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Photonic band gaps of two-dimensional square-lattice photonic crystals based on 8-shaped scatters

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ABSTRACT

A novel photonic crystals (PhC) based on 8-shaped scatters with two-dimensional (2-D) square-lattice is presented. By employing the MIT photonic bands (MPB), the relationship between the structural parameters of the PhC and the properties of photonic band gaps (PBG) are investigated. The calculation results of 8-shaped scatters with 2-D square-lattice demonstrate that the reduction of scatters' symmetry can produce larger number of PBG and broaden the width of PBG only for TM mode, and reversely for TE mode. The peculiarity would meet the distinguish employment of different mode. By optimizing the structural parameters, the maximum absolute PBG 0.1028($\omega a/2\pi c$) at $R = 0.3$, $\varepsilon_r = 11.56$, $\theta = 45^\circ$ is obtained and six absolute PBGs is got at $R = 0.3$, $\theta = 115^\circ$, $\varepsilon_r \in [32.3, 33.5]$.

1. Introduction

Photonic crystals (PhC) are artificial structures with periodically structures and have photonic bandgaps (PBG) in which the propagation of photon is prohibited [1,2]. PhC with PBG have been widely studied as the basis of mirror [3], waveguides [4], lasers and cavities [5,6], filters [7,8], and other important components for high density optical integration. Based on the characteristics of the PBG, designing a PhC with larger PBG will produce significant impacts both in academic and application areas. Originally, most studies of PCs are based on square, triangular or rectangular lattice [9]. In order to more elastic design the PBG properties, the pursuer in the PhC literature struggle with PhC structures. Pervious research findings indicate that the low symmetrical lattice and low symmetrical scatter tend to provide the larger PBG. The PhC with parallelogram [10,11] and rhombus lattice [12–14] have been promoted to advance the width of PBG. Recently, the width of PBG has been improved by elliptic air holes [15], Taiji-shaped dielectric rods [16], dielectric rings [17], S-shaped rods [18] PhC.

Inspired by the effects of shapes and orientations [19] of scatterers and lattice symmetries on the PBG in 2-D PhC, a novel PhC with 8-shaped scatters was proposed. This paper will present a summary of our ongoing research in the area of PBG based PhC applications. Therefore, the remainder of this paper is organized as follows: in Section 2 we present the structure of 8-shaped PhC and highlight the analytical method, in Section 3 the nature of PBG for different structural parameters are analyzed, in Section 4 we present the concluding remarks.

2. Description of the 8-shaped PhC and its analyze method

Fig. 1 depicts the proposed structure of PhC implemented on a 2-D square-lattice consisting of 8-shaped scatters and its structural parameters. The lattice constant is $a = 1\ \mu$m, 8-shaped scatter with small circular radius r and the radius of the scatter R (with the unit of a), satisfy the relationship $R = 2r$. θ is the angle between the axis of the two small circular and x-axis, θ is positive while anticlockwise rolling. The 8-shaped scatters embedded in a air background with relative dielectric constant ε_r. Based on the theory of crystal = lattice + scatter, the first irreducible Brillouin zone (IBZ) must expand to the first Brillouin zone (BZ) because of the symmetry of scatter is lower than the symmetry of lattice.

By employing the MIT photonic bands (MPB), the relationship between the structural parameters ε_r, $R = 2r$, θ of the PhC and the properties of photonic band gaps (PBG) are investigated.

Fig. 2 shows the energy bands of the proposed PhC for TM mode achieved along the wave vector in the first BZ along the boundary. We suppose $k_x \in [-\pi/a, \pi/a]$ and divided into 20 intervals with sign the point from 1 to 21. In other words, 1 corresponding to $-\pi/a$, 11 corresponding to 0 and 21 corresponding to $-\pi/a$ along k_x axis. The expression of k_y is the same as k_x. Fig. 2a shows three dimensional scheme of the first band for TM mode (magnetic field

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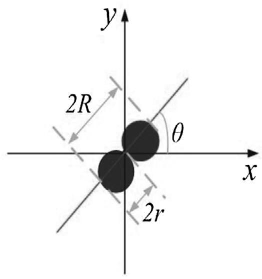
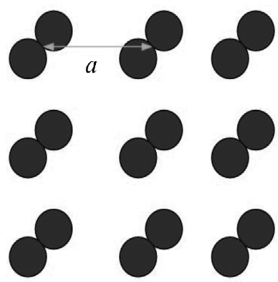
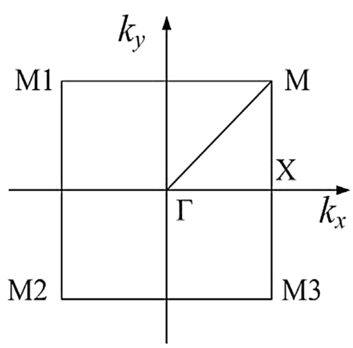


(a) Model of 8-shaped scatter



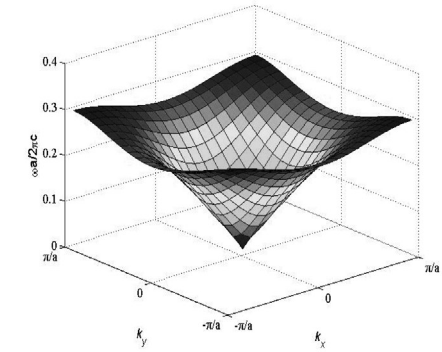
(b) 2-D PhC structure with proposed scatters



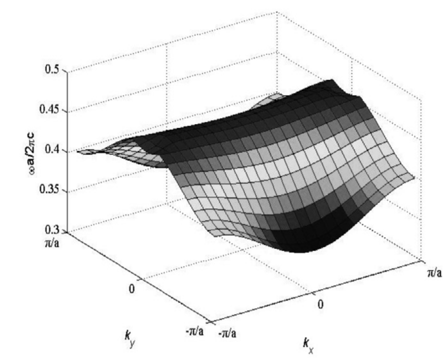
(c) The first Brillouin zone and the first irreducible Brillouin zone

Fig. 1. Schematic view of the proposed 2-D PhC structure with 8-shaped scatters.

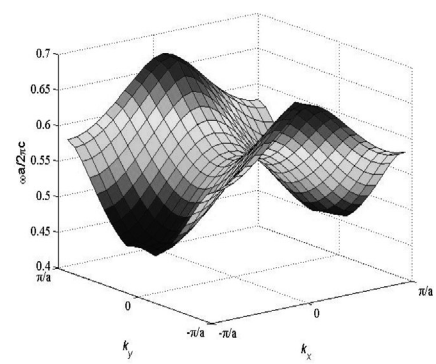
parallel of the cylinders). The minimal value of the normalized frequency (NF) is zero when $x = 11$, $y = 11$ and maximal value of the NF is $0.29\omega a/2\pi c$ when $x = 1$, $y = 1$, $x = 1$, $y = 21$ and $x = 21$, $y = 21$. Fig. 2b shows the second band, the minimal value of the NF is $0.3438\omega a/2\pi c$ when $x = 1$, $y = 11$ and $x = 21$, $y = 11$, the maximal value of the NF is $0.4625\omega a/2\pi c$ when $x = 11$, $y = 3$ and $x = 11$, $y = 19$. With the same means, we get the minimal NF is $0.4586\omega a/2\pi c$ when $x = 9$, $y = 1$, $x = 13$, $y = 1$, $x = 9$, $y = 21$ and $x = 13$, $y = 21$, the maximal NF is $0.6706\omega a/2\pi c$ when $x = 1$, $y = 11$ and $x = 21$, $y = 11$ for the third band shown in Fig. 2c. The fourth band is shown in Fig. 2d, the minimal NF is $0.6419\omega a/2\pi c$ when $x = 11$, $y = 5$, and $x = 11$, $y = 17$, the maximal NF is $0.7068\omega a/2\pi c$ when $x = 1$, $y = 10$, $x = 21$, $y = 10$, $x = 1$, $y = 12$, and $x = 21$, $y = 12$. In conclusion, the maximal and minimal NF value of 8-shaped scatter PhC not appear at the edge of the first IBZ, but at the inner of the first BZ. The PBG between the first band and the second band is $0.0538\omega a/2\pi c$. The PBG is studied in the first BZ consequently.



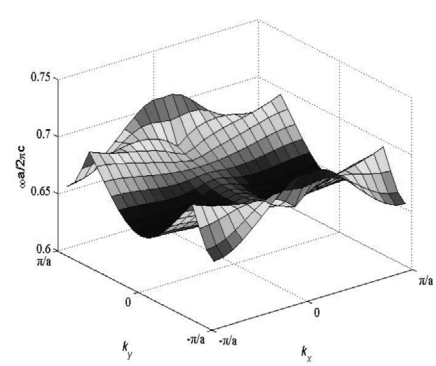
(a) Scheme diagram of the fist band



(b) Scheme diagram of the second band



(c) Scheme diagram of the third band



(d) Scheme diagram of the forth band

Fig. 2. The scheme diagrams of three dimensional bands for TM mode in the first BZ with $\varepsilon_r = 11.56$, $R = 2r = 0.3$, $\theta = 0^{\circ}$.