A Proposed Dual Channel Optical Demultiplexer based on Photonic Crystals

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ABSTRACT
In this paper, we used photonic crystal resonant cavity structure for designing a 2-channel optical wavelength demultiplexer. It has been shown that by using photonic crystal resonant cavity, wavelength separation is possible. In order to select 2 channels with different central wavelengths we employed 2 resonant cavities with different structural parameters. The platform used for designing the proposed demultiplexer is a hexagonal lattice of dielectric rods immersed in air. The demultiplexer has 2 channels with central wavelengths equal to λ_1=1549.4 nm and λ_2=1551.2 nm. The transmission efficiency of the demultiplexer is more than 92%. The quality factors for first and second channels are 1936 and 3021 respectively.

KEYWORDS: Photonic Crystal, Demultiplexer, Crosstalk, Band Gap.

1. INTRODUCTION

In optical communication networks, light travels inside an optical fiber cable. If one assigns one optical fiber for every user, in a city with millions of users, one should has enormous amount of optical fiber cables to cover all the users, which would be very costly. The best solution for this problem is assigning one single optical fiber for multiple users. Using the 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. After transferring multiple channels in on 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 a device that is able to separate multiple channels with different central wavelengths.

Photonic crystals (PhCs) are good candidates for realizing ultra compact optical devices suitable for all optical integrated circuits. Because of their periodic distribution of refractive index, they have the ability to confine light in very small spaces which was one of the major problems for designing ultra compact optical devices. Another feature of PhCs is their Photonic Band Gap (PBG), a wavelength region in their band structure in which no electromagnetic wave can propagate inside these crystals.

Recently there have been many works about PhC based demultiplexers in literature. One of the most common mechanisms used for designing PhC based demultiplexers is coupling and cascading PhC based Waveguides (PCW). One has been proposed by Chien et al [1], in which their PCW coupler was consisted of two line defects of reduced rods in a triangular lattice of PhC and demultiplexing had been implemented by the distinction between coupling and decoupling of PCW. This structure was able to separate 2 channels with 1.31 µm and 1.55 µm central wavelengths. Rawal and Sinha [2] proposed another silicon on insulator PhC based demultiplexer for 1.31 µm and 1.55 µm bands. They used a Y shape waveguide structure for designing their proposed demultiplexer. At the output branches of Y shape waveguide, they changed the radius of air pores and made 2 channels for 1.31 µm and 1.55 µm wavelengths. Another dual band demultiplexer for 1.31 µm and 1.55 µm has been realized by combining multimode inference and PhCs [3]. In this structure, PhC was used as filter, such that light with wavelength of 1.3 µm would pass the PhC part and go toward port A, but light with 1.5µm wavelength would be reflected from the PhC part and would be guided toward port B. Also, Photonic Band Gap can be used as demultiplexing mechanism [4].

A superprism based demultiplexer was a Coarse WDM demultiplexer designed by creating an efficient balance between wavelength dispersion and the beam divergence. It has been shown that a 2D rhombohedral lattice PhC displays both high beam collimation and wavelength dependent angular dispersion. By this method, a 4 channel optical demultiplexer with channel spacing equal to 25 nm and crosstalk level better than -

16 dB has been proposed [5]. Employing resonant cavities, Rostami et al [6] proposed a 4 channel demultiplexer with channel spacing equal to 1 nm, but the overall transmission efficiency of their structure was less than 65%, which results in very high power loss. Recently Rakhshani and Birjandi [7] has proposed a 4 channel demultiplexer by combining 3 PhC ring resonators with different dielectric constants. The channel spacing was about 6.1 nm. Besides, the transmission efficiency and bandwidth were 92% and 2.75 nm respectively.

The rest of this paper organized as following: in section 2, we calculated the band structure and photonic band gap and also the design procedure and different parts of the demultiplexer have been introduced. Simulation and results have been discussed in section 3, and finally in section 4 we concluded from our work and simulations.

2. DESIGN PROCEDURE

To design the proposed demultiplexer, we employed a 30*30 hexagonal lattice of dielectric rods immersed in air. The effective refractive index of the dielectric rods is 2.5 and their radius is $r=0.27*a$, where a is the lattice constant of the PhC. First, we should calculate the band structure of the fundamental structure and extract its PBG region. For this purpose, we used plane wave expansion (PWE) method. PWE is a numerical method in frequency domain by which we can calculate the eigenmodes and eigenfrequencies of periodic structures by iteratively solving the Maxwell's equations in frequency domain [8]. Due to accuracy and time considerations in our work, we used Bandsolve simulation tool of Rsoft Photonic CAD software to extract the band structure diagrams and PBG region of the structure. The band structure diagram of the structure with aforementioned values for refractive index, radius of rods and lattice constant are shown in Fig. 1. It shows that there are two PBGs in transverse magnetic (TM) mode and no PBG in transverse electric (TE) mode. The second PBG in TM mode is wide enough for optical communication applications. The normalized frequency range of this PBG is $0.6<a/\lambda<0.68$ considering a=1010 nm the wavelength range of PBG will be 1485 nm < λ< 1683 nm. Therefore, all the simulations will be done in TM mode.

The proposed structure is composed of three main parts: (a) one input waveguide, (b) two resonant cavities, and (c) two output waveguides. As shown in Fig. 2, to realize the proposed demultiplexer, we removed 23 dielectric rods to create the input waveguide, whose role is to guide input optical signals from input port toward output resonant cavities. The wavelength selection mechanism is based on resonant cavities, which are created by reducing the radius of adjacent dielectric rods. These reduced rods are shown in blue and green for channel 1 and 2 respectively. Finally, by removing 9 rods in the same direction with the resonant cavities we created the corresponding output waveguide of each resonant cavity. In order to improve the coupling efficiency and at the borderline of the resonant cavities and the input waveguide, we removed one dielectric rod for each resonant cavity.

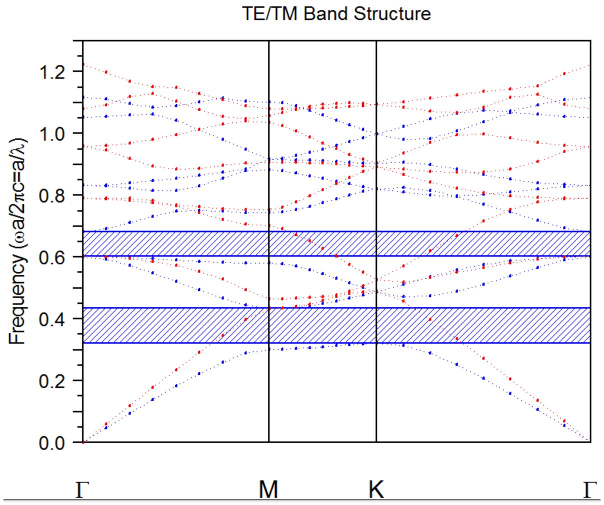


Fig. 1. The band structure of the fundamental structure

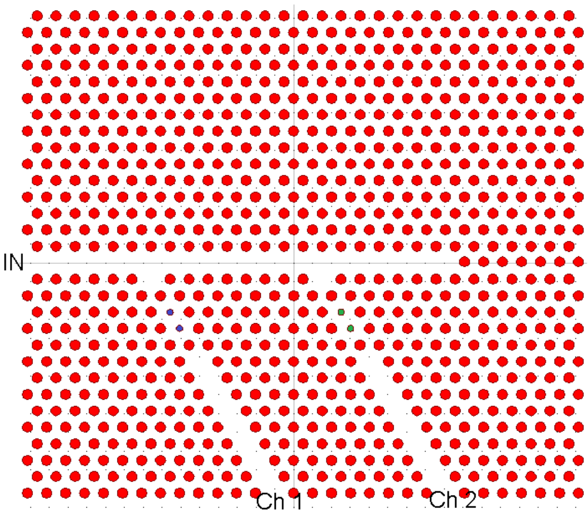


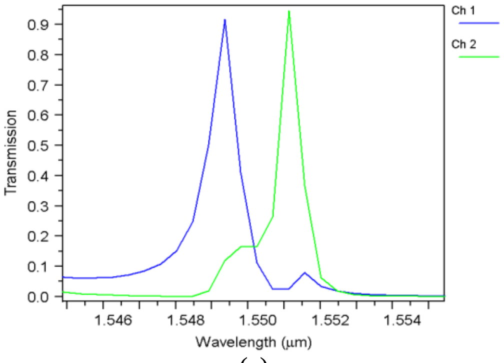
Fig. 2. The final sketch of the proposed demultiplexer

Our goal of designing the proposed demultiplexer is capable of separating optical channels according to their central wavelengths. To do so, the resonant cavities should be different from each other for structural parameters. It has been shown that the resonant wavelength of resonant cavities depends on the radius and refractive index of the reduced dielectric rods. The resonant wavelength is very sensitive upon the variation of the refractive index such that a very slight variation in the refractive index results in very large wavelength shift. Therefore, by choosing different refractive index for the resonant cavities, the channel spacing will be so large. As far as we know having small channel spacing in optical demultiplexers is a Fig. of merit. The sensitivity of resonant wavelength upon radius of the rods is much less than the refractive index, so in this paper we chose two different radiuses for the resonant cavities. For this purpose, the radius of blue and green rods is chosen to be 165 and 170 nm.

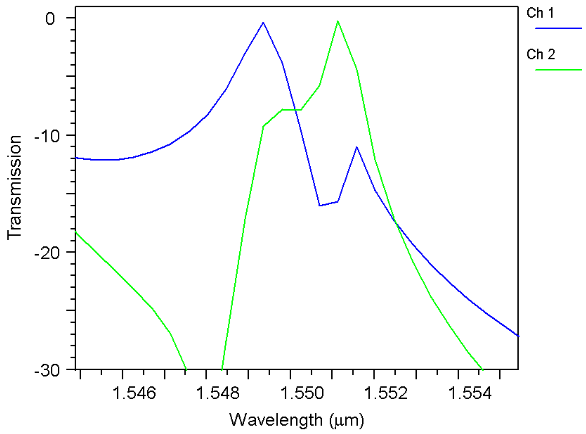
3. SIMULATION AND RESULTS

The final step in designing is simulation and obtaining the optical characteristics of the demultiplexer. Consequently, we used Fullwave simulation tool of Rsoft photonic CAD software to test the device. Fullwave studies the propagation of light inside PhC based devices using finite difference time domain (FDTD) method [9]. For accurate modeling of the demultiplexer we need 3D simulation, but it requires great amount of run time and very powerful computer. So we used effective index approximation method of PhCs to satisfy this requirement and with this approximation we reduced 3D simulations to 2D simulations [9]. Grid size in two dimensions (Δx and Δy) is chosen to be *a* /16 which equals 63 nm. Due to stability considerations of the simulation, the time step (Δt) is equal to 0.041 [9].

The simulation is done during 20000 time steps, which requires 130 min run time and 20 MB memory size for the proposed device. The output spectrum of the demultiplexer has been obtained and shown in Fig. 3. This demultiplexer has 2 channels with central wavelengths equal to 1549.4 nm and 1551.2 nm. The channel spacing for this demultiplexer is 1.8 nm and the transmission efficiency is more than 92%. The bandwidth for the first and second channels is 0.8 and 0.5 nm respectively, so the quality factors (Q) will be 1936 and 3021. Other specifications of the demultiplexer are listed in table 1. Also, the crosstalk values are listed in table 2, in which crosstalk values are named as X_{ij}, (i and j varies from 1 to 2) that shows the effect of j-th channel in i-th channel. In table 2, i and j are column and row indices.



(a)



(b)

Fig. 3. Output spectrum of the demultiplexer (a) linear and (b) dB scales

Table 1. Simulation results of demultiplexer

Channel	λ_0 (nm)	$\Delta\lambda$ (nm)	Q	Transmission
1	1549.4	0.8	1936	92%
2	1551.2	0.5	3021	94%

Table 2. Crosstalk values of demultiplexer (dB)

X_{ij}	1	2
1	-	-15
2	-16	-

Table 3. Comparing our results with some previous works

Proposed Works	Channel Spacing (nm)	Q-Factor	$\Delta\lambda$(nm)	Transmission (%)	Worst case Crosstalk (dB)
Ref [10]	28	< 61	> 25	80	NA
Ref [11]	3	1296	1.2	63	-11
Ref [6]	1	3000	0.5	42	-14
Ref [7]	15	NA	NA	24	NA
Ref [12]	6	460	2.75	92	-24
Ref [13]	3	561	2.8	50	-7.5
Our work	1.8	1936	0.8	92	-10

In table 3 we compared our results with previous works. As one can see the proposed structure has better channels spacing [7,10-11,12-13], quality factor [7, 10-11,12-13], and transmission efficiency [6-7,10-13] compared with some previous works.

4. CONCLUSION

In this paper, we proposed a 2-channel all optical wavelength demultiplexer. Wavelength selection task is done via low loss and high quality factor micro resonant cavities. In order to select to different wavelengths, we chose different values for the structural parameters of the resonant cavities. The proposed structure can separate 2-channels with central wavelengths at 1549.4 nm and 1551.2 nm. Minimum transmission efficiency of the channels is 92%. The quality factor and crosstalk values are better than 1900 and -15dB. Considering the overall performance of the structure, it is suitable for WDM applications.

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