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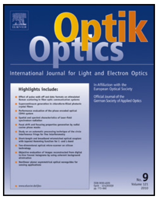

A novel optical filter based on H-shape photonic crystal ring resonators

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ABSTRACT

Photonic crystal based ring resonators are promising structures used for designing optical filters suitable for optical communication networks. In this work we use an H-shaped resonant ring for designing an optical filter. The proposed filter consists of two upper and lower waveguides coupled through an H-shaped resonator which is designed for coupling of an identical wavelength from upper waveguide to the lower one. We use numerical methods such as plane wave expansion and finite difference time domain for performing our simulations and studying the optical properties of the proposed structure. The transmission efficiency and quality factor of our filter is about 100% and 221 relatively.

1. Introduction

Currently photonic crystal (PhC) structures have been the best candidates for designing all optical devices in optical integrated circuits. PhCs are periodic structures, in which the distribution of the refractive index is periodic in one, two or three dimensions. This periodicity of the refractive index distribution creates a special region inside the band structure of the PhC, in which the propagation of some optical waves is forbidden. This region is called photonic band gap (PBG) [1–8]. PBG depends on the refractive index and structural parameters of the PhC [9]. Optical circulator [10], optical filters [11,12], and optical demultiplexers [13,14] are some examples of optical devices designed by PhCs. Optical filters play a crucial role in all optical communication networks. They can be used for removing noise and unwanted waves from the channel and for separating closely spaced optical channels in wavelength division multiplexing (WDM) systems. Plane gratings [15], Fabry-perot interferometers [16], fiber Bragg gratings [17], and Mach–Zehnder interferometers [18] are some examples of optical filters reported in literature but because of some drawbacks they are not suitable for WDM and DWDM applications. For instance they cannot be integrated into ultra-small dimensions which is required for integrated optical circuits, and also achieving narrow band filters with small channel spacing is difficult [19]. On the other hand PhC based filters currently show higher performance with removed disadvantages of previous structures [20].

A variety of structures have been proposed for designing all optical PhC based filters such as defective multilayers [20], quasi crystal defects [21], resonant cavities [22,23], and ring resonators [24]. An add-drop filter based on photonic crystal ring resonators (PhCRR) have been proposed by Qiang et al. [4]. Silicon on insulator PhCRRshad been proposed for separating two different optical wavelengths [25]. It has been shown that combining hybrid PhC with conventional waveguide structures results in high efficiency ultra-compact waveguide bends, splitters and optical filters with controllable quality factor, free spectral range and full width at half maximum [26–28]. By placing a low loss resonant ring at waveguide intersection, we can realize L-shaped bends and T-shaped power splitters [29,30]. For T-shaped splitters, the transmission window can be widened by changing the ring size. Djavid et al. proposed a heterostructure wavelength division demultiplexer using PhCRRs, which separates four wavelength channels [31]. Channel spacing in this structure was reported about 28 nm. They also proposed a T-shaped channel drop filter based on PhCRRs and investigated the effect of different parameters on switching wavelength [32]. They found that the dielectric constant of the inner rods and coupling rods is a main parameter for tuning the filter [30]. Multichannel-drop filter using PhCRR is the most recent work done by Djavid and Abrishamian [31]. Recently two different structures have been proposed for designing optical channel-drop filters using PhCRRs, in which X-shaped structure serve as resonant ring instead of conventional shapes [32]. 12-fold quasi crystal [33] and elliptical shaped [34] ring resonators are the other most recently proposed

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optical filters based on photonic crystal ring resonators. However each of the above-mentioned structures has some advantages and some drawbacks.

In this paper, we propose a novel design of PhCRR filter with H-shape resonant region for performing the wavelength selecting task of the filter and study the effect its performance operation. To our knowledge it is first time that a resonance region with H-shape design is presented.

2. Filter design

For designing our proposed channel drop filter (CDF) we use a 32 × 20 square lattice of dielectric rods immersed in air. The effective refractive index of dielectric rods is assumed to be 4.1. The radius of dielectric rods and the lattice constant are $R = 94$ nm and $a = 500$ nm, respectively. First we obtain the band structure diagram of the basic structure using plane wave expansion (PWE) method [36]. The band-diagram of the PhC with aforementioned values is depicted in Fig. 1. There are 4 PBGs in the band structure diagram, three PBGs in TM mode (blue colored areas) and one in TE mode (red colored area). Only the first PBG in TM mode is suitable for fiber-optic communication window which is between $0.25 < a/\lambda < 0.4$, equal to $1250\text{ nm} < \lambda < 2000\text{ nm}$. This wavelength range covers the optical communication range, so our basic structure is suitable for designing the proposed optical filter. Our proposed filter is composed of two line defects as bus and drop waveguides which are connected to each other through an H-shaped resonant region. Similar to any other PCRR-based CDF, our proposed structure has four ports; input port (A), forward transmission port (B), backward drop port (C) and forward drop port (D). Optical beams enter the structure through port A and exit it from port B, however at the desired wavelength the optical wavelengths drop to other waveguide through the resonant ring and travel toward port D. The final sketch of the proposed PCRR-based CDF is shown in Fig. 2.

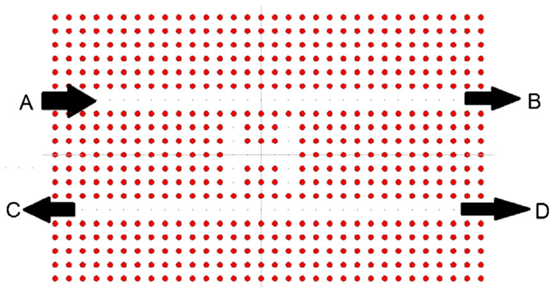

Fig. 1. The band structure of the fundamental structure. (For interpretation of the references to color in the text, the reader is referred to the web version of the article.)

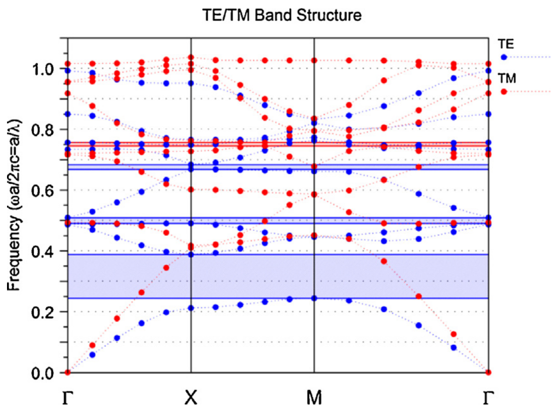

Fig. 2. The schematic diagram of the.

3. Simulations and results

After finalizing the design procedure of the structure, we study the optical performance of the filter and obtain the output spectrum of the proposed structure. For this purpose we use finite difference time domain (FDTD) method. FDTD is a numerical method used for solution of Maxwell's equations in time domain [35]. Obtaining accurate results from FDTD simulations require choosing proper values for mesh sizes and time step of the FDTD calculations. Therefore we choose mesh sizes to be $\Delta x = \Delta z = a/16$. Considering $a = 500$ nm in our structure we have $\Delta x = \Delta z = 32$ nm. In addition, the time step value will be obtained using courant condition $\left(\Delta t \le 1/c\sqrt{(1+\Delta x)^2 + (1/\Delta z)^2}\right)$ where c is the velocity of light in free space. So we have $\Delta t = 0.022$ ns.

Since obtaining accurate results from FDTD calculations requires 3D simulations which are very complex and time consuming, therefore we used effective refractive method to reduce 3D simulations to 2D one with minimum errors [36]. The other crucial parameter that we should consider in our simulations is the boundary condition, where we used perfectly matched layer (PML) condition surrounding our structure. The thickness of PML is assumed 500 nm.

The transmission spectrum of the proposed filter is shown in Fig. 3. The normalized transmission of the structure at port B, C and D are also depicted in this figure. Fig. 3 shows that optical waves in all of the wavelengths will pass toward port B except at $\lambda = 1550$ nm in which optical waves will drop to the drop waveguide and travel toward port D. For port C there is no output wave. The drop efficiency of the structure is 1 at $\lambda = 1550$ nm and the calculated quality factor ($Q = \lambda_0/\Delta\lambda$) is 221. For better understanding the operation of device, the distribution of the optical field within the structure is shown in Fig. 4 for two different wavelengths. Fig. 4(a) shows that at $\lambda = 1550$ nm the optical waves couples to ring resonator and transmit to other waveguide to travel toward port D, however from Fig. 4(b) at $\lambda = 1560$ nm no resonance occurs and hence the optical waves will not drop to the drop waveguide and only will travel toward port B. For optimum design of filter, we investigate the effect of different parameters on the filtering behavior of the proposed filter.

Fig. 5 shows the output spectra of the structure at port D for different refractive indices of the dielectric rods (n_d). As shown in figure, increasing the refractive index of the dielectric rods results in the shift in output wavelengths to higher values. However the Q-factor does not considerably change. The detailed specifications of the output wavelengths for different refractive indices are listed in Table 1. It can be said that when we change the refractive index of rods, the light coupled to the resonator section (by penetrating the

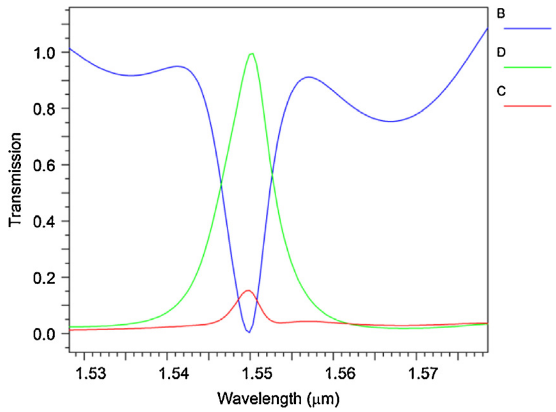

Fig. 3. Output spectrum of the proposed H-shape filter.