Effects of changes in the cavity resonator photonic crystal filters with nano cells

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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, filters have been used and optimized that the operation has been conducted by Rsoft software and FDTD two-dimensional technique. The first is the reduction of the size of cells in waveguide and elimination of some cells in the same direction. The efficiency has increased more than the previous structures, it is about 80%.

Keywords: Band pass filter – resonance cavity – Band Gap – photonic crystal.

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.

TWO-DIMENSIONAL FDTD METHOD

The 2D FDTD time stepping formulas for the modes are:
\[ H_{i,j}^{n+1/2} = H_{i,j}^{n+1/2} + \frac{\Delta t}{\mu} \left( E_{i,n+1/2}^{n} - E_{i,n}^{n} \right) \]  
\[ E_{i,j}^{n+1} = E_{i,j}^{n} + \frac{\Delta t}{\varepsilon_{ij}} \left( H_{i,j+1/2}^{n+1/2} - H_{i,j-1/2}^{n+1/2} \right) \]  
\[ E_{i,j}^{n+1} = E_{i,j}^{n} + \frac{\Delta t}{\varepsilon_{ij}} \left( H_{i+1/2,j}^{n+1/2} - H_{i-1/2,j}^{n+1/2} \right) \]

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:

\[ \Delta t = \frac{1}{\left( \frac{1}{\Delta x} \right)^2 + \left( \frac{1}{\Delta y} \right)^2} \]  

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.

\[ \Delta x = \Delta y \leq \frac{1}{10\sqrt{\varepsilon}} \]

**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 silica 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.
Abstract diagram showing the essential features of the filter from figure 4: a single-mode input waveguide 1, with input/output field amplitudes $s_1+/s_1-$; a single-mode output waveguide 2 with input/output field amplitudes $s_2+/s_2-$; and a single resonant mode of field amplitude $A$ and frequency $\omega_0$, coupled to waveguides 1 and 2 with lifetimes $\tau_1$ and $\tau_2$ ($\tau_1 = \tau_2$ in figure 4). The $s_\pm$ are normalized so that $|s_\pm|^2$ is power in the waveguide, and $A$ is normalized so that $|A|^2$ is energy in the cavity. Now we include the waveguides. Input energy from $s_+$ can couple into the cavity, or it can be reflected into $s_-$ (or both). Energy from the cavity must also flow into $s_-$. The most general linear, time-invariant equations relating these quantities, assuming weak coupling, are:

$$\frac{dA}{dt} = -i\omega_0 A - \sum_{i=1}^{2} \frac{A}{\tau_i} + \sum_{i=1}^{2} \frac{2}{\tau_i} s_{i+}$$

$$s_{i-} = -s_{i+} + \sqrt{\frac{A}{\tau_i}}$$

**SIMULATION RESULTS AND DISCUSSION**

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 Si with a 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. 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

![Figure 4](image1.png)

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

![Figure 5](image2.png)

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

![Figure 6](image3.png)

Figure 6. Resonant band-pass filters realized by one-missing-row PhC waveguide. six cavities are used utilizing 6 extra rods.
Figure 7. Normalized transmission spectra obtained by the two-dimensional finite difference time domain (2D FDTD) simulation for the structure illustrated in fig.7.

Figure 8. Resonant band-pass filters realized by one-missing-row PhC waveguide. seven cavities are used utilizing 7 extra rods.

Figure 9. Normalized transmission spectra obtained by the two-dimensional finite difference time domain (2D FDTD) simulation for the structure illustrated in fig. 8.
Figure 10. Resonant band-pass filters realized by one-missing-row PhC waveguide. Eight cavities are used utilizing 8 extra rods.

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

In the second stage we reduce the radius center cell about 20% for 4 setup. The transmission chart for the filter is shown in Figure 12.
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 multilet types of filters. The filter is introduced by removing a row of cells of structure and creating 7 cavities inside it. 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.

REFERENCES


