Islamic Azad University

Journal of Optoelectronical Nanostructures

Summer 2016 / Vol. 1, No. 2

Design and Analysis of a Novel Hexagonal Shaped Channel Drop Filter Based on Two-Dimensional Photonic Crystals

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(Received 19 June 2016; Revised 18 July 2016; Accepted 16 Aug. 2016; Published 16 Sep 2016)

Abstract: In this paper a new optical channel drop filter (CDF) based on two dimensional (2-D) photonic crystals (PhC) with hexagonal shaped structure is proposed and numerically demonstrated by using the finite-difference-time-domain (FDTD) and plane-wave-expansion (PWE) techniques. Photonic crystals (PhCs) are artificial dielectric nanostructure materials in which a periodic modulation of the material dielectric constant results in a photonic band gap (PBG). By employing defects in the photonic crystals, light can steer in specific direction and consequently in the most of PhC applications, defects are used in their structures. The proposed structure is consisted of two series hexagonal shaped rings of Si rods between two straight waveguides to improve the performance of the channel drop filter. By analyzing the proposed structure, wide ranges of TE photonic band gap (PBG) would be achieved. It will be indicated that the proposed channel drop filter has appropriate characteristics and can be used in future WDM communication systems.

Keywords: Channel drop filter, Hexagonal shaped structure, Photonic band gap, Photonic crystal.

1. Introduction

Photonic crystals (PhCs) are artificial dielectric nanostructure materials in which a periodic modulation of the material dielectric constant results in a photonic band gap (PBG). PhCs are periodic dielectric structures with specific refraction coefficient [1]. The photonic band structures are periodic and propagation of light through them can exhibit behaviors quite different from those of uniform dielectric behaviors [2–4]. Light at frequencies in PhC PBG cannot propagate but at frequencies in PhC pass band can transmit with or without

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dispersion. By employing defects in the PhCs, light can steer in specific direction and consequently in the most of PhC applications, defects are used in their structures [5–8]. Many optical components have been designed and fabricated based on PhCs such as waveguides [9], ring resonators [10-12], waveguides, multimode interferences, polarization beam splitter [13], and all optical logic gates [14–16]. In a research, a new optical add–drop filter (OADF) based on two-dimensional photonic crystal ring resonator (2D PhCRR) with triangular lattice of silicon rods in air has been suggested [17] .Recently, a new optical channel drop filter (CDF) using photonic crystal ring resonator had been proposed, which enhanced the quality factor [18]. Also as another application of photonic crystals, An all-optical 1of 2 De multiplexer based on silicon rods in the air, created by two dimensional square lattice photonic crystals is studied and demonstrated [19]. In this paper, a new CDF based on 2D-PhC with hexagonal shaped defects is proposed and numerically demonstrated by using the 2D-FDTD technique. The present device has appropriate characteristics and could be used in future CWDM communication systems.

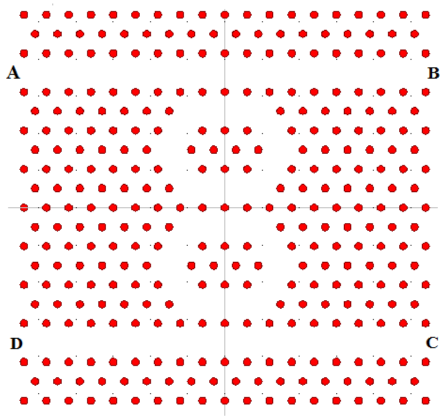

Fig. 1. Schematic diagram of the proposed CDF.

2. Design of the Channel Drop Filter

A 2D hexagonal lattice of 21×19 silicon rods in an air background with refractive index 3.5 and radius 0.16a is being considered, where a is the lattice constant and equals 0.6 µm. It is suggested to have two series hexagonal shaped rings between two straight waveguides to improve the performance of the channel drop filters. Fig. 1 shows two hexagonal shaped rings which are formed between the two straight waveguides. As shown in Fig. 1, the waveguides and hexagonal rings are made by removing rows of silicon rods in the PhCs. Another step in designing and studying PhC based structures is extracting their band structure and obtaining their Photonic Band Gap (PBG), a wavelength region in which the propagation of any electromagnetic wave is forbidden. One of the most popular numerical methods for calculating the PBG of these structures is Plane Wave Expansion (PWE) [20]. Fig. 2 shows the calculated dispersion relation of Fig. 1 for the TE/TM mode polarization [21].

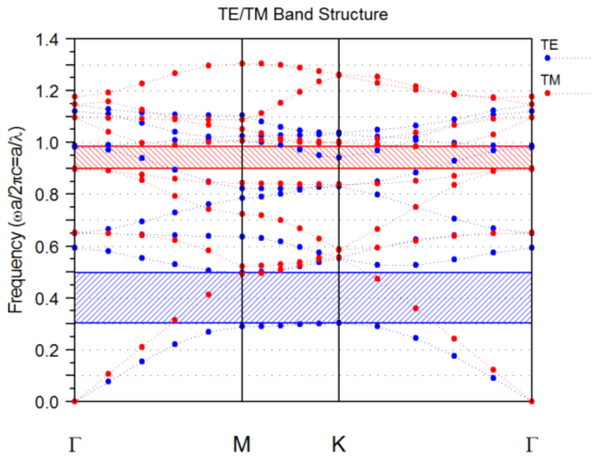

Fig. 2. Schematic of band structures.

Fig. 2, shows that there are 2 PBGs in the band structure, 1 in TM mode and 1in TE mode. The PBGs are $0.3 < a/\lambda < 0.5$ for TE mode and $0.9 < a/\lambda < 0.99$ for TM mode. Therefore wavelength region for the TE mode would be $1.2\mu m < \lambda < 2\mu m$ and for TM mode would be $0.6\mu m < \lambda < 0.66\mu m$. According to the above calculations, TE mode is suitable for WDM applications, so all the simulations will be done in TE mode.

3. Simulations and Results

After designing the structure it is suggested to examine the functionality of the CDF in different wavelengths. Simulations are done through FDTD method. In Fig. 1, port A is considered as input while B, C, D are throughput, add and drop ports. Results of pulse propagation in different wavelengths in the structure are shown below.

3.1 λ=1.55μm

This wavelength is in the middle of TE PBG region, therefore the structure would show a CD filtering behavior. After applying the input Gaussian field to port A, pulse would propagate in the structure as shown in Fig. 3.a.

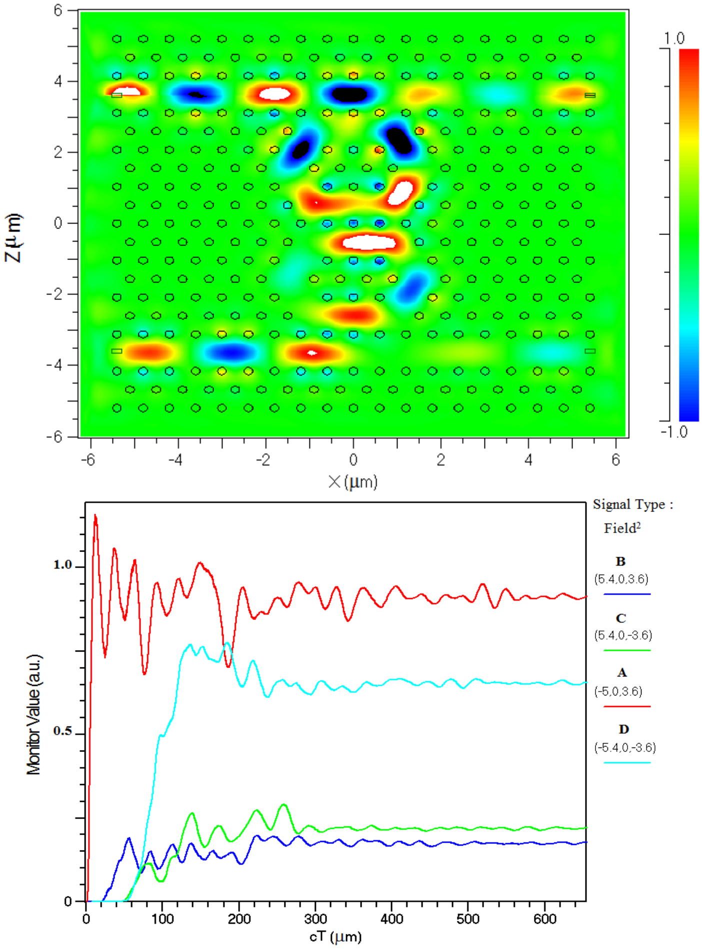

Fig. 3. a) schematic of pulse propagation in the proposed structure in λ=1.55μm, b) schematic of transmitted powers in different ports

It can be seen from Fig. 3.a and b, that in this wavelength, the structure shows a satisfying CD filter behavior.

3.2 λ=1.3μm

To examine the behavior of the proposed structure, another pulse with wavelength near the boundary of the TE PBG region is propagated in the PhC structure. The view of the pulse propagation and transmitted powers are depicted in Fig. 4.

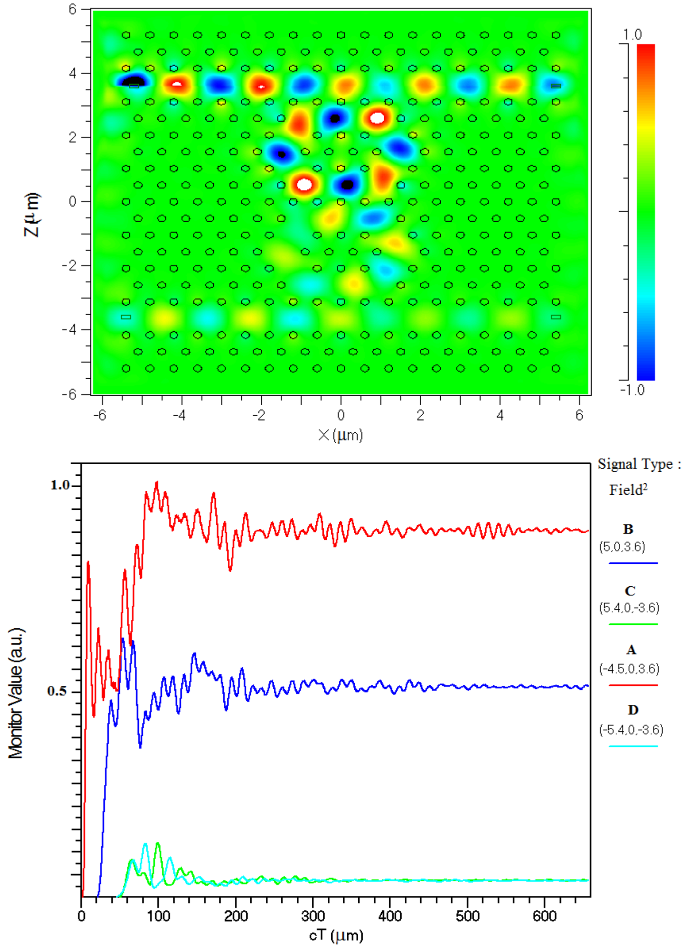

Fig. 4. a) Schematic of pulse propagation in the proposed structure in λ=1.3μm, b) schematic of transmitted powers in different ports.

3.3 *λ=1.2 μm*

Finally, the behavior of the structure at 1.2μm which is exactly at the boundary of the TE PBG region is being investigated.

As can be seen from Fig. 5, in the mentioned wavelength, the structure would act as a straight waveguide; not being able to demonstrate filtering behavior.

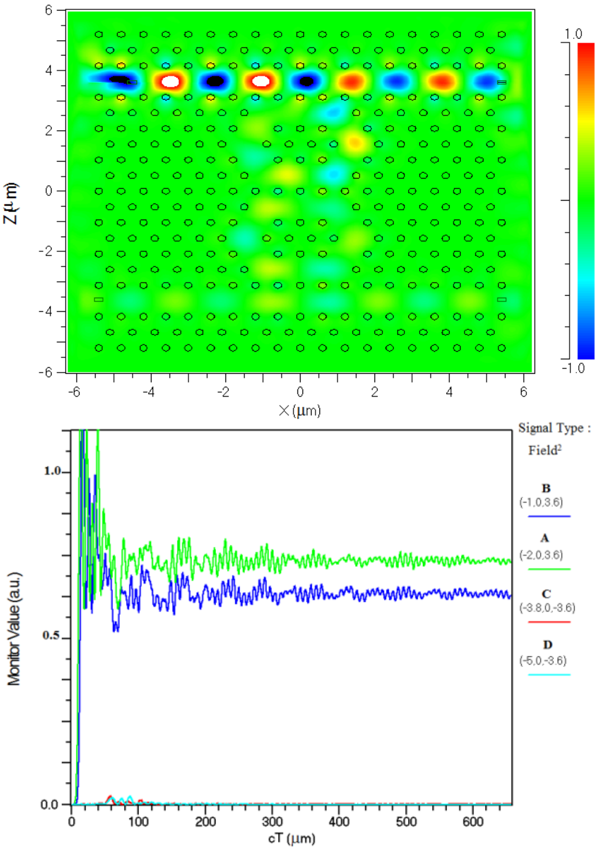

Fig. 5. a) Schematic of pulse propagation in the proposed structure in λ=1.2 µm, b) schematic of transmitted powers in different ports.

4. Conclusion

In this paper, a novel channel drop filter based on 2D photonic crystal with hexagonal shaped defects has been proposed. The proposed CD filter contains two series hexagonal shaped structures. The structure consists of 21*19 silicon rods in an air background with refractive index 3.5 and radius 0.16a; where ais the lattice constant and equals 0.6µm. The simulations has been done with PWE and FDTD methods. According to the TE PBG region which is in the range of $1.2\mu m < \lambda < 2\mu m$, the proposed device has appropriate characteristics and could be used in WDM communication systems.

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