Cross-section and the schematic diagram of the proposed biosensor.

In photonics, an energy-free tape or stop band refers to a range of photon frequencies in which photons with this frequency cannot pass through the material. This property has made photonic crystals very useful. The plate wave propagation technique is used to obtain a photon stop band.

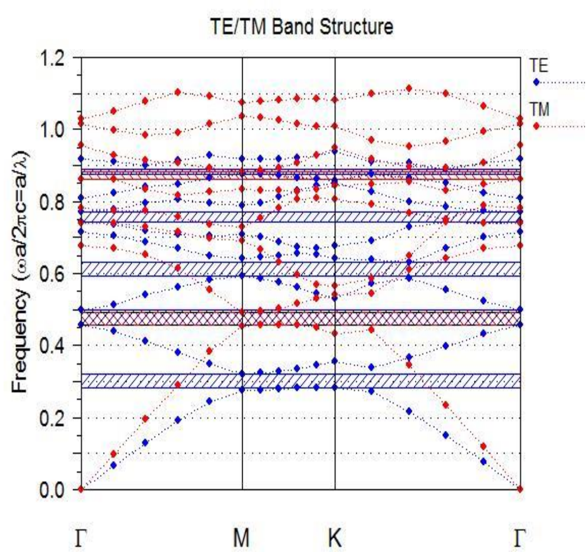

Fig. 2. Band structure of the photonic crystal structure.

Fig. 2 shows the stopping band for the TE and TM modes. The first stop band for the TE modulus is $0.285 \leq \omega a / 2\pi c = a / \lambda \leq 0.315$, where ω is the angular frequency, that a is the lattice constant a = 1μm, c is the light speed in free space and λ is the free space wavelength. The wavelength could be determined as following:

$$\frac{a}{\lambda} = f \tag{1}$$

$$\lambda = \frac{a}{f} = \frac{1}{0.285} = 3.5\mu m$$

$$\frac{a}{f} = \frac{1}{0.315} =$$

$$= 3.17$$

$$3.17 \leq \lambda \leq 3.5$$

3. RESULTS

Photonic crystal sensor transmits high-throughput signal. One of the most important applications of photonic crystals is measuring physical parameters in the environment like temperature, pressure, strain, concentration, electrical field, detection of biomolecule and etc. Sensing hole is considered in the center of the structure and the refractive index around this hole changed by sensor and output transmission spectrum was studied. The location of the sensor cavity is shown in Fig. 3.

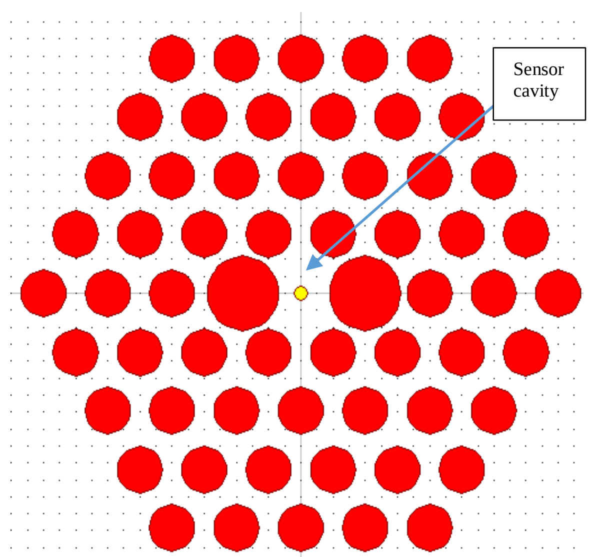

Fig. 3. Band structure of the photonic crystal structure.

If by changing the refractive index, the sensing value can be changed and measured, the sensor can detect biomaterial. Every refractive index can be equal to a particular state in the sensing hole. We can change refractive index from 1.33 to 1.35 and measure the electrical field. Results are shown in Fig. 4.

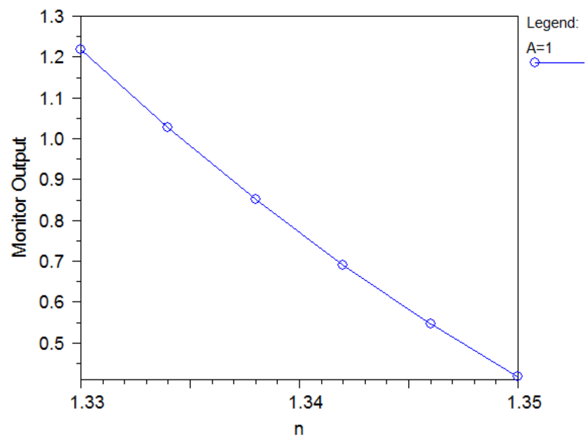

Fig. 4. Normalized curve related to the intensity shifts of transmission spectra with respect to the effective refractive index.

According to the obtained results, the measured electrical field changes when biomaterial refractive index connected to the sensing hole changes. Sensitivity calculation was done during connecting the molecule. Changing the measured electrical field with changing refractive index can help to identify different biomaterials like proteins, viruses, DNA molecule, and glucose molecule concentration.

This is an ideal sensor because it has linear function and output signal linearly corresponds to measured characteristics. The sensitivity of sensor is defined as the output signal to measured quantity ratio. Therefore, sensor sensitivity is:

$$\alpha = \left|\frac{\Delta E}{\Delta N}\right| = \left|\frac{1.23 - 0.67}{1.33 - 1.34}\right| = 56 \quad (2)$$

Photonic crystal has high flexibility in forming the structure due to the lattice constant, radius of bar, and the setting. Therefore, the most optimal mode can be obtained by changing these parameters and drawing different states. We calculated electrical field changes to refractive index for optimizing the diagram structure for three different lattice constants which is shown in Fig. 5.

Blue diagram indicates $a = 1\mu m$ lattice constant, green and red diagrams indicate $a = 2\mu m$ and $a = 3\mu m$ lattice constants, respectively. As seen in the figure, changes interval for a=3um lattice constant is higher. As a result, sensor has higher precision in this lattice constant because changes smaller than measured quantity can be detected and recorded.

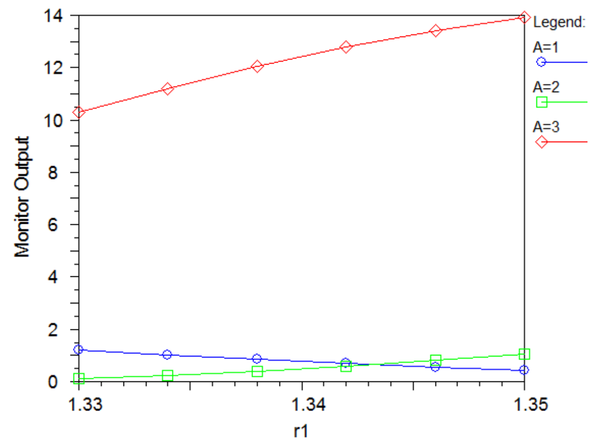

Fig. 5. Electrical field changes to refractive index for optimizing the diagram structure for three different lattice constants.

4. CONCLUSION

A biosensor with two-dimensional photonic crystal is introduced in this research. Electrical field has been measured when biomaterial refractive index mounted to the sensing hole changed. Sensitivity has been calculated during molecule connection. By changing the refractive index, the measured field changes which could be used in identifying different biomaterials including identifying all kinds of proteins, viruses, DNA molecules, and the concentration of glucose molecule.

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