PHOTONIC CRYSTAL RING RESONATOR BASED PRESSURE SENSOR FOR UNDER WATER LOW PRESSURE DETECTION

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Abstract : Here, we propose a design of two dimensional photonic crystal ring resonator based pressure sensor for the detection of under water pressure. Spectral scrutiny has been done for under water low pressure indications. As the refractive index of the water changes at different water pressures, there is a change in resonant frequency & wavelength. The investigation of transmission spectrum is done by using a simulation tool called MEEP. A photonic crystal based ring resonator structure can sense under water low pressures in the wavelength range of 1550 nm with quality factor of 52345 which can be used for marine and aquatic studies.

***Index Terms* -** Under water pressure, Integrated Photonics, Photonic crystal, Ring resonator, FDTD, MEEP.

I. INTRODUCTION

Like all methodical disciplines, the study of marine biology also trails the scientific scheme. The intervening goal in all of science is to find the veracity. Though succeeding the scientific technique is not by any means a stiff progression, research is typically led methodically and rationally to slender the unavoidable fringe of inaccuracy that occurs in any scientific study, and to evade as much bias on behalf of the researcher as conceivable. The major factor of scientific exploration is classification by explanations. And one such study involves the underwater pressure detection. Sensor networks have the promise of revolutionizing many areas of science, industry, and government. While sensor-net systems are beginning to be fielded in applications today on the ground, underwater operations remain quite limited by comparison. Underwater sensor networks have many potential applications. [1]

In the contemporary work, we have validated the integrated photonic approach for developing a two-dimensional “Photonic crystal based Ring resonator sensor” for study of revealing under water pressures [2][3]. MEEP (MIT Electromagnetic Equation Propagation) simulation tool which outfits FDTD (Finite Difference Time Domain) method has been used for modeling and designing of the sensor structure [4]. To up surge the sensitivity of the photonic crystal sensor the ring resonator waveguide structure has been used.

The optical properties of water at low pressures are studied and the normalized transmitted output power, transmission frequency and Q factor have been detected therefore. It has been perceived that for little variation in dielectric constant (ϵ) according to the pressure variations there will be an adequate shift in the transmitted output power, transmission frequency and quality factor and hence it behaves as a sensor.

This stipulates that it is highly sensitive even for the little change in refractive index. These optical sensors are gesture free, have large bandwidth, very high quality factor (Q), provide direct dimensions for exploration of substances in petite duration of time and can be fabricated as an opto-mechanical sensor.

II. THEORY

Photonic crystals arise from the collaboration of periodic scatters - thus, they are called crystals because of their periodicity & photonic because they behave on light. They can befall when the period is on the order of the wavelength of light. Photonic crystals are demarcated as steady arrays of materials with diverse refractive indices & are attractive optical materials for controlling & manipulating the propagation of electromagnetic waves in the same way as the periodic potential in a semiconductor crystal affects the electron motion by defining allowed & forbidden electronic energy bands. The notion behind the photonic sensing technology is that each material has diverse permittivity ‘€’ that is superior than air, as a result the propagation of electromagnetic waves that pass through them is transformed, in response to change in refractive index.

The photonic band gap structure for the photonic crystal defines the interactive and photosensitive chattels and is realized by plotting the resonant frequency beside the 'k', wave vector. The photonic band gap can be detained as a comparison to energy gap in solid state electronics. The photonic band gap acts as ‘photonic insulator '. The photonic band gap property can be utilized for sensing applications. The photonic band gap property can be transformed by generating defects in the photonic crystal. Novel photonic energy states get generated in the photonic crystal due to the existence of defects. Defects can be produced either by changing the dimension or dielectric constants of one or more group of elements or exclusion from the structure and act as optical cavities. Defects control the flow of light inside the photonic crystal [2].

The light is passed through one end of the photonic crystal & the transmission spectrum is observed at the other end. The transmission spectrum observed is unique for the specific analyte. The photonic integrated circuits (PICs) consist of light sources, sensors & detectors which are integrated on one single unit. Hence, the designed sensor can be fabricated as an opto-mechanical sensor to detect under water low pressures.

III. SENSOR DESIGN

We have suggested a photonic crystal based ring resonator structure with rods in air configuration for sensing under water low pressures. The design of the sensor entails of the two dimensional square lattice ring resonator photonic crystal structure in rods (silicon) in air configuration. A straight and circular waveguide is carved out for making a ring resonator structure [5][6][7]. The light is passed through one end of the photonic crystal & the transmission spectrum is perceived at the further end. The propagation of light in the photonic crystal will differ with respect to the diverse dielectric constants of the trial constituents. Design of the photonic crystal ring resonator device is shown in “Figure 1”.

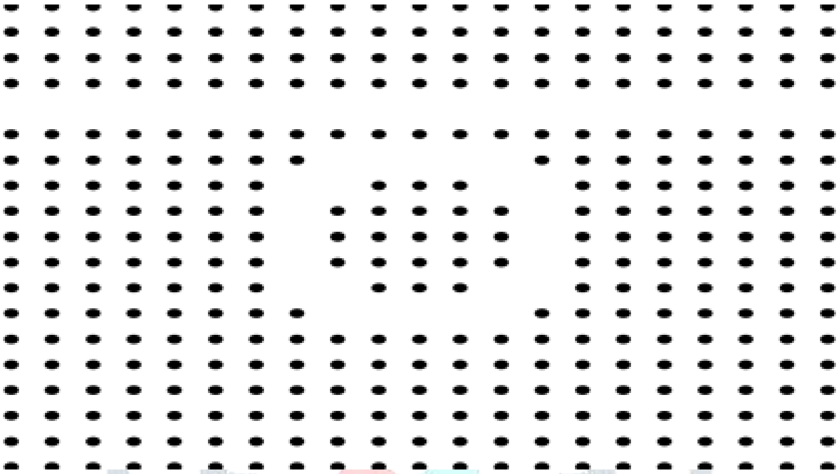

Figure 1: Design of the photonic crystal ring resonator structure

Designing and simulation is done with the help of MEEP tool.
Design Specifications are:
Square lattice structure with rods in air configuration, Lattice constant 'a'=1µm, Radius of rods 'r'=0.19µm, Dielectric constant of silicon slab = 11.56, Dielectric constant of background of the photonic crystal is changed with respect to sample taken, Gaussian Pulse with center frequency at 0.4 and width of the pulse is 0.3 used as light source and wavelength of light taken into consideration is 1550 nm.

IV. ALGORITHM

The Finite difference Time Domain (FDTD) method is implemented using the simulation tool MEEP. The Finite Difference Time Domain method solves the time domain Maxwell's equations.

The method shares the field in time and space and solves for electric and magnetic fields. MEEP is a simulation tool developed by MIT for design, model and stimulate various photonic crystal structures. It is a time domain tool and implements the FDTD method. The transmission and the reflection spectrum are obtained using the MEEP tool.

MEEP solves the Poynting vector (Equation 1) and computed the fluxes.

$$P(\omega) = Re\,\hat{n}\,.\int E_{\omega}\,(x)^{*}\ \times H_{\omega}(x)d^{2}x\ldots\ldots\ (1).$$

Here, 'P' is power, 'E' and 'H' is electric and Magnetic fields,'ω' is the frequency.

V. RESULTS

The transmission spectrum plot for wavelength spectrum is illustrated in the Figure 2, Figure 3 and Figure 4. The y-axis indicates wavelength and the x-axis indicates transmission flux for the corresponding wavelength. It can be observed that as the change in the refractive index is slight; the change in the transmission spectrum is visibly distinct, proving the sensor to be very sensitive to sense low pressure under water from Figure 2.

The transmission spectrum plot for frequency spectrum is illustrated in the Figure 5, Figure 6 and Figure 7. The data were collected from reference [9].

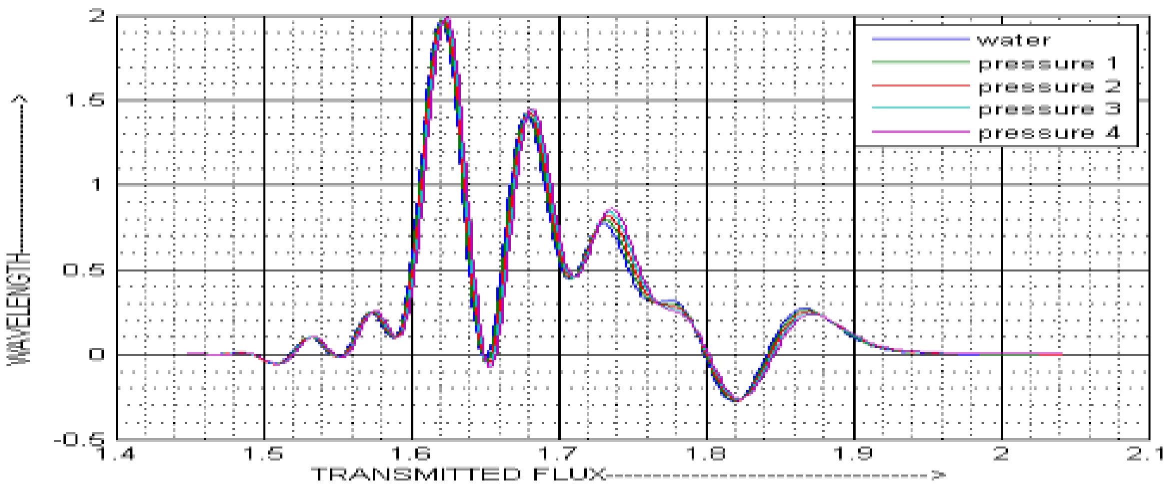

Figure 2: transmission spectrum for wavelength shift

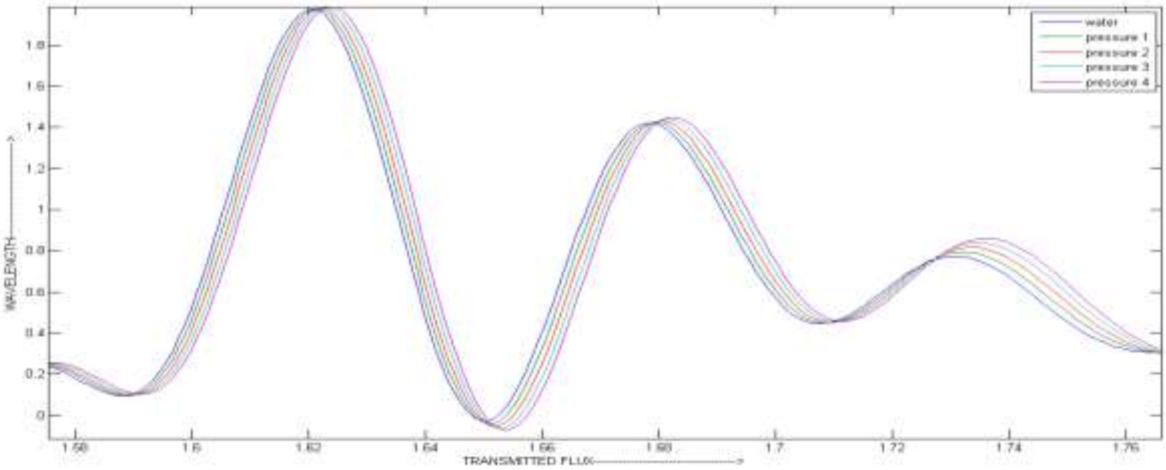

Figure 3: zoomed version of transmission spectrum for wavelength shift

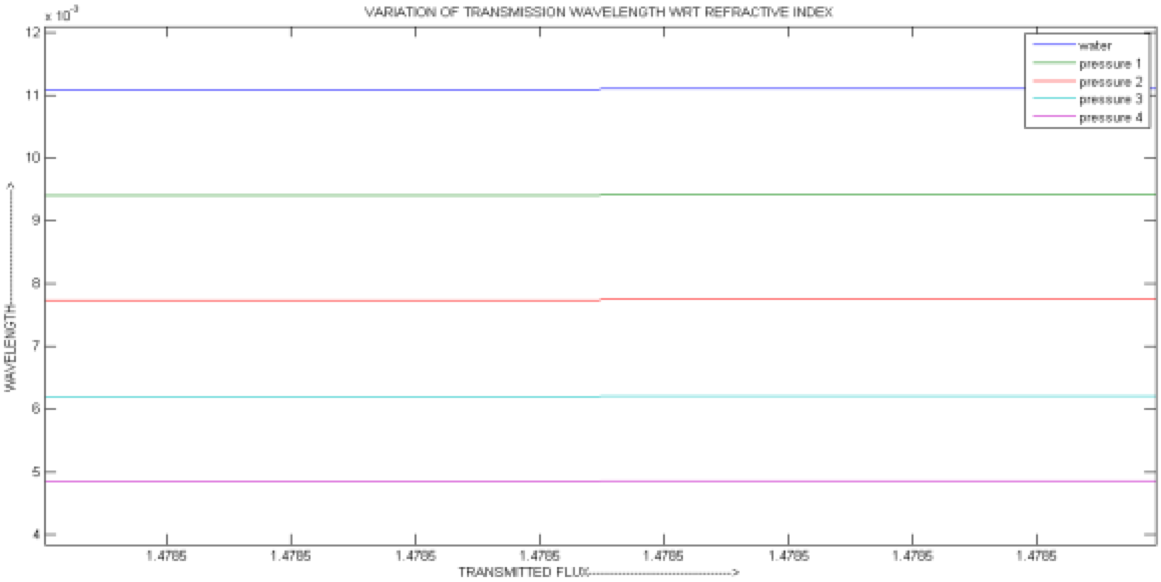

Figure 4: micro zoomed version transmission spectrum for wavelength shift

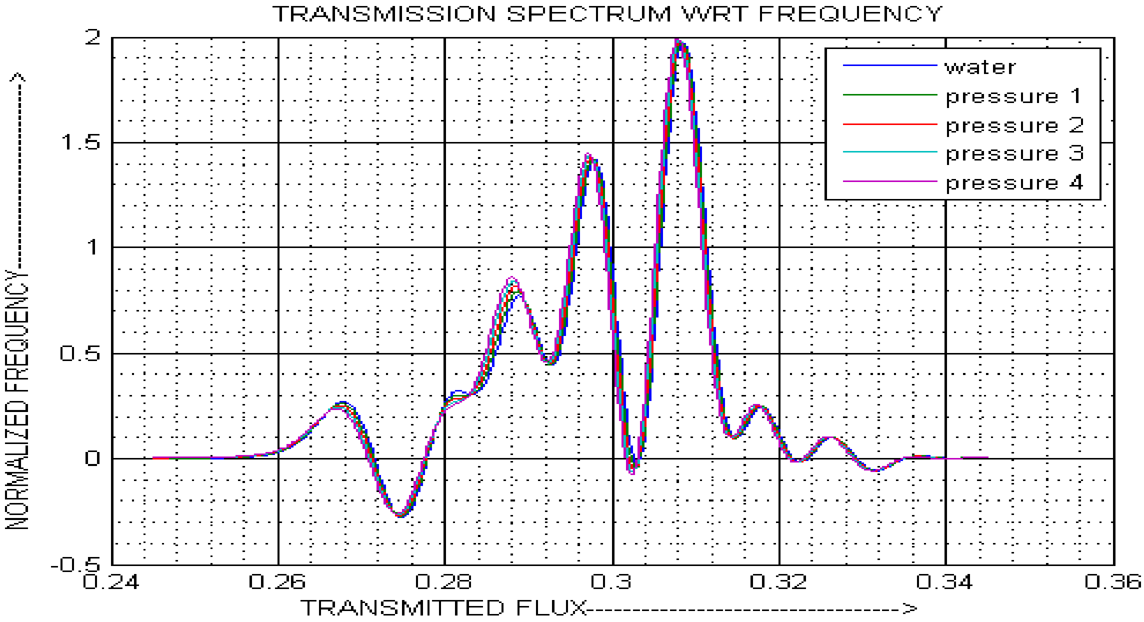

Figure 5: transmission spectrum for frequency shift

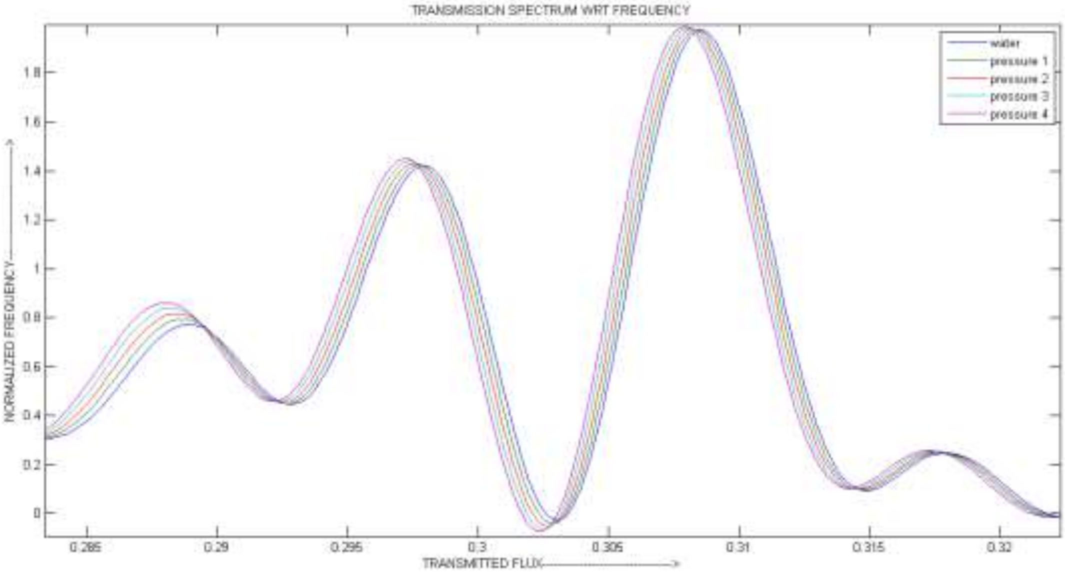

Figure 6: zoomed version of transmission spectrum for frequency shift

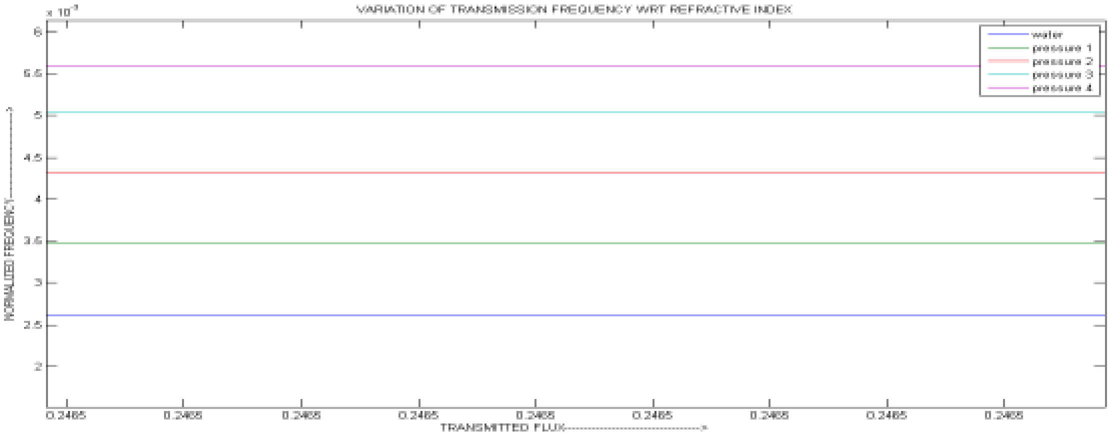

Figure 7: micro zoomed version of transmission spectrum for frequency shift

The energy in the transmission spectrum was calculated as below

$$E_{i1} = 1 \ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

This is through the straight waveguide

$$E_{i2} = \alpha . e^{j\theta} E_{t2} \ldots\ldots\ldots\ldots \text{(3)}$$

This is through the resonator.

Adding both the paths,

$$E = 1 + \alpha . \mathrm{e}^{j\theta}\, E_{t2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Here, α=loss coefficient of the ring
θ=ωL\C
L= circumference
C = C_o/N_{eff} = phase velocity
K = wave number = 2π/λ

Examining these graphs, it can be believed that the design sensor is very subtle to slightest of disparities. The Q-factor has been calculated for the proposed design & its value is 52345.

The quality factor was calculated using

$$Q = \frac{\eta_{eff} L}{\lambda} \times \frac{\Delta\lambda}{2\delta\lambda} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

The sensitivity was found to be calculated in terms of 0.000688 /RIU.

The sensitivity was calculated using the formula $S = \dfrac{\partial\lambda}{\partial\eta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ (6)

Where $\partial\lambda$ = change in wavelength in nm and $\partial\eta$ = change in refractive index.

The peak power was calculated using the formula

$$P_t = \frac{\alpha^2 + |t^2| - 2\alpha\,|\mathrm{t}|\cos(\phi + \psi_t)}{\alpha^2\,|t^2| + 1 - 2\alpha\,|\mathrm{t}|\cos(\phi + \psi_t)} \ldots\ldots\text{(7)}$$

ψ_t = Phase of the coupler

The trend was plotted against each of the pressure values and frequency/wavelength which is as shown in Figure .8 and Figure 9 as shown below.

From the equations (1) and (7), one can note that the increase in pressure under water decreases the peak frequency and vice versa. The increase in pressure under water increases the peak wavelength and vice versa.

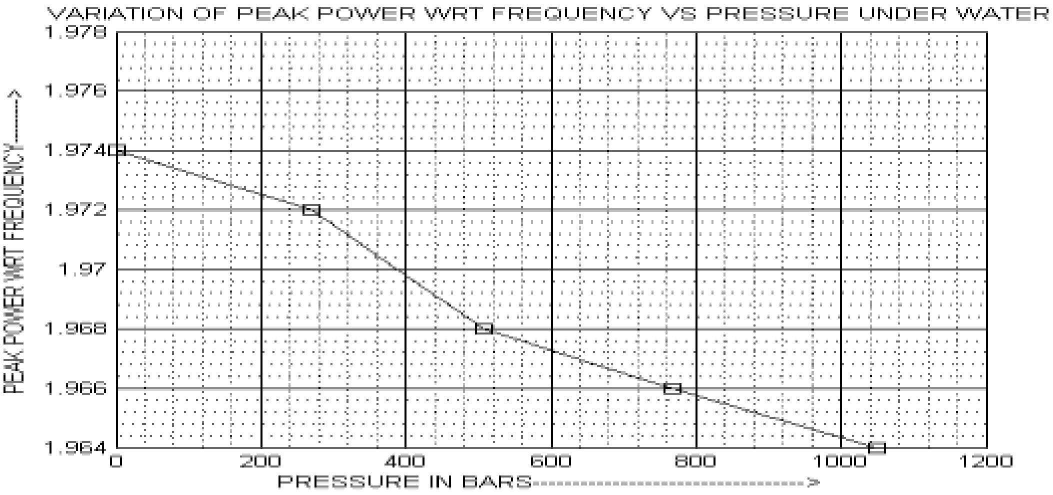

Figure 8: Variation of pressure values and frequency

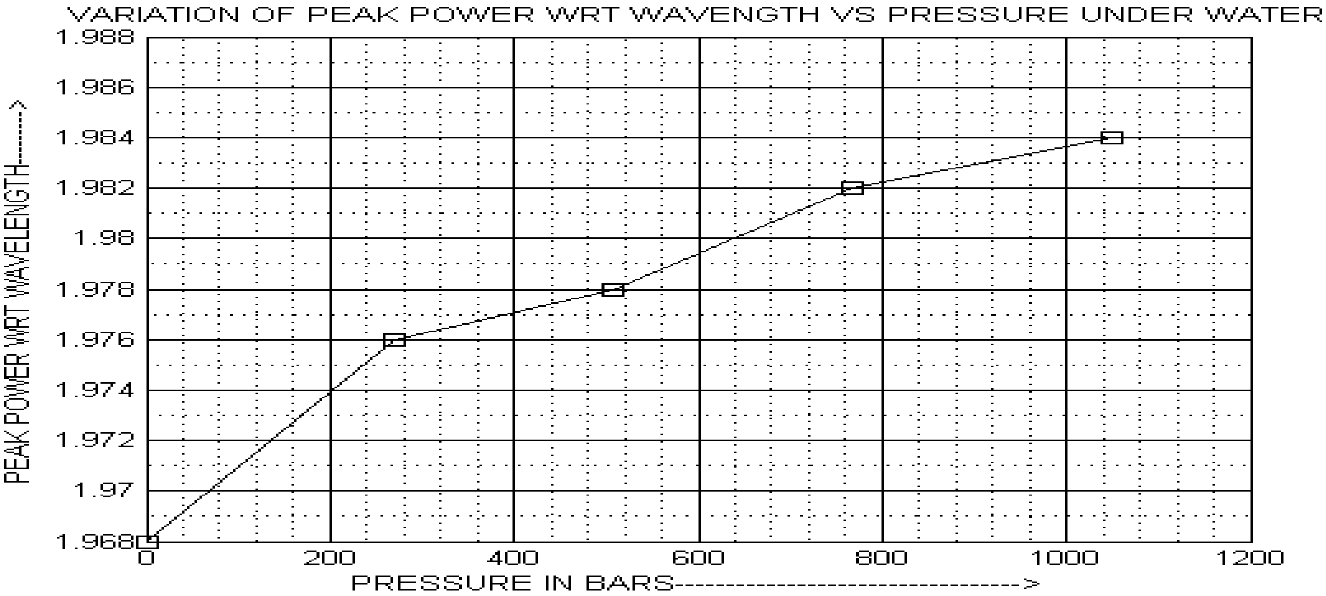

Figure 9: Variation of pressure values and frequency

The designed sensor is transformed into GDSII file using IPKISS software and python tool and it is observed in GDSII viewer (OWLVISION) and it is shown in Figure 10. Then it can be simply deciphered into ASCII format which can be used for fabrication. The GDSII file as shown in Figure.10 was then confirmed with respect to its edicts with the help of K-layout tool and it is shown in Figure. 11.

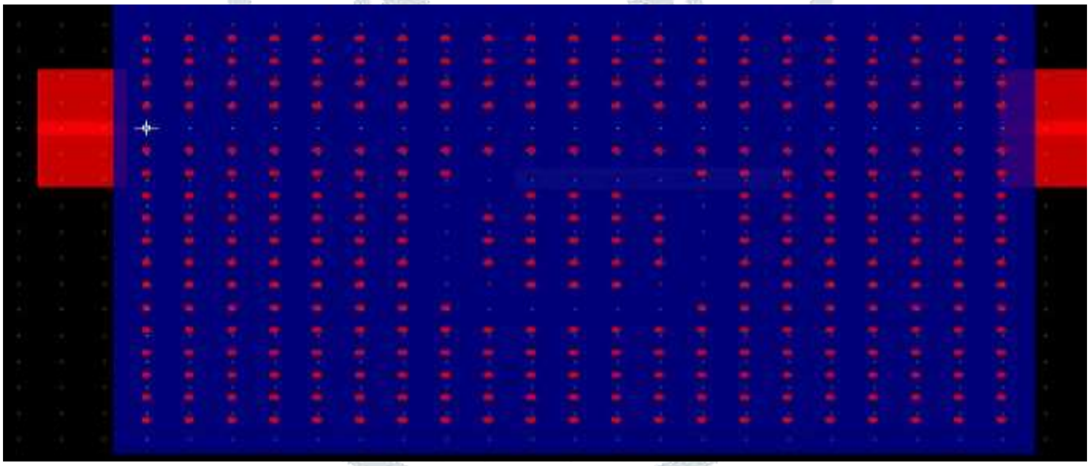

Figure 10: GDSII file from OWLVISION (GDS viewer tool)

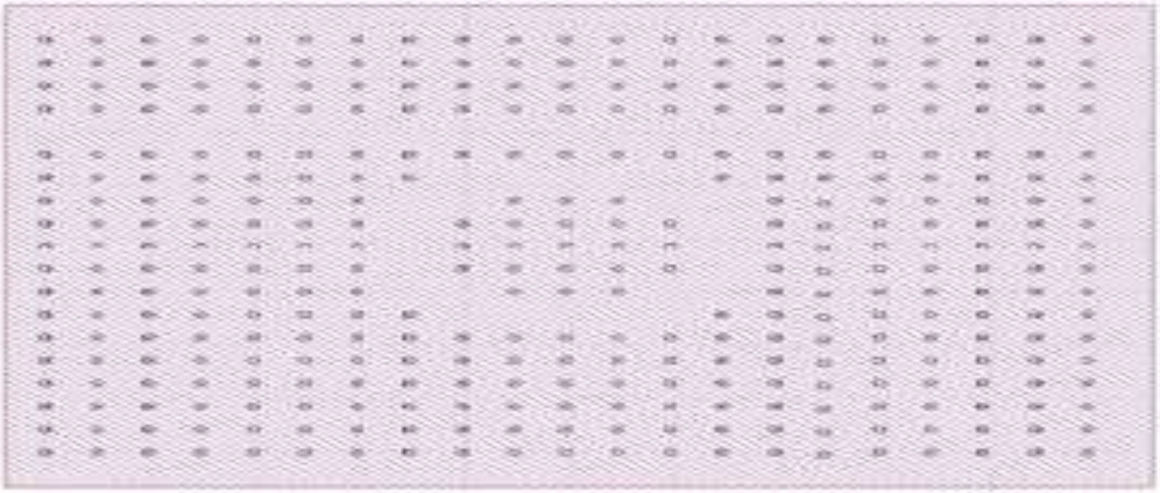

Figure 11: GDSII file from Klayout

The table 1(results) defines significant shifts which can thus help in determining the low pressure under water.

Table 1: shifts in frequency and wavelength spectrum along with power obtained

Pressure in Bars	**Absolute refractive-index**	**Peak frequency (normalized)**	**Peak wavelength (nm)**	**Power in dB**
1	1.33439	0.3085	1620	5.9069
269.5	1.33589	0.3084	1622	5.8981
507.4	1.34213	0.3083	1624	5.8805
768.5	1.34581	0.3079	1626	5.8716
1049.7	1.34948	0.3077	1628	5.8628

VI. CONCLUSION

The photonic crystal ring resonator structure is designed and simulated for the detection of detecting low pressure under water. Discrete transmission spectrums and transmission frequencies are obtained in the wavelength range of nm for different pressures which can act as noteworthy roles in studying the underwater diving, aquatic life in underwater and underwater marine science. The sensor is highly sensitive and has a very high quality factor (Q = 52345). The sensor premeditated can be fabricated as an optical chip sensor providing a diminished, cost effective, low energy sensor system. With this the signatures of the spectrums can be articulated using Table 1. Thus these spectrums can be regulated so as to detect the low pressure under water.

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