Study of band structure characteristics of periodic two-dimensional of photonic crystals with different geometric forms

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ABSTRACT:
In this paper, new structures of two-dimensional periodic photonic crystals in the form of dielectric rods with different geometric shapes, are presented. All photonic crystals presented in this paper are in a square lattice. Band structure and photonic band gap limitation graph of these structures are obtained by using numerical methods of plane wave expansion (PWE) for TE and TM modes. The simulation results for these structures show different photonic band gap widths and places for different structures and modes.

KEYWORDS: Photonic crystal, Photonic band gap, Plane Wave Expansion method, Photonic device

1. INTRODUCTION

Photonic crystal [1], [2] can be defined as a medium with optical periodic characteristics that is assumed like a periodic array of two dielectrics in two dimensions. In a photonic crystal some gaps can be produced in band structure that electromagnetic waves can't transport in some distinct frequencies [3], [4]. Photonic crystals are so considerable for their control capabilities and electromagnetic wave guidance.

Band Gap is one of the most important characteristics of photonic crystals that most of photonic crystal uses and band gap uses like optical fiber designation [5], waveguides [6], filters [7],and most of other optical instruments are based on this photonic band gap. Photonic crystals with wider band gap limitation are so considerable for the possibility to design optical instruments in this limitation.

Different factors are effective in creating band gap and its width in optical band structure like photonic crystal lattice, dielectric material, holes or rods, and photonic crystal shapes. In this paper we study the effect of shape and geometry of photonic crystal in characteristics of optical band structure of them. We have used numerical method of plane wave expansion [8], one of numerical methods in frequency domain and one of the most current methods for simulation, to calculate optical band structure of photonic crystals.

2. METHOD AND SIMULATION

Fig. 1 shows periodic photonic crystal structures, study in this paper, with different geometries.

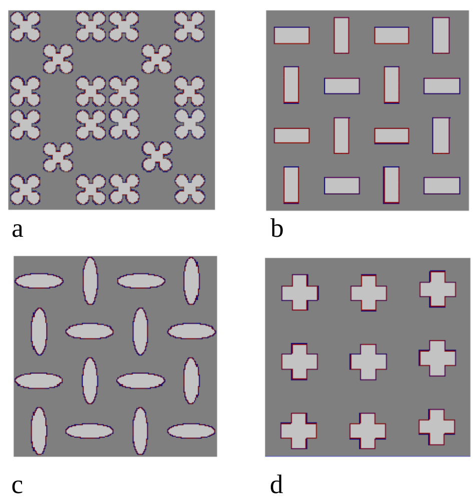


Fig. 1. Two-dimensional periodic photonic crystals with different shapes.

As is seen, we can design photonic crystals in new shapes and with different optical band structure characteristics by combining simple shapes. Photonic crystals in this paper are all in square lattice structure. Rods dielectric constant , ε , is 12 and background.

Fig. 2. shows the photonic crystal cells with side length of “a”. Table 1 shows side length and photonic crystal radius in a square photonic crystal cells which shown in Fig. 2. Periodic photonic crystal structures of Fig. 1 are produced by repeating and combining these cells.

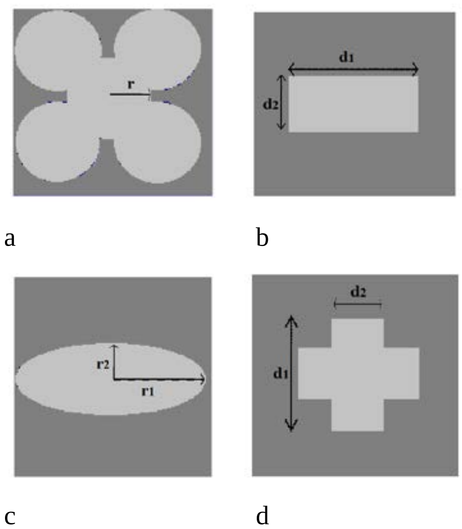


Fig. 2. Photonic crystal cells

Table 1. The side length and radius of photonic crystals with different shapes in a square cell

Figure	The side length or radius of photonic crystal
a	r= 0.2 a
b	d_1 = 0.7 a d_2 = 0.3 a
c	r_1 = 0.47 a r_2 = 0.125 a
d	d_1 = 0.5 a d_2 = 0.2 a

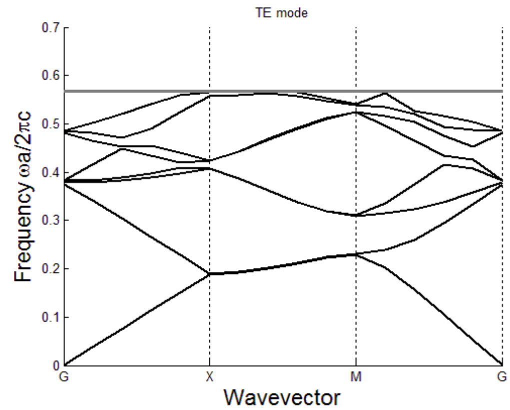
In this paper, diagrams of optical band structure of photonic crystals, using plane wave expansion method, are studied for the first eight bands and in two TE and TM modes. Eq. (1) and Eq. (2) are expressed the final eigen-value equations for electric and magnetic fields in plane wave expansion method. For electric field, the equation is expressed as follow:

$$\sum_{G} \kappa\left(G-G'\right)\left|k+G\right|\left|k+G'\right| C\left(k+G'\right)=\frac{\omega^2}{c^2} C\left(k+G\right) \quad (1)$$

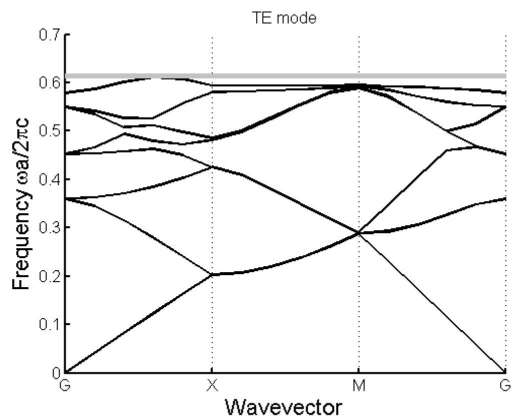
$$\sum_{G'} \kappa\left(G-G'\right)\left(k+G'\right)\left(k+G\right) A\left(k+G'\right)=\frac{\omega^2}{c^2} A\left(k+G\right) \quad (2)$$

Where G is the reciprocal lattice vector, κ is the fourier coefficient, K is the wave vector, C and A are coefficients.

Firstly, we study optical band structure in TE mode for periodic photonic crystal structures. Fig. 3 shows diagrams of optical band structure of photonic crystals after simulation by plane wave expansion method.



a



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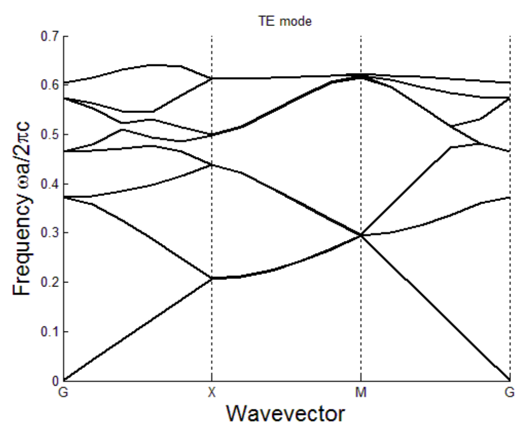

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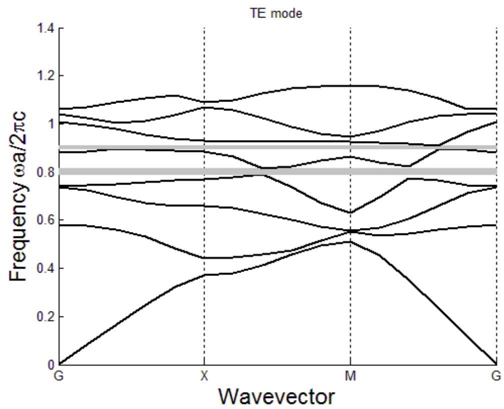


d

Fig. 3. Photonic band structure of two-dimensional periodic photonic crystals in TE mode.

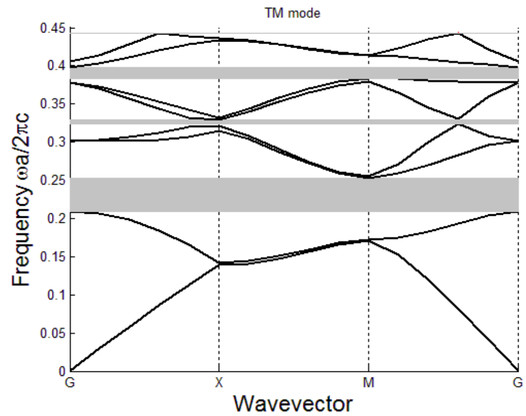
As we see in figure (c), optical band structure diagram has no photonic band gap for its first eight bands. Photonic crystals in figures (a) and (b), has a narrow band gap in its first eight bands with central frequencies of 0.56795 and 0.61465. Optical band structure diagram in figure (d), has two band gaps with central frequencies of 0.80395 and 0.9023. According to the results, the width of band gap for square photonic crystal offered is little.

As it was seen, diagram of optical band structure of periodic photonic crystal structures, in this paper, has no band gap or has band gap with little width in TE mode, not proper for designing optical devices. Table 2 shows the results of simulation by plane wave expansion in TE mode for two dimensional periodic photonic crystals of Fig. 1.

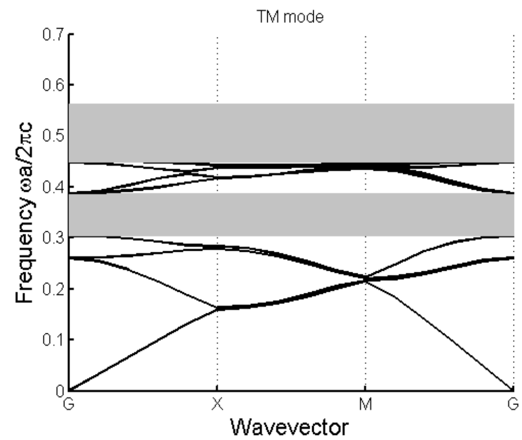
Table 2. The simulation results of plane wave expansion method for TE mode

Photonic crystal shape	Photonic band gap of frequency limitation in TE mode	Central frequency
a	0.5658-0.5701	0.56795
b	0.6106-0.6187	0.61465
c	-	-
d	0.7915-0.8164 0.8953-0.9093	0.80395 0.9023

In the next step, we calculate optical band structure of photonic crystals in TM mode. Fig. 4 shows the results of this simulation.



a



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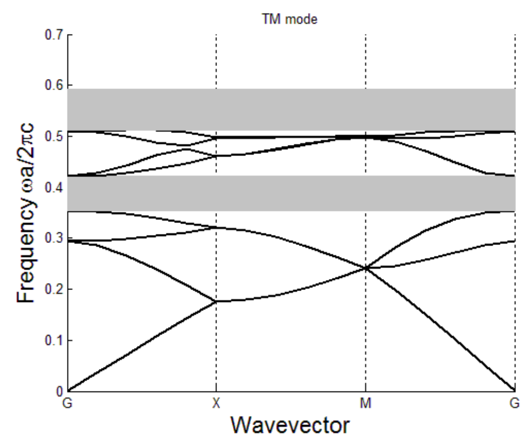

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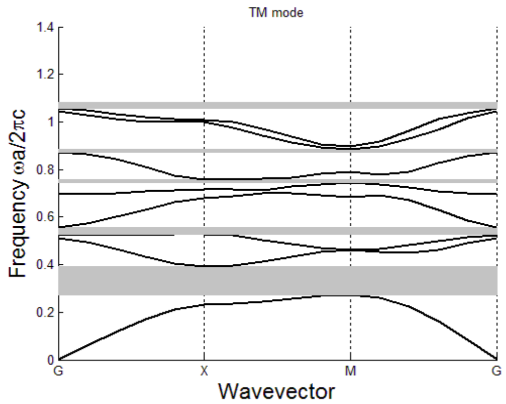

b

Fig. 4. Photonic band structure of two-dimensional periodic photonic crystals in TM mode.

Figure (a) shows three band gaps with central frequencies of 0.2312, 0.32715 and 0.39115 in optical band structure. The first band gap is between second and third bands. This band gap has a wide bandwidth and is proper for designing optical devices. The second and third band gaps are in a higher frequency in the fourth and fifth and sixth and seventh bands limitation of eight bands and have a more little limitation compared to first band gaps.

Figure (b) has two band gaps in its band structure with central frequencies of 0.3459 and 0.5062 and with different widths.

Optical band structure diagram of figure (c) has two band gaps with central frequencies of 0.38775 and 0.55185. The first and second band gaps have proper widths and can be used for designing optical devices with low frequencies.

Optical band structure diagram shown in figure (d) has five band gaps in its first eight bands. The first band gap with central frequency of 0.33125 in contrast to the other four band gaps has proper width and the first band gap is in the frequency limitation of 0.272-0.3905. The second, third, fourth and fifth band gaps are in higher frequencies and has more little bandwidth compared to the first band gap.

Table 3 shows the results obtained from simulation of optical band structure of photonic crystals with different geometric shapes by using plane wave expansion in TM mode.

Table 3. The simulation results of plane wave expansion method for TM mode

Photonic crystal shape	Photonic band gap of frequency limitation in TM mode	Central frequency
a	0.2091-0.2533 0.3245-0.3298 0.3838-0.3985	0.2312 0.32715 0.39115
b	0.3044-0.3874 0.4492-0.5632	0.3459 0.5062
c	0.3547-0.4208 0.5127-0.5915	0.38775 0.55185
d	0.272-0.3905 0.5285-0.5581 0.7438-0.7578 0.7808-0.8831 1.0575-1.0808	0.33125 0.5433 0.7508 0.83195 1.06915

In TM mode, unlike TE mode, optical band structure diagrams have band gaps with proper widths and can be used for designing different optical devices like waveguides, couplers, filters, and more other optical devices.

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