Designing Optimal Filter with Hexagonal Structure to Reduce Two-Channel Communication Demultiplexer Crosstalk Phenomenon with Optical Wavelengths Resolution Technology in Structure of Photonic Crystal

Mohammadreza Pashaei[1], Amir Rastegarnia[2]
1- Department of Electrical Engineering, Ahar Branch, Islamic Azad University, Ahar, Iran.
Email: m-pashaei@iau-ahar.ac.ir
2- Department of Electrical Engineering, Malayer University, Malayer, Iran.
Email: a_rastegar@ieee.org

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ABSTRACT:
In this research crosstalk phenomenon in DWDM two-channel communication demultiplexer was reduced by optimizing 2D photonic crystal network structure and using resonant cavity. Alongside with reduction in crosstalk phenomenon by mean of -19.74 dB, also the average bandwidth $\Delta\lambda$ of 0.2 nm and mean transmission range of 93.47%, the average value of quality factor 7829.25 was reached. In these calculations using finite difference time domain method (FDTD), optimized structures of 2D DWDM two-channel communication demultiplexer photonic crystals to reduce crosstalk phenomenon was obtained.

KEYWORDS: Crosstalk, Demultiplexer, Quality factor, Bandwidth, Photonic Crystals.

1. INTRODUCTION

During recent years photonic crystals have been at the focus of attention by researchers because of their specific capabilities [1, 2]. Photonic crystals could be used as some constituent elements of some communicational devices. Photonic crystals are periodic and regular structures of heterogeneous dielectric materials with variation of the refractive index, and are made by repetition of period and variable refractive index in dielectric with capability of full control on light emission [3]. Periodic and regular structure in dielectric leads to creation of a photonic band gap (PBG) in a wide range of wavelength and in case of controlling certain wavelength range, this band gap zone does not let spontaneous light emission inside photonic crystal [3]. Photonic crystals are used for designing systems with optical technology due to their inherent abilities in light control [4]. Waveguides [5], optical filters [6], optical switches [7], [8], optical power splitter [9, 10], and optical couplers [11], [12] are of applications of photonic crystal structure technology.

Demultiplexers are of the most important communicational elements in recipient side of the communication link and considering reduction of crosstalk effect have been highly addressed. Demultiplexers separate desirable wavelengths with definite central wavelength band definite bandwidth in each output channel with low crosstalk. Reaching high data transfer speed, high data upload and download volume, acquiring proper strategies to increase volume of uploaded and downloaded data, and designing a suitable part for WDM and DWDM standards with minimum crosstalk has always been the aim of researchers [13]. 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 a output of specific filter) ends in adjacent channel (in another channel) [14]. So decrease of crosstalk phenomenon in DWDM optical communication devices and systems is very important. When optical signals arrive from one channel to another, they cause creation of noise in other channel (unwanted receiver of wavelength signal) [15]. This could have important effects on signal to noise ratio and consequently on error rate of system. This multisignaling is the worst condition of crosstalk [16]. And in other definitions crosstalk is placement of some part of one wavelength channel in another optical wavelength channel or in simple words crosstalk is extraction of some information of other channel by current channel which cause transmission power reduce and significantly lowers quality of channel separation alongside with creating of noise and disturbance [17].

Variation in cavity radius, elimination of one or more air or dielectric cavity bars, variation in refractive index and change in type of dielectric material in structures of photonic crystals are called defect [18-22]. Each one of mentioned defects is used alone or in combination with each other in creating distribution zones of photonic band gap to design optical communication systems [23, 24]. One of the most important methods for designing optical filter based on 2D photonic crystal is resonant cavity method [25]. Resonant cavity in structure of photonic crystal passes corresponding resonance wavelength from its photonic band gap zone [26].

In this research to reduce crosstalk phenomena, filter designing has been conducted in structure of 2D photonic crystal in DWDM communication two-channel demultiplexer.

2. MODEL AND ANALYZE

Recent developments in the field of technologies of photonic crystal structures have made it possible to reach optical communication systems and also basic research and investigating phenomena of optical waves. Investigating optical phenomena, light-material interaction, behavior of optical waves, band structure, photonic band gap, and possibility of controlling optical waves in structures of photonic crystals to use in optical communication systems are of the most important and most difficult tasks. Due to complexity in emission of field of optical waves and distribution mode of interacting fields in structures of photonic crystals, calculations of numerical methods are used to study band structure, photonic band gap, and investigating simulation results which are:

1) Plane wave expansion (PWE) numerical method
2) Finite difference time domain (FDTD) method

According to unique properties of photonic crystals, in order to study light emission in structure of photonic crystal we need numerical methods. Specifically for each dielectric of photonic crystal structure it is necessary to find photonic band gap according to emission of light in all directions of photonic crystal. Therefore to calculate field distribution of light waves in photonic crystal one of the most usual methods for computing photonic band gap is plane wave expansion method [27-29]. And also considering the fact that each photonic crystal structure cavity has resonance only in a specific wavelength [30], for such complex calculations finite difference time domain (FDTD) method should be used [31]. In Yee algorithm Cartesian time domain finite equations have been used instead of Maxwell equations for calculating boundary conditions in extremely small dimensions of unit cell [36]. So in suggested plan for calculating and obtaining desired wavelength spectrums of 2D photonic crystal demultiplexer resonant cavity area, Full Wave simulator software would be used [32].

2.1. Designing and Simulation of Baseband Structure

According to the point that extremely small photonic crystal band structure of basic filter with the minimum crosstalk phenomenon fulfills the need of dense wavelength division multiplexing (DWDM) systems in applying electromagnetic waves with ultra-high resolution capability of optical communication wavelengths, therefore with selecting proper Super Cell [33] in structure of photonic crystal and running algorithmic calculations of band structure with numerical method of expanding plain waves [34], distribution curve of photonic band gap structure is obtained.

Structure of 2D photonic crystal network used for designing base filter of suggested demultiplexers, is a hexagonal network inside silicon layer with R=115nm radius of air holes and a=420nm fixed network. Structure of designing 2-D photonic crystal basic filter used for design of "Fig. 1," is a 35*27 array structure.

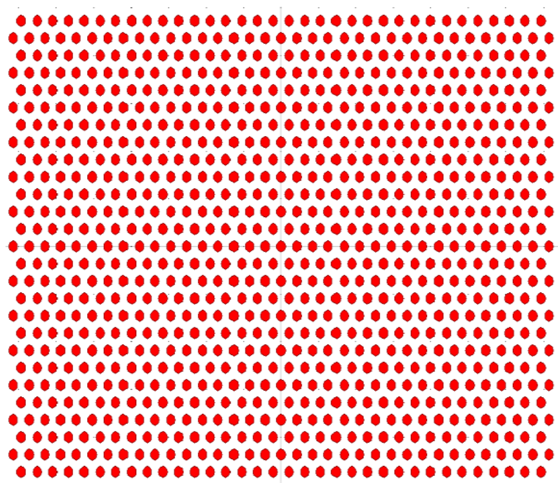


Fig. 1. Structure of designing 2D photonic crystal basic filter

Simulating band structure algorithm and results of photonic band structure of "Fig. 2," has been conducted using Band solve software. In this structure an electromagnetic field with TM polarization is used where the electric field vector is parallel with axis of the cylindrical aerial bars and electromagnetic field is perpendicular to axis of aerial bars of 2D photonic crystal structure.

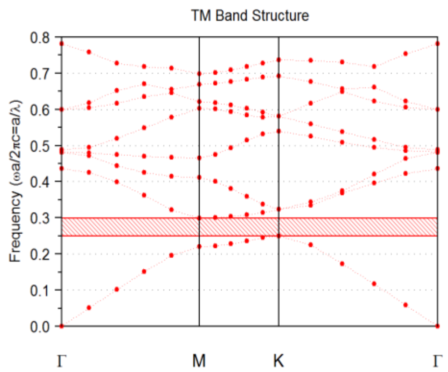


Fig. 2. Scatter diagram of 2D photonic crystal structure of Photonic band gap.

According to "Fig. 2," Ratio of filling radius of air holes to network structure to find the optimum photonic band gap length is r/a=0.2738 And limitation of photonic structure band gap is$0.25026 \le \omega a/2\pi c \le 0.29959$. So the widest photonic band gap of band structure is 0.04933.

Wavelength range which in this structure is possible for optical filter to be used for reducing crosstalk phenomena in optical 2-channel demultiplexer with 2-D photonic crystal structure is equal to wavelengths $1401.9\text{nm} \le \lambda \le 1678.2\text{nm}$.

2.2. Designing and Simulation Basic Filter

Results obtained from the band structure in this research make it possible to design a filter based on waveguide structure and resonant cavity and in terms of approving its functionality in photonic crystal structure, it should be possible for the mentioned design to be applied for reduction in crosstalk phenomena in two-channel demultiplexer. "Fig. 3," with experimenting various methods for designing filter structure, has inspired from hybrid method based on resonant cavity and reference waveguide [35, 36].

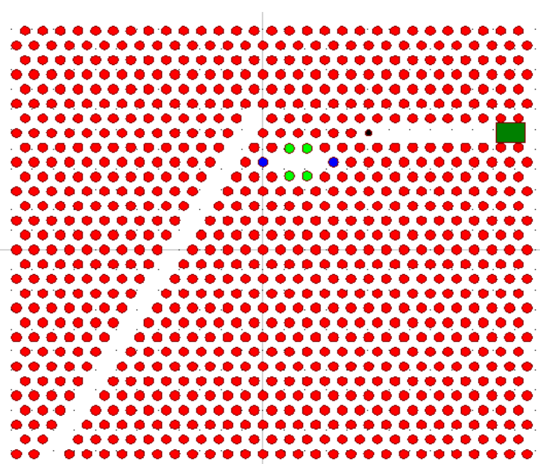


Fig. 3. Designing filter with 2-D photonic crystal structure

Filter structure consists of three parts as hybrid. The first part is a wavelength waveguide with 30˚ bend gapped at the end of its route with 6 aerial cylinders, the second part of structure is a controllable and adjustable resonant cavity with middle and side defects, and the third part is a wavelength amplifier waveguide with defect affecting the output range.

Middle defects of resonant cavity were considered equal to 18 and side defects equal to 115nm and also output waveguide defect equal to A*0.1715 where A is period of the network.

Calculations of proposed structure of "Fig. 3," has been run using FDTD method considering high complexities [37], [38] and since without software running calculations would be a laborious task, simulator software of Fullwave for emission of light in 2D photonic crystal structure was used to extract the results of "Fig. 3,".

"Fig. 4," shows the recommended filter output wavelength transfer spectrum as 72.7% and central wavelength as 1567nm.

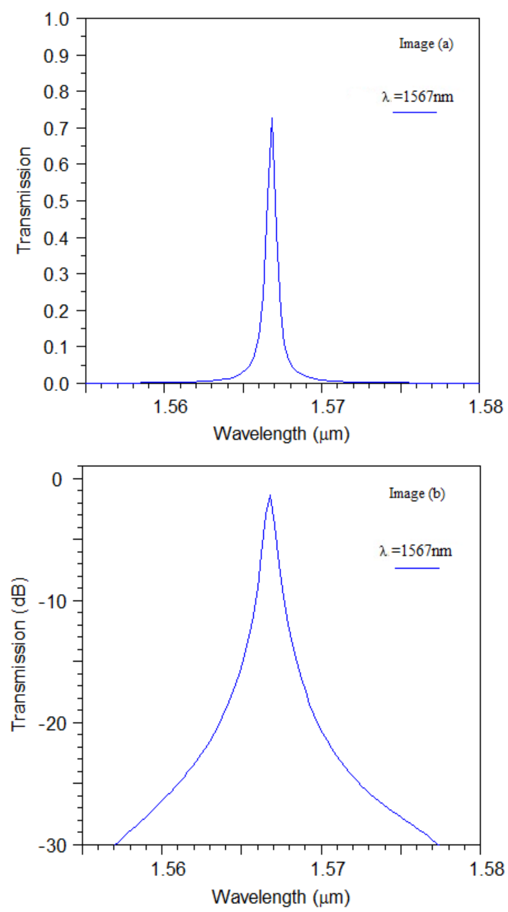


Fig. 4. Results of recommended filter output wavelength transfer spectrum: a) linear transfer b) dB transfer of 2D photonic crystal network

Bandwidth of filter of "Fig. 4," in central wavelength of $\lambda = 1567nm$ is $\Delta\lambda = 0.4nm$. To ensure that bandwidth of recommended filter output central wavelength is in designing range of DWDM demultiplexer, experiment of changing middle defects of recommended filter is conducted for accuracy of obtained results in different values, therefore simulation is conducted by changing middle defects in values of 24nm, 22nm, 20nm, 18nm, and 16nm respectively and results of transmission ranges are obtained according to "Fig. 5," (a- linear transfer b-dB transfer) using Fullwave software.

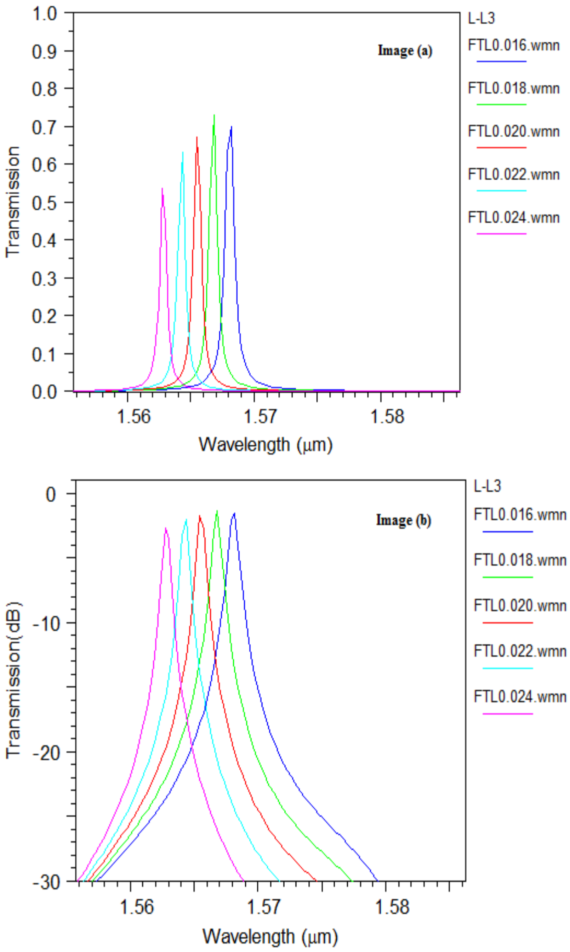


Fig. 5. Results of transmission ranges of filter output wavelengths a) Linear scale b) dB scale
Designing and Simulation Demultiplexer

2.3. Designing and Simulation Demultiplexer

According to results obtained from analyzing the structure of filter in "Fig. 5," it is seen that it is possible to design a two-channel demultiplexer with reducing crosstalk effect using primary filter structure. Since high-capacity optical transmission lines based on zoning DWDM wavelengths to contrast receiving wavelengths need filters with ultra slim and tunable spectral response in the structure of photonic crystal network, therefore using main frame of recommended filter structure, changes in its structure, and various experiments using Fullwave software, demultiplexer structure of "Fig. 6," was obtained.

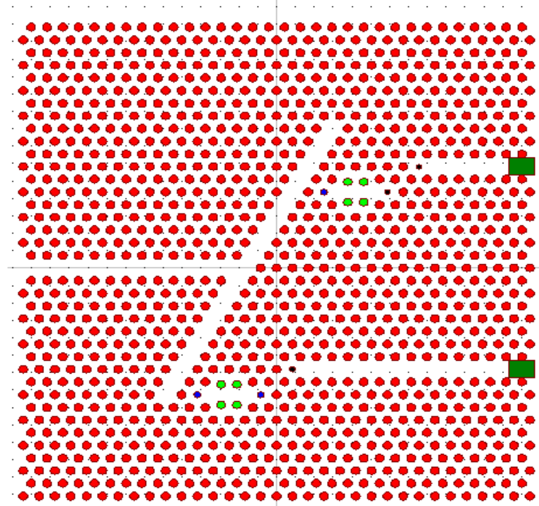
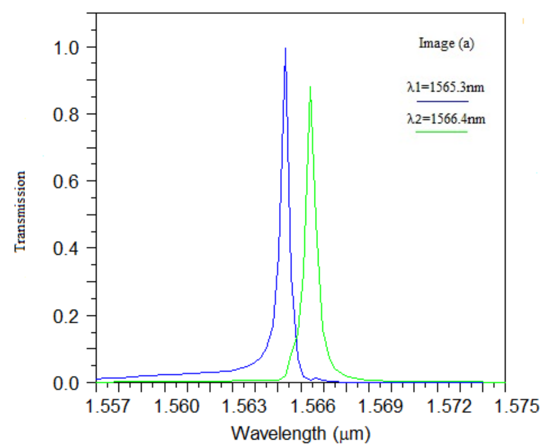


Fig. 6. Structure of 2D photonic crystal network of two-channel demultiplexer

Refractive index of network structure has been considered as 2.73 in order to minimize and reduce crosstalk phenomenon. For simulating structure of two-channel T-shaped demultiplexer based on resonant cavity of "Fig. 6," Full wave software has been used and for reducing crosstalk phenomenon in adsorbent area of Perfect Match Layer (PML) 500nm length has been used. Structural design of photonic crystal based on XZ in network dimensions is 33*38 air holes in dielectric background. All adjustments of structure of "Fig. 6," except changes of middle defects and side defects of resonant cavities are same with adjustments of previous structure. Results from simulating in "Fig. 7," show that two-channel demultiplexer wavelengths of 2D photonic crystal structure are λ1=1571.9nm for channel 1 and λ2=1572.8nm for channel 2.



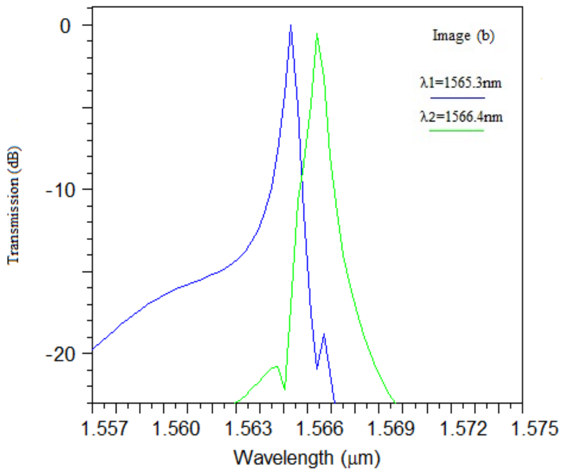


Fig. 7. Analysis of wavelength range of channels 1 and 2 of demultiplexer a) Linear scale b) dB scale.

3. RESULT AND DISCUSSION

Quality index and bandwidth and transmission domain were adjusted for two-channel demultiplexer according to table 1. Table 1 show that we could reach parameters of first stage of designing with ultra-channel spacing with distance of 1.1 nm and extreme narrow bandwidth with mean channel bandwidth of 0.2nm to work in DWDM technology. Also reaching the second goal, which was good efficiency with transmission domain mean of 93.74% and quality index mean of 7829.25 and very suitable wavelength range, was accomplished.

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

Channel	$\lambda_0\,(nm)$	Transmission Domain	$\Delta\lambda\,(nm)$	Q
1	1565.3	99.61%	0.2	7826.5
2	1566.4	87.33%	0.2	7832

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 demultiplexer with mean crosstalk of -19.74dB. Since the main goal of this research is reaching minimum crosstalk in two channel demultiplexer, with 2D photonic crystal structure, table 2 shows that mean crosstalk of -19.74 is the optimum condition to reach very high accuracy in channel resolution and lack of interference in output wavelengths of demultiplexers.

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

Channel	$Xt_{\lambda 1}$	$Xt_{\lambda 2}$
1	-18.496	-
2	-	-20.987

4. CONCLUSION

In this research by obtaining the band structure and wavelength spectrum range of $1401.9nm \le \lambda \le 1678.2nm$, structure of the basic filter with resonant cavity to apply in DWDM systems with 2D photonic crystal structure was designed and used. Proposed structure in this article could be used with very low dimensions for finding wavelengths with very high quality in optical communication systems. Structure of DWDM two-channel demultiplexer system based on recommended filter was obtained with the mean transmission range of 93.47%, average bandwidth value equal to 0.2nm, and distance of 1.1nm between channels 1 and 2. According to available results alongside with reduction in two-channel demultiplexer crosstalk phenomenon to mean of -19.74dB, proper average value of quality factor (Q) 7829.25 was also reached.

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