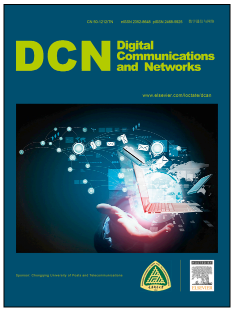

Design and analysis of multi-channel drop filter using dual L Defected Hexagonal Photonic Crystal Ring Resonator

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Design and Analysis of Multi-Channel Drop Filter using Dual L Defected Hexagonal Photonic Crystal Ring Resonator

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ABSTRACT

In this paper, Dual L defected hexagonal Photonic Crystal Ring Resonator (PCRR) using Channel Drop Filter (CDF) is designed for Coarse Wavelength Division Multiplexing (CWDM) systems. In this structure, the external rods of the ring resonator are arranged in a hexagon and the internal rods are removed in L arrangement for introducing the defects. The scatter rods are used to prevent the leakage. By using the L defected hexagonal resonator, the multi-channel CDF is designed, which exhibits multiple wavelengths of CWDM (1500 nm – 1600 nm) region. In addition, the choice of the selection of the rod size and the position of the rods in the proposed multi-channel CDF is validated by varying the radius of coupling beside scattering rods and the position of resonators, respectively. By using plane wave expansion and Opti Finite Difference Time Domain (FDTD) method, the electromagnetic wave propagation and the photonic band gap are obtained.

Keywords: *Channel Drop Filter; Photonic Crystal Ring Resonator; Coarse Wavelength Division Multiplexing; Finite Difference Time Domain.*

I. INTRODUCTION

Photonic crystals are microscopically structured materials, whose unique properties have changed our view of optics and opened up new ways for processing of light. The photonic crystal is composed of a periodic dielectric or metallo-dielectric nanostructures that affect the propagation of electromagnetic waves in the same way as the periodic potential in the semiconductor crystal affects electron motion by defining and allowed electronic energy bands. Photonic crystals contain regularly repeating regions of high and low dielectric constants. The photonic crystals are of three types, namely, 1D, 2D, and 3D photonic crystals. Among them, the Two-Dimensional Photonic Crystals (2DPC) have attracted more towards the design of optical devices than the counterparts as they have better properties like the confinement of light, efficient control of spontaneous emission and easy fabrication. In 2D, the devices can be triangular or square lattice and the lattice may be rod or hole type.

Photonic Crystal Ring Resonator (PCRR) consists of two waveguides, namely, bus waveguide and drop waveguide. When the input signal is given in the bus waveguide, it couples through the resonator that is sandwiched between the two waveguides and it is dropped in the drop waveguide [1-2]. In [1], a Channel Drop Filter (CDF) using 2DPC with a triangular lattice of dielectric rods in air substrate is analyzed. It adopts the structure of X to design the CDF. This structure exhibits a forward drop efficiency of 100% and an approximate quality factor of 1000. In [2], Square lattice dielectric rods are used to design a channel drop filter. Here, a single cavity is used to move power from one waveguide to another, which is designed to support degenerated modes with opposite symmetry. In [3-5], three-port channel drop filters are designed using single defect and spectral characteristics of the waveguide-coupled ring are analyzed. However, these structures are limited to drop three wavelengths at a given time.

In [6], a 2D triangular lattice in the plane is designed that will display a wider band gap than square lattice. In [6], the degenerated modes limit the light in vertical direction and couples equally in the waveguide. Alternatively, the authors in [7] have utilized the quasi-square ring PCRR to achieve a high spectral selectivity and dropping efficiency. Optical channel drop filter using dual curve PCRR is constructed using dual curved Fabry Perot resonators is discussed in [8]. However, this structure exhibit low drop efficiency. For CWDM systems, add drop filter using hexagonal rods are explained [9]. Here, the hexagonal rods are positioned in a square lattice and it resonates at 1511 nm. To achieve high dropping efficiency and quality factor, channel drop filter is designed using elliptical rings in square lattice photonic crystals [10]. In [10], 2D PCRRs CDF is designed in triangular lattice photonic crystal. However, these structures do not support multi-channel channel drop functionality.

A multi-channel drop filter using 2D hetero photonic crystal is suggested in [11]. This structure drops a maximum of four channels at 1516 nm, 1536 nm, 1559 nm, and 1583 nm. However, the structure is realized by cascading four filter units that may result in drop stage of filtering. The design of a channel drop filter using a fractal shaped resonator has been discussed in [12]. For a wavelength of 1542.02 nm, the filter exhibits a drop efficiency of 91.70% for a Q factor of 1078.93. The authors in [13] have designed a T shaped channel drop filter based on PCRR, which exhibits a drop wavelength of 1551 nm. The design of multi-channel drop filter for Dense Wavelength Division Multiplexing (DWDM) has been discussed in [14]. Here, the effect of crosstalk in channel drop filter is analyzed by wavelength-selective reflection feedbacks.

Tunable multi-channel drop filter has been analyzed in [15] that utilize the effect of oval defects. The resonant frequency is adjusted by the rotation angle of oval rods. Using embedded photonic crystal ring resonator, an ultra-narrow band channel drop filter with distributed coupling has been discussed in [16] for DWDM systems. The silicon rods are arranged in the square lattice to obtain a wavelength of 1550 nm and the number of drop lines is limited to three with 600 pm channels spacing. The authors in [17] have designed a photonic crystal based optical filter using triple cavity transmission that display narrow channel transmission in second and third optical fiber windows. Although various structures have been discussed in the literature for channel drop filter, they do not exhibit multi-port structure with multiple wavelengths [18]. Hence, this paper investigates the design of a multi-port multi-channel add-drop filter for CWDM systems.

The paper is structured as follows: Following the brief introduction and related works in the design of photonic devices, a detailed analysis of the proposed structure is given in Section II. The realization of the proposed structure for multi-CDF design is discussed in Section III. The simulation and discussion of the proposed L defected hexagonal PCRR design is carried out in Section IV. In Section V, finally, we discussed the conclusion.

II. DESIGN OF PROPOSED DUAL L DEFECTED HEXAGONAL PCRR

In this section, the channel drop filter is designed using the principle of photonic crystal ring resonator. The proposed design structure has 33×23 silicon rods. It has an air refractive index of 3.4 in a triangular lattice. The photonic crystal ring resonator has a lattice constant 'a' of 650 nm with a radius 'r' of 0.38xa. The dielectric constant 'ε' is set as 11.56 for dielectric rods. The wavelength range in the waveguide mode region corresponds to a range of values from $0.317a/\lambda<f<0.469a/\lambda$, where λ is the wavelength of light in free space as shown in Figure 1. The wavelength range obtained is 1388 nm<λ<2044 nm and the resonant wavelength is chosen as 1550 nm for CWDM systems.

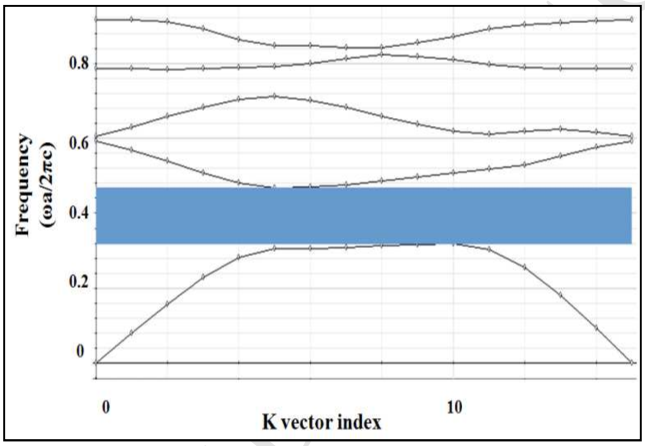


Fig. 1. Region of photonic band gap for the proposed structure

The proposed structure is based on the 2D triangular lattice. The designed PCRR has two waveguides. One is the bus waveguide and the other waveguide is drop waveguide. The proposed dual L defected hexagonal structure is sandwiched between these two waveguides. The superior waveguide is the bus waveguide and the bottom remain drop waveguide. As seen in Figure 2, the port 'A' is taken as an input terminal, port 'B' is taken as transmission terminal, and the port 'C' and port 'D' is taken as backward and forward dropping terminal respectively. In the proposed design, when the optical input signal is sent through the port 'A' it is coupled with the hexagon shaped resonator and dropped in drop waveguide i.e., in 'C' backward port. To avoid direct transmission, transmission reflectors are placed in the bus waveguide i.e., in the port 'B'. The external layer and the internal layer correspond to the structure of hexagonal and dual L assembly, respectively.

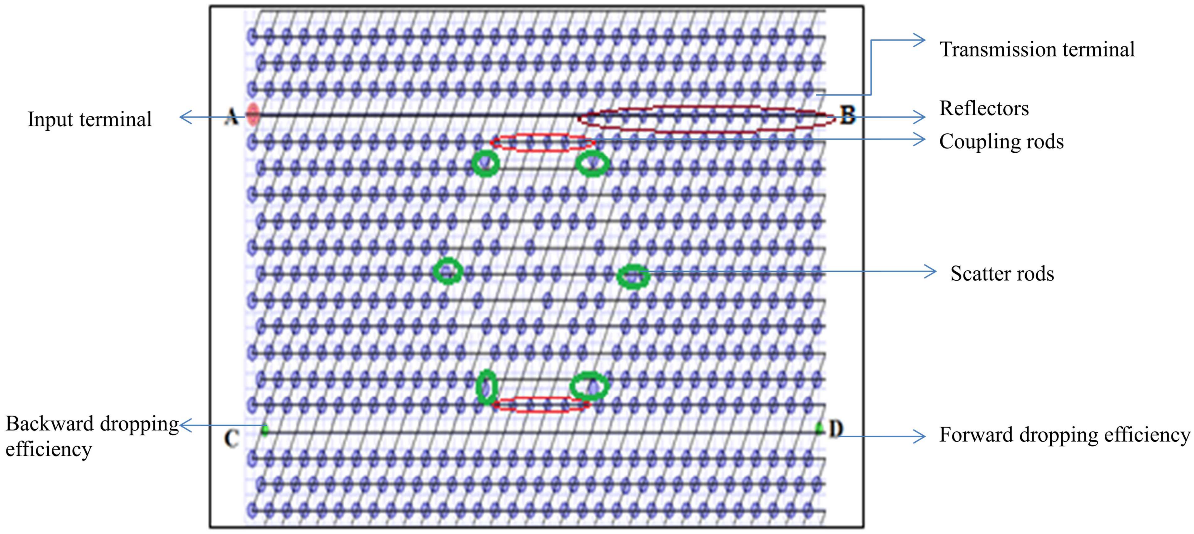
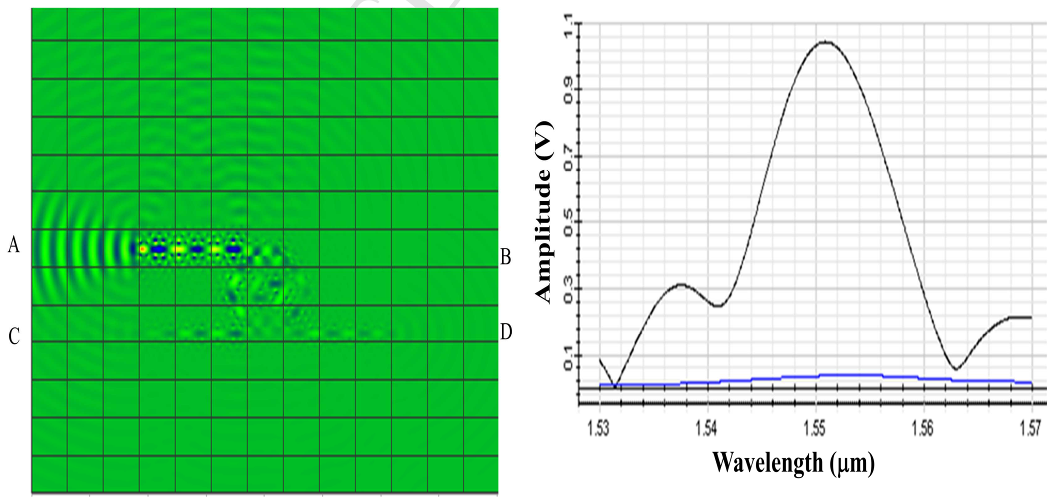


Fig. 2. Schematic representation of the proposed dual L defected hexagonal PCRR

In Figure 2, the coupling rods are indicated in red color and they are used to couple the input signal from bus to drop waveguide with the radius of 0.25a and the scatter rods are indicated in green color and they are used to avoid the leakage of light which has been configured with the radius of 0.3a. These point defect advantage from for efficient signal coupling and avoids signal outflow. With these design parameters, the input signal from the port A is coupled using coupling rods and it is dropped in the port C. Here, we can infer that when the input is given in the port A, it is coupled and dropped in the port C. The dropping efficiency is equal to 100%. By using this basic design, we have designed the multi CDF. This design has a significant wavelength of 1550 nm.



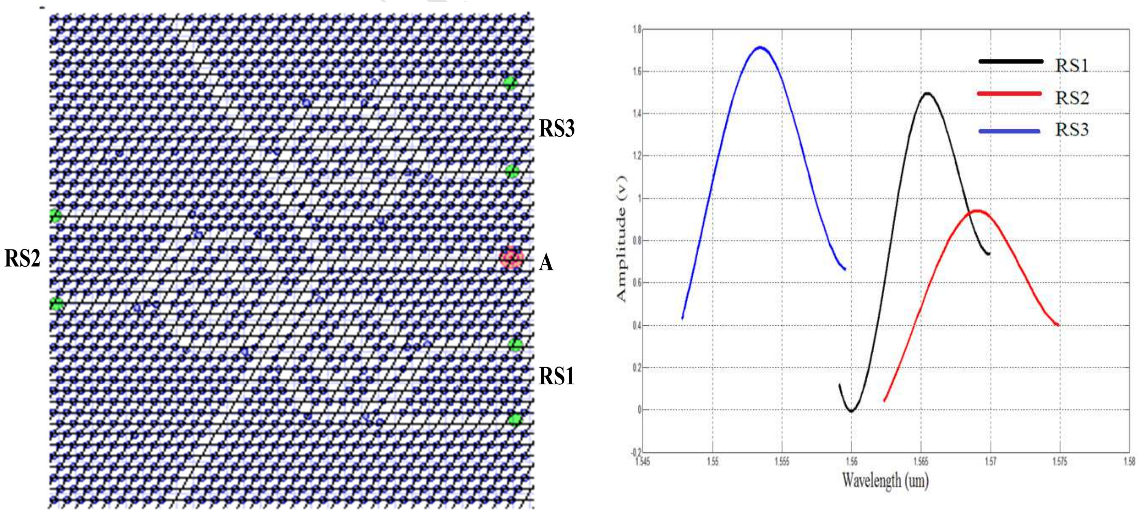
(a) (b)

Fig. 3. (a) Transmission diagram (from port A) and (b) Output spectrum of L defected hexagonal PCRR.

The simulation is carried out in Transverse Electric (TE) mode. The input signal from the port ‘A’ is coupled in the proposed structure and dropped in the port ‘C’ with 100% backward dropping efficiency and it obtains high bandwidth. The transmission diagram for the wavelength of 1550 nm from the input port is shown in Figure 3 (a). When the input signal is given from the Port A, it starts to propagate the light in the bus waveguide. Reflectors are placed in port B to avoid transmission. Hexagonal shaped resonators are placed between the bus waveguide and drop waveguide. In the resonator, coupling rods are used to couple the light and the scatter rods are rods are used to avoid leakage. The input signal from the port A is transmitted through the resonator and dropped in the port C with 100% dropping efficiency. It achieves high bandwidth at the resonant wavelength of 1550nm as shown in Figure 3(b).

III. REALIZATION OF MULTI-CDF DESIGN

In this section by using the abovementioned basic structure, the multi-port CDF is realized. Here, three L defected hexagonal PCRR is used by an inclined arrangement. The resonators used in the structure are designated as RS1, RS2, and RS3. In the proposed structure, one bus waveguide and three-drop waveguides are used. The radius of coupling and scatter rods are 0.2a and 0.25a, respectively. In multi-port CDF, the input signal is given in the bus waveguide where the signal is coupled in the hexagonally shaped resonators and it is dropped in the drop waveguide. Interestingly, the proposed multi-port structure is designed to drop at various wavelengths from 1500 nm to 1600 nm, which make it more suitable for the CWDM system. In addition, a maximum number of bandwidths is achieved at a different wavelength with high dropping efficiency. The wavelengths correspond to 1.554 nm, 1.563 nm, and 1.57 nm. The design of multi-port CDF in Figure (4-a) and the output spectrum is displayed in Figure (4-b). Here, Port A is the bus waveguide, which represents the input port. The signal is passed at the input port from Port A which it is transferred to all the three resonators and then it is coupled and the wave is dropped at the backward port of all resonators. Resonator 1, Resonator 2 and Resonator 3 achieve high bandwidth at the wavelength of 1.565 nm, 1.569 nm, and 1.554 nm, respectively.



(a) (b)

Fig. 4. (a) Schematic design of multi-port CDF and (b) Output spectrum of multi-port CDF

Effect of the change in the position of resonators in multi CDF: In the multi-port CDF, the position of Resonator 1 (RS1) is modified, whereas the other two resonators are kept constant. By changing the position coupling and scattering rods of each resonator, the maximum bandwidth is achieved at a different wavelength. The red color in Figure 5 (a) displays the changes in the position of the rods at Resonator 1. Similarly, the change in the position of rods at Resonator 2 (RS2) and Resonator 3 (RS3) is shown in Fig(5-b) and Fig(5-c), respectively.

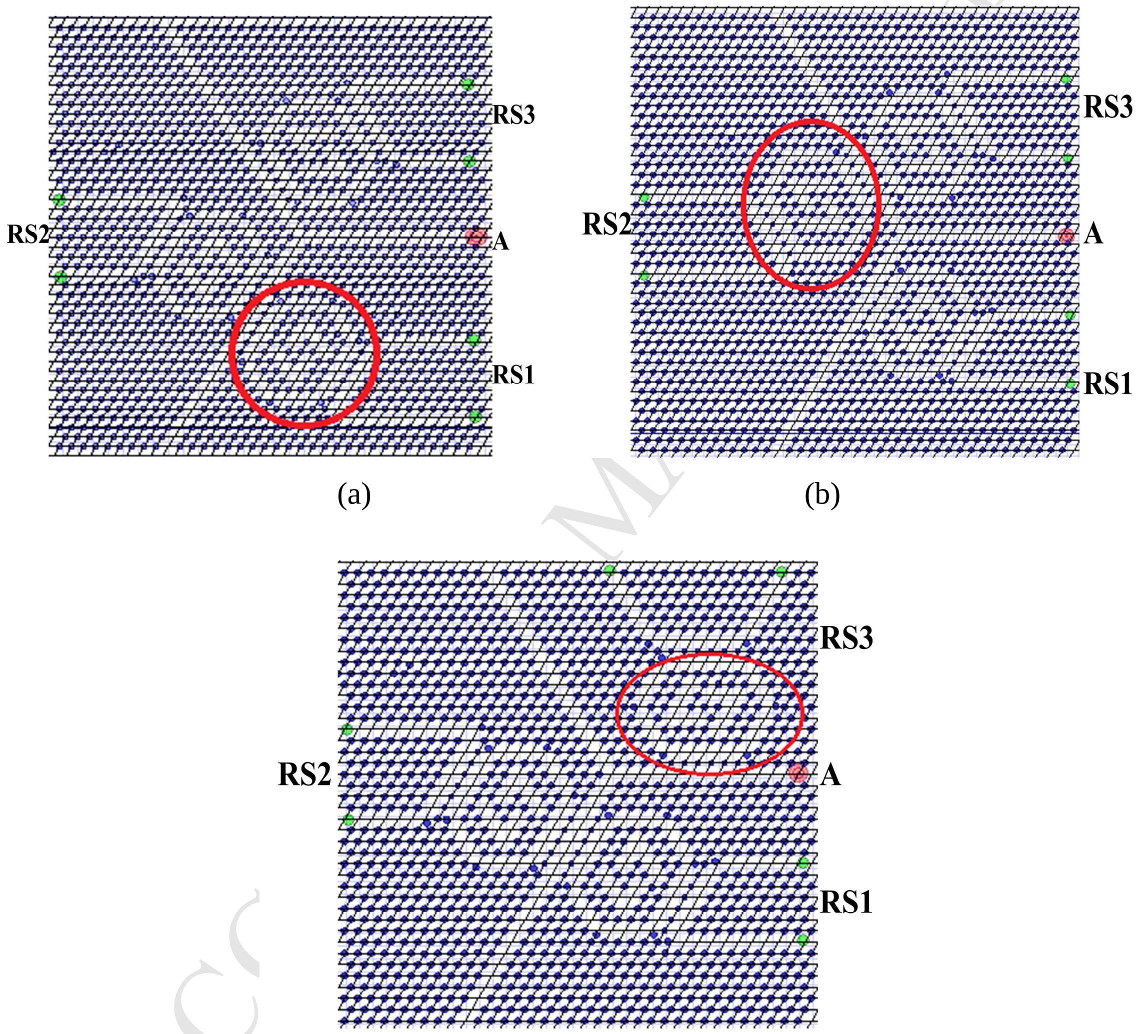


Fig. 5. Change in the position of the rods in (a) RS1 (b) RS2 and (c) RS3

Effect of the change in the radius of the resonator in multi CDF: In addition to the position of the resonators, the radius of coupling rod and scatter rods of resonator1 (RS1) is modified to 0.25a and 0.3a respectively, whereas, the radius of the other two resonators is kept constant. By varying the radius of rods in each resonator, the maximum bandwidth is obtained at a different wavelength. The red color rods represent the changes of the radius in coupling rods and orange color rods shows the changes in the radius of scatter rods in Resonator1, which is shown in Fig(6-a). Similarly, the effect of the change in the radius of the rod is carried out in Resonator 2 and Resonator 3 as shown in Fig (6 -b), and Fig (6 -c), respectively. Such variations provide the change in the wavelength and bandwidth at the various ports of the multi-port CDF.

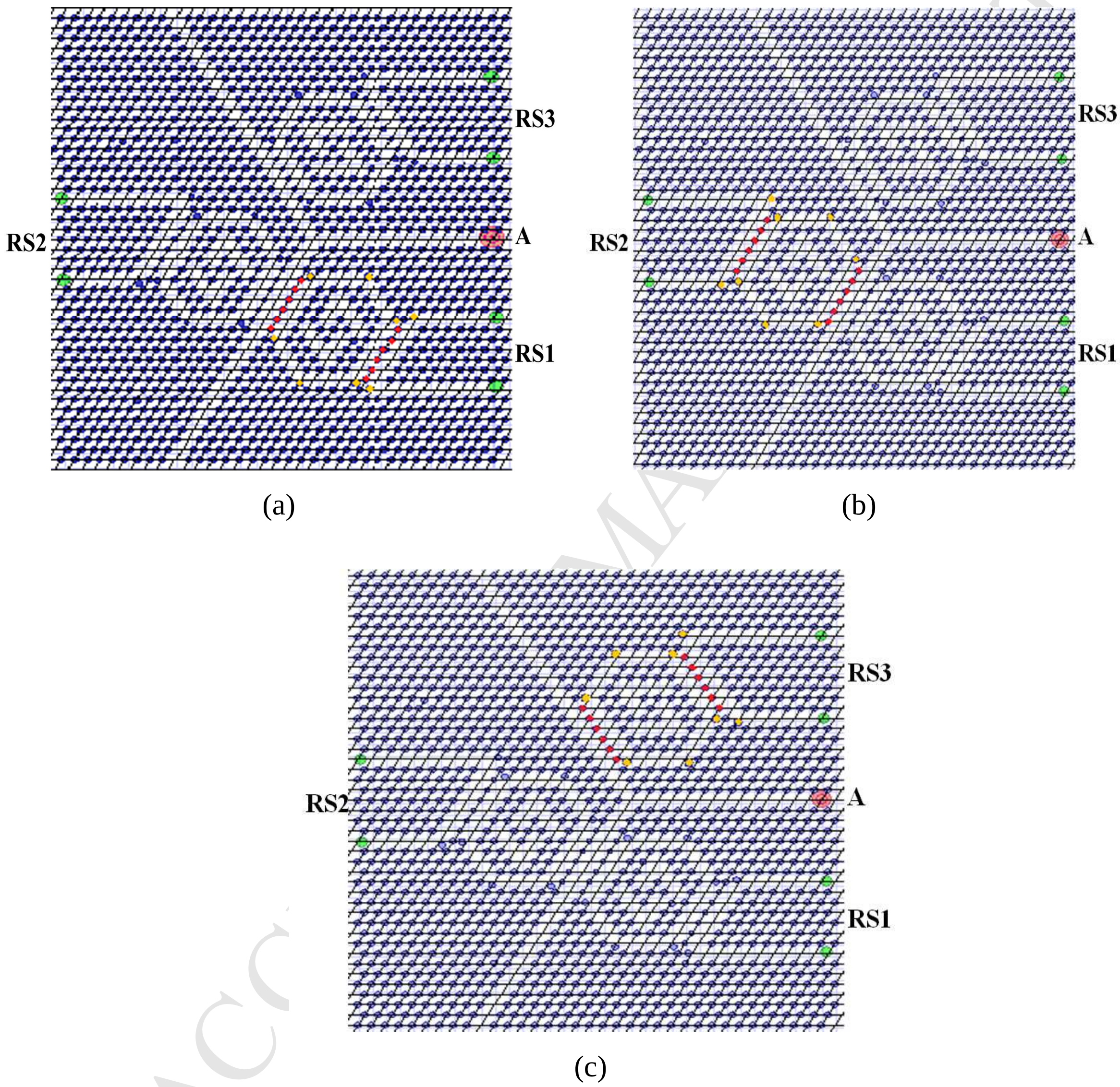


Fig. 6. Change in the rod radius at (a) RS1 (b) RS2 and (c) RS3

IV. SIMULATION RESULTS AND DISCUSSION

The output spectrum of the multi-port Dual L Defected Hexagonal Photonic Crystal Ring Resonator with changes in the position of rods at Resonator1 is shown in Figure 7. The wave with different color represents the output of the forward and backward port of all the three resonators. Here, the 'WL' refers to the wavelength obtained at the various port of multi-port CDF. It has been observed that with a change in the position of RS1, the wavelength WL1, WL2, WL3, WL4, WL5 and WL6 corresponds to 1.52, 1.537, 1.538, 1.557, 1.565 and 1.567 respectively. WL2 and WL3 overlap and the similar intersection is seen among WL3, WL5, and WL6. Hence, the change in the position of the RS1 does not provide distinct wavelength in all the ports of the proposed multi-port CDF.

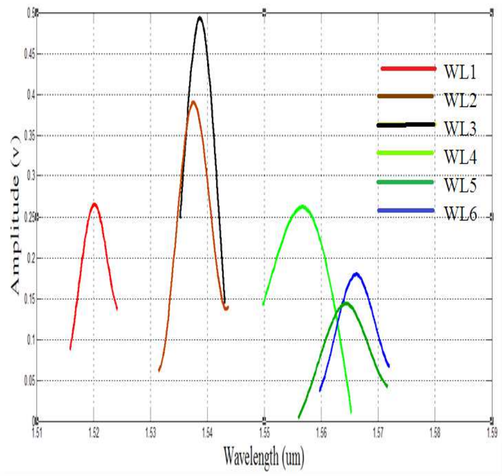


Fig. 7. Output spectrum for change in the position of the rods at RS1

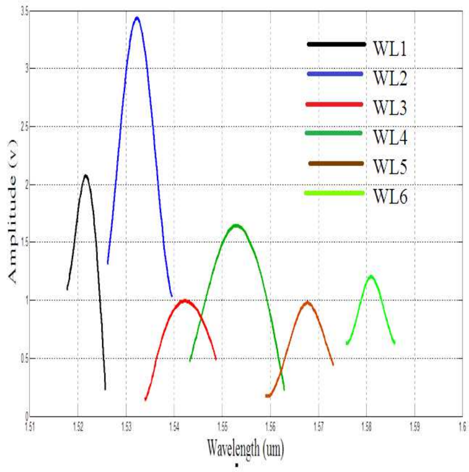


Fig. 8. Output spectrum for change in the position of rods at RS2

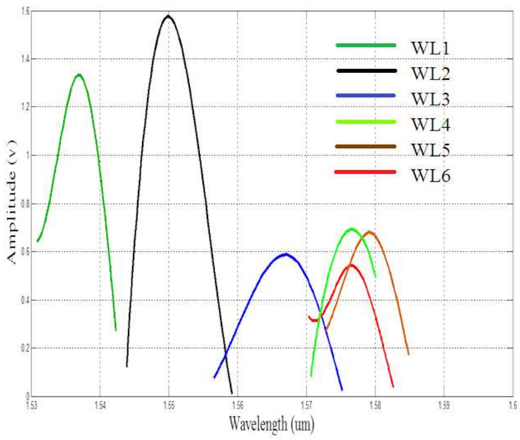


Fig. 9. Output spectrum for change in the position of the rods at RS3

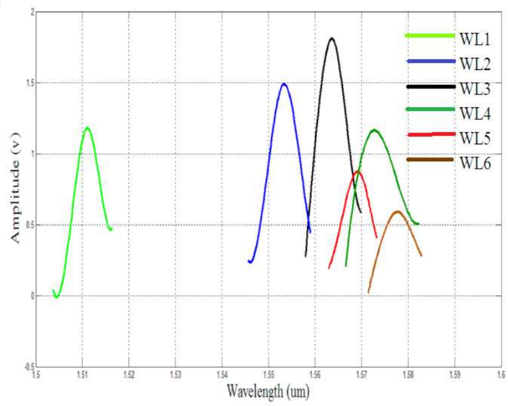


Fig. 10. Output spectrum of change in the radius of the rod at RS1

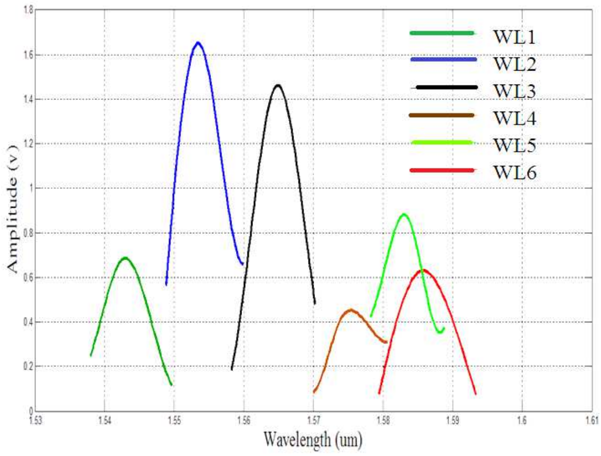


Fig. 11. Output spectrum of change in the radius of the RS2

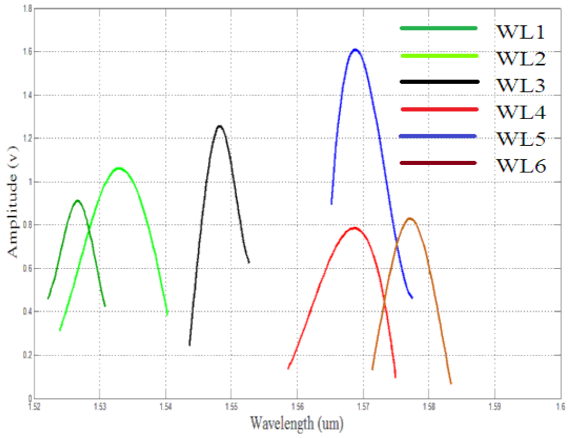


Fig. 12. Output spectrum of change in the radius of the RS3

Figure 8 displays the output spectrum of the change in the position of the rods at Resonator2. As compared to the change in position of the RS1, the RS2 provide distinct wavelengths in all the six ports. The wavelengths WL1, WL2, WL3, WL4, WL5, and WL6 correspond to 1.523 nm, 1.533 nm, 1.542 nm, 1.553 nm, 1.567 nm and 1.581 nm, respectively. In addition, as compared to RS1, the maximum amount of power is coupled with the change in the position at a rod RS2. The output spectrum for change in the position of the rod at Resonator3 is shown in Figure 9. As seen from the curves, although the WL1, WL2 and WL3 at 1.536 nm, 1.55 nm and 1.567 nm, respectively is obtained without any overlapping, the WL4, WL5 and WL6 overlap. Hence, this structure is also not preferred for realizing multi-port CDF. The output spectrum of the changes in the radius of the coupling rods and scatter rods of Resonator1, Resonator2 and Resonator3 are shown in Figure 10, Figure 11 and Figure 12, respectively. As seen from the various curves, it could be inferred that the change in the radius of the rods at RS2 performs better than that of at RS1 and RS3. At RS2, the wavelengths WL1, WL2, WL3, WL4, WL5, and WL6 correspond to 1.544 nm, 1.554 nm, 1.565 nm, 1.575 nm, 1.584 nm and 1.586 nm respectively. Although the tail of WL5 and WL6 exhibits overlapping, this structure provides better dropping characteristics as compared to RS1 and RS3.

V CONCLUSION

In this paper, dual L hexagonal shaped PCRR is implemented and they are designed by an optical channel drop filter in triangular lattice photonic crystal silicon rods. The proposed structure gives 100% backward dropping efficiency and a high bandwidth at a resonant wavelength of 1550nm. By varying the position of coupling and scatter rods in the resonators in multi-channel drop filter and by changing the radius of the coupling, scatter rods in each resonator, 12 distinct wavelengths are obtained using the multi-port CDF.

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