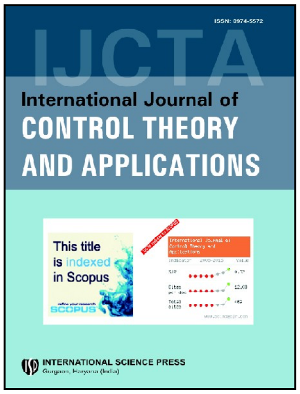

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Light Propagation in 2D Photonic Crystal based Optical Bends

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Abstract: In this paper, we have designed, simulated and analyzed optical bands of 2-Dimensional photonic crystal structure. High transmission of electromagnetic wave is achieved by sharp corners of photonic bandgap waveguides. We propose a simple two-dimensional photonic crystal structure containing line defect to create waveguides using finite difference time domain method to describe the transmission properties and photonic band gap analysis is done using plane wave expansion method. In this paper we have designed optical bends in four categories like 90^o, 45^o, 135^o and 180^o. The optical bends are designed using Silicon (Si) material with refractive index 3.46 and the designed structure is ultra compact in size. The designed structure of the optical bands is designed using square lattice of the structure and that gives better transmission efficiency. The designed optical bands are novel with its designing parameters with the previous work done by the researchers around the world. The optical band gives best response with 1310 nm and 1551 nm resonating wavelength. The size of the device is minimized from a scale of few tens of millimeters to the order of micrometers. The overall size of the BPF is around 123 ìm^2 that is more suitable for the photonic integrated circuits and CWDM network applications.

Keywords: Photonic Crystal (PC); Optical Bands; Photonic Band Gap (PBG); Finite Difference Time Domain method (FDTD); Plane Wave Expansion method (PWE), Optical Waveguides; Optical Networks

I. INTRODUCTION

Photonic crystals have been studied with great interest due to their potential applications of molding the propagation of electromagnetic wave [1]. It is due to the periodic arrangement of alternate high and low dielectric materials [2]. The electromagnetic spectrum for such photonic crystal structures is characterized by allowed and forbidden photonic bands similar to the electronic bands in semiconductor materials [3]. Such periodic structures containing alternate high and low dielectric materials with complete photonic bandgap can have many potential applications like lossless dielectric mirrors, optical filters, switches and resonant cavities [4-8].

The metallic waveguide and dielectric optical fiber are the most commonly designs, which are used to propagate electromagnetic waves along a linear path. The metallic pipe waveguide structure provides transmission without any loss only for microwave regime, whereas optical fiber allows guiding an infrared and visible light [9]. The conventional waveguides are mainly used to steer microwave around tight corners, the conventional optical fibers work on the total internal reflection's principle which restricts the radiation losses to moderate curvature bends [10]. The radius of curvature for dielectric optical fiber must be larger than the wavelength of guided electromagnetic light to avoid large losses at the corners even for high dielectric contrasts [11]. A linear defect introduced a regular photonic crystal structure produce a localized mode with the frequency inside the bandgap. By introducing such a line defect to construct a waveguide in a photonic crystal structure to guide a mode within the photonic bandgap [12]. Therefore, the mode is forced to propagate along the line defect by the photonic band gap (PBG) effect. If a bend is introduced inside a regular photonic crystal structure, no power will be radiated from the guided mode as EM wave travels around the bend. Since there are no any other extended modes available with the propagating mode can be coupled. EM wave will either be transmitted or reflected at the bend corner. Only the reflected part interacts with incident wave and that causes reduction into the 100% transmission. Here, the study of the transmission and reflection spectra for waveguide bend structures are done using a vector finite difference time domain method with quartic perfectly matched layer boundaries[7]. In the simulation, a dipole source is at entry point of a line defect waveguide to create a Gaussian pulse with time. Although the most of EM wave is absorbed which reaches at the computational cell's edge by the perfectly matched boundaries, some part of EM wave is reflected back from the waveguide's end.

Scientists around the world presented numerous PhC based devices like channel drop filters [13-14], add-drop filter [15], multiplexers [16], power combiners, demultiplexers [17], and band pass filter [18] using dielectric materials like: Silicon (Si) [19-20] and others [21]. The silicon is row bust material and easy to available in the nature that why we have designed optical bands with silicon material.

In this paper, we will show a PBG waveguide structure which can efficiently guide EM wave at the corners of bend structure. The losses are much less for a wide range frequency region, and vanishes at specific frequencies, even for the radius of curvature of the bend structure is same order of the wavelength of EM wave.

II. PHOTONIC BAND GAP ANALYSIS

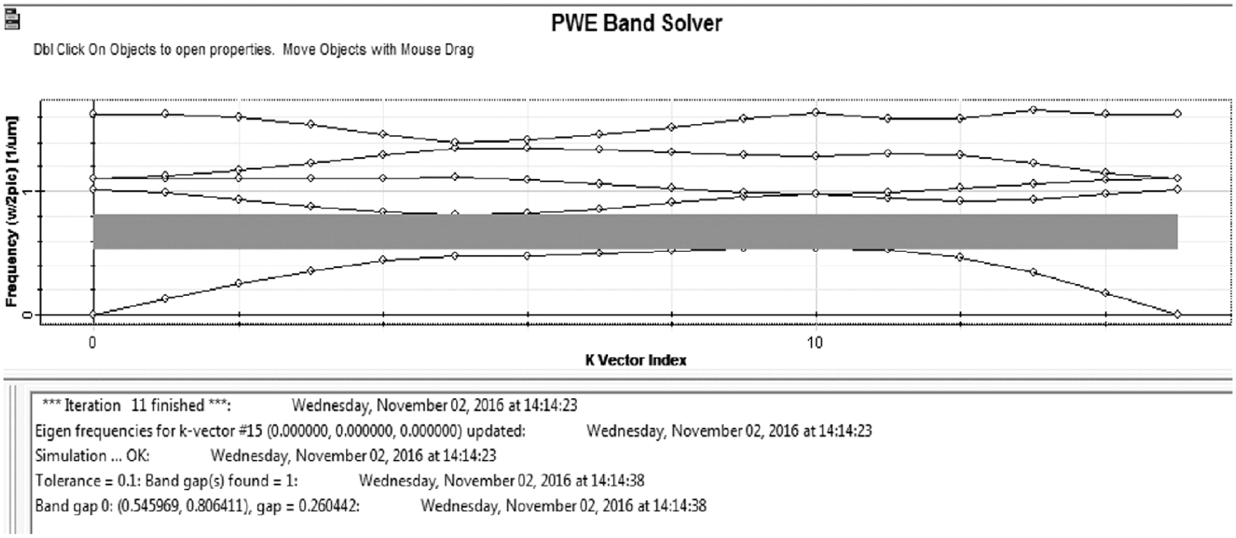
The photonic band gap (PBG) is essentially the gap between the air-line and the dielectric-line in the dispersion relation of the PBG structure. The Photonic band gap (PBG) for the channel drop filter (CDF) is calculated by PWE method by K.M. Leung *et al.* [22]. The Plane Wave Expansion (PWE) method is used to measure PBG of the 2D PC design to find a band structure diagram. The band structure diagram for the 2D photonic crystal is shown in Figure 1, which is plotted for Transverse Electric (TE) modes alone. The PBG is obtained by PWE solver of OptiFDTD software [23].

Hence, we are restricted for TE mode PBG, whose electric field is parallel to the axis to dielectric rods. The PBG range for the forbidden band region is 0.541628 $1/\lambda$ to 0.877675 $1/\lambda$ whose corresponding wavelength ranges are from 1240 nm to 1831 nm as shown in Figure 1.

III. OPTICAL BANDS DESIGN AND ANALYSIS

The proposed photonic crystal based optical bands is designed using 2-Dimensional square lattice photonic crystals (PCs) structure. The number of rods in 'X' and 'Z' directions are 20 and 21. The distance between the two successive rods is 540 nm, which is known as lattice constant 'a'. The dielectric material rods of Silicon (Si) material have the radius 0.1 μm and the rods are embedded in air. The refractive index of Si rods is 3.46.

Here in this paper we have design and simulated optical bands at different angles likewise 45^o, 90^o, 135^o and 180^o. All the optical bands are designed and simulated by OptiFDTD simulation tool software using finite difference time domain method.



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Tolerance = 0.1: Band gap(s) found = 1:          Wednesday, November 02, 2016 at 14:14:38
Band gap 0: (0.545969, 0.806411), gap = 0.260442:          Wednesday, November 02, 2016 at 14:14:38
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Figure 1: Photonic band gap analysis of Si material with refractive index around 3.46

In this section of this part of the paper we are going to analyze the design optical bands at an angle of 45°, as shown in Figure 2 and the refractive index profile in Figure 3.

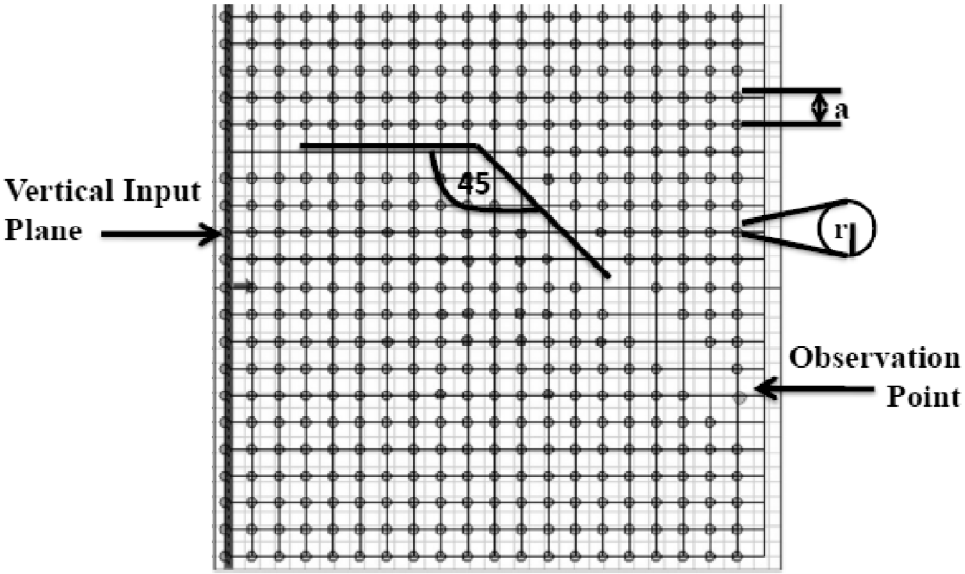

Figure 2: Designed structure of optical bands at 45° angle

In this section of this part of the paper we are going to analyze the design optical bands at an angle of 90°, as shown in Figure 4 and the refractive index profile in Figure 5.

In this section of this part of the paper we are going to analyze the design optical bands at an angle of 135°, as shown in Figure 6 and the refractive index profile in Figure 7.

In this part of this section of the paper we are going to analyze the design optical bands at an angle of 180°, as shown in Figure 8 and the refractive index profile in Figure 9.

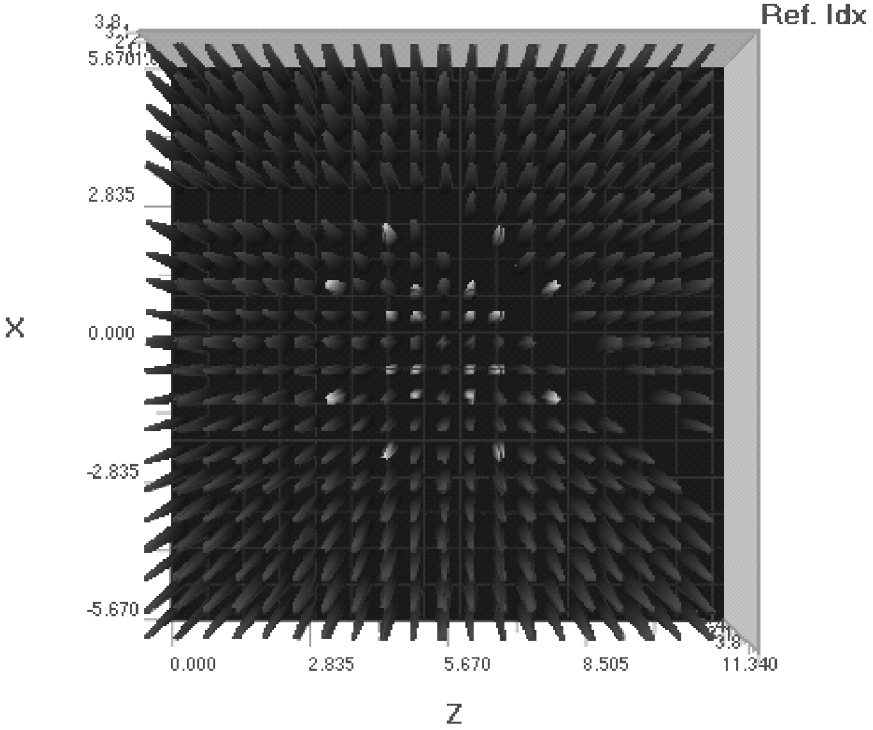

Figure 3: Refractive index view profile of the designed band structure

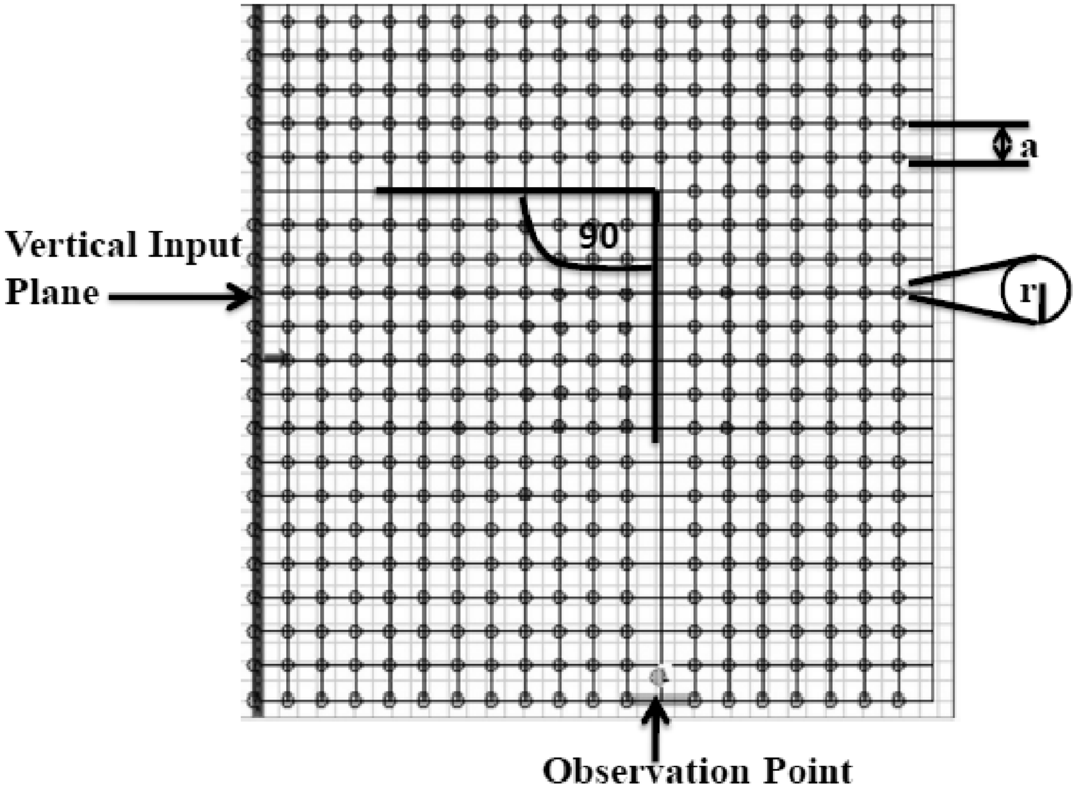

Figure 4: Designed structure of optical bands at 90° angle

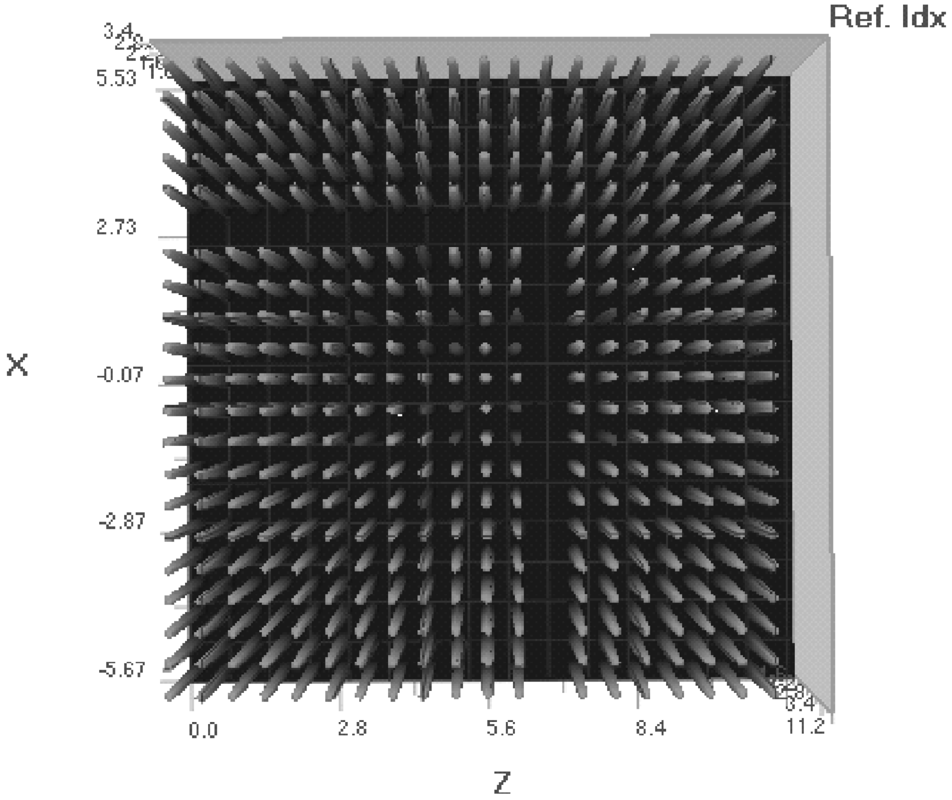

Figure 5: Refractive index view profile of the designed band structure

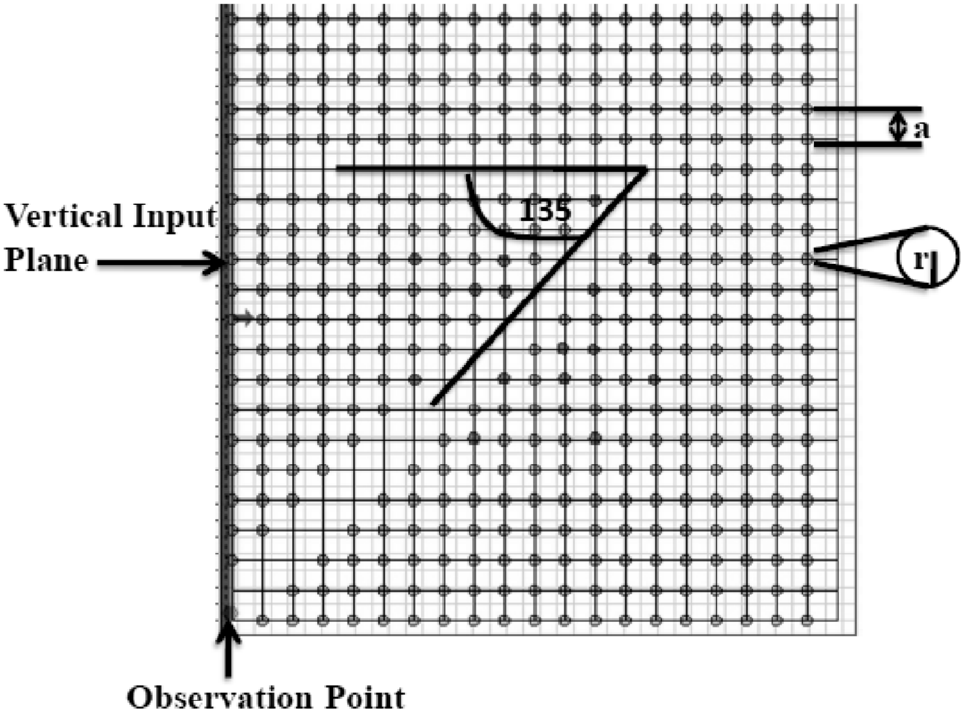

Figure 6: Designed structure of optical bands at 135° angle

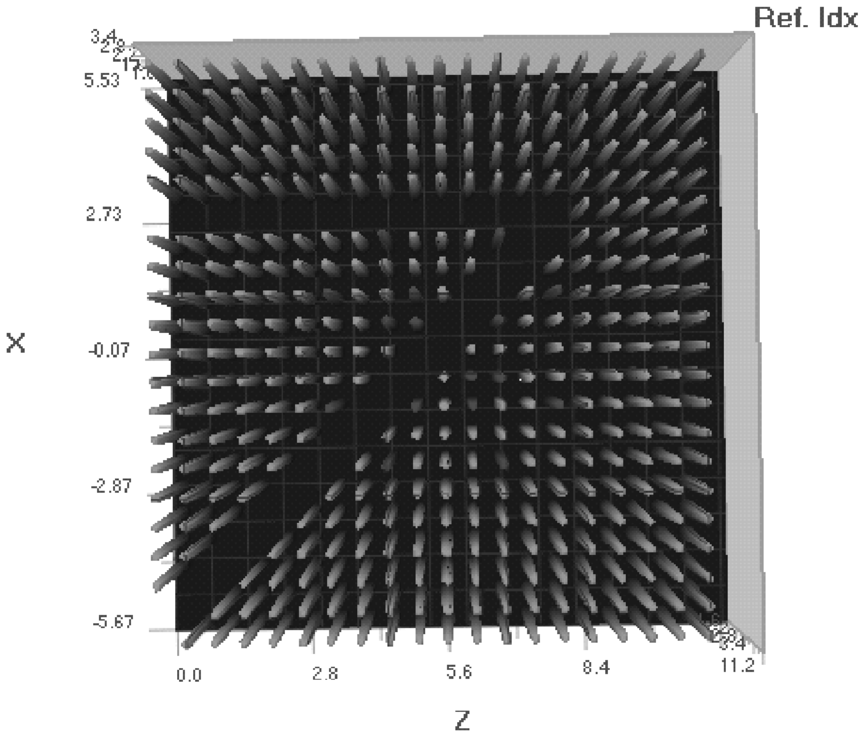

Figure 7: Refractive index view profile of the designed band structure

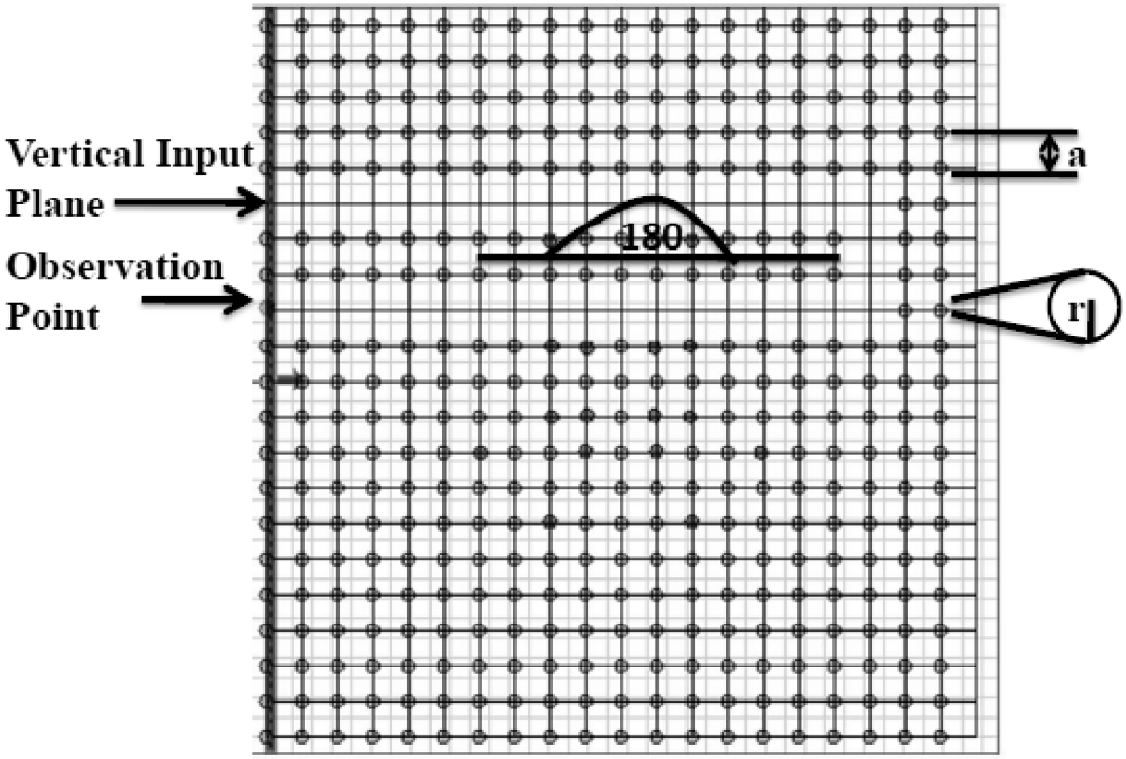

Figure 8: Designed structure of optical bands at 180^o angle

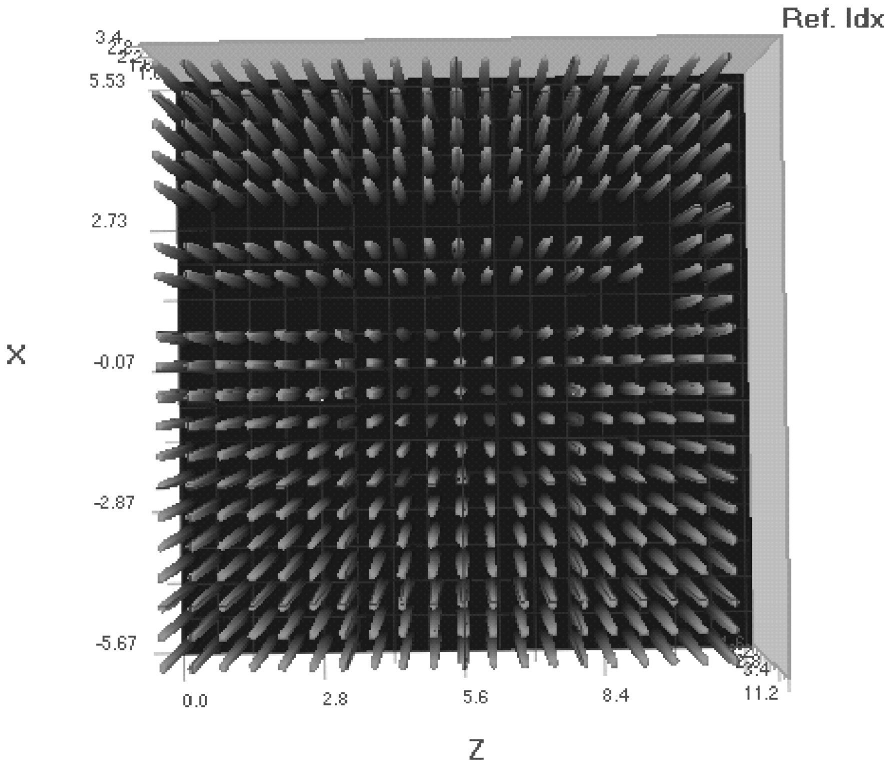

Figure 9: Refractive index view profile of the designed band structure

To design 2D photonic crystal based optical devices we can utilize both point and line defects to design the optical passive components. The proposed optical bands is composed of one input port and one output port. One observation point is placed at the output port. While designing the optical bands using photonic crystal structure we have utilized concept of line defect. And we have created bus waveguide and a drop waveguide at different angles. The bottom waveguides positioned in the below side of the bus waveguide in different direction is called as dropping waveguide and designed by using line defect [24].

To get the desired output response a vertical input plane is put to launch the light as Gaussian modulated continuous wave. Then the light passes through the bus waveguide and travel up to output port while passing through drop waveguide which is being created by the line defect in 2D photonic crystal based square lattice structure [25].

IV. RESULTS AND DISCUSSION

It is clear from the table 1 that in the designed filter structure there is one input vertical plane source to transmit the Gaussian modulated continuous wave to the structure. To get the simulation result a 32-bit OptiFDTD design simulator is used see the transmission spectra of the designed filter. About 10000 time steps were used to run the design. There are different way to see the desired output response like; time, DFT and FFT, in which DFT Ey view is used to see the transmission characteristics.

As it is clear from the photonic band gap structure that the range of wavelength can be passed through the optical bands is from 1240 nm to 1831 nm, so we can say that this material based bands are suitable for the coarse wavelength division multiplexing (CWDM) optical communication applications and future optical networks.

So, the design analysis is done for the range from 1240 to 1830 nm range wavelength and the simulated results are shown in the Table 1. So this shows a range of wavelength that can be passed through the structure and will be having good dropping efficiency and good quality factor as well. We can observe that 90° optical band gets the highest dropping efficiency and we get somehow less dropping efficiency in 135° optical band in comparison to other optical bands.

Table 1
Transmission Response for Optical Bands

S. No.	*Transmission at Output port*		
	Type of Optical Band	*Transmission Efficiency Range*	*Quality Factor*
1.	45°	88-98%	272
2.	90°	94-99%	302
3.	135°	82-90%	254
4.	180°	92-98%	286

The Figure 10 delineates the electric field view of the optical bands at on resonance. The main concern is upon the drop waveguide observation point 1, where signal propagates through the waveguides and gives good dropping efficiency. This is how we can analyze from Figure 10 the electric field view at 45°, likewise it is shown in Figure 11, Figure 12 and Figure 13 for electric field view at different angles as 90°, 135° and 180°.

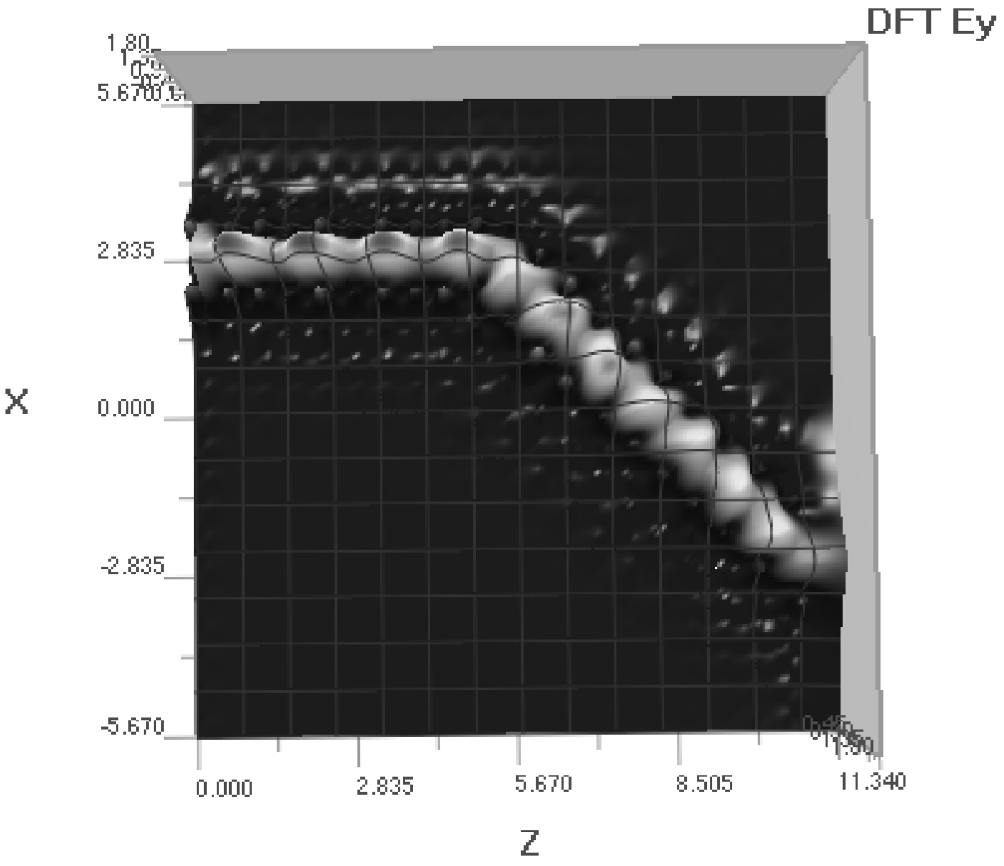

Figure 10: Electric field view of 2D photonic crystal based optical bands at 45° angle

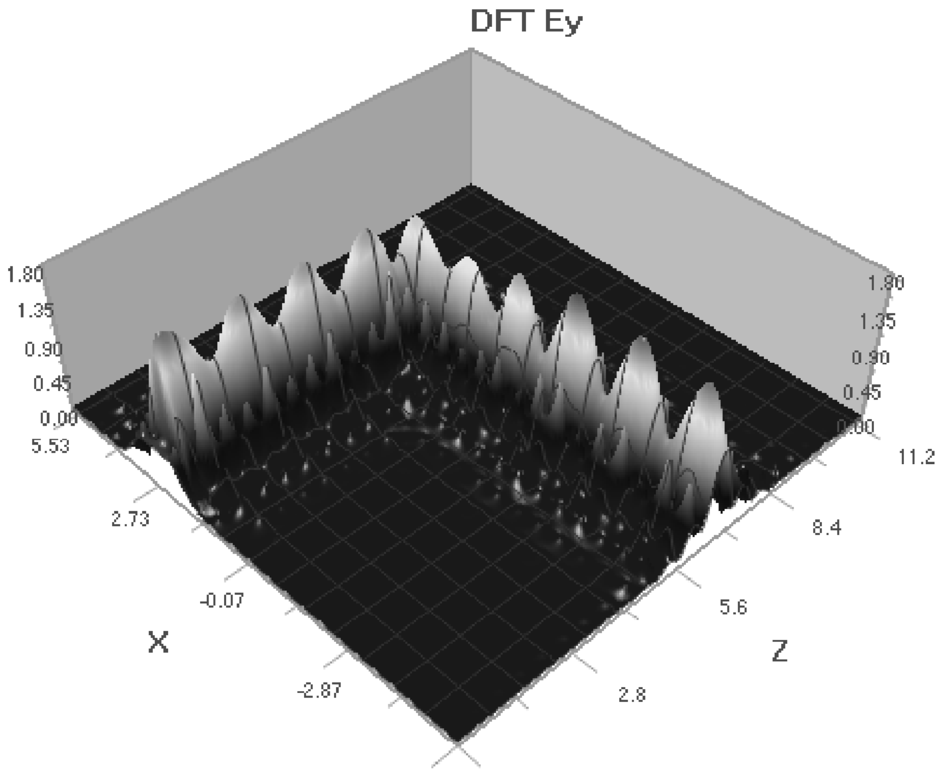

Figure 11: Electric field view of 2D photonic crystal based optical bands at 90° angle

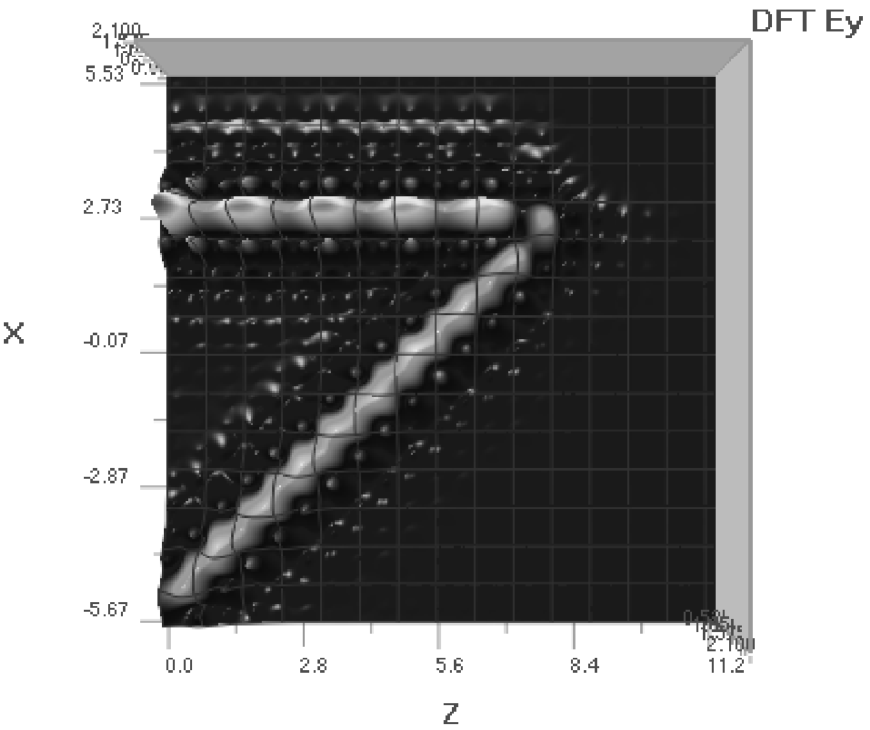

Figure 12: Electric field view of 2D photonic crystal based optical bands at 135° angle

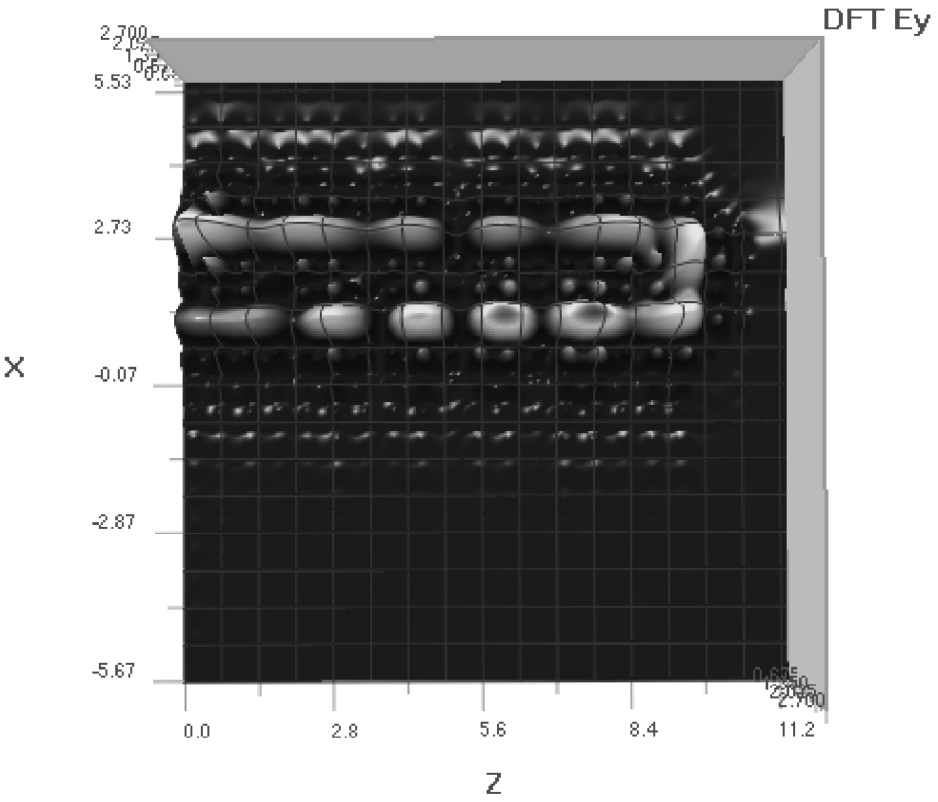

Figure 13: Electric field view of 2D photonic crystal based optical bands at 180° angle

V. CONCLUSION

The outlined optical band structure is designed and simulated using ring resonator of dielectric material Silicon with 3.46 refractive index. The size of the designed structure is about 11.4 µm x 10.8 µm nearly equal to 123 µm^2 which is compact in size. The outlined channel gives good dropping efficiency at the wide range wavelength with around 272 to 286 quality factor at different band angles. Further to get much better output response the designing parameters can be reconfigured. The band structure gives best response for the 1310 nm and 1551 nm wavelengths because these wavelengths fall under low loss window having less attenuation at this wavelength. Most of the optical networks work on these wavelengths. Future work involves to improve more quality factor while changing some designing parameters and to go for the fabrication process for practical applications. So, such sort of devices might be valuable in CWDM networks and photonic integrated circuits (PICs).

VI. ACKNOWLEDGEMENT

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