Prediction of Electric Load Neural Network Prediction Model for Big Data

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Abstract. In this study, the two-dimensional hexagonal Photonic crystal energy band structure was simulated using COMSOL Multiphysics field simulation software. The 2D hexagonal Photonic crystal structure was constructed by setting parameters such as periodic boundary conditions and air hole radius. Using the frequency domain solver of COMSOL software, the transmission and reflection spectra of the structure were calculated, and the energy band structure diagram was obtained. The effects of different parameters on the energy band structure were analyzed by adjusting the structure parameters. The results show that the fine tuning of the energy band structure of 2D hexagonal Photonic crystals can be realized by adjusting the radius of air holes and the periodic boundary conditions. This study provides a useful reference for further research on the properties and applications of 2D photonic crystals.

Keywords: COMSOL, 2D Photonic crystals, energy band structure.

1. Introduction

Photonic crystal is a medium with periodic refractive index change, which can affect the propagation behavior of light, and has the forbidden band property [1]. i.e., light of some specific frequencies cannot propagate in it. As a special kind of photonic crystal, 2D photonic crystal has a wide range of applications, such as photonic crystal waveguides, photonic crystal sensors, photonic crystal lasers and so on. Two-dimensional hexagonal honeycomb-type photonic crystals are a common two-dimensional photonic crystal structure with excellent forbidden band properties, which have been widely noticed and studied. However, there are still many difficulties and challenges in experimentally investigating the energy band structure of 2D hexagonal honeycomb-type photonic crystals. Therefore, in this study, the energy band structure of 2D hexagonal honeycomb Photonic crystals is simulated using COMSOL Multiphysics field simulation software, aiming to provide useful references for further research on their properties and applications.

In this paper COMSOL Multiphysics is able to perform complex multi-physics field simulations that take into account other physical effects; can simulate behaviour in non-linear states; parallel computing capabilities accelerate large-scale, high-complexity models; allows users to customise physics modules; intuitive and easy-to-use graphical interface lowers the threshold of use; provides powerful post-processing and visualization tools; and is tightly coupled with experiments.

2. Theoretical studies of two-dimensional photonic crystals

2.1. Basic Theory of Photonic Crystal Research

In studying the properties and numerical calculations of photonic crystals, we utilize the system of Maxwell's equations as a starting point because Maxwell's equations are the classical system of equations of the electromagnetic field theory, which describes the propagation of electromagnetic waves in a medium. Together with its intrinsic relationship and appropriate boundary conditions solving Maxwell's system of equations can analyze the propagation of electromagnetic waves in photonic crystals.

For the time-harmonic field, the Maxwell system of equations consists of the following four formulas [2-3].

$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J} \tag{1}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \tag{2}$$

$$\nabla \cdot \mathbf{D} = \rho \tag{3}$$

$$\nabla \cdot \mathbf{B} = 0 \tag{4}$$

In photonic crystals, the interaction between light and matter is studied mainly by means of Maxwell's system of equations, where the main interaction is electrostatic. When considering the propagation of electromagnetic waves in a homogeneous, unbounded periodic dielectric, it can be found that there is no free charge or free current present in it. The behaviour of electromagnetic wave propagation in such an environment is an important part of the study of photonic crystals [4].

2.2. Plane-Wave Expansion Method

The plane wave expansion method is an effective method for calculating the energy band structure of photons. It is based on the Bloch theory and the periodicity of the dielectric function, and unfolds the electromagnetic wave in the inverse easy space with a plane wave to form the eigenequation in matrix form. By solving the eigenequations, the eigenfrequencies of photons can be obtained, and these frequency values constitute the photon energy bands. This method is effective for the energy band structure of one-, two-, and three-dimensional photonic crystals without defects, but it may be difficult to calculate or have insufficient accuracy when the structure is complex or defective. The super primary cell technique extends its application, but periodicity limitations and error problems need to be noted. [5]. The two-dimensional photonic crystal plane wave expansion method is a computational method for studying photonic crystals by analyzing the propagation modes of light in the crystal [6]. The method is based on the plane wave expansion, which represents the photoelectric field as a linear combination of basic functions. By solving the eigenvalue problem of Maxwell's equations, the dispersion relation and bandgap structure of the photonic crystal can be obtained. The Fourier transform of the dielectric constant of our 2D conventional photonic crystals was informed in the literature [7].

$$e^{-1}\left(G_{\square}\right) = \begin{cases} \dfrac{1}{\boldsymbol{\varepsilon}_b} + \left(\dfrac{1}{\boldsymbol{\varepsilon}_a} - \dfrac{1}{\boldsymbol{\varepsilon}_b}\right) f, G_{\square} = 0 \\ 2f\left(\dfrac{1}{\boldsymbol{\varepsilon}_a} - \dfrac{1}{\boldsymbol{\varepsilon}_b}\right) \dfrac{\mathbf{J}_1\left(\mathbf{G}_{\square} \cdot \mathbf{r}_a\right)}{\mathbf{G}_{\square} \cdot \mathbf{r}_a}, G_{\square} \neq 0 \end{cases} \tag{5}$$

The eigenequations for the TE mode are [8]

$$\sum_{\vec{G}} (\vec{k} + \vec{G}) \cdot \left(\vec{k} + \vec{G}'\right) \eta_{\vec{G}-\vec{G}} H_{z,\vec{G}'} = \frac{\omega^2}{c^2} H_{z,\vec{G}} \tag{6}$$

The eigenequation for the TM mode is [8]

$$\sum_{\vec{G}'} \left|\vec{k} + \vec{G}\right| \left|\vec{k} + \vec{G}'\right| \eta_{\vec{G}-\vec{G}'} A_{\vec{G}'} = \frac{\omega^2}{c^2} A_{\vec{G}} \tag{7}$$

2.3. Finite Elements Method (F.E.M)

The two-dimensional photonic crystal finite element method is a method for calculating the energy band structure of photonic crystals. It is based on the idea of the finite element method, which divides the photonic crystal into a finite number of small cells, and numerically calculates each cell. By transforming Maxwell's equations into variational equations, the eigenvalue problem of the photonic crystal can be solved to obtain the energy band structure. The method can accurately model complex photonic crystal structures and is applicable to a wide range of different lattices and materials.

In this study, a two-dimensional hexagonal photonic crystal structure was constructed using COMSOL Multiphysics field simulation software. The two-dimensional hexagonal photonic crystal structure was constructed by setting parameters such as periodic boundary conditions and air hole radius. Using the frequency domain solver of COMSOL software, the transmission and reflection spectra of the structure were calculated, and the energy band structure diagram was obtained. The effects of different parameters on the energy band structure were analyzed by adjusting different parameters.

Figure 1 gives the two-dimensional photonic crystal structure of a medium arranged in air in a triangular shape, by analyzing the effect on the results caused by the symmetric lattice points in the lattice, only the lattice symmetry needs to be taken into account because the medium composing the crystal is a cylindrical configuration with the spacing between the different lattice points being α, and the lattice radius is γ [9].

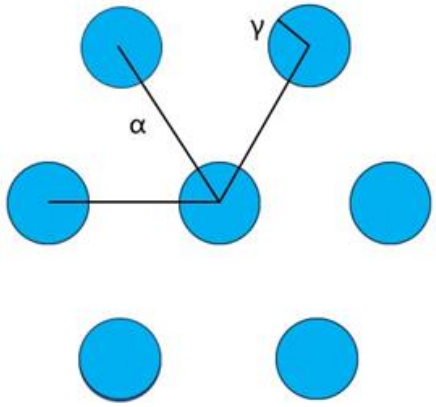

Figure 1. Schematic structure of a two-dimensional triangular lattice photonic crystal

Figure 2 then shows the red triangular region enclosed by the high symmetry points $X=(0,0)2\pi/a$, $M=-\left(0,1/\sqrt{3}\right)2\pi/a$, $\Gamma=\left(1/3,1/\sqrt{3}\right)2\pi/a$. ΓXK is the irreducible Brillouin region of the triangular lattice and k_x, k_y is the component of the Bloch wave vector $\vec{\Gamma}$ [10].

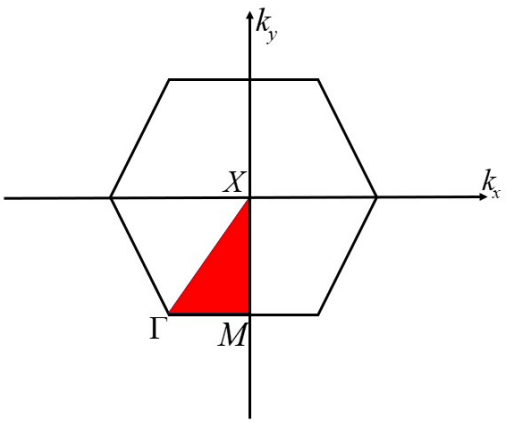

Figure 2. First Brillouin zone of triangular lattice

3. Results

3.1. The establishment of simulation model

COMSOL parameter setting: a=2um, r=0.4*a, w=0.2*a, px=pi/a, py=pi/a, n=13, n_pos=1, kx=px, ky=py.

Geometric construction: Simplify the geometric construction of hexagon to the simulation of parallelogram, construct the parallelogram with side length a=2um, the dielectric constant of the parallelogram material is set to 13, the inner part is a circle, the gap in the middle of the circle is the vacuum part, and the dielectric constant is 1. Setting of boundary conditions: Floquet periodic boundary conditions. Parameterized scan setup: kx=1.0e-4^range (1, n) range (0, (px-0)/(n-1), px) range (px, (0-px)/(n-1), 0), ky= range (0, (py-0)/(n-1), py) py*1^range (1, n) range (py, (0-py)/(n-1), 0), range (1,1, n) range(n, 1,2*n-1) range (2*n-1,1,3*n-2). The eigenfrequency search reference is $1.6\times10^{8}\,HZ$.

3.2. Analysis of experimental results

In a two-dimensional photonic crystal structure, the Bloch wave vector is confined to the first Brillouin zone and moves along the boundary of the first Brillouin zone. Here, the first Brillouin zone is divided into three parts to simulate A, B, and C. From the simulation results, it is easy to see that the results obtained by the mathematical model derived in this paper are basically consistent with the results obtained by the traditional methods in the literature [11].

After setting all the parameters, parametric scanning is carried out using COMSOL software to plot the electric field intensity of the two-dimensional photonic crystal, as shown in Fig. 3. In this study, a two-dimensional hexagonal photonic crystal structure was constructed using COMSOL Multiphysics field simulation software. The 2D hexagonal photonic crystal structure was constructed by setting parameters such as periodic boundary conditions and aperture radius. Using the frequency domain solver of COMSOL software, the transmission and reflection spectra of the structure were calculated, and the energy band structure diagram was obtained, as shown in Fig. 4

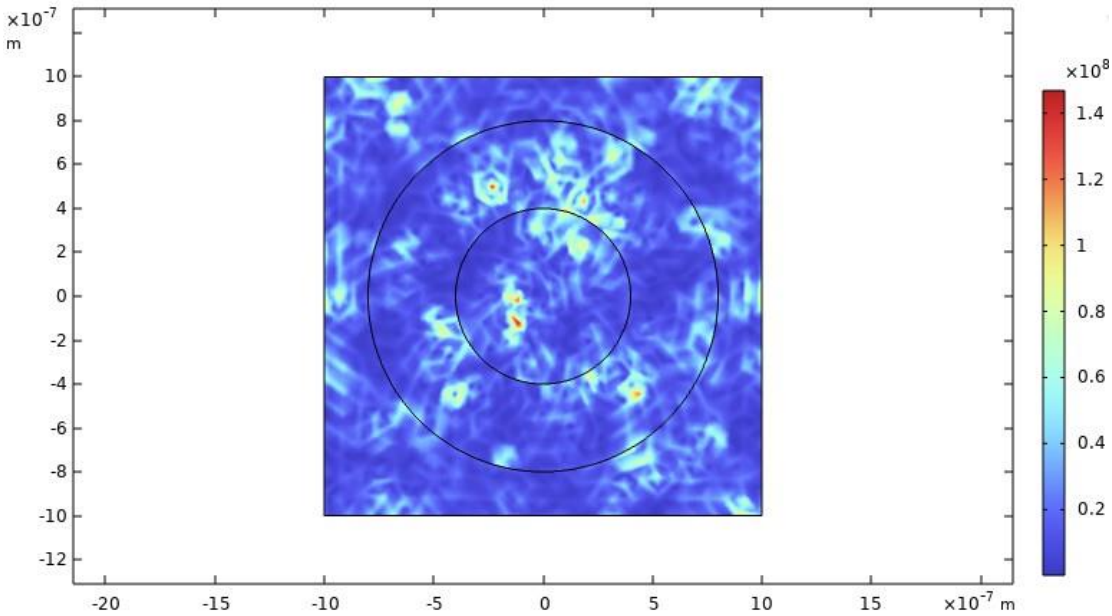

Figure 3. Electric field strength distribution of a two-dimensional hexagonal photonic crystal with legend

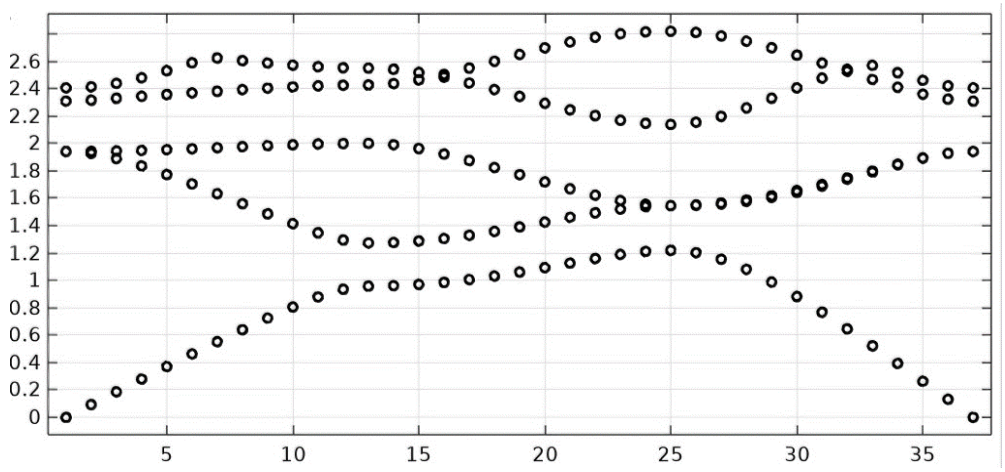

Figure 4. Band diagrams of two-dimensional hexagonal photonic crystals

4. Conclusion

In this paper, the two-dimensional photonic crystal has been accurately simulated by COMSOL software and its energy band structure diagram has been successfully obtained. The analytical results show that the energy band structure of this photonic crystal is affected by its periodic arrangement and exhibits obvious band gap characteristics. From the electric field distribution map, it can be seen that there is the strongest electric field distribution at the center of the structure, which means that the electric field tends to be distributed in the area with the highest symmetry. From the band structure, it can be seen that the energy gap of the system is relatively small, which has many potential application values. By comparing with the classical theoretical model, the simulation results are found to be consistent with the theoretical predictions, further verifying the accuracy of our model and calculations.

The application of COMSOL in the calculation of photonic crystal energy band structure has a wide range of prospects and future development directions. Firstly, the powerful modelling and solving functions of COMSOL can be used for the simulation and calculation of more complex photonic crystal structures and optical phenomena, such as 3D photonic crystals and nonlinear optical effects. Secondly, more efficient photonic crystal design and performance optimization can be achieved through integration and data exchange with other software. In addition, combined with artificial intelligence and machine learning technologies, intelligent design and optimization of photonic crystals can be achieved. Finally, the application of COMSOL in photonic crystal energy band structure calculation will help to promote the development of photonic crystal technology and provide strong support for the development and application of new photonic devices.

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