Design and Simulation of an All Optical Two Channel Filter Based on photonic crystals

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Abstract— Photonic crystals are used in the design and manufacture of optical devices. One of these applications is photonic crystal filters. The advantages of the design of photonic crystals-based multi-channel filters are small size, flexibility in changing the parameters, low loss, and ability to separate wavelengths in the nanometer range. This paper proposed a two-channel filter using photonic crystals with a square lattice. This simple structure has small dimensions and causes separation of the wavelengths very close together, using defect routes. A waveguide has been created by eliminating all the rods to transfer waves from the input to the outputs. In addition to separate wavelengths, two other defect routes have been created, containing line and point defects. The results show that the wavelengths at a distance of a few nanometers of each other can be separated.

Keywords— Photonic crystal, Optical filter, Defect.
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1. Introduction

Due to the rapid advances in the miniaturization of high-speed electronic devices, it is predicted, the next few years this process will be a challenge. That's why researchers are seeking a replacement material, which has high speed data transfer and the small dimensions. Due to a lot of material that has been designed to build communication devices or built and tested, photonic crystals have attracted researchers' attention. Photonic crystals (PCs) are a group of materials in which the refractive index varies periodically. These changes may take place in one, two or three dimensions, which has been producing three types of PCs [1-15].

These three types of photonic crystals are one-dimensional, two-dimensional and three-dimensional. A two-dimensional PCs can be created by placement of alternating dielectric rods. Due to importance of PCs, many studies in recent decades have been conducted on them. According to small size of this materials, it can be used as a foundation for optical integrated circuits. To achieve this goal, initially the optical devices based on photonic crystals should be designed and built, separately [16-25].

So far, many studies have been conducted on devices such as filters, resonators, lasers, sensors, cavity and logic circuits-based PCs. In all these applications, the properties of the photonic band gap (PBG) are used. The PBG is the range of frequencies that cannot pass through the PCs. The band structure is used to calculate the PBG of crystal. To calculate the band structure, the Plane Wave Expansion method (PWE) is used.

For light propagation through the specific paths, defects can be used in the PCs. These defects act as a waveguide for guiding the light. Defects can be created by removing one or more rods or changing in their radiuses. Light by specific wavelengths could be passed from defect paths. Finite Difference Time Domain (FDTD) is used for calculating electric field distribution in defects paths [26-44].

For studying the light propagation in PCs, the Maxwell's equations should be solved. In other words, to analyze the behavior of light in an environment, these equations must be solved.

These equations explained the behavior of light in an environment. These equations consisting of two main equations as [2]:

$$1)\quad \nabla \times E = -\frac{\partial B}{\partial t} \quad , \quad \nabla . B = 0$$

$$2)\quad \nabla \times H = \frac{\partial D}{\partial t} \quad , \quad \nabla . D = 0$$

Where H and E are magnetic and electric fields. D and B are the displacement and magnetic induction fields, and ρ and j are the free charge and current densities. $\mathrm{D(r,t)} = \epsilon_0 \epsilon_r \vec{\mathrm{E}}(\mathrm{r,t})$ and $\vec{\mathrm{B}}(\mathrm{r,t}) = \mu_0 \vec{\mathrm{H}}(\mathrm{r,t})$. In the given relations, ϵ_r is relative electric permittivity, ϵ_0 is the air permittivity and μ_0 is the magnetic permittivity.

2. Two Channel Optical Filter

The proposed structure contains a two-dimensional PCs, with square lattice. In this structure, the dielectric rods with permittivity ε = 11.58 in air are used. The lattice constant is assumed a=0.64μm and the radius of rods is assumed r=0.2a. The number of rods in the X direction is 14 and in the Z direction is 17 rods. PWE method is used to calculating band structure for the structure. Figure1 depicts the calculated band structure for proposed filter.

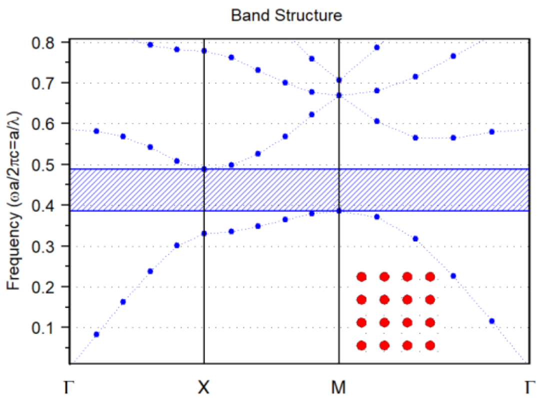

Fig. 1. Band structure for the proposed structure

The results of the band structure simulation show that the normalized frequency band gap (a / λ) located between 0.31 to 0.44 for the structure. A simple calculation will show, this distance is equivalent to the wavelength range of 1.45μm to 2.06μm.

For guidance the light to the outputs, the two defect routes are created. To control the light, the wavelength of the input source should be selected so that the light can pass only in defect routes and it should be reflected in other structure. For this purpose, the wavelength of the light source must be selected in the photonic band gap. A waveguide path has been created by removing all the rods in the horizontal direction and the light is injected to this defect path.

Two paths perpendicular to the previous route intended for filtering wavelengths. Half the rods in the two paths have been removed alternately, and radius of two rods has changed in each arm. To separate wavelengths in two directions, radius rods for "a" and "b" has been changed inequality. For this reason, the radius rods have been changed as $r_a = 0.5r$ and $r_b = 0.6r$.

Two other rods have equal radius as $r_c = r_d = 0.5r$. So, two cavities in two output paths have been created that only differ in the radius of one of the rods. Figure2 shows the structure of proposed filter. Rods with radius r_b and r_d will coupled the waves from horizontal path to the output routes. Because of different radius of these rods the different wavelengths will coupled to the output arms. The rods with r_a and r_c radiuses will transmit the coupled waves to the outputs.

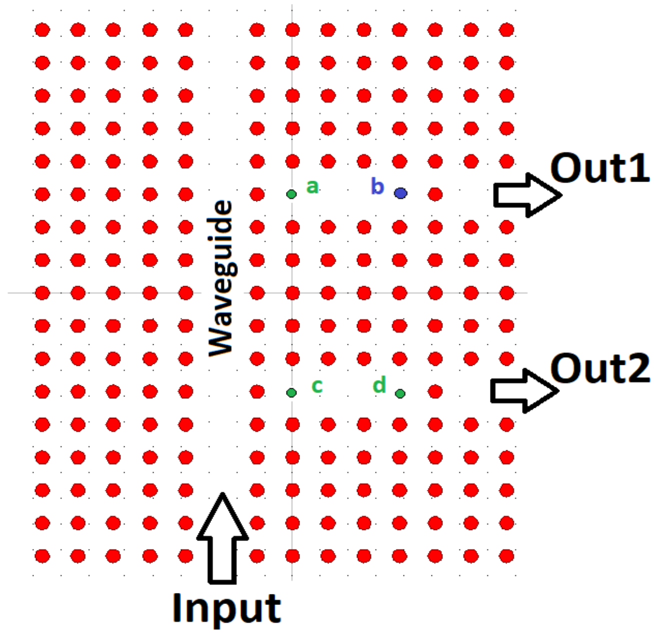

Fig. 2. Proposed structure for optical filter

The light from the horizontal path will injected to the two waveguides and will transmitted to the outputs. Some of the light power by specific wavelength will coupled to the cavities and transmitted to the output. These wavelengths depend on radius of rods r_a, r_b, r_c and r_d. Therefor by creating small different change in two routes the different wavelengths will transmitted to each output.

3. Simulation Results

The FDTD method is used to calculation of optical power distribution in routes. Using the obtained temporal results and using the inverse Fourier transform, frequency and wavelength calculations can also be performed. The simulation results show that this filter can separate the two wavelengths 1.74μm and 1.75μm well and send them to the corresponding outputs. Figure 3 shows the results of this simulation.

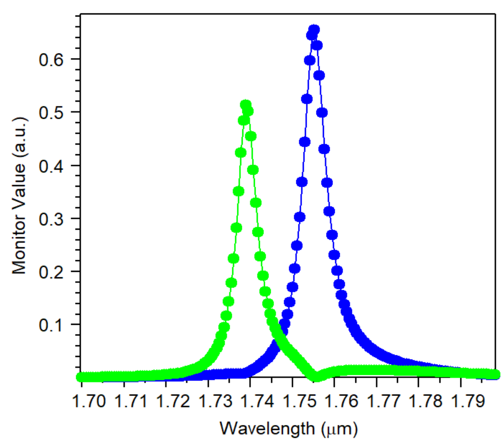

Fig. 3. Separation of two wavelengths at the filter outputs

To investigate the effect of changing the radius of the bars (r) on the wavelength transmitted to Out1, simulations have been performed for different values of r. In this simulation, the radius of the rods is changed from 0.15a to 0.20a and for each mode the power transmitted to out1 is calculated. The graph of these changes is shown in Figure 4.

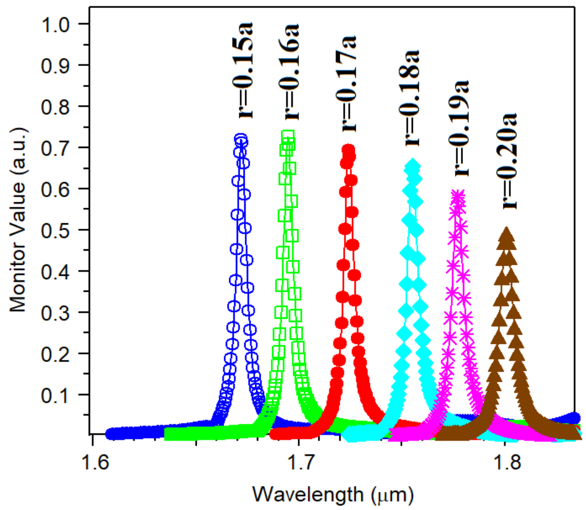

Fig. 4. Optical power diagram at Out1 for different values of "r"

As shown in Figure 4, as the radius of the rods increases, the power transmitted to output 1 will move to higher wavelengths. According to these results, it can be said that this structure can also be used to select the desired wavelength. However, by increasing the radius of the rods, the optical power at the output decreases slightly.

4. Conclusion

Photonic crystals are proper structures for designation of optical filters. The proposed structure is used to separate two near wavelengths. The structure consists of one input and two outputs. Defects are created by eliminating rods or changing in radiuses of rods. Structural flexibility to change physical characteristics and therefore ability to choose the desired wavelength in outputs are the advantages of the proposed structure based on photonic crystals. The simulation results show that, by changing the parameters of route defect, the output wavelength can be changed. Therefore, it can be designed structure for the desired wavelengths. But if we want to change the network profile, we must consider the range of PBG to filtering is done properly.

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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