

# Optical filter based on photonic crystal resonant cavity

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An optical filter based on photonic crystal structure has been proposed in this paper. For designing the proposed filter we introduced an L3 resonant cavity between the input and output waveguides. We study the impact of different parameters on the filtering behavior of the structure using plane wave expansion and finite difference time domain methods. The initial form of this filter is capable of selecting the optical waves at  $\lambda=1555$  nm and the transmission efficiency of the filter is obtained about 100%.

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*Keywords:* Photonic Crystal, Optical Filter, refractive index, Photonic band gap

## 1. Introduction

Currently designing ultra-compact and fast optical devices suitable for optical communication and optical switching networks is very crucial for optics and photonics engineers. Photonic crystals (PhCs) are one of the promising candidates for designing optical devices. PhCs have a special frequency (wavelength) range in which the propagation of optical waves inside these artificial structures is forbidden. This special range is called photonic band gap (PBG) [1]. PBG depends on the refractive index and structural parameters of the PhC [2]. Optical circulator [3], optical filters [4], and optical demultiplexers [5] are some examples of optical devices designed by PhCs.

Among the different optical devices designed based on PhCs, optical filters are the most significant ones. Beside their crucial role in choosing the desired wavelength and for separating the very closely spaced optical channels in wavelength division multiplexing (WDM) applications [6], Remote sensing [7], hyper spectral imaging [8], and biomedical sensing [9] they are the basic structure used for designing other optical devices such as optical demultiplexers [10], optical switches [11] and optical logic gates [12].

Different mechanisms have been proposed for designing optical filters based on 2DPhCs. Resonant cavities [13-14], line defect waveguides [15], ring resonators [16] and quasi crystals [17] are some common mechanisms used for performing wavelength selection task in 2D PhC based devices. Robinson and Nakkeeran [18] proposed eight filters using different resonant cavities. For filtering and selecting the desired wavelength they proposed eight kinds of cavity namely quasi square, tri-quarter square, square, hexagonal, circular, elliptical, diamond and annular ring based cavities. A tunable WDM optical filter based on Quasi-2D Photonic Crystal (Q2DPhC) has been proposed [17]. In which a 2D photonic crystal is combined with a Q2DPhC. The

Q2DPhC performs the wavelength selecting and by changing the radius of its rods a tunable filter is attainable.

In this paper we used a L2 resonant cavity for designing a optical filter and investigated the effect of different parameters on the filtering behavior of the proposed structure.

The rest of the paper is organized as follow: in section 2 we introduce the methods and the design procedure of the filter, in section 3 we simulate the proposed structure and discuss the results obtained from our simulations and finally in section 4 we conclude from our paper.

## 2. Filter design

For designing the proposed filter we use a 30\*20 hexagonal lattice of dielectric rods immersed in air. The effective refractive index of dielectric rods is 2.8. And the radius of dielectric rods is  $r=0.27a$ , ( $a=600$  nm is the lattice constant of the PhC structure). First of all we should calculate the PBG region of the fundamental structure used for designing the CDF. Currently the best solution for studying the band structure and obtaining the PBG of PhCs is numerical methods. One of these numerical methods is Plane Wave Expansion (PWE). The band structure diagram of our structure with aforementioned values for refractive index, radius of rods and lattice constant is shown in Fig. 1. We have 3 PBGs in TM mode which are shown with blue colored areas and no BPG in TE mode. The first PBG in TM mode are between 0.28 and 0.40. Considering  $a=600$  nm only the first PBG in TM mode will be suitable for our goals which is between 1500 nm and 2142 nm. Therefore all the simulations will be done in TM mode.

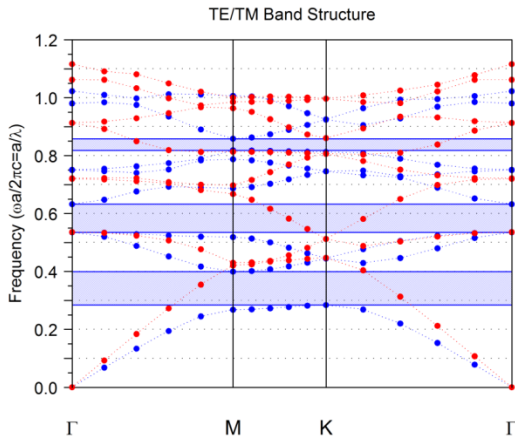


Fig. 1. The band structure of the PhC.

Similar to any other resonant cavity based optical filters, the proposed filter consists of three main parts: (1) input waveguide, (2) resonant cavity, and (3) output waveguide. The input waveguide was created by removing 11 rods in X direction, then we created the resonant cavity by removing 3 rods two rows above the input waveguide at each corner of the resonant cavity we placed defect rods. The radius of these defect rods -  $R=122$  nm - are less than the fundamental structure rods. These rods are shown with blue color in Fig. 2. Finally, the output waveguide was created 2 rows above the resonant cavity by removing 6 rods in X direction.

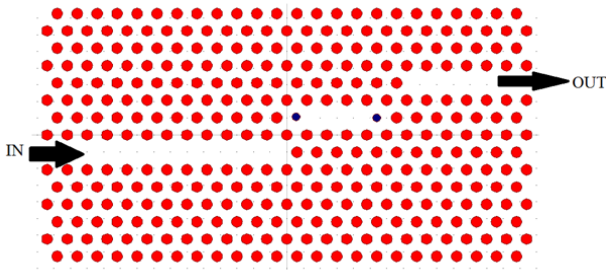


Fig. 2. Schematic Diagram of the proposed filter.

### 3. Simulation and results

Using finite difference time domain (FDTD) method we simulated the proposed structure and obtained the output spectrum of the filter. Obtaining accurate results require a 3D simulation of the structure which is very time consuming and requires very powerful computer systems so we used effective refractive method to reduce the 3D calculation to a 2D one with minimum errors. After all the output spectrum of the proposed filter is shown in Fig. 3. Fig. 3 shows that are structure works as an optical filter which only selects the wavelength of 1555 nm, the bandwidth ( $\Delta\lambda$ ) is 0.8 nm and the Q-factor ( $Q=\lambda_0/\Delta\lambda$ ) is 1943. The transmission efficiency of this filter is 100%. At

the following we are going to investigate the effect of different parameters on the filtering behavior of the proposed filter.

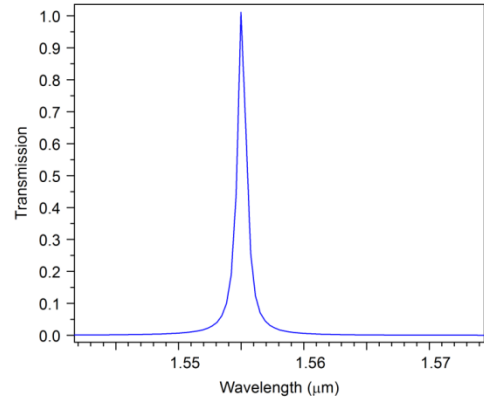


Fig. 3. The output spectrum of the filter.

The output spectra of the structure for different values of  $R$  is shown in Fig. 4. As shown in Fig. 4 by increasing  $R_c$ , we have a red shift in output wavelengths, because the resonant wavelengths increase. Such that for  $R_c = 110, 115, 1120, 125,$  and  $130$  nm the output wavelengths are  $\lambda=1551.1$  nm,  $1552.8$  nm,  $1554.7$ ,  $1556.3$  nm, and  $1587$  nm respectively. The detailed specifications of the output wavelengths for different values of  $R_c$  are listed in Table 1.

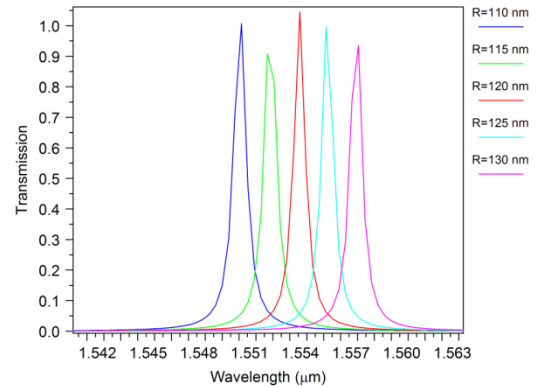


Fig. 4. The output spectra of the filter for different values of  $R$ .

Table 1. Significant parameters of the proposed filter for different values of  $R$ .

R	$\lambda$ (nm)	$\Delta\lambda$ (nm)	Q	T. E.* (%)
110	1551	0.8	1938	100
115	1552.8	0.9	1725	90
120	1554.6	0.8	1943	100
125	1556.2	0.8	1945	100
130	1558	0.8	1947	94

\*Transmission Efficiency

The output spectra of the structure for different radius of fundamental structure rods -  $R_0$  - are shown in Fig. 5. As shown in Fig. 5 by increasing  $R_0$ , we have a red shift in output wavelengths, because the resonant wavelengths increase. Such that for  $R_0 = 150, 155, 160, 165,$  and  $170$  nm the output wavelengths are  $\lambda = 1517$  nm,  $1532.9$  nm,  $1549.6$  nm,  $1570.2$  nm, and  $1591.9$  nm respectively. The detailed specifications of the output wavelengths for different values of  $R_0$  are listed in Table 2.

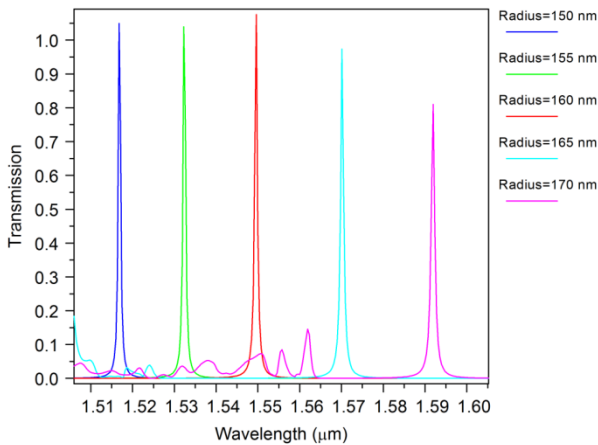


Fig. 5. The output spectra of the filter for different values of Radius.

Table 2. Significant parameters of the proposed filter for different values of  $R_0$ .

$R_0$	$\lambda$ (nm)	$\Delta\lambda$ (nm)	Q	T. E.* (%)
150	1517	0.7	2167	100
155	1532.5	0.7	2189	100
160	1549.6	0.8	1937	100
165	1570.2	0.8	1962	98
170	1591.9	1.1	1447	81

\*Transmission Efficiency

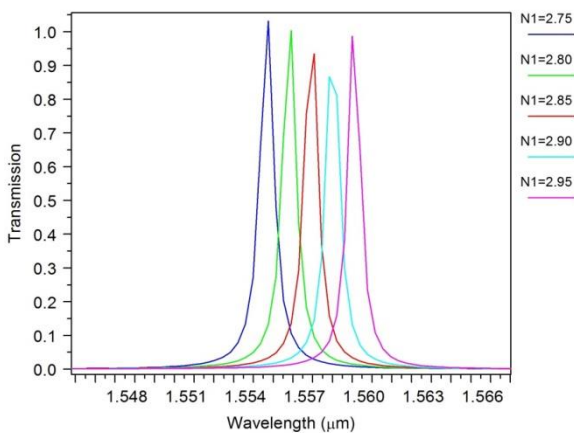


Fig. 6. The output spectra of the filter for different refractive indices of the defect rods ( $n_d$ ).

The output spectra of the filter for different refractive indices of the defect rods ( $n_d$ ) is shown in Fig. 6. As shown in Fig. 6 by increasing the refractive index of the defect rods, the output wavelengths shift toward higher wavelengths. Such that for  $n_d = 2.75, 2.80, 2.85, 2.90,$  and  $2.95$  the output wavelengths are  $\lambda = 1555.7$  nm,  $1556$  nm,  $1557$  nm,  $1558$  nm, and  $1569$  nm respectively. The detailed specification of the output wavelengths for different refractive indices are listed in Table 3.

Table 3. Significant parameters of the proposed filter for different values of  $n_d$ .

$n_d$	$\lambda$ (nm)	$\Delta\lambda$ (nm)	Q	T. E.* (%)
2.75	1555.7	0.9	1728	100
2.8	1556	0.9	1730	100
2.85	1557	0.9	1731	94
2.9	1558	0.9	1732	87
2.95	1559	0.9	1733	99

\*Transmission Efficiency

#### 4. Conclusion

In this paper, we proposed a novel structure for designing an optical filter based on photonic crystal resonant cavity. The resonant part of the filter is an L3 resonant cavity, which performs the filtering behavior of the structure. The transmission efficiency of the structure is about 100% and quality factor is about 1943. Our simulations show that the resonant wavelength of the filter depends on the refractive index and radius of the dielectric rods.

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