A dual cavity optical channel drop filter based on two dimensional photonic crystals

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In this paper, based on completely circular two dimensional photonic crystals, a channel drop filter is proposed which benefits from applying feedback in its structure. Filtering is achieved by creating a L4 cavity and imposing two defects in the cavity. Feeding back is done by using an arc type cavity. As a result, wavelength selectivity of output port is improved. Dropping the desired wavelength is furthermore studied by changing three parameters (i.e. radius of basic structure rods, radius of defect rods and refractive index of structure). Near 100% power transmission efficiency made the proposed structure suitable for all optical communication applications.

1. Introduction

Photonic crystals are periodic structures which have attracted tremendous tendency in literatures and industrial schemes in recent years [1]. Since these structures can be fabricated in very small sizes, they are among the best candidates for designing optical integrated circuits. One of the most important features of photonic crystals is photonic band gap (PBG) for electromagnetic waves (EM), in which the propagation of optical waves in any direction and any polarization is forbidden [2].

If the periodicity of photonic crystal be broken by some defects, the localization of electromagnetic field would be around the volume [3]. Using this concept, many optical devices can be designed [4-10]. By removing a complete row of rods, an optical waveguide can be formed [11]. Removing two, three or more rods result a cavity [12-14]. The created cavity may act as a filter. The destructive and instructive interference of waves inside the cavity is responsible of wavelength selecting [12, 15]. This extracted wavelength depends on many parameters such as dielectric constant of photonic crystal rods, radii of rods, length of the cavity and etc. Optical channel drop filters (OCDFs) based on cavities have been investigated in literatures [16-17].

By removing 4 air pores and then creating two defects in the resulted cavity and also by shifting down and up of some pores, a filter has been proposed by Mehdizadeh et al [12]. However the power coupling efficiency they reported is lower than 70%.

Mahmoud Youcef Mahmoud et al proposed an optical add drop filter (OADF) based on 2D photonic crystals [15]. By using X shape cavity and also using coupling and scatterer rods, channel dropping in their filter is done. They reported 100% drop efficiency but they didn't report the quality factor of their filter.

In this paper, we proposed an OCDF based on 2D photonic crystals. By creating two cavities, i.e. L4 cavity and an arc cavity, channel dropping is done. Furthermore to the interference of these two cavity fields, which will result an instructive and destructive interference, the Arc cavity may be considered as a feedback. The average drop efficiency is near 100% and quality factor as high as 750. These characteristics are suitable for wavelength division multiplexing. The overall size of the proposed structure is 255 μm^2 which makes it appropriate for photonic integrated circuits (PICs). The paper is further organized as following: in section 2 we will present the proposed filter. In section 3, the simulation and results are discussed. Finally in section 4 the conclusion will be provided.

2. Proposed filter

In order to investigate applicability of the proposed filter, extracting band structure and PBG of a filter is essential. We used BandSolve to perform the Plane Wave Expansion (PWE) calculation and also to obtain band structure of the filter. For accurate modeling of the proposed device, 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 for satisfying this requirement and with this approximation we reduced the 3D simulations to 2D simulations [18]. We used 2D completely circular photonic crystal in which the x and z direction are composed of 30 and 30 rods respectively. Lattice constant of structure (a) is 533 nm and the radius of rods (R) is 125 nm. The effective refractive index of rods and background in λ = 1550 nm are chosen n = 2.93 (for $As_{40}Se_{55}Cu_5$) and n_1 = 1 (for air) respectively. PBGs of the proposed structure are displayed by dark area in the Fig. 1.
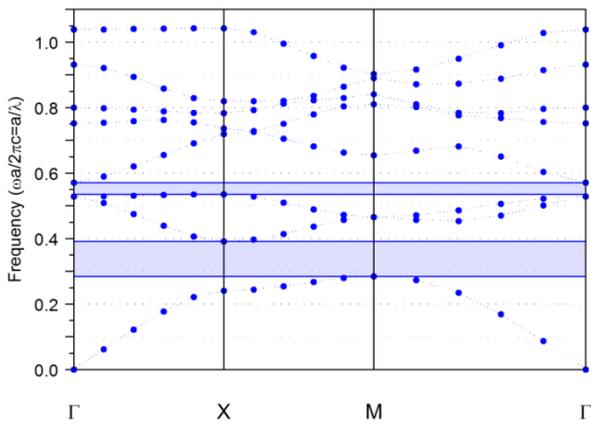
Fig 1. Band structure of fundamental photonic crystal.

One can see from figure1 that there are two PBG regions. The lower one is $0.2814 < a/\lambda < 0.390$ which is equal to the 1366 nm $< \lambda <$ 1894 nm and the upper PBG is $0.53081 < a/\lambda < 0.5691$ which is analogous to 936.4 nm $< \lambda <$ 1004 nm. Designing the filter in the lower PBG means that the device is suitable for optical communication applications.

Schematic of the proposed filter is shown in Fig. 2. By removing a complete row of rods the input waveguide is created. The structure consists of two cavities. The L4 cavity is created by removing 4 rods and then replacing two scatterer rods with radius R1 = 84 nm. The Arc cavity which can be considered as a feedback waveguide is created by removing 21 rods in an arc shape.
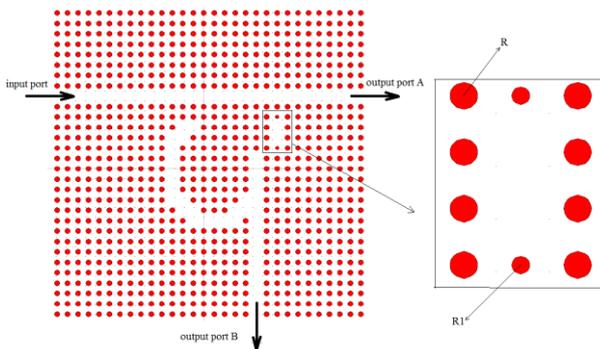

Fig. 2. Schematic diagram of the proposed filter.

Input signal is coupled into the L4 cavity. Then based on the parameters which have been set, R, R1, refractive index of rods and etc., specific wavelengths are dropped and go toward the output port B. Here by creating Arc cavity we seek two goals. The first one which is obvious is the interference between fields of two cavities which based on being destructive or instructive would result an outcome wavelength to the output port B. The second goal is looking it as a feedback.

By returning the wavelengths, which are going to be extracted from output port B to the input waveguide, feeding back is done. Using feedback results the proposed filter to have sharp wavelength selectivity. The transmission spectrums of input port, output ports A, B are shown in the figure3.

3. Simulation Result

We employed FullWave software to study the optical properties and also to simulate the proposed filter. The normalized transmissions at the output port A and output port B are shown by green and blue respectively. Fig. 3 shows that light from input port will drop at the desired wavelength (here $\lambda_0 = 1550$ nm) and travel toward the output port B. The passband of the desired wavelength ($\lambda_0 = 1550$ nm) is $\Delta\lambda = 2.09$, dropping efficiency is around 97% and quality factor (QF = $\lambda_0/\Delta\lambda$) is around 740 which are acceptable for optical applications.
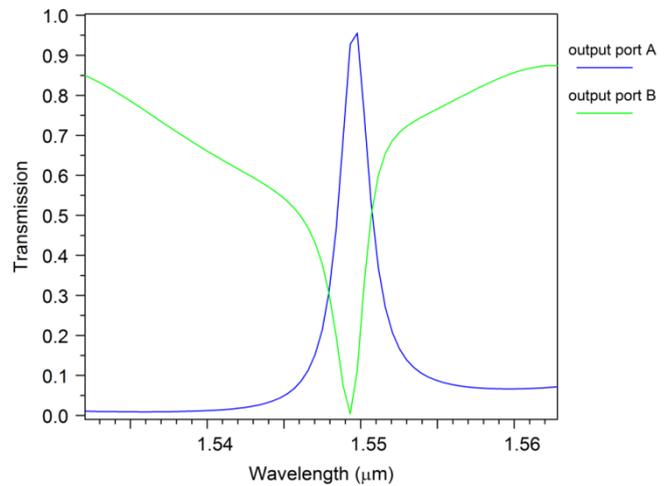

Fig. 3. Output spectrum of the filter.

Distribution of Field inside the OCDF for two different wavelengths ($\lambda = 1550$, 1550 nm) is shown in the figure4. Both wavelengths are in the PBG region, so they can't scatter in the structure and will propagate inside the waveguides. One can see from figure4 that at $\lambda = 1550$ nm the interfering of the cavities is instructive and this wavelength can be dropped to the output port B. However the interfering of wavelength at $\lambda = 1555$ nm is destructive and as a result this wavelength cannot be dropped and will be observed at the output port A. It's even possible to look at this filter as a 2 to 1 demultiplexer which can separate two channels from each other.
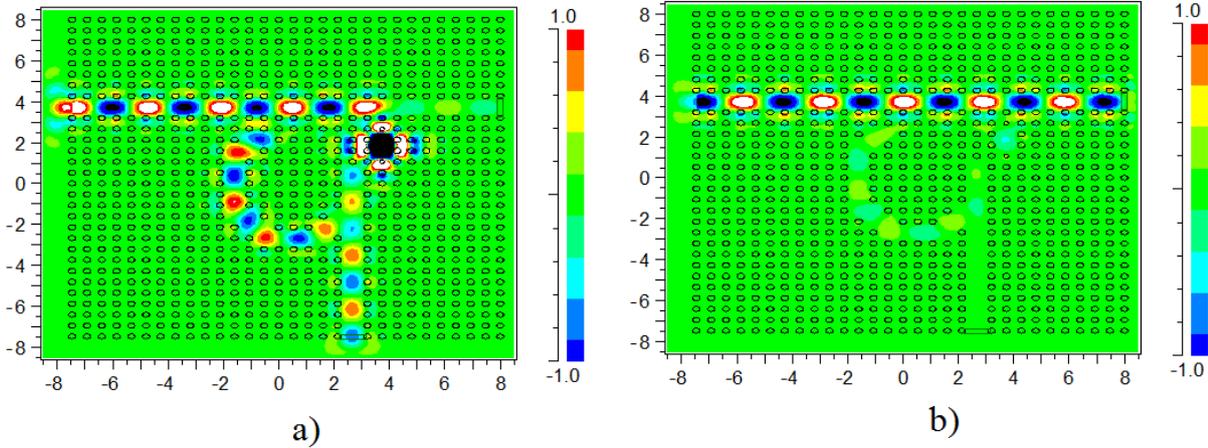
Fig. 4. Field distribution inside the structure a) at λ=1550 nm, at λ= 1555 nm.

Furthermore, in order to study the effects of lattice parameters (such as R, R_1 and n) we changed them and explored their influences on output spectrum of the proposed filter at port B.

In the first attempt, we changed the value of radius of structure rods. Selecting R= 122, 123, 124, 125 and 126 nm caused the output wavelength at output port B be at λ = 1530, 1533, 1536, 1539 and 1542 nm respectively. Output spectrum at port B for different values of R is shown in the fig. 5.

After that, we changed the radius of two rods (R1 in the fig. 2) that are created as defects in the L4 cavity. By changing the radius from 80 nm to 84 nm, the wavelengths at port B shifted from 1541 nm to 1549 nm respectively (fig. 6).

Fig. 6. Output spectra of the suggested filter for different defect Radius (R1).
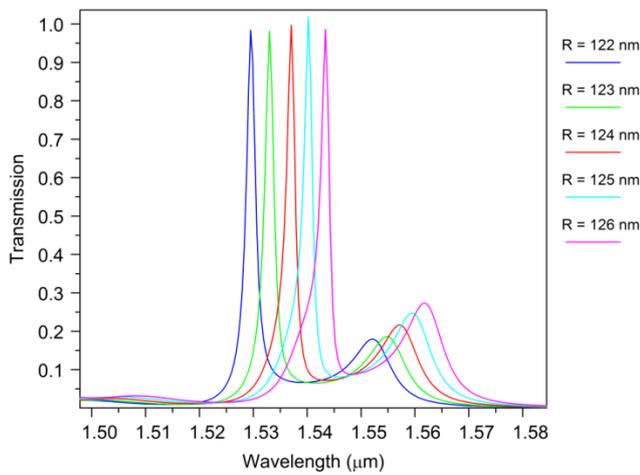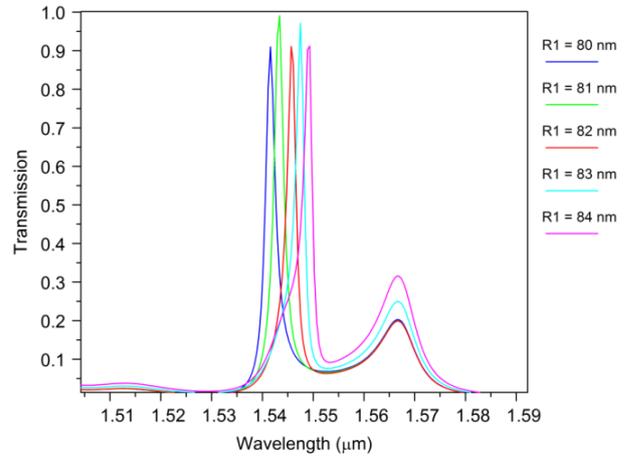

Fig. 5. Output spectra of the proposed filter for different Radius (R)

As it can be seen from Fig. 5, by increasing the radius of the rods, the central wavelength will go toward higher wavelengths. The average quality factor of outputs is around 750 and the power transmission efficiency is more than 97%. These results make the filter suitable for optical applications.

Similar to the variation of basic radii, by increasing the radius of defects, wavelength at output port B will be shifted to higher wavelengths. The average quality factor of outputs is 770 and the average power transmission efficiency is more than 94%.
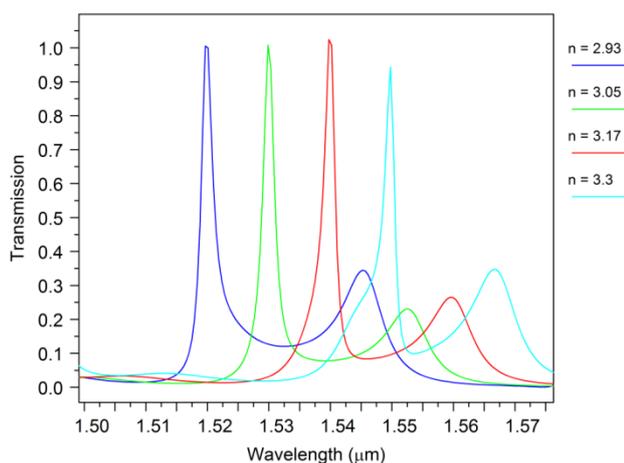
Fig. 7. Output spectra of the proposed filter for different refractive indices.

Also, we changed refractive index of rods form n =2.93 (for chalcogenide glass $As_{40}Se_{55}Cu_5$) to n = 3.3 (for high refractive index Te-enriched bulk chalcogenide glass $Ge_{20}As_{20}Se_{14}Te_{46}$). figure7 shows output spectrum at port B.

By increasing the refractive index from 2.93 to 3.3 the central wavelength of light at output port B will shift from 1488 nm to 1490 nm respectively. Average quality factor is around 740 and average power transmission efficiency is around 96%.

4. Conclusion

In this paper a new optical channel drop filter is proposed which benefits the advantage of having feedback in its structure. By using completely circular chalcogenide rods in the 2D photonic crystal, a filter is suggested which shows power transmission efficiency near to 100%. Variation of three parameters is studied and it is shown that by changing radius of rods (R), Radius of two defect rods inside the L4 cavity (R1) and refractive indices of rods, wavelength selectivity is achieved. All of these features make the proposed filter suitable for wavelength Division Multiplexing (WDM) and optical communication applications.

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