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# طراحی، آنالیز و شبیه سازی حسگر زیست پزشکی ریز حلقه برپایه بلور نوری

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**چکیده- این مقاله به طراحی حسگرهای زیستی بر ا ساس ریزحلقه های بلور نوری می‌پردازد. ملکول های زیستی ضرایب شکست منحصر به فرد خود را دارند؛ بنا بر این مشخصه های حسگر(. خروجی، ضریب کیفیت و طول موج نوسان) برای هر کدام از ملکول‌های مقداری متفاوت و خاص خواهد داشت. دو ساختار متفاوت در این مقاله مورد بررسی قرار داده شده اند تا بهترین آن ها انتخاب گردد.**

**کلید واژه-** حسگر، بلور نوری، ضریب شکست، طول موج نوسان، سیستم های میکرو الکترو مکانیک.

## Design, analysis and simulation of a Ring Resonator Based bioMEMS sensor by using a photonic crystal

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**Abstract- This paper presents the design of a photonic crystal ring resonator based bio MEMS sensor to detect divergent biochemical molecules. As the biochemical molecules have exclusive refractive indices, the resonant wavelength, output transmission and other parameters are varied from one chemical to the other. Two different structures are surveyed to choose the best one.**

Keywords: sensor; Photonic crystal; refractive index; *resonant wavelength*; MEMS

## 1. Introduction

This MEMS technology is used to produce this device because of its small size (they are less than 1 µm). The photonic crystals bioMEMS sensors have different usages in medical fields in recent decade. They are divided into various groups: ring resonators [1,2,3], plasmonic metamaterials [4,5,6], and wave guides [7]. These sensors are able to detect DNA, protein, antigen antibody interaction, cells and Bacteria [8,9].

Photonic Crystals are periodic structures which consist of different rods with different diameter and materials. They consist of periodic dielectric nanostructures. If electromagnetic waves pass through these crystals, their propagation is varied due to greater refractive index of these rods compared to that of air [1]. The motion of photons, which is affected by lattice properties, helps to detect and identify molecules easily. Thanks to these special properties, there is a band gap which does not let special wavelength pass [1]. However, it is possible to manipulate the wave propagation through PC by using defects in the structure.

In this paper, a photonic crystal ring resonator (PCRR) sensor is designed and analysed to detect different chemical and biochemical molecules. The design steps and simulation results are established.

## 2. Theory

PBG wavelengths cannot propagate through the PC; then, adding some defects into the structure manipulates the propagation. The sensor comprises of a ring resonator in a way that line defect performs as waveguides and the circular one is the ring. Changing the refractive index of the background causes a change in the resonant wavelength and output transmission. The Maxwell's electromagnetic equation withdraws the sensor's function.

The equation (1) demonstrate the sensing performance of the PC.

$$L_{eff} = Q\lambda/(2\pi\eta) \quad (1)$$

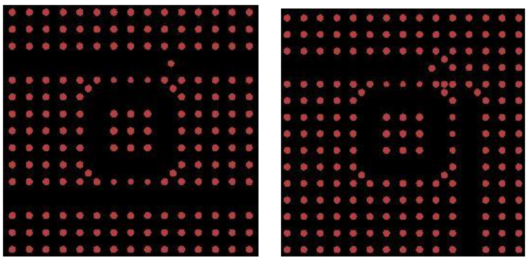
$Q$ is the resonator quality factor, $\lambda$ is the resonant wavelength, and $\eta$ is the refractive index of ring resonator, And L is the effective interaction length.

## 3. Designe

Both of sensors are fabricated by two dimensional photonic crystal ring resonator based on silicon rods in an air background. parameters of them are given in the table 1. The size of these structures is 9.45 µm * 9.45 µm. they involve 15 rods in length and 15 in width. The sensors are demonstrated in fig.1.

Table1: features of sensor

| features | amount |
|---|---|
| The lattice constant (a) | 0.63 um |
| Refractive index of Silicon rod's | 3.42 |
| Refractive index of air | 1 |
| Radius of Rod (r) | 0.132 um |



(a) (b)

Fig. 1: schematic of the proposed bio MEMS sensor: (a) parallel straight waveguides, (b) Cross straight waveguides

the first structure consists of two parallel straight waveguides. The other one consists of two Cross straight waveguides. The QF, resonance wavelength and transmission of first sensor are 445.6, 1.544 µm and 0.4. The QF, resonance wavelength and transmission of second sensor are 525.19, 1.97 µm and 0.4.

The band structure diagram of these structures are the same and demonstrated in fig. 2. In this figure, the vertical axial is the normalized frequency. The band diagram consists of two PBG modes (TM and TE). There are two wavelength range for TE range. Moreover, from the fig. 2, there are two wavelengths for TM range, too. TE mode which is ranged from 2.51Hz to 4.35 Hz is chosen.

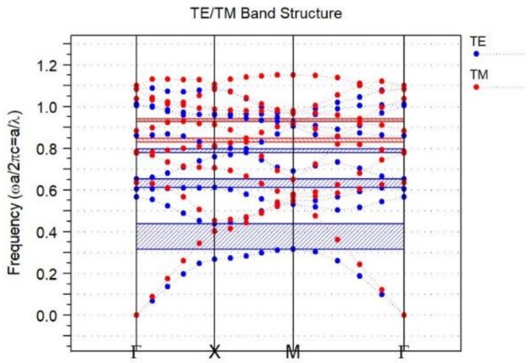
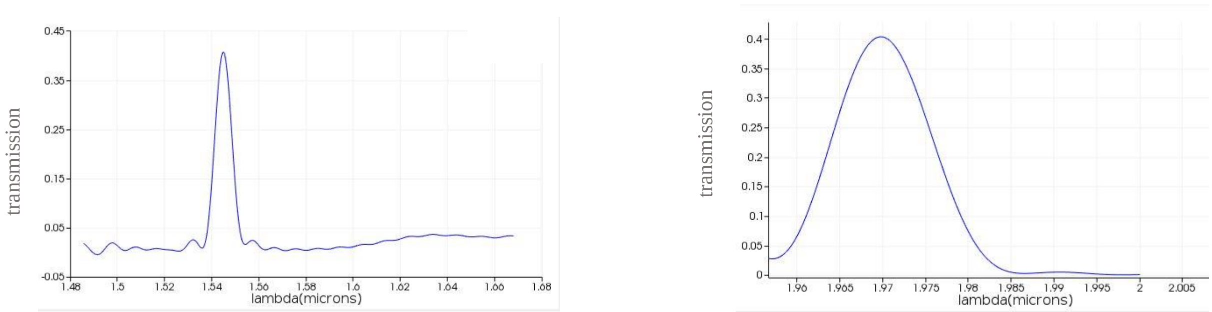



Fig. 2 band structure diagram of both structures.

## 4. Simulation results and discussion

Fig. 5 shows the normalized transmission spectrum to wavelength for first and second structures. Furthermore, Table 3 demonstrates the same parameters of second sensor for unlike molecules.
The distinct refractive index of various molecules consequences in diverse transmission output and resonance wavelength volume. This information shows that which structure is able to sense the molecules.

From the above tables, it is obvious that the second PC based sensor has better properties. As it is seen, the QF has really low and unacceptable amount when the wave guides are parallel. However, the cross wave guides sensors show better amount of QF and transmission output. In addition, the sensitivity of parallel straight waveguides is 1300 nm/RIU, and the sensitivity of cross straight waveguide is 9250 nm/RIU. In comparison with parallel straight waveguides sensor, cross straight waveguide sensor shows better properties.




(a) (b)

Fig. 3 normalized transmission spectrum (a) the parallel straight waveguides sensor (b) the cross straight waveguide sensor

Table 2 refractive index, resonant wavelength, Q factor and transmission output of first sensor for different molecules.

| Name of molecular | Refractive index | Resonant wavelength (um) | Q factor | Output transmission | references |
|---|---|---|---|---|---|
| water | ١,٣٣٣ | ١.٩٢٧ | ١٠٤,١ | ٠,٧٨ | [10] |
| RK3E-ras | ١,٣٧٣ | ١.٩٧٩ | ١٠١ | ٠,٧٦ | [11] |
| YD-10B | ١,٣۶٩ | ١.٩٧٥ | ١٠٠,٢ | ٠,٧٥ | [11] |
| Cytosol | ١,٣٦ | ١.٩٦٥ | ٩٩,٦ | ٠,٧٦ | [12] |
| Nucleus | ١,٣٥٥ | ١.٩٥٨ | ٩٩ | ٠,٧٦ | [12] |
| Blood Plasma | ١,٣٥ | ١.٩٥٢ | ٩٩,١١ | ٠,٧٦ | [1] |

Table 3 refractive index, resonant wavelength, Q factor and transmission output of second sensor for different molecules.

| Name of molecular | Refractive index | Resonant wavelength (um) | Q factor | Output transmission | references |
|---|---|---|---|---|---|
| water | 1.333 | 2.32 | 300.5 | 0.82 | [10] |
| RK3E-ras | 1.373 | 2.25 | 202.09 | 0.74 | [11] |
| YD-10B | 1.369 | 2.41 | 237.9 | 0.34 | [11] |
| Cytosol | 1.360 | 2.08 | 297 | 0.85 | [12] |
| Nucleus | 1.355 | 2.04 | 379.3 | 0.58 | [12] |
| Blood Plasma | 1.350 | 2.04 | 373 | 0.7 | [1] |

## 6. Conclusions

In this paper, the sensors, consisting of two dimensional PC ring resonator with the cubic lattice of circular rod in air, was designed to detect different molecules. Numerical method was used to analyse the functional characteristics of these sensors. In addition, the different parameters of the sensor were measured, which showed significant differences in transmission output amplitude and resonant wavelength. In comparison with parallel straight waveguide sensor, cross straight waveguide sensor presented better QF. The sensor simplifies the detection of different molecules, assisting earlier finding of health problems.

## References

**[1]** Arunkumar, R., T. Suaganya, and S. Robinson, *Design and Analysis of 2D Photonic Crystal Based Biosensor to Detect Different Blood Components.* Photonic Sensors, 2019. **9**(1): p. 69-77.

**[2]** Zarifi, M.H., et al., *Microwave ring resonator-based non-contact interface sensor for oil sands applications.* Sensors and Actuators B: Chemical, 2016. **224**: p. 632-639.

**[3]** Olyaee, S. and A. Mohebzadeh-Bahabady, *Designing a novel photonic crystal nano-ring resonator for biosensor application.* Optical and Quantum Electronics, 2015. **47**(7): p. 1881-1888.

**[4]** Ertürk, G., et al., *Microcontact imprinting based surface plasmon resonance (SPR) biosensor for real-time and ultrasensitive detection of prostate specific antigen (PSA) from clinical samples.* Sensors and Actuators B: Chemical, 2016. **224**: p. 823-832.

**[5]** Hameed, M.F.O., et al., *Highly sensitive plasmonic photonic crystal temperature sensor filled with liquid crystal.* IEEE Photonics Technology Letters, 2016. **28**(1): p. 59-62.

**[6]** Azzam, S.I., et al., *Multichannel photonic crystal fiber surface plasmon resonance based sensor.* Optical and Quantum Electronics, 2016. **48**(2): p. 142.

**[7]** Michel, D., F. Xiao, and K. Alameh, *A compact, flexible fiber-optic Surface Plasmon Resonance sensor with changeable sensor chips.* Sensors and Actuators B: Chemical, 2017. **246**: p. 258-261.

**[8]** Zeng, S., et al., *Graphene–MoS2 hybrid nanostructures enhanced surface plasmon resonance biosensors.* Sensors and Actuators B: Chemical, 2015. **207**: p. 801-810.

**[9]** Sharma, P. and P. Sharan, *Design of photonic crystal based ring resonator for detection of different blood constituents.* Optics Communications, 2015. **348**: p. 19-23.

**[10]** Ghoumazi, M., A. Hocini, and M. Hameurlain. *Study and Simulation of the Power Flow Distribution of an Optical Channel Drop Filter in Structure Based on Photonic Crystal Ring Resonator for Different Organic Liquids*. in *International Conference in Artificial Intelligence in Renewable Energetic Systems*. 2018. Springer.

**[11]** Choi, W.J., et al., *Full-field optical coherence microscopy for identifying live cancer cells by quantitative measurement of refractive index distribution.* Optics express, 2010. **18**(22): p. 23285-23295.

**[12]** Choi, W., et al., *Tomographic phase microscopy.* Nature methods, 2007. **4**(9): p. 717.