Design of Optical Band Pass Filter Based on Photonic Crystal with Resonance Cavity

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ABSTRACT:
Recently, regarding the performance of photonic crystal band-pass filters in optical networks connection, optical integrated circuits, and short wavelength with high frequency, has attracted a lot of attention. In this paper, Our goal is designing a new type of photonic crystal band-pass filters using a waveguide cavity in the form of reduction in size of the cell, that as a result we create a filter in the function of the urban wavelength with an acceptable bandwidth. Here, two types of filters have been used and optimized that the operation has been conducted by Rsoft software and FDTD two-dimensional technique. The first method is the reduction of the size of cells in waveguide and elimination of some cells in the same direction. The second method is the elimination of two cells in the vicinity of waveguide in the center of the structure. Numerical results show that the light in a band around 1.550 um passes through with maximum value. The efficiency has increased more than the previous structures, it is about 80%.
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KEYWORDS: Band pass filter – resonance cavity – Band Gap – photonic crystal

1. INTRODUCTION

Photonic crystal represents a new class of optical media which has been made by periodic Modulation by natural or artificial structure which are made in one-dimensional, two-dimensional and three-dimensional forms [1]. Our structure, in the paper, is to design a two-dimensional photonic crystal filter. The filter can have large scale of settings because of having permittivity alternation along 2 directions, while the third direction is uniform. If we want the structure resonates in a particular frequency, we will use of defect [2]. Light can be controlled by introducing defect in periodic structure and creating waveguide and micro-cavity, that localized electromagnetic modes can be established by light emission in the band gap frequency [3]. Since 1987, photonic crystals (PC) is rapidly developing and receives special attention by the scientific and research communities due to the existence of photonic band gap (PBG). Recent years, PC based optical devices have attracted great interest owing to their compactness, high speed of operation, better confinement, long life period and suitability for integration. Essentially, PCs are composed of periodic dielectric structures that have alternate low and high dielectric constant materials to affect the propagation of electromagnetic waves in certain frequency bands inside the structure. In other words, at certain frequency bands a periodical structure behaves totally reflective that is no transmission occurs and thus, PBG is formed [4]. Because they can be used as multiplexing for selecting or isolating specific channel or channels in the choice of wavelength division of optical communications systems [5]. Introducing defect, inside of their periodic structure are broken and some intervals are created for light movement with particular frequency in those area. The structures can be used for the design of new optical components with high-effects and better quality such as: multiplexing, optical couplers, optical filters and so etc. There are various types of the optical filters for example: add drop filter, channel drop filter, band-pass filter, band-stop filter and so etc.[6]. In the paper, we study band-pass filter. A band-pass filter is built by introducing defect by removing a row of a structure and creating a waveguide that the electromagnetic waves inside the waveguide are guided by narrowing band gap effect.

2. TWO-DIMENSIONAL FDTD NETHOD

The 2D FDTD time stepping formulas for the modes are:

$$H_z\Big|_{i,j}^{n+1/2} = H_z\Big|_{i,j}^{n+1/2} + \frac{\Delta t}{\mu}\begin{pmatrix} \dfrac{E_x\Big|_{i,j+1/2}^{n} - E_x\Big|_{i,j-1/2}^{n}}{\Delta y} \\ \dfrac{E_y\Big|_{i+1/2,j}^{n} - E_y\Big|_{i-1/2,j}^{n}}{\Delta x} \end{pmatrix} \quad (1)$$

$$E_z\Big|_{i,j}^{n+1} = E_z\Big|_{i,j}^{n+1} + \frac{\Delta t}{\varepsilon_{i,j}}\left(\frac{H_z\Big|_{i,j+1/2}^{n+1/2} - H_z\Big|_{i,j-1/2}^{n+1/2}}{\Delta y}\right) \quad (2)$$

$$E_y\Big|_{i,j}^{n+1} = E_z\Big|_{i,j}^{n} + \frac{\Delta t}{\varepsilon_{i,j}}\left(\frac{H_z\Big|_{i+1/2,j}^{n+1/2} - H_z\Big|_{i-1/2,j}^{n+1/2}}{\Delta x}\right) \quad (3)$$

Where, the index n denotes the discrete time step, indices i and j denote the discretized grid point in the x-y planes, respectively. The FDTD time stepping is given by:

$$\Delta t = \frac{1}{{}^{c}\sqrt{\left(\dfrac{1}{\Delta x}\right)^2 + \left(\dfrac{1}{\Delta y}\right)^2}} \quad (4)$$

Where c is the light speed, to satisfy the numerical stability condition and x and y are the intervals between two neighboring grid points along the x- and y-direction in the xy- coordinate system, respectively [7-10].

$$\Delta x = \Delta y \leq \frac{1}{10.\sqrt{\varepsilon_r}} \quad (5)$$

3. BAND-PASS FILTERS CHARACTERIZATION

In this paper, using a two-dimensional hexahedron lattice in the x and z directions, The number of circular rods considered for both ‘X’ and ‘Z’ directions are 21. During the design process, the dielectric rods are made of soI with dielectric coefficient of 3.24 (the dielectric constant of the material is (10.5) and is used in the air field. The lattice constant is equal to 480 nm that shows the distance between two radiuses of the adjacent cells. In the design used time step is 5000 and The radius of cell is equal to 0.167um. According to the band structure, the area of Band gap for TE mode has been created in normalized frequency 0.235<c/a<0.340 that it involves the range of the broad wavelength 1128<f<1632 nm. The interval is suitable for designing telecommunication wavelength. Figure 1 shows photonic crystal structure and Figure 2 shows the structure of the band.

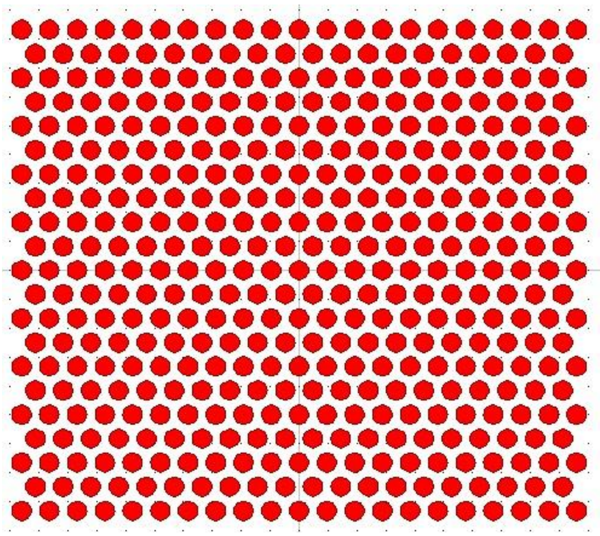


Fig. 1. The basic structure of a 2D hexagonal PhC

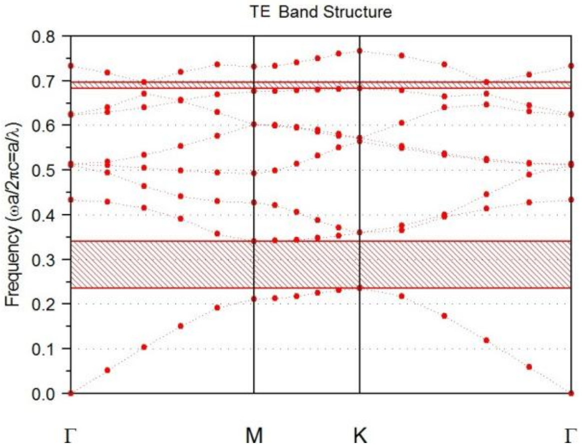
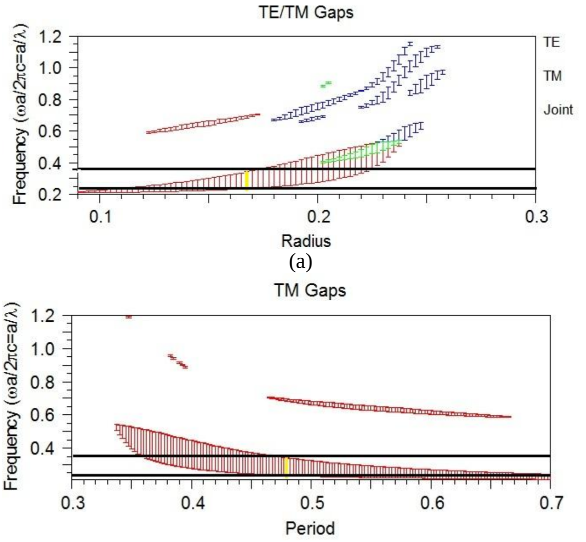


Fig. 2. The band structure of the proposed structure with R = 0.48*0.348 um and a = 0.48 um

When a photonic crystal piece is designed, it is necessary to clarify some issues. Band structure is used not only for measuring and understanding the characteristics of the frequency parameters also measuring the other characteristics. The gap map shown in Fig. 3(a) and 3(b) represent variation of TE/TM PBG, which is obtained by varying the defect size or the radius of the rod (a) lattice constant (b). In these figures, the blue region indicates the variation of TE PBG with respect to radius of the rods, period similarly red region indicates for TM PBG. The vertical yellow line over blue region shows the TE BPG region of the structure without introducing defects. The values to design the PCBPF in the first reduced TE PBG are optimized through gap map, which are rod radius (0.167um), refractive index (3.24) and period (480 nm) is indicated in the down gap map.



(a)

(b)

Fig. 3. Effect of gap map by varying (a) radius of the rod, (b) period (lattice constant)

4. SIMULATTON RESULTS AND DISCUSSION

4.1. First filter

In this section, we conduct various settings for determination of the desired filter parameters. For using filter, we need a range of distinct wavelength. In this structure, we consider the wavelength to be 1.550 um that the wavelength is widely used in telecommunications. The creation of a cavity within filter is conducted by reducing the size of the cells in the waveguide on 0.064 um. The structure is shown in Figure4. There are 7 cavities within the waveguide. As it can be seen in chart of Figure 5 (Transmission Chart), the transmission frequency includes of wavelengths that we consider. The efficiency of the filter is approximately 100%. This filter is suitable for separation of frequencies for the pass or return of light. The green color represents the output light and the blue indicates return light. As it can be seen in Figure 6, guiding electromagnetic wave 1.550 um (transition period) inside waveguide, transmission of the light is from output side and it can be seen in Figure 7 that conducting wave with 1.450 um length, the light is transferred to the output and we have no light from output.

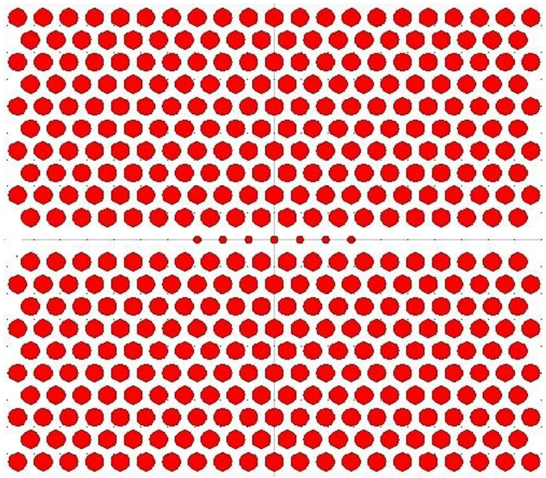


Fig. 4. Resonant band-pass filters realized by one-missing-row PhC waveguide. seven cavities are used utilizing 7extra rods

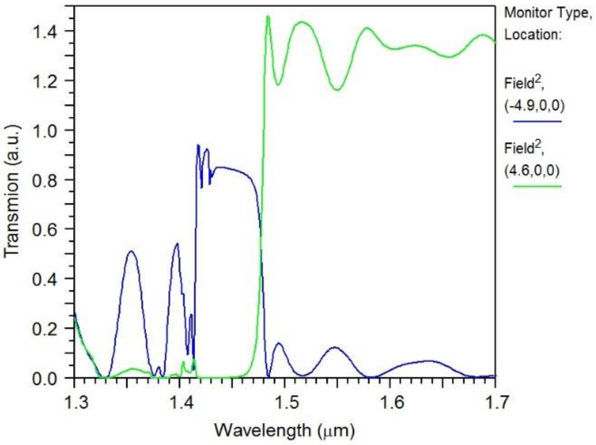


Fig. 5. Normalized transmission spectra obtained by the two-dimensional finite difference time domain (2D FDTD) simulation for the structure illustrated in fig. 4.

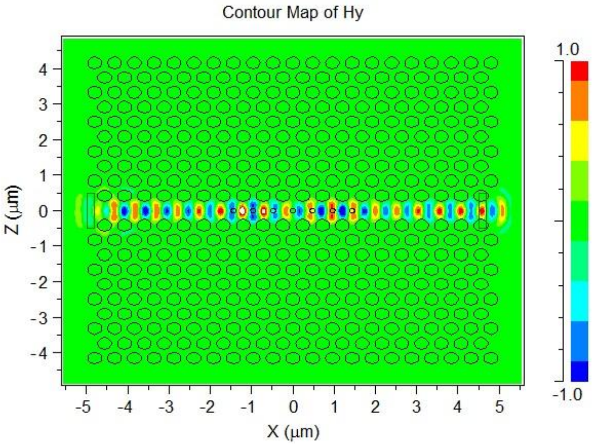


Fig. 6. The electric field distribution of circular cavity based PCBPF at (1.55 um) simulation for the structure illustrated in fig. 5.

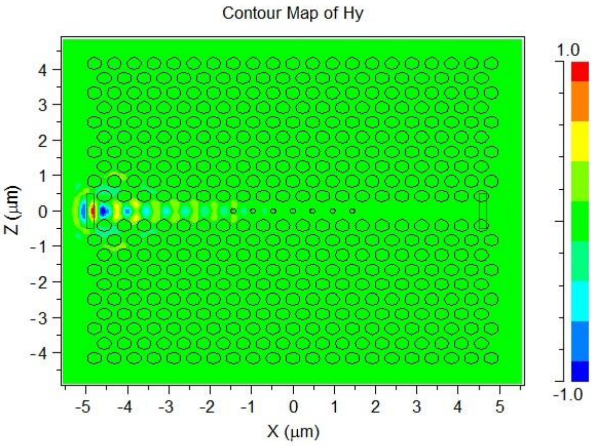


Fig. 7. The electric field distribution of circular cavity based PCBPF at (1.445um) simulation for the structure illustrated in fig. 5.

4.2. Second filter

We remove 2 numbers of adjacent cells in the center for designing the second filter, we see that the transmission is zero in the desired interval and the return light in the frequency of 1.550 um is about 80% that filter structure is shown in Figure 8 and transmission diagram is shown in Figure 9.

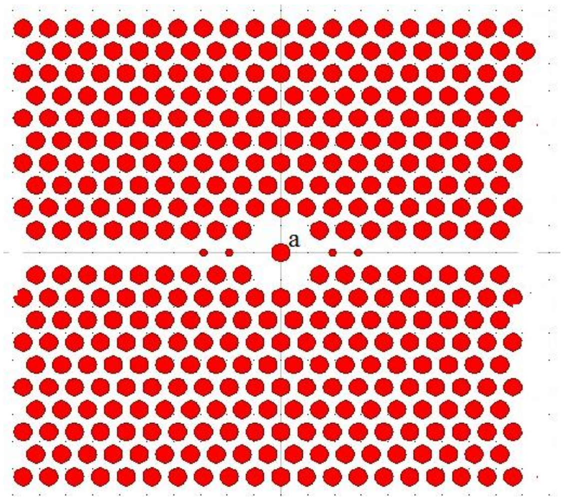


Fig. 8. Resonant band-pass filters realized by cascading cavities in a one-missing-row PhC waveguide and omitting two neighboring air holes, four cavities are used utilizing 5 extra rods. (the radius of (a) cell is 0.167um)

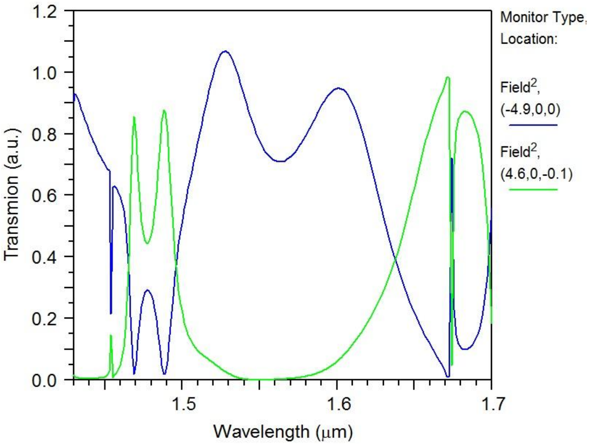


Fig. 9. Normalized transmission spectra obtained by the two-dimensional finite difference time domain (2D FDTD) simulation for the structure illustrated in fig. 8.

We reduce the radius center cell of the filter up to the size of other cavities (0.064 um) to improve the performance of the filter figure10. The transmission chart for the filter is shown in Figure 11. The shape of magnetic field in 1.550 um and 1.450 um intervals are shown in Figure 12 and Figure 13, respectively.

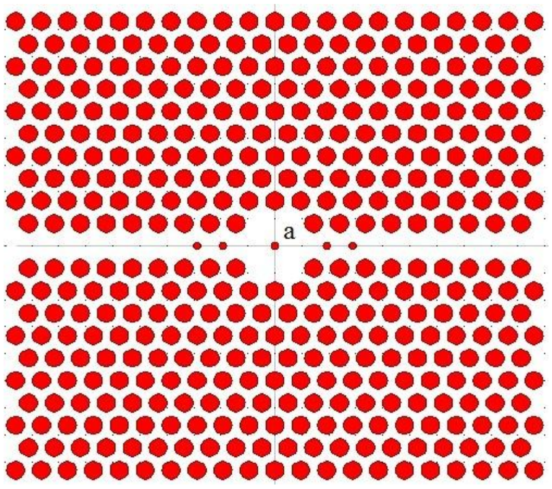


Fig. 10. Resonant band-pass filters realized by cascading cavities in a one-missing-row PhC waveguide and omitting two neighboring air holes, four cavities are used utilizing 5 extra rods.(the radius of (a) cell is 0.064um)

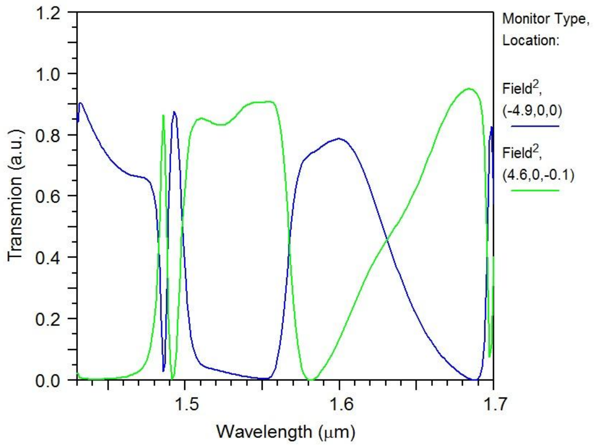


Fig. 11. Normalized transmission spectra obtained by the two-dimensional finite difference time domain (2D FDTD) simulation for the structure illustrated in fig. 10.

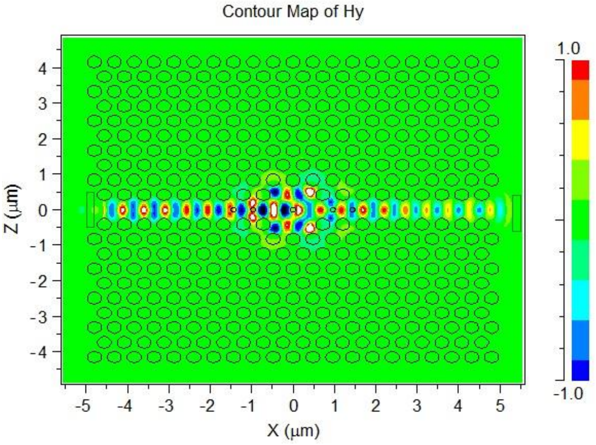


Fig. 12. The electric field distribution of circular cavity based PCBPF at (um) simulation for the structure illustrated in fig. 10.

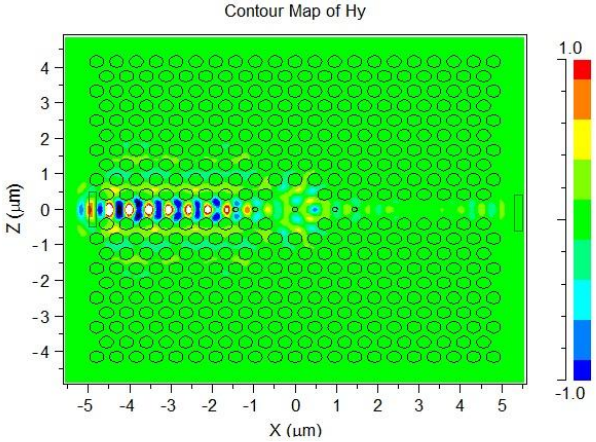


Fig. 13. The electric field distribution of circular cavity based PCBPF at (um). simulation for the structure illustrated in fig. 10.

5. CONCLUSION

In this paper, a new design of photonic crystal band-pass filter has been shown. This filter has been designed using the software Rsoft. We simulate and consider two types of filters. The first type filter is introduced by removing a row of cells of structure and creating 7 cavities inside it and the second type of filter is designed by removing adjacent cells in the center of the filter. Numerical results indicate a band at about 1128<f<1632, that in the frequency of 1.550 um, maximum transmission is approximately 100% for band-pass filter type I and 80% for filter type II.

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