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Novel design of optical channel drop filters based on two-dimensional photonic crystal ring resonators

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ABSTRACT

Ring resonators are useful elements especially in channel drop filters. In this paper, a novel design of optical channel drop filter (CDF) based on two-dimensional photonic crystal ring resonators with square lattice is proposed. The rods of this structure is silicon with the refractive index $n_{si}=3.46$ and the surrounding environment is air with the refractive index of $n_{air}=1$. The widest photonic band gap obtains for the filling ratio of $r/a=0.2$. The filter's transmission spectrum is calculated using the two-dimensional (2D) finite-difference time-domain (FDTD) numerical method. The simulation shows, close to, 100% dropping efficiency and suitable quality factor at 1644.7 nm wavelength achieved for this filter. Also in this paper, we investigate parameters which have an effect on resonant wavelength and transmission spectra in this CDF, such as refractive index of inner rods and the refractive index of whole rods of the structure. The area of the proposed structure is about 12.36 μm × 12.36 μm which is suitable for photonic integrated circuits and optical communication network applications.

1. Introduction

Due to ever increasing developments in optical communication networks, designing all optical devices suitable for integrating in all optical circuits has become very popular among researchers [1]. One crucial challenge in designing ultra-compact optical devices is the poor confinement of light in small spaces. This challenge has been solved through employing photonic crystals (PCs) [1]. In the recent years, using of Photonic crystals have attracted more and more attention by the scientific and research communities [2]. PCs 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 [3,4]. PCs are periodic optical nanostructures composed of two different materials with low and high dielectric constant [2,4]. As a result of this periodicity, it possesses photonic band gap (PBG), where the transmission of light in certain frequency range is absolutely zero [5]. Depending on the geometry of the structure, PCs can be divided into three broad categories, namely one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D) structures. 2D PCs due to their complete PBG and ease of design and fabrication attract more attention than 1D structures [6].

With the advent of photonic crystals, wide development in the manufacture of optical components in the nanometer scale was reached. In recent years, several optical devices were designed based on PCs such as multiplexers [7], demultiplexers [8], polarization beam splitters [9], triplexers [10], switches [11], directional couplers [12], bandpass filters [13–15], channel drop filters/add-drop filters [16–21].

Special limitations of these devices are quality factor (*Q*) and output efficiency of the needed wavelength [22]. To compensate these shortages and also to enhance them, PCs resonant cavities are used which can improve the interaction of light [19]. Optical filtering elements are among the most important components of the telecommunication systems. On the other hand, channel drop filters are essential components of photonic integrated circuits (PICs) and wavelength division multiplex (WDM) optics communication systems.

An optical filter is a device, which has the property of adding or dropping a given wavelength channels from the multi-wavelength network [23]. There are several attempts to design and realize the CDF for real time applications. The photonic crystal based CDF is generally designed by using defects and ring resonator [24–27]. The Photonic Crystal Ring Resonator (PCRR) based CDF is designed by using square ring resonator [28,29], hexagonal ring resonator [30,31], quasi square ring resonator [32], diamond shaped ring resonator [33], X shaped ring resonator [34]. In this paper, we have proposed a new configuration for the ring resonator inspiring the ring designs reported in [21,23,35]. In this paper, a CDF based on a flower shaped PCRR is proposed and designed and its essential parameters such as transmission efficiency, dropping efficiency,

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quality factor and resonant wavelength are evaluated. The proposed CDF is smaller with better quality factor and higher transmission efficiency comparing with other state of art designs [3,4,22,37]. The ring resonator introduced in this study can be used as the basic element for other devices as well.

The paper is arranged as follows: In Section 2, the numerical analysis methods namely FDTD method and PWE method are discussed. The proposed design of PCRR based on CDF and the simulation results are discussed in Section 3 and finally Section 4 concludes the method.

2. Numerical analysis

To study, extract and analyze the properties of PC devices, one needs to employ some numerical methods. Plane wave expansion (PWE) method and the finite-difference time-domain (FDTD) method are most popular methods which is used for theoretical analysis of photonic crystal structures at frequency domain [35]. First method is initially used for theoretical analysis of photonic crystal structures, which can express periodic structures as a superposition of a set of plane waves. Although this method can obtain an accurate solution for the dispersion properties of a PC structure, but due to considering propagation modes, transmission spectra and field distribution cannot be extracted.

FDTD is an accurate method for studying electromagnetic problems including the simulation of many PC-based devices. The FDTD method for solving Maxwell's equations has been the workhorse of computational electromagnetic in the time domain, due to its simplicity. For a linear isotropic material in a source-free region, the time-dependent Maxwell's equations can be written in the following form:

$$\frac{\partial H}{\partial t} = \frac{1}{\mu(r)}\nabla \times E \tag{1}$$

$$\frac{\partial E}{\partial t} = \frac{1}{\varepsilon(r)}\nabla \times H \tag{2}$$

where $\mu(r)$ and $\varepsilon(r)$ are the position dependent permeability and permittivity of the material, respectively. In the two-dimensional case, the fields can be decoupled into two transversely polarized modes as the TM and TE. These equations are discretized in space and time domain using the principles of Yee algorithm [20].

The FDTD method is useful for analyzing the transmission spectrum while performing the simulation. The equations are:

$$E_x\Big|_{i,j}^{n+1} = E_x\Big|_{i,j}^{n} + \frac{c\Delta t}{\varepsilon_0}\left[\frac{H_z\Big|_{i,j+1/2}^{n+1/2} - H_z\Big|_{i,j-1/2}^{n+1/2}}{\Delta_y}\right] \tag{3}$$

$$E_y\Big|_{i,j}^{n+1} = E_y\Big|_{i,j}^{n} - \frac{c\Delta t}{\varepsilon_0}\left[\frac{H_z\Big|_{i,j+1/2}^{n+1/2} - H_z\Big|_{i,j-1/2}^{n+1/2}}{\Delta_x}\right] \tag{4}$$

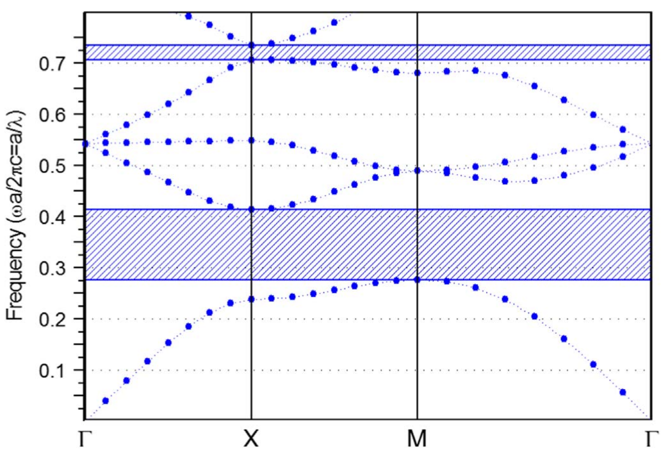

Fig. 1. Band structure of square lattice photonic crystal of TM polarized light.

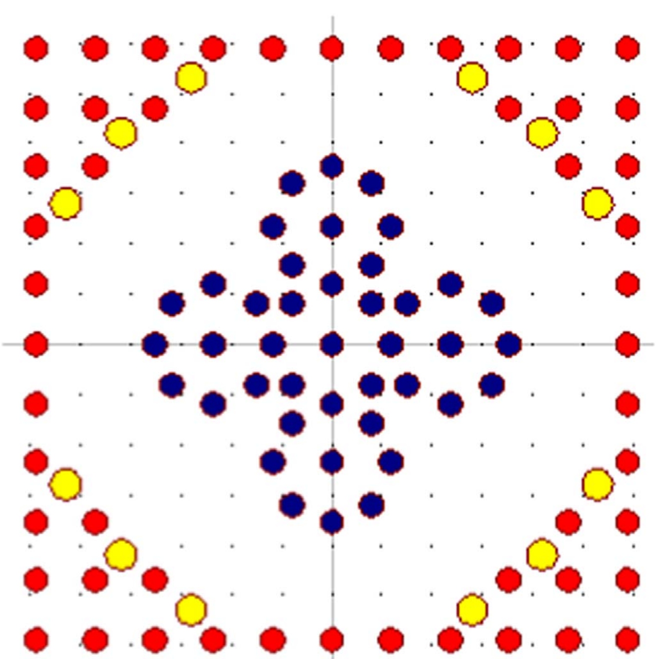

Fig. 2. Schematic structure of PCRR. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

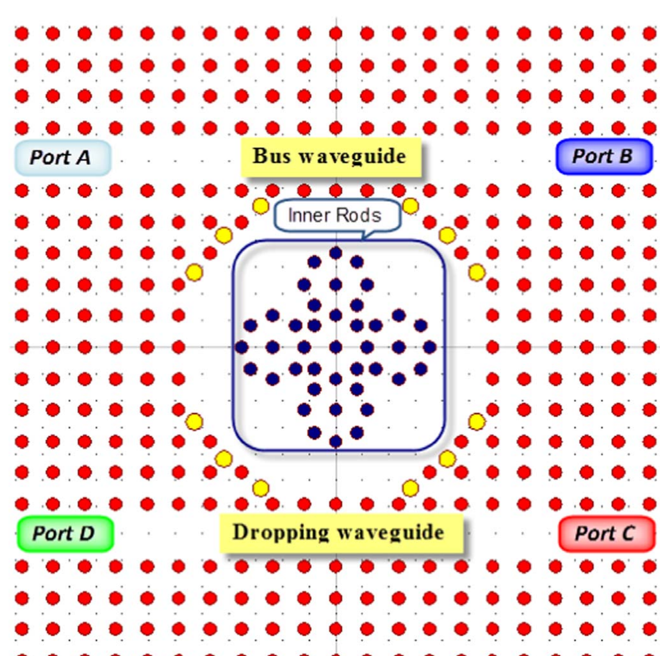

Fig. 3. Schematic diagram of the CDF.

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