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# NANOCAVITY AND MICROCAVITY BASED PHOTONIC CRYSTAL BIOSENSOR FOR DENGUE DETETCTION

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**Abstract— Photonic crystal biosensors is a new, advance and accurate measurement technology for bio sensing application. In this paper, a two dimensional (2D) photonic crystal nanocavity and microcavity sensor is designed for the detection of dengue using human blood plasma and platelets. The optical properties of plasma and platelets are observed and refractive index of normal plasma, infected plasma, normal platelets and infected platelets are used. The change in output transmission spectrum and Q factor has been observed with the shift in wavelength, thus by observing these changes dengue is detected. The designed sensor can predict results accurately and in short time, hence can be used for medical application. By designing micro and Nano cavity in same structure of biosensor, comparison is also done and results of Q factor and transmission are also observed. The band gap range of structure is 1360 nm to 2190 nm and 1550 nm continuous modulated wave is used in this design. The finite difference time domain (FDTD) method is used to analyze the result and Plane wave expansion (PWE) method is being used for band gap calculation.**

**Keywords— Nanocavity, Microcavity, Refractive index, Photonic Crystal, Finite Difference Time Domain (FDTD).**

## I. INTRODUCTION

With the rapid advancement in science and technology in today`s world, especially in field of medicine, in different fields of medicine such as micro/nanotechnology, wireless technology, wireless communication, information technology, and biomedical sciences during past 10 to 15 years. Various wide range of models and designs are built for a wide range of biosensors [1]. Recently, biosensors are used in health care monitoring to detect diseases such as diabetics, dengue, early detection of cancer and various other diseases biomarkers. This provides the way of improving quality in health care system [2]. Biosensors provides monitoring of patients, athletes, premature infants, children, psychiatric patients, people who need long term care, they are also effective in prevention, timely diagnosis, control and treatment of diseases[3].A biosensor mainly comprises three parts theses are Bioreactor System, Transducer and an Output System [4]. These are designed to react only with a particular substance and result of this comes in form of a message that can be used by any electronic device. These are considered as receptor, communication systems based sensor can display, simulate, treat, or substitute human biophysics performance. Biosensors are recently increasing attention in the field of health care monitoring, in order to solve the health related issues rapidly, economically, accurately and precisely for users , and also provides real time performance of athletes, or disease status of patient[5]. The important part in biosensors are the transducers that selectively and sensitively, translate biosignals into detectable signals in detectable form. Biosensors fulfills the requirement of healthcare system in terms of miniaturization, flexibility, conformability and starchability [6]. There are several wireless biosensors proposed in past 10 to 15 years [7]-[13].

### 1.1 Photonic crystal

Photonic crystals composed of the periodic arrangement of materials having different dielectric constants, which allows them to control and modulate the motion of photons [14]. These materials reflect specific wavelengths of light because of the photonic band gap, which allows them to display different structural colors. PC structures are common in nature, such as in opals and butterfly wings, presenting as periodic nanostructures and bright structural colors [15]. The structural color of PCs is obtained from their geometric structure, which is capable of controlling and manipulating the diffraction of light by the periodically structures. After various research [16], a large number of PC-related projects was proposed. Over the past several years, PCs have been broadly used in many applications, including sensing [17], biodetection [18]. One of the basic properties of PC is the photonic band gap (PBG), and the propagation of light within the frequency range of PBG [19]. Nevertheless, the periodicity of this structure will be broken when some defects are introduced in PC, which makes it possible for PC to give strong electromagnetic field confinement, small mode volume, and low extinction loss [20]. On the other hand, by adjusting the structural parameters of PC or infiltrating suitable materials in the air holes of PC, the propagation of light can be altered. Therefore, many PC based devices have been used in the applications of light flow control, such as filters [21,22], electro-optical modulators [23,24], switches [25,26], and delay devices[27]. Specially, PC based sensors are much more popular due to their promising characteristics like ultra-compact size, high measurement sensitivity, flexibility in structural

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design, and more suitable for monolithic integration[28-30].

### 1.2 Dengue

Dengue is the most rapidly spreading, acute febrile mosquito-borne viral disease caused by dengue virus. Over the past 50 years, the incidence of dengue has increased by approx. thirty times, spreading across increasing number of countries as well as from the rural to urban regions. This disease has become endemic in most tropical and subtropical regions. An estimated number of about 50 million cases of dengue fever occur each year with 500,000 cases of dengue hemorrhagic fever and 22,000 deaths. Presently, about 2.5 billion people live in over 100 dengue endemic countries [31]. The presence of dengue has inflicted significant health, social and economic burden on these endemic areas [32]. There are several factors that contribute to the occurrence of the disease, mainly the increases in international travel and human population, besides global climate change [33]. Dengue virus belongs to the flavivirus genus of the flaviviridae family. The dengue virus is transmitted to vertebrates by infected Aedes aegypti and Aedes albopictus mosquitoes. The dengue virus is divided into four antigenically related but distinct Current and nano-diagnostic tools for dengue infection 807 serotypes; the Dengue 1, Dengue 2, Dengue 3 and Dengue 4. The mature dengue virus is spherical in shape and ~50 nm in size. Dengue fever is usually characterized by a sudden onset of fever which last for 2-7 days, together with a variety of signs and symptoms such as high fever, headache, nausea, vomiting, joint pain, fatigue and rashes. The entire stage of illness can be broadly divided into three phases; febrile, critical and recovery phase [31]. During the critical phase, some individuals may progress to severe plasma leakage in cases with dengue hemorrhagic fever (DHF) or dengue shock syndrome (DSS), severe hemorrhage and severe organ involvement. The warning signs for severe dengue include persistent vomiting, mucosal bleeding, lethargy, abdominal pain or tenderness, clinical fluid accumulation, restlessness, liver enlargement of more than 2 cm and an increase in hematocrit count with a rapid decrease in platelet count [31]. Shock ensues when a critical volume of the plasma is lost through leakage. Prolonged shock may lead to coagulopathy and multi-organ failure. Careful monitoring of the blood counts, assessment of hemodynamic status and recognition of warning signs allow early treatment intervention. Appropriate fluid management and supportive care are vital for the recovery of patient. Laboratory diagnosis methods relies on genome and antigen detection as well as serological methods have been widely applied routinely. However, several disadvantages presently limit these methods. For example, antibodies may take approx. 5 days to appear after an infection [31], thus antibody detection can contribute toward epidemic research but is less effective for early diagnosis compared to methods that detect virus or viral proteins directly. Alternative diagnostic systems that can detect dengue virus or related biomarkers during the early phase of infection with comparable sensitivity, selectivity, diagnosis time as current methods can be operated by non-experts would be non-preferable. Basic test for dengue detection includes complete blood count (CBC), which provides the information of platelets count, WBC, RBC and many other blood components. In this paper, we used blood plasma and blood platelets refractive index as the detection tool for the determination of dengue. Samples from healthy person and infected person from dengue are taken for detection. The Refractive index of normal plasma, infected plasma, normal platelets and infected platelets is 1.35, 1.33, 1.39, and 1.35. All design and simulation are performed in the FDTD tool.

## II. DESIGNING OF BIOSENSOR

In 1st design, the biosensor has four Nano cavities. The light propagated inside the structure is continuous wave which has wavelength of 1550 nm is used. The observation points are used on the output port to detect the input wave. In this layout, the structure uses a hexagonal lattice shape with Si rods and air in background wafer. The silicon material used in designing of biosensor have Refractive Index of 3.45 and refractive index of air is 1. Design 1 have radius of 150 nm with lattice constant a= 600 nm. We used four types of refractive index in the four Nano cavity. Transmission spectrum is changed according to refractive index and this changed is sense by bio sensor, four Nano cavities are created by reducing a radius from 150nm to 120nm. Fig 1 shows a 2-D photonic crystal liner wave guide nanocavity based bio sensor.

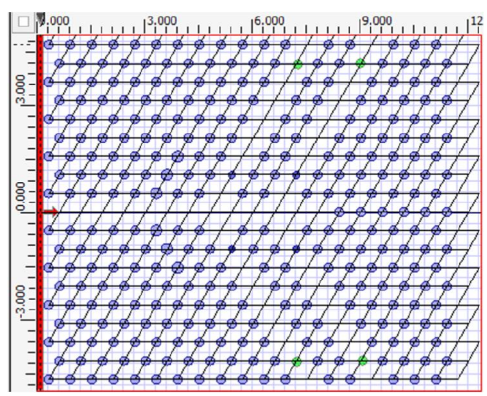


Fig 1: Nano cavity based biosensor layout

In design 2, the biosensor has four micro cavities. The light propagated inside the structure is continuous wave which has wavelength of 1550 nm is used. The observation points are used on the output port to detect the input wave. In this layout, the structure uses a hexagonal lattice shape with Si rods and air in background wafer. The silicon material used in designing of biosensor have Refractive Index of 3.45 and refractive index of air is 1. Design 2 have cavity radius of

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**Table 1. Design Parameter and its value in Biosensor**

| S. No. | Name of Parameter | Value |
|---|---|---|
| 1 | Radius of Si(rod) | 150nm |
| 2 | Lattice constant | 600nm |
| 3 | Refractive index of Si | 3.45 |
| 4 | Refractive index of Wafer(air) | 1 |
| 5 | Refractive index of normal Plasma | 1.35 |
| 6 | Refractive index of normal Platelets | 1.33 |
| 7 | Refractive index of injected Platelets | 1.39 |
| 8 | PGB range | 1360-2191 |
| 9 | Polarization | TE |

122 µm with lattice constant a= 600 µm. In this design, we used four types of refractive index in the four microcavity. Transmission spectrum is changed according to refractive index and this changed is sense by bio sensor four micro cavities are created by reducing a radius from 150nm to 122µm. Fig 2 shows a 2-D photonic crystal liner wave guide microcavity based bio sensor.

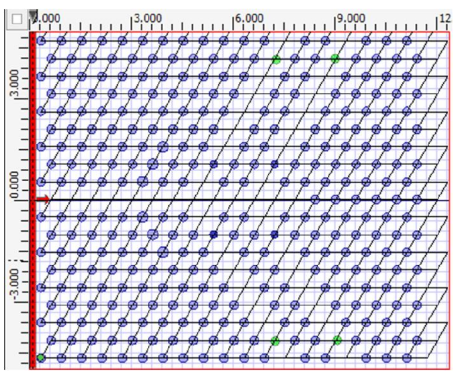

Fig 2: Microcavity based biosensor layout

Fig 3 shows the band diagram of the sensor. The band gap structure is depend on three parameter, refractive index of material, lattice constant, ratio of radius to lattice constant (r/a)[34] . The entire structure consists a one band gap. The band gap range is 1360 nm and 2191 nm. The band gap is calculated by plane wave expansion (PWE) method.

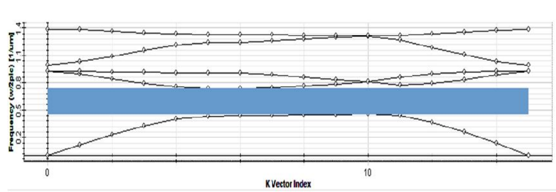


Fig 3: TE band diagram square lattice with defects

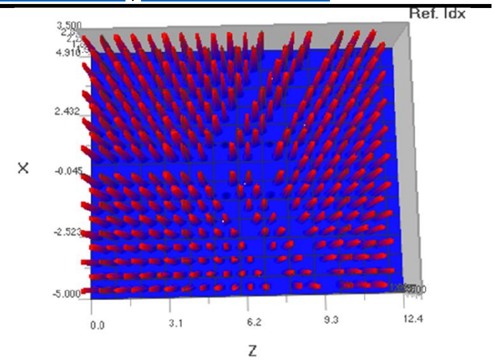


Fig 4: Refractive Index of Structure

## III. SIMULATION AND RESULTS

The performance of sensor is observed by 2 D finite difference time domain (FDTD) method. An input wavelength of 1550 nm is used at the input port. Fig 5 shows the output transmission spectrum of nanocavity based biosensor.

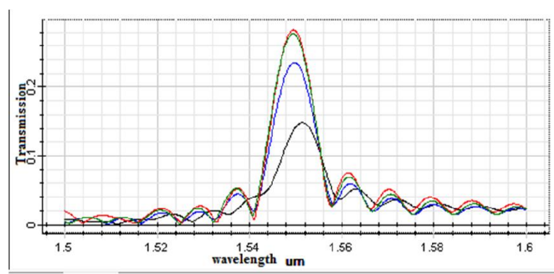


Fig 5: Output transmission spectrum of nanocavity based biosensor

**Table 2. Analysis of design 1 wavelength according to Refractive Index**

| S.No. | Refractive Index | | Normalized Transmission |
|---|---|---|---|
| 1 | 1.35 | Normal plasma | 15% |
| 2 | 1.33 | Infected plasma | 24% |
| 3 | 1.39 | Normal platelets | 29% |
| 4 | 1.35 | Infected platelets | 28% |

Fig 6 shows the output transmission spectrum of micro cavity based biosensor.

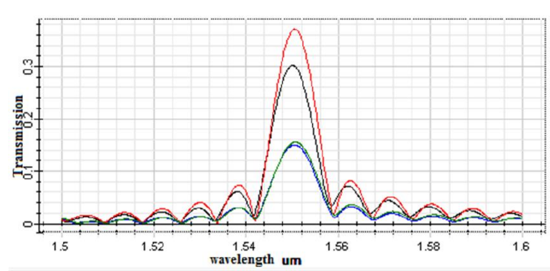


Fig 6: Output transmission of microcavity based biosensor.

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**Table 3. Analysis of design 2 wavelength according to Refractive Index**

| S.No. | Refractive Index | | Normalized Transmission |
|---|---|---|---|
| 1 | 1.35 | Normal plasma | 30% |
| 2 | 1.33 | Infected plasma | 15% |
| 3 | 1.39 | Normal platelets | 36% |
| 4 | 1.35 | Infected platelets | 15% |

Above tables shows the transmission of normal plasma infected plasma, normal platelets and infected platelets and with their respective refractive index in different cavities. The Nano cavity and microcavities are filled according their refractive index and transmission results measured. The design of bio sensor is highly sufficient for sensing various dengue pathogens. This sensor is providing a good accuracy and better transmission and suitable for real time application. As the sensitivity of any biosensor is defined by its Q factor, below tables shows the Q factor of two biosensors and thus result of this Q factor helps us to decide whether nanocavity or micro cavity biosensor is better.

**Table 4. Analysis of Quality factor of Nanocavity Sensor**

| S.No. | Refractive Index | Wavelength (λ) | Quality Factor |
|---|---|---|---|
| 1 | 1.35 (Normal Plasma) | 1.552 | 154 |
| 2 | 1.33 (Infected Plasma) | 1.548 | 145 |
| 3 | 1.39 (Normal Platelets ) | 1.550 | 165 |
| 4 | 1.35 (Infected Platelets) | 1.550 | 145 |

**Table 5. Analysis of Quality factor of Microcavity biosensor**

| S.No. | Refractive Index | Wavelength (λ) | Quality Factor |
|---|---|---|---|
| 1 | 1.35 (Normal Plasma) | 1.550 | 153 |
| 2 | 1.33 (Infected Plasma) | 1.550 | 111 |
| 3 | 1.39 (Normal Platelets ) | 1.549 | 141 |
| 4 | 1.35 (Infected Platelets) | 1.551 | 128 |

Quality factor is defined as the ratio of resonant wavelength ($\lambda 0$) to the full width at half maximum ($\Delta\lambda$) of the resonator Lorentzian response i.e. $\lambda 0/\Delta\lambda$ [35]. It is represented by 'Q'.

$$Q = \omega 0/\Delta\omega = \lambda 0/\Delta\lambda$$

Where $\lambda 0$ is the resonance wavelength and $\Delta\lambda$is the full width at half maximum (FWHM) response.

## IV. CONCLUSION

In this paper, transmission shift biosensor detects dengue in blood plasma and blood platelets using the two dimensional photonic crystal. The designed sensor is very small in size, compact, low cost, less losses and operates at very high speed. Simply by varying the refractive index of material transmission can be obtained. The designed biosensors are based two dimensional four nano cavities and four micro cavities with hexagonal shaped lattice. By observing the results obtained from Q factor we can say that nano caivity structure have better sensitivity as compared to microcavity structure. As nanocavity structure of biosensor reduces the overall size of biosesnsor, thus reducing the complexity and overload. For both structures 1550 nm wavelength is used at input port. The purpose of this structure is to detect dengue in blood plasma and platelets. The designing and simulation are performed in Finite Difference Time Domain (FDTD).

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