All optical 8-channel wavelength division demultiplexer based on photonic crystal ring resonators

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Abstract

In this paper we are going to propose an 8 channel all optical wavelength division demultiplexer. For this purpose first of all we will proposed and design a channel drop filter based on photonic crystal ring resonator. Then generalize the proposed filter into an 8 channel optical demultiplexer. The obtained desmultiplxer has average band width about 2.5 nm. The minimum transmission efficiency is about 79% and the crosstalk values vary between -12 dB and -40 dB.

Keywords: Cross talk, Optical Demultiplexer, Ring Resonator, Quality factor.

1. Introduction

The idea of using light waves for carrying data and information packets in optical communication networks, offered excellent advantages such as high speed, high band width, immunity, etc. in optical communication networks, optical fibers serve as the transmission medium for propagation of optical waves. Recently wavelength division multiplexing (WDM) technologies have been proposed in order to make the optimum use of the effective capacity of optical fibers. Such that one can allocate one single optical fiber for multiple users, and send multiple optical channels inside one single optical fiber. In user end of the network one needs a device to separate these channels from each other and deliver them to their corresponding users. Optical demultiplexer is what we need, a device that is capable of separating multiple channels with different central wavelengths [1].

Due to significant role of photonic crystal (PhCs) based demultiplexers in the future optical communication networks so many different mechanisms have been proposed for designing all optical wavelength demultiplexers. One common mechanism is employing the superprism effect of PhCs. For instance a superprism based structure has been proposed by Barnier et al [2] by creating an efficient balance between wavelength dispersion and the beam divergence, which has 4 output channels with channels spacing equal to 25 nm and crosstalk level better than -16 dB. By combining superprism effect with negative diffraction and refraction a 4 channel demultiplexer with channel spacing equal to 8 nm and crosstalk level better than -6.5 dB has been proposed [3].

Another common mechanism is using heterostructure devices. This kind of optical demultiplexers are obtained by cascading multiple optical filters with different structural parameters such as refractive index or lattice constant. A 5-channel demultiplexer has been proposed by horizontally cascading five single channel drop filters with different lattice constants, in this structure the channel spacing was around 8 nm [4]. Rakhshani and Birjandi [5] cascaded three PhC ring resonator based channel drop filters with different refractive indices to realize a four channel demultiplexer. In this structure the channel spacing was about 6.1 nm with bandwidth and average transmission efficiency being 2.75 nm and 95%. Crosstalk and footprint were obtained -24.44 dB and 294.25 um^2 respectively. As we can see in heterostructure based optical demultiplexers the channel spacing is quite large.

Multi-channel filters are the other mechanism proposed for realizing optical demultiplexers. In this kind of demultiplexers, the total structure has the same refractive index and lattice constant, and only the resonant parts of the structure are different from each other. By combining a T-branch waveguide with four resonant cavities Rostami et al [6] obtained a structure capable of separating four channels with channel spacing as low as 1nm. The transmission efficiency of the channels in their structure was not flat such that the minimum and maximum transmission efficiencies were 49% and 79% respectively. A year later, their combined Y-branch waveguide with the four resonant cavities improved the transmission efficiency at the expense of channel spacing [7]. Alipour-Banaei et al [8] proposed a resonant defect structure for designing multi-channel demultiplexers. In their 8 channel demultiplexer the channel spacing was about 1 nm. The minimum transmission efficiency and the largest crosstalk were 40% and -8 dB. Most recently and 8 channel optical demultiplexer has been proposed using PhC defective cavity. In the proposed demultiplexer 8 optical wavelength have been separated by choosing 8 different values for the width of resonant cavities. In this structure the channel spacing was about 3 nm [9].

In this paper we are going to propose an optical channel drop filter with improved quality factor value, and then employ the obtained result in designing an optical 8 channel demultiplexer. For performing the required simulations and calculations we will use plane wave expansion (PWE) [10] and finite difference time domain (FDTD) methods [11].

The rest of the paper was organized as follows: in section 2 we proposed a photonic crystal ring resonator based channel drop filter, in section 3 we discussed the design procedure and simulation results for the proposed demultiplexer and finally in section 4 we make conclusion from our work.

2. Channel Drop Filter

The fundamental PhC structure used for designing the channel drop filter (CDF) is a 29*23 array of dielectric rods with square lattice. The effective refractive index of dielectric material is 3.46 and the r/a (radius of rods to lattice constant) ratio is 0.2. Using PWE method the band structure diagram for this PhC with aforementioned values for structure parameters is shown in figure 1. According figure 1, there are two PBGs in TM mode (blue color areas) and one PBG is TE mode (red color area). The first PBG in TM mode which is between $0.28<a/\lambda< 0.41$, has the appropriate frequency range for our goals. By choosing the lattice constant to be a=620 nm the PBG will be at 1512 nm $<\lambda<$ 2214 nm, which completely covers the wavelength range of the third optical communication window.

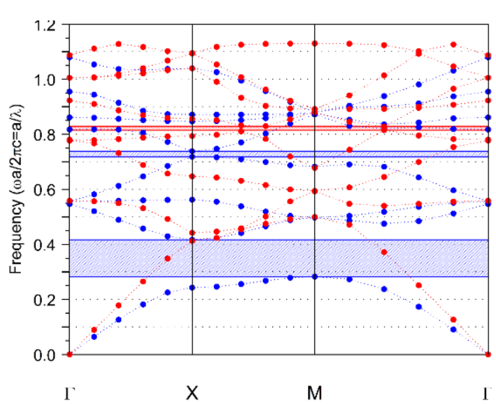


Figure 1. The band diagram of the fundamental PhC structure.

For designing the optical CDF, by removing a complete row of dielectric rods we created the BUS waveguide, then an L shaped waveguide has been created as the DROP waveguide. Finally a ring resonator structure was sandwiched between the BUS and DROP waveguides for creating the resonant ring, first we removed a 7*7 square of rods and then placed a12-fold quasi crystal in the middle of the resulted empty square area. The lattice constant of the quasi crystal is r=0.78*a. the radius of quasi-crystal rods is the same as the fundamental structure. The proposed CDF is shown in figure 2, which has three ports: input port (A), forward transmission port (B) and backward drop port (C). The output spectrum of the CDF is shown in figure 3. The normalized transmission of the structure at port B and C are depicted with blue and green curves. Figure 3 shows that optical waves in all the wavelengths will go toward port B except at λ=1547.7 nm in which optical waves will drop to the drop waveguide and travel toward port C. The drop efficiency of the structure is 100% at λ=1547.7 nm and the quality factor ($Q=\lambda_0/\Delta\lambda$) is 3869. At the following we are going to investigate the effect of some structural parameters on the output spectrum of the CDF.

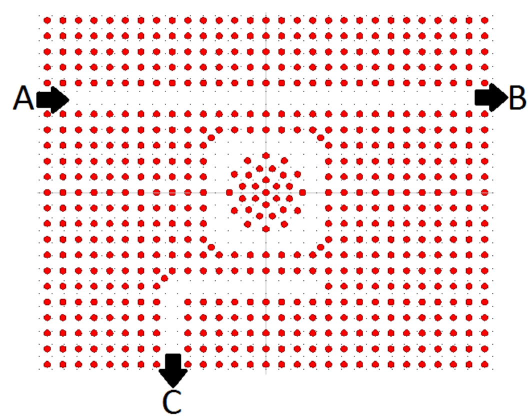


Figure 2. The proposed CDF.

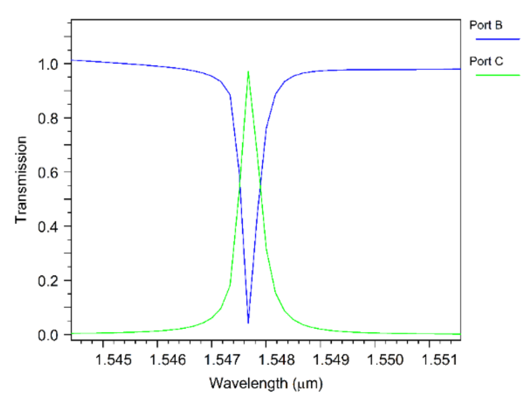


Figure 3. The output spectrum of the CDF.

The output spectra of the CDF for different values the quasi-crystal lattice constant (r) is shown in figure 4. As shown in figure 4 by increasing r, the output wavelengths shift toward lower wavelengths. Such that for r=485, 483, 481, 479 and 477 nm the output wavelengths are λ=1547 nm, 1548 nm, 1549.2 nm, 1550.5 nm, and 1551.7 nm respectively.

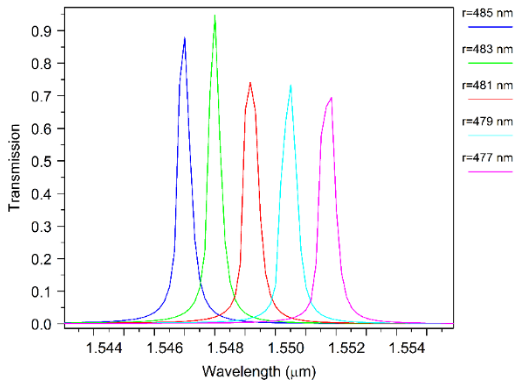


Figure 4. The output spectra of the CDF for different values of r.

The output spectra of the CDF for different raddi of the quais-crystal outer rods (R_o) is shown in figure 5. As shown in figure 5 by increasing R_o, the output wavelengths shift toward higher wavelengths. Such that for R_0=125, 123, 121, 119 and 117 nm the output wavelengths are λ=1548.6 nm, 1546.9 nm, 1545.4 nm, 1544 nm, and 1542.7 nm respectively.

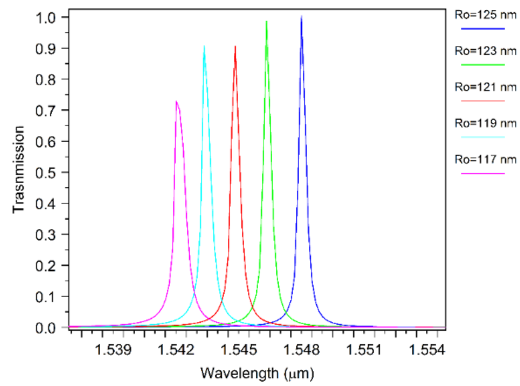


Figure 5. The output spectra of the CDF for different values of R_o

3. Demultiplexer Design

Now we are going to discuss the design procedure for the proposed optical demultiplexer. The proposed demultiplexer consists of three main parts one input waveguide, eight output waveguides and eight resonant rings. For creating the input waveguide we removed 65 dielectric rods in Γ-M direction, and then created 8 output L-shaped waveguides. Finally we located a ring resonator structure between the input waveguide and every output waveguides. In order to separate different channels with different wavelengths, these resonators should be different from each other. So for 8 resonant rings, we choose 8 different values for the radii of outer rods (R_j where j=1, 2, 3, 4, 5, 6, 7, and 8 is the channel number) in every ring resonator. The R values for the eight resonant cavities are: R_1= 125 nm, R_2= 121 nm, R_3= 117 nm, R_4= 113 nm, R_5= 109 nm, R_6= 105 nm, R_7= 101 nm and R_8= 97 nm. The final sketch of the demultiplexer is shown in figure 6.

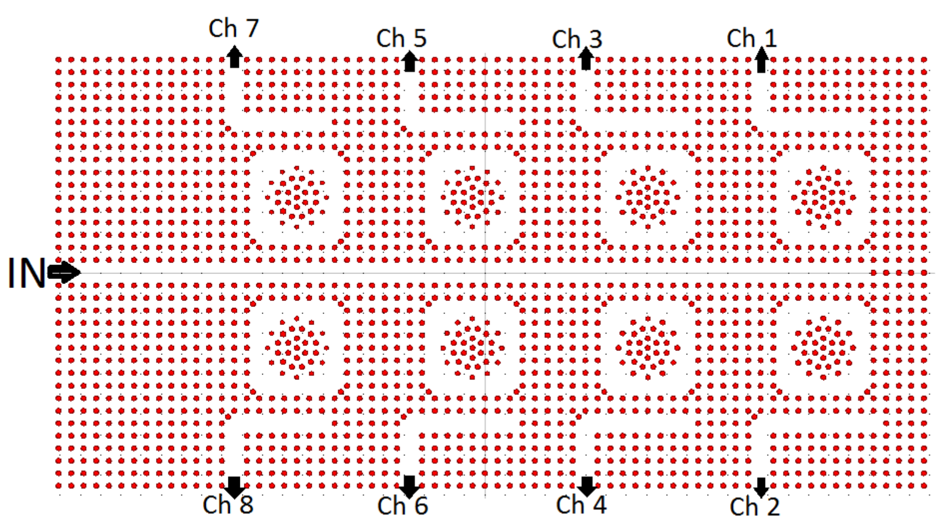
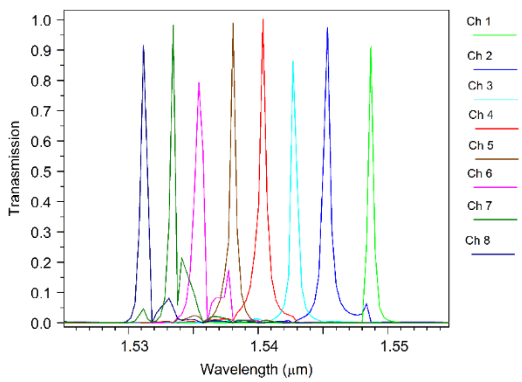
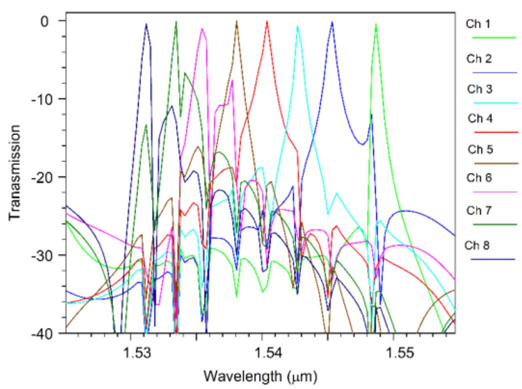


Figure 6. The final sketch of the proposed demultiplexer.

The output spectrum of the demultiplexer has been obtained and shown in figure 7. This demultiplexer has 8 channels with central wavelengths equal to λ_1= 1548.8 nm, λ_2=1545.3 nm, λ_3= 1542.8 nm, λ_4= 1540.2 nm, λ_5= 1538 nm, λ_6= 1535.4 nm, λ_7= 1533.3 nm, and λ_8= 1531.2 nm. For this structure the minimum and maximum transmission efficiency is about 79% and 100% respectively. The average channel spacing is about 2.5 nm. For the proposed demultiplexer the maximum and minimum band width is about 0.6 nm and 0.3 nm respectively. The detail specification for the demultiplexer are listed in table 1.



(a)



(b)

Figure 7. The output spectrum of the proposed demultiplexer (a) Linear and (b) dB scale.

Another quality index in assessing the performance of optical demultiplexers is the crosstalk values of the proposed structure, which shows the magnitude of interference between adjacent channels. The crosstalk values are listed in table 2, in which they are named as X_{ij}, (i,j varies from 1 to 8) that means the effect of i-th channel in j-th channel. The crosstalk level for the structure varies from -12 dB to -40 dB. Finally the overall footprint of the proposed structure is about 482 μm^2.

Table 1. The physical and optical parameters of the 8-channel demultiplexer.

Channel	R (nm)	λ (nm)	Δλ (nm)	Q	T. E*. (%)
1	125	1548.8	0.3	5162	92
2	121	1545.3	0.5	3090	98
3	117	1542.8	0.5	3085	86
4	113	1540.2	0.5	3080	100
5	109	1538	0.4	3845	99
6	105	1535.4	0.6	2559	79
7	101	1533.3	0.3	5111	98
8	97	1531.2	0.5	3062	92

*Transmission Efficiency

Table 2. The crosstalk value of the channels in dB scale.

X_{ij}	1	2	3	4	5	6	7	8
1	-	-30	-27	-31	-40	-28	-40	-40
2	-32	-	-24	-28	-38	-28	-32	-36
3	-31	-20	-	-20	-30	-27	-28	-30
4	-34	-28	-22	-	-26	-24	-26	-28
5	-35	-30	-23	-20	-	-16	-22	-26
6	-31	-33	-27	-26	-22	-	-22	-20
7	-30	-34	-30	-28	-14	-26	-	-12
8	-31	-35	-32	-32	-20	-30	-14	-

The comparison of this study with some recent works is presented in table 3. According to table 3 the proposed structure has better channel spacing [5,7,12,13], quality factor [7,9,12, 13], footprint [6,9,12], transmission efficiency [5-7,12], and crosstalk values [7,9,12] compared with previously proposed works.

Table 3.Comparing our results with some previous works.

Works	Channel Spacing (nm)	QF	Footprint (μm^2)	Minimum T.E(%)	Largest Crosstalk (dB)
[13]	28	< 61	NA	80	NA
[7]	3	1296	313	63	-11
[6]	1	3000	536	42	-14
[5]	15	NA	317	24	NA
[12]	3	561	498	50	-7.5
[9]	2.1	2300	495	94	-11.2
Our	2.5	2559	482	79	-12

4. Conclusion

In this paper we proposed a photonic crystal ring resonator based channel drop filter with improved quality factor. We employed a quasi-crystal as the core part of the ring resonator. Investigating the effect of structural parameters on the resonant wavelength of the CDF showed that by choosing proper values for the radii of outer rods of the ring resonator one can obtain different resonant wavelengths for the proposed CDF. We employed this fact to generalize the CDF and design an eight-channel optical demultipexer. The obtained desmultiplxer has average band width about 2.5 nm. The minimum transmission efficiency is about 79% and the crosstalk values vary between -12 dB and -40 dB.

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