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PERFORMANCE OPTIMIZATION OF SIX CHANNELS WDM DEMULTIPLEXER BASED ON PHOTONIC CRYSTAL STRUCTURE

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In this paper, we propose a WDM demultiplexer, permits the separation of six wavelengths, based on 2D photonic crystal structures. Therefore, the input wavelengths are demultiplexered by placing appropriate filter at each output. By adjusting the radius of different filters, we separated channels with spectral width and wavelength spectrum equal to 0.35 nm and 3.68 nm, respectively. Moreover, the crosstalk between channels is about -24.74 dB, the maximum quality factor equal to 5101 and the total device size is around 199 **μ**m². The performance analysis is simulated by finite difference time domain (FDTD) and plan wave expansion (PWE) methods.

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Keyword: Demultiplexer, Photonic crystal, Filters, Quality factor, Crosstalk, PWE, FDTD.

1. Introduction

In recent years, the use of light waves has gained importance, since it can provide a higher speed in optical communication networks and can transfer big data with fast speed up to large distances in optical fiber.

In wide cities that have millions of users, it is important to associate an optical fiber for each user, this results in a massive quantity of cables in order to cover all customers in a specific area, which will be very costly. One of the solutions for this complication is to provide one single fiber for many customers, since it is possible to transfer many wavelengths together inside signal optical fiber with the help of a wavelength-division multiplexing (WDM) technique. [1]

Once wavelengths arrive to the optical network end, a device that can separate and send wavelengths for each corresponding user is needed. This device is known as optical demultiplexer. Many scientists have concentrated to design optical device suitable for optical integrated circuits. To realize these devices, the light waves in the waveguide in all-optical systems should be controlled. With the help of photonic crystals (PC) and the photonic band gap (PGB) contained therein, the light waves inside waveguides can be controlled efficiently [2,3].

Many optical devices based on photonic crystal with different applications have been investigated and used, such as optical filters [4,5], circulators [6], power splitters [7], switches [8-10], sensors [11] and demultiplexers which is the subject of this work [12-20]. The most important performances that can characterize an optical demultiplexer are a quality factor, crosstalk, channel spacing, number of output channels and size of device. Many researchers have concentrated on

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improving the aforementioned characteristics based on different techniques such as resonant cavities, filters and ring resonator. Alipour et al designed an optical demultiplexer which separated eight wavelengths using 2D PC resonant cavity[21]. Structure showed an important value of quality factor equal to 5202 and low value of transmission efficiency around 60% with largest value of crosstalk equal to -8dB. Furthermore, its fabrication is very difficult due to their different radii and displacements. Also, Mahdizadeh et al reported photonic crystal demultiplexer which permits to separate eight wavelength channel spaced by 2 nm with smaller quality factor (Q=2200) , smaller crosstalk (C_{ij}=11.2 dB) and larger transmission around 94%[22]. Reza et al designed four channel demultiplexer based on resonant cavity with a channels spacing equal to 2 nm. This device shows an important value of crosstalk and quality factor equal to -27.33dB and 4107.37 with a small footprint which around $360\mu m^2$with an important value of transmission 93.45%[23].

In this work, we propose a six channels wavelength demultiplexer based on photonic crystal filters. The structure parameters are analyzed in order to optimize its performances such as quality factor, crosstalk, channel spacing, transmission and size of device.

This work is organized as follows: In section 2, the structure parameters and design are presented. The simulation results are discussed in section 3, and finally, in section 4, we conclude our work.

2. Design structure

The proposed structure consists of silicon rods, having refractive index equal to 3.47, surrounded by air ($n_0=1$). The simulation window composed of 31 numbers of rods in x direction and 23 in the y direction. The lattice constant (a) and radius (r) equal to 546 nm and 0.185**a* nm, respectively[24].

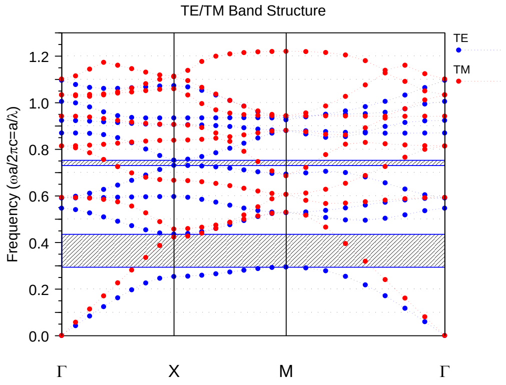

Fig. 1.Photonic band gap map of proposed structure.

The photonic band gap (PBG) of our design with aforementioned parameters is presented in Fig. 1. The normalized frequency of the first band is between 0.291 and 0.435 and the second band between 0.7251 and 0.7529. This is corresponding to the wavelength ranges1255.17nm - 1876.28nm and 725.19nm -752.29nm, respectively. Thus, the first TE photonic band gap (PBG) is considered as it falls on the 3rdwindow of optical communication.

Our proposed demultiplexer is composed of several photonic crystal waveguides (PCW) (fig. 2):

- A vertical waveguide to inject the input signal
- Three horizontal waveguides in the left and three in the right for output signals

The proposed demultiplexer is designed to separate six wavelengths. Therefore, six values of filter radius (r_i) are chosen 0.297**a*, 0.296**a*, 0.295**a*, 0.3**a*, 0.299**a* and 0.298**a* nm to select channels wavelength 1512.1 nm, 1516.3 nm, 1519.5 nm, 1523.1 nm, 1527.0 nm and 1530.5 nm, respectively.

The difference between radius of different filters is chosen, after many iterations, to be equal to 0.001**a* because smaller values didn’t give any wavelength shift and higher values will increase the wavelength separation (Δλ) between channels.

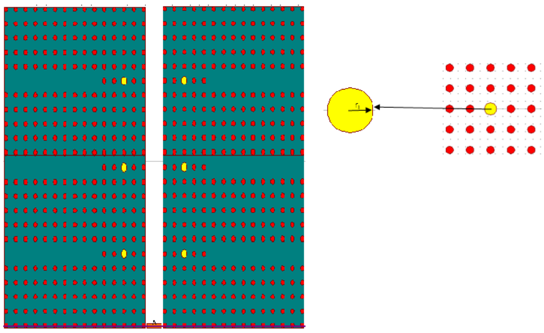

Fig. 2. The schematic diagram of proposed demultiplexer

3. Simulation and results

In this work, plan wave expansion PWE and finite difference time domain FDTD methods are employed to calculate the PBG and electromagnetic waves propagation [25,26]. The perfectly matched layers (PML) boundary conditions are assumed with width equal to 500 nm. Moreover, in order to reduce the computation time and memory consumption, the grid size in the x direction is fixed to *a*/16. For the simulation stability, the time step Δt must satisfy the condition

$$\Delta t \le \frac{1}{c\sqrt{\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}}} \tag{1}$$

where c is the velocity of light in free space, and Δx, Δy is the step size of simulation in the x and y directions, respectively. Following the above equation for time step, Δt should be equal to 0.019375. In figure 3, we show the spectrum response of the proposed design when all wavelengths are lunched together in the input PCW.

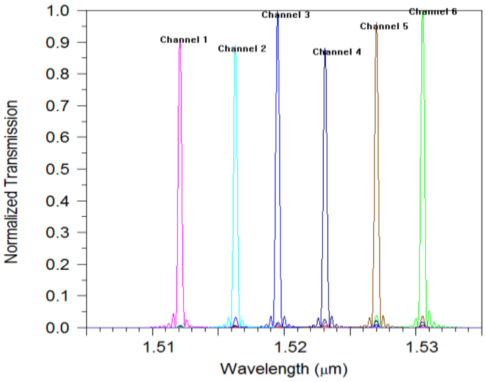

Fig. 3. Channels transmission spectrum.

The first parameter used to evaluate the device performance is the quality factor, which defined as the ratio between resonance wavelength λ_0 and channel width ($\Delta\lambda$) around λ_0 at FWHM (Full Width Half Maximum). We found that the average value of quality factor is about 4437 (table 1).

Table 1. Channels performances

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6
Wavelengths (nm)	1512.1	1516.3	1519.5	1523.1	1527.0	1530.5
Bandwidth (nm)	0.3	0.4	0.4	0.4	0.3	0.3
Quality factor	5040	3790	3798	3807	5090	5101
Transmission (%)	91	89	100	87	96	100

The second parameter also studied for performance evaluation is the crosstalk which give an idea about interference between adjacent channels. In our case, the maximum and minimum values of crosstalk of the proposed demultiplexer are -14.38 and -30.71 dB, respectively (figure 4, Table 2).

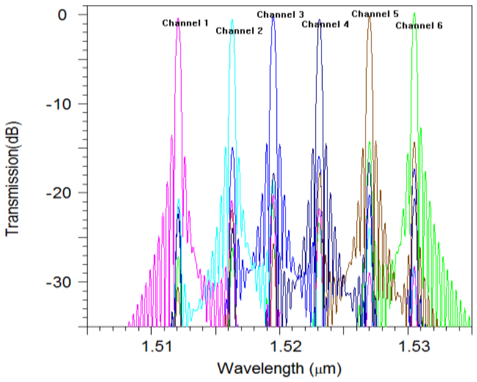

Fig.4. Transmission (dB) spectrum for various channels

Table 2. Crosstalk values (dB)of proposed demultiplexer

Channel	1	2	3	4	5	6	Average value
1	***	-20.8	-21.81	-23.16	-27.22	-30.71	-24.74
2	-21.34	***	-15	-24.16	-22.16	-26.27	-21.78
3	-19.5	-20.47	***	-17.82	-25.76	-22.01	-21.11
4	-21.9	-21.4	-16.03	***	-17.82	-23.52	-20.13
5	-29.14	-24.07	-20.3	-16.63	***	-14.4	-20.90
6	-28.72	-28.35	-17.36	-20.81	-14.38	***	-21.90

The above results show that our proposed demultiplexer outperformance the devices reported in [13,22]. In the following table, we compared the performance of our proposed structure with that published in previous works

Table 3.Comparing our results to some previous works

Authors, reference	Numbers of output	Channel Spacing (nm)	Quality factor (maximum)	Footprint μm²	Largest crosstalk(dB)
Rostami et al [15]	4	3	1296	313	-11
Rostami et al [13]	4	1	3000	536	-14
Rakhshani and Birjandi[27]	4	15	****	317	****
Alipour-Banaei et al [28]	4	3	561	498	-7.5
Djavid et al. [29]	4	28	<61	****	****
Reza Talebzadeh et al [23]	4	2	4107.37	360	-28.66
Vahid Fallahi et al [30]	4	2	1943	424.5	-14
Our proposed structure	6	4	5101	199.63	-24.74

**** not discussed

Based on the above table, we found that the proposed demultiplexer has best performance (Q, crosstalk and spectral width) compared with reported results with very small size and acceptable value of crosstalk. Therefore, our proposed demultiplexer suitable to be used in integrated optical devices.

4. Conclusions

In this paper, we optimized the performance of six-channel WDM demultiplexer based on photonic crystal waveguide and resonant filters. The wavelength separation is ensured by adjusting the radius of resonant filters at the output PCW. In comparison with recently published results, the performance analysis shows that the proposed device has higher quality factor, lower crosstalk, higher transmission and smaller size 5101, -24.74 dB and 100% and 199 μm², respectively.

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