Vijay Laxmi Kalyani, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 12, Issue 6, (Series-V) June 2022, pp. 05-11

RESEARCH ARTICLE OPEN ACCESS

Design and simulation of nano cavity and microcavity based 2D photonic crystal biosensor for Melanoma (skin cancer) detection

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ABSTRACT:
In this paper, we propose a design of nano cavity and microcavity based 2D Photonic Crystal biosensor for Melanoma (skin cancer) detection. Both the sensors are designed using normal cell and Melanoma cell with refractive index (1.35) and (1.59) which are used in the cavity and change of wavelength shift according to the refractive index are sense by bio sensor. Change in output transmission spectrum and Q factor has been observed with the wavelength shift, therefore by observing these changes Melanoma (skin cancer) is detected. By designing nanocavity and microcavity in the same structure of biosensor, comparison is also done that which sensor is having good accuracy and better transmission. The proposed biosensor is designed using OptiFDTD simulation software which is used to analyze the results. Plane wave expansion (PWE) is also used in this paper for calculation of photonic bandgap. The band gap from 1316nm-1940nm and 1550 nm continuous modulated wave is used in this design. The wafer dimensions of the proposed structure is 8x12 µm. The proposed sensor achieved high Q factor 382.70 in nanocavity structure and 362.54 in microcavity structure during simulation. The proposed sensor design can predict results accurately and in short time. Hence it can be used for medical applications.

Keywords: — Melanoma Cancer cell; Finite Difference Time Domain; Photonic Crystal; Plane Wave Expansion; Refractive index; Simulation Results

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Date of Submission: 07-06-2022 Date of Acceptance: 22-06-2022

I. INTRODUCTION

Skin is the largest organ in the human body. Skin protects from infection and injury. It helps regulate body temperature and produces vitamin D. The outer layer of skin called epidermis is located just above the inner layer of skin called dermis which contains cells called melanocytes. Melanoma begins when healthy melanocytes change and grow out of control, forming a cancerous tumor. A cancerous tumor is malignant which can grow and spread to other parts of the body. It can develop anywhere on the body, including the head and neck, the skin under the fingernails, the genitals, and even the soles of the feet or palms of the hands. Melanoma may not be colored like a mole. It may have no color or be slightly red, which is called amelanotic melanoma [1, 2]. Melanoma is the most serious type of skin cancer which develops in the melanocytes cells. The risk of melanoma seems to be increasing in people under 40, especially women [1].

People are worldwide affected from this disease specially, people those who are having fair complexion, blond or red hair, blue eyes and freckles are at increased risk for developing melanoma. Detection of melanoma (skin cancer) at early stage can save millions of life worldwide. According to study, Worldwide, an estimated 324,635 people were diagnosed with melanoma in 2020 and In 2020, an estimated 57,043 people worldwide died from melanoma [2]. Melanoma can be treated successfully if it is detected early.

In this paper, the proposed sensors are designed using photonics crystal (PC). The photonics crystal based devices have a better confinement of light due to the photonic bandgap. The bandgap does not allow the light to passes through the walls of the created waveguide. Thus PC based biosensors provide fast and accurate results. It is a new and accurate measurement technology for bio-sensing applications. Photonic crystals are periodic dielectric structures that have a band gap that forbids propagation of a certain frequency range of light. This property enables one to control light with amazing facility and produce effects that are impossible with conventional optics.

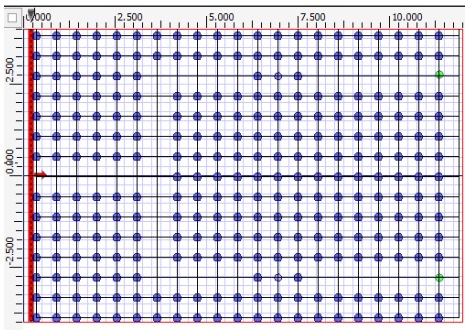
Photonic crystal has a many advantage such as easy fabrication, better light confinement through the bends, small size etc. Photonics crystal based biosensors are of many types such as nanocavity based biosensor , microcavity based biosensors, optical fiber based biosensors etc.

In the past few years, many researchers has designed the biosensors by using the photonic crystal. **Saeed Olyaee et.al** described a four channel two dimensional photonic crystal based biosensor with hexagonal symmetry and air hole in Si background. The bio sensing mechanism is based on the effective refractive index change of the sensing hole [3]. **Fleming Dackson Gudagunti et.al** designed and simulated a 2-D photonic crystal based ring resonator biosensor with point and line defects which is detect early stage breast cancer. Finite difference time domain (FDTD) method used for analysis and MEEP tool are used to modelling and designing a ring resonator based biosensor. The frequency is shift is observed to change a dielectric constant from normal cell to breast cancer cell [4]. **Saronika et.al** designed a nanocavity-coupled photonic crystal waveguide as highly sensitive platform for cancer detection. A bio-sensing platform based on nanocavity-coupled photonic crystal waveguide (PCW) is proposed for diseased cell detection [5]. **Giampaolo Pitruzzello and Thomas F Krauss** , This review provided an insight into the recent developments of photonic crystal (PhC)-based devices for sensing and imaging, with a particular emphasis on biosensors [6]. **Guruprasad L et.al** designed Photonic Crystal Based Optical Biosensor for Melanoma Cancer cell Detection. Proposed work was comprised a novel of Photonic Crystal structures for the carcinogenic sensing application consist of two types of resonator to a complex bus waveguide so as to achieve high quality factor and high sensitivity. Sensor is designed and analyzed in Rsoft photonic design software. Novel design is achieved by creating two types of resonator i.e. triangular and ring resonators connecting to a bus waveguide [7].

In this paper nanocavity and microcavity based photonics crystal biosensor have been designed to detect melanoma (skin cancer).The optiFDTD (Finite difference time domain photonics simulation software) provide all simulation results and PWE band solver simulator is also used for photonics band gap calculation. In this paper our main objective is to design the nanocavity and microcavity based photonics crystal biosensor and comparison also done between them that which sensor is provide better accuracy and good transmission spectrum after simulation.

II. PROPOSED DESIGN OF BIOSENSORS

The proposed biosensors structure uses 2D rectangular lattice structure with silicon rods and air in background wafer. This type of structure is used for reducing the scattering loss and for effectively controlling the transverse electric (TE) mode propagation. The structure have 21 silicon rod in Z-direction and 15 silicon rods in X direction. Wafer dimensions are 8x12 µm. The distance between the two adjacent rods is lattice constant (a). In this design lattice constant is 550 nm. For the propagation of light inside the structure an optical wavelength 1550 nm continuous wave is used in the input side. Two observation points are used on the output port to detect the input wave. The refractive index of silicon material is 3.45 and air is 1. The radius of silicon rods are 110 nm. In this paper, R.I. of normal cell (1.35) and R.I. of Melanoma cell (1.59) are used [7] in the nanocavity and microcavity structure and change of wavelength shift according to refractive index are sense by bio sensor. The layout has two linear waveguides with two cavities (acting as a resonant cavity) for normal cell and melanoma cell which is closely coupled with linear waveguide which serve as optical input and output path for the device. To design the nanocavity and microcavity based biosensor we are using same layout of biosensor by slightly changes the radius of silicon rods. In nanocavity based biosensor, two nanocavities are created by reducing the radius of silicon rods from 110 nm to 100 nm and in microcavity based biosensor, two microcavities are created by increasing the radius of silicon rods from 110 nm to .120 um.



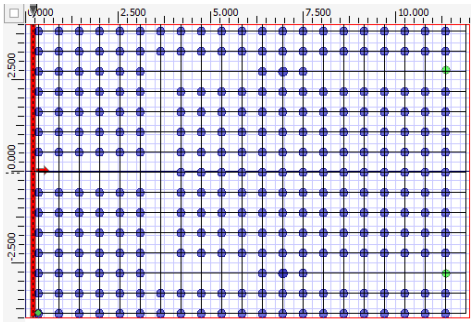
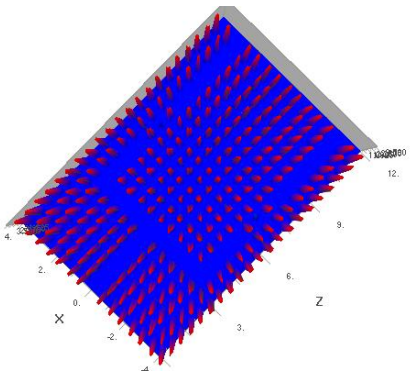


Fig.1: Nano cavity based photonics crystal biosensor layout (Design 1)

Fig.2: Microcavity based photonics crystal biosensor layout (Design 2)

In above design 1, the biosensor has two nanocavities. These cavities are created by reducing a radius of silicon rods from 110 nm to 100 nm. The light propagated inside the structure is continuous wave has a wavelength of 1550 nm is used. Two observation points are used on the output port to detect the input wave. The refractive index of silicon material is 3.45 and air is 1. The radius of silicon rods are110 nm. The R.I. of normal cell is 1.35 and R.I. of Melanoma cell is 1.59 are using in this structure [7]. The sensing mechanism of proposed design is used to change the R.I. of analytes which led to shifting in transmission.

In above design 2, by using the same structure of biosensor, two microcavities are created by changing the radius of silicon rods from 110 nm to .120 µm. The light propagated inside the structure is continuous wave has a wavelength of 1550 nm is used. Two observation points are used on the output port to detect the input wave. The sensing mechanism of proposed design is used to change the R.I. of analytes which led to shifting in transmission. Both type of sensor devices are able to detect Melanoma cancer cell from normal cell at the early stage.



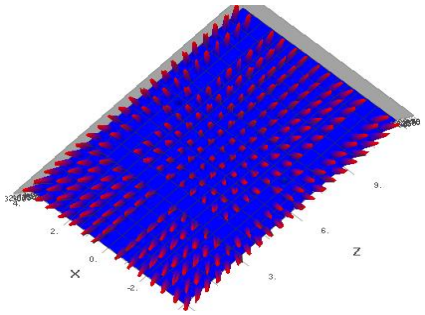


Fig.3: silicon rods in air configuration in nanocavity based sensor

Fig.4: silicon rods in air configuration in microcavity based sensor

Above figures indicates the 3D view of the nanocavity and microcavity based sensor structure. In both structure, the silicon rods are suspended into the air configuration. The main advantage of this type of structure is that the propagation of light inside the structure is easy and the designing of devices is simple.

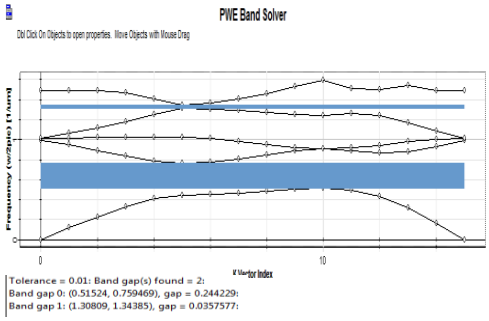


Fig.5: TE band gap diagram of design 1 using PWE band solver

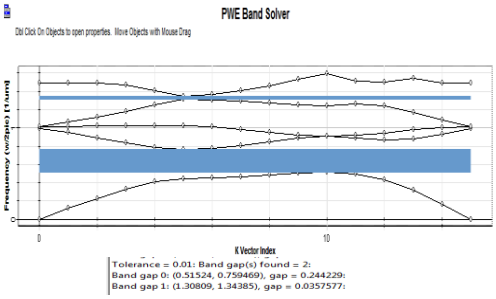


Fig.6: TE band gap diagram of design 2 using PWE band solver

Above band diagram of both sensor structures gives the Photonic Band Gap for Transverse Electric (TE) modes. The band gap structure depends upon three parameters, refractive index of material, lattice constant, and ratio of radius to lattice constant (r/a). The Plane wave expansion (PWE) method is used, to estimate the band gap and propagation modes of the photonics crystal structure without and with defects. The complete structure of both biosensors are having two band gaps. The first photonic band gap (PBG) is in the range between the wavelength 1316 nm and 1940 nm, and the second PBG is from 744 nm and 764 nm. As our proposed designed structure lie in the first PBG range (1316nm-1940nm). Therefore, in this paper the first PBG range is considered. Continuous wave is used in this paper at wavelength 1550 nm and its wavelength is exactly center wavelength of this PBG wavelength range.

Table 2.1 Design parameter and its value used in biosensor nanocavity and microcavity based sensors

S.No.	Name of parameters	Values
1.	Radius of silicon (rod)	110nm
2.	Lattice constant	550nm
3.	Refractive index of Si	3.45
4.	Refractive index of Wafer (air)	1
5.	Refractive index of Normal Cell	1.35
6.	Refractive index of Melanoma cancer Cell	1.59
7.	Input wavelength	1550nm
8.	Wafer dimensions	8x12 µm
9.	PBG range	1316nm-1940nm
10.	Polarization	TE

The above table shows the design parameters and their values which are used in nanocavity and microcavity based sensor structure.

III. SIMULATION AND RESULTS

OptiFDTD simulation software is used for the designing and simulation purpose. A continuous wave is applied at the input side with wavelength 1550 nm. At this wavelength the waveguide is fully coupled and reached at the output port. Therefore at this wavelength very small amount of losses occurs inside the structure. So it is considered as a resonance wavelength of this structure. The transverse electric (TE) polarization mode is selected for the propagation of light inside the structure. Good performance of biosensor is achieved by getting a high transmission spectrum.

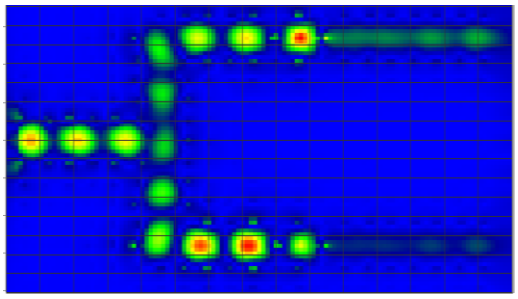


Fig.7: 2D electric field distribution in nanocavity based sensor

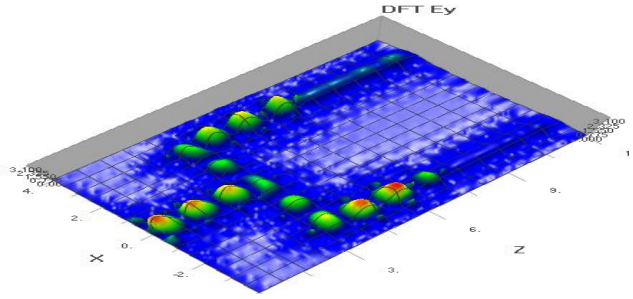


Fig.8: 2D electric field distribution in microcavity based sensor

Above figures shows the 2D electric field distribution of the sensor at 1550nm. In this the electric field of the waveguide is fully coupled in the nanocavity and microcavity and reaches at the output port.

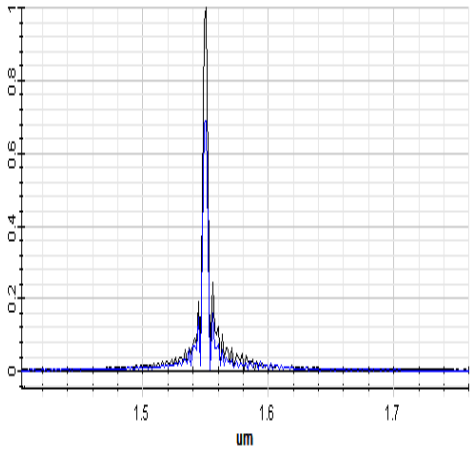


Fig.9: Transmission graph of nanocavity based biosensor

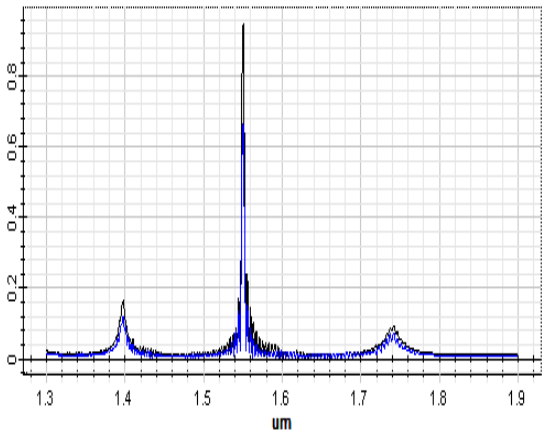


Fig.10: Transmission graph of microcavity based biosensor

Above figure (9&10) shows the output transmission spectra of normal Cell and Melanoma Cell in nanocavity and microcavty based biosensor at refractive index 1.35 and 1.59. The black curve depicts normal cell response and blue curve depicts melanoma cell response in both diagrams.

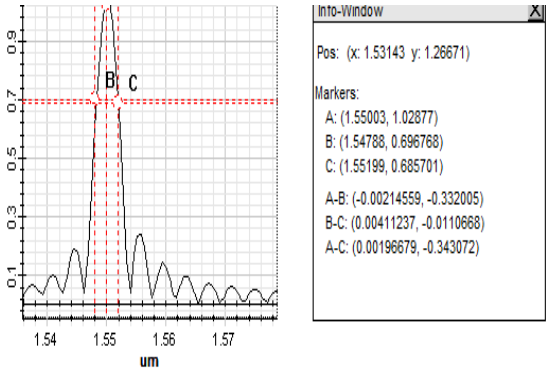


Fig.11: Transmission graph of normal cell in nanocavity based sensor

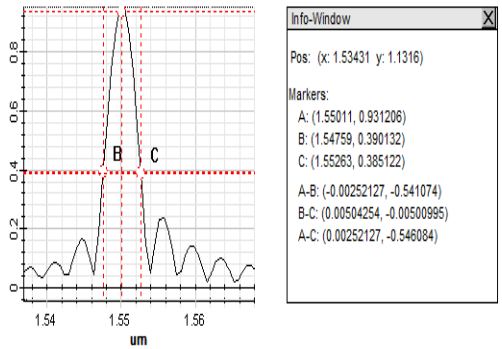


Fig.12:Transmission graph of normal cell in microocavity based sensor

Above figure 11 shows the transmission graph of normal cell in nanocavity based biosensor at 1.35 refractive index. In this refractive index, transmission is 100%. As the sensitivity of any biosensor is defined by its Q factor, thus in this paper Q factor helps us to decide whether nanocavity or micro cavity biosensor is better. Using information window we can calculate the

quality factor of both sensors. The quality factor is the ratio of resonance wavelength and full width half maximum of resonator.
Therefore $Q = \lambda/\Delta\lambda$
Where λ is the resonance wavelength and $\Delta\lambda$ is the full width half maximum (FWHM)
Using above formula the quality factor of normal cell response in nanocavity based sensor is 376.91.

Figure 12 shows the transmission graph of normal cell in microcavity based biosensor at 1.35 refractive index. In this refractive index, the quality factor is 307.40 and transmission is 94%.
The results shows that the normal cell response in nanocavity based structure is having good transmission and quality factor in comparison with microcavity based sensor.

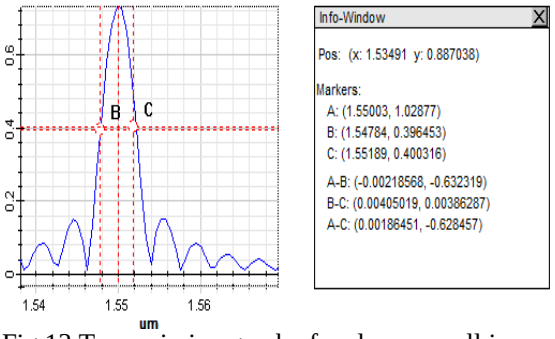


Fig.13:Transmission graph of melanoma cell in nanocavity based sensor

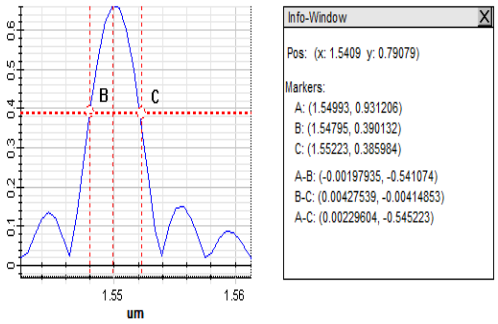


Fig.14:Transmission graph of melanoma cell in microcavity based sensor

Above figure 13 shows a transmission graph of Melanoma Cell in nanocavity based biosensor at refractive index 1.59. Using this refractive index, transmission is 74% and quality factor is 382.70.
Figure 14 shows a transmission graph of Melanoma Cell in microcavity based biosensor at refractive index 1.59. The quality factor is 362.52 and transmission is 72% using the 1.59 refractive index.
The results shows that the melanoma cell response in nanocavity based structure is having good transmission and quality factor in comparison with microcavity based sensor.

Table 3.1 Transmission Spectrum and quality factor according to their refractive index used in nanocavity based biosensor.

Cell Name	Refractive index	Transmission	Wavelength (μm)	Q-factor
Normal Cell	1.35	100%	1.550	376.91
Melanoma Cancer Cell	1.59	74%	1.550	382.70

Table 3.2 Transmission Spectrum, quality factor and wavelength according to their refractive index used in microcavity based biosensor.

Cell Name	Refractive index	Transmission	Wavelength (μm)	Q-factor
Normal Cell	1.35	94%	1.550	307.40
Melanoma Cancer Cell	1.59	72%	1.549	362.52

Above tables shows the transmission of normal cell and melanoma cell with their respective refractive index in different cavities. The nano cavities and microcavities are filled according to their refractive index and transmission results measured. As the sensitivity of any biosensor is defined by its Q factor, therefore the above table also shows the Q factor of biosensors and thus result of this Q factor helps us to decide whether nanocavity or micro cavity biosensor is better. In above tables 3.1 and 3.2, the results shows that the quality factor and transmission of nanocavity based sensor structure at wavelength 1550 nm are good in comparison with microcavity based sensor structure. Thus nanocavity based structure provides good accuracy and better transmission.

IV. CONCLUSION

Nano cavity and microcavity based sensor structures are designed and analyzed for detection of melanoma (skin cancer). High transmission spectrum and quality factor are observed in nanocavity based sensor structure in comparison with microcavity based sensor structure. Both designs are helpful to detect melanoma (skin cancer) disease in early stage. All the simulation work are done using OptiFDTD simulation software and PWE band solver are used for band gap calculation. The proposed sensor design can predict results accurately and in short time with good accuracy and better transmission. Therefore it can be useful for medical applications.

DISCLOSURES

The authors have no conflict of interest.

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