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Design and verification of the polarization beamsplitter based on photonic crystals

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ABSTRACT

Photonic crystals have a great prospect in the field of integrated optics due to their high integration and low transmission loss. In this paper, a beam splitter based on the bandgap of photonic crystal is designed and demonstrated experimentally for polarization-dependent beam splitting. The simulated radiation patterns show excellent polarization purity, with a cross-polarization level above 20 dB. Furthermore, the angle deviation of the incident and the temperature change of device have slight impact on beamsplitting. Larger shifting range of incident wavelength is allowed. What is more, the range of medium radius with good splitting effect is relatively large, which reduces the difficulty of production and processing.

1. Introduction

Polarization beamsplitter can separate two orthogonal polarization modes of electromagnetic waves into different directions, which plays an important role in optical communications [1,2], information-recycle [3] and integrated optical circuits [4,5]. Many kinds of beamsplitter have been proposed [6–9]. Conventional ones generally use birefringence effect of natural crystal (e.g. Wollaston prism), either polarization splitter cubes or multi-layer film structure to achieve beams splitting. These polarization beamsplitters cannot meet the development of high-density integrated optical circuits. Now many methods in photonic crystals are used for beam polarization as its high integration, good beam effect, and low transmission loss [10,11]. The one based on directional coupler [12] must insert waveguide bend in the output as a small splitting angle, which increases the size of device; another is based on crystal structure [13], whose design is complex, and the manufacture is difficult. Moreover the polarization splitting depends on structural parameters and operating wavelength.

In this paper, we propose a beamsplitter based on photonic crystal band gap. The beam splitting will not be affected by drifting of incident wavelength and changing of device temperature, which has a stable and reliable performance. The range of medium radius with good splitting effect is relatively large, which reduces the difficulty of production and processing, What is more, the structure is simple and easy processing.

2. Structure of the two-dimensional photonic crystals

Photonic crystal is a material that has been structured to possess a periodic modulation of the refractive index. The rectangular photonic crystal structure applicated in the mathematical simulation experiment is shown in Fig. 1(a). In which, the black dots represent the silica column (refractive index n is 3.42), the cell shape of dielectric rod is cylinder, arranging in a triangle. Lattice period (the distance between two silicon column centers) is represented by a (a=λ*Frequency, *Frequency* is the normalized frequency, λ is the free space wavelength), which is shown in Fig. 1 (b). Diameter of dielectric column is $2r$, another saying is waveguide width, which is often defined as $b*a$ (b is a constant, which is greater than 0 and less than 1, denotes the waveguide width parameter).

3. Simulation data and result discussion

This paper uses the FDTD method to carry on the simulation of the 2D photonic crystal fabricated from a hexagonal array of circular dielectric rods with Si. With the simulation software RSoft, the photonic band structure is shown in Fig. 2. The horizontal coordinate is value b while the vertical coordinate is normalized frequency. The shadow section is called conduction band, where photon can transmit. On the contrary, the blank sections represent forbidden regions. It can be seen from Fig. 2 that the changing of value b will influence the band structure. With the increase of value b, the band gap are all broadening then narrowing and

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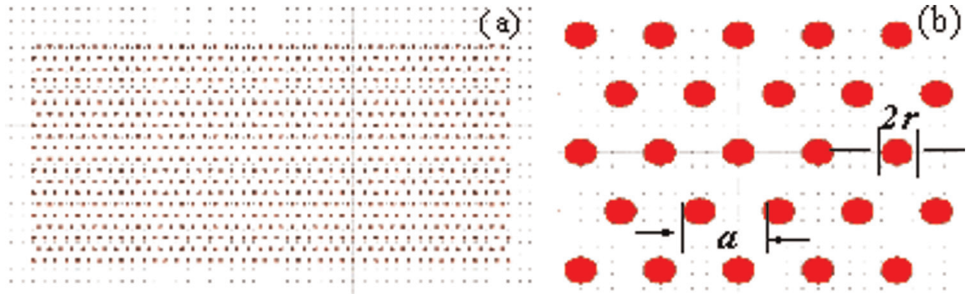

Fig. 1. (a) Structure for 2D photonic crystal and (b) hexagonal structure.

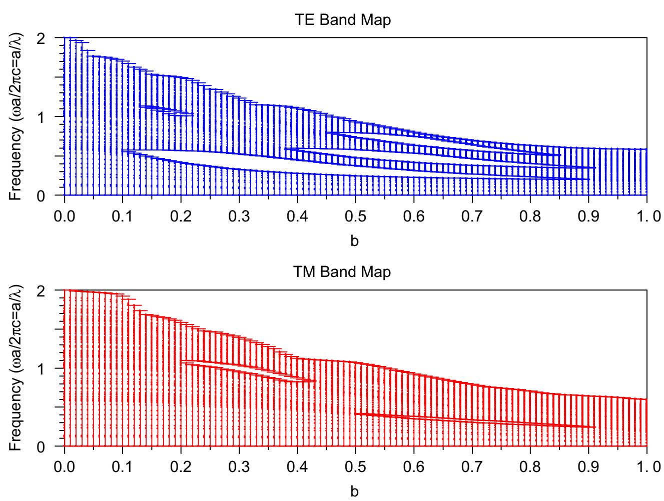

Fig. 2. The band structure of photonic crystal polarization influenced by wave guide width parameter *b*.

falling gradually. When the value *b* ranging from 0.15 to 0.4 with the normalized frequency is 0.4717, which is just in the conduction band of *TM* but the forbidden band of *TE*. Without defects the *TM* wave can pass through in no loss, however the *TE* wave will be reflected.

Defining incident power as 1, then the output power becomes relative value. Simulating with the Fullwave method of Rsoft, the propagation is presented in Fig. 3. θ is incident angle, T_{TE} and T_{TM} are the transmition R_{TE} and R_{TM} are the reflection of *TE* and *TM* respectively.

Normally the performance of polarization splitter can be evaluated by splitting ratio or extinction ratio (*ER*). Therefore the *ER* of the two cores are defined as

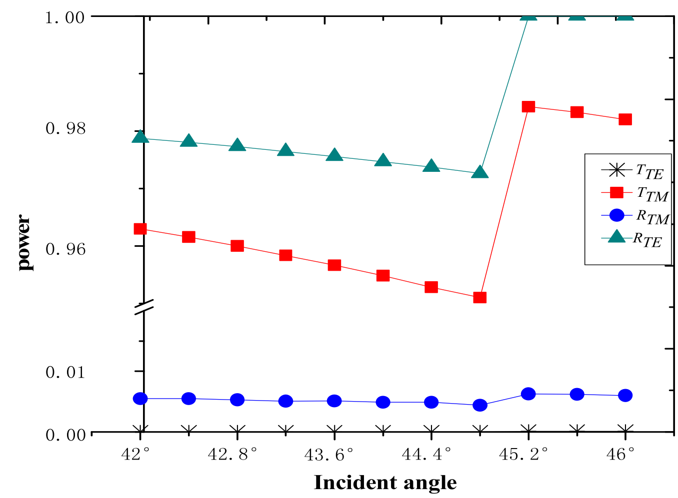

Fig. 4. Relation between the output power and incident angle θ.

$$ER_1 = -10 * \lg(T_{TE}/T_{TM}) \quad (1)$$

$$ER_2 = -10 * \lg(R_{TM}/R_{TE}) \quad (2)$$

By setting a suitable incident angle and value *b*, the photon can fall in conduction band of *TM* but the forbidden one of *TE*, so the whole transmission of *TM* and the whole reflection of *TE*. When $\theta = 44°$ and value *b* ranging from 0.16 to 0.33, excellent polarization purity can be achieved, with a cross-polarization level above 20 dB. To reduce the difficulty of production and processing, we set *b* as 0.25 ($b = 0.25 \pm 0.08$ all the value *b* can achieve excellent polarization). At the same time, If the incident angle has a deviation ($\theta = 44° \pm 2°$), efficient separation can also be achieved. The relation between the output power and incident angle is shown in Fig. 4.

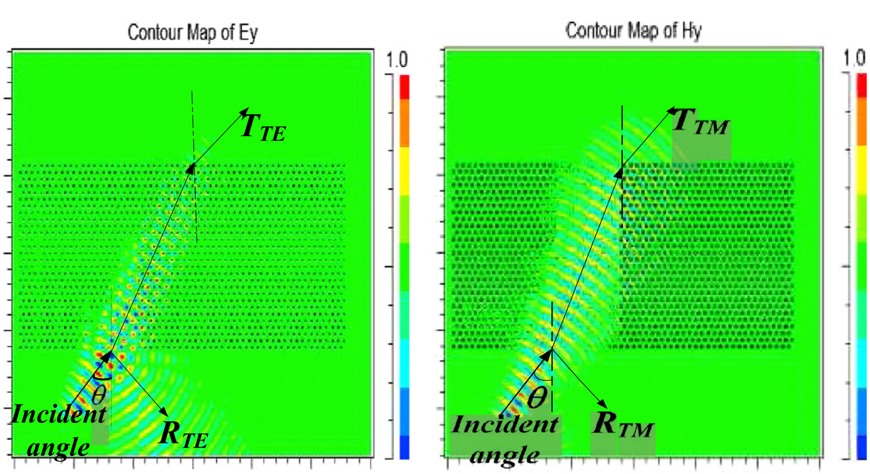

Fig. 3. Light propagation (*Ey* represents *TE* and *Hy* represents *TM*).