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# Photonic Crystals for Malaria Detection

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## Abstract

Cell refractive index is a key biophysical parameter, which has been extensively studied. Healthy red blood cells have a homogeneous distribution in refractive index, while infected red blood cells in malaria disease show non-homogeneous refractive index throughout the cytoplasm of the cell. In this paper we design and simulate a 2D photonic crystal ring resonator based refractive index biosensor for malaria detection. The simulation results have analyzed by using the finite difference time domain (FDTD) method, the band gap calculation is performed using the plane wave expansion method. The grating design, incorporated in the photonic crystal waveguide increases the efficiency and sensitivity of the designed sensor.

**Keywords:** Biosensor; Malaria; Refractive index; OptiFDTD; Band gap

## Introduction

Malaria is a very devastating disease that still affects millions of people and kills more than a million people a year. Here, it is important to detect malaria more effectively, allow for early treatment and reduce mortality. Malaria is caused by a protozoan parasite, transmitted by mosquitoes that invade liver cells and red blood cells.

The malaria infection cycle starts when mosquitoes feed on people [1].

During asexual development, the structural changes occurring in the RBC are commonly characterized into three stages:

1. the ring stage with ring-like features that lasts for 24 h
2. the trophozoite stage during the period of 24–36 h
3. the schizont stage during the period of 36–48 h [2]

Healthy red blood cells have a homogeneous distribution in refractive index, while infected red blood cells show non-homogeneous refractive index throughout the cytoplasm of the cell. So there is a significant refractive index difference between the healthy and the infected red blood cells. As a result, the red blood cells refractive index and morphology can be used as important parameters for disease diagnosis such as malaria and anemia [1].

The major impediment to effective treatment of malaria prevention and control, the lack of low-cost diagnostic tools and strategies capable of assessing the status of the infection rapidly in rural areas where the majority of the cases of malaria [3]. Several techniques have been used for the detection of malaria in blood samples including: Giemsa staining of the parasite DNA followed by examination of the samples with light microscopy, fluorescent DNA/RNA stains, malaria pigmentation detection, molecular methods, and antigen testing. Recently, Tripathy (2013) have been demonstrated that third harmonic generation (THG) imaging is highly sensitive and specific for the detection of malaria infection due to the strong nonlinear optical response of the hemozoin crystals within parasites inside the infected host red blood cell [4,5]. A new detection method is proposed and demonstrated using dark-field in conjunction with cross-polarization imaging and spectroscopy to identify hemozoin in fresh rodent blood sample [6].

A wide range of techniques for quantitative measurements of critical homeostatic parameters in malaria-infected red blood cells [7].

There are other methods to detect Malaria using non-blood samples: saliva, urine and buccal mucosa this technique is invasive, increases risk of blood-borne disease transmission, and is uncomfortable for the patient [8].

Optical techniques are revolutionizing the way in which biological questions can be addressed directly in the living cell. The optical techniques that inform on the changes in mechanical properties during the infection cycle.

Their sensitivity, specificity and non-intrusiveness make optical techniques indispensable to generate high-fidelity data, significantly improving the tools available to future research into blood disease [7].

Photonic crystal based biosensor is one of this optical techniques. Photonic biosensor are presents early diagnostic tool and provide a superior sensitivity, reliability, stability, fast response in vivo and vitro diagnostics [9].

In this paper we design and simulate a 2D photonic crystal biosensor. Where the biosensor chip is filled by blood sample and according their refractive index transmission is deliberated. The 'PWE band solver' of the software package OPTIFDTD is used to investigate the band gap of 2D rectangular PCs with GaAs rodes distributed in air wafer and its relationship with the refractive index of blood samples filled in order to improve the sensitivity.

## The Structure

By creating point defects or cavity or by changing the size of each rod causes defect which act as a resonator. The optical resonator is also designed by creating some defects into the structure which breaks the periodicity of structure and also localized the light. Another type of optical resonator is designed by creating ring resonator [10].

We choose a ring resonator because the sensitivity is derived from the long photon lifetime inside the cavity. It provides high field localization, which increases the interaction between the light and the matter, that's why the sensitivity increases also, for this reason we choose to implement a ring resonator in our design.

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In this paper, our ring resonator is based on GaAs rods suspended in Air wafer, the refractive index of GaAs material is 3.9 and air is 1 where the radius of rods and the lattice constant are 0.1 µm and 0.59 µm respectively.

The layout of 2 d photonic crystal biosensor based on ring resonator represented in (Figures 1 and 2).

## Band Gap Calculation

The band gap for the transverse electric mode of designed biosensor is calculated by using plane wave expansion method (PWE band solver) where the complete structure has one gap with a wavelength range from 2,099 to 2,756 µm. The frequency of the photonic crystal structure is given by $\omega a/2\pi c = a/\lambda$, where **ω** represents angular frequency, **a** represents lattice constant, **c** represents the velocity of light in the free space, and **λ** represents the free space wavelength (Figure 3).

## Simulation and Results

The finite difference time domain (FDTD) method is used to investigate the photonic crystal biosensor.

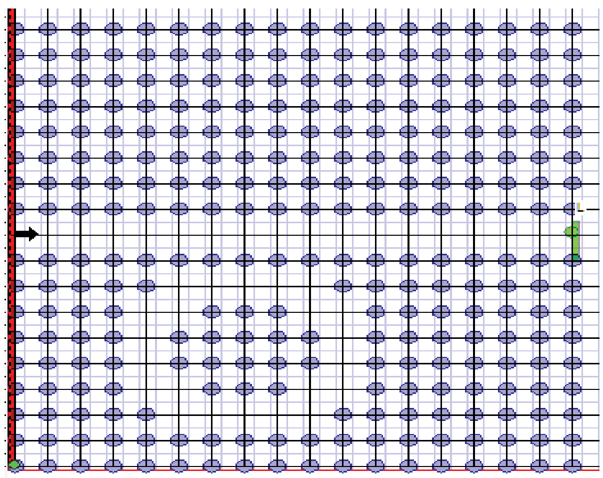

**Figure 1:** Rectangular distribution of GaAs rods in Air wafer.

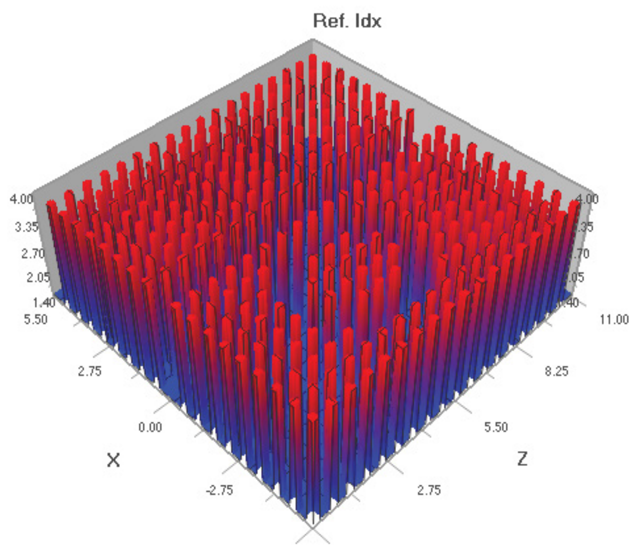


**Figure 2:** Refractive index profile of the photonic crystal structure.

The photonic crystal biosensor is excited from the light source by a Gaussian pulse with a center frequency of 2.09 µm and by applying an appropriate boundary condition (perfectly matched layer, PML) (Figure 4).

At the end of the structure we detect the transmission spectrum for normal red blood cell and infected red blood cells in ring stage, trophozoites stage, schizont stage corresponding their refractive indices n=1.402, 1.395, 1.383, 1.373.

Figure 5 represents the transmission spectrum for normal red blood cell and infected red blood (Figure 5).

Table 1 shows a refractive index for normal red blood cell and infected red blood cell in ring stage, trophozoites stage, schizont stage

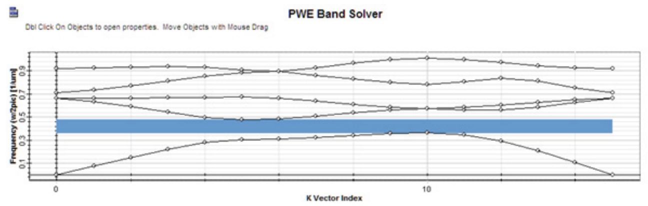


**Figure 3:** The band gap.

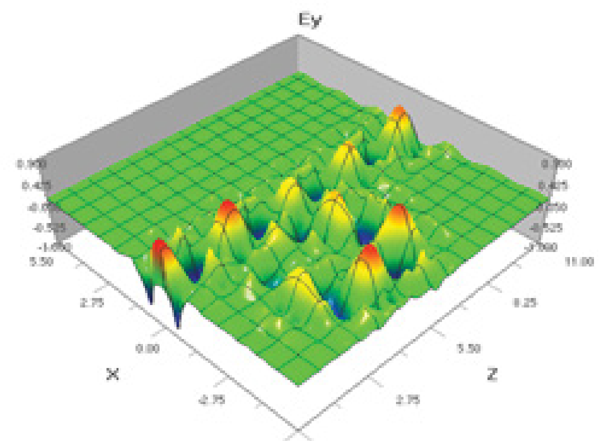


**Figure 4:** The distribution field.

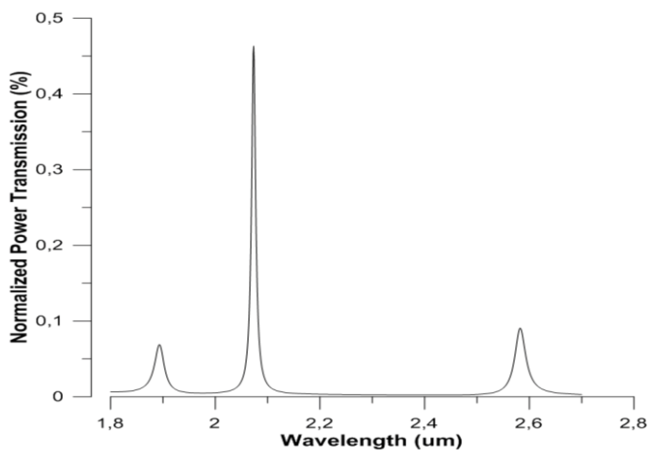


**Figure 5:** The normalized power transmission spectrum for normal red blood cell.

with normalized transmission spectrum. The infected red blood cell transmission result measured and compared to normal red blood cell transmission result (Figure 6).

Figure 7 represents the normalized power transmission *vs*. refractive index of normal and infected red blood cells filled (Figure 7). From the Figure 7 the transmission is increasing while decrease of refractive index. The shifts of the power transmission according to refractive index represent the sensing principal of our ring resonator sensor (Figure 8).

In our structure the maximal power transmission reached 94.4% in scizont stage where the maximal transmission does not exceed 50% we can say that our design biosensor provide a good accuracy and better transmission [9].

## Sensitivity

At each infiltration of normal and infected red blood cells the achieved band gap of the different infiltration is noted and summarized in Table 2.

Using the value of Table 2, we draw a curve in Figure 8 that represents the change of the band gap according to the refractive index variation. It is visible that the variation is linear; a slight adjustment in resulting coordinate gives us a straight line. The absolute value of the inclination of this straight line represents the sensitivity which has reached 151%. We can say that this design biosensor sense minute change and improve a very high sensitivity [11].

## Conclusion

We design and simulate a 2D photonic crystal ring resonator which is used for malaria detection

The proposed sensor is composed of GaAs rods of a rectangular lattice distributed in air background because the refractive index of red blood cells to represent important parameters for malaria diagnosis, we filled our structure with both healthy and infected red blood cells where the shift in normalized power transmission spectrum has been detected by OptiFDTD software where the finite deference time domain has been applied. By emphasis to this point, the sensor can be calibrated to detect malaria disease.

The photonic band gap of the designed biosensor has been investigated. The dependence of the band gap with the refractive index of the red blood cells filled allows us to know the sensitivity which has reach a very high degree.

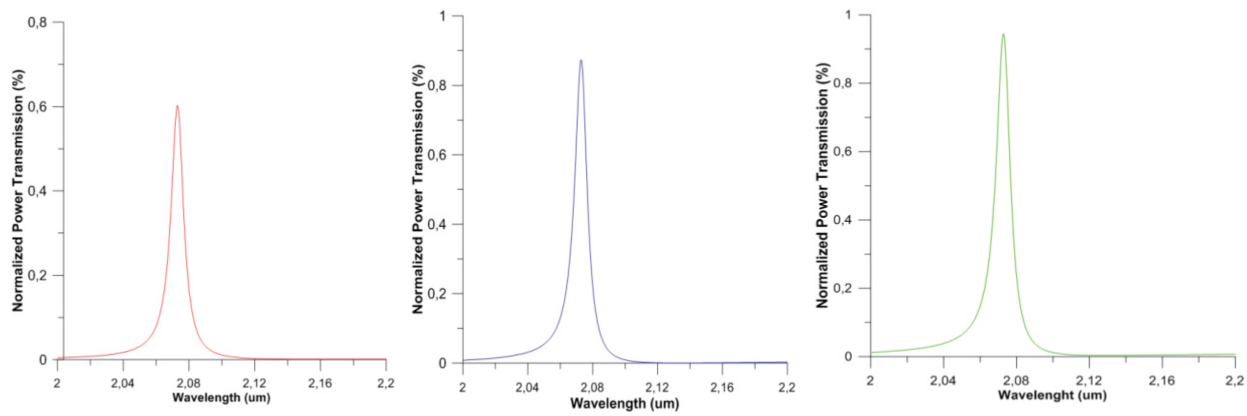


**Figure 6:** The normalized power transmission spectrum for infected red blood in: Ring stage, Trophozoites stage and Schizont stage.

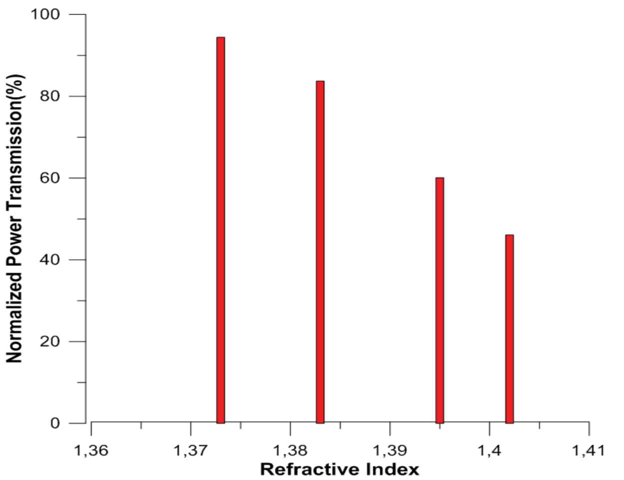


**Figure 7:** The normalized power transmission *Vs*. refractive index of normal and infected red blood cells.

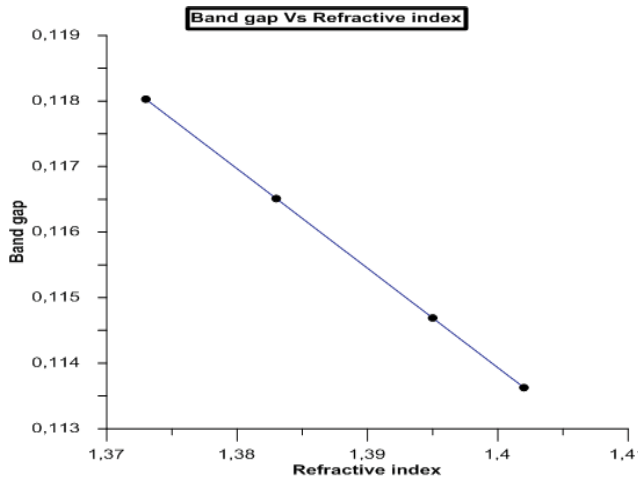


**Figure 8:** Band gap *vs*. refractive index.

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| Refractive Index | | Normalized Power Transmission (%) |
|---|---|---|
| 1.402 | Normal red blood cell | 46.1 |
| 1.395 | Infected cell ring stage | 60.1 |
| 1.383 | Infected cell trophozoites stage | 83.7 |
| 1.373 | Infected cell schizont stage | 94.4 |

**Table 1**: Analysis of transmission according to Refractive Index.

| Refractive Index | | Band gap |
|---|---|---|
| 1.402 | Normal red blood cell | 0.113627 |
| 1.395 | Infected cell ring stage | 0.11469 |
| 1.383 | Infected cell trophozoites stage | 0.116512 |
| 1.373 | Infected cell schizont stage | 0.118028 |

**Table 2:** Analysis of band gap according to refractive index.

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