

High Resolution Biosensor with Simultaneous Detection of Two Refractive Index Sample in Optical Microstructure

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Abstract

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In this work, a biosensor is designed with simultaneous detection of cancer cell and diabetes cell in all-optical microstructure. Hexagonal photonic crystal with silicon rods are placed in the air bed with a refractive index of $n_0 = 2.64$. In the proposed structure, from two nonlinear cavities have been used to place the samples in those cavities. The main operation is to detection diseases by the refractive index of the samples. Detection of Samples have been performed at central wavelength $\lambda = 1550$ nm. The percentage of transmission power is between 91% and 100%. The total two dimensional of the biosensor is $61.56 \ \mu\text{m}^2$. The sensitivity range is between S = $3080 \ \text{nm}$ / RIU and $1294 \ \text{nm}$ / RIU. The Figure of Mertie (FOM) at best is FOM = $1550.11 \pm 150.11 \ \text{RIU}^{-1}$ and Detection range is $31 \times 10^{-6} \ \text{RIU}$. Detection of the disease through two nanocavities simultaneously (blood and tear samples) is one of the important applications of the proposed structure.

Keywords:

High Resolution, Optical Microstructure, Figure Of Mertie (FOM), Simultaneous Detection.

1. Introduction

Integrated all-optical circuits have significant advantages over electronic circuits. For example, the property of light compared to current is high speed, low power losses and data transmission with the least error and high security. Photon crystals have found a very important place in the Integrated all-optical circuits. Most scientists design a variety of structures in the bed of photon crystals, such as fibers (Ayyanar, Raja, Sharma, & Kumar, 2018), analog to digital converter(Mehdizadeh, Soroosh, Alipour-Banaei, & Farshidi, 2017; Sani, Khosroabadi, & Nasserian, 2020; Sani, Khosroabadi, &

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Shokouhmand, 2020), filters (Hosseinzadeh Sani, Ghanbari, & Saghaei, 2020; Robinson & Nakkeeran, 2013), logical gate (Jiang, Liu, Zhang, & Kong, 2015; Karkhanehchi, Parandin, & Zahedi, 2017; Sani, Tabrizi, Saghaei, & Karimzadeh, 2020), decoder (Mehdizadeh, Soroosh, & Alipour-Banaei, 2016; Parandin, Karkhanehchi, Naseri, & Zahedi, 2018), demultiplexer(Jiu-Sheng, Han, & Le, 2015; Sani, Khosroabadi, & Talebiyan, 2019; Talebzadeh, Soroosh, Kavian, & Mehdizadeh, 2017), biosensors(Arafa, Bouchemat, Bouchemat, Benmerkhi, & Hocini, 2017; Sani & Khosroabadi, 2020; Yan et al., 2011; Yaroslavsky et al., 2012). Photon crystals are designed in one-dimensional, two-dimensional and three-dimensional, which in this paper is a proposed structure based on two-dimensional photonic crystals.

Biosensor is a device used to detection of samples with different characteristics. There are two general approaches to different detection: 1) the use of traditional labels to represent analyzes, and 2) the use of non-invasive unlabeled methods, in which there are no markers required to identify analytes. Does not exist. Since no label is attached to the molecules, therefore, the actual information and nature of the biodegradable material remains intact. Biosensors can also be used in cancer research to analyze target cell lines or protein changes in the cell. All-optical biosensors are suitable structures for fast and disposable detection. The main function of the structure of biosensors based on photon crystals is based on the refractive index of the samples used. The structure designed in this work has the ability to simultaneously detection two samples of human blood and tear fluid, which makes the function of the church structure different from the similarly designed structure, and on the other hand, you can identify samples of two different people simultaneously. Inadequate and crowded hospital conditions can be a good option to speed up the diagnosis and the number of people diagnosed with the disease(Erim, Erim, & Kurt, 2019).

The structure of the biosensor is based on the finite difference time domain method for twodimensional mode (2D-FDTD). The grid size (ΔX , ΔZ) is selected in different values in the FDTD solution. In order to achieve a steady state in the simulations, it is based on Equation (1), which describes the propagation of light in a photonic crystal and is obtained by solving Maxwell's electromagnetic equations.

$$\nabla \times (\frac{1}{\varepsilon} \nabla \times H) = (\frac{\omega}{C})^2 H \tag{1}$$

In Equation (1), ε is the permittivity, ω is the frequency. Equation (1) states that the frequency " ω " is proportional to the dielectric function. *FWHM* represents the full width at half maximum of the optical signal and *Q*.*f* represents the quality factor and is derived from (2). The sensitivity for each step of the restructuring is calculated from (3).

$$Qf = \frac{\lambda_0}{FWHM}$$
(2)

$$S = \frac{\Delta \lambda_0}{\Delta RI} \left(\frac{nm}{RIU}\right) \tag{3}$$

Another important parameter used to describe the sensor capability of a sensor, considering the full width at half the maximum (FWHM) resonance, is the figure of merit (FOM), which is calculated from (4).

$$FOM = \frac{S}{FWHM}$$
(4)

The λo parameter indicates the resonant frequency of the output signal. $\Delta \lambda$ shows the difference between the resonant frequencies of the two output signals detected in the biosensor. ΔRI is also the difference between the refractive index of the samples used in the diagnosis. A laser source with continuous wave tuning provides optical signal input to the structure and its outputs, and analyzes the optical output in the structure of a digital time monitor.

2. Optical Microstructure Biosensor

The proposed structure is shown in Figure (1) and has two linear nanocavities that can simultaneously detect two cancer cells and diabetes cells in one or two different humans. Hexagonal photonic crystal with silicon rods are placed in the air substrate ($n_{air} = 1$) with a refractive index of $n_0 = 2.46$ and the lattice index is a = 600 nm Tunable laser source with a central wavelength of $\lambda = 1550$ nm is applied to the structure input waveguide. The red nanocavity has a radius of $R_{C1} = 0.9$ a = 540 nm and the radius nanocavity with color of light cyan has been $R_{C2} = 1.1$ a = 660 nm. This structure works in such a way that a sample of human blood is placed inside a nano-red cavity and a sample of human tear fluid is poured into a turquoise nano-cavity. Based on the refractive index of the samples, the resonance wavelength shifts and two resonant wavelengths are received simultaneously at the output of the structure. The structure works in such a way that a sample of human tear fluid is poured into a sample of human tear fluid is poured into a turquoise nano-cavity. Based on the refractive index of the samples, the resonance wavelengths hifts and two resonant wavelengths are received simultaneously at the output of the structure. The structure works in such a way that a sample of human blood is placed into a light cyan nanocavity. Based on the refractive index of the samples, the resonance wavelengths have shifts and at the output of the structure as Two resonance wavelengths are received simultaneously.



Fig. 1. The proposed structure of Optical Microstructure Biosensor.

3. Result and Discussion

In Figure (2), first, blood and tear fluid samples of healthy individuals with refractive indexes of 1.36 and 1.35 are placed inside red and light cyan nanocavities, respectively. As can be seen in the figure, two resonance wavelengths are received at the output, the values of these resonance wavelengths represent healthy people. The resonant wavelength with a central frequency of 0.387 has been applied to the structure and the shifted resonant wavelength for a healthy human blood sample is equal to $\lambda_{s2} = 1.59315 \ \mu m$ and also the shifted wavelength for a healthy human tear sample is equal to $\lambda_{s_1} = 1.56235 \ \mu\text{m}$. So, if we get these two resonance wavelengths at the output of our structure, we will find that the person or persons are healthy and there are no cancer or diabetes cells in the samples. Important parameters in an optical biosensor are the amount of sensitivity (S), the figure of merit (FOM), quality factor (Q.f), width at half maximum (FWHM), and the detection limits (DL). For the resonance wavelength of the refractive index of 1.35 tears fluid normal samples, the value of full width at half maximum is equal to FWHM = 1.8 nm, and value of width at half maximum of the refractive index of 1.36 blood normal is equal to FWHM = 2.2 nm. In the detection of a healthy person without cancer cells and diabetes cells, the sensitivity value is S = 3080 nm/RIUand the figure of merit is FOM= 1550.11 ± 150.11 RIU⁻¹. The transfer power percentage is 95% for sample1 and 100% for sample2. The figure 2 shows the resonance wavelength of normal blood samples and tears fluids, which is shown in section (a) normalized transmission power and in section (b) transmission power in dB scale.



Fig. 2. Resonance wavelength of normal blood and tears fluid samples, (a) Normalized Transmissions power, (b) Transmissions power in dB scale.

Up to this section, only human normal blood samples1 and tear fluid samples2 were examined. In the following, we introduce the refractive index values of different cancer cells and diabetes cells and examine all the values and determine the intensification wavelengths of each refractive index. Table 1 shows the Refractive index of normal cells of different cancer and diabetes cells.

Analytic Used	Refractive Index
Blood Sample1	RI
Basal cell (Normal)	1.360
Basal cell (Cancerous)	1.380
Hela cell (normal)	1.368
Hela Cell (Cancerous)	1.392
MDA-MB-231 Cell (normal)	1.385
MDA-MB-231 Cell (Cancerous)	1.399
Tears Fluid Sample2	RI
Normal Cells of diabetes	1.350
Effected Cells of diabetes	1.410

Table 1. Refractive index of blood sample2 and tears fluid sample2 of human.

Figure 3 shows basal cell normal and basal cancer cell with refractive indexes of 1.360 and 1.380, respectively. The basal cell normal is placed in sample₁ and the basal cancer cell is placed in sample₂. Basal cancer cells form in the outer layer of the skin (epidermis) due to intense sun exposure. These cells do not spread to other parts of the body (Tavousi, Rakhshani, & Mansouri-Birjandi, 2018). The cancer cell index has a refractive index of 1.38 and the healthy stem normal cells have a refractive index of 1.36. In Figure 3 (a), the sensor output is plotted for two types of basal cancer cell and normal, without cancer cells, which in each case shows a specific amplitude wavelength. The full width at half the maximum output signal is FWHM = 2.2 nm for normal and FWHM = 2 nm for basal cell carcinoma, and the figure of merit parameter level is FOM = 940.475 \pm 025 RIU⁻¹ at best and sensitivity for this state of S = 1893 nm/RIU. Figure 3 (b) shows the sensor output to detect the presence or absence of Hela cancer cells. HeLa cancer cells are human cancer cells. They are not very controlled compared to normal cells. These cells become cancerous due to infection with the human papillomavirus 18 (HPV18) (Chopra, Kaler, & Painam, 2016) . The refractive index of these cells is 1.392, while the normal HeLa cell line has a refractive index of 1.368. The full width at half the maximum output signal is FWHM = 2.2 nm for normal and FWHM = 1.9 nm for Hela cell carcinoma, and the figure of merit parameter level is FOM = 940.475 \pm 025 RIU⁻¹ at best and sensitivity for this state of S =1642 nm/RIU and transmissions power for normal and Hela cell is TE_N = 99% and TE_H = 95%. MDA-MB-231 is extracted from the human chest and isolated from pleural disease from a breast cancer patient (Mohamed, Hameed, Areed, El-Okr, & Obayya, 2016), the level of the FOM suitability shape value for FOM = 6097 RIU⁻¹ cancer cells. Figure 3 (c) shows the resonance wavelength for the MDA-MB-231 normal Cell and MDA-MB-231 cancer cell. The refractive index of this type of cancer is 1.399 and the normal cell of breast cells has a deflection coefficient of 1.385. Detections of diabetes is made on human tear fluid. The refractive index for normal people is 1.35 and the refractive index for diabetes cell from the sensor output. Sensitivity for this state of S = 1294 nm/RIU and transmissions power for normal and diabetes cell is TE_N = 95% and TE_H = 100%. The full width at half the maximum output signal is FWHM = 1.8 nm for normal and FWHM = 1.9 nm for diabetes cell.





Fig. 3. Resonant wavelengths of normal and cancerous cells. (a) Basal cell. (b) Hela cell. (c) MDA-MB-231 cell. (d) Diabetes.

In this section, we have studied and analyzed the radius effects of sample1 and sample2 nanocavities as important structure parameters. Figure 4 (a) shows the effects of the nanocavity radius of sample1 on the transmission power percentage, resonant wavelength and full width at half the maximum (FWHM). These calculations are calculated for the state of a normal person with basal cell normal refractive index of 1.36. As can be seen in this figure, the percentage of power transfer in a radius of $R_{C1} = 540$ nm reaches 100%, and from this case it can be concluded that the best radius to reduce power losses to zero and pass 100% of the transmitted power is this radius. On the other hand, the full width at half the maximum (FWHM) in different radii has different values, but in the radius of $R_{C1} = 540$ nm, it has less value, which represents the optical signal received with the lowest bandwidth. Figure 4 (b) examines the effects of sample2 radius with a refractive index of 1.38 on the basal cell (Cancer) on important structural parameters. In this case, by increasing the radius of the sample nanocavity sample2 to $R_{C2} < 660$ nm, the amount of transfer power is almost constant, and by increasing the radius, the amount of transfer power decreases, and therefore in the radius of $R_{C1} = 660$

nm with 94% transfer power is the best. The amount of bandwidth has also reached the lowest value in this radius. Therefore, we were able to select the best radii for samples1 ($R_{C1} = 540$ nm) and samples2 ($R_{C2} = 660$ nm) by reviewing and analyzing the results.



Fig. 4. Calculate resonant wavelengths, transmission power and FWHM for different cavity radius. (a) Normal cell. (b) Cancer cell.

In the final section, all the final results calculated and analyzed are shown in Table 2. In this table, the values of sensitivity parameters, quality factor, transmission power, average bandwidth and figure of merit are calculated for different refractive indexes in nanocavity of sample1 and sample2. The best detection and the highest sensitivity obtained for the detection of normal blood MD-MB-231 Cell (normal) in nanocavity sample1 is equal to 2214 nm/RIU. The highest form of competence is to detect a normal blood MD-MB-231 Cell (Cancerous) in nanocavity sample2, which is equal to FOM = 1109.51±55.235 RIU⁻¹.

Analytic Used	RI	λ₀ (µm)	FWHM (Shi, Zhang, & Sha)	Quality factor	T.E (%)	FOM (RIU ⁻¹)	S (nm/RIU)
Blood Sample1							
Basal cell (Normal)	1.360	1.59315	2.2	840.45	100	-	Ref
Basal cell (Cancerous)	1.380	1.63101	2.0	946.50	94	940.475	1893
Hela cell (normal)	1.368	1.60010	2.2	746.36	99	-	Ref
Hela Cell (Cancerous)	1.392	1.63951	1.9	864.25	95	805.283	1642
MDA-MB-231 Cell (normal)	1.385	1.60511	2.1	464.33	93	-	Ref
MDA-MB-231 Cell (Cancerous)	1.399	1.63611	1.9	861.11	91	1109.51	2214
Tears Fluid Sample2							
Normal Cells of diabetes	1.350	1.53235	1.8	867.97	95	-	Ref
Effected Cells of diabetes	1.41e 0	1.64001	1.9	863.31	100	699.96	1294

Table 2. Calculation of important parameters in biosensor with blood and tear fluid samples.

Table 3 also compares the important parameters of the structure proposed in this paper with other proposed articles. As can be seen in the table, our proposed structure is better than other structures in terms of detection sensitivity, Transmission power, Quality factor, figure of merit and Simultaneous application of detection of two samples with two intensified nanocavities.

Reference	Detection Sample	Quality factor	FOM (RIU ⁻¹)	Transmission power (%)	Sensitivity (nm/RIU)
<u>(Tavousi,</u> <u>Rakhshani, &</u> <u>Mansouri-</u> <u>Birjandi,</u> <u>2018)</u>	Blood	650 ± 50	1400 ± 200	80	2500
<u>(Chopra, Kaler, & Painam, 2016)</u>	Blood and Tears fluid	1082	-	-	6.5764
<u>(Mohamed,</u> <u>Hameed,</u> <u>Areed, El-</u> <u>Okr, &</u> <u>Obayya,</u> <u>2016)</u>	Glucose	-	-	86	422
<u>(Arafa et al.,</u> <u>2017)</u>	Glucose	1.11×10 ⁵	1117	92	462
<u>(Arunkumar,</u> <u>Suaganya, &</u> <u>Robinson,</u> <u>2019)</u>	Blood	262	-	100	-
<u>(Almpanis &</u> <u>Papanikolaou,</u> <u>2016)</u>	-	-	88	98	263
<u>(Lu et al.,</u> <u>2018)</u>	-	1264	84	90	840
This work	Blood, Tears fluid	946.50	1109.51±55.235	100	2214

Table 3. Comparison of detection sample1 and sample2, quality factor, transmission power and sensitivity parameters of the proposed sensor with the reported sensors.

4. Conclusion

The designed sensor has the ability to detect a person with cancer and diabetes from a healthy person by a human blood sample and a tears fluid sample. One of the features that distinguishes this structure is the simultaneous detection of two samples with two resonance nanocavity. By diagnosing

these cells, cancer cells, diabetic cells in blood samples and human tear fluid, diseases can be detection. The main task is detection by two resonance nanocavity at the center of the biosensor structure. Due to the importance of the accuracy and sensitivity parameter in the design of the sensors, the full width at half maximum FWHM = 1.8 nm and the shape FOM = 1550.11 \pm 150.11 RIU⁻¹. The sensitivity is at best S = 3080 nm / RIU and the resolution detection range is 31 \times 10⁻⁶ RIU.

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