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Investigation on two dimensional photonic crystal resonant cavity based bandpass filter

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ABSTRACT

In this paper, different cavities, namely quasi square, tri-quarter square, square, hexagonal, circular, elliptical, diamond and annular ring based photonic crystal bandpass filters (PCBPFs) are proposed and investigated by exploiting coupling between two in-line quasi waveguides and a resonant cavity. The resonant wavelength, output efficiency and bandwidth of designed PCBPFs are studied by varying the size of the cavity. The normalized transmission spectra of PCBPF are observed using 2D finite difference time domain (FDTD) method. The photonic band gap (PBG) is calculated by plane wave expansion (PWE) method. The circular cavity based PCBPF gives better performance than others because of its circular resonating modes. The number of passbands is increased linearly while increasing the size of the cavity. The overall size of the PCBPF chip is about 11.4 μm × 11.4 μm, which is more suitable for photonic integrated circuits (PIC), wavelength division multiplexing (WDM) systems and sensing applications.

1. Introduction

Since 1987, photonic crystals (PC) is rapidly developing and receives special attention by the scientific and research communities due to the existence of photonic band gap (PBG) [1,2]. Recent years, PC based optical devices have attracted great interest owing to their compactness, high speed of operation, better confinement, long life period and suitability for integration. Essentially, PCs are composed of periodic dielectric structures that have alternate low and high dielectric constant materials to affect the propagation of electromagnetic waves in certain frequency bands inside the structure. In other words, at certain frequency bands a periodical structure behaves totally reflective that is no transmission occurs and thus, PBG is formed [3].

By creating the defects (point or line) in the periodic structure, it is possible to guide the propagation of light through the PBG region. This peculiar behaviour can lead to realize almost all kinds of PC based active and passive optical devices. Generally, PCs are basically classified into three types according to orientation of their materials, namely one dimensional photonic crystal (1DPC), two dimensional photonic crystals (2DPC) and three dimensional photonic crystals (3DPC). The 1DPC is proposed in the year 1887. After a century, the 2DPC and 3DPC were introduced [4,5]. Out of these, the 2DPC which has refractive index change in two perpendicular directions plays an important role in designing the photonic devices owing to precise band gap calculation, efficient light confinement, simple structure and easy fabrication.

In wavelength division multiplexing (WDM) systems, number of incoming channels is departed into an optical fiber with designated wavelengths. Hence, optical filters are necessary to select a required channel(s) at any destination. The BPF is a right device to select either a single or a multiple channels from the multiplexed signals. Many PC based optical filters have been proposed such as add-drop filters [6–11], channel drop filters [12–20], bandstop filters [21], bandpass filters [22–25], and so on. In the literature, the bandpass filter has been analyzed by introducing point defects and line defects [22,23], with biperiodic structures [24] and using circular photonic crystal ring resonator (PCRR) where the quasi waveguides are placed in top and bottom of the cavity [25].

In this paper, eight cavities, namely quasi square, tri-quarter square, square, hexagonal, circular, elliptical, diamond and annular ring based 2D-PCBPFs are proposed and investigated. The resonant wavelength, output efficiency and bandwidth of the proposed PCBPFs are examined by varying the size of the cavity. The size of the cavity is varied uniformly from the center point (Γ) of the structure. The most popular PWE method is used for calculating the band structure with and without defects. This simulation study is carried out by 2D finite difference time domain (FDTD) method. Both PWE and FDTD are simulated by Bandsolve and Fullwave simulators of Rsoft.

The rest of the paper is arranged as follows: the PBG with and without defects, and effects of gap map are presented in Section 2. The geometrical design of three inner ring cavities based PCBPFs are clearly pictured in Section 3. Section 4 discuses filter response, out-

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put efficiency, bandwidth and center wavelength. Finally, Section 5 concludes the paper.

2. Structure design

In this paper, all the proposed PCBPFs are designed using 2D square lattice PC. The number of circular rods considered for both '*X*' and '*Z*' directions are 21. The lattice constant is 540 nm, which is a distance between the two neighbouring rods, denoted as '*a*'. The radius of the rod is $0.185 \times a$ (0.1 μm). The permittivity of rods present in the structure is $\varepsilon_r = 11.97$ (refractive index = 3.4641). The circular silicon (Si) rods are perforated in air.

Fig. 1(a) sketches the band diagram of the structure without any defects, which usually gives the transverse electric (TE) and transverse magnetic (TM) PBG, and propagation modes in the first Brillouin zone. There are two TE PBGs exist in the structure which are indicated by blue region. As TM PBG is not present in the structure, TE polarization is considered for this simulation. The normalized frequency of first reduced TE PBG is observed from 0.435 a/λ to 0.295 a/λ whose corresponding wavelength ranges from 1241 nm to 1830 nm and second PBG is from 0.754 a/λ to 0.732 a/λ whose corresponding wavelength spans from 716 nm to 737 nm. Out of these, the first reduced PBG is considered for designing PCBPFs as it covers the second and third windows in optical region.

When the defects are introduced in the structure, the PBG is broken and the guided modes are allowed to propagate inside the

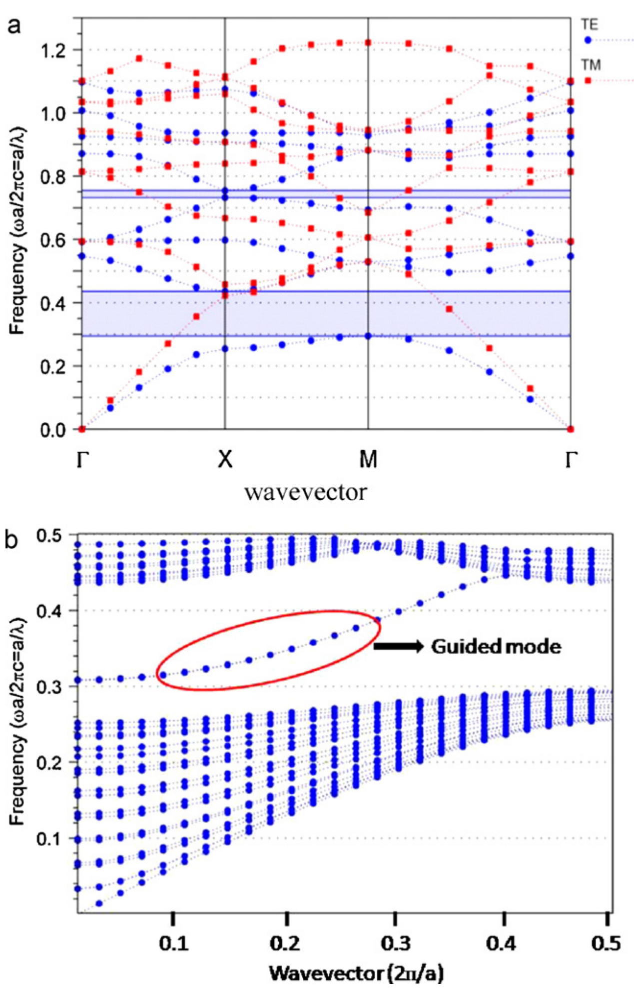

Fig. 1. Band diagram of 21×21 square lattice (a) without introducing any defects and (b) after the introduction of line and point defects.

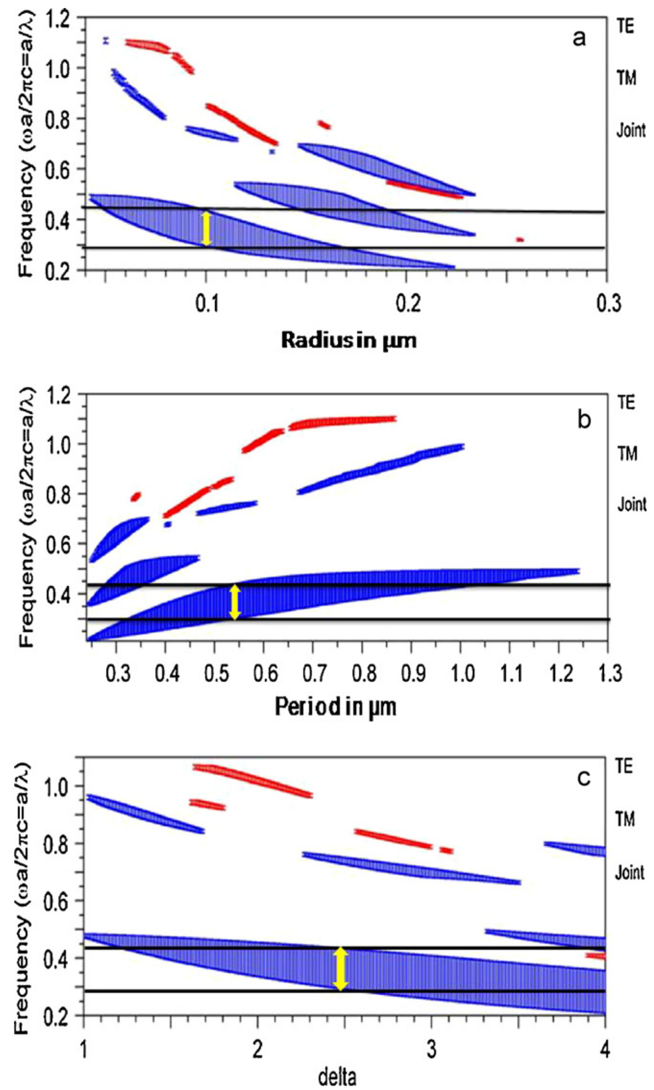

Fig. 2. Effect of gap map by varying (a) radius of the rod, (b) period (lattice constant), and (c) delta (index contrast).

PBG region as shown in Fig. 1(b). Both point and line defects are introduced for designing the filter. The guided modes are regulated by controlling the defect size and shape.

The gap map shown in Fig. 2(a)–(c) represent variation of TE/TM PBG, which is obtained by varying the defect size or the radius of the rod (a) lattice constant (b) and refractive index difference (c). In these figures, the blue region indicates the variation of TE PBG with respect to radius of the rods, period and delta similarly red region indicates for TM PBG. The vertical yellow line over blue region shows the TE BPG region of the structure without introducing defects. The values to design the PCBPF in the first reduced TE PBG are optimized through gap map, which are rod radius (0.1 μm), refractive index (3.4641) and period (540 nm) is indicated in the above gap map. Perfect matched layer (PML) is placed as absorbing boundary condition [26]. (For interpretation of the references to color in this text, the reader is referred to the web version of this article.)

3. Cavity based photonic crystal bandpass filter

Fig. 4(a)–(h) sketches the quasi square, tri-quarter square, square, hexagonal, circular, elliptical, diamond and annular ring cavity based PCBPFs. They consist of two in-line quasi waveg-