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Design Two Dimensional Nanocavity Photonic Crystal Biosensor Detection in Malaria

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Abstract—

In this paper we design a two dimensional (2-D) photonic crystal based biosensor implemented by linear waveguide and nanocavity detection in malaria. The bio molecules such as a red blood cell, infected red blood cell, trapped inside the nanocavity cause transmission shift at the output terminal. The sensing mechanism of biosensor is change in refractive index of analytes. The layout biosensor is consists a linear waveguide with a nanocavity in square symmetry For the proposed photonic based biosensor, the band gap from 2210nm to 1420 nm and input wavelength of 1550nm are used in this design. The simulation results have analysed by using the finite difference time domain (FDTD) method, bandgap calculation is performed using plane wave expansion method.

Keywords— Red blood cell, Finite Difference Time Domain, Photonic Crystal; Plane Wave Expansion; Refractive Index,

I. INTRODUCTION

The term "biosensor" is a biological sensor which is used for sensing the device that has the immobilized materials such as enzyme, antibody, nucleic acid hormones, organelle, or whole cell. The bio element collaborates with sensing element and biological response is converted into an electrical signal by the transducer. Many types of biosensor are use- electrochemical biosensors, amperometric biosensors, blood-glucose biosensor, potentiometric biosensors, and optical biosensors. A biosensor should be a small size, manufacturable in large numbers and at low cost, give a rapid result within a time of process.

1.1 Photonic Biosensor-

Photonic based bio sensor is new research direction in optical field. In last year many developments are done in biosensor device, photonic based biosensor is one of them. Photonic biosensor are presents early diagnostic tool and provide a superior sensitivity, reliability, stability, fast response in vivo and vitro diagnostics [1]. Photonic crystal is natural material and the periodicity of material is maintaining different background material. It is a periodic dielectric structure with lattice parameter based on order of wavelength of propagated electromagnetic wave. One of very important characteristics of photonic crystal is its light confinement and controlling property. These characteristics allowed the crystal to use in various sensing applications [2]. In this paper, we design a bio sensor for detection malaria.

1.2 Malaria –

Malaria is a leading cause of disease and death across the globe, accounting for up to 500 million febrile cases and as many as 1 million deaths per year Malaria is a mosquito-borne infectious disease affecting human and other animal. This disease generally transfers by an infected female Anopheles mosquito. The mosquito bites introduces the parasites from the mosquito's saliva into a person blood. The parasites travel to liver where they grown up and reproduce. Five types of plasmodium infect and are spread by human. The type of plasmodium is P falciparum, P vivax, P ovale, P malariae, and P knowlesi. The most fatal is P falciparum. The life cycle of Plasmodium begins when an infected Anopheles mosquito bites a human and injects sporozoites into the host's blood. As the mosquitoes feed on human blood, malaria parasites called sporozoites are injected into human tissues. The sporozoites travel to the blood stream and invade the liver cells, which are called hepatocytes. As the hepatocytes burst, the parasites are released into the bloodstream as merozoites to attack the red blood cells and start an intraerythrocytic cycle [3].The intraerythrocytic cycle causes structural, biochemical and mechanical changes to the red blood cells. The cycle starts from the ring stage at which the merozoites invade the red blood cells and become uni-nucleated trophozoites. At the schizont stage, trophozoites develop into multi nuclei cells called schizont. The growth of the schizont is based on the digestion of haemoglobin with the production of hemozoin [4]. Mostly Smears blood test is a more sensitive test for malaria infection. A greater volume of blood is examined under the microscope and the parasites are therefore more likely to be seen. The result of smears test is depend on a quality of equipment, the result not suitable for large- scale epidemiological studies. In this paper, we consider a 2D-PC based biosensor detection in malaria because it has a simple structure, small size, and high confinement of light and more convenient. PC is providing an accurate sensing platform because of the strong confinement of light inside the device [5]. The nanocavity biosensor chip is filled by blood sample and according their refractive index transmission is deliberated.

All design and simulation are done in FDTD tool. Finite-difference time-domain or Yee's method is a numerical analysis method used for modelling differential equation. FDTD is time domain method with wide frequency range and treat nonlinear material property. FDTD method based on Maxwell equation.

II. THEORY

Photonic crystals (PCs) consist of a periodic arrangement of regularly shaped materials having different dielectric constants in a substrate [6]. Depending on geometry of the structure, Photonic crystals are of three types included one-dimensional (1D), two dimensional (2D), and three dimensional (3D) structures. 1-D photonic crystal structures insufficient band gap and it is difficult to make 3D structures due to small lattice [7]. 2D structures have a complete band gap and it is easier to make 2D structure rather than 3D. Generally, two type of design in 2D photonic structures: air holes in dielectric wafer and dielectric rod in air wafer. The phenomenon of propagation of light within PC is explained by Solving Maxwell equations. Photonic crystals are having many applications in the field of optical communication and optical information processing because Photonic crystals provide a common platform to fabricate a large number of optical components on a single Chip down [8]. The light within the PBG frequency range is not allowed to pass, it can be localized only by introducing certain defects in the PCs structure and otherwise light is completely forbidden within PBG. These PC bandgap structures can be utilized for various applications [9].

III. DESIGNING OF BIOSENSOR

The layout of photonics crystal biosensor based on linear waveguide with one nanocavity. The 2D photonic crystals have a 21 silicon rod in Z-direction and 19 silicon rods in X-direction. For the propagation of light inside the structure 1550 nm wavelength is used. For the detection of wave at another end optical detector is used. The design of bio sensor structure is based on Si rods background wafer in air type with the square lattice shape. The refractive index of silicon material is 3.47 and air is 1. The radius of rods is 130 nm and lattice constant of structure is a=550 nm. In this paper, use a normal red blood cell and infected red blood cell refractive index in the centre one nanocavity and change of wavelength according to refractive index are sense by bio sensor. Nanocavity is created for centre one rods by changing a radius of rods from 130 nm to 100 nm. Fig 1 shows a 2D photonic crystal linear waveguide nanocavity based biosensor.

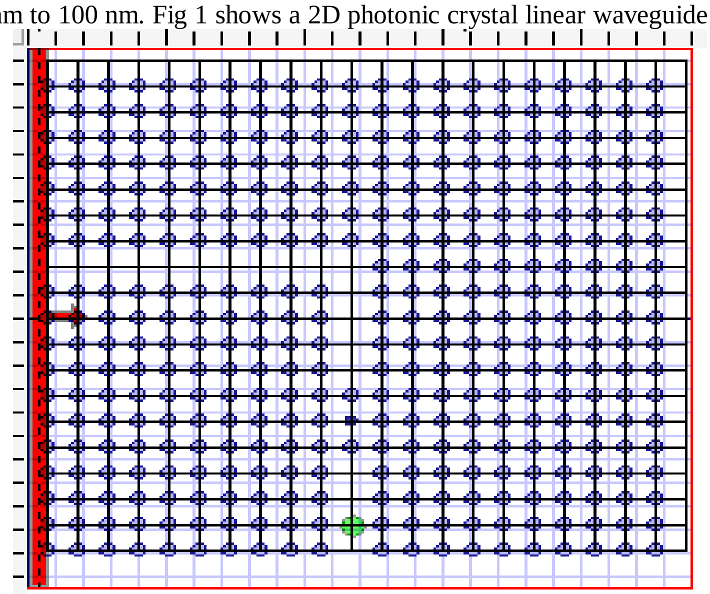

Fig.1 2D Photonic crystal based biosensor layout

In the Fig. 2, the band diagram of Sensor structure has shown which gives the Photonic Band Gap for Transverse Electric modes. The band gap structure is depend on a three parameter first is refractive index of material, lattice constant, ratio of radius to lattice constant (r/a) [10]. The complete structure has two band gaps. The first PBG is in the range between the wavelength 1483 nm and 2135 nm, and the second PBG is from 1014 nm and 1126 nm. The Plane wave expansion (PWE) method is used, to estimate the band gap and propagation modes of the PC structure without and with defects. First range is considered to PBG range.

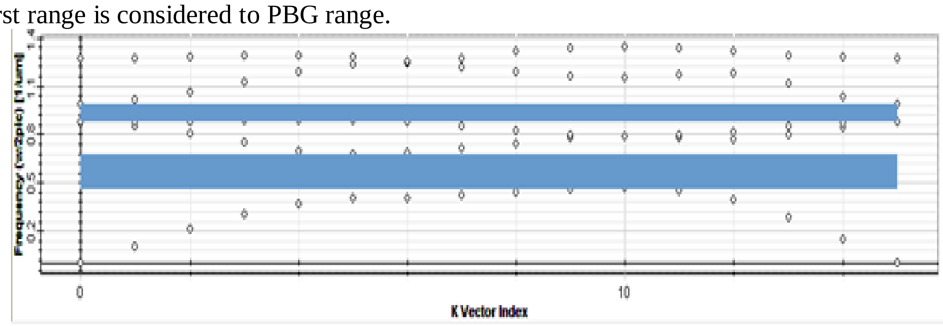

Fig.2 TE band diagram square lattice with defects

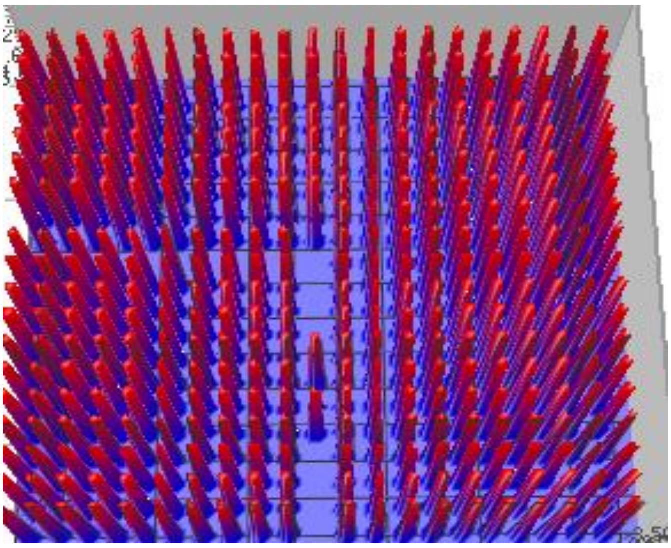

Fig. 3 Refractive index of structure

IV. SIMULATION AND RESULT

The performance of sensor has measured by 2D finite-difference time-domain (FDTD) method. A 1550 nm wavelength is use input port at. Fig 4 shows a normal red blood cell transmission power at 1.402 refractive index. In this refractive index, transmission is 47%

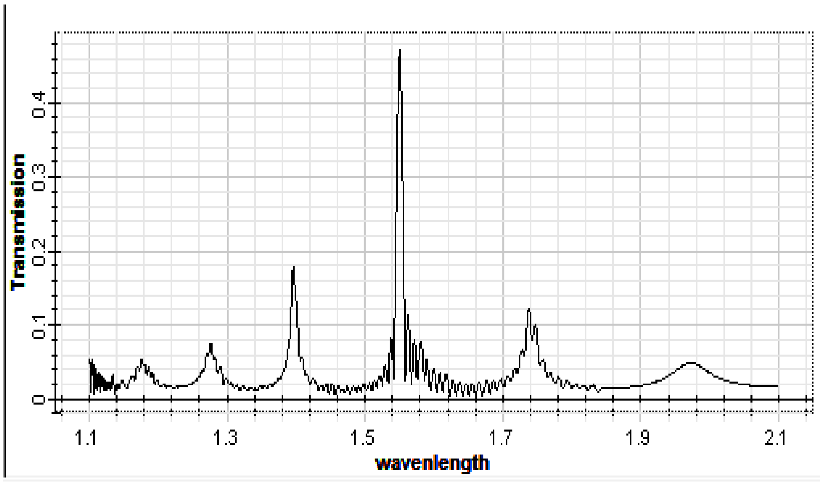

Fig 4: Transmission graph Normal red blood cell with refractive index (1.402)

Fig 5 shows a infected red blood cell ring stage transmission at refractive index 1.395. In this refractive index transmission is 48%.

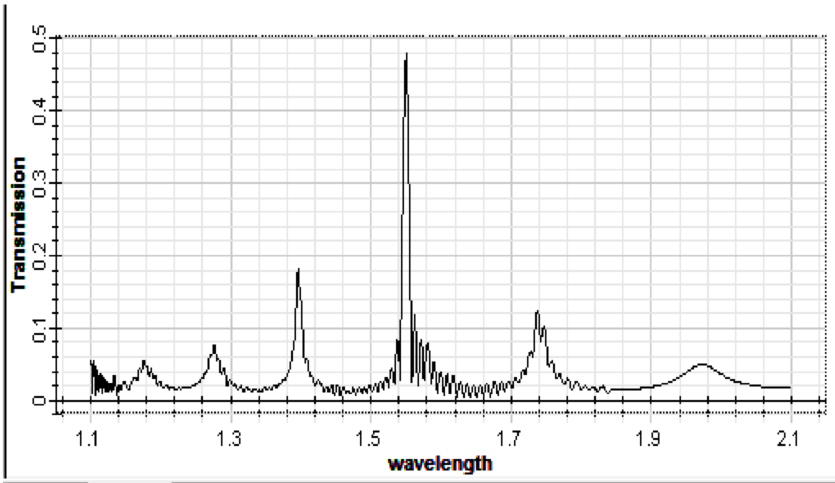

Fig. 5 Transmission graph infected red blood cell ring stage with refractive index (1.395)

Fig 6 shows infected red blood cell trophozoites transmission at refractive index 1.383. In this refractive index transmission is 49%.

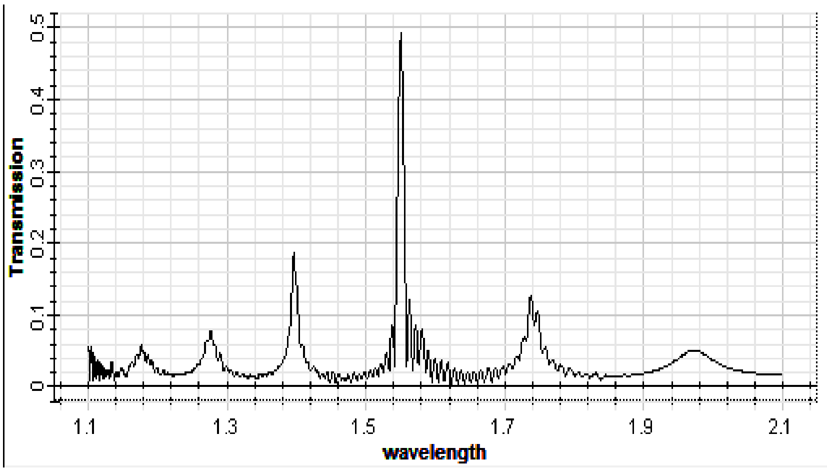

Fig 6: Transmission graph infected red blood cell trophozoites stage with refractive index (1.383)

Fig 7 shows an infected red blood cell schizont Stage transmission at refractive index 1.373. In this refractive index transmission is 50%

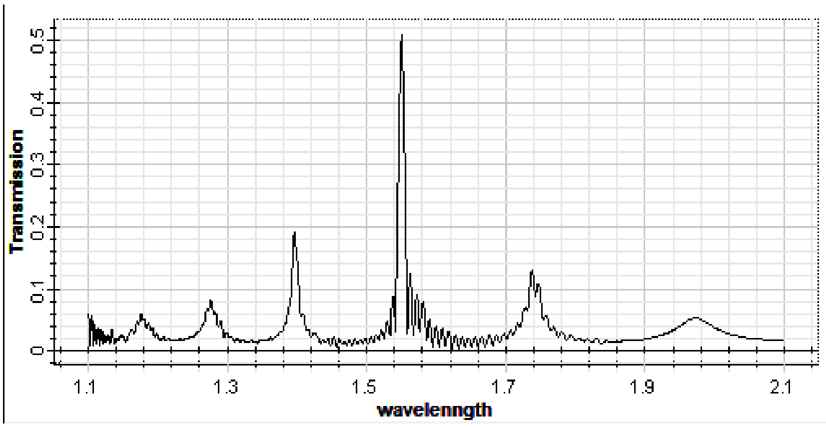

Fig 7: Transmission graph infected red blood cell schizont Stage cell with refractive index (1.373)

Fig (4-7) shows a transmission spectrum for normal red blood cell and infected red blood cell ring stage, trophozoites stage, schizont stage corresponding their refractive indices n=1.402,1.395,1.383,1.373.The transmission is increase while decrease of refractive index.

Table. Analysis of wavelength according to Refractive Index

S.NO.	REFRACTIVE INDEX		NORMALIZED TRANSMISSION
1.	1.402	Normal red blood cell	47%
2.	1.395	Infected red blood cell ring stage	48%
3.	1.383	Infected red blood cell trophozoites stage	49%
4.	1.373	Infected red blood cell schizont stage	50%

Table shows a refractive index normal red blood cell and infected red blood cell ring stage, trophozoites stage, schizont stage with normalized transmission spectrum. In the cavity, centre defect is filled by normal and infected red blood cell and transmission result measured and compared to 1550 nm input wavelength. This design biosensor sense minute change and provide a good accuracy and better transmission.

V. CONCLUSION

The purpose of our study was to design a 2Dphotonic crystal based biosensor in red blood cell malaria application. The design biosensor much smaller, compact, lower cost, less losses. The normal red blood cell and infected red blood cell refractive index are used to detect a disease. Transmission is shift according to refractive index. The design structure is based on 2-D linear waveguide nanocavity with square lattice. Silicon rod is use in air background. The structure dimension is 21×19 μm^2. 1550 nm wavelength is used. The purpose of this structure is determining malaria in human body at less time and low losses. All simulation is done in Finite difference time domain (FDTD) tool.

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