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A super narrow band filter based on silicon 2D photonic crystal resonator and reflectors

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ABSTRACT

In this paper, a novel structure of super narrow band filter based on two-dimensional square lattice photonic crystals of silicon rods in air for 1.5 um communication is proposed and studied. COMSOL Multiphysics4.3b software is used to simulate the optical behavior of the filter. The filter consists of one point-defect-based resonator and two line-defect-based reflectors. The resonance frequency, transmission coefficient and quality factor are investigated by varying the parameters of the structure. In design, a silicon rod is removed to form the resonator; for the rows of rods above and below the resonator, a part of the rods are removed to form the reflectors. By optimizing the parameters of the filter, the quality factor and transmission coefficient of the filter at the resonance frequency of 2e14 Hz can reach 1330 and 0.953, respectively. The super narrow band filter can be integrated into optical circuit for its micron size. Also, it can be used for wavelength selection and noise filtering of optical amplifier in future communication application.

1. Introduction

Photonic crystals (PCs) have been studied extensively since the concept was proposed by S. John and E. Yablonovitch independently in 1987 for its photonic band gaps and its control over light propagation [1,2]. And for the low loss periodic dielectric medium, PCs have been used to design kinds of devices, such as solar cell [3], optical fiber [4], mirror [5], resonator/cavity [6,7], waveguide [7,8], power splitter [9], demultiplexer [10–12], sensor [13], filter [7,14] and so on. For their scalable size, the PCs-based devices are suitable to be integrated into circuits instead of the conventional ones. By coupling a resonator with waveguides, filter can be realized. A narrow band filter is an element used to select electromagnetic wave with narrow frequency band efficiently. With the development of optical communication networks, optical narrow band filters are more and more needed in optical integrated circuits. Hadjira Abri Badaoui presented a narrow band filter consisting of three cascaded waveguides with different radii of air holes. The transmission coefficient is 0.77 at resonance wavelength of 1.55um by using FDTD method [15]. Narrow band filter was also studied by Samiye Matloub [16] and S. Robinson [17] by using ring resonator and reflector. A magnetically tunable narrow band filter using voltage controlled wavelength selection was investigated by Shaopeng Li [18]. J. M. Foley proved a narrow band transmission filter using finite element modal analysis. All these studies are significant for research of narrow band filter. But the transmission efficiency and quality factor are not high. In our work, a super narrow band filter with resonance frequency of 2e14 Hz is designed by coupling a point-defect-based resonator with two quasi-line-defect reflectors, which are designed in many papers [12,19,20]. Point resonator is smaller than ring resonator, so our super narrow band filter is easier to be integrated. On the other hand, the operating frequency is 2e14 Hz, mainly used in long distance communication. In our work, both structure parameters of the resonator and the reflectors are optimized to achieve higher transmission coefficient (T) and quality factor (Q).

COMSOL Multiphysics4.3b software is based on the finite element method and realizes the simulation of real physical phenomena simulation by solving a partial differential equation or partial differential equations.

2. Design of super narrow band filter

2.1. Structure design

As shown in Fig. 1, the filter consists of a resonator and two reflectors, and is based on a square lattice PC (13*13 arrays) of

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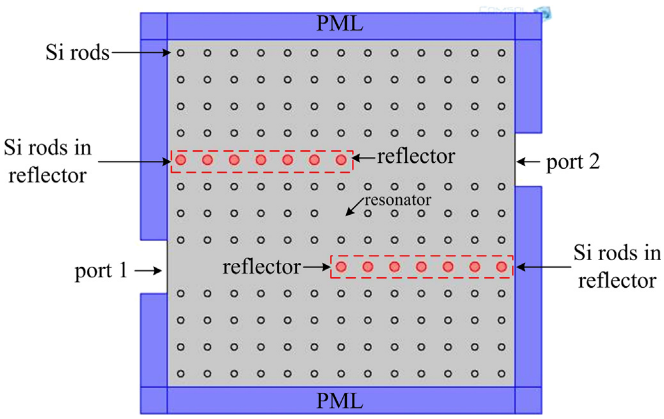

Fig. 1. The schematic diagram of the super narrow band filter including a point-defect-based resonator which is formed by removing a Si rod and two line-defect-based reflectors which are indicated in two red dotted boxes. The materials of the red reflector rods with radius '*rr*' and all other rods with radius '*r*' are all Si. The blue strips are the PML. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

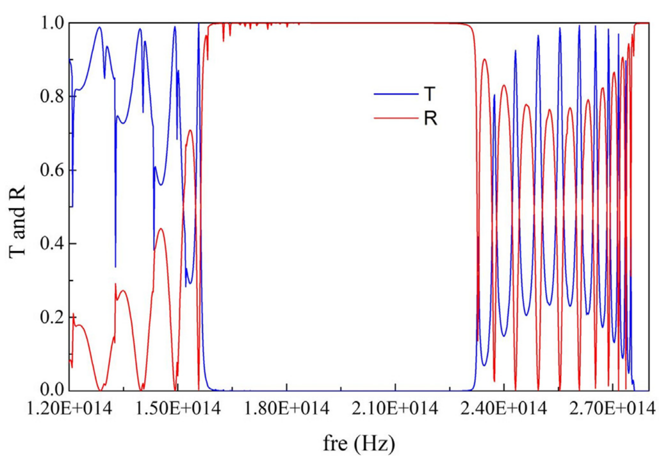

Fig. 2. Transmission and reflection spectra of the PC with lattice constant of 0.6384 um.

silicon (with dielectric constant 11.4) rods in air. For the band gap of Si is 1.12 eV, the absorption at the operating frequency of 1.5 um is very small and can be neglected. The resonator is based on a point defect with one Si rod removed, and both the reflectors are based on a line defect with part of a row of rods removed. The two reflectors are positioned at the lower right and upper left of the resonator, respectively. In the structure, Perfect Matched Layer (PML) of blue stripes surrounding the PC in Fig. 1 is used as boundary condition, and the input and output ports are labeled as port 1 and port 2, respectively. TM mode (the direction of electric field parallel to the axis of dielectric rods) plane wave with input power 1w is incited from port 1 and coupled by the resonator to the port 2 if the plane wave is just the resonant frequency. The whole filter is about 8 um*8 um in size, suitable to be integrated into optical circuit. In this paper, the influence of two-dimensional transverse structure in light modulation is mainly discussed. The default thickness of the filter is infinite. In case of finite thickness, i.e., in photonic crystal slab, the optical slab thickness will be

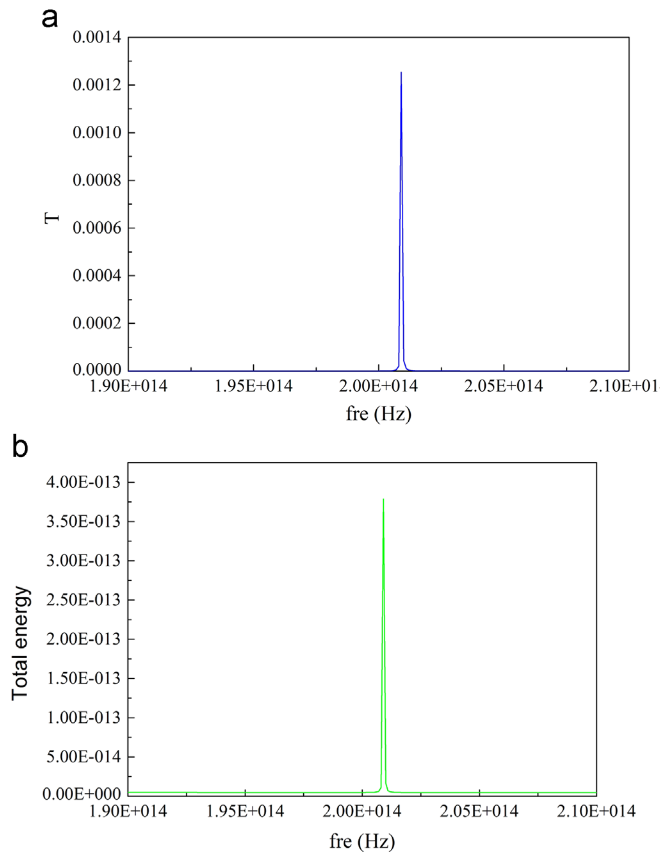

Fig. 3. (a) Transmission spectrum of the point-defect-based resonator. (b) Total energy distribution of the point-defect-based resonator.

strongly related to polarization, thereby, the gap size will be changed and the performance of filter will be affected finally.

In the above structure, the point-defect-based resonator is a primary filter element which is mainly used to limit light at corresponding frequency. The resonator is not only smaller than all kinds of ring resonator [21–25] but also has a higher *Q* value. Fig. 3a shows the transmission spectrum of the point-defect-based resonator. We can find that the *T* is only 0.00125 under its resonance frequency of 2.009e14 Hz, with a higher *Q* value up to 1826.4. Fig. 3b shows the total energy distribution of the point-defect-based resonator. We can find that the maximum energy value is 3.786e-13 J at 2.009e14 Hz, that is, the 2.009e14 Hz EM wave can be localized in the point defect mostly. From Fig. 3a and b, the localization effect of the point-defect-based resonator is good enough to act as the basic structure of our design, it confines EM wave with 2.009e14 Hz frequency efficiently. The resonance frequency and *Q* can be varied and improved by the reflectors introduced as below.

2.2. Parameter selection

In the study, in order to improve the transmission efficiency of the super narrow band filter, the PC parameters, such as the lattice constant '*a*' and the radius '*r*' are optimized to be 0.6384 um and 0.1159*a*, respectively. And the photonic band gap (PBG) of the PC is in the range of 1.572e14–2.322e14 Hz, which can be observed in the transmission/reflection (*T*/*R*) spectra in Fig. 2. On the other hand, the reflector parameters, including the radius '*rr*', number '*N*'