ISSN: 2395-1680 (ONLINE)
DOI: 10.21917/ijme.2016.0027

NETWORK IMPLEMENTATION OF PHOTONIC CRYSTAL CIRCULAR SPLIT RING RESONATOR BASED ADF

R. Arunkumar[1] and S. Robinson[2]
Department of Electronics and Communication Engineering, Mount Zion College of Engineering and Technology, India
Email: [1]mail2robinson@gmail.com, [2]arunec002@gmail.com

Abstract

Photonic Crystal based optical devices have attained a widespread attention for ultra-fast communications and Photonic Integrated Circuits. In this paper, Two Dimensional Photonic Crystal Circular Split Ring Resonator (PCCSRR) based Add Drop Filter is proposed and designed. The normalized transmission spectra of circular Photonic Crystal Split Ring Resonator are taken using 2D Finite Difference Time Domain method. The Photonic Band Gap is calculated by Plane Wave Expansion method. The resonant wavelength, coupling/ dropping efficiency and Q factor of the ADF are 1490nm, 100 % and 243nm, respectively. The overall size of the device is much smaller that is 10.4µm × 11.4µm which is highly suitable for photonic integrated circuits and all optical photonic network applications. In addition, the proposed device is incorporated in the point to point networks and its network parameters such as Bit Error Rate, Quality factor, receiver sensitivity are examined.

Keywords:

Photonic Crystal, Channel Drop Filters, Split Ring Resonator, Plane Wave Expansion Method, Finite-Difference Time-Domain Method

1. INTRODUCTION

Very promising ultra-compact devices for photonic integrated circuits could be attained using Photonic Crystals (PCs). Generally, PCs are patterned artificial materials with periodicity of refractive index in one, two or three dimensions. The periodicity in a nano structured material creates a range of forbidden frequencies called Photonic Band Gap (PBG). The PBG is the range of wavelength for which material neither absorbs nor allows the light propagation inside the structure. [1, 2]. The existence of PBG in PCs is more suitable for designing almost all kind of optical devices with nanometer scale. The completeness of the periodicity can be broken by introducing defects and hence PBG, which allows the guided modes to propagate inside this region. Two dimensional PCs (2DPC) are receiving keen attention by the scientific community as they have attractive features including relatively simple fabrication, better confinement of light, efficient PBG calculation, effective control of spontaneous emission and easy integration with other devices [3].

Recent years, many PC based optical devices are proposed both theoretically and experimentally. To name a few, waveguides [4], add-drop filters [5], power splitters [6], demultiplexers [7], directional couplers [8], bandstop filters [9,10], etc. Add Drop Filter (ADF) is one of the prominent components for optical networks, which is used to add/drop a particular/desired channel without disturbing other channels travelling through the fiber. The ADF is one of the fundamental building blocks for Optical Add Drop Multiplexers (OADMs), reconfigurable OADMs, optical modulators, and optical switches needed for Photonic Integrated Circuits (PICs), and Wavelength Division Multiplexing (WDM) optical communication systems.

In the literature, so far, the ADF is designed in the square lattice by introducing point defects and/or line defects [11], and using PCRR [12]. The square lattice PCRR based ADFs are reported using square cavity, quasi square cavity, dual curved cavity, hexagonal cavity, 45° square cavity, diamond cavity, X shaped cavity [12], fractal cavity [13], elliptical cavity [14] and H shaped cavity [15]. In the aforementioned cavity based ADFs, the cavity resonator has a proper corner that reduces the output power at resonance owing to scattering at corners. However, the designed circular ring resonator has gradual changes at corners, which is subtle in nature; it reduces the scattering and improves the output efficiency through circular resonant modes.

Split Ring Resonators (SRR) are widely used in Microwave communication. The SRR is an artificially produced structure common to meta-materials [16]. A single cell SRR has a pair of enclosed loops with splits in them at opposite ends and has a small gap between them. The Fig.1 shows schematic representation of Circular SRR (CSRR) which is primarily used to design microwave devices. The CSRR is employed here to design ADF using 2DPC.

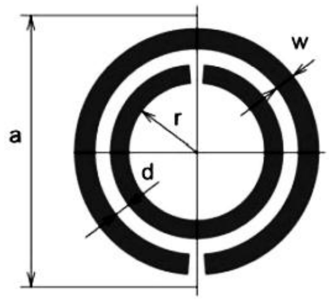


Fig.1 Schematic structure of circular Split Ring resonator

In this paper, a Circular Split Ring Resonator based ADF is newly proposed and designed using circular rod in square lattice. The ADF is designed to add and drop a channel centered at 1490nm, which is essential for metro/access, enterprise and regional optical networks. The coupling and dropping efficiencies, Q factor and resonant wavelength of the ADF are investigated. The PBG and propagation modes of the designed structure are calculated by Plane Wave Expansion (PWE) method. Using Two Dimensional (2D) Finite Difference Time Domain (FDTD) method, the coupling and dropping efficiencies of ADF is investigated.

The rest of the paper is structured as follows: In section 2, the structure design of circular photonic crystal circular split ring resonator based ADF is presented and its simulation results are discussed in section 3. Section 4 involves the implementation of proposed ADF in point to point network and its simulation results. Section 5 concludes the paper.

2. DESIGN OF SPLIT RING RESONATOR BASED ADD DROP FILTER

The band diagram of PC based structure before introducing the defects is represented in Fig.2. The total number of rods, Lattice constant, refractive index and radius of rod of the designed filter are 399nm, 550nm, 3.47nm and 100nm respectively. The band diagram has a TE PBG over a wavelength range of 2141nm to 1830nm. The size of the device is 10.4µm × 11.4µm. The Perfect Matched Layer (PML) is used to truncate the computational regions and to avoid the back reflections from the boundary [17].

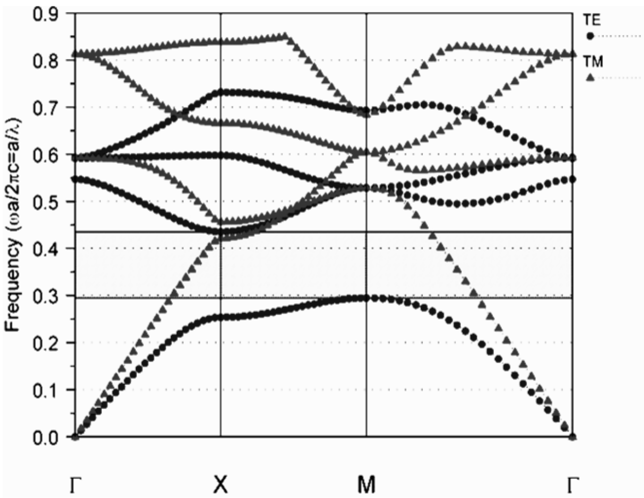


Fig.2. Band Diagram of PC Based Structure before Introducing Defects

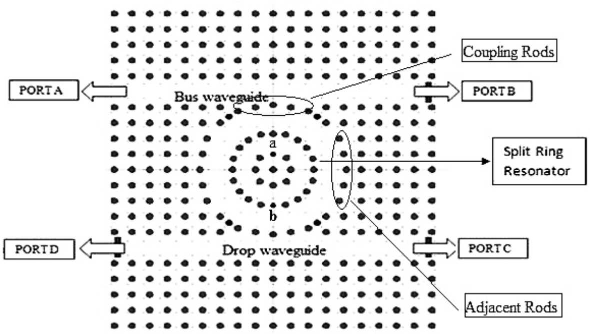


Fig.3. Schematic Structure of PCRR Based CDF

The proposed PCCSRR based ADF is shown in Fig.3 which consists of two waveguides in horizontal (Γ-x) direction and a circular SRR is positioned between them. The detailed representation of Bus/Drop waveguides and circular ring resonator is reported [12]. However the radius of the rod '*a*' and '*b*' is 50nm positioned top and bottom of the inner rods which act as the split ring resonator. The bus and the dropping waveguides are formed by introducing line defects whereas the circular PCRR is shaped by creating point defects. The rods which are located inside the circular PCRR are called inner rods whereas the coupling rods are placed between PCCSRR and waveguides.

3. RESULTS AND DISCUSSION

A Gaussian input signal is launched into the input port and it is transferred to output port B. However, the signal is reached the dropping waveguide at resonant condition whose respective transmission spectra is obtained by measuring the power at port B and D.

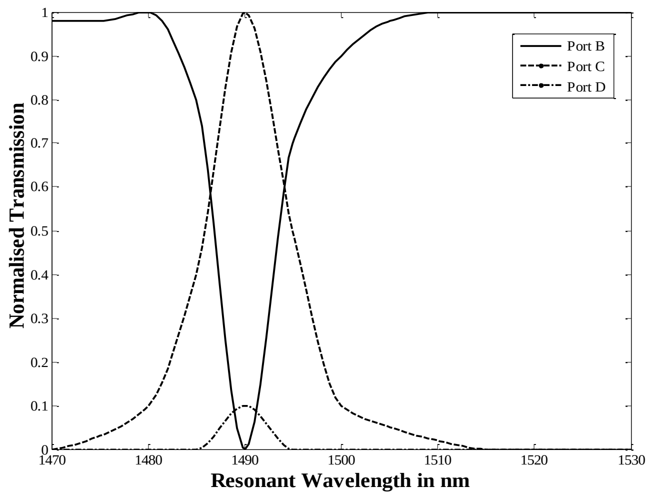
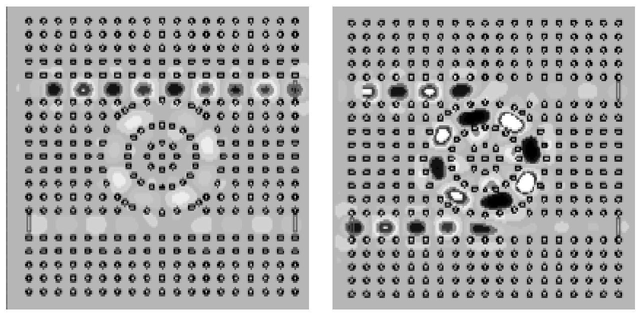


Fig.4. Optical Power Transmission of Proposed PCRR Based ADF

The Fig.4 shows the normalized transmission spectra of PCCSRR based ADF. The resonant wavelength and passband width of the ADF is observed at 1490nm and 7nm, respectively. The simulation shows 100% coupling and dropping efficiencies. The Q factor, which is calculated as $\lambda/\Delta\lambda$ (resonant wavelength/full width half maximum), equals to almost 243. The obtained results are meeting the requirements to drop or add a desired channel which is centered at 1490nm for ITU-T G.694.2 CWDM systems.



(a) (b)

Fig.5. Field Distribution of PCRR Based ADF (a) OFF Resonance (b) ON Resonance

The Fig.5 depicts the electric field pattern of OFF resonance (1400nm) and ON Resonance (1490nm). At a resonant wavelength, λ = 1490nm, the electric field of the bus waveguide is fully coupled with the ring and reached into its output port D. In this condition there is no signal flow in port B. Similarly, at off resonance, λ = 1400nm, the signal directly reaches the transmission terminal (the signal is not coupled into the ring).

4. NETWORK IMPLEMENTATION

The proposed PCCSRR based ADF (discussed in Section 3) is incorporated in point to point networks and its network parameters such as bit error rate, receiver sensitivity are evaluated. The proposed architecture is shown in Fig.6 which comprises of transmitter, receiver and channel. The transmitter consists of CW laser, Mach-Zehnder modulator, Pseudo-Random Bit Sequence (PRBS) Generator and NRZ Pulse Generator. The transmitted signal (1Gbps) at 1490nm is transmitted through optical fiber. The proposed PCCSRR based ADF is incorporated in the channel where the channel at 1490nm can be dropped/added according to their requirements. The receiver consists of photo detector, Bessel filter and a decision circuit. The bit error rate is analyzed for every channel which is estimated by comparing the output signal with input signal.

The impact of BER vs. received power and BER vs. transmission distance of the proposed PCCSRR based ADF in the network is represented in Fig.7(a) and Fig.7(b), respectively. The channel centered at 1490nm is transmitted to the fiber. The distance from source to ADF and ADF to destination is varied from 125km to 165km in order to calculate the impact of BER vs. Received power for drop port and add port, respectively. The input power 0dBm is kept as constant for add port as well as drop port over the distance between 125km to 165km. From the simulation, it is observed that the attained BER (number of corrupted bits to total number of transmitted bits) at 125km is about 10^{-300} and it is decreased while increasing the transmission distance. The receiver sensitivity (minimum average optical power required to achieve a certain BER at a particular data rate, it is usually measured at a BER of 10^{-12} for good CWDM system performance) is -37dBm. The receiver sensitivity for the channel at drop port and add port increases while increasing the distance. This attempt will create a way to incorporate a miniaturized device in the optical networks to enhance the quality of service.

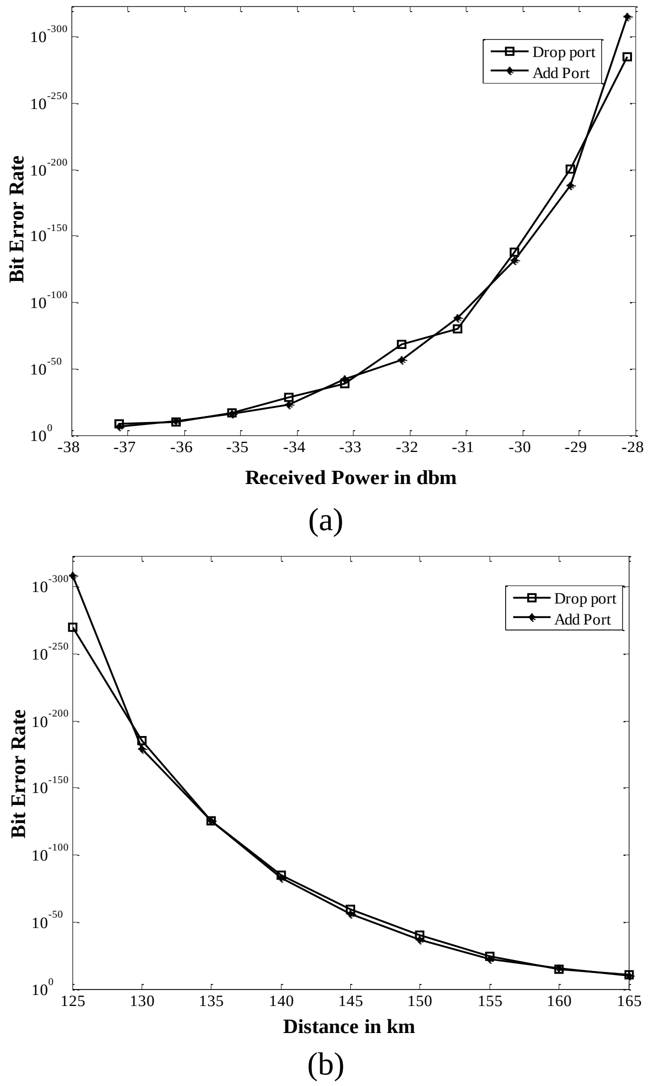


Fig.7. (a) BER vs. received power and (b) BER vs. trasmitting distance

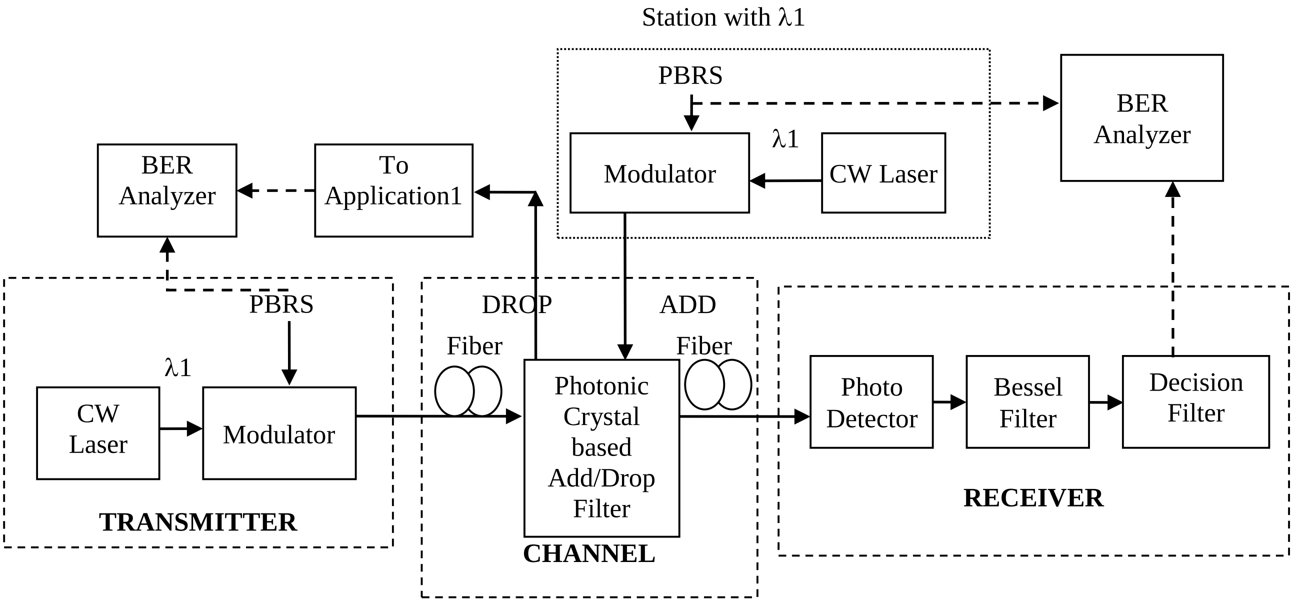


Fig.6. Block diagram of point to point network

5. CONCLUSION

The Photonic Crystal Circular Split Ring Resonator based ADF is designed using circular rods to add/drop a channel at center wavelength of 1490nm for ITU-T G.694.2 CWDM systems. Approximately, 100% of coupling and dropping efficiencies are observed at 1490nm through simulation. The passband width and Q factor of the designed ADF is 7nm and 243nm, respectively. The suggested ADF is compact and the overall size of the chip is around 10.4μm × 11.4μm which would be more useful for the realization of integrated optics circuits. Further, the proposed PCCSRR based ADF is incorporated in the point to point network whose network parameters are evaluated. The performance of network is investigated for the bit rate of 1Gbps over the fiber length of 125km to 165km. The receiver sensitivity is required to get typical BER (10^{-9}) is about -37dBm at 165km. This attempt may be useful to incorporate the PC based devices into the networks for Photonic Integrated Circuits.

REFERENCES

[1] Eli Yablonovitch, "Inhibited Spontaneous Emission on Solid-State Physics and Electronics", *Physical Review Letters*, Vol. 58, No. 20, pp. 2059-2062, 1987.

[2] Sajeev John, "Strong Localization of Photons in Certain Disordered Dielectric Superlattices", *Physical Review Letters*, Vol. 58, No. 23, pp. 2486-2489, 1987.

[3] John D. Joannopoulos, Steven G. Johnson, Robert D. Meade and Joshua N. Winn, "*Photonic crystal: Modeling of Flow of Light*", Princeton University Press, 2008.

[4] Nagesh Janrao, Rukhsar Zafar and Vijay Janyani, "Improved Design of Photonic Crystal Waveguides with Elliptical Holes for Enhanced Slow Light Performance", *Optical Engineering*, Vol. 51, No. 6, pp. 4001-4008, 2012.

[5] Zexuan Qiang, Weidong Zhou and Richard A. Soref, "Optical Add-drop Filters based on Photonic Crystal Ring Resonators", *Optics Express*, Vol. 15, No. 4, pp. 1823-1831, 2007.

[6] Zhenhai Wu, Kang Xie, Huajun Yang and Ping Jiang, "Bends and Splitters for Self-Collimated Beams in Two Dimensional Triangular Lattice Photonic Crystals", *Optical Engineering*, Vol. 50, No. 11, pp. 4002-4008, 2011.

[7] G. Manzacca, D. Paciotti, A. Marchese, M.S. Moreolo and G. Cincotti, "2D Photonic Crystal Cavity-based WDM Multiplexer", *Proceedings of International Conference on Transparent Optical Networks*, Vol. 4, pp. 233-236, 2006.

[8] M.K. Moghaddam, A.R. Attari and M.M. Mirsalehi, "Improved Photonic Crystal Directional Coupler with Short Length", *Photonics and Nanostructures-Fundamentals and Applications*, Vol. 8, No. 1, pp. 47-53, 2010.

[9] Robinson Savarimuthu and Nakkeeran Rangaswamy, "Bandstop Filter for Photonic Integrated Circuits using Photonic Crystal with Circular Ring Resonator", *Journal of Nanophotonics*, Vol. 5, No. 1, pp. 053521-1-13, 2011.

[10] Chun-Chih Wang and Lien-Wen Chen, "Channel Drop Filters with Folded Directional Couplers in Two-Dimensional Photonic Crystals", *Physica B: Condensed Matter*, Vol. 405, No. 4, pp. 1210-1215, 2010.

[11] Mehrdad Djavid and Mohamad Sadegh Abrishanian, "Photonic Crystal Channel Drop Filters with Mirror Cavities", *Optical and Quantum Electronics*, Vol. 39, No. 14, pp. 1183-1190, 2007.

[12] Savarimuthu Robinson and Rangaswamy Nakkeeran, "Photonic Crystal Ring Resonator-Based Add Drop Filters: A Review", *Optical Engineering*, Vol. 52, No. 6, pp. 060901-1-11, 2013.

[13] Ali Dideban, Hamidreza Habibiyan and Hassan Ghafoorifard, "Photonic Crystal Channel Drop Filters Based on Fractal Structures", *Physica E: Low-Dimensional Systems and Nanostructures*, Vol. 63, pp. 304-310, 2014.

[14] Hamed Alipour-Banaei, Farhad Mehdizadeh and Mahdi Hassangholizadeh-Kashtiban, "A New Proposal for PCRR Based Channel Drop Filter Using Elliptical Rings", *Physica E: Low-Dimensional Systems and Nanostructures*, Vol. 56, pp. 211-215, 2014.

[15] Saba Rezaee, Mahdi Zavvari and Hamed Alipour-Banaei, "A Novel Optical Filter Based on H-Shape Photonic Crystal Ring Resonators", *Optik-International Journal for Light and Electron Optics*, Vol. 126, No. 20, pp. 2535-2538, 2015.

[16] J. Naqui, M. Duran-Sindreu and F. Martin, "Modeling Split Ring Resonator and Complementary Split Ring Resonator Loaded Transmission Lines Exhibiting Cross Polarization Effects", *IEEE Antenna and Wireless Propagation Letters*, Vol. 12, pp. 178-181, 2013.

[17] A. Lavrinenko, P.I. Borel, L.H. Frandsen, M. Thorhauge, A. Harpoth, M. Kristensen, T. Niemi, and H.M.H. Chong, "Comprehensive FDTD Modeling of Photonic Crystal Waveguide Components", *Optics Express*, Vol. 12, No. 2, pp. 234-248, 2004.