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Pressure Sensing Using a Two-Dimensional Photonic Crystal Sensor

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ABSTRACT- The noticing qualities such as the level of Sensitivity and Quality factor (Q-factor) are evaluated deliberately. A two-dimensional photonic crystal (2DPC) centered stress sensing unit is modeled and designed. The 2DPC centered pressure sensing unit is designed using holes in slab configuration. The L3 defect is created by customizing the spans of three silicon poles and is introduced between two waveguides. It has been revealed that the sensor's wavelength is transferred linearly to a larger wavelength area, which improves the sensor's performance.

General Terms: Photonics crystal-based pressure sensor, Photonic Band Gap.

Keywords: Q-factor, pressure sensor, photonic crystal, waveguide, L3 defect, holes in slab configuration.

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1. INTRODUCTION

Eli Yablonovitch et. al., at1987 released their study research dealing with photonic crystals, anticipating the presence of a photonic band gap in addition to limiting spontaneous emission to the potential and within defects to localize light in a Periodic lattice of acceptable measurements [14], [20]. The photonic crystal consists of periodic dielectric or metallic-dielectric nanostructures with differing dielectric constants and refractive indices that affect the propagation of electromagnetic waves inside the structure [14], [20]. By creating point and line defects in the structure light can be confined in the photonic band gap (PBG) area [15]. The photonic crystal (Phc) is a new study topic in the realm of optical sensing. A Phc is a structure made of periodic dielectrics with a lattice parameter equal to the wavelength of an electromagnetic wave carried through it [10], [14], [19]. One of the most essential properties of photonic crystals is their ability to contain and regulate light. These properties of the crystal can be employed in a variety of applications. [1], [2], [18]. Pressure sensors are examined and implemented to great extent these days due to easy, rapid, and highly sensitive characteristics regarding pressure range detection. An optical sensor is a device that converts pressures into waves and can be utilized for sensing applications including process control, clinical analysis, weather monitoring, and armed forces. Typically, two ways of optical sensing have been documented, namely intensity and change in wavelength for Wavelength change, which is favored for sensing because wavelength change tends to have a high sensitivity [3, 4, 11]. When compared to 1DPCs and 3DPCs, the 2DPC sensor-based attracts increased attention from the scientific community due to its comparatively simple pattern, small size, good light confinement, accuracy in band gap calculation, and ease of integration. Different teams have done various research study functions based on the photonic crystal pressure sensors. It discovers a different range of pressures by their refractive indices. In the absence of pressure, the resonant wavelength, Q-factor, and output power are 1500nm, 75.5, and 57.5%, respectively [14]. To enhance the high-quality factor, we have developed a pressure sensor. A lot of PC-centered stress sensing units were recommended and made, nevertheless, the reported sensing unit was unable to offer a greater level of sensitivity and bigger vibrant vary. In get to boost the noticing attributes the L3 flaw-centered sensing unit was made and evaluated. In this paper, a photonic crystal waveguide-centered stress sensing unit is developed, and noticing qualities are evaluated over the range from 0Gpa to 4Gpa [5, 9, 16, 17].

2. SIMULATION

2.1 Simulation Process

A two-dimensional photonic crystal-centered stress sensing unit framework is developed by utilizing line problems to create a waveguide from an input port to an output port so that the light resource can be directed with it. From the literary work-study, several writers have shown that openings in piece setup are much better compared to poles in Air setup in regards to high-Q-factor [8], [12], [13]. Inspired by these research studies searching for a unique photonic crystal-centered 'Holes in Slab' setup utilizing Lumericals device is suggested in this work to improve the efficiency specifications like high-quality factor [1], [3], [19].

2.2 Steps to be followed

The steps to design the sensor are as follows,

- The pressure sensor is designed using Lumericals software application
- Various design specifications are observed.
- Refractive Index (RI) for different pressure ranges are tabulated.
- Various pressures are applied to the sensor holes, the laser beam is fed into the pressure sensor and readings for various pressure ranges are taken.
- Change in wavelength is observed and recorded.
- Then the Quality-Factor (Q-Factor) should be calculated.

Table 1: Design Specifications

Parameters	Values
Structure	Dielectric slab with Holes
Structure made of Lattice	Square
Square Lattice constant	540 nm
Size	(21×17 holes)
The radius of the holes	123 nm
Holes and Slab Thickness	220 nm
Silicon slab Refractive Index	3.46
Background index	1

Table 1 shows the design parameters of the photonic crystal-based pressure sensor designed in this work.

A “Holes in slab” configuration is chosen over “Rods in air” type from the literature survey of the previous papers [1-4].

A Square lattice structure is chosen over a triangular lattice structure in this work and the refractive index (RI) of silicon is chosen as 3.46 with the background RI of 1 (RI of air = 1). The radius of the holes is varied from 110 nm to 125 nm and the radius of 123 nm is fixed for the selected structure to provide maximum parameter values. Simulation of the selected structure is done using a finite difference time domain (FDTD) tool called Ansys Lumericals software.

3. STRUCTURE DESIGN

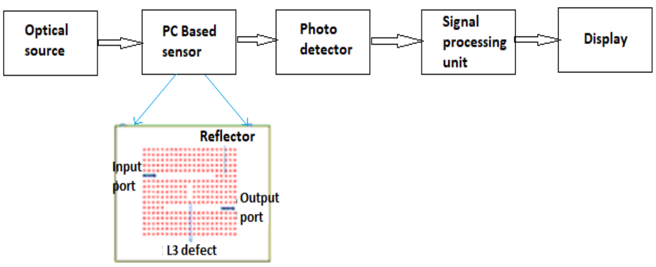

Figure 1: The structure of a photonic crystal-based sensor

Figure 1 shows the schematic representation to feel the stress utilizing the 2DPC. The optical signal is generated by the optical resource and sent to the Phc-focused sensing unit. This sensor unit is used to control light with the stress's refractive index variance [6], [7], [20]. After that, the photodetector receives the regulated light. Then the indication refining systems use the lookup table to transfer the detected amount into a comprehensible form.

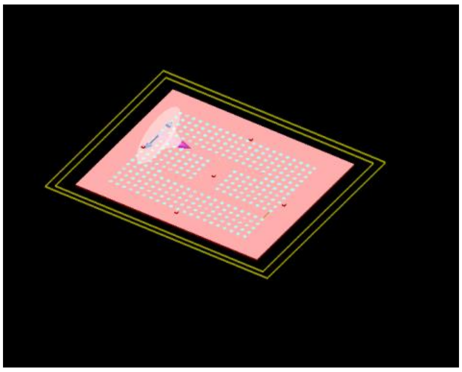

Figure 2(a): Schematic view

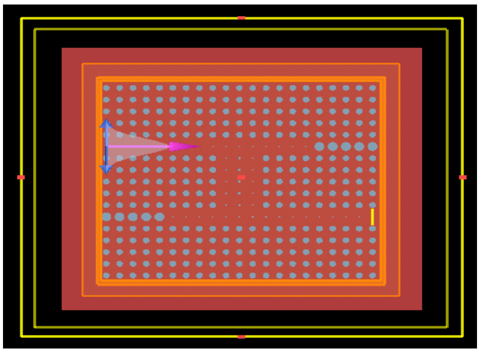

Figure 2(b): Perspective view

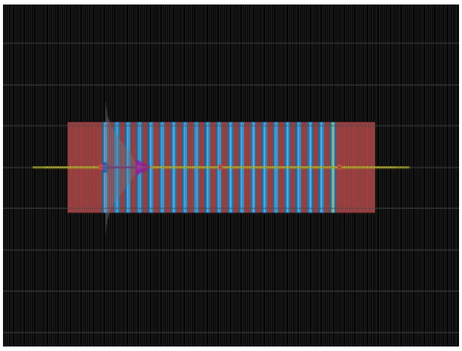

Figure 2(c): XZ view

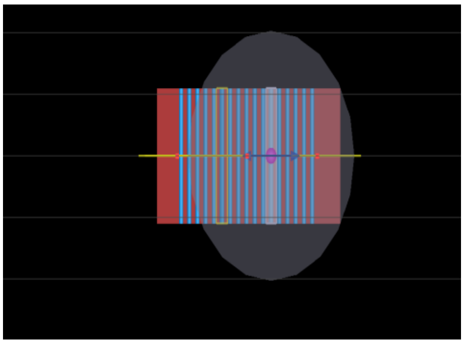

Figure 2(d): YZ view

Figure 2 (a), (b), (c), and (d) shows the schematic view, Perspective view, XZ view, and YZ view of the designed pressure sensor structure respectively.

4. RESULT AND DISCUSSION

There are different types of structure configurations for different applications. Here the holes are removed to form an 'I'

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shaped structure using the L3 pattern in defect engineering using point and line defects. Since the structure consists of only straight waveguides, the coupling and calculations are simpler as compared to the structure which consists of circular waveguides.

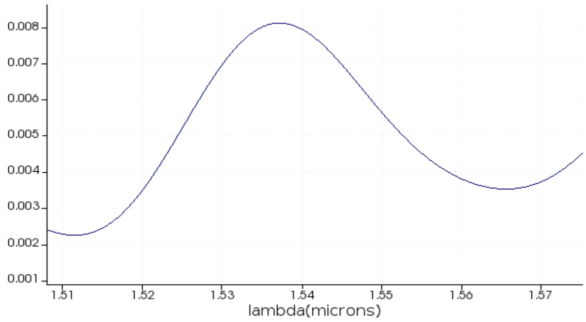

Figure 3: Transmission spectrum in the absence of pressure

Figure 3 shows the transmission spectrum of the proposed pressure sensor, without the application of pressure.

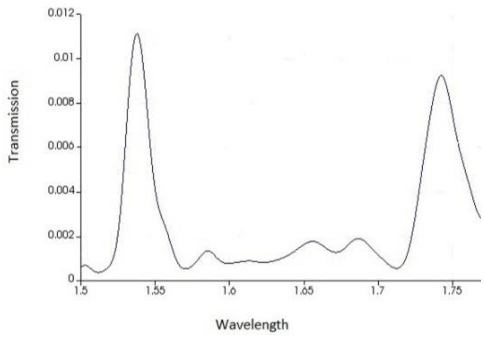

Figure 4(a): 0GPa Pressure is applied

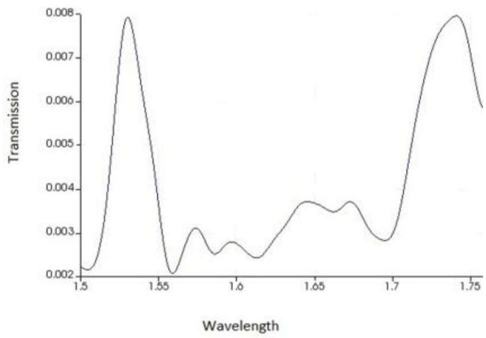

Figure 4(b): 1GPa Pressure is applied

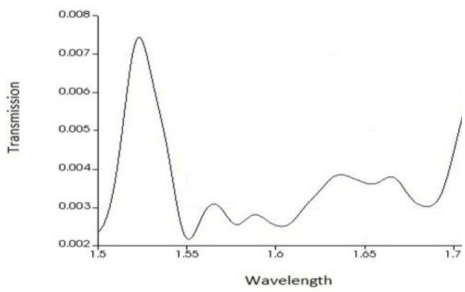

Figure 4(c): 2GPa Pressure is applied

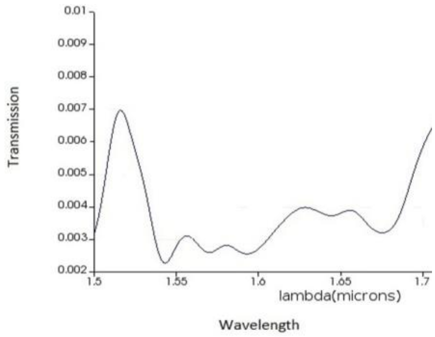

Figure 4(d): 3GPa Pressure is applied

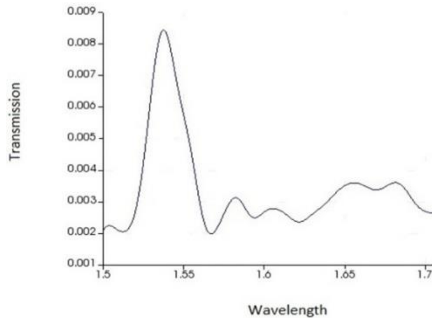

Figure 4(e): 4GPa Pressure is applied

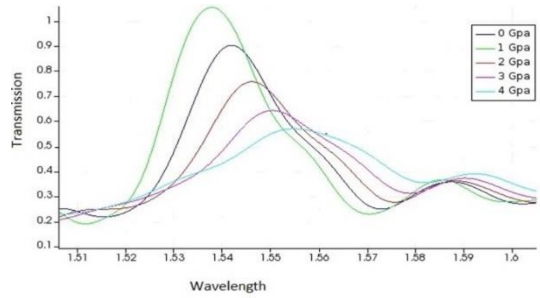

Figure 4(f): 0-4GPa Pressure is applied

Figure 4: Transmission spectrum in the pressure range 0-4Gpa

Figure 4(a) to *4(e)* show the transmission spectrum of the pressure sensor designed in this work for 0,1,2,3 and 4Gpa pressure respectively. *Figure 4(f)* shows the resonant wavelength shifts for different pressure values from 0 to 4Gpa.

Table 2: RI values, Wavelengths, and Q-factor for the different pressure range from 0-4Gpa

Level of pressure	RI	λ (nm)	Q Factor
0Gpa	2.50	1.5371	95.3
1Gpa	2.53	1.5412	162.7
2Gpa	2.57	1.5450	159.4
3Gpa	2.61	1.5490	155.5
4Gpa	2.65	1.5530	79.7

4.1 Sensitivity (S) and Quality Factor (Q)

Q-factor is calculated using *equation (1)* as shown below,

$$Quality\ factor = \frac{\lambda_{res}}{FWHM} \quad (1)$$

λres = resonant wavelength and FWHM = Full Width Half Maximum.

Sensitivity is calculated using *equation (2)* as shown below,

$$Sensitivity = \frac{Change\ in\ wavelength}{Change\ in\ Refractive\ index} \quad (2)$$

Table 3: Observations of the designed sensor

Pressure	RI	λ (nm)		Q Factor	
		R	P	R	P
0Gpa	2.50	1500	1537	75.5	95.3
1Gpa	2.53	1530	1541	153	162.7
2Gpa	2.57	1510	1545	151	159.4
3Gpa	2.61	1520	1549	152	155.5
4Gpa	2.65	1525	1553	52.5	79.7

R=Referral paper [20]
P=Present paper

In above *table 3*, the resonant wavelength values and Q-factor values of referred paper [20] and the present paper are seen for various refractive indices and pressure values ranging from 0Gpa to 4Gpa. It is seen that the Q-factor of this work is better as compared to the referral paper [20] for all the pressure values ranging from 0Gpa to 4Gpa. The outcome of this research work is that a 2DPC pressure sensor with a high Q-factor is designed using an FDTD tool called Ansys Lumericals.

5. CONCLUSION

The FDTD approach is used to construct a 2DPC-based pressure sensor with an L3 defect for detecting a pressure range from 0Gpa to 4Gpa. Ansys Lumericals is the FDTD tool used in this work. For the resonant wavelength of 1541nm, for the pressure of 1Gpa, the Q-factor obtained is 162.7 which is high as compared to the referred paper [20]. Hence the proposed sensor can be best used for the pressure sensing application in the pressure range of 0-4Gpa.

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