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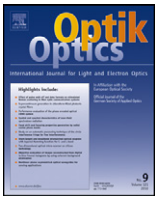

Tunable multichannel drop filters based on the two-dimensional photonic crystal with oval defects

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ABSTRACT

Light propagation through the channel filter based on the two-dimensional photonic crystals with oval-rod defects is studied by the finite-difference time-domain method. In addition to the traditional size tuning, shape alteration of the defects from the usual circle to the ellipse offers a powerful approach to tune the resonant frequency of channel-drop filters based on two-dimensional photonic crystals. It is found that the resonant frequency can be flexibly adjusted only by changing the orientation angle of the oval defects. The sensitivity of the resonant frequency to the alteration of the oval rods' rotation angle is systematically studied. Because the rotation angles of the ellipse can be continuously adjusted, so the channel drop filter based on this kind of defects with different rotation angles is more suitable to the occasion where a large number of output channel filters is need.

1. Introduction

Photonic crystals (PCs) are the subject of extensive investigation due to the existence of photonic band gaps [1,2]. This prominent characteristic enables people to control the propagation of the electromagnetic waves in the PCs. Due to the advantages of high precision and facility in fabrication, two-dimensional (2D) PC devices have attracted much interest as ultracompact integrated photonic components. By localizing photons through different cavities within the photonic band gap, the multichannel filter has a unique advantage for signal transmission, which allows tight confinement and exact routing of light. Noda et al. used a heterogeneous structure to confine photons in line cavities and formed a surface-emitting laser with an extremely high-quality factor in the vertical direction [3]. The resonant cavity traps photons at resonant frequency from the waveguide through evanescent coupling, and emits some of them in the vertical direction. Notomi et al. designed a multichannel filter by changing the width of the side channels [4]. The side-coupled technique was employed to construct in-plane channel drop filters in the 2D PCs, which utilize resonant coupling between microcavity modes produced by point defects and waveguide modes created by line defects [4–11]. In our previous work, the influence of the irregular shape of air holes on the optical characteristics of channel-drop filters built in a 2D PC slab was studied both theoretically and experimentally [12].

The quality of an actual optical device can be evaluated by the two important factors, efficiency and flexibility. Efficiency demands low loss in the coupling, while flexibility demands an easy way in connection. Side-coupled devices have an excellent efficiency owing to their less bending requirement. The output region is separated from the input region, so the trouble in component arrangement as well as interference between forward and backward transmission signals can be avoided. It has been found that the device shape is also an important element influencing the quality of the optical device in addition to the size factor, although much attention is focused on the size factor. The shape changing offers a new method to engineer the optical characteristics of PC devices. In this paper, we proposed a method to flexibly engineering the frequency of the output light from the multichannel filters by changing the shape of the scatters from a traditional circle to a ellipse and altering the orientation angle of the ellipse. A ten-channel drop filter is proposed according to above principle, which can choose the frequency by changing the obliquity of the ellipse. Our theoretical result indicates that it is feasible to design an efficient multichannel filter.

2. Numerical simulation and discussion

The structure studied in this paper is based on the two-dimensional square-lattice PC consisting of dielectric cylinders immersed in air. The permittivity of the dielectric is 8.9, the radius of the cylinders is 3.0 mm, and the length of the lattice constant is 10.0 mm. For such a perfect PC, a photonic band gap exists extending from 14.1 to 17.0 GHz. Based on above PC, we constructed a kind of channel filter shown in Fig. 1. It was constructed by the

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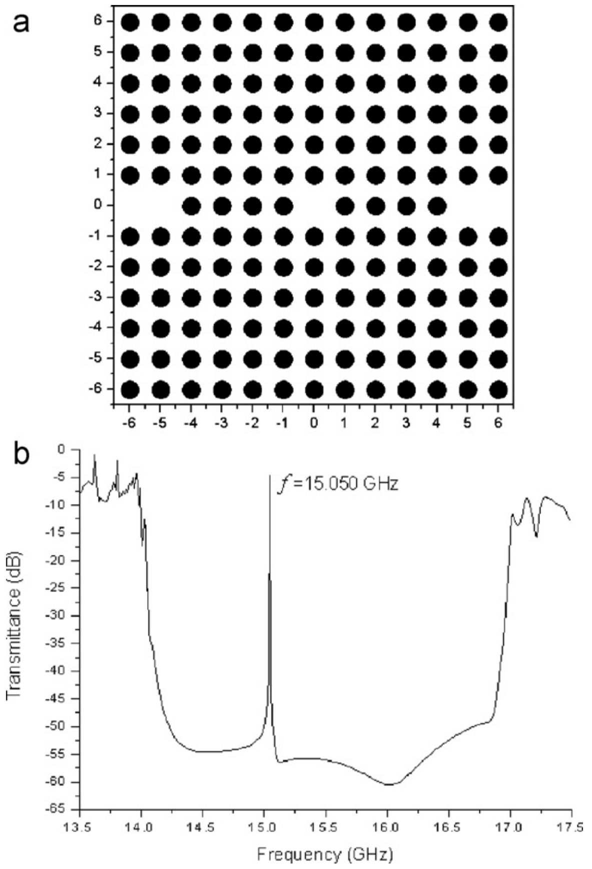

Fig. 1. Schematic geometry of one channel filter composed of W1 waveguide and one-point defect resonant (a), and the corresponding transmission spectra for the structure (b).

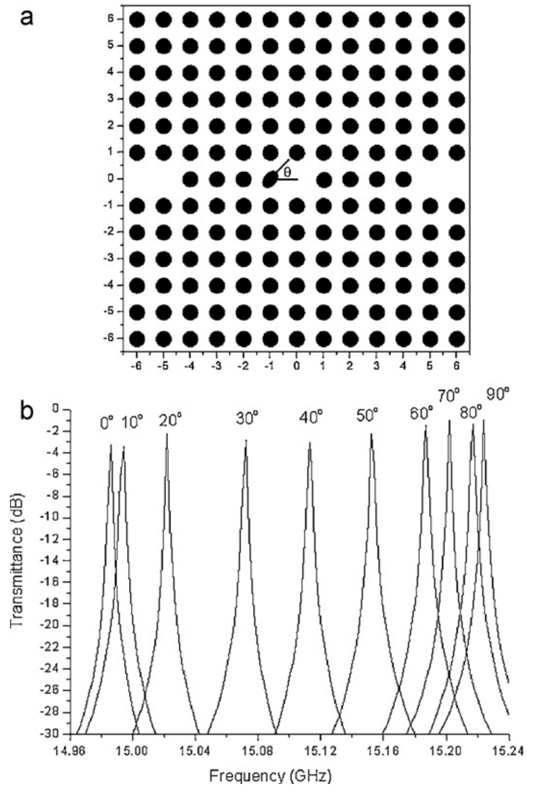

Fig. 2. Schematic geometry of one channel filter, the shape of whose rod adjacent to the central point defect changes from a circle to an ellipse (a), and the corresponding transmission spectra for the structure with different orientation angles (b).

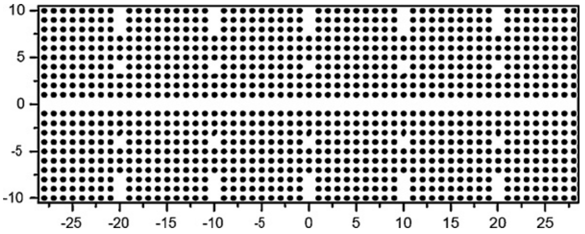

Fig. 3. Structure of ten-channel-drop filter composed of W1 waveguide and ten oval-rod defect resonators with different rotation angles.

connection of a W1-typed waveguide and a single defect, which is formed by removing a dielectric rod from an otherwise-perfect PC. Fig. 2 shows the light transmittance through this channel filter calculated by the finite-different time-domain method [13,14] with absorbing boundary conditions of perfect-matched layer, from which it can be seen that the frequency of the output light is 15.050 GHz. In all the calculation, the length of a lattice constant is divided into 80 square grids, and through a long total calculation time of several million time intervals, a frequency interval of 0.001 GHz is ensured.

A large number of spaced channels require a filter with a very small scale and the resonant frequency should be easy to be adjusted. So we constructed a kind of channel filter based on the oval-rod defect, which is formed by substituting the circular rod with an elliptical rod adjacent to the central one-point defect (as can be shown in Fig. 2(a)). The length of the ellipse's long axis is $0.367a$, and that of the ellipse's short axis is $0.245a$, so the area of each ellipse is equal to that of the circle. The angle from the direction of the light transmission (also the PC's ΓX direction) to the direction of the ellipse's long axis is depicted by "θ".

Fig. 2(b) shows the corresponding transmission spectra of the incident light through the channel filters with different θ values. When θ equal to 0°, the ellipse's long axis is placed along the direction of light propagation (also the PC's ΓX direction). It can be seen from Fig. 2(b) that the resonant peak is located at 14.986 GHz. Comparing with the structure shown in Fig. 1(a), it can be seen that there is a frequency variation of 0.064 GHz when the circular rod is replaced by the elliptical rod. When the values of θ are changed to be 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80° and 90°, the frequencies of the corresponding resonant peak become 14.994, 15.022, 15.072, 15.113, 15,152, 15.187, 15.202, 15.217, and 15.224 GHz, respectively. The variation of the resonant frequency is more sensitive to the alteration of θ when its value is around 40°, and all the resonant light transmits the corresponding structures with an excellent efficiency (also can be seen in Fig. 2(b)).

Based on above results, we constructed a ten-channel PC filter, which is displayed in Fig. 3. The ten cavities are located on the two sides of the central linear W1-typed waveguide. The elliptical rods in ten channels have the same long and short axes, but their orientation angles are different. The input light signal propagates along the central waveguide, and each cavity is coupled with another W1 waveguide serving as the output channel. The distances between two adjacent channels are $9a$ (a is lattice constant of the PC), which is far enough to avoid the interaction of the output signals. The electric field distributions of the light propagation with different frequencies through the above ten-channel filter are shown in Fig. 4. When the incident frequency is 15.002 GHz, the light energy resonant with the oval-rod defect whose rotation angle is $\theta = 20°$. The light beam transmits the adjacent cavity when the frequency becomes 15.072 GHz, the angle of whose ellipse is 30°. When incident frequency is changed to be 15.152 GHz, an excellent-quality