International Journal of Natural and Engineering Sciences 7 (2): 08-12, 2013
ISSN: 1307-1149, E-ISSN: 2146-0086, www.nobel.gen.tr

Realization of Tunable Channel Drop Filter Based on Square Photonic Crystal Ring Resonator

Mohammad Ali MANSOURI-BIRJANDI[1] Mohammad Reza RAKHSHANI[2*]

[1,2] Faculty of Electrical and Computer Engineering, University of Sistan and Baluchestan.

*Corresponding author:

E-mail: m.rakhshani@mail.usb.ac.ir

Received: September 05, 2012

Accepted: October 11, 2012

Abstract

We have proposed a tunable two dimensional photonic crystal channel-drop filter (CDF) using ring resonators with suitable quality factor and transmission efficiency; we investigate parameters which affects resonant wavelength in this CDF, such as dielectric constant of inner, coupling, adjacent and whole rods of the structure and radius of inner rods. Dropping efficiency at the resonance and quality factor (*Q*) of our proposed CDF are 100% and 196, respectively. The footprint of the proposed structure is about $125\mu m^2$.

Keywords: Filter, Photonic crystal, Ring Resonator, Wavelength.

INTRODUCTION

Photonic crystals (PhCs), also known as photonic bandgap (PBG) materials, can control the spontaneous emission and the propagation of electromagnetic (EM) waves [1-3]. Due to existence of PBG, PhCs have applications in different areas of optical engineering such as optical filters [4], polarizers [5], polarization splitters [6], and demultiplexers [7] which may ultimately pave the way for photonic integrated circuits (PICs). By engineering the photonic band gap, the confinement of light in given wavelengths can be tuned. It means that, we can control the transmittance and reflectance wavelengths interval by adjusting the bandgap of each PhC structure. In other words, PhC structures suggest high spectral selectivity that is necessary for filter designing [3]. Filtering is the operation enabling us to extract from one waveguide one frequency and to send it to another waveguide [8]. Ring resonators have been used as the building blocks for the synthesis of high-order optical filters [9,10]. The distinctive feature of our proposed structure is that the resonant wavelength of ring resonator is tunable. Also design parameters for this ring resonator can be the dielectric constant of the coupling, adjacent and whole rods of the structure. Compared to point-defect or line-defect PhC cavities, PhC ring resonators offer scalability in size and flexibility in mode design due to their multimode nature [11]. We used this element to achieve a new type of CDF with high normalized transmission (100%) and acceptable quality factor (over 196) 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 parameter on the resonance wavelength and transmission spectrum of the structure are investigated. The proposed device provides a possibility of optical channel drop filter and can be used in the future photonic integrated circuits.

Channel Drop Filter Design Using Photonic Crystal Ring Resonator

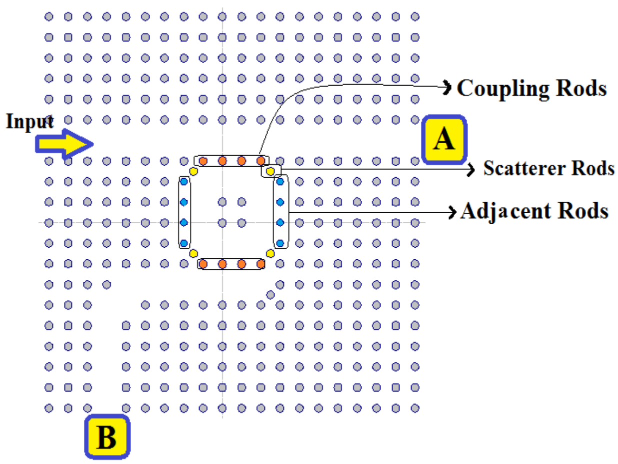


Figure 1. (a) A channel drop filter

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 Fig. 1(a). The dielectric rods have a dielectric constant (ε_r) of 11.56, and radius r=0.2a 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 Fig. 1(a). This additional rod at each corner acts as a right angled reflector reducing the back-reflection at the corresponding corner [12,13]. For improving transmitted power to port B, and obtaining more coupling efficiency, radius of coupling, scatterer and adjacent rods is set to 1.05r, 1.05r and 0.95r, respectively, while r is the radius of other rods [7,12]. 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. This structure consists of an input waveguide and two output channels labeled as A and B.

In normal case when the ring does not resonate, whole of power remains in the horizontal bus waveguide and goes through port A. At resonance case, most of the power transfers to the bottom waveguide and goes through port B.

SIMULATIONS AND RESULTS

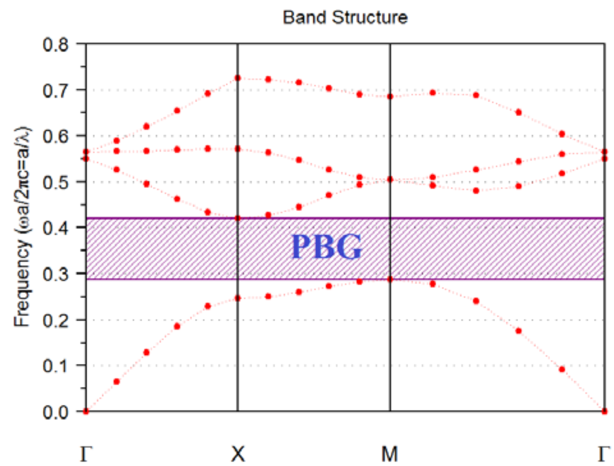


Figure 1. (b) Band diagram of our proposed CDF for ε=11.56.

In this structure, as shown in Fig. 1(b), band gap exists from a/λ=0.29 to a/λ=0.42 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 [14]. FDTD is a time domain simulation method for solving Maxwell's equations in arbitrary materials and geometrics. The basic principle is to substitute the curl equations and partial time differential with finite central differences in spatial domain and time domain respectively.

Berenger's perfectly matched layers (PML) are located around the whole structure as absorbing boundary condition [15]. The result of the FDTD simulation for this CDF that shows the normalized optical power transmissions of the structure is shown in Fig. 2. As shown in Fig. 2, the wavelength of λ=1543nm 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 100%. The value of Q for the proposed structure is obtained 196.

Figs. 3 (a) and (b) shows the electric field distributions of the structure proposed in Fig. 1(a) for two different wavelengths, λ_1=1543nm, the resonant and λ_2=1500nm, the off-resonance wavelength. At resonant wavelength, the field of the waveguide fully couples to the ring, whereas at off-resonance it does not couple and continues to propagate through the top waveguide.

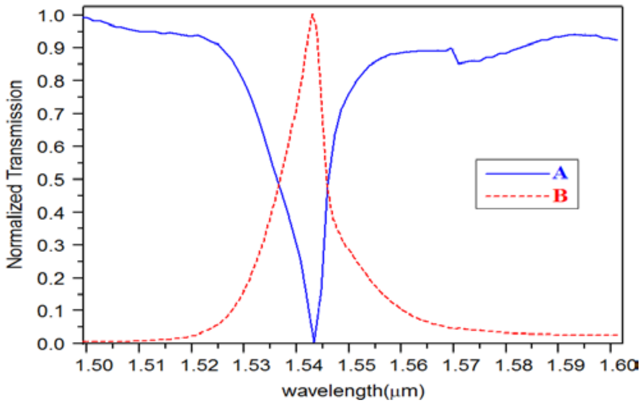


Figure 2. Optical power transmission characteristic of our proposed CDF in Fig. 1.

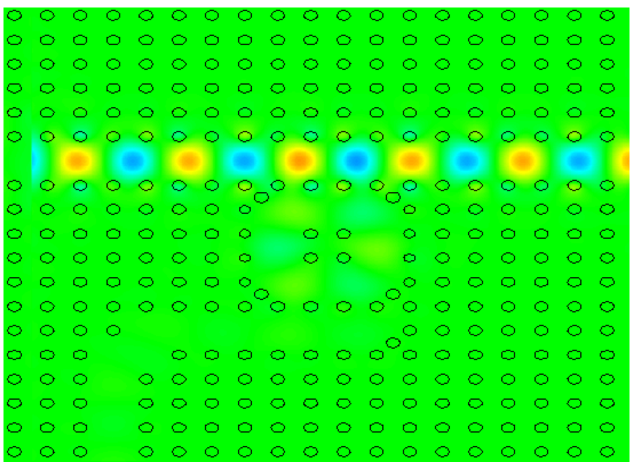
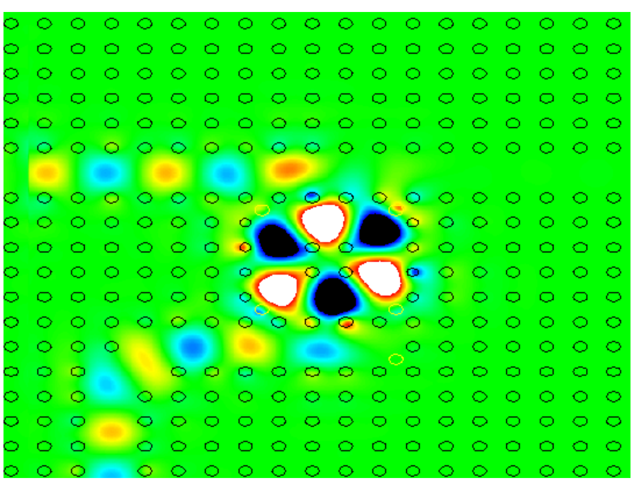


Figure 3. (a) Electric field intensity of the ring resonator's non-resonant wavelength at 1500*nm* and



(b) electric field intensity of the ring resonator's resonant wavelength at 1543*nm*.

The salient feature of this structure is that by varying the ring's parameters, the resonant wavelength can be tuned. In next section, the effect of varying some parameters on ring resonator performance will be studied. Section 3.1 describes effect of varying dielectric constant of rods, Section 3.2 describes effect of varying radius of rods and Section 3.3 describes effect of varying fill factor in resonance wavelength.

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. As seen in Fig. 4, the proposed structure, when simulated with the different dielectric constants equal to 10.24, 11.56 and 12.96 can select wavelengths of 1526*nm*, 1543*nm*, and 1561*nm*, respectively.

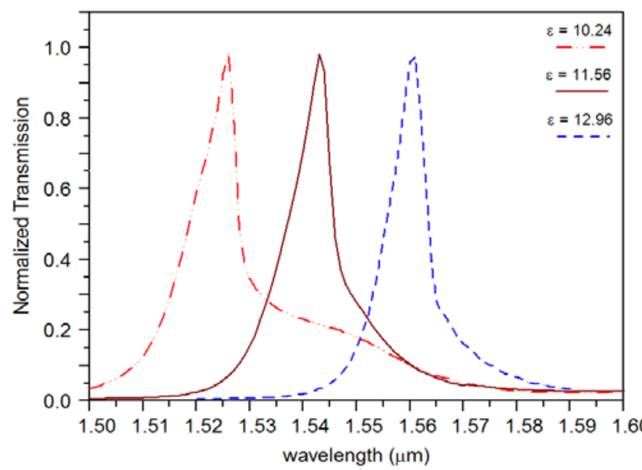


Figure 4. Power transmission spectra of our proposed CDF for different dielectric constants of whole rods.

As shown in Fig. 4, by raising the dielectric constant, the resonant wavelength of the device is increased accordingly. In other words, a red shift occurs in resonant wavelength. We can create the different dielectric constants in reality by using thermo-optic or electro-optic material. We can use the thermo-optic effect caused by two-photon absorption (TPA) in *Si* to control the resonator's refractive index through the heat generated by optically produced carriers; also we utilize electro-optic materials which change their refractive indexes in response to external electric field [16].

With localized change in inner rods' dielectric constant, the resonant wavelength can be tuned. This leads to a tunable CDF. Fig. 5 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. As shown in Fig. 5, 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, can select wavelengths of 1540.8*nm*, 1543*nm*, and 1544.2*nm*, respectively.

In similar way, we can show if the dielectric constant of coupling or adjacent rods are changed, the resonant wavelength and so the whole CDF's characteristic spectrum will be changed similar to those of Fig. 5.

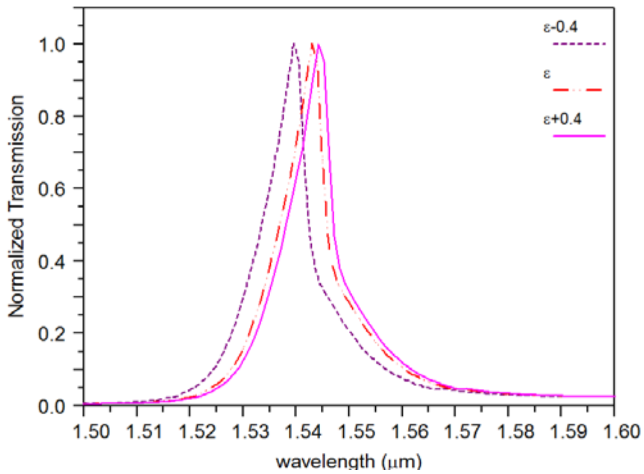


Figure 5. Power transmission spectra of our proposed CDF for different dielectric constants of inner rods.

Varying Radius of Rods

In this section we probe another parameter which affects on resonance behavior of the CDF. We study varying the radius of inner rods from 0.92*r* to 1.1*r*. This leads to shift of resonant wavelength to higher values as shown in Fig. 6. For best resolution and tuning the filter, varying the dielectric constant of the inner rods as well as coupling rods can be used [16].

As shown in Fig. 6, it is obvious that when the radius of inner rods of CDF increases, the curves shift to right (greater wavelengths), which means that this structure is tunable for desired wavelengths. As shown in Fig. 6, it is obvious that resonant wavelength increases as radius of inner rods increases from 0.92*r* to 1.1*r*. As shown in Fig. 6, with different radius of inner rods equal to 0.92*r*, *r* and 1.1*r*, we obtained wavelengths of 1538.6*nm*, 1543*nm* and 1550.5*nm* in port B, respectively.

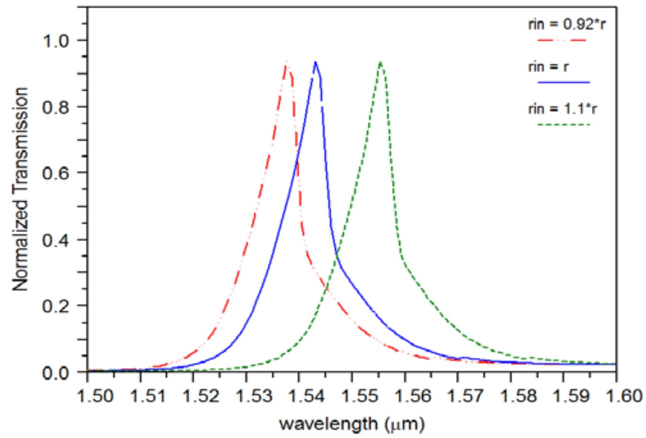


Figure 6. Power transmission spectra of our proposed CDF for different radius of inner rods.

Varying Fill Factor of Structure

In this section, we investigate varying the fill factor of the structure from 0.98×*r*/*a* to 1.02×*r*/*a*. This leads to shift of resonant wavelength to higher values as shown in Fig. 7. Our numerical simulations reveal the dependence of the CDF's characteristic on different ring parameters such as dielectric constant of inner, coupling, adjacent and whole rods. Also varying the fill factor as well as changing the dielectric constant of rods affects the CDF's characteristic.

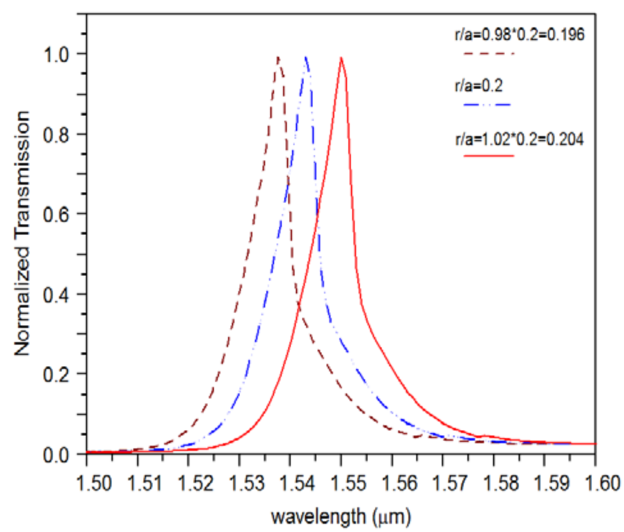


Figure 7. Power transmission spectra of our proposed CDF for different fill factors.

CONCLUSIONS

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 100%. We investigated the effects of ring's parameters such as inner rods' radius; inner, coupling, adjacent and whole rods' dielectric constant and fill factor 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.

REFERENCES

[1] Joannopoulos JD, Meade RD, Winn JN. 1995. Photonic Crystals: Molding the Flow of Light, Princeton University Press, Princeton, NJ, USA.

[2] Mansouri-Birjandi MA, Moravvej-Farshi MK, Rostami A. 2008. Ultrafast low threshold all-optical switch implemented by arrays of ring resonators coupled to a Mach–Zehnder interferometer arm: based on 2D photonic crystals. Appl. Optic. 47:5041-5050.

[3] Rostami A, Alipour Banaei H, Nazari F, Bahrami A. 2011. An ultra compact photonic crystal wavelength division demultiplexer using resonance cavities in a modified Y-branch structure. Optik. 122:1481– 1485.

[4] Hsu HT, Lee MH, Yang TJ, Wang YC, and Wu CJ. 2011. A multichannel filter in a photonic crystal containing coupled defects. Progress In Electromagnetics Research. 117: 379-392.

[5] Khalaj-Amirhosseini M, and Razavi SMJ. 2009. Wide-angle reflection wave polarizers using inhomogeneous planar layers. Progress In Electromagnetics Research M. 9:9-20.

[6] Li Y, Gu P, Li M, Yan H, and Liu X. 2008. Research on the wide- angle and broadband 2D photonic crystal polarization splitter. Journal of Electromagnetic Waves and Applications. 20:265-273.

[7] Rakhshani MR, Mansouri-Birjandi MA. 2012. Heterostructure four channel wavelength demultiplexer using square photonic crystals ring resonators. Journal of Electromagnetic Waves and Applications. 26:1700-1707.

[8] Pennec Y, Vasseur JO, Djafari-Rouhani B, Dobrzyński L, Deymier PA. 2010. Two-dimensional photonic crystals: Examples and applications. Surface Science Reports. 65:229-291.

[9] Robinson S, Nakkeeran R. 2012. PCRR based add drop filter for ITU-T G.694.2 CWDM systems. Optik - Int. J. Light Electron. Opt. doi:10.1016/j.ijleo.2011.12.005.

[10] Chu ST, Pan W, Sato S, Kaneko T, Kokubun Y, Little BE. 1999. An eight-channel add/drop filter using vertically coupled microring resonators over a cross grid. IEEE Photonics Technology Letters. 11:691-693.

[11] Manolatou C, Khan MJ, Fan S, Villeneuve PR, Haus HA, and Joannopoulos JD. 1999. Coupling of modes analysis of resonant channel add-drop filters. IEEE Journal of Quantum Electronics. 35:1322-1331.

[12] Saghirzadeh Darki B, Granpayeh N. 2010. Improving the performance of a photonic crystal ring-resonator- based channel drop filter using particle swarm optimization method. Optics Communications. 283:4099-4103.

[13] Dinesh Kumar V, Srinivas T, Selvarajan A. 2004. Investigation of ring resonators in photonic crystal circuits. Photonics and Nanostructures – Fundamentals and Applications. 2:199-206.

[14] Taflove A, Hagness SC. 2005. Computational Electrodynamics: The Finite-Difference Time-Domain Method, third ed., Artech House, Inc.

[15] Berenger JP. 1994. A perfectly matched layer for the absorption of electromagnetic waves. J. Computational Physics. 14:185-200.

Djavid M, Ghaffari A, Monifi F, Abrishamian MS. 2008. T-shaped channel-drop filters using photonic crystal ring resonators. Physica E. 40:3151- 3154.