Photonic crystal-based demultiplexers using defective resonant cavity

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In this paper we used defective resonant cavity for designing a 4-channel photonic crystal demultiplexer. We show that by introducing appropriate waveguides and defects the desired wavelengths can be separated. The platform used for designing the proposed demultiplexer is a square lattice of dielectricrodsimmersedin air. The minimum and maximum transmission efficiency for the proposed structure is 70% and 96% and the channel spacing is less than 1.4 nm. In addition, the maximum value of crosstalk for channels is -10dB. Comparison of the obtained results with other worksdemonstrates that the proposed device has ability to be used in WDM communication applications.

1. Introduction

Ever increasing progress in development of optical communication networks had created new opportunities for designing ultra-compact optical devices suitable for optical integrated circuits. Photonic crystal (PhC) structures due to their photonic band gap (PBG) region have an excellent ability in confining light waves inside small spaces. Therefore, there are the most suitable platforms for designing ultra-compact optical devices [1]. Wavelength division multiplexing (WDM) and dense wavelength division multiplexing (DWDM) technologies can be used to make optimum use of a single optical fiber capacity, such that one can launch multiple optical channels with different wavelengths into one single optical fiber [2]. At the user end, one can separate these channels via wavelength optical demultiplexer.

The simplest solution proposed for designing optical demultiplexers is coupling and cascading PhC based waveguides with different waveguide widths [3-4]. In optical couplers the resonant wavelength depends on the width of the waveguides so by cascading two waveguides with different widths one can separate two channels with different wavelengths, but the channel spacing in these structures is quite large and this kind of demultiplexers were mainly used for separating 1550 and 1310 nm channels. Multimode inference [5] and PBG [6] also can be used for demultiplexing goals, too. PBG based structures have large channels spacing, because variation of PBG is very sharp. Super prisms [7-10], cascaded channel drop filters [11], photonic crystal ring resonators (PhCRRs) [12-13], resonant cavities [14-15], L-shaped waveguides and line defect waveguides [16] are other examples of mechanisms proposed for designing optical demultiplexers. The resonant wavelength of channel drop filters depends on refractive index and lattice constant of the overall structure, so by changing refractive index or lattice constant one can choose different wavelengths. By cascading two or more filters with different refractive indices or lattice constants one can design an optical demultiplexer. As an example for this kind of demultiplexer one can mention the structure reported by Manzaca et al [13], in which they cascaded 4 channel drop filters with different lattice constants, the result was a structure capable of separating four channels with different central wavelengths. Another cascaded filter based demultiplexer has been reported by Rakhshani and Birjandi [22], in which they proposed a 4 channeldemultiplexer by combining 3 PhCRRs with different dielectric constants. The channel spacing was about 6.1 nm. The transmission efficiency and bandwidth were 92% and 2.75 nm respectively.

In this paper, we proposed a method for designing optical demultiplexer. The wavelength selection mechanism employed in this paper is based on defective resonant cavity. In order to select four channels with different wavelengths we changed the width of the cavities, and combined four resonant cavities with different widths in one structure.

The rest of this paper organized as following: in section 2 we calculated the photonic band gap and presented the design procedure and then 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. Demultiplexer design

The fundamental platform used for designing the proposed demultiplexer is asquare lattice of dielectricrodsimmersed in airbackground. The number of dielectric rods in x and y directions are 40 and 22 respectively. The effective refractive index of dielectric

material is 3.47. Theradius of dielectric rods is 112 nm and the lattice constant of the structure (a) is 558 nm. Before designing the demultiplexer we have to calculate the band structure of the fundamental PhC and extract its PBG region. For this purpose, we employed Bandsolve simulation tool of R soft photonic CAD software, which calculates the band structure of periodic structures based on plane wave expansion (PWE) method [17]. The band structure diagram for this PhC with aforementioned values for refractive index of dielectric material, radius of rods and lattice constant is shown in Fig. 1. According Fig. 1, there is no PBG for TE mode so all the simulations will be performed in TM mode. We observe from figure 1 that the first PBG is in the range of $0.28 < \lambda/a < 0.42$ or in other words $1328\ nm < \lambda < 1992\ nm$ (λ is light wavelength).

In this work, we are going to use defective resonant cavity as wavelength selection mechanism. Therefore, we briefly introduce the proposed defective resonant cavity structure. The schematic diagram of this structure is shown in Fig. 2. The defective resonant cavity is composed of three central dielectric rods as core rods with reduced radius; the radius of the core rods is R0. The central rods are shown in Blue color to be distinguished from other rods. At left and right sides of core rods, we have another three rods constructing the left and right walls of the cavity. In order to control the width of the resonant cavity we shifted these rods toward the central rods by L. These sidewall rods are shown with green color. By choosing different values for L one can change the resonant wavelength of the defective resonant cavity.
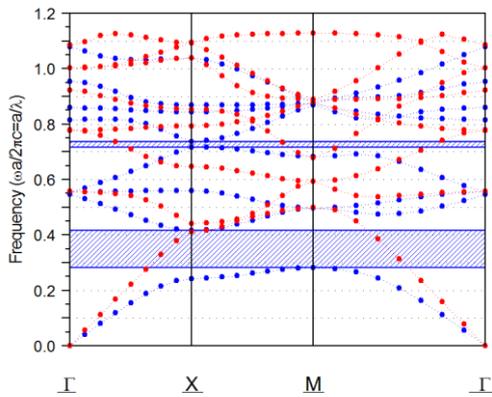

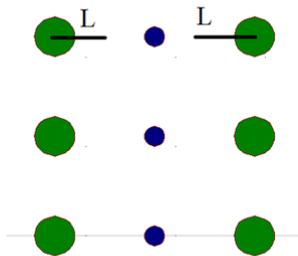*Fig. 1. The band structure of the proposed device.*

*Fig. 2. The schematic diagram of the proposed
defective resonant cavity.*

The final sketch of the proposed demultiplexeris shown in Fig. 3. As one can see the demultiplexer is composed of three main parts, one horizontal input waveguide, four vertical output waveguides and four defective resonant cavities located between input waveguide and every output waveguides. For all defective resonant cavities, the values of R0 are similar and equal to 58 nm. In addition, the only distinction between the defective resonant cavities is their L values. The L values for the resonant cavities are: $L_1 = 2$ nm, $L_2 = 5$ nm, $L_3 = 8$ nm and $L_4 = 11$ nm.
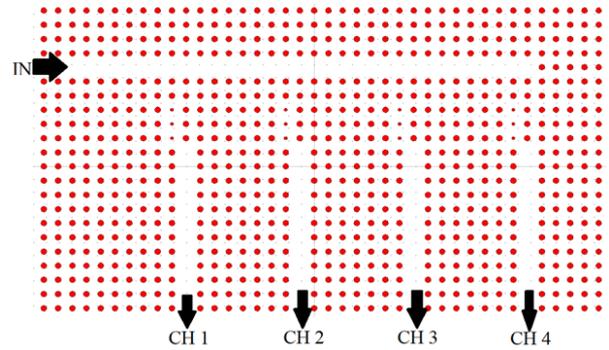

Fig. 3. The final sketch of the proposed demultiplexer.

3. Simulation and results

After finalizing the design process of the demultiplexer we have to investigate the optical behavior of the proposed demultiplexer. For this purpose, we used Fullwave simulation tool of R soft photonic CAD software totestthe proposed demultiplexer. Fullwave studies the propagation of light inside PhC based devices based on finite difference time domain (FDTD) method [18]. We used Perfectly Matched Layer (PML) boundary condition for simulating the proposed demultiplexers [19]. We choose the PML width surrounding the structures to be 500 nm. 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 PhCsto satisfy this requirement and with this approximation we reduced the 3D simulations to 2D simulations [20]. The output spectrum of the demultiplexerhas been obtained and shown in Fig. 4. This demultiplexerhas4 channels with central wavelengths equal to $\lambda_1 = 1570.8\ nm$, $\lambda_2 = 1569.9\ nm$, $\lambda_3 = 1568.5\ nm$ and $\lambda_4 = 1567.3\ nm$.
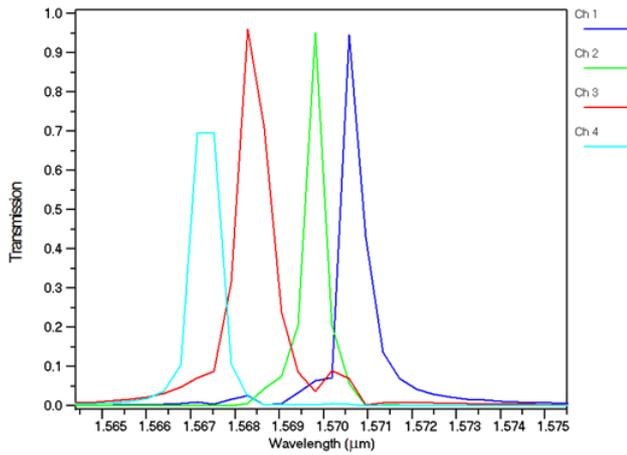
(a)
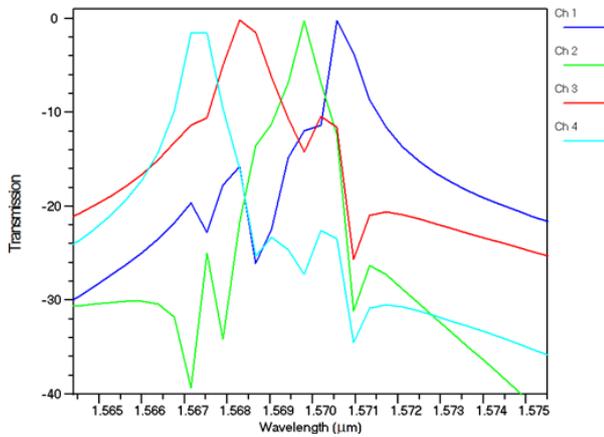
(b)

Fig. 4. Output spectrum of the demultiplexer (a) linear and (b) dB scales.

The transmission efficiency (T.E) for the proposed demultiplexer is between 70% and 96% which is better than some previously proposed structures [14,25-26]. These relatively high transmission values guarantees very low insertion loss for the structure. Another crucial parameter in optical demultiplexers is the quality factor (QF) and defined ascentral wavelength of the channel to bandwidth ($\Delta\lambda$) of it. Consequently, one can see that the less bandwidth results in higher quality factor. In the proposed structure the bandwidth of first, second, third and fourth channels are 0.5, 0.6, 0.4 and 0.4 nm therefore the corresponding quality factors will be 3139, 2620, 3937 and 3934 respectively. Compared with previous works, the proposed structure has better quality factor values than the works reported in [13-14, 22,25-26]. The maximum channel spacing for the proposed structure is about 1.4 nm, which is better than some previously reported works [13-14,22,25-26]. The complete specification of the demultiplexer are listed in Table 1.

Crosstalk is another crucial parameter in designing optical wavelength demultiplexers. Thecrosstalk values are listed in Table 2, in which they are named as X_{ij}, (i,jvaries

from 1to4) that means the effect of i-th channel in j-th channel. In Table 2, i and j indices are shown in column and row respectively. The crosstalk level for the structure varies from -10 dB to -33dB. The comparison of the proposed structure with some recent works is given in Table 3.

Table 1. Simulation results of the demultiplexer.

Channel	λ(nm)	$\Delta\lambda$(nm)	QF	T.E(%)
1	1570.8	0.5	3139	95
2	1569.9	0.6	2620	95
3	1568.5	0.4	3937	96
4	1567.3	0.4	3943	70

Table 2. Crosstalk values of the demultiplexer (dB).

Channel	1	2	3	4
1	-	-18.5	-18.5	-33
2	-12.7	-	-12.7	-27
3	-19	-19	-	-19
4	-22	-33	-10	-

Table 3. Comparing our results with some previous works.

Works	Channel Spacing (nm)	QF	$\Delta\lambda$(nm)	Worst case T.E(%)	Worst case Crosstalk (dB)
Ref [13]	28	< 61	> 25	80	NA
Ref [14]	3	1296	1.2	63	-11
Ref [15]	1	3000	0.5	42	-14
Ref [22]	15	NA	NA	24	NA
Ref [25]	6	460	2.75	92	-24
Ref [26]	3	561	2.8	50	-7.5
Our work	1.4	2600	0.6	70	-10

According to the results proposed in Table 3 and compared with previously reported works the proposed structure has better performance and has a good potential to be used in WDM and DWDM applications.

4. Conclusion

By using the defects in a 2D photonic crystal, a four channel demultiplexer has been proposed. It is shown that structure is suitable for communication application in WDM systems. Crosstalk between channels is calculated and the maximum valueis -10dB.In addition, the minimum and maximum transmission efficiency for the proposed structure is 70% and 96% and the channel spacing is less than 1.4 nm. Quality factor value for the channels varies from 2620 to 3943.

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