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Tunable Channel Drop Filter using Hexagonal Photonic Crystal Ring Resonators

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Abstract

In this paper, we have proposed a tunable two dimensional (2D) photonic crystal (PhC) channel drop filter (CDF) using ring resonators with suitable quality factor (Q) and transmission efficiency; we investigate parameters which have an effect on resonant wavelength in this CDF, such as dielectric constant of inner, coupling, adjacent and whole rods of the structure. Dropping efficiency at the resonance and quality factor of single ring are 90% and 1046, respectively. The footprint of the proposed structure is about 125.6μm^2; therefore this structure can be used in the future photonic integrated circuits.

Keywords: *Filter, Photonic Crystal, Ring Resonator, Wavelength*

1. Introduction

Photonic crystals (PhCs), also known as photonic bandgap (PBG) materials, can manage the spontaneous emission and the propagation of electromagnetic (EM) waves [1, 2]. Due to existence of PBG, PhCs have applications in various areas of optical engineering such as optical filters [3], switches [4], power splitters [5], and demultiplexers [6] which may ultimately make preparations for photonic integrated circuits (PICs). Filtering device enabling us to extract from one waveguide one wavelength and send it to another waveguide [7]. For Wavelength Division Multiplexing (WDM) systems, optical channel drop filter is one of the important components to select a single channel or multiple channels. So far, several topologies have been proposed for channel drop filters, such as using ring resonators [8]. Ring resonators have been used as the building blocks for the synthesis of high-order optical filters [9, 10].

In this paper, a wavelength filter structure has been designed by using ring resonator for selecting desired wavelength. The distinctive feature of this structure is that the resonant wavelength of ring resonator is tunable. We used PhC ring resonator to achieve a new type of CDF with high normalized transmission (about 90%) and acceptable quality factor (over 1046) in 1500-1600*nm* window. The new ring resonator introduced in this study can be used as the basic element for other devices as well.

In this paper effects of ring resonator parameters on the resonance wavelength and transmission spectrum of the ring resonator are investigated. The proposed structure provides a possibility of optical channel drop filter and can be used in the future photonic integrated circuits.

2. Design of Photonic Crystal Channel-Drop Filter

A typical ring resonator obtained by removing a ring shape of columns from a square lattice of dielectric rods in air background is displayed in Figure 1(a). The dielectric rods have a dielectric constant of 10.65, and radius r=0.213a is located in air, where a is a lattice constant. To minimize the effect of counter propagating mode resulting from back-reflections at the sharp corners of the ring, we add one scatterer rod at each corner at half lattice constant as shown in Figure 1(a). This additional rod at each corner acts as a right angled reflector reducing the back-reflection at the corresponding corner [11,12]. For improving transmitted power to port B, and obtaining more coupling efficiency, radius of scatterer rods is set to 0.215a. By putting a waveguide beside the ring resonator, the waveguide at its resonant frequency can be coupled

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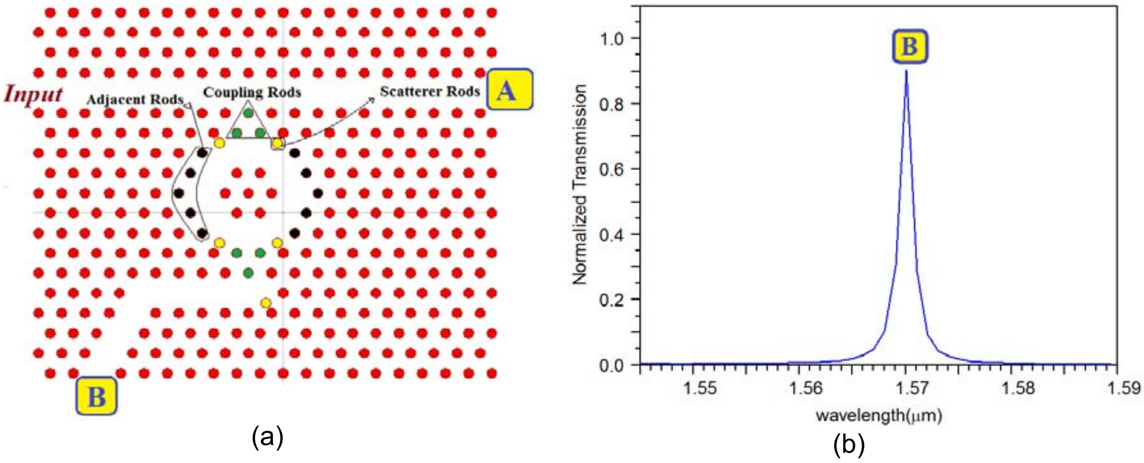
to the ring resonator to trap the electromagnetic energy propagating in the waveguide and localize it in the ring resonator. In other words, the ring resonator drops light from the top waveguide and sends it to the bottom waveguide. Two output ports of the structure are labeled as A and B, shown in Figure 1(a).

3. Simulations and Results

In this structure, band gap opens for the normalized frequency $0.281<a/\lambda<0.442$ 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 method is the most famous method for PhC analysis [13]. FDTD is a time domain simulation method for solving Maxwell's equations in arbitrary materials and geometrics. Berenger's perfectly matched layers (PML) are located around the whole structure as absorbing boundary condition [14]. The result of the FDTD simulation for this CDF that shows the normalized optical power transmissions of the structure is shown in Figure 1(b).



(a) (b)

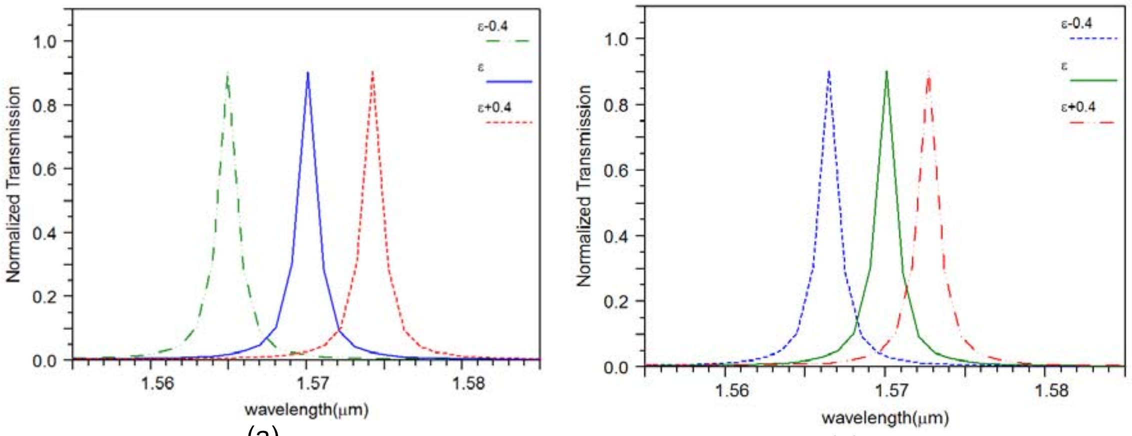
Figure 1. (a) A channel-drop filter with ring resonator and (b) Optical power transmission spectrum of our proposed CDF

As shown in Figure 1(b), the wavelength λ=1570 *nm* of the input port is removed from the upper waveguide and transmitted to the port 'B'. The transmitted power efficiency in this wavelength is about 90%. The value of Q for the proposed structure is obtained 1046. Q factor can be calculated with $Q = \lambda/\Delta\lambda$, where λ and $\Delta\lambda$ are central wavelength and full width at half power of output, respectively. We note that the amount of 1046 is a high quality factor for ring resonator based filter. Djavid and et al [8] and Robinson and et al [9] proposed a PhC based filter by using ring resonators. Quality factor in their structures are about 70 and 128, respectively.

In next section, the effect of varying dielectric constant of rods on ring resonator performance will be studied.

4. Varying Dielectric Constant of Rods

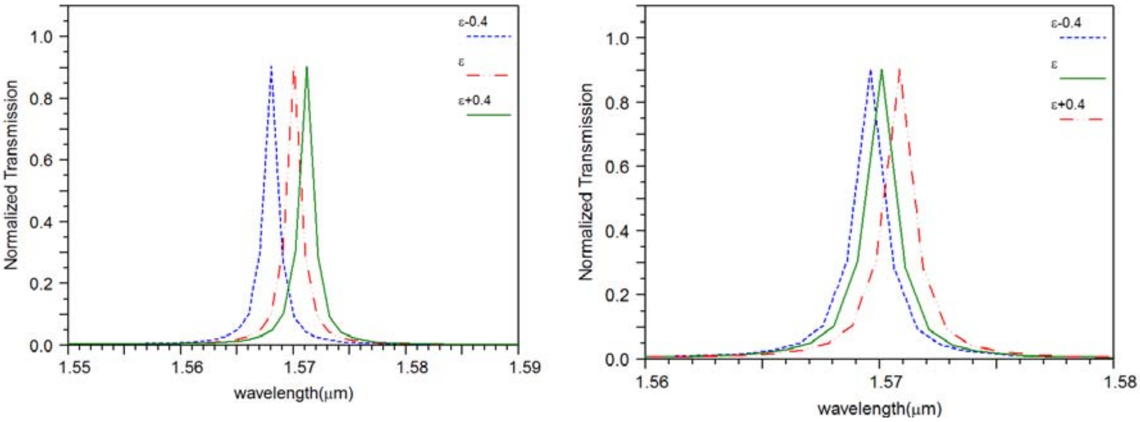
One of the most important features of any filter is its tunability. Here we investigate parameters which affect resonant frequency in photonic crystal CDFs. First of all, we change the dielectric constant of the whole rods. Three different curves are displayed in Figure 2(a) for ε_r-0.4, ε_r and ε_r+0.4 which ε_r is 10.65. As seen in Figure 2(a), the proposed structure, when simulated with the different dielectric constants of whole rods equal to ε_r-0.4, ε_r and ε_r+0.4, which ε_r is 10.65, can select wavelengths 1564.9 *nm*, 1570 *nm*, and 1574.3 *nm*, respectively.



(a) (b)

Figure 2. Normalized power transmission spectra of the proposed CDF for different dielectric constant of (a) whole and (b) inner rods

As shown in Figure 2(a), by raising the dielectric constant of whole rods, the resonant wavelength of the device is increased accordingly. In other words, a red shift occurs in resonant wavelength. We can create the different refractive indexes in reality by using electro-optic or thermo-optic (T-O) material. We utilize electro-optic materials which change their refractive indexes in response to external electric field; also we can use the T-O effect caused by two-photon absorption (TPA) in *Si* to control the resonator's refractive index through the heat generated by optically produced carriers [15].



(a) (b)

Figure 3. Normalized power transmission spectra of the proposed structure for different dielectric constant of (a) coupling and (b) adjacent rods

With localized change in inner rods' dielectric constant, the resonant wavelength can be tuned. This leads to a tunable CDF. Figure 2(b) shows the normalized power transmissions of the structure with three different dielectric constants of inner rods, ε_r-0.4, ε_r and ε_r+0.4, which ε_r is 10.65. In similar way, coupling and adjacent rods dielectric constant can be changed. Figures 3(a) and (b) show the normalized transmissions of the structure with three different dielectric constants of coupling and adjacent rods.

As shown in Figure 2(b), our proposed structure, when simulated with the different dielectric constants of inner rods equal to ε_r-0.4, ε_r and ε_r+0.4, which ε_r is 10.65, can select wavelengths 1566.5 *nm*, 1570 *nm*, and 1572.8 *nm*, respectively. Based on the results illustrated in Figure

3(a), with different dielectric constant of coupling rods equal to ε_r-0.4, ε_r and ε_r+0.4, which ε_r=10.65, we obtained wavelengths 1568.1 *nm*, 1570 *nm* and 1571.2 *nm*, respectively in port B. As shown in Figure 3(b), If we choose dielectric constant of adjacent rods such as ε_r-0.4, ε_r and ε_r+0.4, which ε_r=10.65, wavelengths equal to 1569.6 *nm*, 1570 *nm* and 1570.9 *nm* in port B appear.

5. Conclusion

A tunable 2D photonic crystal CDF based on ring resonators had been introduced and investigated through FDTD method. By using a single ring resonator, we obtained the output power efficiency close to 90%. We investigated the effects of ring's parameters such as inner, coupling, adjacent and whole rods' dielectric constant on the resonance wavelength. It was shown that the resonance wavelength of CDF has been tuned by varying this parameter appropriately. We have shown that there is flexibility in design of the CDF with photonic crystal ring resonators.

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