Design of Optimized Structure Resonant Defects with Enhancement Ultra-narrow Communication Channels in Two-Channel De-multiplexer Wavelength Photonic Crystal to Decrease of Crosstalk

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ABSTRACT:
In this paper, to decrease of crosstalk phenomenon at de-multiplexer two-channel of optical communication, we designed a de-multiplexer two-dimensional (2D) photonic crystal (PhC) using resonant line defect cavity and by removing four defects. In this research, we reached to decrease in crosstalk phenomenon with mean of -24.681 dB in photonic crystal two-channel de-multiplexer according to ultra-narrow bandwidth mean of 0.25 nm and quality factor Q with ultra-average amount of 6546.5. PWE calculation methods were used to obtain band structure and photonic band gap and FDTD numerical calculation method was used to obtain output spectrum of photonic crystal two-channel de-multiplexer.

KEYWORDS: Photonic Crystal, Demultiplexer, Crosstalk, PWE, FDTD.

1. INTRODUCTION

Photonic crystals (PhCs) are periodic optical nanostructures that affect the motion of photons in much the same way that ionic lattices affect electrons in solids. Photonic crystals occur in nature in the form of structural coloration and promise to be useful in different forms in a range of applications. In 1887 the English physicist Lord Rayleigh experimented with periodic multi-layer dielectric stacks, showing they had a photonic band-gap in one dimension. Research interest grew with work in 1987 by Yablonovitch and John on periodic optical structures with more than one dimension, now called photonic crystals [1].

Photonic crystals can be fabricated for one, two, or three dimensions. Many applications of two dimensional photonic crystals are directed towards integration of photonic devices. It is important to evolve into the photonic and electronics circuits, which will require high-density photonic and electronic circuits. The example of photonic crystals devices is LED, waveguide, resonator and photonic crystal fiber [2].

Photonic crystals with periodic structures and dielectric environments have photonic band gap (PBG) due to the difference in inherent refractive index [2]. Photonic band gap is a range of electromagnetic wavelength spectrum which could not be propagated in photonic crystal structure [3, 4]. Defect in these crystals create a gap of frequency band and photons which have the frequency within this forbidden gap are not allowed to pass through the crystal structure and hence this property of photonic crystal allows us to guide the light along the defect efficiently in photonic communication [2]. By introducing the defects (point defects or line defects or both) in these periodic structures, the periodicity and thus the completeness of the PBG are entirely broken which allows to control and manipulate the light [5, 6]. It ensures the localization of light in the PBG region which leads to the design of the PC based optical devices.

One of the important factors in designing filter based optical systems for researchers, is to reduce crosstalk rate [7]. Crosstalk occurs in hybrid structures of optical filter based machines and discrete wavelengths and a small part of optical power which should end in a specific channel (in an output of specific filter) ends in adjacent channel (in another channel) [8]. So decrease of crosstalk phenomenon in DWDM optical communication devices and systems is very important.

One of the best choices for selecting proper wavelength in photonic crystal structures is use of resonant cavities [9]. Based on designing type, resonant cavities in photonic crystal structures make it possible to select desired wavelength with proper bandwidth accurately by resonance [10], [11]. It is possible to mention to optical waveguides [12], extremely small filters [13], optical transistors [14], optical integrated circuits [15], optical low threshold lasers [16], and etc. as usages of resonant cavities with photonic crystal structures in engineering systems.

In this article we tried to reach some main parameters to reduce de-multiplexer DWDM crosstalk phenomenon. First level parameters are low channel distance and extremely narrow bandwidth for working in DWDM technology and second aim is high accuracy, good efficiency, and very high wavelength quality index. These mentioned two aims caused very low wavelength crosstalk, which is main factor significant crosstalk reduction in two-channel de-multiplexers of suggested plan and facilitates the usage in integrated network of DWDM optical communication systems. To reach mentioned goals we used resonant cavity method after using different methods to reach our aim. In a way that by moving especial cavities to proper place and situation and testing new resonant cavities we can select proper wavelength with desired conditions.

2. DESIGNING AND SIMULATION

Currently the best computational method of electromagnetic waves of band photonic crystal structures is numerical methods. There are various numerical modeling techniques for the modeling of photonic devices such as:

- Beam Propagation Method
- Finite-Element Method
- Finite-Difference Time-Domain (FDTD) Method
- Finite-Volume Time-Domain Method
- Finite Integration Technique
- Multi-resolution Time-Domain Method
- Plane Wave Expansion (PWE) Method

Each method has its own pros and cons. Among these, PWE and FDTD methods are dominating with respect to their performance and also meeting the demand required to analyze the PC based optical devices [9-11].

One of the first tasks in studying and investigating photonic crystal periodic structures, is to obtain photonic band gap using plane wave expansion (PWE) numerical method [17]. The PWE was adapted by Sakoda [18] to compute the diffraction of two-dimensional periodic band gap materials with a finite thickness. Using a plane wave expansion in the direction of periodicity of the dielectric function and an arbitrary Fourier expansion normally to that same plane, diffracted fields were successively matched to the field expansions within the periodic medium. Predictions of the diffraction of triangular and square lattices of air rods in planar waveguides were obtained in this way with good accuracy [19], [20].

An alternative approach which has been widely adopted to calculate both transmission spectra and field distribution is based on numerical solutions of Maxwell's equations using FDTD method. Typically, the PWE method is used to calculate the PBG and propagation modes of the PC structure and FDTD is used to calculate the spectrum of the power transmission [3].

To extract photonic band gap crystal structure for reducing crosstalk phenomenon of suggested de-multiplexer structure, we will run PWE computations using Band Solve software. And also considering the fact that each photonic crystal structure cavity has resonance only in a specific wavelength [21], for such complex calculations finite difference time domain (FDTD) method should be used [22]. So in suggested plan for calculating and obtaining desired wavelength spectrums of 2D photonic crystal de-multiplexer resonant cavity area, Full Wave simulator software would be used.

2.1. Designing and Calculation of Baseband Structure

1) Designing of Baseband Structure:

To Structure of 2D photonic crystal network used for designing base filter of suggested de-multiplexers, according to "Fig. 1" the lattice constant has been considered 420 nm with refractive index of 2.73.

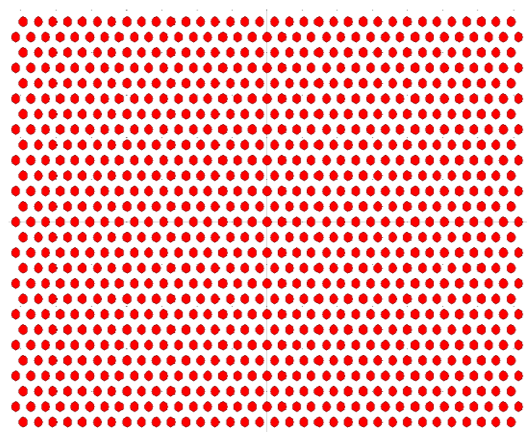

Fig. 1. Photonic 2D photonic crystal lattice structure for designing two-channel demultiplexer basic filter

2) Simulation of Baseband Structure:

Considering the fact that photonic band gap determines working range of wavelengths of two-channel demultiplexer basic filter, simulated diagram for distribution of photonic band structure of optical band gap has been shown in "Fig. 2".

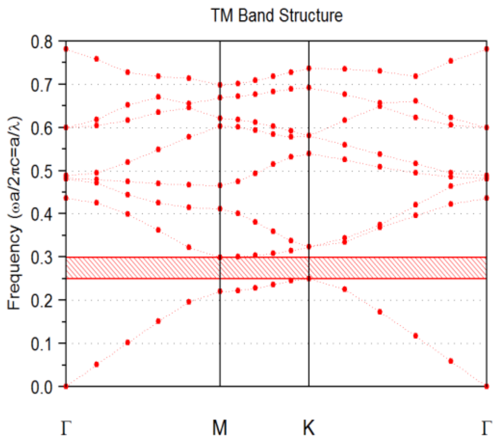

Fig. 2. Structure of 2D photonic crystal band gap for designing two-channel demultiplexer basic filter

According to "Fig. 2", bandwidth of photonic gap in terms of ratio of structure radius filling to the lattice constant is r/a=0.2738. Limitation of photonic structure band gap is $0.25026 \leq \omega a/2\pi c \leq 0.29959$. Also based on mentioned calculations photonic band gap in range of wavelength spectrum will be $1401.9nm \leq \lambda \leq 1678.2nm$.

2.2. Designing and Simulation Basic Filter of Demultiplexer Structure

1) Designing of Filter Structure:

Minimizing crosstalk of two-channel de-multiplexer working wavelengths needs detailed designing of basic filter in 2D photonic crystal structure. We achieved the design of "Fig. 3", after conducting and attaining many methods based on resonant cavity in designing basic filter of two-channel demultiplexer to work in range of DWDM communicational systems. Structure of suggested base filter for two-channel de-multiplexer of 2D photonic crystal includes three parts of input waveguide, resonant cavity, and output waveguide.

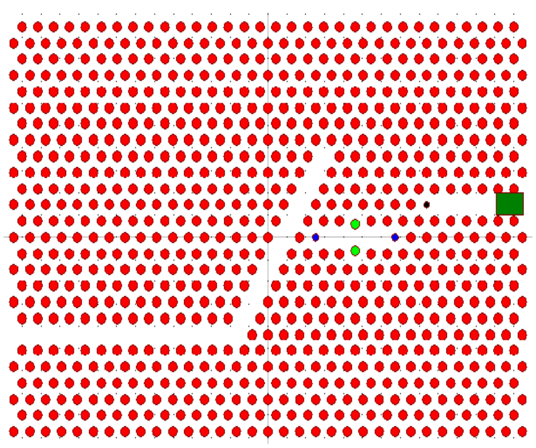

Fig. 3. Schematic structure of suggested base filter for two-channel demultiplexers of 2D photonic crystal

To reduce crosstalk phenomenon in resonant cavity area according to "Fig. 3" by omitting 4 cavities in 0.0920nm size with total length of 1870µm from crystal network structure and changing the size of two cavities in corners to RC=88nm and 2 middle cavities to a range of L=68.5nm to 70nm we can obtain the main structure of designing de-multiplexers base filter.

2) Simulation of Filter:

Results from output of designing mentioned base filter in "Fig. 4" have been obtained for changes at least in 4 different sizes of middle cavities with difference of 0.5nm from L1-4= 68.5nm to 70nm and wavelengths are as $\lambda 1$= 1567 nm for L1=68.5nm, $\lambda 2$=1566.7nm for L2=69nm, $\lambda 3$=1566.4nm for L3=69.5nm and $\lambda 4$=1566.1nm for L4=70nm.

Also according to output results of spectral detection of base filter in "Fig. 4" it is possible to see that mean of wavelengths resolution is 0.4nm and this base filter reduces crosstalk phenomenon and at the same time is completely suitable for designing two-channel de-multiplexer DWDM with 2D photonic crystal structure.

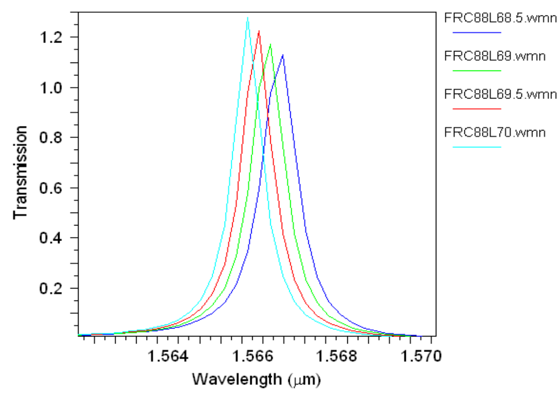

Fig. 4. Results from output of demultiplexers base filter for changes at least 4 different sizes of middle cavity with 0.5nm difference from L=68.5nm to70nm.

2.3. Designing and Simulation Demultiplexer

1) Designing of Demultiplexer Structure:

After providing proper structure of base filter, by testing different structures of photonic crystals based on resonant cavity, we reached a T-shaped two-channel de-multiplexers design according to "Fig. 5", characteristics of which are ability of transmitting input wavelength with the highest transmission to output and minimum crosstalk phenomenon. Structure of demultiplexer in "Fig. 5", composed for receiving spectrum of optical wavelengths from input waveguide, for selecting working wavelength in range of DWDM communicational systems from resonant cavity and for amplifying desired wavelength from output waveguide.

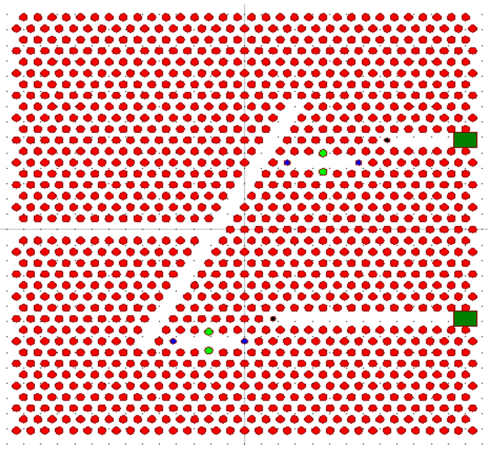

Fig. 5. Structure of two-channel T-shaped demultiplexer based on resonant cavity

Refractive index of network structure has been considered as 2.73 in order to minimize and reduce crosstalk phenomenon and cavity radius size in output waveguide is a*0.175 to obtain the maximum transmission wavelength amplitude. Also to minimize crosstalk phenomenon, corner mirror cavities of channels 1 and 2 were adjusted to 88nm and middle cavities of channels 1 and 2 were adjusted to 61nm and 60nm respectively.

2) Simulation of Demultiplexer:

For simulating the proposed structure in “Fig. 5”, the fullwave software (Rsoft) has been used. In addition, the finite difference time domain (FDTD) is utilized for numerical solution. Results from simulating in “Fig. 6,” show that two-channel de-multiplexer wavelengths of 2D photonic crystal structure are λ1=1570.8nm for channel 1 and λ2=1571.7nm for channel 2.

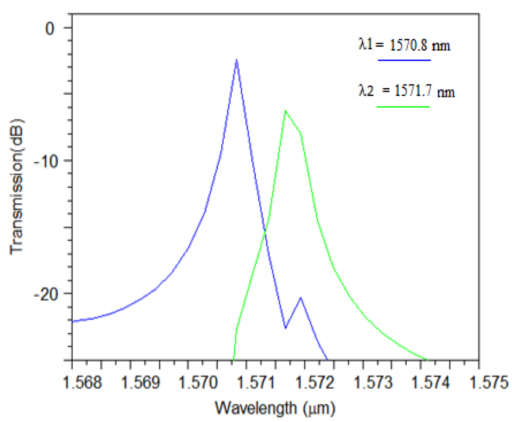

Fig. 6. Transmission spectrum of two-channel T-shaped demultiplexer based on resonant cavity

3. RESULT AND DISCUSSION

Using simulation of designing basic filter, two-channel de-multiplexer based on photonic crystal structure simulated. To decrease de-multiplexer crosstalk we considered refractive index, lattice constant, and cavity radius as n=2.73, 420nm, and 115nm respectively. In simulation, the perfectly matched layer boundary condition (PML) has been used because it gives high performance. The width of PML in the surround of structure has been supposed equal to 500nm. Structure of has been composed of de-multiplexer in TM mode, and 33*38 aerial cylinders respectively in X and Z axes.

Important parameter in wavelength division de-multiplexer is quality factor (Q) that demonstrates the resolution of wavelength selecting and can be calculated with the following relation:

$$Q=\lambda/\Delta\lambda \qquad (1)$$

Which λ is central wavelength and Δλ is the full width at half power of output and bandwidth, respectively. The compendium of results consists of center wavelength, bandwidth and Q of every channel shown in the table 1. Table 1 shows that we could reach parameters of first stage of designing with extreme narrow bandwidth with mean channel bandwidth of 0.25nm to work in DWDM technology. Also reaching the second goal, which was good efficiency with quality index mean of 6546.5 and very suitable wavelength range, was accomplished.

Table 1. Result of two-channel t-shaped demultiplexer simulation

Channel	$\lambda_0\,(nm)$	$\Delta\lambda\,(nm)$	Q
1	1570.8	0.2	7854
2	1571.7	0.3	5239

When level of light power reaches a point in which new components are created as a result of non-linear phenomena and interference is created between channels, crosstalk happens. So, two mentioned parameters and goals cause very low interference of wavelengths, which are main factors in reducing crosstalk in two-channel de-multiplexer with mean crosstalk of -24.681dB. Since the main goal of this research is reaching minimum crosstalk in two channel de-multiplexer, with 2D photonic crystal structure, table 2 shows that crosstalk effect of channel 1 in channel 2 is -22.677 dB and crosstalk effect of channel 2 in channel one is -26.685 dB, which is the optimum condition to reach very high accuracy in channel resolution and lack of interference in output wavelengths of de-multiplexers.

Table 2. Values of crosstalk for simulation two-channel t-shaped demultiplexer

Channel	$Xt_{\lambda1}$	$Xt_{\lambda2}$
1	-22.677	-
2	-	-26.685

4. CONCLUSION

In this article we designed and proposed an optimized method for reducing two-channel DWDM de-multiplexer crosstalk phenomenon using resonant cavity for 2D photonic crystal network structure. With reducing crosstalk phenomenon to mean of-24.681 in suggested de-multiplexer, ultra narrow bandwidth mean reached significant number of 0.25nm and mean quality index of channels reached 6546.5.

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