Physica E 56 (2014) 211–215

Contents lists available at ScienceDirect

Physica E

journal homepage: www.elsevier.com/locate/physe

A new proposal for PCRR-based channel drop filter using elliptical rings

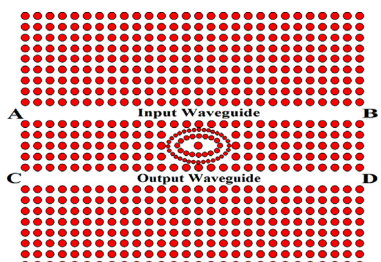
Hamed Alipour-Banaei [a], Farhad Mehdizadeh [b,*], Mahdi Hassangholizadeh-Kashtiban [b]

[a] Department of Electronics, Tabriz Branch, Islamic Azad University, Tabriz, Iran
[b] Department of Electrical Engineering, Ahar Branch, Islamic Azad University, Ahar, Iran

HIGHLIGHTS

- In this paper we proposed an elliptical shape ring resonator based channel drop filter.
- The drop efficiency and the quality factor of our proposed filter is 100% and 647.
- For vertical, double and triple ring configurations the quality factor will be 387, 865 and 1559, respectively.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 April 2013
Received in revised form
18 July 2013
Accepted 24 July 2013
Available online 23 September 2013

Keywords:
Photonic crystal
Channel-drop filter
Ring resonator
FDTD
Elliptical ring

ABSTRACT

In this paper using elliptical resonant ring we proposed a channel drop filter based on photonic crystal structures suitable for optical communication applications. The drop efficiency and the quality factor of our proposed filter is 100% and 647. We also investigated the optical properties of different configurations of the proposed photonic crystal ring resonator such as vertical ring, dual ring and triple ring structures. According to the results different configurations show different optical properties, so for vertical, double and triple ring configurations the quality factor will be 387, 865 and 1559, respectively.

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. Optical filters [1–4], optical demultiplexers [5–10], and optical switches [11] are some examples of optical devices, which had attracted a great deal of interest most recently. 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 (PhCs). PhCs have a special frequency (wavelength) range in which the propagation of optical waves inside these artificial structures is forbidden. This special range is called photonic band gap (PBG) [12–16]. Optical filters play a crucial role in optical communication networks. They used for choosing the desired wavelength and also for separating the very closely spaced optical channels in wavelength division multiplexing (WDM) applications [17]. Remote sensing [18], hyper spectral imaging [19], and biomedical sensing [20,21] are other potential applications of optical filters.

Photonic crystal ring resonators (PhCRRs) are common structures for designing optical channel-drop filters. PhCRRs also can be used for realizing optical switches, optical sensors, optical

* Corresponding author. Tel.: +98 9143419336.
E-mail addresses: alipour@iaut.ac.ir (H. Alipour-Banaei), f-mehdizadeh@iau-ahar.ac.ir (F. Mehdizadeh).

1386-9477/$ - see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.physe.2013.07.018

demultiplexer, etc. Kim et al. [22] for the first time used PhCRR for designing a waveguide ring laser cavity. Kumar et al. [23] investigated the implementation of waveguide coupled ring resonators in PhC, they found that ring dimensions and crystal parameters play important role in resonance behavior of ring resonator. An add-drop filter based on PhCRRs had been proposed by Qiang et al. [24]. Silicon on insulator PhCRR had 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 resonant ring at waveguide intersection, we can realize L-shaped bends and T-shaped power splitters [29]. For T-shaped splitters the transmission window can be widened by changing the ring size. Djavid et al. [30] proposed a heterostrucutre wavelength division demultiplexer using PhCRRs, this demultiplexer separates four wavelength channels. Channel spacing in this structure was approximately 28 nm. They also proposed a T-shaped channel drop filter based on PhCRRs and investigated the effect of different parameters on switching wavelength. They found that dielectric constant of the inner rods and coupling rods is a suitable parameter for tuning the filter [31]. Multichannel-Drop filter using PhCRR is the most recent work done by Djavid and Abrishamian [32]. Recently two different structures have been proposed for designing optical channel-drop filters using PhCRRs, in which instead of conventional shapes for resonant ring the authors used a X-shaped structure as resonant ring [33,34].

In this paper we proposed a novel structure for designing a tunable PhCRR-based channel drop filter (CDF). For this purpose we used an elliptical structure and combined it with a square lattice PhC. After design and realizing the proposed CDF we investigated the effect of different parameters on the drop wavelength of the filter.

The rest of the paper is structured as follows: in Section 2 we introduced the analytical methods and also discussed the design procedure of the structure. In Section 3 we propose the simulation results in this section we obtained the output spectrum of the filter and then investigate the effect of different parameters on the filtering behavior of the structure and finally in Section 4 we conclude from our work.

2. Theoretical modeling and methods

In designing PhC-based devices, we have to investigate the behavior of electromagnetic and optical waves inside photonic crystals and extract the optical properties of these artificial structures. Currently the best solution for studying the optical properties of these structures is numerical methods, one of which is plane wave expansion (PWE) method [35]. PWE is used for obtaining the eigen frequencies and dispersion properties of PhCs by which we can calculate the PBG of PhCs. despite being a very powerful method for extracting the PBG of PhCs, PWE is not capable of calculating the transmission properties and distribution patterns of optical waves inside PhCs.

Finite difference time domain (FDTD) [36] is another numerical method used for studying optical properties of PhCs. FDTD can be used for obtaining the distribution patterns of optical waves and the transmission properties of PhC-based devices. In our work, we used both methods in our designing procedure. 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 $a = 560$ nm in our structure we have $\Delta x = \Delta z = 35$ nm. In addition, the time step value will be obtained using courant condition ($\Delta t \le 1/c\sqrt{(1/\Delta x)^2 + (1/\Delta z)^2}$) where c is the velocity of light in free space. So we have $\Delta t = 0.025$.

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 [37]. The other crucial parameter we should consider in our simulations is the boundary condition, for this purpose we used perfectly matched layer (PML) [38] boundary condition surrounding our structure whose thickness is assumed to be 500 nm.

For designing our proposed channel drop filter (CDF) we use a 30×40 square lattice of dielectric rods immersed in air. The effective refractive index of dielectric rods is 4.2. And the radius of dielectric rods and the lattice constant $R = 95$ nm and $a = 560$ nm respectively. The band structure diagram of the PhC with aforementioned values is depicted in Fig. 1.

As we see there are two PBG in TM mode (blue colored areas) and there is no PBG in TE mode. The TM PBGs are in $0.258 < a/\lambda < 0.421$ and $0.670 < a/\lambda < 0.722$. Only the first PBG in TM mode is wide enough for covering the sufficient wavelengths for optical communication applications. Considering the lattice constant equal to $a = 560$ nm, the suitable PBG of our initial PhC structure will be in 1330 nm $< \lambda <$ 2170 nm range in TM mode, therefor all the simulations will be done in TM mode.

Our proposed CDF is composed of three main parts: 2 line defects as bus waveguide (the upper one) and drop waveguide (the lower one) and an elliptical resonant ring located between the waveguides. The schematic diagram of our proposed PCRR-based CDF is shown in Fig. 2 along with its ellipse-shaped resonant ring. As we see from Fig. 2 the resonant ring is composed of one inner ellipse and one outer ellipse. As we know every ellipse has 2 diameters called the major diameter and the miner diameter. The miner (D_{1n}) and major (D_{2n}) diameters of the inner ellipse are: $D_{1i} = 2k_2$ and $D_{2i} = 2L_2$ (where $k_2 = 1.1$a and $L_2 = 1.8$a). And the miner and the major diameter of the outer ellipse are: $D_{1O} = 2k_1$ and $D_{2O} = 2 \times L_1$ (where $k_1 = 1.6$a and $L_1 = 2.7$a). Also the radius of the dielectric rods of the inner and outer ellipse are $R_2 = 95$ nm and $R_1 = 52$ nm respectively. These parameters – k_1, k_2, L_1, L_2, R_1 and R_2 – are shown in Fig. 2 (b). 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 waves enter the structure through port A and exit it from port B, however at the desired wavelength the optical wavelengths drop to drop waveguide through the resonant ring and travel toward port D.

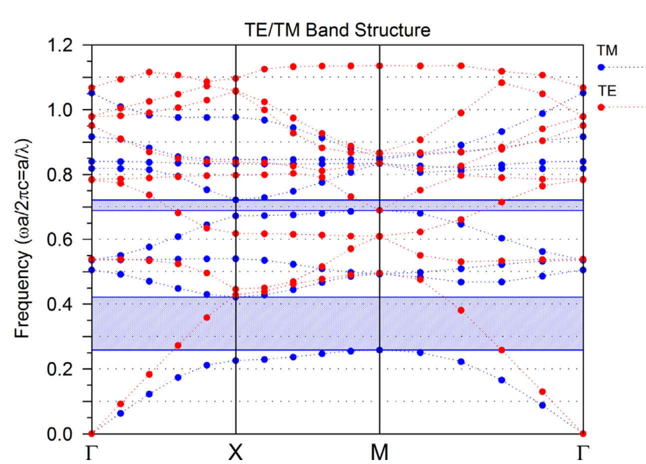


Fig. 1. The band structure of the basic PhC structure. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

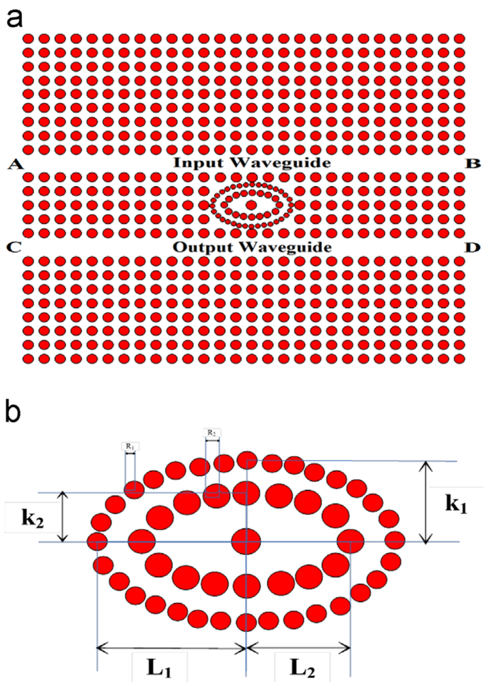


Fig. 2. The schematic diagram of (a) the proposed CDF (b) and its resonant ring.

3. Simulation and results

The transmission spectrum of the CDF is shown in Fig. 3. The normalized transmission of the structure at port B, C and D are depicted with green, red and blue curves. Fig. 3(a) shows that optical waves in all the wavelengths will go toward port B except at $\lambda=1555$ nm in which optical waves will drop to the drop waveguide and travel toward port D. We have no output wave at port C. The drop efficiency of the structure is 1 at $\lambda=1555$ nm and the quality factor ($Q=\lambda_0/\Delta\lambda$) is 647. The distribution of the optical wave inside the structure at $\lambda=1555$ nm is shown in Fig. 3(b).

After simulating and studying the optical properties of our proposed structure for PCRR-based CDF we are going to study and investigate the optical properties of different configurations of the proposed structure. The results are discussed at the following subsections.

3.1. Vertical ellipse-ring PCRR

In this part we change the direction of the elliptical ring, and employed a vertical elliptical ring as our resonant part of the CDF. The schematic diagram of the new configuration and its output spectrum are shown in Fig. 4 and 5respectively. All the parameters are as the same as the original structure and we only changed the orientation of the elliptical resonant ring. We see that the drop wavelength will be at $\lambda=1550$ nm. In this configuration 75% of the dropped optical will travel toward port C and 25% will travel toward port D, unlike the original configuration in which all of the dropped optical power will travel toward port D. the quality factor of the CDF in this configuration is 387. In this configuration due to reduction in the effective interface between resonant ring and waveguides we have reduction in the transmission efficiency. Also this reduction in the transmission efficiency can be due to the special shape of vertical ellipse-ring which splits the optical power into two parts.

3.2. Dual and triple-ring PCRR

In this part of our study we are going to investigate the effect of employing multiple rings in cascaded form. So design two new configurations with two and three resonant rings. The schematic diagram of these configurations is shown in Figs. 6 and 7. In dual ring configuration the transmission efficiency at port D and C are 79% and 27% respectively and the quality factor at $\lambda=1558$ nm is 865. The output spectrum and the distribution of the optical power for dual ring configuration are shown in Fig. 8. In triple ring configuration the transmission efficiency at port D for

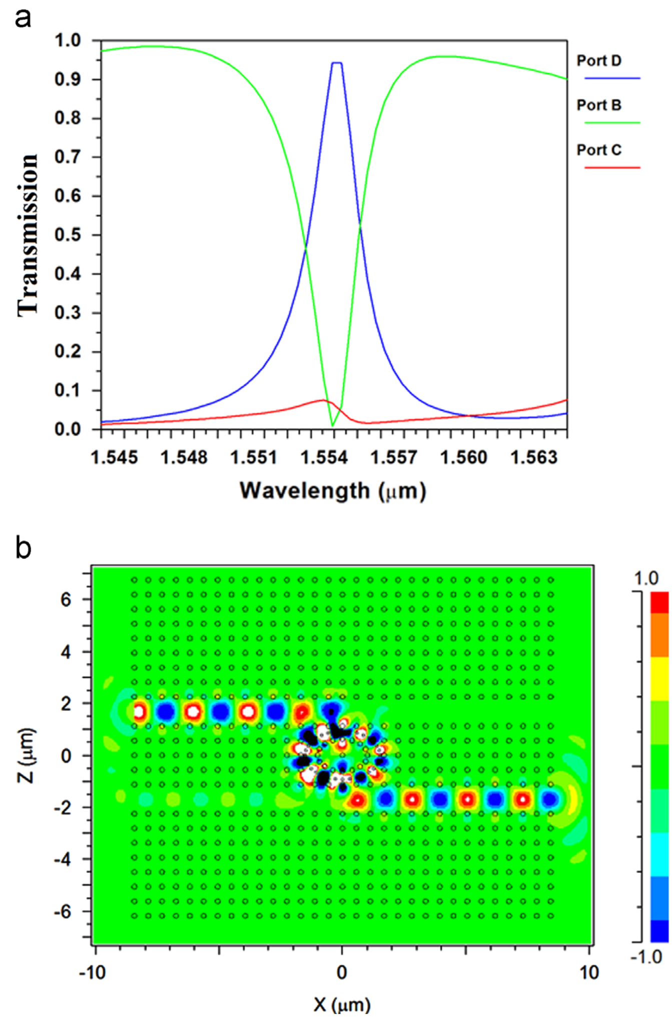


Fig. 3. (a) The output spectrum of the proposed CDF and (b) Distribution of optical power at $\lambda=1555$ nm. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

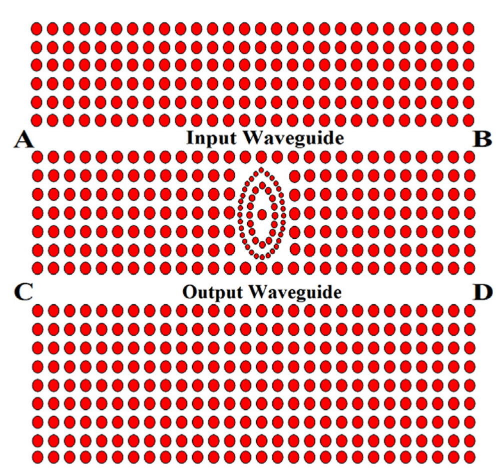


Fig. 4. The schematic diagram of the proposed CDF with vertical resonant ring.

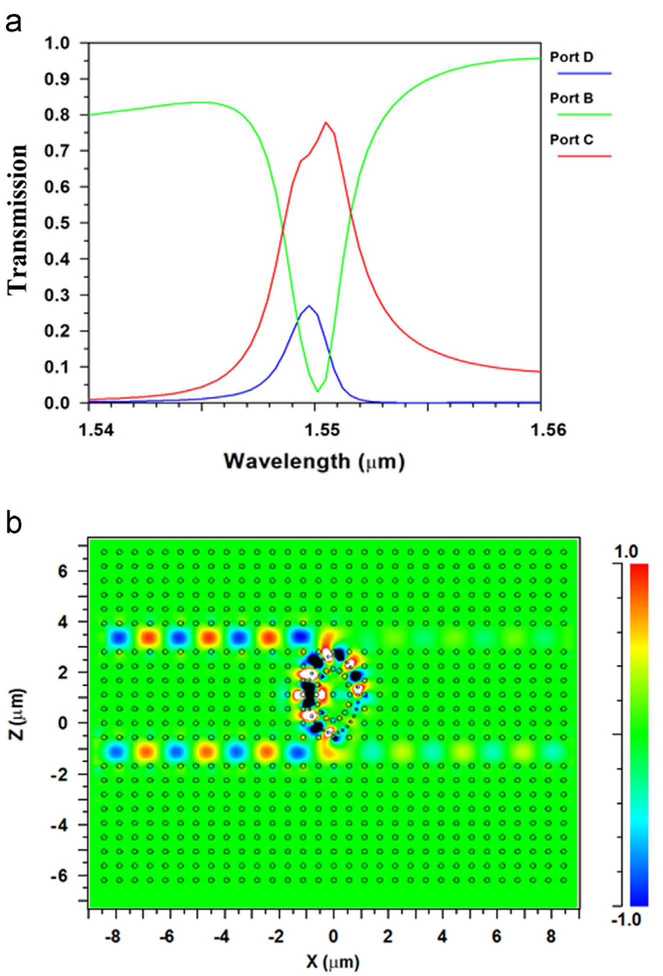


Fig. 5. (a) The output spectrum of the CDF with vertical ring and (b) Distribution of optical power at $\lambda = 1550$ nm.

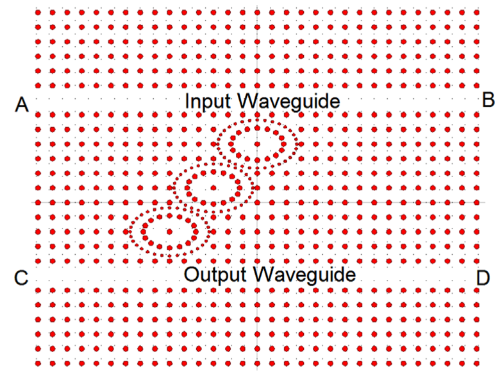


Fig. 7. The schematic diagram of the proposed CDF with triple resonant ring.

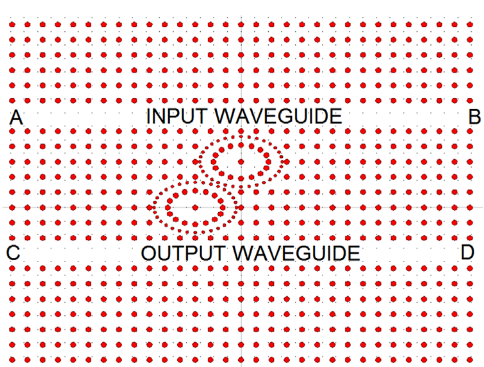


Fig. 6. The schematic diagram of the proposed CDF with dual resonant ring.

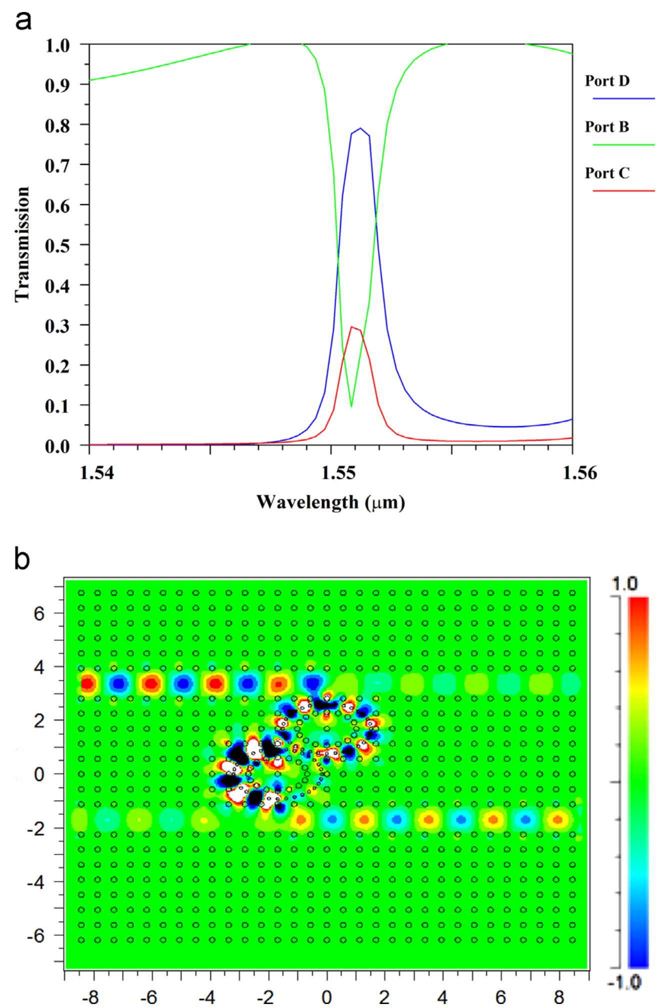


Fig. 8. (a) The output spectrum of the CDF with dual ring and (b) Distribution of optical power at $\lambda = 1558$ nm.

$\lambda = 1559$ nm is 80% and its quality factor is 1559. We observe that by increasing the number of the rings the quality factor of the filter increases. The output spectrum and the distribution of the optical power for triple ring configuration are shown in Fig. 9. In these configurations due to multiple resonants through multiple rings we have reduction in the transmission efficiencies. The next important point in multiple ring configurations is the space between the adjacent rings. Our simulations show that separating the rings from each other will ruin the output spectra and the output spectra will not be so good.

4. Conclusion

In this paper we proposed a novel structure for designing all optical PCRR-based CDF. We employed an elliptical shaped resonant ring for realizing our proposed CDF. The quality factor of the structure is 647. We also investigated the optical properties of different configurations of the CDF. Our results show that by using a vertical ring instead of horizontal ring the optical waves at the drop wavelength will go toward port C. we also show that by increasing the number of the resonant rings the quality factor of

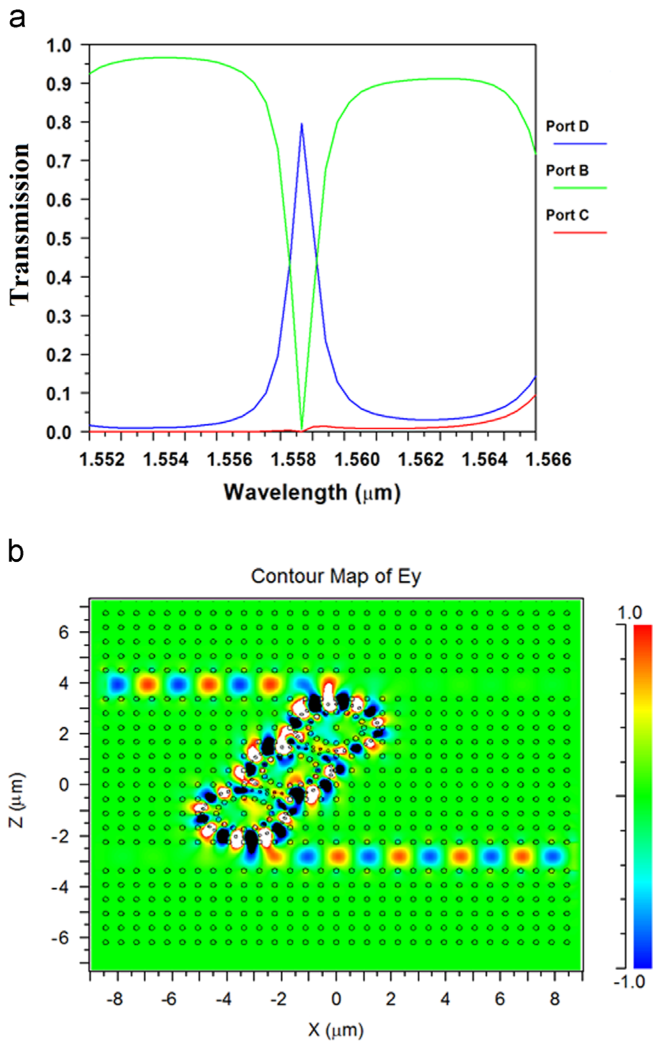


Fig. 9. (a) The output spectrum of the CDF with triple ring and (b) Distribution of optical power at $\lambda = 1559$ nm.

the filter will increase but we have a reduction in the transmission efficiency of the filter.

References

[1] S. Robinson, R. Nakkeeran, Optik 123 (2012) 451.
[2] H. Alipour-Banaei, F. Mehdizadeh, Digest Journal of Nanomaterials and Biostructures 7 (2012) 361.
[3] H. Alipour-Banaei, F. Mehdizadeh, Optik 124 (2013) 2639.
[4] F. Mehdizadeh, H. Alipour-Banaei, Z. Daie-Kuzekanani, Optoelectronics and Advanced Materials-Rapid Communications 6 (2012) 527.
[5] H.P. Bazargani, Optics Communication 685 (2012) 1848.
[6] A. Rostami, H. Alipour Banei, F. Nazari, A. Bahrami, Optik 466 (2011) 1481.
[7] S.C. Cheng, J.Z. Wang, L.W. Chen L.W., C.C. Wang, Optik 123 (2012) 1928.
[8] A. Rostami, F. Nazari, H. Alipour-Banaei, A. Bahrami, Photonic and Nanostrucutres – Fundamentals and Applications 8 (2010) 14.
[9] S. Rawal, R.K. Sinha, Optics Communication 686 (2009) 3889.
[10] B. Momeni, J. Huan, M. Soltani, M. Askari, S. Mohammadi, M. Rakhshandehroo, A. Adibi, Optics Express 42 (2006) 2410.
[11] T. Ahmadi-Tame, B.M. Isfahani, N. Granpayeh, A.M. Javan, International Journal of Electronics and Communications (AEU) 65 (2011) 281.
[12] B. Rezaei, M. Kalafi, Optics Communications 266 (2006) 159.
[13] W.L. Liu, Y.Y. Liou, J.C. Wei, T.J. Yang, Physica B 404 (2009) 4237.
[14] Z. Wu, K. Xie, H. Yang, Optik 123 (2012) 534.
[15] D. Liu, Y. Gao, D. Gao D, X. Han, Optics Communications 285 (2012) 1988.
[16] F. Mehdizadeh, H. Alipour-Banaei, Journal of Optical Communications 34 (2013) 61.
[17] H.J.R. Dutton, Understanding Optical Communications (IBM Corporation), 1998.
[18] H. Kurosaki, H. Koshiishi, T. Suzuki, K. Tsuchiya, Advances in Space Research 32 (2003) 2141.
[19] A.J. Chaudhari, F. Darvas, J.R. Bading, R.A. Moats, P.S. Conti, D.J. Smith, S.R. Cherry, R.M. Leahy, Physics in Medicine and Biology 50 (2005) 5421.
[20] S.J. Woltman, G.D. Jay, G.P. Crawford, Nature Materials 6 (2007) 929.
[21] N. Gat, Proceedings of SPIE 4056 (2000) 50.
[22] S.H. Kim, H.Y. Ryu, G.H. Kim, Y.S. Choi, Y.H. Lee, Applied Physics Letters 81 (2002) 2499.
[23] V.D. Kumar, T. Srinivas, A. Selvarjan, Photonics and Nanostructures-Fundamental and Applications 2 (2004) 199.
[24] Z. Qiang, W. Zhou, R.A. Soref, Optics Express 15 (2007) 1823.
[25] W.Y. Chiu, T.W. Huang, Y.H. Wu, Y.J. Chan, C.H. Hou, H.T. Chien, C.C. Chen, Optics Express 15 (2007) 15500.
[26] G.P. Nordin, S. Kim, J. Cai, J. Jiang, Optics Express 10 (2002) 1334.
[27] S. Kim, G.P. Nordin, J. Cai, J. Jiang, Optics Letters 28 (2003) 2384.
[28] S. Kim, J. Cai, J. Jiang, G.P. Nordin, Optics Express 11 (2004) 2356.
[29] A. Ghaffari, F. Monifi, M. Djavid, M.S. Abrishamian, Optics Communications 281 (2008) 5929.
[30] M. Djavid, F. Monifi, A. Ghaffari, M.S. Abrishamian, Optics Communications 281 (2008) 4028.
[31] M. Djavid, A. Ghaffari, F. Monifi, M.S. Abrishamian, Physica E 40 (2008) 3151.
[32] M. Djavid, M.S. Abrishamian, Optik 123 (2011) 167.
[33] A. Taalbi, G. Bassou, M.Y. Mahmoud, Optik 124 (2013) 824.
[34] M.Y. Mahmoud, G. Bassou, A. Taalbi, Z.M. Chekroun, Optics Communications 285 (2012) 368.
[35] S.G. Johnson, J.D. Joannopoulos, Optics Express 8 (2001) 173.
[36] S.D. Gedney, Introduction to Finite-Difference Time-Domain (FDTD) Method for Electromagnetics, Morgan&Claypool, Lexington KY, 2010.
[37] Qiu Min, Applied Physics Letters 81 (2002) 1163.
[38] A. Taflove, S.C. Hegnese, Computational Electrodynamics: The Finite-Difference Time-Domain Method, Artech House, Boston, MA, 1998.