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Precision Diabetes Detection Using Nano Photonic Crystal Sensors

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Abstract

Diabetes mellitus is a metabolic disorder characterized by persistently elevated blood glucose levels in otherwise healthy individuals. The primary aim of this study is to explore the simulation of photonic crystal-based biosensors for diabetes monitoring. The results indicate that the sensor can detect glucose concentrations as low as 7 mM (0.13%). Moreover, the study demonstrates that the sensor can accurately measure resonance shifts even for minor fluctuations in glucose concentration. Therefore, the photonic crystal-based sensor shows potential for diabetes monitoring. The sensitivity of the sensor is measured at 282.1304 nm/RIU with a Q factor of 70.56. The findings of this study are significant for the design and development of photonic crystals for diabetes monitoring.

Keywords:- Nano, Photonic crystal, Diabetes, Sensor, Wavelength.

Introduction

Diabetes mellitus, more commonly referred to by its colloquial term, is a metabolic disorder characterized by chronically elevated blood glucose levels. Type 2 diabetes is distinguished by a prolonged increase in glucose levels in the bloodstream. Diabetes can lead to several adverse health conditions, including cardiovascular disease, diabetic ketoacidosis, chronic renal disease, stroke, and mortality [1]. Blood glucose levels aid in the diagnosis of diabetes. Post-meal glucose concentrations below 8 mM are considered healthy. Levels between 7.8 and 11.11 mM indicate pre-diabetes, while levels greater than 11.11 mM are indicative of diabetes [2].

A glucose concentration of 10 mM in the blood signifies the presence of 10 millimoles or 0.01 moles of glucose per liter of blood. To convert this to grams, multiply the relative mass of glucose by 0.01 mol of glucose. To determine the percentage of glucose level in the blood, divide the mass of glucose in grams by the blood volume in liters or milliliters, then multiply the result by 100. A concentration of 10 mM of glucose is equivalent to 0.18016% [3].

To detect extremely low concentrations of biological molecules, a highly sensitive sensor is desirable. This article focuses on designing a photonic crystal-based sensor for detecting glucose levels in blood. Photonic crystals (PhCs) are periodic materials with distinctive features that prevent the transmission of electromagnetic (EM) waves through the crystal within specific band gaps. The photonic band gap (PBG) refers to a range of wavelengths in which light transmission through the material is either prohibited or allowed [4].

This study presents the design and modeling of photonic crystal-based biosensors using the MEEP tool. MEEP, an open-source tool from MIT, is computer-aided design software that assists in assessing the performance of photonic components. It facilitates the simulation of light diffraction, reflection, propagation, and polarization effects. This scholarly work provides a comprehensive and meticulous analysis of the structure at the nanoscale to detect diabetes mellitus. The sensor is designed using a 2D double ring structure with a cavity, incorporating rods arranged in the air. The structure comprises two rings and a waveguide, both initially empty [5]. When the sensor is immersed in the analyte, the air is displaced by the analyte. Light is then passed from one end to the other of the photonic crystal sensor. As light interacts with the sensor's constituent analyte, its propagation changes based on the refractive index [7].

Design Parameters:

- Basic Configuration: Double ring structure
- Rod Radius: 0.2 µm
- Lattice Structure: Square
- Dielectric Constant: Silicon
- Rod Height: 0.65 µm
- Analyte: Glucose Concentration

Using the MEEP tool, the photonic crystal is designed. Table 1 provides the refractive index of the analyte corresponding to different glucose concentration percentages.

Table 1 Refractive index of various glucose concentrations

mM	% Concentration	Refractive Index
277.5	5	1.4196
222	4	1.4099
166.6	3	1.4014
111	2	1.3940
55.5	1	1.3853
22	0.40	1.3765
17	0.31	1.3671
12	0.22	1.3572
7	0.13	1.3481
0	0	1.3391

The design of the structure and the propagation of light through it are shown in Figure 1 to Figure 3.

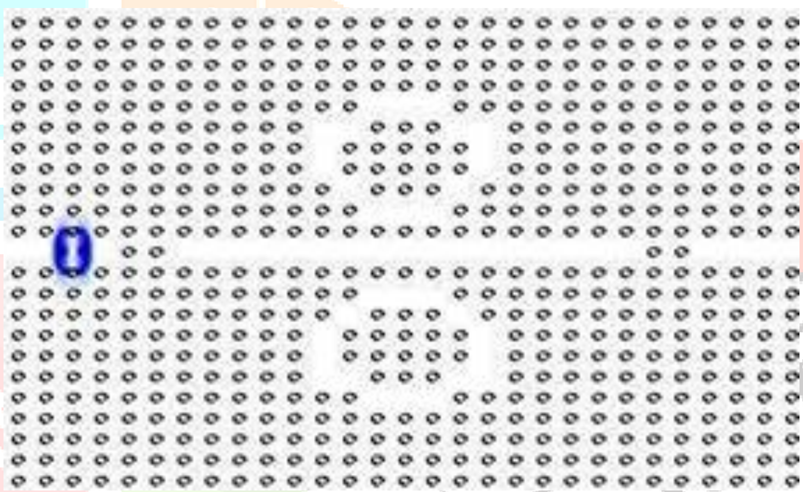

Figure 1: Structure with rods in air configuration

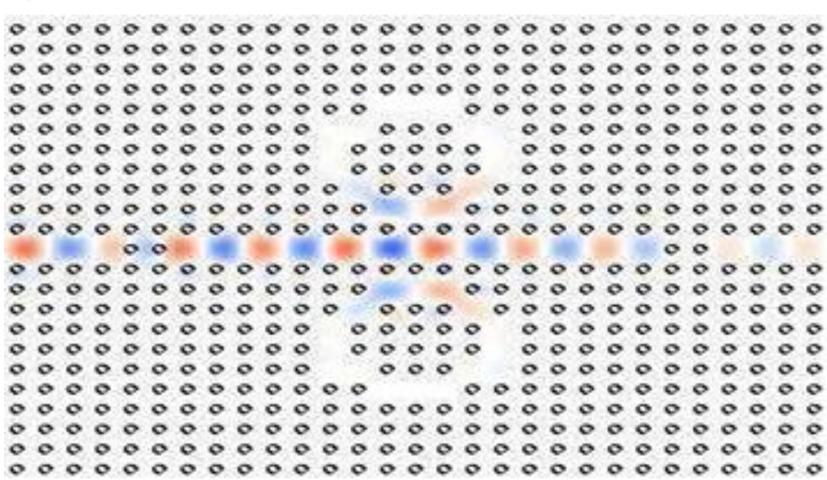

Figure 2: Light transmission through the structure

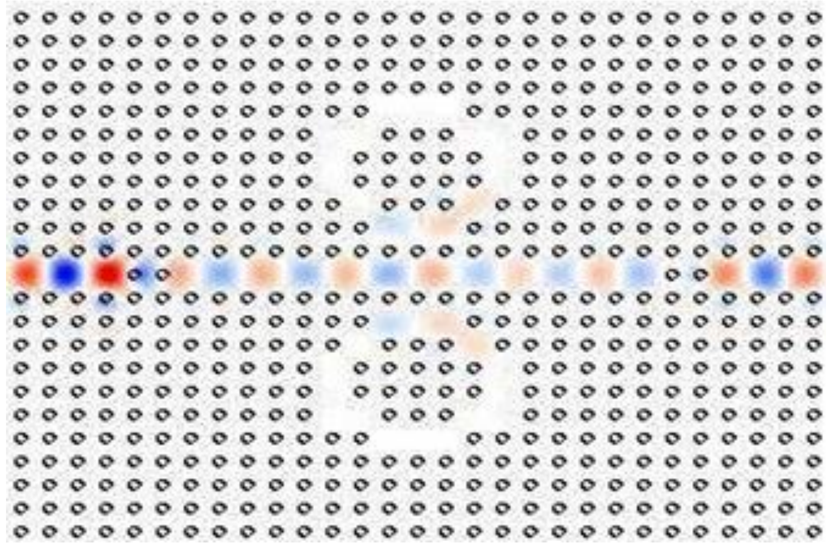

Figure 3: Light is transmitted to the other end

Results

The proposed structure consists of two rings with a bus waveguide. Light transmitted through this structure is confined within the waveguide and subsequently reaches the detector. The center frequency of the incident light beam is set at 0.3. The structure is optimized to achieve high sensitivity and a favorable Q factor. The transmission spectrum shifts in response to changes in glucose concentrations in the sample, as illustrated in Figure 4. A linear variation in the resonant peak shift is observed with varying glucose concentrations.

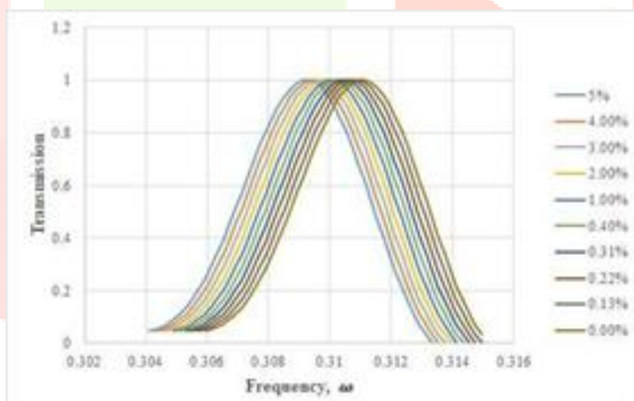

Figure 4: Transmission spectrum for different glucose concentrations

Table 2 shows the peak wavelength, amount of shift in wavelength, sensitivity and Q factor for different glucose concentrations. The obtained results conclude that the proposed structure gives better sensitivity.

Table 2 Refractive index of various glucose concentrations

Glucose Concentration (%)	Shift in Wavelength (μm)	Resonant Peak Wavelength (μm)	Sensitivity (nm/RIU)	Q factor
5	0.002093	3.232912	215.7914	70.15
4	0.002090	3.230819	245.9374	70.20
3	0.002088	3.228729	282.1304	70.25
2	0.002085	3.226641	239.6628	70.29
1	0.002082	3.224556	236.6333	70.34
0.40	0.002080	3.222473	221.2431	70.38
0.31	0.002077	3.220394	221.2431	70.43
0.22	0.002074	3.218317	209.7983	70.47
0.13	0.002072	3.216242	227.7479	70.52
0.00	--	3.214171	230.1837	70.56

Q factor and sensitivity are the two most important parameters of the sensor performance. The maximum sensitivity obtained is 282.1304 nm/RIU and a Q factor of 70.56. Table 3 presents a comparative analysis between the findings of past studies and the current research.

Table 3 Comparative results with the previously reported work

Reference	Sensitivity (nm/RIU)	Q factor	Year of Publication
[6]	4.125	1750	2014
[7]	330	35517	2014
[8]	260	--	2015
[9]	462	$1.15*10^5$	2017
Present work	**295.1304**	**73.56**	-

Conclusion

This study focuses on the design and modeling of a biosensor using photonic crystals to detect various glucose concentrations. The MIT-MEEP tool is employed to design and analyze the proposed sensor structure. Peak wavelength shift, sensitivity, and Q factor are recorded, yielding a sensitivity of 282.1304 nm/RIU and a Q factor of 70.56. The proposed sensor demonstrates potential as a suitable candidate for measuring different glucose concentrations in a given sample.

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