Malaria Diagnosis Using High Quality-Factor Photonic Crystal Biosensor

Hadjira Tayoub[1,2*], Abdesselam Hocini[1], Ahlam Harhouz[1]

[1]Laboratoire d'Analyse des Signaux et Systèmes, Department of Electronics, University of M'Sila BP.166, Route Ichebilia, M'Sila, 28000, Algeria

[2]Research Center in Industrial Technologies CRTI, P.O.BOX :64, Cheraga 16014, Algiers-Algeria

*hadjira.tayoub@univ-msila.dz

abdesselam.hocini@univ-msila.dz

harhouz7ahlam@gmail.com

***Abstract*—In 2019, they accounted for 67% (274,000) of all malaria deaths worldwide, according to the World Health Organization; the african region was home to 94% of malaria cases and deaths. In this context, it is vital to detect malaria more effectively and accurately, we have developed in this paper a two-dimensional photonic crystal biosensor based on refractive index changes that can be used to diagnose malaria. The proposed design is simulated by using the FDTD algorithm. Reasonable sensitivity, ultra-high quality-factor up to 10^7 by inserting blood sample into the cavity and remarkable detection limit can be achieved for the proposed design.**

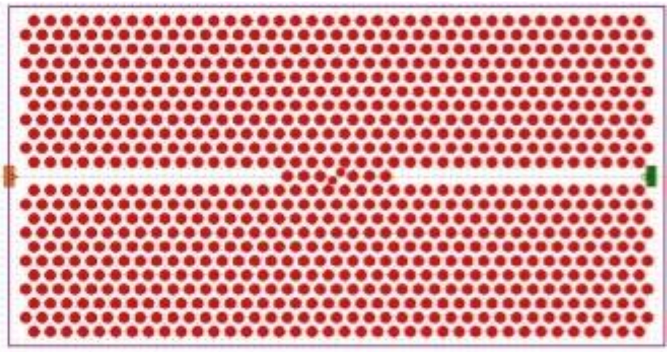
***Keywords*—Photonic crystal, Biosensor, Malaria, Sensitivity, Quality-factor.**

I. Introduction

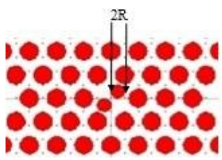
Today, malaria is one of the most deadly diseases worldwide, together with tuberculosis, HIV/AIDS and hepatitis [1]. In most cases, malaria is spread through the bites of mosquitoes that attack red blood and liver cells. As a result of malaria infection, red blood cells degenerate, and the characteristics of red blood cell structure change into three stages: first, the ring stage lasting 24 hours, and then the trophozoite stage within 24-36 hours. Finally, the schizont stage within 36-48 hours, according to these stages, the refractive index of each stage is 1.396, 1.381, and 1.371, respectively [2]. Different sensitive biosensors for malaria diagnosis were discussed, Sharma et al proposed 2D PhC biosensor using red blood cells as an analyte, the sample was trapped into the nanocavity and a shift in the transmitted peak is observed [3]. 2D PhC ring resonator-based biosensor was proposed by Bendib et al at 2.07 μm [4]. In the present work, 2D PhC biosensor that uses a microcavity is designed to sense the three stage of malaria in the human body. The proposed high-performance PhC biosensor can be used as a valuable diagnostic tool for malaria detection, all design and simulation are done using FDTD (finite-difference time domain) tool of Rsoft Photonic Suite CAD.

II. Design of Photonic Crystal Biosensor

The proposed biosensor device is presented as shown in Fig.1.a, it consists of a 2D hexagonal lattice of air where the radius of the air holes is r= 0.33×a, the lattice constant (a) is considered as 400nm and the index profile of Si slab n_{si}=3.48. To break the periodicity of the structure and localize the light, two waveguides are created by removing one row of air holes in the ΓK direction and we create a defect into the structure by changing the radius (R) and moving away the both centered holes (Fig.1.b).



(a)



(b)

Fig.1. (a) Schematic of the proposed 2D-PhC biosensor, (b) Zoom of the cavity region.

III. Results and Analysis

Fig.2. illustrates that the change in the cavity radius affects the sensitivity and the quality-factor (Q-factor) for refractive index of each stage, the increase in the cavity radius increses the device sensitivity. Hence, the cavity radius R=0.25×a provides the higher sensitivity (Fig.2.a). It is observed also that the Q-factor depends on the radius of the microcavity (Fig.2.b), the highest value of the Q-factor reached for the smallest microcavity radius (R=0.15×a).

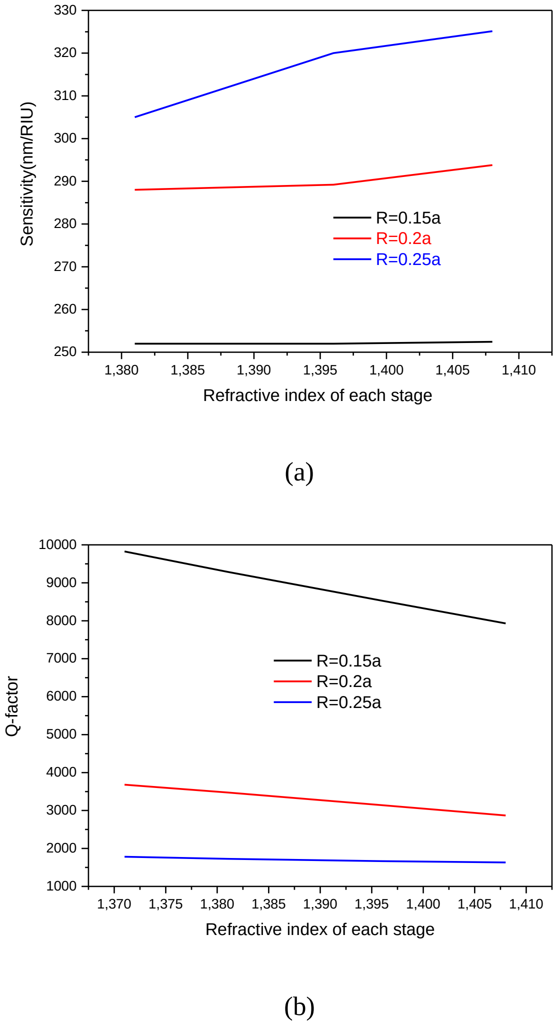


Fig.2. The sensitivity (a) and The Q-factor (b) versus refractive index of each stage for different cavity radius R.

Fig.3 indicates a shift in the normalized transmission for different stages of malaria. The change in the refractive index of the analyte led to a shift in the resonant wavelength.

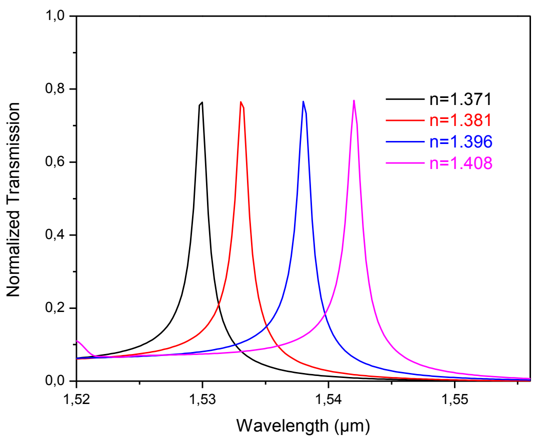


Fig.3. Normalized transmission spectrum for R=0.25×a.

The modified biosensor device is shown in Fig.4. By infiltrating the samples only on the microcavity (showing in black color in Fig. 4), for R=0.25×a, the device provides better performance .

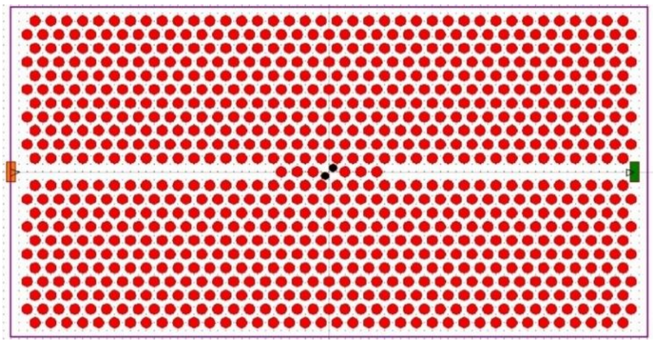


Fig.4. Schematic of the modified 2D-PhC biosensor.

TABLE I. REFRACTIVE INDEX OF BLOOD CELLS,QUALITY FACTOR IN DIFFERENT STAGES OF MALARIA

Malaria different stages	**Refractive index**	**Quality-factor**
Schizont stage	1.371	1.2497×10^{7}
Trophozoites stage	1.381	8.0804×10^{6}
Ring stage	1.396	4.1916×10^{6}
Normal stage	1.408	6.9879×10^{7}

The quality factor of the modified structure is presented in Table.1 for different infected stages of malaria along with the refractive index values. A high Q-factor of 6.9879×10^{7} can be reached in the normal stage.

IV. CONCLUSION

In the present paper, a 2D photonic crystal biosensor has been designed for detecting malaria disease for each stage.The radius of the microcavity to detect the different stage of malaria has been optimized. which provides a high sensitivity of 325,13 (nm/RIU), a Q-factor as high as 9825.3 and the lowest detection limit is equal to 6.77×10^{-5}. A modified design may lead to an ultra-high quality-factor up to 10^{7}. Therefore, the proposed biosensor is a perfect device for biosensing detection.

REFERENCES

[1] R. Nash, Accelerating progress on HIV, tuberculosis, malaria, hepatitis and neglected tropical diseases: a new agenda for 2016-2030. Geneva: World Health Organization, 2015.

[2] M. A. Agnero et al., "Malaria-infected red blood cell analysis through optical and biochemical parameters using the transport of intensity equation and the microscope's optical properties," Sensors (Switzerland), vol. 19, no. 14, 2019, doi: 10.3390/s19143045.

[3] V. Sharma and V. L. Kalyani, "Design Two Dimensional Nanocavity Photonic Crystal Biosensor Detection in Malaria," Int. J. Emerg. Res. Manag. Technol., vol. 6, no. 6, p. 16, 2018, doi: 10.23956/ijermt.v6i6.239.

[4] S. Bendib and B. C, "Photonic Crystals for Malaria Detection," J. Biosens. Bioelectron., vol. 09, no. 03, 2018, doi: 10.4172/2155-6210.1000257.