Optik - International Journal for Light and Electron Optics 172 (2018) 662–667

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Study on band gaps structure and eigenfield distribution of two-dimensional function photonic crystals with point defect

Xin-Guo Yin*, De-Chuan Li, Shan-Rong Tang, Hua-Xin Wu

School of Physics and Electronic Information, Huaibei Normal University, Huaibei 235000, China

ARTICLE INFO

Keywords:
Two-dimensional function photonic crystals
Band gaps structures
Defect mode
Eigenfield distribution

ABSTRACT

In the paper, we studied the two-dimensional function photonic crystal include point defect, and calculated the band gap structure, defect mode and defect mode eigenfield distribution by COMSOL software. The two-dimensional function photonic crystals, in which the dielectric constants of medium columns are the linear function, $\varepsilon(r) = k \cdot r + b$. We researched the effect of point defect dielectric column radius R and dielectric column parameter b on band gap structure, defect mode and defect mode eigenfield distribution. Through adjusting the point defect dielectric column radius R and dielectric column parameter b, we found the band gap structure, defect mode and defect mode eigenfield distribution has the adjustability for the two-dimensional function photonic crystal. These conclusions will provide important theoretical basis and design methods for the optical devices.

1. Introduction

Photonic crystals are a new type of artificial materials consisting of a periodic distribution in which the dielectric constant has a periodicity that provide control of light at a wavelength scale [1–5]. The photonic crystal are divided into one-dimensional [6], two-dimensional and three-dimensional structures [7–10]. The most important feature of photonic crystals is its band gap structure and defect mode. The line defect of the two-dimensional photonic crystals constitute the waveguide [11–13], and the point defect constitute the micro-cavities [14–18]. Photonic crystal micro-cavities are typically characterized by two key quantities, the quality factor and the modal volume. They have attracted much interest. Several authors have reported photonic crystal cavities with high Q-values and various techniques have been used to couple light into the cavities. Therefore, the photonic crystal materials have more advantages in the designing of optical device [19–22].

In the paper, we studied the two-dimensional function photonic crystal include point defect, and calculated the band gap structure, defect mode and defect mode eigenfield distribution by COMSOL software. For the two-dimensional function photonic crystals, in which the dielectric constants of medium columns are the linear function, i.e., $\varepsilon(r) = k \cdot r + b$. We researched the effect of point defect dielectric column radius R and dielectric column parameter b on band gap structure, defect mode and defect mode eigenfield distribution. By calculation, we found when the point defect dielectric column radius R is changed, there are different band gaps structures and defect modes. When the dielectric column parameter b increasing, the width of band gap is wider, the position of defect mode is changed, and the eigenfield distribution is also mainly concentrated in the center defect, but the intensity become weak. Through adjusting the point defect dielectric column radius R and dielectric column parameter b, the band gap structure, defect mode and defect mode eigenfield distribution has the adjustability for the two-dimensional function photonic crystal. With the Kerr

* Corresponding author.
E-mail address: phys2006@163.com (X.-G. Yin).

https://doi.org/10.1016/j.ijleo.2018.06.059
Received 22 April 2018; Accepted 11 June 2018
0030-4026/

effect, the function forms of the medium column dielectric constants are changed, through adjusting the external light intensity distribution, which make the band gaps structure and defect mode changed. Then the two-dimensional function photonic crystal need not be remade. These conclusions will provide important theoretical basis and design methods for the optical devices.

2. Calculation method

In Ref. [23], the Fourier transform of dielectric constant for two-dimensional function photonic crystals is derived in detail, and its expression is

$$\varepsilon^{-1}(\vec{G}_{\|}) = \begin{cases} \frac{1}{\varepsilon_b}(1-f) + \frac{2f}{r_a^2}\int_0^{r_a} r\frac{1}{\varepsilon_a(r)}\mathrm{d}r (G_{\|}=0) \\ \frac{2f}{r_a^2}\int_0^{r_a} r\frac{1}{\varepsilon_a(r)}J_0(G_{\|}r)\mathrm{d}r - \frac{2f}{\varepsilon_b}\frac{J_1(G_{\|}r_a)}{G_{\|}r_a}(G_{\|}\neq 0) \end{cases}, \tag{1}$$

when $\varepsilon_a(r) = \varepsilon_a$ (the ε_a is a constant), Eq. (1) becomes

$$\varepsilon^{-1}(\vec{G}_{\|}) = \begin{cases} \frac{1}{\varepsilon_b} + \left(\frac{1}{\varepsilon_a} - \frac{1}{\varepsilon_b}\right)f (G_{\|}=0) \\ 2f\left(\frac{1}{\varepsilon_a} - \frac{1}{\varepsilon_b}\right)\frac{J_1(G_{\|}r_a)}{G_{\|}r_a}(G_{\|}\neq 0) \end{cases}. \tag{2}$$

Eq. (2) is the Fourier transform dielectric constant of two-dimensional conventional photonic crystals. So, the two-dimensional conventional photonic crystals is the special case of two-dimensional function photonic crystals.

The eigenvalue equations of TE wave with plane-wave expansion method [24,25] is

$$\sum_{\vec{G}'} |\vec{k} + \vec{G}'||\vec{k} + \vec{G}|\varepsilon^{-1}(\vec{G} - \vec{G}')E_k(\vec{G}') = \frac{\omega^2}{c^2}E_k(\vec{G}). \tag{3}$$

3. Numerical result

The Ref. [23] have calculated the band gaps structures of two-dimensional function photonic crystals in the triangle lattice. On this basis, we calculate the band gaps structures, defect mode and eigenfield distribution of two-dimensional function photonic crystals in the square lattice. The square lattice structure is shown in Fig. 1, the cylindrical medium columns are located in the air. In Fig. 1(a), $a = 10^{-7}m$ is lattice constant, r_a is medium column radius. The Fig. 1(b) is the first Brillouin zone of square grid.

From Figs. 2–6, we study the effect of defect dielectric column radius on the band gaps structures, defect mode and eigenfield distribution. The band gaps structure, defect mode and eigenfield distribution are numerically simulated by COMSOL software. Because the defect has only one medium column, the 5 × 5 super cellular structure is selected as the computing area which are shown in Figs. 2(a) and 4(a). The Fig. 2(b) shows the band gaps structure of two-dimensional function photonic crystals with point defect, we take $\varepsilon(r) = k\cdot r + b$, where $k = 15 \times 10^7$, $b = 5.1$, $r_a = 0.26a$ and the radius of defect dielectric column $R = 0.1a$ ($R < r_a$). In the normalized frequency range 0–0.45, there is a wide band gap, its normalized frequency is in the range of 0.3046–0.3898. In the band gap, there is one band, which is the defect mode that produced by the defect, the defect model normalized frequency is in the range of 0.3568–0.3627. The Fig. 3(a) is the enlarged figure of defect mode Fig. 2(b). We choose one point A in Fig. 3(a), the defect mode point A eigenfield distribution is shown in Fig. 3(b). The eigenfield distribution is mainly concentrated in the defect. By calculating, the other points in the defect mode have the same eigenfield distribution form as A point, but their intensity are different.

The Fig. 4(b) is the band gaps structure of two-dimensional function photonic crystals with point defect, we take $\varepsilon(r) = k\cdot r + b$, where $k = 15 \times 10^7$, $b = 5.1$, $r_a = 0.26a$ and the defect dielectric column radius $R = 0.4a$ ($R > r_a$), the schematic diagram is shown in Fig. 4(a). In the normalized frequency range 0–0.45, there is a wide band gap, its normalized frequency is in the range of 0.3078–0.3936. In the band gap, there are two bands (band one: 0.3221–0.3256, band two: 0.322–0.3255). Comparing Fig. 4(b) with Fig. 2(b), when the point defect dielectric column radius R is different, the band gaps structures are different, the position of defect mode changed.

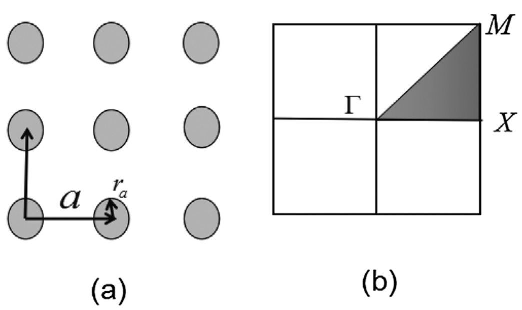

Fig. 1. (a) The square lattice structure of two-dimensional photonic crystals. (b) The first Brillouin zone of square grid.