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High Sensitivity Refractive Index Sensor Based on Two-Dimensional Photonic Crystal for Chikungunya Virus

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Early detection of chikungunya virus disease is critical for effective management of the disease. This study focused on developing the performance of a refractive index detector based on a photonic crystal biosensor that can quickly and accurately detect virus-infected blood and urine components. A geometrical study was performed to improve the sensitivity in which a very high value of 973.24 um/RIU has been reached. In this article we have proposed a 2D photonic crystal structure biosensor to detect the influence of chikungunya virus on blood components and uric acid. After a geometric study, we found a performance parameter that led to achieve a very high sensitivity of 973.24 μm a transmission efficiency of 68.42 % and aquality factor of 695.18.

Keywords: Photonic crystals, Refractive index, Chikungunya virus sensor, Optifdtd.

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1. INTRODUCTION

Chikungunya virus disease is a mosquito-borne viral disease that primarily affects the joints, causing severe joint pain and swelling. It also causes fever, headache, muscle pain, and rash [1]. The name "chikungunya" is derived from the Makonde language, spoken in Tanzania and Mozambique, and means "to become contorted," which describes the posture of people affected by the disease. The virus was first isolated in Tanzania in 1952, but cases have been reported in Africa, Asia, Europe, and the Americas. The virus is transmitted by mosquitoes of the Aedes genus, particularly Aedes aegypti and Aedes albopictus, which are also responsible for the transmission of dengue fever and Zika virus [2].

People at risk for more severe disease include newborns infected around the time of birth, older adults (more than 65 years) and people with medical conditions such as high blood pressure, diabetes, or heart disease [3].

Chikungunya virus is known to target red blood cells whose refractive index is 1.40, causing them to become deformed and leading to a reduction in the number of red blood cells in the body becomes its refractive index is 1.39 [4]. This can lead to anemia and other complications [5].The virus can also affect platelets, which are responsible for blood clotting a condition known as thrombocytopenia where their refractive index convert from 1.35 to 1.33, this can cause bleeding, bruising, and other complications, particularly in vulnerable populations such as pregnant women mostly during the second trimester and the elderly. Intrapartum transmission has also been documented when the mother was viremic around the time of delivery [6].

Research has also suggested that the chikungunya virus can affect the immune system, causing it to produce certain antibodies that can lead to further complications. For example, some studies have suggested that the virus can trigger the production of autoantibodies, which can cause damage to healthy cells and tissues in the body [7]. Early detection of chikungunya virus disease is crucial for the effective management of the disease. Biomedical research has focused on developing diagnostic tools that can detect the virus quickly and accurately [8].

The detection of the Chikungunya virus in a biosensor involves the use of specific antibodies that can bind to the virus and generate a signal that can be detected by the sensor. Biosensors can be designed to detect various aspects of the virus, such as the presence of viral particles, viral proteins, or antibodies produced in response to the virus. Biosensors have several advantages for virus detection, including high sensitivity, specificity, and speed, which make them a promising tool for the rapid and accurate diagnosis of Chikungunya virus infection [9]. Optical techniques are revolutionizing how 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.

The addition of photonic crystals to biosensors has enabled highly sensitive and facilitated the development of highly miniaturized biosensors that can be integrated into portable devices. Photonic crystals are periodic structures that can manipulate the propagation of light through a photonic bandgap, by creating point defects or cavities.Their sensitivity, specificity, and non- intrusiveness make optical techniques indispensable to generating high-fidelity data, significantly improving the tools available for future research into blood disease [10].

Several research on biosensors-based photonic crystals focuses to ameliorate the phc parameters such as sensitivity and quality factor.

Tayoub in Ref [11] propose a design for the diagnosis of malaria- infected red blood cells (RBCs) in the wavelength range of 1130-1860 nm for TM-polarized light,

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where a high sensitivity of 700 nm/RIU can be achieved.

Sujit Kumari in ref [12] design a biosensor structure to detect infected red blood cells by malaria parasites where the maximum sensitivity value obtained from his structure is 327.7 nm/RIU.

In our study we propose a two-dimensional phc waveguide as a biosensor to detect the infected blood component and urine by the chikungunya virus, we design and simulate a 2D photonic crystal biosensor. Where the biosensor chip is filled with a blood sample and urine and according to their refractive index transmission is deliberated. The software package OPTIFDTD and the 'PWE band solver' are used.

2. ARTICLE STRUCTURE AND THE CORRESPONDING STYLES

The proposed structure is based on GaAs rods distributed hexagonally in an Air wafer, the refractive index of GaAs material is 3.35 and air is 1 where the radius of rods and the lattice constant are 0.21 μm and 0.6 μm respectively. Fig. 1 represents the proposed design. Parameters design are summarized in Table 1.

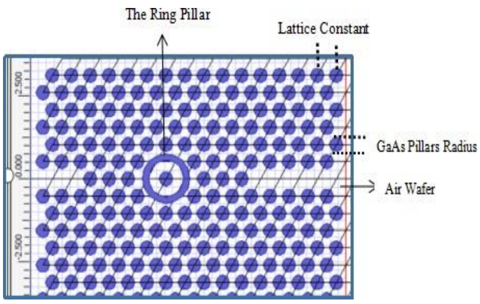

Fig. 1 – The proposed design

Table 1 – Design Parameters

Design parameter	The Value
Length × Width	17 × 16
The refractive index of GaAs	3.35
Pillars radius	0.210 μm
Lattice constant	0.6 μm
The refractive index of the area	1
Ring width	0.65 μm
Ring radius	0.2 μm

The band gap of the photonic crystal structure has been calculated with the plane wave extension method (PWE) The complete structure has a certain range of wavelength in transverse electric mode From 2.078492 to 2.797416 μm. The results bad gap was shown in Fig. 2. The photonic crystal biosensor is excited from the light source by a Gaussian laser pulse with a central frequency of 2.31499 μm and by applying an appropriate boundary condition (perfectly matched layer, PML). Fig. 3 represents the distribution field.

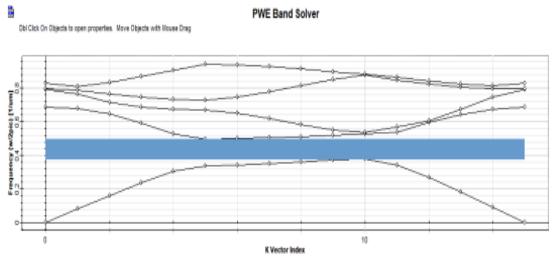

Fig. 2 – The band gap of the photonic crystal structure

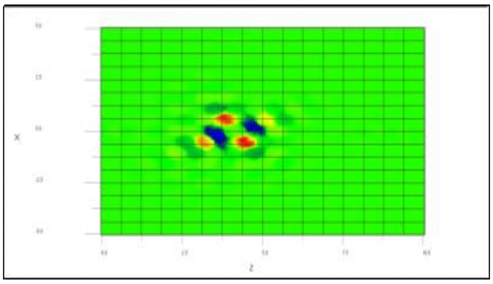

Fig. 3 – Field distribution.

3. GEOMETRIC STUDY

In this section, we present 3 studies on the design structure:

In the first one, we change the radius of the annular pillar from 0.4 to 0.65 μm and in the second study we change the width of the annular pillar from 0.27 to 0.35, and finally in the third one we change the radius of the central pillar from 0.21 to 0.41 μm and we calculate the sensitivity for each change. We limit our study by these value to ovoid interference between pillars. Table 2 summarized the calculation results.

The curve in Fig. 4 represents the change in the sensitivity according to the ring pillar width where the highest sensitivity reached was 933.78 nm/RIU at this point the width and the radius of the annular pillar were 0.35 μm, and 0.65 μm respectively, and the central radius was 0.21 μm. Fig. 5 represents the final design.

Table 2 – Sensitivity value for each Parameter change.

Change of:		The sensitivity
The radius of the annular pillar	$R_a = 0.4$	377.115 nm
	$R_a = 0.5$	399.299 nm
	$R_a = 0.6$	534.4 nm
	$R_a = 0.65$	475.117 nm
The width of the annular pillar	$W = 0.27$	773.44 nm
	$W = 0.30$	499.123 nm
	$W = 0.35$	933.78 nm
The radius of the central pillar	$R_c = 0.21$	475.117 nm
	$R_c = 0.26$	665.498 nm
	$R_c = 0.31$	737.474 nm
	$R_c = 0.41$	749.088 nm

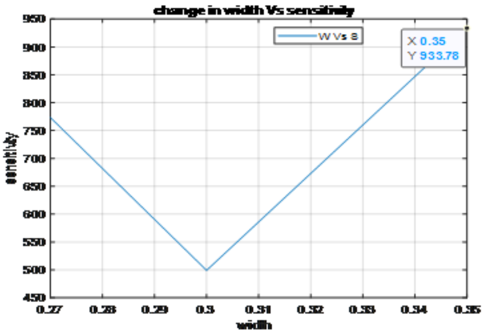

Fig. 4 – Change in the width Vs the sensitivity

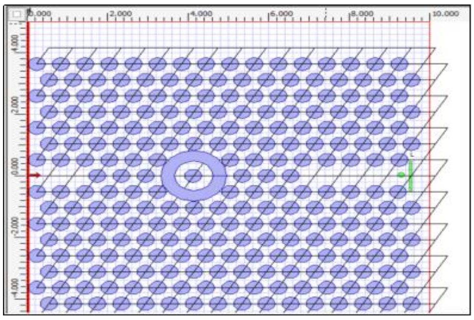

Fig. 5 – The final design

4. DISCUSSION

It appears in Fig. 4 that strong light is confined in the cavity, this localization of light increases after infiltration of the interaction light-matter where a higher level of sensitivity can be reached.

We detect the normalized transmission spectrum after the infiltration of the structure of normal and infected blood components such as red blood cells, platelets, and plasma and also the uric acid. All refractive index of our samples are cited in the Table 3

The normalized taransmission spectrum detected at the end of the struc- ture by the photodetector looks like a lauraintz Pic, a shift in the wavelength of our pic between the infiltration by healthy and infected components was shown in Fig. 6-8

After infiltration of the design by the uric Acid, another Pic appears Fig. 9, this phenomenon called by the Fano resonance which is predominantly used to describe asymmetric resonance [13].

This Fano resonance is sensitive to the small change of the environment refractive index [14].

The sensitivity and the quality factor has been calculated for each detection shift. All results are summarized in the Table 3

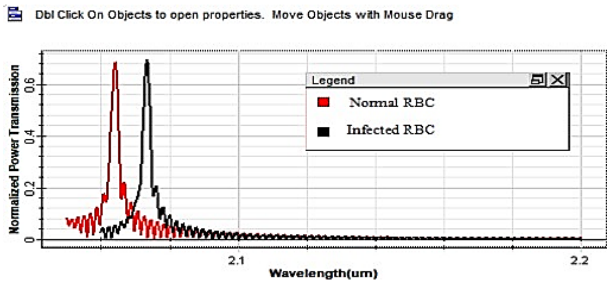

Fig. 6 – Normalized transmission spectrum of healthy and infected RBC

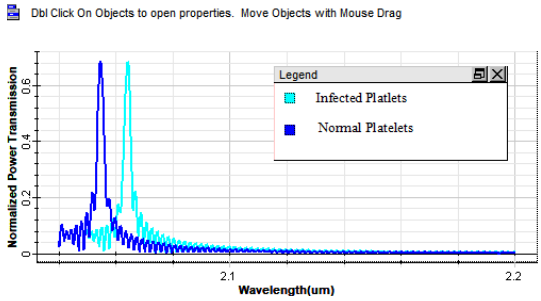

Fig. 7 – Normalized transmission spectrum of healthy and infected Platlets

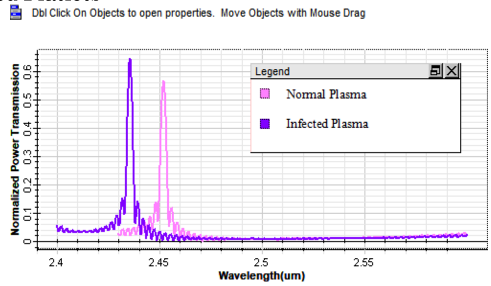

Fig. 8 – Normalized transmission spectrum of healthy and infected plasma

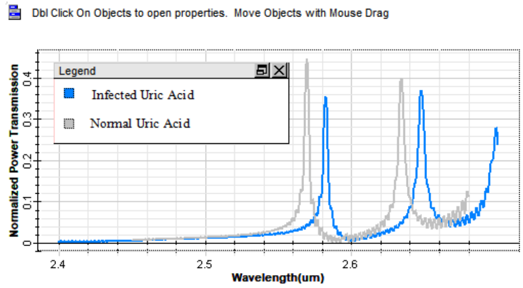

Fig. 9 – Normalized transmission spectrum of healthy and infected uric acide

Table 3 – Refractive index of each analyte.

The targuet sampels		Refractive index
RBC	Normal	1.4
	lInfected	1.39
plasma	Normal	1.35
	lInfected	1.33
platlets	Normal	1.39
	lInfected	1.38
uric acid	Normal	1.72
	lInfected	1.7

Table 4 – Sensitivity, effectiveness and quality factor for each anlyte

The ana-lyte	The sensitivity	Quality factor	Transmission efficiency
Uric acid	665.12 nm/RIU	483.05	39.70 %
Platlets	973.24 nm	695.18	68.42 %
Plasma	814.0 nm	727,59	64 %
RBC	933.78 nm	778.61	69.2 %

A brief comparison between our study and a few examples of other recent work has been presented in

Table 5.

Table 5 – Comparison Research

References	Year	Structures	Targeted Application	The Sensitivity
[15]	2023	Basal_ MCF-	Label-Free cancer	308.5(nm/RIU)
[16]	2023	Deionized water	bacterial waterdetection	232 nm/RIU
My work	2023	RBC_UricAcid	Chikungunya virus	973.24nm/RIU

5. CONCLUSIONS

In this article we have proposed a 2D photonic crystal structure biosensor to detect the influence of chikungunya virus on blood components and uric acid. After a geometric study, we found a performance parameter that led to achieve a very high sensitivity of 973.24 μm a transmission efficiency of 68.42 % and aquality factor of 695.18. Due to the importance of the accuracy and sensitivity parameter in the sensors' design we can say that the achieved sensitivity compared to a recent works prove the value of our design.

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Високочутливий датчик показника заломлення на основі двовимірного фотонного кристала для вірусу Чикунгунья

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Раннє виявлення хвороби, викликаної вірусом чикунгунья, має вирішальне значення для ефективного лікування хвороби. Це дослідження було зосереджено на розробці продуктивності детектора показника заломлення на основі фотонно-кристалічного біосенсора, який може швидко й точно виявляти заражені вірусом компоненти крові та сечі. Для покращення чутливості було проведено геометричне дослідження, у якому було досягнуто дуже високого значення 973,24 мкм/RIU. У цій статті ми запропонували двовимірний біосенсор фотонної кристалічної структури для виявлення впливу вірусу чикунгунья на компоненти крові та сечову кислоту. Після геометричного дослідження ми знайшли параметр продуктивності, який дозволив досягти дуже високої чутливості 973,24 мкм, ефективності передачі 68,42 % і коефіцієнта якості 695,18.

Ключові слова: Біосенсор, Фотонні кристали, Показник заломлення, Датчик вірусу Чикунгунья.