Design of Tunable Channel Drop Filter using Hexagonal Photonic Crystal Ring Resonators by FDTD Method

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ABSTRACT
In this paper, we have proposed a new design of two dimensional (2D) photonic crystal (PhC) Tunable channel drop filter (CDF) using ring resonators. The increasing interest in photonic integrated circuits (PIC's) and the increasing use of all-optical fiber networks as backbones for global communication systems have been based in large part on the extremely wide optical transmission bandwidth provided by dielectric materials. Based on the analysis we present novel photonic crystal channel drop filters. Simulations demonstrate that these filters exhibit ideal transfer characteristics. Dropping efficiency at the resonance of single ring are 92% and quality factor is obtained 1046. The footprint of the proposed structure is about 125.6μm2; therefore this structure can be used in the future photonic integrated circuits.

General Terms
FDTD method, PCRR, Variable, Rods.

Keywords
Photonic Crystal, Channel Drop Filter, FDTD, Filter, Wavelength**.**

1. INTRODUCTION
The increasing interest in photonic integrated circuits (PIC's) and the increasing use of all-optical fiber networks as backbones for global communication systems have been based in large part on the extremely wide optical transmission bandwidth provided by dielectric materials. This has accordingly led to an increase demand for the practical utilization of the full optical bandwidth available [1, 2, 4, and 5]. In order to increase the aggregate transmission bandwidth, it is generally preferred that the spacing of simultaneously transmitted optical data streams, or optical data channels, be closely packed to accommodate a larger number of channels. In other words, the difference in wavelength between two adjacent channels is preferably minimized [6, 7].

The PBG materials show potential of changing the whole scenario of light guiding in the near future. In the traditional waveguides operated at optical range, the light is guided by the total internal reflection at the boundary of the waveguide [3,9]. This is quite different from the waveguide operated at microwave range, where the metallic waveguides are used. Though in some sense, the propagation of microwave in such waveguides can also be regarded as internal reflection, but there is no restriction on the reflection angle [15].

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 changed while changing the dielectric constant. We used PhC ring resonator to achieve a new type of CDF with high normalized transmission about 92% 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[8,10].

2. DESIGN OF 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, so the refractive index came out as 3.26 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 scatter 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 scatter rods is set to 0.215a.

By putting a waveguide beside the ring resonator, the waveguide at its resonant frequency can be coupled 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). The footprint of the proposed structure is about 125.6μm2; therefore this structure can be used in the future photonic integrated circuits.

3. SIMULATION AND RESULTS
In this structure, band gap opens for the normalized frequency $0.290<a/\lambda<0.450$ 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). The dimensions of these structure is taken as 20a x 19a where a is the lattice constant.

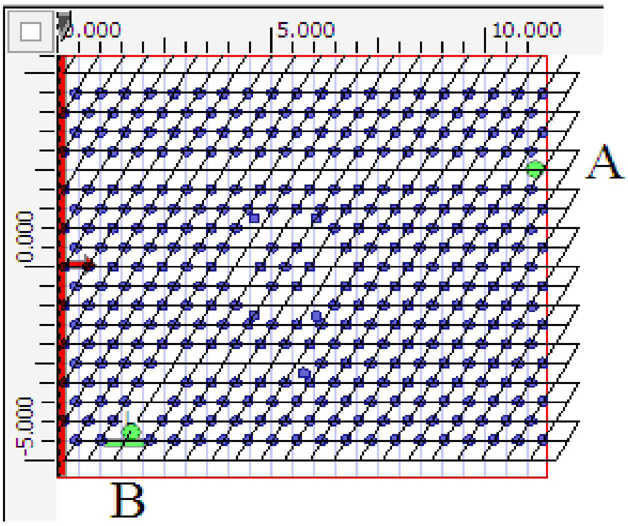

Fig 1(a)

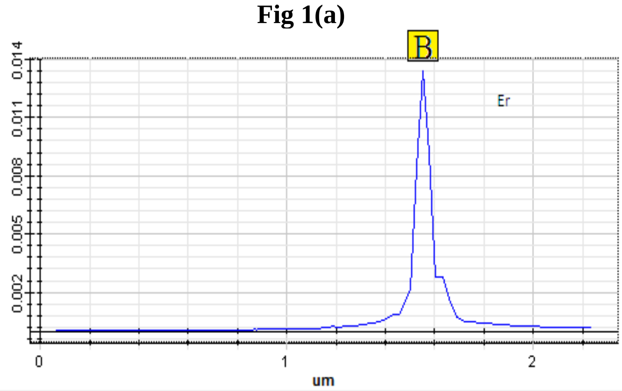

Fig 1(b)

Fig 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 92%. The value of *Q* for the proposed structure is obtained 1046. *Q* factor can be calculated with $Q = \lambda/\Delta\lambda$, where λ and Δλ 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.

4. VARYING DIELECTRIC CONSTANT OF WHOLE 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(b), 2(c), 2(d) 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.

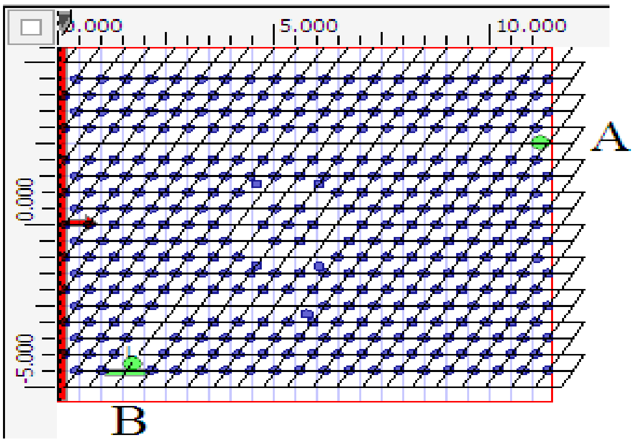

Fig 2(a) A channel-drop filter with ring resonator.

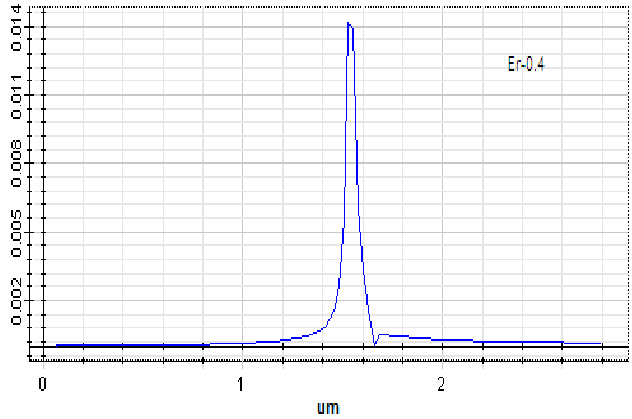

Fig 2 (b) Simulation result at wavelength 1564.9 nm.

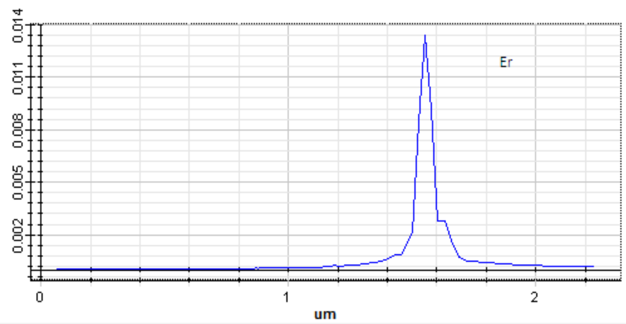

Fig 2 (c) Simulation result at wavelength 1570 nm.

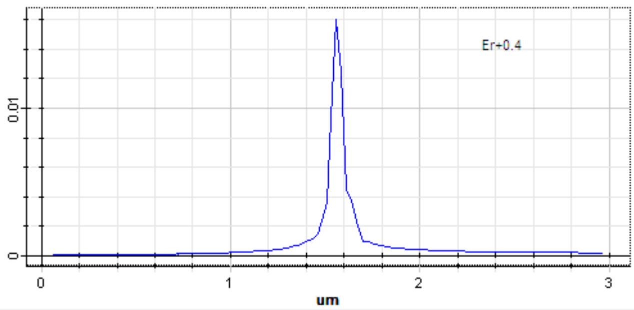

Fig 2 (d) Simulation result at wavelength 1574.3 nm

Fig 2. Normalized power transmission spectra of the proposed CDF for different dielectric constant of whole rods.

5. VARYING DIELECTRIC CONSTANT OF INNER RODS

With varying localized change in inner rod's dielectric constant, the resonant wavelength can be tuned. This leads to a tunable CDF. Figure 3(b), 3(c), 3(d) 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 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.

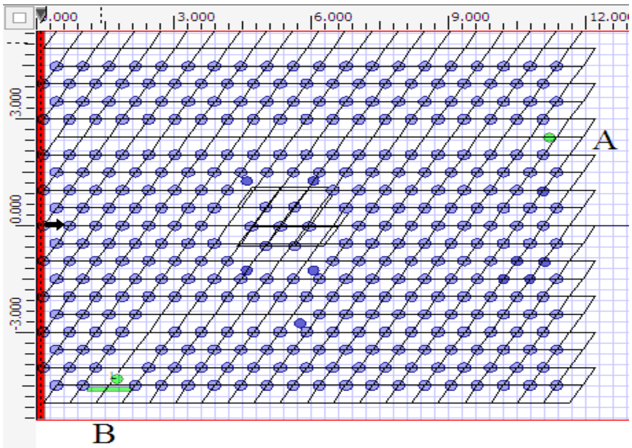

Fig 3 (a) Channel drop filter structure by changing dielectric constant of inner rods

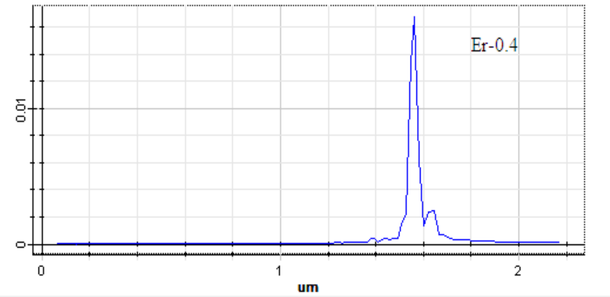

Fig 3 (b) Simulation result at wavelength 1566.5 nm

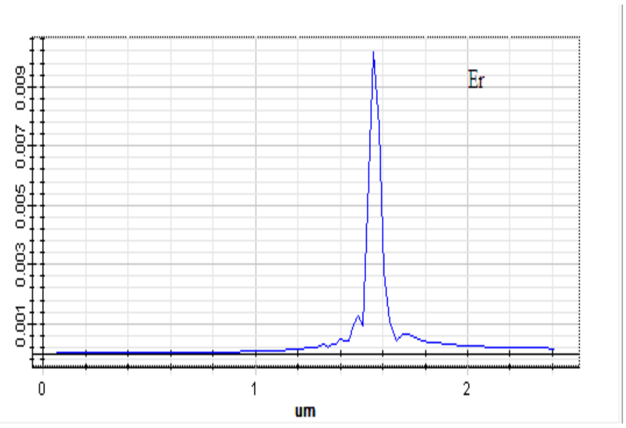

Fig 3 (c) Simulation result at wavelength 1570 nm.

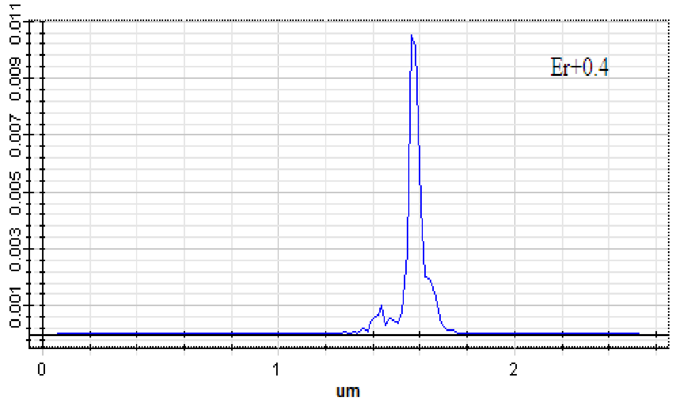

Fig 3 (d) Simulation result at wavelength 1572.8 nm.

Fig 3. Normalized power transmission spectra of the proposed CDF for different dielectric constant of inner rods

6. VARYING DIELECTRIC CONSTANT OF COUPLING RODS

With localized change in coupling rod's dielectric constant, the resonant wavelength can be tuned. This leads to a tunable CDF. 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. Figure 4(b), 4(c), 4(d) shows the normalized power transmissions of the structure with three different dielectric constants of coupling rods.

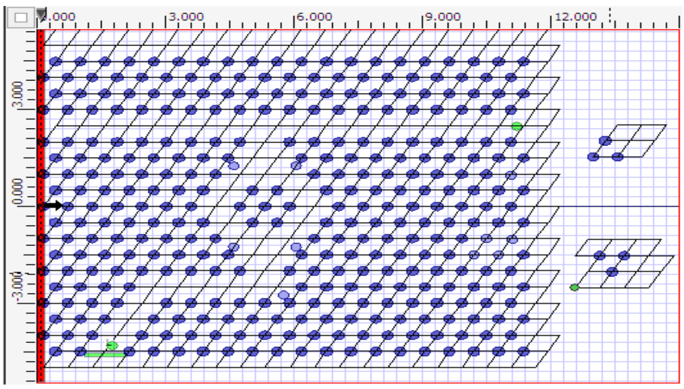

Fig 4 (a) Channel drop filter structure by changing dielectric constant of coupling rods.

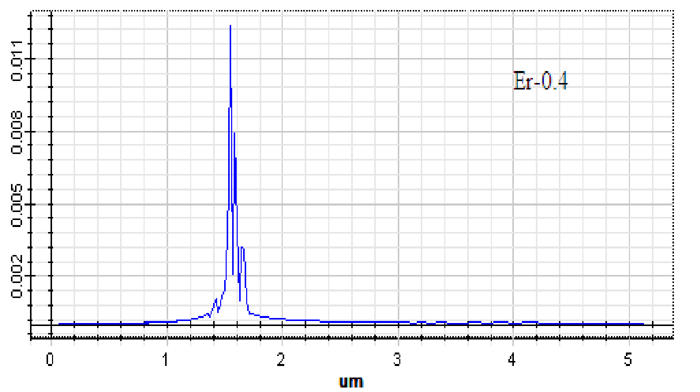

Fig 4 (b) Simulation result at wavelength 1568.1 nm.

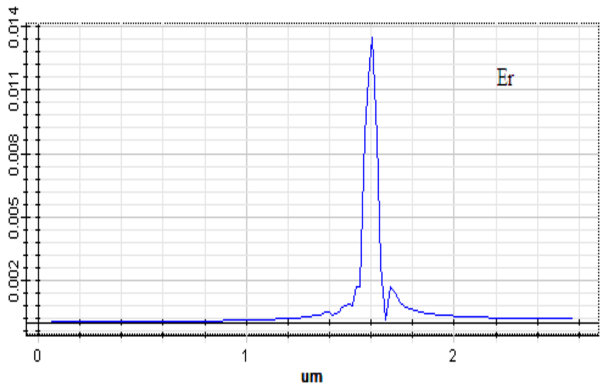

Fig 4 (c) Simulation result at wavelength 1570 nm.

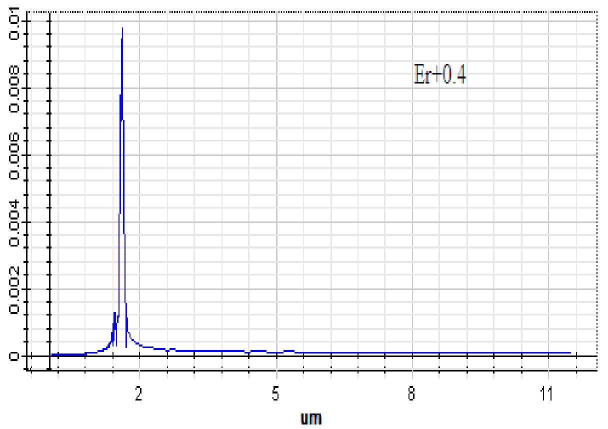

Fig 4 (d) Simulation result at wavelength 1571.2 nm.

Fig 4. Normalized power transmission spectra of the proposed CDF for different dielectric constant of coupling rods

7. VARYING DIELECTRIC CONSTANT OF ADJACENT RODS

With localized change in coupling rod's dielectric constant, the resonant wavelength can be tuned. This leads to a tunable CDF. 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 appears. Figure 5(b), 5(c), 5(d) shows the normalized power transmissions of the structure with three different dielectric constants of adjacent rods.

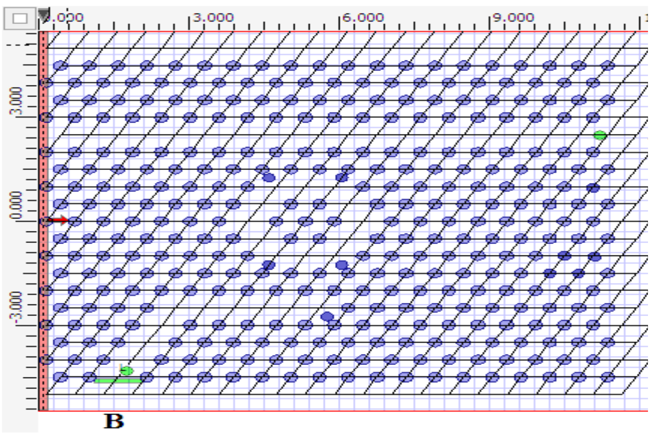

Fig 5 (a) Channel drop filter structure by changing dielectric constant of adjacent rods.

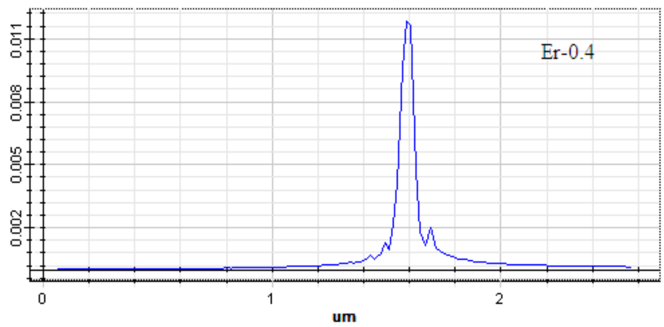

Fig 5 (b) Simulation result at wavelength 1569.6 nm.

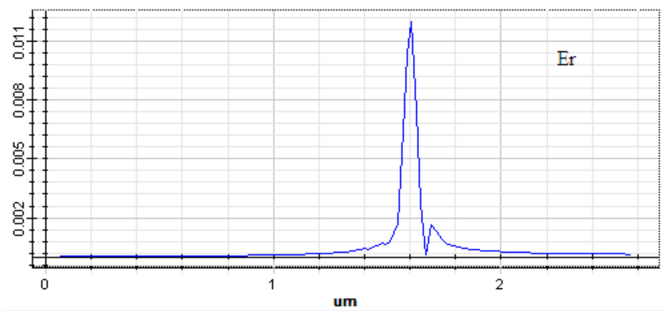

Fig 5 (c) Simulation result at wavelength 1570 nm.

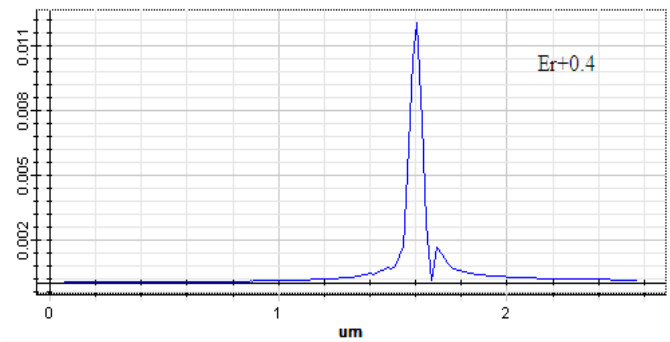

Fig 5 (d) Simulation result at wavelength 1570.9 nm.

Fig 5. Normalized power transmission spectra of the proposed CDF for different dielectric constant of adjacent rods

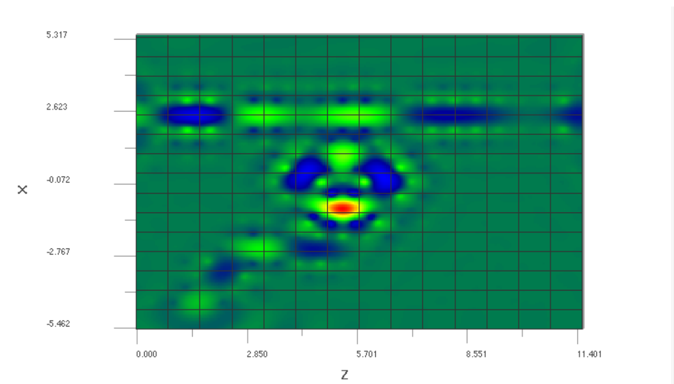

Fig 6. Simulation results at Opti FDTD

Shown in Figure 2, 3, 4, 5 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 [16].

8. CONCLUSION

A 2D photonic crystal Tunable 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 92%. We investigated the effects of ring's parameters on whole, inner, coupling and adjacent dielectric constant on the resonance wavelength. It was shown that the resonance wavelength of CDF has been varied 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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