

# 2-channel all optical demultiplexer based on photonic crystal ring resonator

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**Abstract** In this paper, we proposed a 2-channel demultiplexer based on photonic crystal ring resonator (PCRR). For performing wavelength selection, we used two ring resonators, two different wavelengths were obtained by using two resonant rings with different values for the radius of dielectric rods. All the simulations and calculations have been done using Rsoft Photonic CAD software, which employs finite difference time domain (FDTD) method. The output channels were respectively at 1590.8 and 1593.8 nm, correspondingly had the quality factors of 7954 and 3984, the crosstalk values of  $-22$  and  $-11$  dB separately. The total footprint of our proposed structure is  $681.36 \mu\text{m}^2$ . Results suggest that 2-channels in the proposed structure are characterized with high transmission efficiency and low band width, resulting in a very sharp output spectrum and high quality factor values.

**Keywords** photonic crystal ring resonator (PCRR), 2-channel demultiplexer, all optical communication

## 1 Introduction

Thanks to wavelength division multiplexing (WDM) and dense wavelength division multiplexing (DWDM) techniques, it is possible to transfer multiple light waves with different wavelengths in single optical fiber. Optical demultiplexers and optical filters play a crucial role in WDM and DWDM applications. These devices are used for separating the very closely spaced optical channels in all optical communication networks. Due to the importance of these devices in optical communication, there have been many works reported in relation with photonic crystal (PhC) based filters [1–3] and demultiplexers [4,5].

Superprisms [6,7], coupled and cascaded waveguides [8,9], L-shaped waveguides and line defect waveguides in a 12-fold photonic quasicrystal [10], cascaded channel drop filters [11], resonant cavities [12,13] are some examples of mechanisms used for designing all optical PhC-based demultiplexers.

Other popular device designed using PhC structures is ring resonators. A photonic crystal ring resonator (PCRR) simply consists of three main parts: two waveguides and a resonant ring located between the waveguides. One of the two waveguides is called add waveguide and the other one is called drop waveguide. PCRR can be used for designing optical channel-drop filters [14,15], optical demultiplexers [16], optical splitters and optical bends [17]. So many works have been done relating to PCRR. For the first time, Kim et al. [18] used PCRR for designing a waveguide ring laser cavity. Recently, Mahmoud et al. [19] had proposed a new optical filter based on PCRR, and used an X-shaped structure as their resonant ring. In another paper, they reported the effect of different parameters on the filtering behavior of PCRR [20].

In designing optical demultiplexers, increasing the transmission efficiency and quality factor of the output channels is very important. The other important parameter in optical demultiplexers is the bandwidth of the output channels. In order to have high quality factor and improve the wavelength separation performance for the demultiplexer, we should decrease the bandwidth of the output channels. Our goal is designing an all optical demultiplexer, which has better transmission efficiency, quality factor and bandwidth values compared with previously reported works. In most of the reported papers, the transmission efficiencies [8–13] and quality factor values [8–13] are less than our proposed demultiplexer.

In this paper, we presented a 2-channel optical demultiplexer using a PCRR structure. For designing the proposed demultiplexer, we used a PCRR structure with two resonant rings with different radius. It was found that

the proposed structure has some excellent characteristics as follows. One is that both channels have very high transmission efficiency, which is very close to 90%. The other is that the two channels are endowed with very low band width, resulting in a very sharp output spectrum and high quality factor values.

## 2 Design procedure

Photonic band gap (PBG) in PC structures is important for designing PC-based devices, so we should firstly define the PBG region used for designing our proposed structure. Using the plane wave expansion method, we calculated the PBG of the fundamental structure, and it is a  $40 \times 35$  square lattice of dielectric rods in air environment. The refractive index of dielectric rods is 3.49, and the radius of them is  $0.2 * a$ , here 'a' is the lattice constant of the PC equal to 595 nm. Figure 1 shows that there are three PBGs, two PBGs in transverse magnetic (TM) mode (blue color areas in Fig. 1) and one in transvers electric (TE) mode (red color area). The normalized frequencies of the first PBG in TM mode are between 0.28 and 0.41, the second one between 0.71 and 0.73, and the PBG in TE mode between 0.81 and 0.82. Considering  $a = 595$  nm, only the first PBG in TM mode will be suitable for our goals which is between 1451 and 2125 nm. Therefore, all the simulations will be done in TM mode.

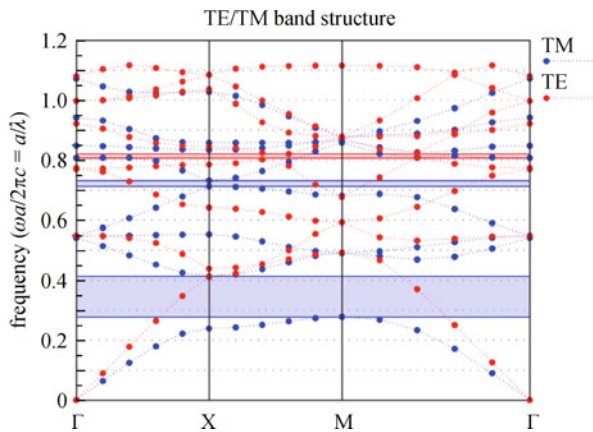


Fig. 1 Band structure of basic PhC structure

Our proposed 2-channel demultiplexer consists of three main parts as follows: 1) one input waveguide in the center line of the structure; 2) two output waveguides in the upper and lower parts of the structure respectively; and 3) two resonant rings located between the input waveguide and each output waveguide. In addition, in order to improve the resonant performance of the resonant rings, we introduce four scattering rods at the corners of each resonant ring which are highlighted with blue color in schematic diagram of Fig. 2. The radius of these scattering rods is

the same as the fundamental structure. To make the ring having resonant effect, we firstly obtained two empty  $7 \times 7$  square cavities by removing a  $7 \times 7$  square structure of dielectric rods, and then we put a  $5 \times 5$  square structure of dielectric rods inside each  $7 \times 7$  square cavity whose basic parameters are different from the original structure. The lattice constant of the  $5 \times 5$  structures is  $A = 0.95 * a$  ('a' is the lattice constant of the original structure), and the radius of their dielectric rods for the upper and lower rings are  $R_2 = 0.28 * A$  and  $R_1 = 0.29 * A$  respectively. This difference in the radius between the two rings results in different resonant wavelengths, therefore the structure can separate two different channels with different central wavelengths.

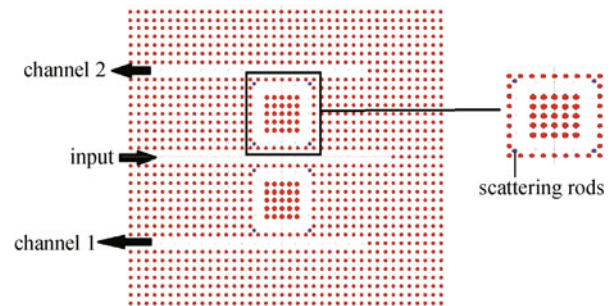
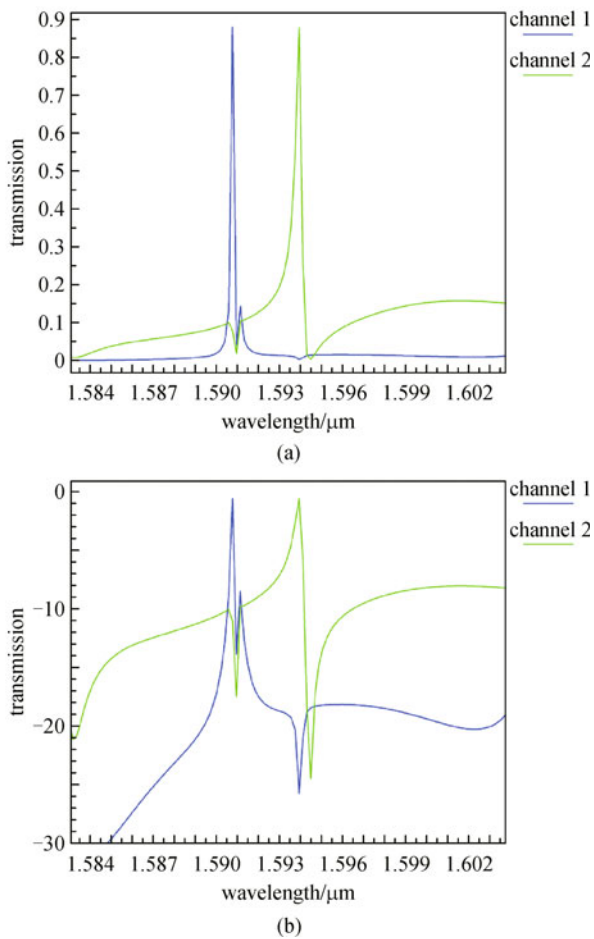


Fig. 2 Schematic diagram of proposed demultiplexer

## 3 Simulation and results

Using finite difference time domain (FDTD) method, we simulated the proposed structure and obtained the output spectrum of the demultiplexer. As we known, three dimensional (3D) simulation of the structure is required to achieve accurate results, but it is very time consuming and needs very powerful computer systems. In this paper, effective refractive method was used to reduce the 3D calculation to a 2D one with minimum errors. We used perfectly matched layers around the structure as boundary condition whose thickness is 500 nm. The output spectrum of the proposed demultiplexer is shown in Fig. 3. The output spectra in linear scale are shown in Fig. 3(a), and Fig. 3(b) shows that the dB scale of the output spectra, which is suitable for obtaining the bandwidth and crosstalk values of the channels. Figure 3 shows that output channels are respectively at  $\lambda_1 = 1590.8$  nm and  $\lambda_2 = 1593.8$  nm, it is also denoted in Fig. 3 that both channels in this demultiplexer have very high transmission efficiency, and which is very close to 90%, which is much more better than the most previously reported optical demultiplexers [8–13]. These high transmission efficiencies results in very low loss of the transmitted optical power, and this is very crucial in optical communication networks. The spacing between these two channels is 3 nm and is suitable for WDM applications. The other important parameter of the demultiplexers is quality factor. As far as we known,



**Fig. 3** Output spectrum of demultiplexer. (a) Linear scale; (b) dB scale

more quality factor contribute to better wavelength separation performance for the demultiplexer. The bandwidth of the channels in the proposed demultiplexer for first and second channels is 0.2 and 0.4 nm, respectively. Therefore, the quality factors of them are 7954 and 3984 corresponding, which are much better than most of the reported demultiplexers in literature [8–13]. The complete parameters are listed in Table 1.

**Table 1** Simulation results of demultiplexer

channel	$\lambda_0/\text{nm}$	$\Delta\lambda$	$Q$	transmission
1	1590.8	0.2	7954	90%
2	1593.8	0.4	3984	90%

Crosstalk is the other crucial property in optical demultiplexer and it shows that how much our channels interfere with each other. The crosstalk values of our demultiplexer are shown in Table 2 where  $X_{ij}$  shows the crosstalk value of channel  $i$  in channel  $j$ . According to the results, the crosstalk of channel 1 at the central wavelength

of channel 2 is about  $-22$  dB and the crosstalk of channel 2 at the central wavelength of channel 1 is about  $-11$  dB. These results show that wavelength separation performance of channel 2 is better than channel 1.

**Table 2** Crosstalk values of demultiplexer/dB

$X_{ij}$	1	2
1	–	$-22$
2	$-11$	–

## 4 Discussion

In designing optical demultiplexers, transmission efficiency, quality factor and the bandwidth of the output channels are very important. For obtaining high quality factor we need to decrease the bandwidth. Our goal is designing an all optical demultiplexer, which has better transmission efficiency, quality factor and bandwidth values compared with previously reported works. In most of the reported papers, the transmission efficiencies [8–13] and quality factor values [8–13] are less than our proposed demultiplexer.

## 5 Conclusions

In this paper, we proposed a 2-channel all optical demultiplexer using PCRRs. To separate the desired channels with different central wavelengths, we used two resonant rings with different values for the radius of dielectric rods. Our proposed demultiplexer is capable of separating to channels with central wavelengths equal to 1590.8 and 1593.8 nm. The quality factor of the output channels are 7954 and 3984. And the crosstalk values are  $-22$  and  $-11$  dB. Our suggestion for future works can be improving the crosstalk values and reducing the channel spacing. Also we can consider increasing the number of output channels.

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