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Photonic Crystal Based Micro Mechanical Sensor in SOI Platform

Indira Bahaddur[1]*, Preetha Sharan[2] and P. C. Srikanth[1]

[1]*Department of ECE, Malnad College of Engineering, Hassan, India*
[2]*ECE, Oxford College of Engineering, Bangalore, India*

ABSTRACT

Two-dimensional photonic crystals with nano-rod configuration integrated in a silicon-on insulator are analysed in this study. A photonic crystal waveguide suspended over a silicon substrate then weight can be applied on that substrate to change the displacement of substance and to measure sensitivity for pressure in terms of micro units. The overall objective of this work is to detect displacement, which indicates the force applied on the slab with photonic crystals that have line defects. Stress and displacement of the slab reveal the pressure applied. Stress is calculated by the power distribution/excitation in the slab. The displacement of the slab is due to the force, while pressure is determined by the photonic crystal sensor. The quality and sensitivity of the sensor are 1496 and 1200 RIU, respectively. The transmission spectrum is 0.1 micron to 0.5 microns shift, respectively, which are found to be distinct.

Keywords: Photonic crystal (PhC), silicon-on insulator (SOI), micro pressure, stress, optical membrane, nano rods

INTRODUCTION

The silicon-on insulator (SOI) is a fascinating technology introduced some decades ago. It integrates the technique of using a highly sensitive photonic crystal membrane layer and the silicon-on insulation process in a new way and provides a sophisticated design for a photonic crystal-based sensing mechanism. The silicon photonic crystal membrane layer is integrated with circuits on silicon using CMOS technology in a CMOS fabrication process. Better thermal expansion and stability of the insulator in the CMOS (Biallo, Orazio, Sario, Marrocco, & Petruzzelliet, 2006) integration process are the great advantages of silicon photonics. Silicon photonics and photonic crystal sensors have major applications in biochemical sensing,

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E-mail addresses:
indirabahaddur@gmail.com (Indira Bahaddur)
sharanpreeta@gmail.com (Preetha Sharan)
pcs@mcehassan.ac.in (P. C. Srikanth)
*Corresponding Author

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environmental monitoring, high speed communications and medical diagnostics (Yablonovitch, 1987). The advantages of this technology are low manufacturing cost, a small size, a low weight, low use of power, good reliability and ruggedness.

Photonic technology (Bahaddur, Srikanth, & Sharan, 2006) includes all technology that uses light, creates light, detects light or modifies lights. Light is used to make electricity, for instance in photovoltaic cells for solar panels, while it is created using electricity, as in LED lighting (Joannopoulos, Meade, & Winn, 1995), detected in cameras and modified in lasers. We know that nothing travels faster than light. The high speed of light enables photonic crystal sensing and accounts for its sensitivity (Seitz, 1984) in practical use in products that emit light such as projectors, television screens, light displays in cars and mobile phones and cameras. Sometimes, photonic technology is not discernible, for instance in action (Nieva, Kuo, Chiang, & Syed, 2009). Photonic technology is also used in the oil and gas industries for gathering information on temperature and pressure and providing visual images of drilling operations (John, 1987). High-power lasers are used to cut and weld metal (Tao, Chen, Wang, Qiao, & Duan, 2016).

Structural health monitoring is an important area of application of photonic base strains and displacement sensors. Each structure undergoes deformation for micro pressure or displacements even though such deformations or displacement may not be noticeable to the naked eye as micro pressure and progress deformation of materials depend on the properties of the material such as Young's modulus and density.

The optical membrane structure contributes considerably to fields that use optical communications, photonic crystal sensors and quantum electronics. The study of light, to be more precise, the science of photonics includes the generation of transmission signals. Modulating intensity and, refractive index changes in overall waveguide configuration are key facts involved in photonics (Wu, Jan, & Solgaard, 2013). Sensing the mechanical deformation of membrane structures using optical media is a breakthrough technology of the era, giving sensing mechanism a brighter future. Generation, detection and manipulation of light in nano scale structures (Lu, Xu, & Hu, 2008) and features are primary factors involved in photonic-based micro sensors that measure mechanical pressure or stress detection. The nanometer scale is different from the macroscopic scale. Properties like colour and refractive index depend on geometry. SOI involves placing thin layers of silicon on top of an insulating material in order to speed up the performance of the microprocessor by reducing the capacitance of the transistors, making them operate faster.

The micro-mechanical sensor proposed here was designed using photonic crystal rods in air configuration and simulated using the MEEP tool (MEEP_Introduction). The proposed sensor was integrated with a silicon-on insulator platform and analysed for micro pressure and displacements. Pressure was applied at the centre of the photonic crystal membrane layer due to deviation of the membrane from its original position and structural deformation that could obstruct the light and to allow for wavelength and intensity modulation. The quality factor and sensitivity of the proposed model are discussed.

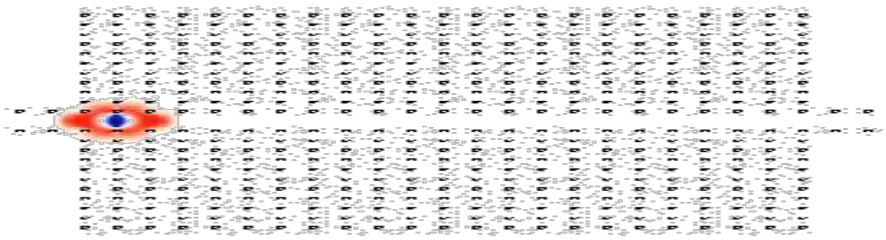

Figure 1. Structure of photonic crystals at zero displacement defect

Design and Operation Principle

The overall sensor sensitivity can be expressed as:

$$St= ϱP/ϱT= ϱT/ϱh \quad (1)$$

where, T = optical transmittance, P = applied pressure and h = height of photonic crystal.

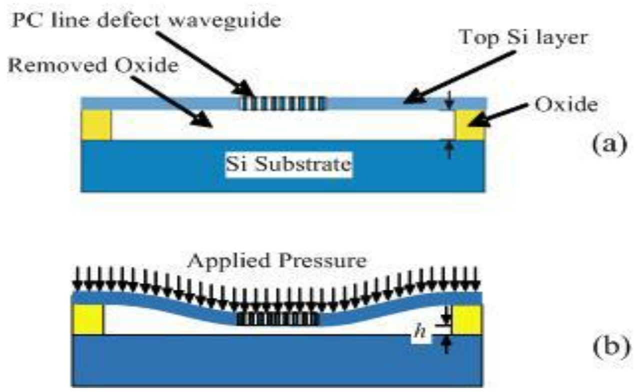

Figure 2. (a) Optomechanical pressure sensor photonic crystal in SOI platform before applying pressure; (b) Sensor structural behaviour during pressure application

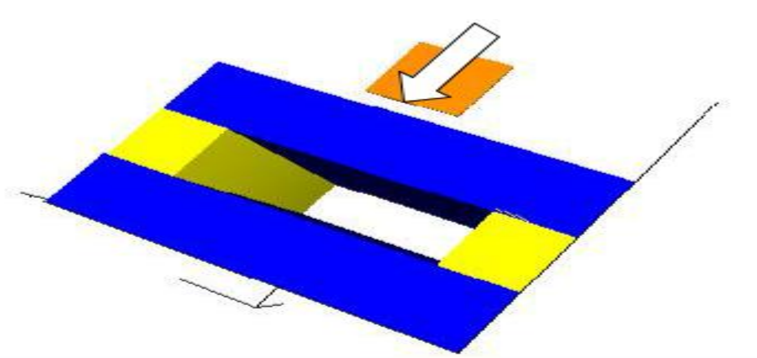

Figure 3. 3D representation of the structure

Figure (3) shows the 3D implementation of the pressure sensor when force is applied on the structure or the Si layer embodied with the photonic crystal sensor (Wu et al., 2013). The photonic crystal sensor tracks the distance between the upper Si waveguide and the lower Si substrate. When force is applied to the structure, stress increases and the sensor experiences a depression in the power absorbed (Bahaddur, 2016).

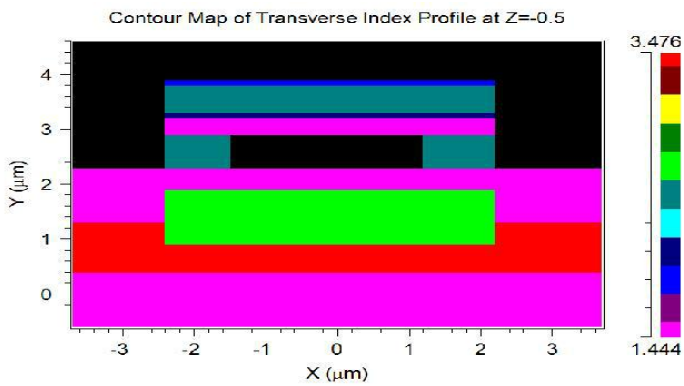

Figure 4. Contour of index profile of the structure

The refractive index profile is depicted in Figure 4. The variation in the colour shows the refractive index distribution in the structure. The stress and restraining movement of the Si slab are justified through propagation, as discussed in the next section.

FDTD SIMULATION RESULTS

The transmission spectrum is from zero micro displacement of the dielectric slab up to 6 micron displacements. In these spectrum results, there is a change in peak amplitude from one displacement to another.

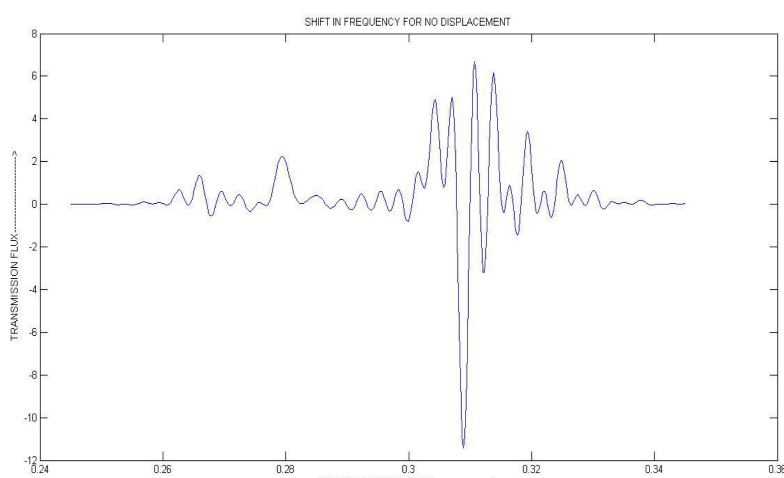

Figure 5. Spectral behaviour with 0-micron displacement

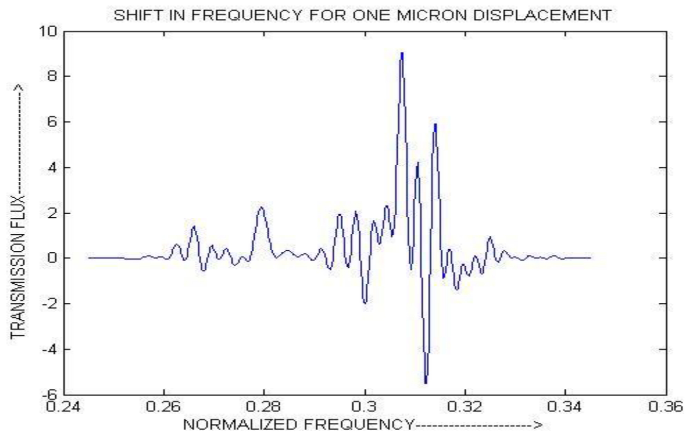

Figure 6. Spectral behaviour with 1-micron displacement

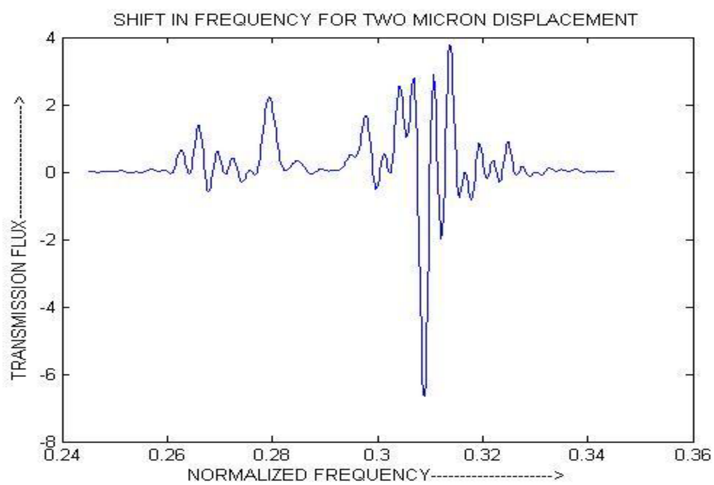

Figure 7. Spectral behaviour with 2-micron displacement

Figure 5 to figure 7 represent the transmission spectrum for 0-micron displacement to 2-micron displacement, respectively. A distinct frequency shift as well as intensity shift is obtained for every displacement, making it an unambiguous solution for various applications.

STRESS ANALYSIS

For the 0-micron displacement slab, stress was lower and a peak was observed at 1.3 µm wavelength. Displacement ranging from 1 to 6 microns produced the shortest wavelengths of 1.2-1.4 µm, as shown in the table below.

Table 1
Micro displacement and corresponding wavelength values

Displacement	Amplitude/ Wavelength	Intensity
No displacement (Zero displacement)	0.4	1.2
1 micron	0.23	1.2
2 micron	0.2	1
3 micron	0.18	1.254
4 micron	0.15	1.3
5 micron	0.1	1.36

From the above readings it was observed that for displacement, the sensor not only exhibited the wavelength shift, but also exhibited relative intensity shifts. This characteristic of the device can be implemented in barometers and other pressure/stress-orientated applications such as water level controllers.

CONCLUSION

Highly sensitive photonic crystals integrated in a silicon-on insulator (SOI) was analysed for micro displacement and stress. A novel approach in the design using an SOI platform was used for the photonic crystal-based pressure sensor, while the oxide layer was partially etched, thus providing a window for stress analysis by forming a cavity. For each structural deformation of the photonic crystal membrane in the silicon-on insulator, there was a shift in wavelength for range of micro displacements in the proposed sensor design up to a quality factor of 1495 and a high sensitivity of 1200 RIU. This type of sensor has remarkable applications in blood pressure monitoring, damage monitoring and structural health monitoring.

REFERENCES

Bahaddur, I., Srikanth, P. C., & Sharan, P. (2016, March). A photonic crystal based pressure sensor. *International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT),* (pp. 3902–3905). IEEE.

Biallo, D., Orazio, A. D., Sario, M. D., Marrocco, V., & Petruzzelliet, V. (2007). Photonic crystal sensors. *Journal of the European optical society - Rapid Publications, 2*(2007). doi: 10.2971/jeos.2007.07017.

Joannopoulos, J. D., Meade, R. D., & Winn, J. N. (1995). *Photonic crystals: Modeling the flow of light.* New York, NY: Princeton University Press. Retrieved from http://ab-initio.mit.edu/book/

John, S. (1987, June). Strong localization of photons in certain disordered dielectric super lattices. *Physical Review Letters, 58*(23), 2486–2489. https://doi.org/10.1103/PhysRevLett.58.2486

Lu, Z., Xu, X., & Hu, X. (2008, January). Extracellular superoxide dismutase deficiency exacerbates pressure overload-induced left ventricular hypertrophy and dysfunction. *Hypertension, 51*(1), 19–25. doi: 10.1161/HYPERTENSIONAHA.107.098186

Nieva, P. M., Kuo, J., Chiang, S. H., & Syed, A. (August 2009). A novel moems pressure sensor: Modelling and experimental evaluation. *Sadhana (Indian Academy of Science), 34*(4), 615–623. https://doi.org/10.1007/s12046-009-0039-4

Seitz, W. R. (1984, May). Chemical sensors based on fiber optics. *Analytical Chemistry, 56*(1), 16A–34A. doi: 10.1021/ac00265a711.

Tao, S., Chen, D., Wang, J., Qiao, J., & Duan, Y. (2016). A high sensitivity pressure sensor based on two-dimensional photonic crystal. *Photonic Sensors, 6*(2), 137–142. https://doi.org/10.1007/s1332.

Wu, X., Jan, C., & Solgaard, O. (2013, August). Monolithic photonic crystal-based fiber-tip Fabry-Pérot static pressure sensor. In *International Conference on Optical MEMS and Nanophotonics (OMN), 2013* (pp. 49–50). IEEE.

Yablonovith, E. (May, 1987). Inhibited spontaneous emission in solid-state physics and electronics. *Physical Review Letters, 58*(20), 2059-2062. doi: https://doi.org/10.1103/PhysRevLett.58.2059