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Sensitivity Enhancement of an Optical Sensor Based on A Binary Photonic Crystal for The Detection of Escherichia Coli by Controlling the Central Wavelength and The Angle of Incidence

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Abstract

The detection process of Escherichia coli (E. coli) bacteria in drinking water is a global problem as they can lead to hazardous conditions in the human body. In this work, a one-dimensional binary photonic crystal with the structure $\text{air}/(\text{GaAs}, \text{SiO}_2)^N/\text{D}/(\text{GaAs}, \text{SiO}_2)^N/\text{glass}$ is proposed as an optical sensor to detect E. coli bacteria, where D is the defect layer. Water and E. coli bacteria are treated as the defect layer. The sensing mechanism of the proposed detector is based on the refractive index difference between pure water and waterborne bacteria samples. The transmission spectra of the photonic crystal are investigated and the sensitivity to E. coli bacteria is calculated. The effects of the central wavelength and the angle of incidence on the sensitivity and sensor performance parameters are studied. It is found that the central wavelength increase can enhance the sensor sensitivity and most of the performance parameters. Increasing the incidence angle can improve the sensitivity and all the performance parameters such as full width at half maximum, quality factor, detection limit, sensor resolution, signal-to-noise ratio, dynamic range, detection accuracy and figure of merit.

Keywords: photonic crystal; Escherichia coli; biosensing; defect mode; transmission spectrum.

1. Introduction

Varying types of bacteria have different water body contamination levels. The presence detection of bacteria in water, therefore, plays a significant role in ensuring drinking water in a safe manner. Escherichia coli (E. coli) is a prokaryotic bacterium which in humans and other animals is known to cause diarrhea. This is a key bacterial indicator for environmental monitoring of water quality and food security [1]. At present, the most common existing detection techniques of E. coli bacteria are protein-chip technology [2], polymerase chain reaction [3], nucleic acid hybridization [4], immunology [5] and isolation and culture [6]. These results are exact, however certain restrictions still remain, such as complicated operation and extended analysis time. To realize bacteria rapid detection, several spectroscopy techniques, such as Raman [7], infrared [8] and fluorescence [9], have been employed for the detection of bacteria. These approaches have the disadvantage of high-performance requirements for instruments and the inability to give precise information on the structural and compositional features of bacterial cells.

Due to the vast range of applications in optics, optoelectronics and chemical and biological sensing, photonic crystals (PCs) have become very attractive in both technology and science [10-

15]. PCs are composite materials made up of a periodic combination of two or more media of different indices of refraction. Spectral properties such as the rate of spontaneous emission, group velocity, band structure, reflectance and transmittance are greatly affected by the periodic variation of the index of refraction. Each PC is characterized by forbidden and allowed bandgaps. The prohibited bandgap is known as a photonic bandgap that prevents light propagation through the PC over a range of frequencies [16-18]. PCs have been employed widely for the detection of chemicals, microorganisms, temperature and gas [19-23]. Optical sensors based on PCs are compact and have the capability for wide dynamic range and real-time monitoring. Several PC configurations have shown advantages in the detection of temperature, pressure, drugs and cancer. Introducing various analytes into the PC structure shows unique detection modes and tunable photonic properties. Due to their simple manufacturing, low cost and less parameter to optimize, 1-D PC structures are more attractive than 2-D and 3-D PC structures. 1-D PCs having plasma, dielectric, graded index and negative index materials have been reported. They have shown tunable photonic bandgaps and unusual optical properties for optical sensors, omnidirectional reflectors and multi-channel filter applications. Nowadays, the detection of the presence of microorganisms such as bacteria is a challenging task in the field of medicine. In most cases, blood analysis plays a major role in bacteria detection. The refractive indices of waterborne bacteria are unique and different from that of pure water. This property is useful for clinical diagnoses and the detection of diseases. Various types of PC detectors with multi-functionality and sound performances have been presented. The photonic bandgaps and optical PC-based sensors properties in different periodic and aperiodic multilayer structures have been investigated using computational techniques such as transfer matrix method, finite difference time domain, finite element method and plane-wave expansion.

The main objective of the current work is to design a PC- based sensor for monitoring the E. coli bacteria. The defect mode analysis is employed for the refractive index monitoring. It is also intended to investigate the effect of variation of central wavelength and angle of incidence on the performance of the PC detector. When Bragg quarter-wave condition is applied to determine the layer thicknesses of the PC, then changing the central wavelength is expected to have a significant effect on the performance of the PC-based detector. Moreover, the angle of incidence is one of the most significant parameters affecting the transmission spectrum of a PC. Therefore, it is expected to significantly affect the defect mode and hence the PC-based sensor.

2. Theoretical model

Figure 1 shows a schematic diagram of a one-dimensional binary PC with a defect layer of the form air/(AB)^ND(AB)^N/glass, where A and B are GaAs and SiO₂ respectively, and layer D is the defect layer. The transmission spectra are investigated for water and E. coli bacteria as defect layers. The transfer matrix method is employed to study the transmission properties through the PC. The characteristic matrix of one layer is given by

$$M_l = \begin{bmatrix} \cos \psi_l & \frac{-j \sin \psi_l}{\zeta_l} \\ -j\zeta_l \sin \psi_l & \cos \psi_l \end{bmatrix}, \quad (1)$$

where ψ_l is the phase in layer l and is given by $\psi_l = \frac{2\pi n_l d_l \cos \theta_l}{\lambda}$, where n_l and d_l are the refractive index and thickness of layer l . $\cos \theta_l = \sqrt{1 - \frac{n_0^2 \sin^2 \theta_0}{n_l^2}}$ is the angle in layer l . n_0 and θ_0 are the refractive index of ambient (air) and initial incident angle. For TE mode $\zeta_l = n_l \cos \theta_l$. The total transfer matrix M_{system} of the proposed PC is given by

$$M_{system} = M_0 (M_A M_B)^N M_D (M_A M_B)^N M_s = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}, \quad (2)$$

where M_s is the transfer matrix of the substrate layer.

The transmission coefficient can be written in terms of the total matrix elements as

$$t = \frac{2 \zeta_0}{(M_{11} + M_{12} \zeta_s) \zeta_0 + (M_{21} + M_{22} \zeta_s)}, \quad (3)$$

with, $\zeta_0 = n_0 \cos \theta_0$ and $\zeta_s = n_s \cos \theta_s$

The transmittance through the PC can be obtained as

$$\Gamma = \frac{\zeta_s}{\zeta_0} |t|^2. \quad (4)$$

Fig. 1. A binary photonic crystal for the detection of E. coli bacteria.

To determine the refractive indices of both water and E. coli, the Sellmeier equation can be used. For water, the index of refraction is given by

$$n_{water}(\lambda) = 1.32367 + \frac{3.13770 \times 10^{-3}}{\lambda^2} + \frac{1.04697 \times 10^{-6}}{\lambda^4}, \quad (5)$$

and the refractive index of E. coli is given as

$$n_{E.coli}(\lambda) = 1.37673 + \frac{1.99963 \times 10^{-3}}{\lambda^2} + \frac{1.86907 \times 10^{-4}}{\lambda^4}, \quad (6)$$

where the wavelength of the incident radiation is used in μm to find the indices in Eqs. (5) and (6).

The sensitivity (S) is the main parameter to estimate the proposed structure performance. The sensitivity is defined as the ratio of the change in the wavelength position of the transmission peak, $\Delta\lambda_R = \lambda_{bacteria} - \lambda_{water}$, to the change in the refractive index, $\Delta n = n_{bacteria} - n_{water}$. Then, it is given by

$$S = \frac{\Delta\lambda_R}{\Delta n} = \frac{(\lambda_{bacteria} - \lambda_{water})}{(n_{bacteria} - n_{water})} \quad (7)$$

Several parameters that determine the optical detector performance can be investigated. These parameters determine the quality and accuracy of the optical sensor. Among these parameters are the full width at half maximum (FWHM), quality factor (QF), detection limit (DL), sensor resolution (SR), signal-to-noise ratio (SNR), dynamic range (DR), detection accuracy (DA) and figure of merit (FoM). The following mathematical equations are used to find these parameters

$$FWHM = \Delta\lambda_{R\frac{1}{2}} \quad (8)$$

$$QF = \frac{\lambda_R}{FWHM} \quad (9)$$

$$DL = \left(\frac{2\Delta n}{3}\right) \left(\frac{FWHM}{\Delta\lambda_R}\right)^{1.25} \quad (10)$$

$$SR = \frac{\Delta\lambda_R}{\Delta n} DL \quad (11)$$

$$SNR = \frac{\Delta\lambda_R}{FWHM} \quad (12)$$

$$DR = \frac{\lambda_R}{\sqrt{FWHM}} \quad (13)$$

$$DA = \frac{1}{FWHM} \quad (14)$$

$$FoM = \frac{\Delta\lambda_R}{\Delta n * FWHM} \quad (15)$$

where $\Delta\lambda_{R\frac{1}{2}}$ is the difference between defect mode right and left edges at half maximum.

3. Numerical Results

Based on the transfer matrix method and using MAPLE 2017 software, the transmission spectra of the proposed PC are simulated. The spectral range of 300 to 800 nm is adopted. At the interfaces separating the neighboring layers of the PC, incident radiation at an angle of incidence (θ_0) encounters sequential transmissions and reflections. The incident beam's electric field vector is considered to be perpendicular to the plane of incidence (s-polarization or TE mode). The materials used in the proposed structure are nonmagnetic (relative permeability equals unity). The refractive indices of the defect layers (water and E. coli) are calculated using the Sellmeier approximation formula at room temperature (Eqs. 5 and 6, respectively). The refractive indices of GaAs, SiO₂,

and glass are 3.36, 1.46, and 1.5 respectively. The thicknesses of GaAs and SiO₂ layers are selected based on Bragg quarter-wave conditions such as $d_i = \frac{\lambda_c}{4 n_i}$, where λ_c is the central wavelength. The thickness of the defect layer is taken as $d_D = d_{\text{GaAs}} + d_{\text{SiO}_2}$. In Fig. 2, the variations of the refractive indices of water and E. coli bacteria with the incident radiation wavelength are shown. The sensing mechanism of the proposed PC is based on the refractive index difference between the two samples. This index variation leads to a resonant peak shift in the transmission spectra. Figure 3 illustrates the transmission spectrum of the proposed PC without a defect layer. The PC is considered to have the structure air/(GaAs,SiO₂)^N(GaAs,SiO₂)^N/glass. N and λ_c are taken as 4 and 450 nm, respectively. Normal incidence is assumed in which $\theta_0 = 0^\circ$. Figure 4 illustrates the transmission spectra through the structures air/(GaAs,SiO₂)^N/water/(GaAs,SiO₂)^N/glass and air/(GaAs,SiO₂)^N/E. coli/(GaAs,SiO₂)^N/glass, when water and E. coli bacteria are treated as defect layers at $\lambda_c = 450$ nm and $\theta_0 = 0^\circ$. The resonant peaks are found at wavelength positions of 488.3 and 494.5 nm for water and E. coli bacteria, respectively. The sensitivity of the proposed PC to the E. coli bacteria is calculated as 128.923 nm/RIU, where RIU is the refractive index unit. The quality factor (QF) of the proposed sensor is 1052.17 which is calculated using Eq. (9). It is found that the defect mode gets shifted towards longer wavelengths when E. coli bacteria instead of water is used as a defect layer. This shift is due to the refractive index-dependent resonant wavelength of the defect layer.

Fig. 2. Refractive index variation of E. coli bacteria and water as functions of the wavelength of the incident radiation.

Fig. 3. Transmission spectrum of the structure $\text{air}/(\text{GaAs}/\text{SiO}_2)^{2N}/\text{glass}$ without any defect layer at a central wavelength of $\lambda_c = 450 \text{ nm}$ and $\theta_0 = 0^\circ$.

Fig. 4. Transmission spectra of the structures $\text{air}/(\text{GaAs}/\text{SiO}_2)^N/\text{water}/(\text{GaAs}/\text{SiO}_2)^N/\text{glass}$ and $\text{air}/(\text{GaAs}/\text{SiO}_2)^N/\text{E. coli}/(\text{GaAs}/\text{SiO}_2)^N/\text{glass}$ at a central wavelength of $\lambda_c = 450 \text{ nm}$ and $\theta_0 = 0^\circ$.

Bragg quarter-wave condition is used to determine the layer thicknesses of the PC. Therefore, any variation of the central wavelength has a significant effect on the layer's thicknesses and hence on the detector performance. The transmission spectra at different central wavelengths (λ_c) and normal incidence angle ($\theta_0 = 0^\circ$) are investigated in Fig. 5. The central wavelength is varied from 350 nm to 600 nm by a step of 50 nm. Some enlarged views of the defect mode of these results (at $\lambda_c = 350, 400, 450$, and 500 nm) are shown in Fig. 5. All these results are shown in Table 1 which presents the full width at half maximum (FWHM), the defect mode position and the PC sensitivity at different central wavelengths. The defect mode gets shifted towards a longer wavelength region when E. coli bacteria replace pure water samples in the defect layer. Moreover, the increase of λ_c at constant θ_0 leads to a redshift of the wavelength positions of the defect modes. As can be seen from the table, the FWHM of both structures increases as the central wavelength increases, and the defect mode position of both analytes gets shifted towards a higher wavelength region as λ_c increases. The sensitivity enhances from 100.183 nm/RIU to 180.422 nm/RIU as the central wavelength changes from 350 nm to 600 nm. The variation of the defect mode FWHM of both analytes with the central wavelength variation is shown in Fig. 6. As the central wavelength increases for the same incidence angle, the FWHM enhances linearly for both structures. The central wavelength dependence of the transmission peak positions is linear for both analytes as shown in Fig. 7. The structure with E. coli bacteria as a defect layer has higher transmission peak positions when compared to those of water. Figure 8 shows that the sensitivity variation of the proposed detector with the central wavelength variation. It is linearly dependent on the central wavelength. It can be enhanced from 100.183 nm/RIU to 180.422 nm/RIU by increasing the central wavelength from 350 nm to 600 nm.

The effect of the central wavelength variation on the E. coli sensor performance parameters is studied in Table 2. The quality factor does not show a considerable dependence on the central wavelength. With the variation of λ_c , the quality factor shows some fluctuations in the range 1031 to 1052.17 which can be considered as small oscillations. The sensor is more efficient as the figure of merit gets higher. For $\lambda_c = 350$ nm, the figure of merit is 270.8 and it then shows a slight improvement to 286.4 as $\lambda_c = 600$ nm. The detection limit, which is the smallest change in the refractive index that can be precisely detected, decreases as the central wavelength enhances. It starts at 1.318 when $\lambda_c = 350$ nm and becomes 1.211 when $\lambda_c = 600$ nm, which is a good sign. Smaller detection limit values correspond to better performance of the sensor. Detection accuracy is defined as the reciprocal of the full width at half maximum. The sensor has a good performance when the full width at half maximum is narrow and the detection accuracy is as high as possible. With the increase of the central wavelength, the detection accuracy changes from 2.7 at $\lambda_c = 350$ nm to 1.59 at $\lambda_c = 600$ nm. The signal-to-noise ratio is a measure of the resonant peak signal strength relative to the background noise. The higher signal-to-noise ratio means a narrower resonant peak and a minute shift in wavelength is measurable. As can be seen from the table, signal-to-noise ratio is enhanced from 12.16 at $\lambda_c = 350$ nm to 13.65 at $\lambda_c = 600$ nm. The sensor resolution describes the smallest possible spectral shift that can be estimated precisely. The smaller the value of the sensor resolution the better is its performance. As the central wavelength increases from 350 nm to 600 nm, the sensor resolution increases from 0.132 to 0.219, respectively. Dynamic range is the ratio between the maximum value of amplitude and root mean square of the noise

floor. It starts at 633.1 when the central wavelength = 350 nm and attains a value of 829.88 at $\lambda_c = 600$ nm.

In conclusion to Table 2, increasing the central wavelength can improve the sensitivity, the quality factor, the detection limit, the signal-to-noise ratio, the dynamic range, and the figure of merit.

Fig. 5. Transmission spectra of the structures $\text{air}/(\text{GaAs}/\text{SiO}_2)^N/\text{water}/(\text{GaAs}/\text{SiO}_2)^N/\text{glass}$ and $\text{air}/(\text{GaAs}/\text{SiO}_2)^N/\text{E. coli}/(\text{GaAs}/\text{SiO}_2)^N/\text{glass}$ at normal incidence and central wavelengths of 350, 400, 450 and 500 nm.

Table 1. Variation of FWHM, defect mode position and the PC sensitivity with the central wavelength.

Central wavelength (λ_c) (nm)	FWHM of the defect mode of	FWHM of the defect mode of	Defect mode position (water)	Defect mode position (E coli)	Sensitivity = $\Delta\lambda / \Delta n$ (nm/RIU)
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	Water (nm)	E. coli (nm)	λ_1 (nm)	λ_2 (nm)	
350	0.34	0.37	380.6	385.1	100.183
375	0.36	0.40	407.5	412.4	106.641
400	0.38	0.42	434.5	439.8	113.251
425	0.41	0.45	461.4	467.1	119.994
450	0.44	0.47	488.3	494.5	128.923
475	0.46	0.50	515.3	521.8	133.75
500	0.48	0.53	542.2	549.2	142.785
525	0.50	0.55	569.2	576.6	149.807
550	0.53	0.58	596.1	603.9	156.883
575	0.55	0.60	623.1	631.3	163.998
600	0.57	0.63	650.1	658.7	180.422

Fig. 6. Variation of the defect mode FWHM of both water and E. coli bacteria with the central wavelength at $\theta_0 = 0^\circ$.

Fig. 7. Variation of the defect mode positions of both water and E. coli bacteria with the central wavelength at $\theta_0 = 0^\circ$.

Fig. 8. Sensitivity variation of the proposed PC with the central wavelength at $\theta_0 = 0^\circ$.

Table 2. Variation of the quality factor, figure of merit, detection limit, detection accuracy, signal-to-noise ratio, standard deviation, sensor resolution and dynamic range with the central wavelength.

Central wavelength (λ_c) (nm)	Quality factor (QF)	Figure of merit (FOM)	Detection limit (DL) $\times 10^{-3}$	Detection accuracy (DA)	Signal-to-noise ratio (SNR)	Sensor resolution (SR)	Dynamic range (DR)
350	1040.8	270.8	1.318	2.7	12.16	0.132	633.1
375	1031	266.6	1.337	2.5	12.25	0.143	652.06
400	1047.1	269.6	1.312	2.38	12.62	0.149	678.63
425	1038	266.7	1.325	2.22	12.67	0.159	696.31
450	1052.1	274.3	1.275	2.13	13.19	0.164	721.3
475	1043.6	267.5	1.312	2	13	0.176	737.94
500	1036.2	269.4	1.298	1.89	13.21	0.185	754.38
525	1048.4	272.4	1.278	1.82	13.45	0.191	777.49
550	1041.2	270.5	1.287	1.72	13.45	0.202	792.96
575	1052.2	273.3	1.269	1.67	13.67	0.208	815
600	1045.6	286.4	1.211	1.59	13.65	0.219	829.88

The transmission spectra of the proposed PC are investigated at different incident angles at a constant central wavelength of 450 nm. The angle of incidence is varied from 0° to 70° by steps of 5° . Enlarged views of the defect mode of some of these results (at $\theta_0 = 10^\circ, 20^\circ, 30^\circ$ and 40°) are plotted in Fig. 9. It is found that the defect mode gets shifted towards longer wavelengths when E. coli bacteria sample replaces the pure water. Increasing the incidence angle at constant λ_c leads to a blue shift of the resonant modes. Table 3 shows the variation of FWHM, defect mode position and PC sensitivity with the angle of incidence variation. It is shown that the FWHM for both analytes decreases as the angle of incidence increases as shown in Fig. 10 with the FWHM of the E. coli sample is greater than that of water. The variation of the defect mode position as a function of the angle of incidence for both analytes is plotted in Fig. 11. In contrary to its variation with the central wavelength, the defect mode position does not vary linearly with the incident angle. As the incident angle increases, the defect mode positions shift towards a lower wavelength region. The sensitivity variation as a function of the incident angle is illustrated in Fig. 12. As the incident angle increases from 0° to 70° , the sensitivity is considerably enhanced from 128.923 nm/RIU to 213.259 nm/RIU.

Table 4 presents the effect of the angle of incidence variation on the E. coli detector performance parameters. The quality factor, figure of merit, detection accuracy, signal-to-noise ratio and dynamic range show considerable enhancements with the increase of the angle of incidence. With the variation of incidence angle from 0° to 70° , the quality factor exhibits an improvement from 1052.1 to 10010, the figure of merit gets higher from 274.3 to 5331, the detection accuracy also enhances from 2.13 to 25, the signal-to-noise ratio shows an improvement from 13.19 to 240 and dynamic ranges also enhances from 721.3 to 2002. All of these enhancements are good signs for the detector efficiency. As the angle of incidence increases, the detection limit and sensor

resolution get smaller and smaller. When $\theta_0 = 0$, the detection limit and sensor resolution are 1.28 and 0.1644 and they continue decreasing to 0.0318 and 0.0068 as the angle increases to 70° . As the detection limit and sensor resolution get smaller, the sensor gets more efficient.

In conclusion of Table 4, increasing the angle of incidence can improve the sensitivity, the FWHM, the quality factor, the figure of merit, the detection limit, the detection accuracy, the signal-to-noise ratio, and the dynamic range.

Fig. 9. Transmission spectra of the structures $\text{air}/(\text{GaAs}/\text{SiO}_2)^N/\text{water}/(\text{GaAs}/\text{SiO}_2)^N/\text{glass}$ and $\text{air}/(\text{GaAs}/\text{SiO}_2)^N/\text{E. coli}/(\text{GaAs}/\text{SiO}_2)^N/\text{glass}$ at $\lambda_c = 450 \text{ nm}$ and different incident angles of $\theta_0 = 10^\circ, 20^\circ, 30^\circ$ and 40° .

Table 3. Variation of FWHM, defect mode position and the PC sensitivity with an the angle of incidence.

Incident angle (Deg)	FWHM of the defect mode of Water (nm)	FWHM of the defect mode of E. coli (nm)	Defect mode position (water) λ_1 (nm)	Defect mode position (E coli) λ_2 (nm)	Sensitivity = $\Delta\lambda / \Delta n$ (nm/RIU)
0	0.44	0.47	488.3	494.5	128.923
5	0.43	0.45	487.6	493.8	128.962
10	0.4	0.44	485.6	491.8	129.074
15	0.38	0.42	482.2	488.6	133.458
20	0.34	0.37	477.5	484	135.845
25	0.31	0.33	471.7	478.4	140.433
30	0.26	0.28	464.6	471.6	147.276
35	0.23	0.24	456.6	463.8	152.149
40	0.17	0.2	447.8	455.3	159.316
45	0.14	0.16	438.3	446.1	166.689
50	0.11	0.12	428.3	436.6	178.626
55	0.08	0.1	418.3	426.9	186.462
60	0.07	0.08	408.4	417.4	196.725
65	0.05	0.06	399.1	408.4	204.956
70	0.04	0.04	390.8	400.4	213.259

Fig. 10. Variation of the defect mode FWHM of both water and E. coli bacteria with the angle of incidence at $\lambda_C = 450$ nm.

Fig. 11. Variation of the defect mode positions of both water and E. coli bacteria with the angle of incidence at $\lambda_c = 450$ nm.

Fig. 12. Sensitivity variation of the proposed PC with the angle of incidence at $\lambda_c = 450 \text{ nm}$.

Table 4. Variation of the quality factor, figure of merit, detection limit, detection accuracy, signal-to-noise ratio, standard deviation, sensor resolution and dynamic range with the angle of incidence.

Incident angle (Deg)	Quality factor (QF)	Figure of merit (FOM)	Detection limit (DL) $\times 10^{-3}$	Detection accuracy (DA)	Signal-to-noise ratio (SNR)	Standard deviation (σ)	Sensor resolution (SR)	Dynamic range (DR)
0	1052.1	274.3	1.28	2.13	13.19	0.0548	0.1644	721.3
5	1097.3	286.6	1.21	2.22	13.78	0.0519	0.1557	736.11
10	1117.7	293.4	1.17	2.27	14.09	0.0505	0.1514	741.42
15	1163.3	317.8	1.06	2.38	15.24	0.0472	0.1417	753.93
20	1308.1	367.1	0.887	2.7	17.57	0.0402	0.1205	795.69
25	1449.7	425.6	0.738	3.03	20.3	0.0345	0.1036	832.79
30	1684.3	526	0.567	3.57	25	0.0278	0.0835	891.24
35	1932.5	634	0.449	4.17	30	0.0228	0.0684	946.73
40	2276.5	796.6	0.338	5	37.5	0.018	0.0539	1018.1
45	2788.1	1042	0.242	6.25	48.75	0.0135	0.0404	1115.3

50	3638.3	1489	0.155	8.33	69.17	0.0092	0.0277	1260.4
55	4269	1865	0.117	10	86	0.0073	0.0219	1350
60	5217.5	2459	0.0832	12.5	112.5	0.0055	0.0164	1475.7
65	6806.7	3416	0.0553	16.7	155	0.0038	0.0113	1667.3
70	10010	5331	0.0318	25	240	0.0023	0.0068	2002

Conclusion

A binary PC having the structure air/(AB)^ND(AB)^N/glass has been investigated as an optical sensor for the E coli bacteria, where A and B are GaAs and SiO₂, respectively. D is the defect layer which can be pure water or waterborne bacteria samples. The transfer matrix method has been employed to study the transmission spectra of the structure. There is a minute difference between the refractive index of pure water and that of E. coli bacteria which is the principle of operation of the proposed detector. This index variation leads to a shift in the resonant peak position. All the sensor parameters such as sensitivity, full width at half maximum, quality factor, detection limit, sensor resolution, signal-to-noise ratio, dynamic range, detection accuracy and figure of merit have been investigated with the central wavelength and the angle of incidence. Many interesting findings have been found. Any increase of the central wavelength can enhance the sensor sensitivity and most of the performance parameters. The increase of the incidence angle is found to be more influential and significant than that of the central wavelength. The increase of the incidence angle can improve the sensitivity and all the performance parameters.

Declarations

Conflicts of interest: The authors declare no conflict of interest.

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