

New Design of Channel Drop Filter by Triangular Photonic Crystal

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ABSTRACT

We have designed a new type of optical channel drop filter (CDF) based on two dimensional triangular lattice photonic crystals. CDF operation is based on coupling to the photonic crystal waveguide. The proposed structure is optimized to work as a CDF. For obtaining the CDF characteristics and band structure of the filter, the finite difference time domain (FDTD) method and plane wave expansion (PWE) method are used respectively. Dropping efficiency at 1556nm and quality factor (Q) of our proposed structure are 100% and 260, respectively. The quantities of quality factor and transmission efficiency are suitable for optical applications. The overall size of the proposed add drop filter is $191.97\mu\text{m}^2$, which is smaller than the filters already reported and it is highly desirable for photonic integrated circuits (PICs).

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1. INTRODUCTION

The photonic crystals (PhCs) have attracted a great deal of attention due to their ability to manipulate light at wavelength scale and some features such as compactness, electromagnetic wave emission controllability, high rate of performance speed, long life period, and property for integrating on optical circuit [1]. PhCs are composed of periodic dielectric or metallo-dielectric nanostructures that have alternate low and high dielectric constant materials in one, two or three dimension(s), which affects the propagation of electromagnetic (EM) waves inside the structure [2,3]. As a result of this periodicity, it possesses photonic band gap (PBG), where the transmission of light in certain frequency range is absolutely zero. Photonic crystals (PhCs) are very suitable candidates for realization of future passive and active optical devices because of their ability to control light-wave propagation, high speed of operation, better confinement, long life period and suitability for integration [4,5]. By creating the defects (point or line) in the periodic structure, it is possible to guide the propagation of light through the PBG region. This peculiar behavior can lead to realize almost all kinds of PhC based active and passive optical devices. Structures based on PhCs enable researchers to design small-scale devices [4]. In recent years, many PhC based optical devices are designed such as, power splitters [6], multiplexers [7], demultiplexers [8], polarization beam splitters [9], triplexers [10], switches [11], directional couplers [12], band stop filters [13], band pass filters [14,15], channel drop filters [16].

Filtering device enabling us to extract from one waveguide one wavelength and send it to another waveguide. For Wavelength Division Multiplexing (WDM) systems, optical channel drop filter is one of the important components to select a single or multiple wavelength channels.

2. DESIGN OF PHC CDF

As shown in Fig. 1, our design is based on 2D triangular lattice of silicon rods with refractive index of $n_{\text{Si}}=3.46$, in an air background with $n_{\text{air}}=1$. In this investigation, the ratio of the rod radius r to the lattice constant a , is 0.2. In this structure, band gap opens for the normalized frequency $0.337 a/\lambda$ to $0.442 a/\lambda$ for TM polarization (in which the magnetic field is in propagation plane and the electric field is perpendicular), where λ is the wavelength in free space. The spectrum of the power transmission is obtained with finite difference time domain (FDTD) method. FDTD is a time domain simulation method for solving Maxwell's equations in arbitrary materials and geometrics [17]. Berenger's perfectly matched layers (PML) are located around the whole structure as absorbing boundary condition [18].

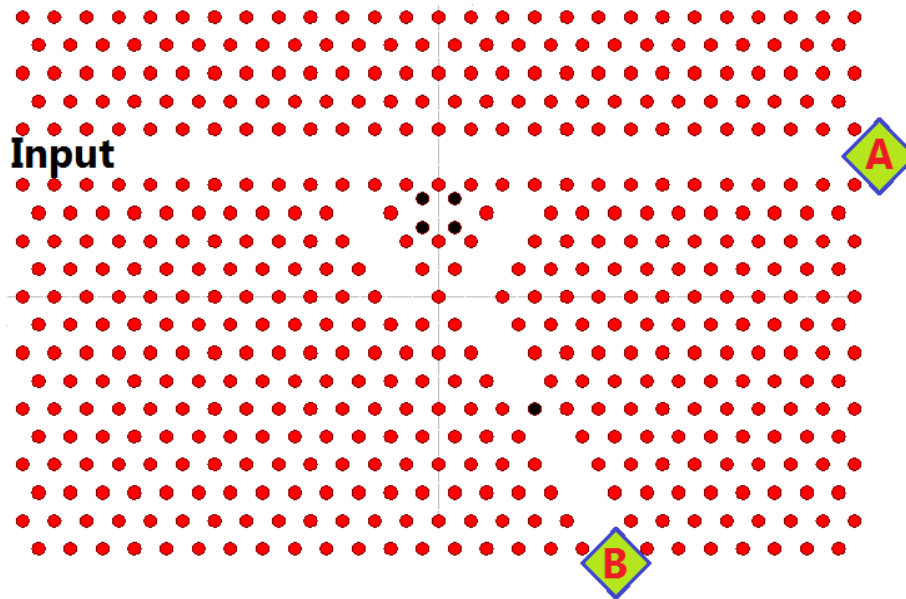


Figure 1. Schematic of a photonic crystal based CDF

Five additional extra scattering rods with black color are introduced to improve the spectral selectivity and obtain a very high dropped efficiency. These scatterers have exactly the same refractive indexes as all other dielectric rods in PhC structure and their diameters is chosen to be $r_s=0.965r$ for better performance [4].

Fig. 2(a) sketches the band diagram of the structure without any defects. When the line defect is introduced in the structure, the PBG is broken and the guided modes are allowed to propagate inside the PBG region as shown in Fig. 2(b). Both point and line defects are introduced for designing the filter. The guided modes are regulated by controlling the defect size and shape. In general, a ring resonator is positioned between two optical waveguides provides an ideal basic structure for CDF such that power in one waveguide is transferred into the other through the resonance of the ring, which is used to add or remove a channel from the multiplexed input/output signals. Fig.3 shows the schematic layout of CDF, which consists of bus and dropping waveguides.

A Gaussian pulse input signal is launched into the input port and its output is detected at the ports 'A' and 'B' using power monitor. The normalized transmission spectrum is obtained by taking Fast Fourier transform (FFT) of the fields that are calculated by 2D FDTD method.

The normalized transmission spectra for two output ports (A and B) in the CDF are displayed in Fig. 3 as red and blue lines, respectively. It can be seen that the spectral selectivity is significantly improved, 100% dropping efficiency can be obtained at the resonant wavelength of 1556nm . The quality factor (Q) of dropping peak is 260. Such Q values are enough for optical communication applications.

Fig. 4(a) and (b) depicts the electric field pattern of resonance and off resonance at 1556nm and 1530nm , respectively. At resonant wavelength of $\lambda=1556\text{nm}$, the electric field of the bus waveguide is to output port 'B', whereas at 'off' resonance $\lambda=1530\text{nm}$, the signal directly reaches to the transmission port 'A'.

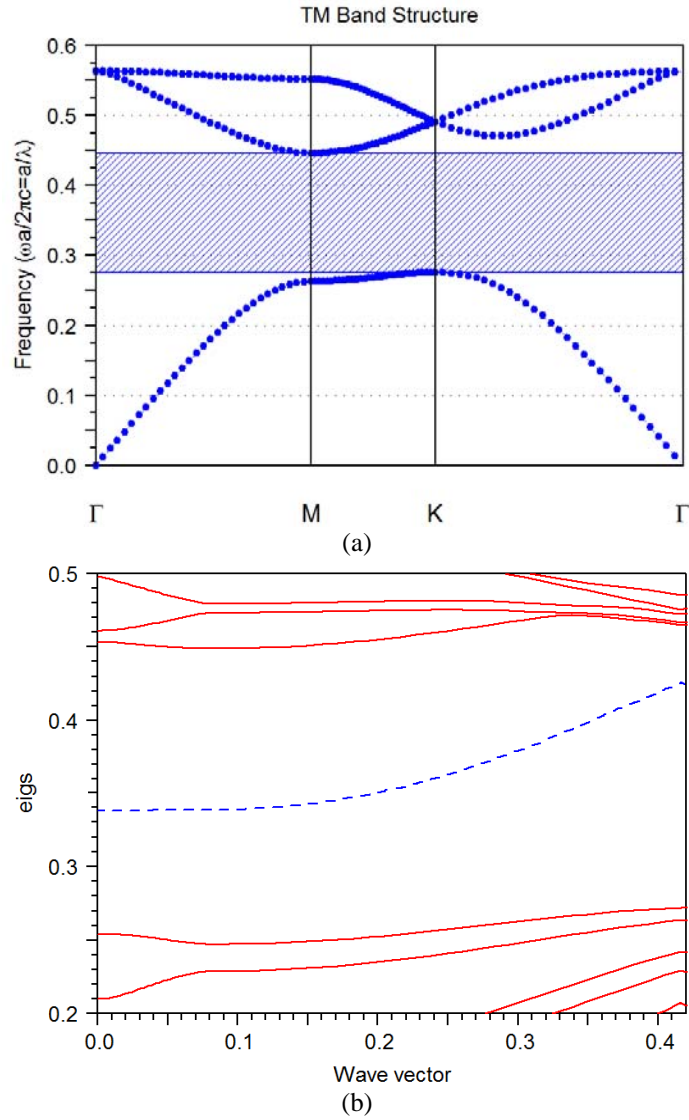


Figure 2. Band diagram of triangular lattice, (a) before and (b) After introducing line defect

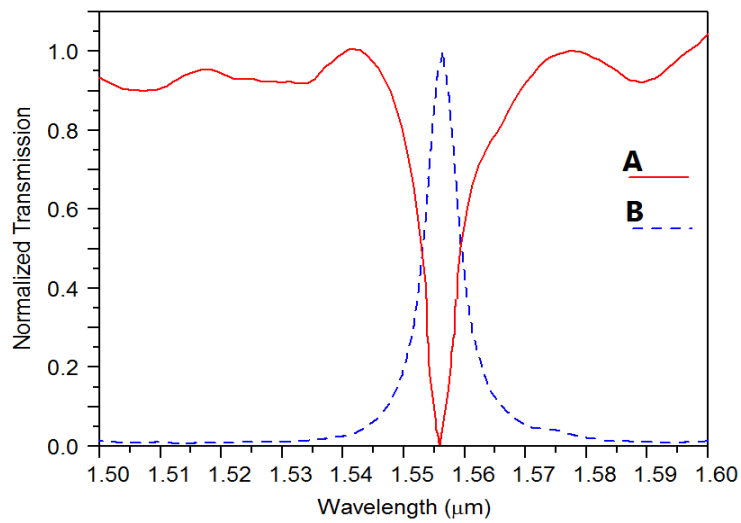


Figure 3. Normalized optical power transmission characteristic of CDF

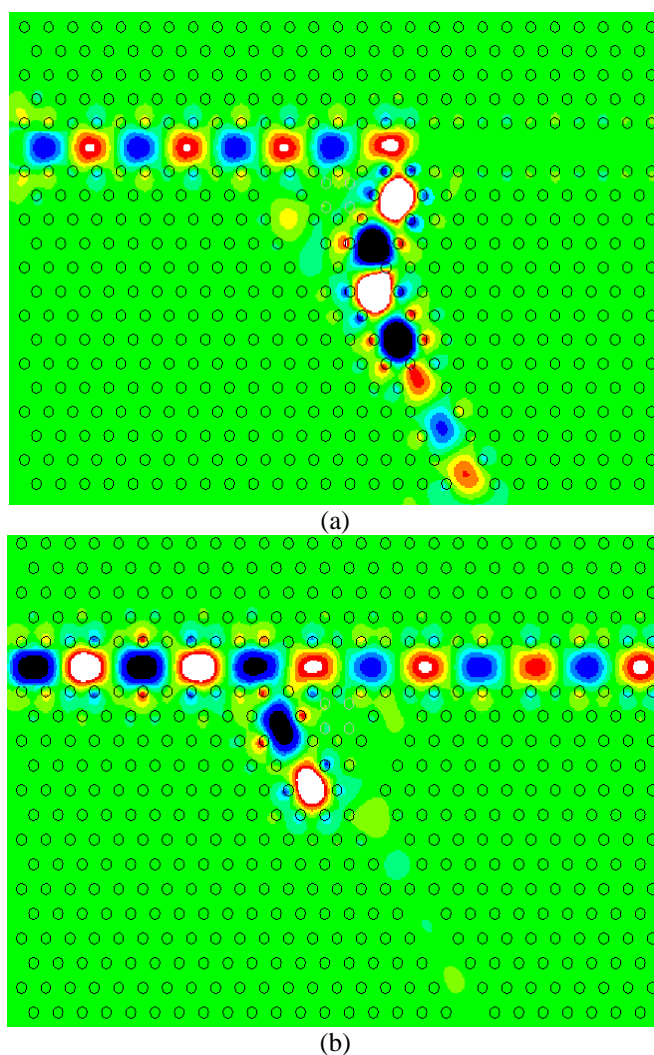


Figure 4. (a) Electric field pattern of the PhC based CDF at (a) 1556 nm (at resonance) and, (b) 1530 nm (off resonance).

3. CONCLUSION

A 2D photonic crystal CDF had been introduced and investigated through FDTD method in triangular lattice silicon rods. 100% drop efficiency and quality factor of 260 can be obtained at 1556nm that this is an important advantage for CDF is proposed than the CDFs already reported in the literature. We have shown that there is flexibility in design of the CDF with photonic crystal. Such structure may offer promising applications for photonic integrated circuits based on PhCs and other nanophotonic structures.

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Mohammad Ali Mansouri-Birjandi received his BSc and MSc degrees in electrical engineering from the University of Sistan and Baluchestan, Iran and the University of Tehran, Iran in 1986 and 1991, respectively. He then joined the University of Sistan and Baluchestan, Iran. In 2008, he obtained his PhD degree in electrical engineering from Trabiati Modares University, Iran. As an assistant professor at the University of Sistan and Baluchestan, his research areas are photonics, optoelectronics, analog integrated circuits, and metamaterial. Dr. Mansouri has served as a reviewer for a number of journals and conferences.