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# Simulation of force sensor based on ring resonator in photonic crystal structure

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## Abstract

*In this paper, we have presented the design of resonator structure in photonic crystals to improve two parameters i.e., Quality Factor and Sensitivity. Photonic Crystal based force sensor includes hexagonal rings in 2-D Photonic Crystal silicon slab of hexagonal lattice which are to be integrated on the top of Silicon Microcantilever for Sensing applications. Ring resonator has been arranged in between two silicon Photonic Crystals waveguides, i.e., bus and drop waveguides. The new ring-resonators has formed by removing the holes of a hexagonal lattice from two-dimensional silicon Photonic Crystals slab. The parameters Quality Factor and Sensitivity can be improved by tuning the size of holes in the hexagonal resonator structure. 2-D Finite Difference Time Domain Method and Finite Element Method has been used for simulation.*

**Keywords:** Photonic crystals, Ring Resonator, Sensor.

## Introduction

The discovery of photonic crystals and periodic dielectric materials with a photonic band gap, has opened up new methods for controlling light which lead to proposal for many novel devices. Nature provides remarkably effective and optimal mechanisms for the designing of sensors. The development of nanotechnology and MEMS (micro electromechanical systems) has made it possible to realize the micro devices and nano devices which mimic the optimal functions or structures that are found in nature. Two-dimension photonic crystals has shown the advantages of high contrast of light confinement, ultracompact size and ease in the integration of various functional elements such as microelectronics and MEMS[1]. Photonic Crystals are the nanostructures that provides the capability of controlling and manipulating the propagation of electromagnetic wave within a specified frequency range[2, 3].

Photonic Crystals (PhCs) are the materials with refractive index which is spatially periodic modulated. The periodic refractive index results in a Photonic Band Gap (PBG) .The propagation of light within the band gap frequency range is forbidden in the PhCs structure. The confinement of light can be achieved by introducing certain defects in the PhCs structures. The light is allowed only to exist within a defect region[4,5]. The PBG effect has been adapted for developing many optical devices such as channel drop filter, light sources and power splitter. The PhCs structures exhibit significant confinement of light when comparing with conventional optical devices. This feature enables us to downsize the device based on PhCs structures[6].

Micrometer sized ring resonator has been investigated as Sensors. The basic configuration of ring resonator comprises of four ports namely input port, transmission port, forward port, backward port as shown in Figure-1. It consists of a ring waveguide which is sandwiched by two straight waveguides, viz., bus waveguide and drop waveguide, has been reported as biosensors and biochemical sensors with good sensitivity due to high Quality Factor of resonant peak in the output spectra. The circular resonant mode of ring waveguide is excited by incoming light from bus waveguide and the light of resonant wavelength will be coupled into the drop waveguide eventually. C Lee et al has proposed the resonant peak reveals at 1550.5 nm with the quality factor for two-hole and three-hole coupling distances as 2400 and 3200 respectively[7]. Later C Lee[8] has derived quality factor for the single nanoring resonator as 2400. Bo Li has reported a strong peak at 1536.60nm and at forward drop port for Triple ring resonator[9] and 1551.41 nm at forward drop port for Dual ring resonator with Quality Factor of about 3800[10]. In order to enlarge the range of free space and enhance the quality factor of ring resonator, the reduction in the radius of ring is required.

## Designing of Ring Resonator Structure

The Photonic Crystal employed in our study is consisted of hexagonal lattice of air holes that are embedded in Silicon slab. The refractive index of air holes and Silicon considered as 1 and 3.46 respectively. The Silicon plate thickness is 220 nm and hexagonal lattice considered is of 35 × 35. By using Plane Wave Expansion (PWE) Method, the band gap structure of a 220 nm silicon PhCs slab of the hexagonal lattice of air holes is calculated. According to the derived band gap as shown in Figure-2, the value of lattice constant and the radius of the holes are chosen as 410 nm and 120 nm respectively. The ratio between the radius of air holes and the lattice constant is 0.292. The normalized frequency range of first photonic band gap extends from 0.26 to 0.33 in TM polarization electromagnetic wave i.e., the magnetic field is parallel to the surface of the Silicon slab. The corresponding band gap wavelength range extends from 1.242 µm to 1.577 µm.

The proposed PhCs ring resonator consists of a hexagonal ring which is sandwiched between the two line defects waveguides in a photonic crystal of hexagonal lattice of air holes drilled on a 220 nm thick Silicon device layer. The hexagonal ring has been formed by removing the holes along the contour of hexagonal lattice as shown in Figure-3.

The top terminal waveguide is referred to as the bus waveguide which allows the input light from the left side of waveguide to excite the resonant mode of the ring resonator. Then the resonant light is coupled to the lower terminal waveguide, i.e., the drop waveguide. A temporal light pulse is launched into the bus waveguide. The output signal can be recorded by a time monitor at the drop port or output port. The output spectrum is obtained by applying the Fast-Fourier Transform to the temporal signal which can be recorded by the time monitor. 2-D Finite Difference Time Domain Method are to be employed for investigating the performance of ring-resonator.

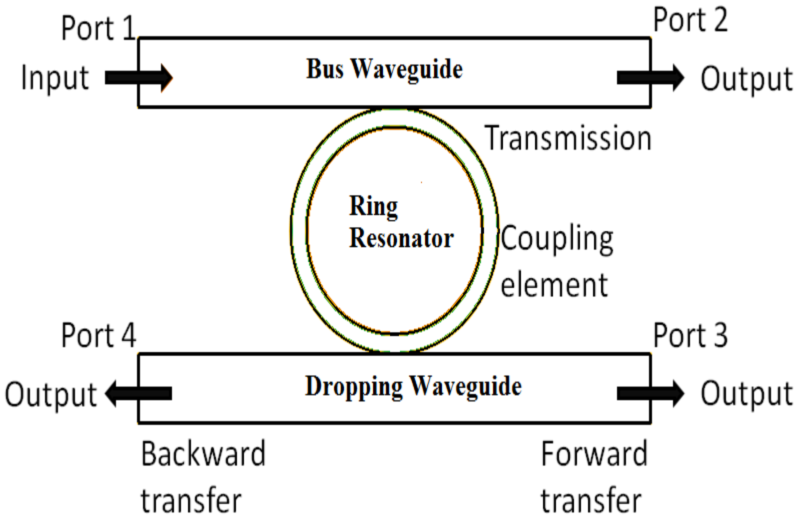

**Figure-1:** Basic structure of ring resonator[11]

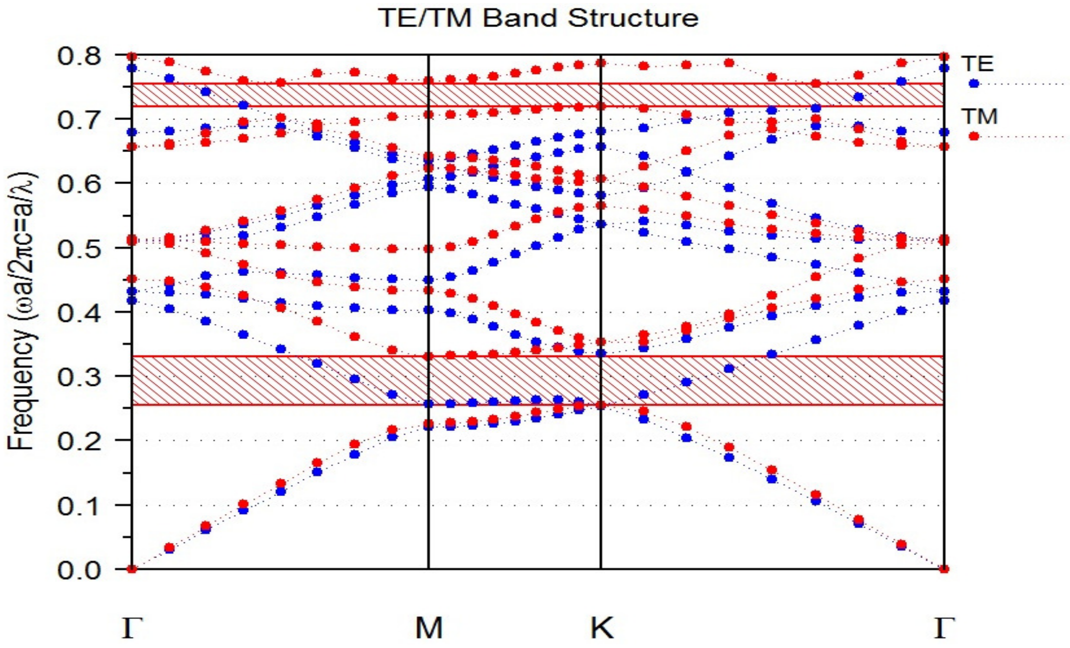

**Figure-2:** Band structure of the PhCs structure of hexagonal lattice.

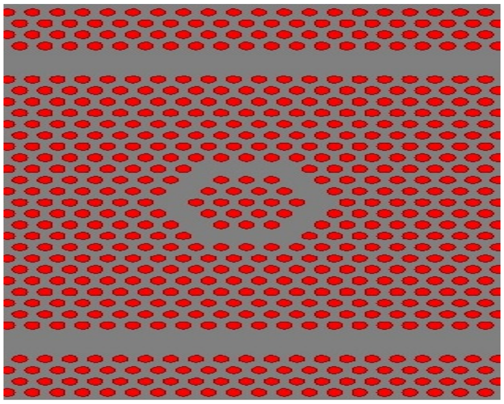

**Figure-3:** Schematic of PhCs ring resonator.

## Force Sensor Characteristics

The schematic of PhCs cantilever sensor is shown in Figure-4. The PhCs device is integrated on the top of the cantilever in such a way that the PhCs ring resonator will undergo maximum stress. The force sensor modeling involves two phases. In the first phase, the mechanical deformation data of the PhCs device is computed by performing FEM simulations for each applied force. In the second phase, the computed deformation data is applied in the FDTD simulation of deformed PhCs device. In FEM simulations, two parameters i.e., Young's modulus and Poisson's ratio are taken as 130GPa and 0.3 respectively[12]. The ring resonator faces the maximum stress since its vertex is placed at the junction of the base and cantilever beam as shown in Figure-4.

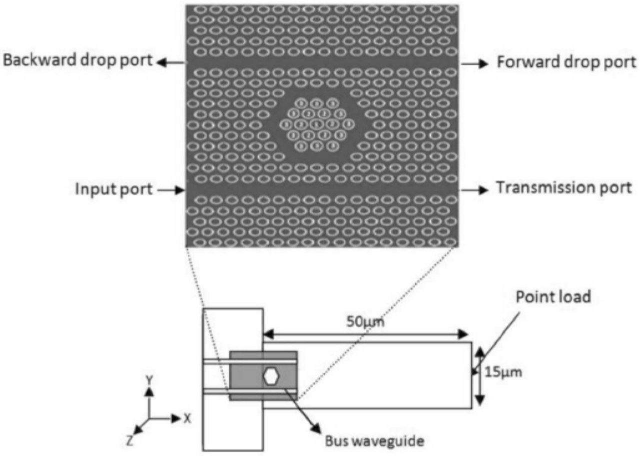

**Figure-4:** Schematic of force sensor with PhCs resonator[12]

The point load is to be applied at the tip of the Cantilever in the Z-direction. As the resonator undergoes deformation, the refractive index get altered causing shift in the resonant wavelength. The shift in resonant wavelength of the sensor is defined as the difference between the resonant wavelength of unloaded sensor and loaded sensor for each applied force. The resonant wavelength shift shows the strong dependence on the position of a sensing holes[12].

## Conclusion

To design Force Sensor Based which are based on ring resonator structure in Photonic crystal with improved Quality factor and Sensitivity, it can be concluded that using 4-hole, 5-hole or 6-hole coupling distance, the Quality factor can further be improved since higher coupling distances enhances Quality Factor. By varying the position sensing holes and the ratio of radius of water holes and lattice constant, then Photonics Band Gap can be extended such that its wavelength should lie very close to the communication optical fiber window region.

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