Journal of Artificial Intelligence in Electrical Engineering, Vol. 2, No.7, November 2013

Optical Filter Based on Point Defects in 2D Photonic Crystal Structure

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ABSTRACT

In this paper, we proposed a novel structure for designing all optical filter based on photonic crystal structure. In designing the proposed filter, we simply employed a point defect localized between input and output waveguides as wavelength selecting part of the filter. The initial form of this filter is capable of selecting optical waves at λ*=1560 nm, the transmission efficiency of the filter is 100%. In designing and studying the optical properties of the filter, we used plane wave expansion and finite difference time domain methods. After designing the filter, we studied the impact of different parameters on the filtering behavior of the structure. The total footprint of the filter is less than 100* 100 μ*m2. Simplicity of design and ultra-compact dimensions are the most significant characteristics of our filter.*

KEYWORDS: Photonic Crystal, Optical filter, Defect, FDTD

1. INTRODUCTION

Optical filters [1-2] are crucial devices for WDM and DWDM systems. Beside omitting the noise from channel information optical filters are used for separating the undesired WDM and DWDM channels from desired channels. Other crucial applications of filters are in demultiplexing multiple channels in WDM and DWDM systems. Since the discovery of photonic crystal in 1987 [3], designing compact and highly selective optical filters become possible. PhCs mainly are composed of 2 different dielectric materials with different refractive indices. The arrangement of these 2 dielectric materials is such that the distribution of refractive index is periodic. According to this periodicity, these artificial structures are divided into 3 categories: 1D, 2D and 3D PhCs. Because of their periodic distribution of refractive index, they have the ability to confine light in very small spaces, which was one of the major problems for designing ultra-compact optical devices. Another feature of PhCs is their Photonic Band Gap (PBG), a wavelength region in their band structure in which no electromagnetic wave can propagate inside these crystals [4].

Different mechanisms have been proposed for designing optical filters based on 2DPhCs. One way of realizing optical filter in 2DPhCs is putting a resonant cavity between input and output waveguides [5]. It has been shown that the resonant wavelength of the cavity can be controlled by changing the effective length of the resonant cavity. Using quasi crystal structures are other ways of realizing optical filters based on 2DPhCs [6]. The most common mechanism used for designing 2DPhC based filters is ring resonators [7]. Different kinds of ring resonators have been proposed more recently. In these structures the resonant wavelength depends on the refractive index and the dimensions of the resonant ring [8].

In this paper, we are going to propose a novel structure for designing optical filter. The wavelength selection part of the proposed filter is composed of some point defects. The significant characteristics of our proposed structure are its high transmission efficiency and very small footprint. The transmission efficiency of the proposed filter is about 100% and its footprint is less than 100 um^2.

The rest of the paper is structured as follows: in section 2 we discussed the design procedure of the structure. In section 3 we propose the simulation results in this section we obtained the output spectrum of the filter and then investigate the effect of different parameters on the filtering behavior of the structure and finally in section 4 we conclude from our work.

2. DESIGN PROCEDURE

The fundamental platform employed for designing the proposed filter is 18*16 square lattice of dielectric rods immersed in air. The effective refractive index of dielectric material and the radius of dielectric rods is n=3.1 and $r=0.18*a$, respectively, where a is the lattice constant of PhC and equal to a=600 nm. First, we should calculate the band structure diagram of the fundamental structure and extract its PBG regions. For this purpose, we used plane wave expansion (PWE) method [9]. The dispersion curve simulated and displayed in figure 1. We found a PBG in TM mode (blue color areas) between $0.33<a/\lambda< 0.46$. Considering $a=600$ nm the PBG will be 1239 nm< λ<1726 nm, that is in the range of optical communication applications.

The proposed optical filter is composed of three main parts: input waveguide in X direction, output waveguide in the Z direction and the wavelength selective part which is composed of one central defect (shown in green) with eight defects around the central defect (shown in blue). We call these blue colored defects as peripheral defects. The radius of central defect is R=50 nm and the radius of peripheral defects are R1=90 nm. The final sketch of the proposed filter is shown in figure 2.

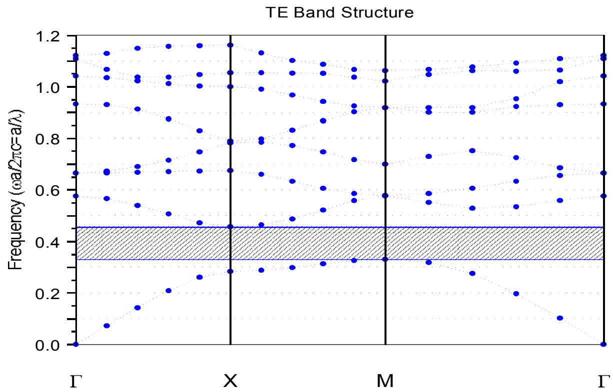

Fig.1. The band structure of the photonic crystal

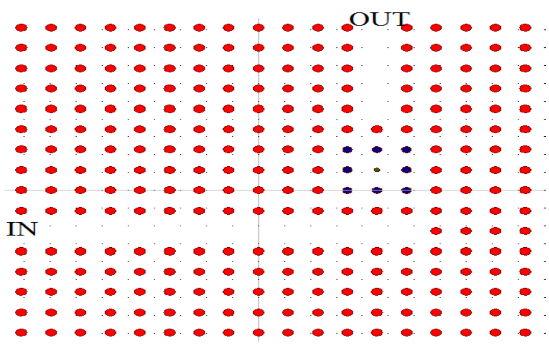

Fig.2. The final sketch of the filter

3. SIMULATION AND RESULTS

After finalizing the design process of the proposed filter, we simulated the structure and obtained its output spectrum. The most commonly used method for obtaining the optical properties of PhC-based devices are finite difference time domain (FDTD) [10]. Due to calculation time and accuracy considerations, we used FullWave simulation tool of Rsoft photonic CAD software, which simulates optical devices based on FDTD method. The output spectrum of the filter has been obtained like figure 3. Figure 3 shows that the proposed structure has a resonant mode at λ=1560 nm with transmission efficiency equal to 100%. The bandwidth and the quality factor of the filter is 4 nm and 390 respectively. At the following, we will study the effect of different parameters on the output wavelength of the filter. The output spectra of the structure for different values of R – radius of central defect- is shown in figure 4. As shown in figure 4 by increasing the R, the output wavelengths shift toward higher wavelengths. Such that for R=50, 51, 52, 53 and 54 nm the output wavelengths are λ=1561 nm, 1566 nm, 1576, 1582nm, and 1587 nm respectively. The detailed specification of the output wavelengths for different of R are listed in table 1.

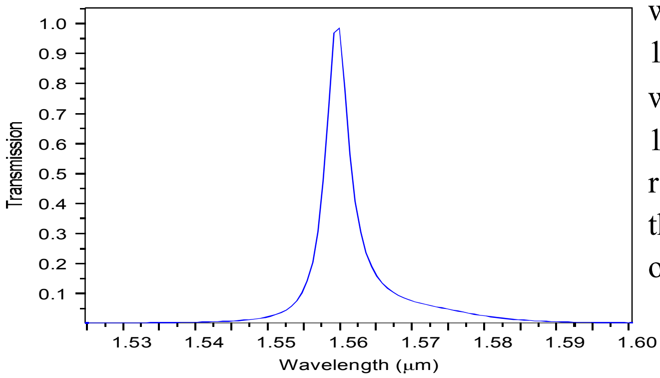

Fig.3. The output spectrum of the filter

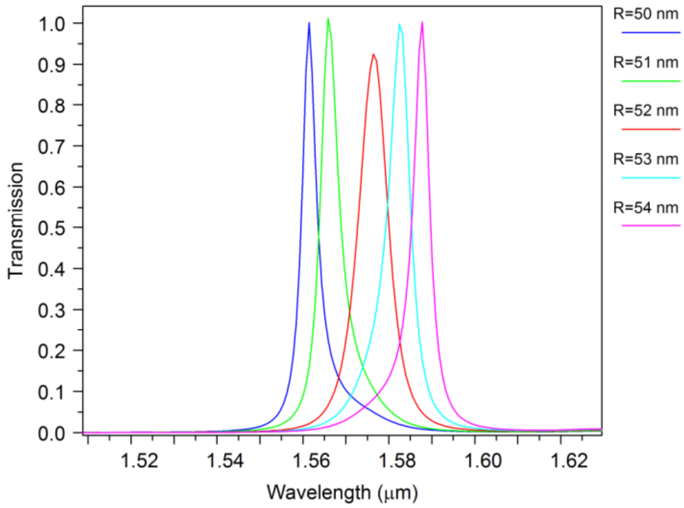

Fig.4. The output spectra of the filter for different values of R

Table1. Significant parameters of the proposed filter for different values of R

R(nm)	λ_0(nm)	$\Delta\lambda$(nm)	Q	TE(%)
50	1561	5	312	100
51	1566	5	313	100
52	1576	8	197	96
53	1582	5	316	100
54	1587	5	317	100

The output spectra of the structure for different values of R1 –radius of peripheral defects- is shown in figure 5. As shown in figure 5 by increasing the R1, the output wavelengths shift toward higher wavelengths. Such that for R1=100, 101, 102, 103 and 104 nm the output wavelengths are λ=1552 nm, 1555 nm, 1558 nm, 1560 nm, and 1563 nm respectively. The detailed specification of the output wavelengths for different values of R1 are listed in table 2.

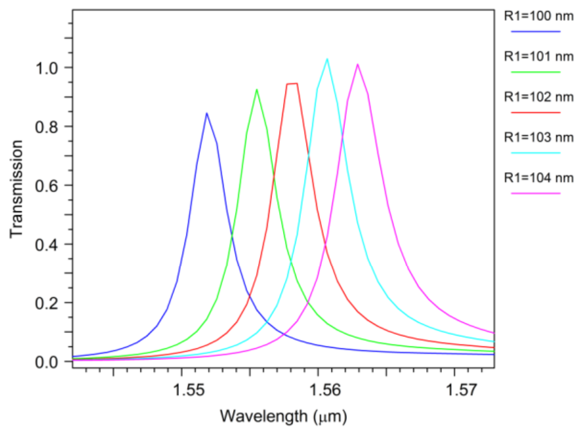

Figure.5. The output spectra of the filter for different values of R1

Table2. Significant parameters of the proposed filter for different values of R

R1	λ_0	$\Delta\lambda$	Q	TE
100	1552	3.5	443	84
101	1555	3.5	444	93
102	1558	3.5	445	93
103	1560	3.5	445	100
104	1563	3.5	446	100

4. CONCLUSION

In this paper employing a point defect inside a 2D photonic crystal we proposed an optical filter. Using numerical methods such as PWE and FDTD methods we obtained the optical properties of our proposed structure and investigated the effect of different parameters on the output wavelength of the filter. The proposed structure has a resonant mode at λ=1560 nm with transmission efficiency equal to 100%. The bandwidth and the quality factor of the filter is 4 nm and 390 respectively. Our results show that by increasing the radius of defects the output wavelength of the filter increases. The total footprint of the filter is less than 100 μm^2, this shows that our filter is compact enough to be used in all optical integrated circuits. Simplicity of design is the other advantage of our proposed structure.

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