Photonic Crystal Sensor For The Detection of RedBlood Cells Clotting In Blood

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***Abstract*—A photonic crystal biosensor with a y-shape cavity structure is proposed in this paper to sense the Red Blood cell (RBCs) concentration in blood. This sensor is proposed for biomedical applications to analyze the concentration based on the refractive index profile. Blood is a very crucial component of the human body. This blood is composed of several components and RBCs are very important parameters in blood. RBC concentration detection is essential for the diagnosis of red thrombus conditions and several critical diseases. So, the identification of variation in RBC concentration in blood with higher accuracy and maximum sensitivity is critical. This photonic crystal sensor detects changes in the detecting waveguide's refractive index, which change in response to changes in the blood's red blood cell (RBC) content. The change in the refractive index also changes the normalized output power and also shifts the position of the resonant peak. The dimension of the proposed structure is very .compact. The sensitivity of the design structure is 1820 nm/RIU and the normalized output power is around 60%. The Simulation is done in the Finite Difference Time Domain (FDTD).**

***Index Terms*—Hemoglobin, blood clotting, Red Thormbus, FDTD Method, Sensitivity.**

I. INTRODUCTION

Biosensing is a new analytical discipline that uses electrical, optical, calorimetric, and electrochemical transducing systems to detect biological interactions [1]- [2]. These transduction mechanisms are used to transform a signal from the biological domain into one that can be read and quantified. Most commonly, biosensors are used to detect cells, bacteria, viruses, proteins, hormones, enzymes, and nucleic acids, all of which play important roles in illness diagnosis and prognosis [3]- [10]. In recent years, several new diseases reported worldwidefrom time to time. These diseases may be the reason of humandeath because these diseases are not diagnose at early stages and no prominent sympthoms visible on human body [11]- [12]. Most of these diseases are due to in balance of blood component in human blood [13]- [14]. In Covid-19, most of the post Covid deaths are due to the heart stroke and brain stroke.

Human blood is the composition of several component. Hemoglobin, plasma, platelets, red blood cells (RBC), White blood cell(WBC) and water are the important components among them. One or more than one blood component concentration variation create a significant impact on human body and responsible of several critical hematological diseases like leukaemia, anaemia, diabetes, cancer and blood clotting. Blood is consisting of 45% blood cells and 55% plasma [15]. Blood clotting is the effect of concentration variation of platelets or red blood cells [16] . Blood clotting is known as thrombus. If the clotting is due to qualitative or quantitative abnormalities in platelets concentration, than clotting is known as white thrombus. If the clotting is due to qualitative or quantitative abnormalities in RBC concentration, than clotting is known as red thrombus [17]. This thormbus is the main reason of heart stoke/brain stoke or some kind of disabilities . TableI shows the refractive index of RBC and effect of refractive index of RBC. From the table it is clearly shows that refractiveindex 1.370-1.420 is the refractive index of normal personthat means the concentration is lies between 4.7-6.1 millions per microlitre of blood. If the RBC shape is varies or RBC Concentration is varies than refractive index is less than 1.370 or greater than 1.420.

TABLE I
REFRACTIVE INDEX OF RBC AND EFFECT OF REFRACTIVE INDEX

Refractive Index	Effect of Refractive Index
1.370-1.420	Normal RBC Concentration
< 1.370	Variation in RBC Concentration\Decrease in Hemoglobin Concentration\RBC shape variation. Chances of apoptosis
> 1.420	Variation in RBC Concentration\ Increase in Hemoglobin Concentration\

In this paper Si based y-shape photonic crystal is designed. Section-I introduce the blood component, RBCs concentra- tion and effect of RBC Concentration with photonic crystal structure. The Design structure with essesntial parameter for designing is discussed in section-II. In Section-III, simulation results are discussed. In this section normalize power of reference and sensing waveguides and sensitivity of this structure is also discussed. Section-IV discussed the conclusion of this paper.

II. Literature Review

PC structures are made up of spatially ordered periodic dielectric materials that have a one-of-a-kind interaction with light and allow for very efficient reflection at narrow wavelengths. Micro cavities, wave guides, slabs, and multilayer thin films are only some of the building blocks for a wide variety of one, two, and three dimensional PC structures [18]- [20]. Bragg reflectors, slabs, opals, micro cavities, and colloids are just some of the geometries that can be used to create PC structures. Assuming familiarity with a basic Bragg structure, one can infer the existence of an optical phenomena that describes the vast majority of these structures. Thin film layers of dielectric with alternating high and low refractive indices make up the standard Bragg reflector.

Photonic crystal is the prominent device for bio-sensing application due to compact size and higher sensitivity. Photonic biosensor has been worked on two mechanism to sense the analytic. The two sensing mechanism is label-free detec- tion mechanism and fluorescence- based detection mechanism[21]-[23]. The most widely utilised class of PhC sensorsis refractive index-based sensors. In reality, a lot of cutting- edge architectures (such interferometric configurations and integrated micro cavities) use refractive index sensing as a form of detection. PhC sensors based on RI have several advantages over alternatives, including as their ability to detectin real time, their high sensitivity and selectivity, and the fact that they require little to no sample preparation (and so donot require fluorescent labelling). The use of photonic crystals(PhCs) in sensing applications is very promising. As a matter of fact, PhCs feature impressive optical confinement of light to a vanishing small volume, enabling the detection of chemical species with dimensions on the nanometer scale; this is made possible by the intensive study and use of a wide varietyof photonic architectures in photonic sensing (for example, ring resonators, surface Plasmon resonance (SPR) - based sensors, micro disks, micro spheres, and so on). Additionally, by utilising state-of-the-art chemical surface fictionalization methods and integrating with micro fluidic systems, extremely high performance may be achieved on ultra tiny sensor chips. For the analysis of specific component, label-free detection mechanism is prefer. In label-free detection, the refractiveindex of sensing nodes is change with refractive index ofanalyte. When the optical signal is pass through this analytic nodes having different refractive index, the resonating peakof optical signal is shifted accordingly [24]. By detecting the shifting in resonant peak, concentration of RBC is detected to analyse that RBC concentration is normal or not. For analysing the performance of design structure, sensitivity and normalized output power is important parameter. The sensitivity is the ratio of shifting the position of resonant peak by changing the refractive index of medium to change in refractive index [25].

$$S = \frac{\delta\lambda}{\delta n} nm/RIU \quad (1)$$

Sensitivity tells that how minimum refractive index can sense through this design structure.

III. Design Structure

The photonic crystal structure is design with a Si substrate. The design structure proposed in this paper is shown in Fig. 1. This design structure consists of three waveguide region i.e Input waveguide, reference waveguide and sensing waveguide. The refractive index of Reference waveguide region is air and refractive index of air holes in sensing waveguide region is change according to the refractive index of analyte. Table II shows the design parameter for the design structure. Lattice constant and radius of air holes is important parameter for proper confinement of signal. For proper confinement of optical signal ratio of radius and lattice constant should lies from 0.25-0.4.

All the simulation is done on 1550nm wavelength for this design structure. Lattice dimension is 17x19 is select for the proper confinement of signal. This dimension is select on the basis of multiple simulation for different lattice dimension to detect that no signal will go outside of this design structure.

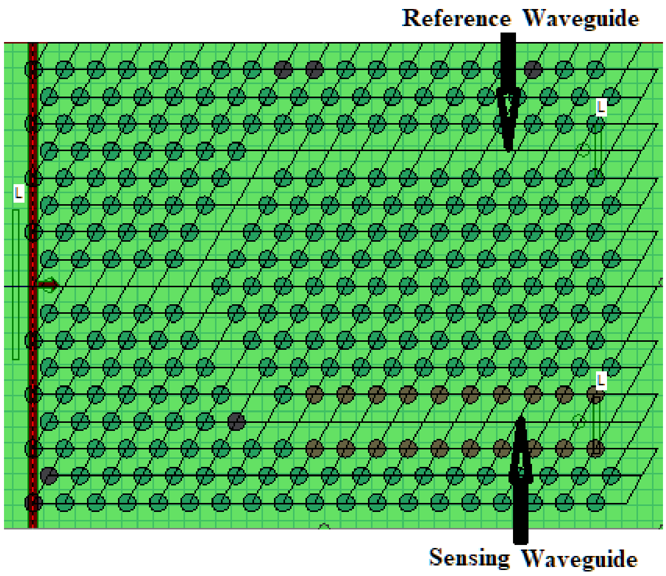

Fig. 1. PC structure indicating sensing and reference waveguide

TABLE II DESIGN STRUCTURE PARAMETER

Paameter	Value
Lattice constant	0.5μ m
Air Rods radius	0.14mm (r/a = 0.28)
Lattice dimension	a= 17; c=19
Refractive index of substrate	3.45 (3.42-3.48)
Refractive index of sensing waveguide nodes	refractive index of analyte (1.343-1.351)
Resonating Wavelength	1550 nm

For the proper transmission of optical signal Photonic band gap (PBG) is important property. This photonic band gap define the range of operation at which the optical signal will travel through the structure with minimum interaction. This PBG structure is similar to electronic band gap (SBG) in semiconductor. Solving Maxwell's electromagnetic equation yields the following equation for the photonic crystal's TE and TM modes' light controlling equation:

$$\nabla \times E(r) - j\omega\mu_0 H(r) = 0 \quad (2)$$

$$\nabla \times H(r) + j\omega\epsilon_0\epsilon(r)E(r) = 0 \quad (3)$$

$$\nabla \times (1/(\epsilon(r))\nabla \times H(r)) = \left(\frac{\omega}{c}\right)^2 H(r) \quad (4)$$

Transverse electric (TE) and transverse magnetic (TM) optical signal modes, as well as the behaviour of photonic crystal structures, may be solved by employing these Maxwell equations.

IV. Simulation Result

The design structure is simulate through Finite difference time domain (FDTD) method. Fig.2 shows the photonic band gap for this design structure.

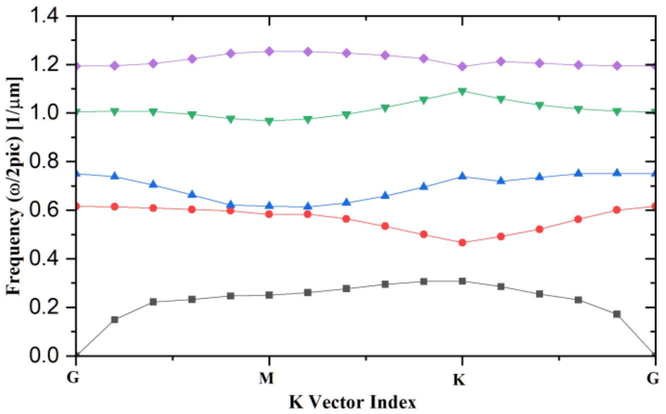

Fig. 2. Photonic Bandgap of proposed structure

From this fig the operating wavelength is calculated as.

$$\lambda = \frac{a}{f} \quad (5)$$

Where a is the lattice constant, f is the frequency of the photonic band gap and λ is the resonating wavelength. for this sensor, the photonic bandgap region is 0.31-0.42 μm^{-1} and 0.76-0.97 μm^{-1}, so the operating wavelength is 515-657nmand 1219-1620nm. The input wavelength 1550nm lies in this operating wavelength region.

Fig.3 is the normalized input power at input port. The input wavelength for the design structure is 1550nm, so all the operation is performed on this wavelength.Fig.4 is the normalized output power from the reference port. The normalized output power is 67% as compare to input signal power and the location of the resonant peak is 1561.7nm. Fig.5 is the normalized output power passes through the sensing region. The normalized output power from the sensing region when the sensing region refractive index is 1.34 and the normalized output power is 60%. By comparing the power of fig.4 and fig.5, it is clearly identified the shifting of resonating peak for analytic refractive index and variation of normalized output power.

TABLE III TABLE TYPE STYLES

Refractive Index of RBC	Shift in Resonant Peak (nm)	Sensitivity (nm/RIU)
1.342	1561.70 (As Reference)	-
1.341	1.82	1821.7
1.34	3.64	1818.5
1.339	5.46	1819.2
1.338	7.28	1819.3
1.337	9.1	1819.3
1.336	10.9	1816.8
1.335	12.76	1823.4
1.334	14.56	1820.5

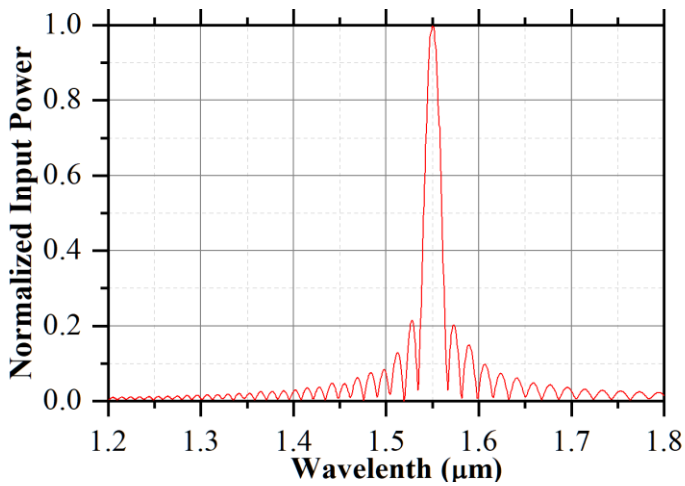

Fig. 3. Normalized input power at Input port

When the signal is applied as input port, it will distribute in two parts. One part of signal is pass through reference waveguide region. The normalized output power and position of resonating peak is observed by observation point. This is taken as a reference observation. The another part of signal pass through sensing waveguide region. The refractive index of air holes in sensing waveguide region is changes from 1.334to 1.342 according to the concentration of RBC cells. TableIII shows that the sensivity of structure is approximate 1812 nm/RIU.

V. Conclusion

This research proposes a Y-shaped photonic crystal structure based on Si for analysing RBC concentration (RBCs). A shift in the red blood cell concentration causes a shift in the refractive index. The structure is useful for label-free detection

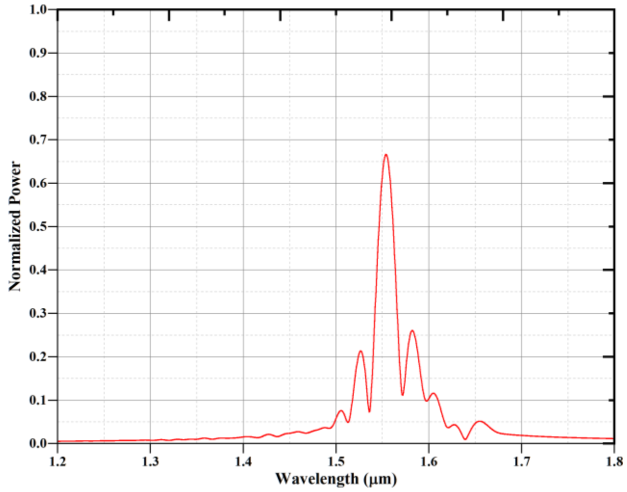

Fig. 4. Normalized output power from Reference waveguide

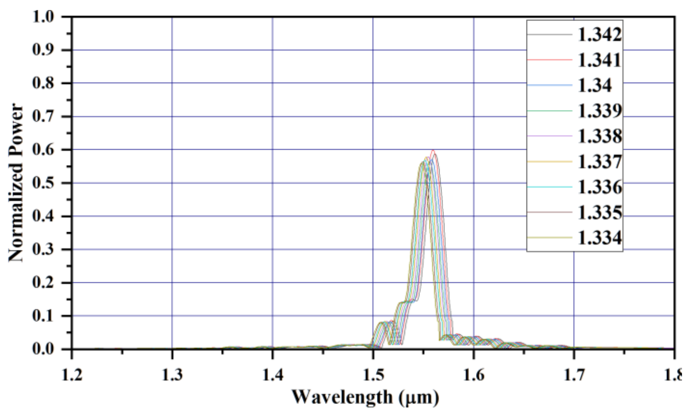

Fig. 5. Normalized output power from sensing waveguide

mechanisms. When the light pass through a medium having the refractive index of anlayte, the resonant peak is shifted from its original position. According to this shifting, the RBCs concentration is calculated. The dimension of design structure is 10.5*8.6 μm and the sensitivity of design structure is 1812 nm/RIU. The normalized output power from the sensing waveguide is 38.3% and reference waveguide is 56.4%.

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