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GLUCOSE OPTICAL SENSOR BASED ON A TERNARY PHOTONIC CRYSTAL COMPRISING A SUPERCONDUCTOR LAYER

Safaa Alqrinawi[1*], Sofyan Taya[1]
scientistakai@gmail.com, staya@iugaza.edu.ps
[1]Physics Department, Islamic University of Gaza, P.O.Box 108, Gaza, Palestine

KEYWORDS

Photonic crystal, superconductor, defect layer, glucose detection.

SHORT SUMMARY

The detection of glucose is one of the most challenging issues in the medical field. A novel sensor based on a one-dimensional ternary photonic crystal is proposed for the detection of glucose. The proposed structure consists of a defect layer sandwiched between two identical periods. The proposed structure has the materials: air/ dielectric/ superconductor/ metal/ air, i.e. (SiO_2/ $YaBa_2Cu_3O_7$/Ag)^5. The transmission spectra are investigated using the transfer matrix method. The effects of varying the incident angle, the defect layer thickness, and the number of periods on the sensitivity are exhaustively investigated. High sensitivity of 487.804 nm/RIU is obtained for the proposed detector. Moreover, the proposed sensor has a low cost, easy to design with a nano-scale size. The aforementioned outcomes could open up an effective and applicable path for bio- and chemical detection.

EXTENDED ABSTRACTS

Introduction

In this work, a highly sensitive glucose optical sensor based on a 1D photonic crystal is proposed. Using the transfer matrix method (TMM) [1], we detect glucose concentration in a sample. We also investigate the temperature effects on the sensitivity of the proposed sensor. A ternary defective photonic crystal is used for this purpose. It is made by sandwiching a layer of superconductor ($YaBa_2Cu_3O_7$) between two layers of Silicon dioxide (SiO_2) and silver (Ag). Photonic crystals (PCs) are optical nano- or microstructures with different dielectric constants arranged periodically in 1D, 2D, or 3D. The interaction of light with the PCs is analogous to the interaction of electrons in the atomic crystal. This interaction leads to a forbidden frequency window for photons in a certain direction. As a result, a photonic band gap (PBG) is formed.

Theoretical Model

We consider a 1D ternary PC structure with three constituent materials. The proposed structure is formed by sandwiching a layer of superconductor ($YaBa_2Cu_3O_7$) between two layers of Silicon dioxide (SiO_2) and silver (Ag) to form a 1D PC sequence of the shape (SiO_2/ $YaBa_2Cu_3O_7$/Ag)^5 defect (SiO_2/ $YaBa_2Cu_3O_7$/Ag)^5. The thicknesses of SiO_2, $YaBa_2Cu_3O_7$ and Ag are h_1, h_2, and h_3, where h_1 = 120 nm, h_2 = 80 nm, and h_3 = 10 nm. The unit cell of the PC structure has a thickness given by $h = h_1 + h_2 + h_3$. The defect layer has a thickness given by h_4= 230 nm. The refractive index of SiO_2 is n_1 = 1.45. The refractive index of $YaBa_2Cu_3O_7$ is given by the Gorter-Casimir two-fluid model [2,3] and the refractive index of the Ag layer is given as $n_3 = \sqrt{\varepsilon(\lambda)}$ where ε is the metallic dielectric function. The transmission spectrum of the proposed structure is investigated using TMM. For a plane wave injected into 1D ternary PC at an angle θ_0, the relation between field amplitude of the first two layers can be obtained in a matrix form by solving Helmholtz equation as

$$\begin{pmatrix} C_1 \\ D_1 \end{pmatrix} = \begin{pmatrix} \frac{1}{2}(1+\frac{k_{1z}}{k_{2z}})e^{ik_{1z}d_1} & \frac{1}{2}(1-\frac{k_{1z}}{k_{2z}})e^{-ik_{1z}d_1} \\ \frac{1}{2}(1-\frac{k_{1z}}{k_{2z}})e^{ik_{1z}d_1} & \frac{1}{2}(1+\frac{k_{1z}}{k_{2z}})e^{-ik_{1z}d_1} \end{pmatrix} \begin{pmatrix} A_1 \\ B_1 \end{pmatrix} = M_{12} \begin{pmatrix} A_1 \\ B_1 \end{pmatrix} \quad (1)$$

such that the electric field has forth and back amplitudes A_1 and B_1, respectively, and it has forth and back amplitudes C_1 and D_1, respectively in the second layer, k_{1z} and k_{2z} are the wavenumbers.

For the structure of 1D photonic crystals of period N, the field amplitude at the ambient and the last

*Corresponding author

layer can be written as

$$\begin{pmatrix} A_0 \\ B_0 \end{pmatrix} = (M_{qp})_1 \, (M_{qp})_2 \, \dots \, (M_{qp})_N \begin{pmatrix} A_{N+1} \\ B_{N+1} \end{pmatrix} = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} \begin{pmatrix} A_{N+1} \\ B_{N+1} \end{pmatrix} \quad (2)$$

The transmission coefficient "*t*" is given in terms of the matrix elements as

$$t = \left| \frac{A_{N+1}}{A_0} \right| = \sigma_{11} \quad (3)$$

The transmitance "*TR*" can be written of *t* as

$$TR = |t|^2 \quad (4)$$

The main idea of an optical sensor based on a defective PC is the existence of a defect mode in the PBG as a result of the defect layer which is filled with glucose solution. Both the position and intensity of the defect mode depend on the refractive index of the defect layer. The refractive index changes with the change in the concentration and temperature of glucose solution as

$$n_4(C,T) = 1.3356 + (1.5333 * 10^{-3}) * C - (9.* 10^{-5}) * C^2 - (1.2647 * 10^{-4}) * (T - 273.15) - (4.0 * 10^{-8}) * (T - 273.15)^2 \quad (5)$$

Numerical Result

The transmission spectra are investigated with the variation of the strcuture parameters. The following observations are found:

(i) Transmission spectra at different glucose concentrations C starting from C = 0 % to *C* = 50 % with a 10 % step are studied. Redshift of the defect mode is observed. Moreover, transmission spectra are studied at different temperatures of *T* = 273.1, *T* = 303.1, and *T* = 313.1 K at a glucose concentration of 50 %. The results show a significant Red shift.

(ii) Transmission spectra are also studied at different temperatures of *T* = 298.1, *T* = 308.1, and *T* = 318.1 K at a glucose concentration of 30 %. The resonant peak shifts from 811.08 nm to 810.81 nm, and 810.53 nm.

(iii) The effect of changing the angle of incidence θ_0 on the transmittance spectra is also investigated. The resonant peak is significantly blue shifted. The sensitivity is dramatically enhanced with the increase of the incidence angle.

(iv) A number of repetitions N = 3 is considered an optimum number that corresponds to the highest sensitivity.

(v) The quality factor of an optical sensor is a significant parameter. It was calculated for concentrations of C = 0 % and C = 50% and found as 710.037 and 709.628, respectively.

Conclusion

In this work, we have assumed a 1D PC as an optical sensor. The proposed PC is ternary and it has a superconductor layer as one of the constituent layers. The superconductor material has a frequency and temperature dependent dielectric function. The structure of the PC is $(SiO_2/YaBa_2Cu_3O_7/Ag)^5$ defect $(SiO_2/YaBa_2Cu_3O_7/Ag)^5$. The transmission spectra of the PC have been investigated with the different parameters of the structure. Many interesting features have been found. The most important feature is that a high sensitivity of 487.804 have been obtained for the optimized parameters.

References

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