Design of Photonic Crystal Wavelength Demultiplexer & its Application: Wavelength Filter

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Abstract— In This paper a wavelength division demultiplexer has been proposed based on hexagonal lattice 2D photonic crystal. This structure can be used as a filter for 1.290 µm and 1.468 µm wavelength. The structure has been designed using silicon rods, refractive index 3.4, which are suspended in air. The plane wave expansion method and finite difference time domain method has been utilized for simulating the photonic band gap and results respectively. The localization property of photonic crystal has been demonstrated to guide the wavelength in two different output port with low crosstalk and near about 90% transmission at 1.290 µm and 70% transmission at 1.468µm.

Keywords— Photonic crystal; photonic band gap(PBG); FDTD method; PWE method; wavelength demultiplexer; wavelength filter; Opti-wave software.

INTRODUCTION

Photonic crystals (PhCs) [1]-[3] are periodic dielectric structures. They are called crystals because of their periodicity and photonic because they act on light. They occur when the period is less than the wavelength of the light [2]. PhCs may inhibit the propagation of certain range of wavelengths in either one direction or in all directions, providing the possibility to confine and trap the light in a cage [1]. Their effect to the propagation of electromagnetic waves is similar to the periodic potential in a semiconductor crystal. but from the communication capacity point of view, the electron-based conventional communication system has shown the physical limitation due to a rapid growth of the internet and multimedia. If the information is processed as an optical signal itself, not an electrical signal, then the information processing speed will be increased and it can provide much more convenience. Therefore the optical communication system will be expected that it will lead the future communication system by using a photonic device [3]-[4].

In this paper, we analyzed a photonic crystal (PhC) demultiplexer structure and proposed 1.290/1.468 µm wavelength filter which plays a very important role in an optical communication system. The PhC filter structure was analyzed by utilizing the plane wave expansion (PWE) method and the proposed wavelength demultiplexer was optimized by utilizing the finite-difference time domain (FDTD) method [5].

PROPOSED STRUCTURE

For this design the PhCs with a wide photonic band gap (PBG) is chosen, because two wavelength signals to be split have a wide wavelength difference.

A. Selection of material

The structure proposed here is a Y- junction with material silicon is chosen because of its high refractive index (RI= 3.4). This high RI provides a high RI contrast with air which helps in getting a large band gap for the photonic crystal.

B. Selection of Lattice Structure

The lattice structure can either be a square lattice or a hexagonal lattice. A hexagonal lattice has advantage that its geometry provides a smaller angle (60 degrees) for bending the light unlike the right angle provided by the square lattice [6]. The smaller angle results in lesser scattering of light and in tum lower losses.

C. Selection of lattice constant and radius of cells

r/a Ratio of lattice play a very important role in determining its band-gap, where, r is the radius of the silicon rod and 'a' is the lattice constant of the structure. For silicon material r/a is 0.2 chosen for wide band gap [7].

Here a= 0.50 µm is chosen then

r/a = 0.2

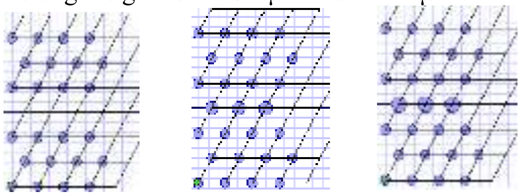
$r = 0.2\times 0.50$

$r = 0.100\ \mu m$

D. Adding Defects

Defects are added to allow a particular wavelength to pass through a particular direction while reflecting the rest. The one-line defect waveguide can transmit two wavelength signals, and it is named as Filter-A. Filter-B and Filter-C for transmitting 1.290 and 1.468 µm wavelengths, respectively, are implemented by inserting some point defects into the waveguide.

The r′/a ratio for filter-B and filter-C are 0.2736 µm and 0.3140 µm respectively. Where r′ is the changed radius for each defect. Also the transmitted power is Maximum when the number of defect rods in each output waveguide is 3, so in this way a wavelength demultiplexer can perform a work of wavelength filter. So it is confirmed that filter-B and filter-C can work as band pass filter for the wavelength signal of 1.290 µm and 1.468 µm



Filter-A Filter-B Filter-C

Fig 1.Schematic diagrams of three different filter structures.

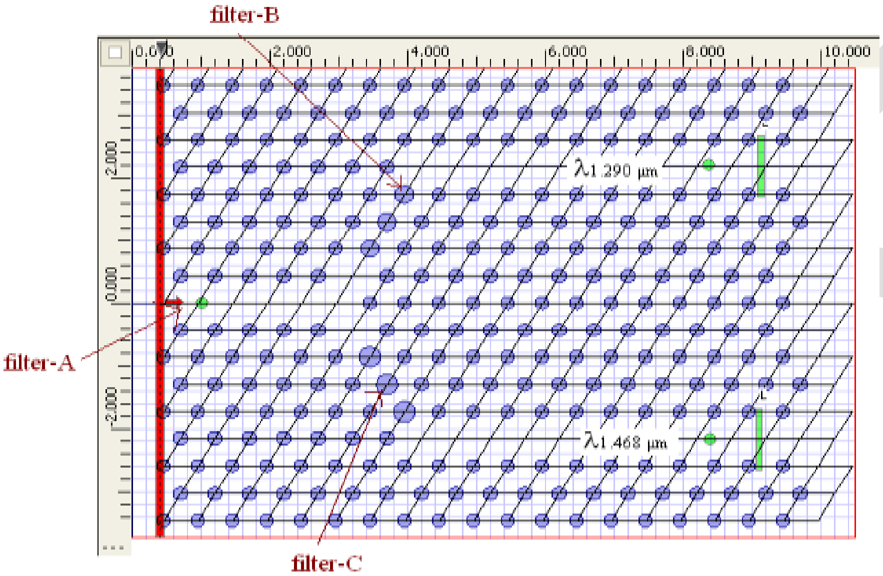


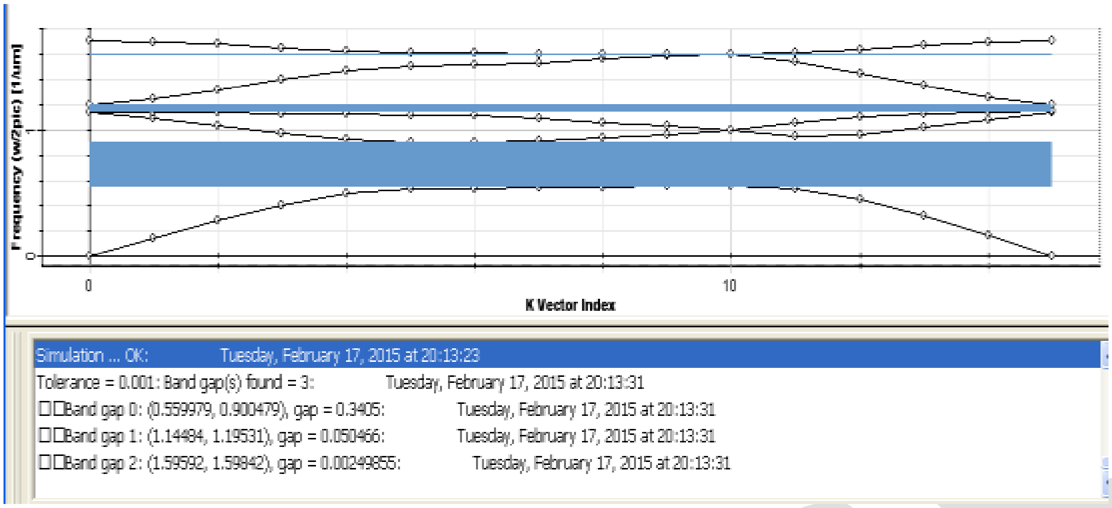
Fig. 2 Layout of the proposed 1.290/1.468 µm wavelength demultiplexer having the three different filter structures

SIMULATION RESULTS

After finalizing the architecture, we simulated it using the Opti-wave. The results are demonstrated in the following figures.

A. Band-gap Calculation

Fig. 3 depicts the photonic band-gap for the proposed structure .

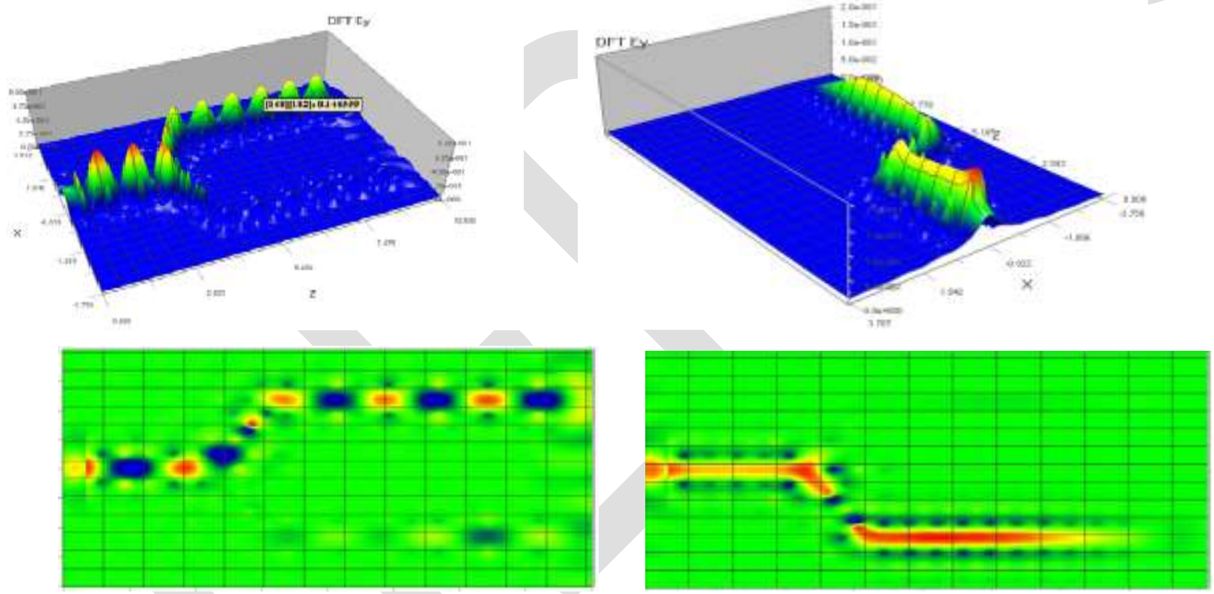


Simulation ... OK: Tuesday, February 17, 2015 at 20:13:23
Tolerance = 0.001: Band gap(s) found = 3: Tuesday, February 17, 2015 at 20:13:31
□□Band gap 0: (0.559979, 0.900479), gap = 0.3405: Tuesday, February 17, 2015 at 20:13:31
□□Band gap 1: (1.14494, 1.19531), gap = 0.050466: Tuesday, February 17, 2015 at 20:13:31
□□Band gap 2: (1.59592, 1.59842), gap = 0.00249855: Tuesday, February 17, 2015 at 20:13:31

Fig. 3 Photonic band-gap diagram for the proposed PhC structure

B. Electric-field Distribution

Fig. 4 represents the e-field distribution in the proposed device for both the wavelengths.



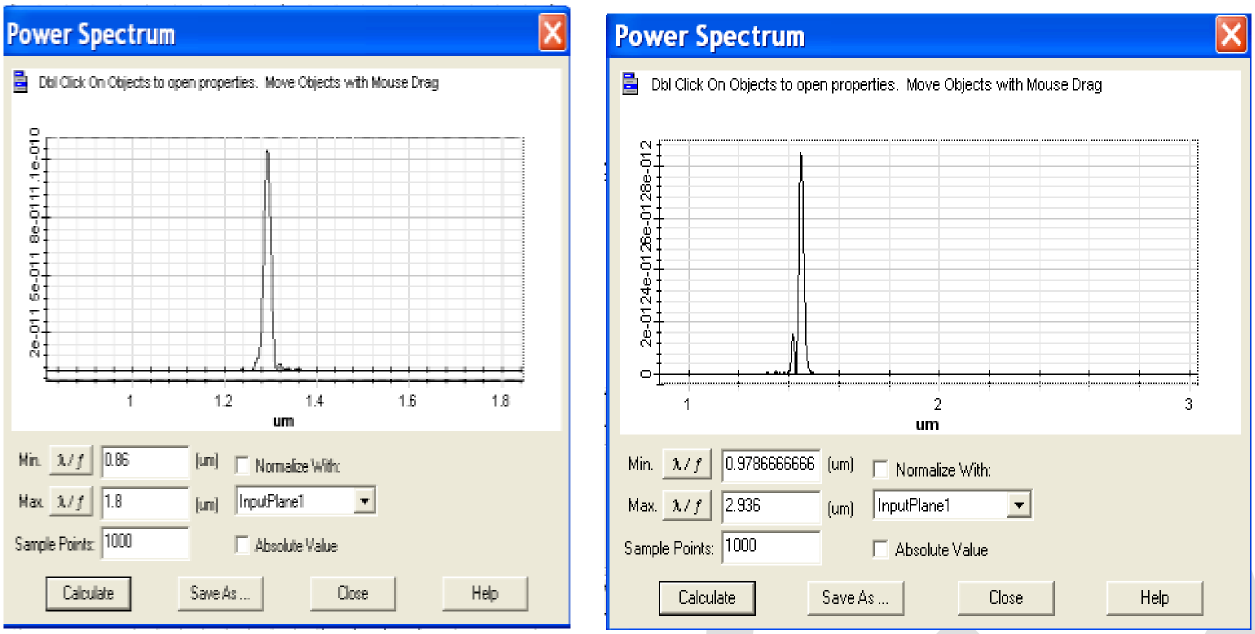
(a) (b)

Fig. 4 Simulated electric-field distribution for (a) 1.290 µm, and (b) 1.468 µm

So it is clear from figures 4(a) and 5(b) that, when two signals of wavelengths 1.290 and 1.468 µm will be applied at the input of the device, signal with wavelength 1.290 µm and 1.468 µm are filtered by filter-B and filter-C respectively and follow different path Thus the Demultiplexing action is realized.

C. Power Spectrum Measurement

Fig. 5(a) and 5(b) illustrate the power spectra for both 1.290 µm and 1.468 µm wavelengths respectively.



Power Spectrum

Dbl Click On Objects to open properties. Move Objects with Mouse Drag

Min. 0.86 (um) ☐ Normalize With:
Max. 1.8 (um) InputPlane1
Sample Points: 1000 ☐ Absolute Value

Power Spectrum

Dbl Click On Objects to open properties. Move Objects with Mouse Drag

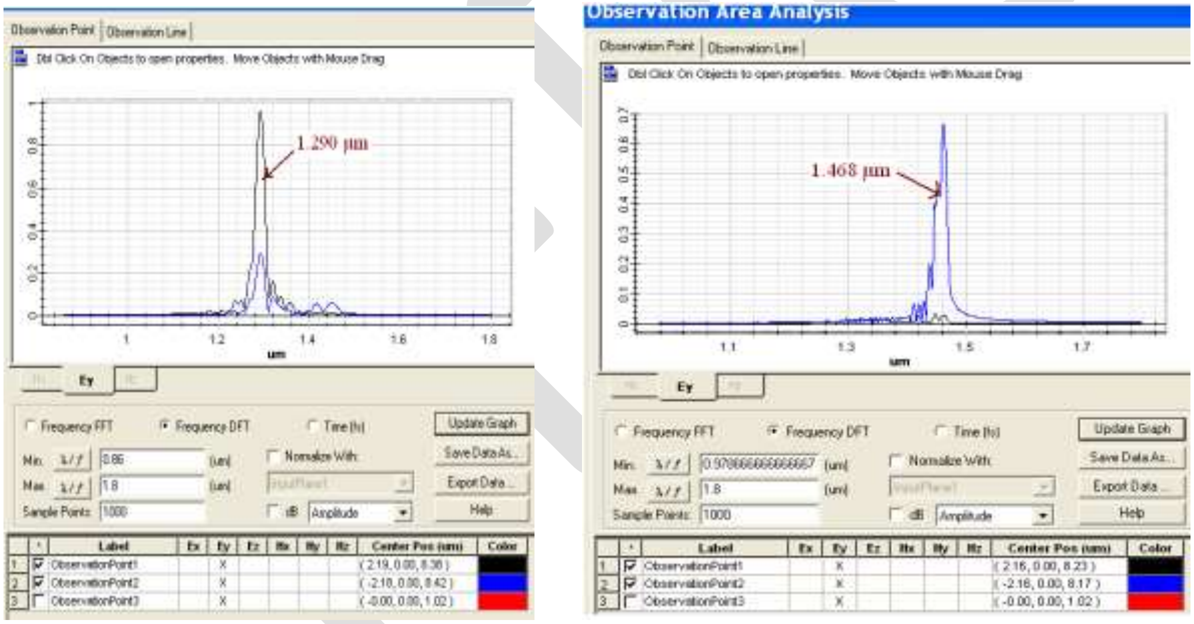
Min. 0.9786666666 (um) ☐ Normalize With:
Max. 2.936 (um) InputPlane1
Sample Points: 1000 ☐ Absolute Value

(a) (b)

Fig. 5 Power Spectrum for (a) 1.290 µm, and (b) 1.468 µm.

D. Coupling Measurement

Fig. 6(a) and 6(b) represents the coupling for both 1.290 µm and 1.55 µm wavelengths respectively.



Observation Point | Observation Line

Dbl Click On Objects to open properties. Move Objects with Mouse Drag

○ Frequency FFT ● Frequency DFT ○ Time (fs)

Min. 0.86 (um) ☐ Normalize With:
Max. 1.8 (um)
Sample Points: 1000 ☐ dB Amplitude

	*	Label	Ex	Ey	Ez	Hx	Hy	Hz	Center Pos (um)	Color
1	☑	ObservationPoint1		X					(2.19, 0.00, 8.38)	■
2	☑	ObservationPoint2		X					(-2.18, 0.00, 8.42)	■
3	☐	ObservationPoint3		X					(-0.00, 0.00, 1.02)	■

Observation Area Analysis

Observation Point | Observation Line

Dbl Click On Objects to open properties. Move Objects with Mouse Drag

○ Frequency FFT ● Frequency DFT ○ Time (fs)

Min. 0.97866666666667 (um) ☐ Normalize With:
Max. 1.8 (um)
Sample Points: 1000 ☐ dB Amplitude

	*	Label	Ex	Ey	Ez	Hx	Hy	Hz	Center Pos (um)	Color
1	☑	ObservationPoint1		X					(2.16, 0.00, 8.23)	■
2	☑	ObservationPoint2		X					(-2.16, 0.00, 8.17)	■
3	☐	ObservationPoint3		X					(-0.00, 0.00, 1.02)	■

(a) (b)

Fig. 6 Coupling for (a) 1.290 µm, and (b) 1.468 µm

Fig. 6(a) and 6(b) show that 90% transmission is done at1.290 µm also 1.290 µm is associated with a low cross-talk, whereas 1.468 µm exhibits negligible cross-talk with high transmission with 70% transmission.

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CONCLUSION

In this work, we have proposed a wavelength demultiplexer for splitting 1.290 and 1.468 µm wavelength signals by using the filtering property of the photonic crystal structure with local point defects. The de-multiplexing action is involved with two wavelengths 1.290 µm and it is associated with a low cross-talk, whereas 1.468 µm exhibits negligible cross-talk with high transmission. Also 90% transmission is done at 1.290 µm and 70% transmission at 1.468 µm wavelength. The optimally designed device has the dimension of 10.5×7.5 µm² for a = 500 nm. So this structure can be used in the future photonic integrated circuits also the mutual interaction between two combined filters will be considered to improve the device performance.

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