A Novel Structure for Optical Channel Drop Filter using Two-Dimensional Photonic Crystals with Square Lattice

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Abstract

In the present paper a novel structure for optical Channel Drop Filter (CDF) based on photonic crystal ring resonator with circular core has been proposed. In order to design the proposed CDF, the plan wave expansion (PWE) method is applied for calculation of band structure and photonic band gap while the transmission characteristics of proposed CDF have been calculated using the finite difference time domain (FDTD) method. The transmission efficiency of 100%, quality factor of 2583 and bandwidth of 0.6 are achieved at a wavelength near to 1550 nm which proved this filter is usable and suitable for optical communication applications.

Keywords: Photonic crystal, Ring resonator, Channel drop filter, FDTD method.

1. Introduction

Photonic crystals (PhCs) which are nowadays among the most common structures used for the design of optical electronic devices, are optical media represented by natural or artificial structures that the refractive index of them has periodic modulation [1]. PhCs are divided into three broad categories consisting of one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D) structures [1] and are widely used in optical waveguide, optical switches [2], optical filters [3] and optical de-multiplexers [4]. The most important practical significance of the PhCs is the presence of the photonic band gap. Photonic band gap (PBG) is a wavelength region in which no optical waves can propagate inside the structure [1,5]. Creation of any phenomenon in the periodic structure of photonic crystals leading to loss of lattice periodic property is called defect which causes breaking the band gap and thus, the propagation of light inside the PBG can be possible [6]. One example for the application of PhCs is designing channel drop filters (CDFs) which are essential for wavelength division multiplexing (WDM) systems [7].

Optical filter can be designed by creation of linear and point defects in the suitable places of two-dimensional photonic crystals. Add-Drop and channel drop filter with circular ring resonator by A.Tavousi et al.[8], resonant cavity channel drop filter by Sh. Fan et al. [9], channel drop filter with an elliptical resonator by H. Alipour-Banaei [10], T-shaped channel drop filter by M. Djavid et al. [11], circular resonator by F. Mehdizadeh et al.[12] and X-shaped add drop filter by M.

Youcef-Mahmoud et al. [13] are samples of Optical filters based on photonic crystal designed by different researchers. In the following sections procedure of filter designing, simulation and results' analysis are discussed.

2. Filter Designing Procedure

In order to design the proposed channel drop filter, the plan wave expansion (PWE) method [14] is applied for Calculation of band structure and photonic band gap while the transmission characteristics of proposed CDF are calculated using the finite difference time domain (FDTD) method [15] , with perfectly matched layers (PMLs) [16] absorbing boundary conditions. In order to have proper value for mesh sizes and time step, the mesh sizes were chosen as Δx=Δy=a/16 where a is the lattice constant and in order to obtain stable calculation, time step was chosen as Δt≤0.02 according to the courant condition ($\Delta t = 1/c\sqrt{(\frac{1}{\Delta x})^2 + (\frac{1}{\Delta y})^2}$) where c represents the velocity of light in free space [17]. A 25*23 square lattice of dielectric rods immersed in air is used to design the proposed filter. The effective refractive index of dielectric rods and the radius of dielectric rods are 3.42 and R=0.23*a respectively, where a (i.e. lattice constant of the PhC structure) is equal to 537nm. The band-diagram of the PhC with aforementioned values is displayed in Fig. 1. As shown, Totally there are 3 PBGs which two of them are in TM mode at the ranges of $0.264 < \frac{a}{\lambda} < 0.381$ and $0.504 < \frac{a}{\lambda} < 0.547$ while the third PBG is in TE mode at the range of $0.740 < \frac{a}{\lambda} < 0.756$. According to lattice constant of the structure (a), the first PBG at TM mode covers the wavelength at the range of $1409nm < \lambda < 2034nm$ which is suitable for optical communications.

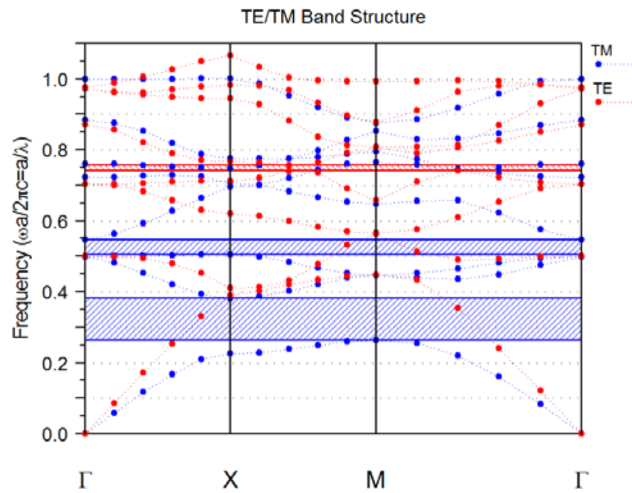

Fig. 1. The band structure of the basic PhC

The proposed filter consists of 3 parts including input and output waveguides and a ring resonator between two waveguides. A horizontal and a vertical linear defect were created for realizing input and output waveguide, respectively. For creating the ring resonator, first a 7*7 array of dielectric rods in middle of the structure was removed and then a circular core inside the empty square has been located. The resonator has 4 orbitals and there are 6, 12, 18and 24 rods in the first, second, third and fourth orbitals, respectively. The radius of the orbitals respectively are A1, 2A1, 3A1 and 4A1, where A1=B*a and B=0.58. The radius of resonator dielectric rods is R1=0.3*A1 and the refractive index of resonator is the same as the basic structure. The final structure of the filter is displayed in figure 2.

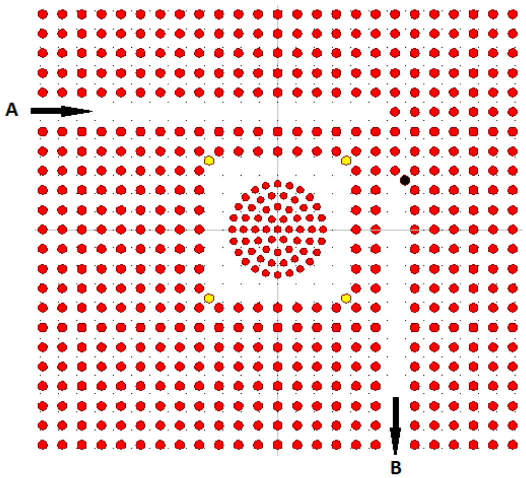

Fig. 2. Schematic diagram of the filter

As shown in Fig. 2 for improving the coupling efficiency and Optimized performance of ring resonator 4 scattering rods (indicated by yellow color) at the corner of the square with half lattice constant whose radius (R_S') were the same with the basic structure have been located.

Moreover, another scattering rod was located at top corner of output wavelengths (indicated by black color) with radius equal to R_S=1.09R to achieve higher coupling efficiency.

3. Simulation and Results

The output spectrum of proposed filter is displayed in figure 3. As shown, Optical waves entered the structure from port A and at the wavelength of 1550 nm dropped to port B. The output spectrum of port B is indicated with blue color. The bandwidth of achieved output spectrum is 0.6 nm, the transmission efficiency and quality factor are 100% and 2583, respectively.

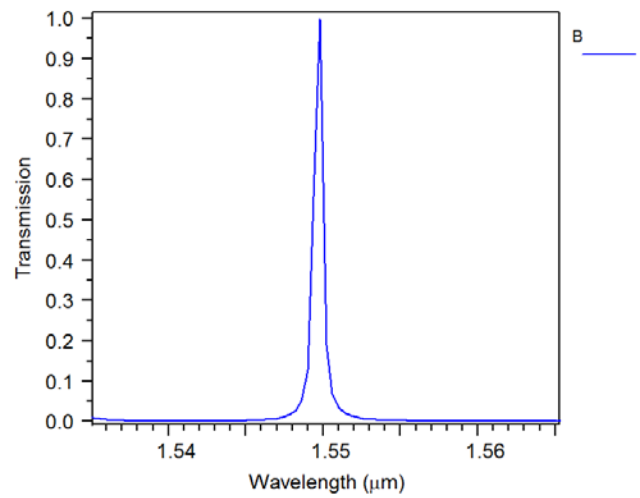

Fig. 3. Output spectrum of the proposed filter

The distribution of optical waves inside the structures for two different wavelengths is shown in figure 4. Figure 4(a) shows that at wavelength of 1550nm optical waves dropped to port B, while figure 4(b) shows at wavelength of 1560nm the resonance is not occurred and these waves did not drop to portB.

As it can be observed due to the PBG effect, the waves for both wavelengths did not scatter inside the structure and only propagated inside the waveguides. Significant parameters of the proposed channel drop filter are shown in table.1

Table.1. Significant parameters of the proposed filter

------	λ_0(nm)	$\Delta\lambda$(nm)	Q	TE^a(%)
Proposed CDF	1550	0.6	2583	100
a: Transmission Efficiency				

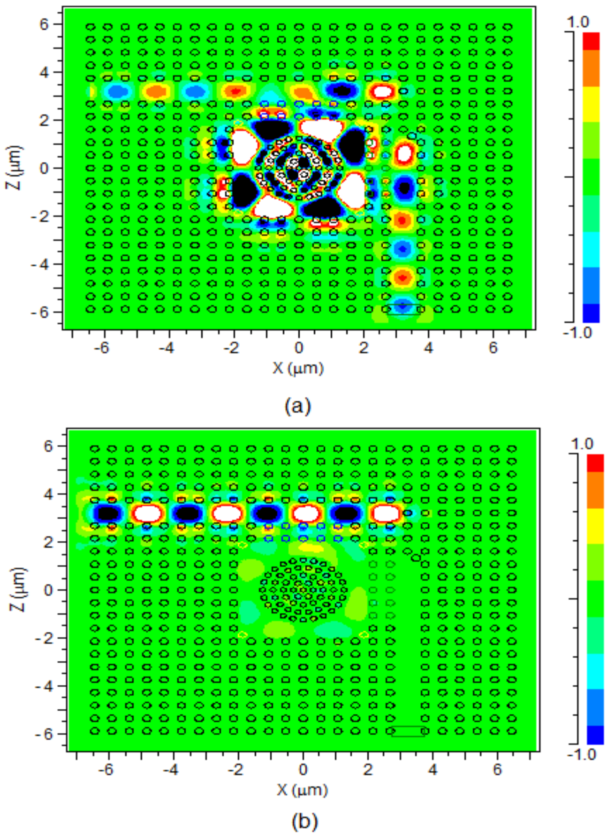

Fig. 4. Electric field distribution of CDF (a) at the resonance wavelength of 1550 nm,(b) at the wavelength of 1560 nm

4. Conclusion

In this paper a channel drop filter using Two-dimensional photonic crystals with square lattice was proposed. For designing of this filter ring, a resonator with circular core was used placed between the input and output waveguide. PWE and FDTD numerical methods were applied to calculate the band structure and the transmission characteristics of proposed CDF, respectively. The transmission efficiency, the bandwidth and quality factor of the proposed CDF are 100%, 0.6 and 2583, respectively, at wavelength of 1550nm which demonstrated it as a suitable filter for optical communication applications.

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