DESIGN OF TWO DIMENSIONAL PHOTONIC CRYSTAL BASED PRESSURE SENSOR USING DIAPHRAGM

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Abstract - *In this paper, a two-dimensional photonic crystal based pressure sensor using diaphragm is proposed and designed, and the sensing characteristics such as the sensitivity and range of pressure analyzed from from 0 GPa to 5 GPa. The sensor is based on two dimensional photonic crystal with the square array of silicon holes on slab. The two dimensional photonic crystal consist of two straight waveguides, the hexagonal ring is placed between two waveguides and is formed by removing holes by hexagonal shape. It is noticed that through simulation, the resonant wavelength of the sensor is shifted linearly towards the higher wavelength region while increasing the applied pressure level. The achieved sensitivity and dynamic range of the sensor is 2 nm/GPa and 5 Gpa, respectively.*

Key Words: photonic crystal, waveguide, optical sensor, photonic band gap, hexagonal ring

1. INTRODUCTION

Photonic crystals are found to have a great application in optical sensing field. Light confinement and controlling are the two important characteristics of photonic crystal that allowed it to be used in photonic sensing technology. With the help of photonic crystal characterization and assessment of physical quantities like temperature, pressure, stress, strain is possible. Photonic crystal based sensor could overcome the limitations of electrical sensors and have a good quality factor and sensing ability.

Photonic crystal (PC) consists of material with distinct refractive index arranged in periodic manner. They are used to control the flow of light. Photonic crystals control different properties like transmission, reflection and refraction. Crystal allows certain range of wavelength to pass through it, that range is called photonic band and the range it do not allow is called photonic band gap. Photonic crystals can be classified as 1D, 2D and 3D structures. 2D can operate bizarre wavelengths. 3D crystals used in optical computers. Photonic gems reflect light just inside a specific recurrence extend. Therefore PC has only one mode. At high frequencies for some application dielectrics are less lossy. The quality factor of photonic crystal is very high that they can be used in many sensing application. At near-optical frequencies dielectrics can withstand higher electric fields. These advantages made PCs to be used in various applications. In the literature, the pressure sensor using the photonic crystal was reported periodically. In 2007, Chengkuo Lee *et al.* reported a pressure sensing based 2DPC microcavity structure and achieved a linear resonant wavelength shift according to the applied pressure from 1 MPa to 5 Mpa [1]. Bakhtazad *et al*. designed a pressure sensor based on a photonic crystal waveguide suspended over a silicon substrate. Under the applied pressure, the photonic crystal waveguide is deflected toward the substrate, causing a decrease in optical transmission due to the coupling of the waveguide field to the silicon substrate [1].

In this paper, we design and simulate a 2D-PhC based pressure sensor using the coupling of two PhC-based waveguides with hexagonal ring .The refractive index of Si holes varies under pressure, and the resonant wavelength of the hexagonal ring made of Si holes shifts. The sensor properties such as the quality factor, resonant wavelength, transmittance, sensitivity, and dynamic range are investigated. The electromagnetic analysis of the sensor has been conducted by applying a commercial finite element method code, i.e. COMSOL multiphysics.[2]

1.1 Structure design

The designed photonic crystal based pressure sensor consists of the square array of Si holes . In the square lattice, the number of rods in *X* and *Z* directions is 10×10µm. The distance between the two adjacent holes is 410 nm which is termed as the lattice constant and denoted by *a*. The radius of the rod is 0.11 µm, and the refractive index of the Si holes is 1(refractive index = 1).[1]

Here we design ring resonator based photonic crystal which acts as a pressure sensor. The sensing is done based on the resonance wavelength. When pressure applied to the PC there will be a shift in resonance wavelength, that displacement is proportional to change in pressure helps to detect the pressure. Lumericals design tool is used to stimulate optical components. Finite difference time domain method (FDTD) is a Maxwell solver which plans, performs analysis and optimization of photonic devices, processes and materials.

The port marked “input” with an arrow in Fig. 1 is the input port. The light source is put at the input port in order to excite the structure. The port marked “output” or forward drop in Fig.1 is the output port. The monitor is placed at the output port to detect the output light so that the resonant wavelength of the structure can be analyzed.

The part of the sensor, i.e., the waveguides ends and hexagonal ring is shown in Fig.1 lines are studied and optimized in order to achieve better performance.[2]

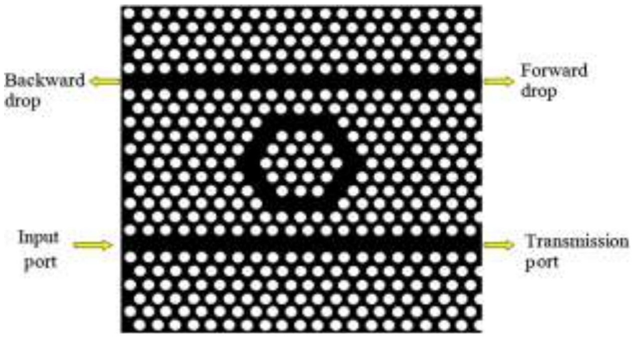

Fig-1: photonic crystal based pressure sensor

1.2 Design of waveguides and hexagonal ring

The structure shown in figure 2 is a square array of silicon holes on slab. The straight waveguide is formed by removing holes in a straight line as shown in figure. The hexagonal ring is formed by removing holes by hexagonal shape it is placed between the two waveguides. Under different pressures from 0 to 2 GPa. It is clear that with increasing the pressure, the coupling resonant mode red-shifts, the transmittance decreases from 96% to 72%, and the quality factor decreases from 1140 to 838.[2]

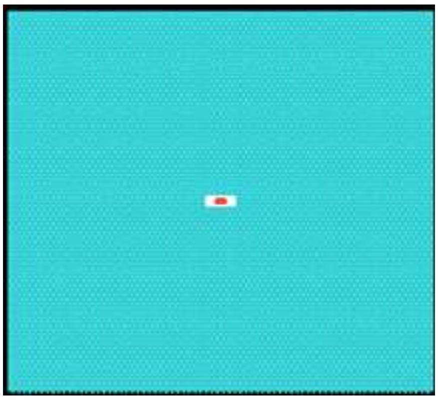

Fig -2:Sqaure shape silicon holes on slab

2. Square Diaphragm

The square diaphragm has the maximum induced stress for a given pressure. The bending of square plates with all edges is fixed. Thus the square diaphragm square sensor is approved geometry for pressure sensors because of, the large stresses produced by enforced pressure packing result in great sensitivity. Further, it is simple to dice the diaphragm from typical wafers[3]

Maximum stress calculated by centre of each edge is

$$\sigma_{\max} = \frac{0.308\,pa^2}{h^2} \qquad (1)$$

The maximum deflection at the center for a given pressure is

$$W_{\max} = -\frac{0.0138\,pa^4}{Eh^3} \qquad (2)$$

Table -1: Parameters and its values used for sensor.

Parameter	Value
Radius of the hole	110nm
Lattice constant(a)	410nm
Refractive index	3.46
Thickness (h)	820nm
Length(l)	10 μm×10 μm
Wavelength of light	1.5 to 1.65μm

2.1 Sensing mechanism.

The applied hydrostatic pressure based on the electronic and optical properties of the material such as the energy gap and refractive index can be considered for sensing applications. When a crystal is compressed by the pressure, the band gap is increased. The refractive index of Si is modified when optical coefficients such as photoelastic, piezoelectric, and permittivity changes in different pressures. In the PC structure, the PBG is dependent on the refractive index, lattice constant, and radius to lattice constant ratio r/a. By applying the pressure to the PC, the refractive index of the material, the geometrical shape of the PC, and the PBG of the structure change. In the PC waveguide coupled to the resonator output, the spectrum of the waveguide changes with different pressures. On the other hand, the resonant wavelength of the resonator is dependent on the geometrical shape of the defect that forms the cavity. By applying certain pressure to the structure, the resonant wavelength shift and intensity variation of the resonator can be measured as a function of the pressure.[1]

2.2 Simulation results

The 2D pressure sensor based photonic crystal with diaphragm is proposed. A light signal is launched into the input port of the waveguide. The output signal is recorded by a power monitor at the output port. The output signal power from the power monitor which is positioned at the output port is normalized by the input signal power i.e., the output power is the normalized output power. The obtained output response is used to analyze the resonant wavelength, quality factor, and output power. In this simulation the pressure range will be analysed on the basis of wavelength shifting positions. For a sensor sensitivity can be the amount that input parameter to be varied to observe a change in the output. Here it is calculated as the ratio of smallest amount of shift to the amount of refractive index change occurred for different pressure value.

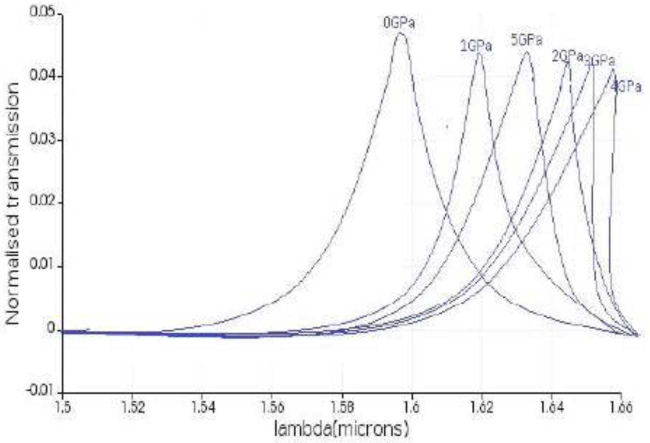

Fig-3: wavelength shift for different applied pressure

3. CONCLUSIONS

The two-dimensional photonic crystal based pressure sensor using diaphragm is designed, and its sensing characteristics are analyzed. The sensor is designed using the two-dimensional photonic crystal with the square array of silicon holes . The sensor is designed for 1500 nm to 1650 nm, which is used for the analysis of the pressure from 0 Gpa to 5 Gpa. The sensor is designed with the lattice constant a=410 nm, the radius of the holes r=110 nm, and the index difference 2.45. It is noticed that the resonant wavelength of the sensor is shifted to the longer wavelength while increasing the pressure. In the absence of the pressure, the resonance wavelength, Q-factor, and output power are 1500 nm, 76.7, and 58.5%, respectively. The size of the pressure sensor is 10 μm×10 μm which is highly suitable for the sensing applications.

REFERENCES

[1] Krishnan VIJAYA SHANTHI* and Savarimuthu ROBINSON “Two-Dimensional Photonic Crystal Based Sensor for Pressure Sensing” PHOTONIC SENSORS / Vol. 4, No. 3, 2014: 248–253

[2]Shangbin TAO, Deyuan CHEN*, Juebin WANG, Jing QIAO, and Yali DUAN “ A High Sensitivity Pressure Sensor Based on Two-Dimensional Photonic Crystal” PHOTONIC SENSORS / Vol. 6, No. 2, 2016: 137–142

[3]A. Nallathambi, T. Shanmuganantham “Design of Diaphragm Based MEMS Pressure Sensor with Sensitivity Analysis for Environmental Applications” Sensors & Transducers, Vol. 188, Issue 5, May 2015, pp. 48-54