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Optical channel drop filters based on photonic crystal ring resonators

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ABSTRACT

A new optical channel drop filters (CDFs) configuration based on photonic crystals ring resonators (PCRRs) is provided. The transmission characteristics for single-ring and multiple-ring configurations have been investigated by using the two-dimensional (2D) finite-difference time-domain (FDTD) technique in triangular lattice photonic crystal (PC) silicon rods. Both forward and backward dropping were achieved in dual-ring PCRR structures. In this filter, 100% drop efficiency and acceptable quality factor can be obtained at 1550 nm. The present device can be used in the future photonic integrated circuits.

1. Introduction

Photonic crystals (PCs) are very suitable candidates for realization of future passive and active optical devices because of their ability to control light-wave propagation. Structures based on PCs enable researchers to design small-scale devices. Such structures offer the potential to be integrated into optical circuits. By introducing the defects in the PC structures, various optical components can be realized [1,2].

Channel drop filters (CDFs), on the other hand, are essential components of photonic integrated circuits (PICs) and wavelength division multiplex (WDM) optics communication systems. Various CDFs exist, such as fiber Bragg gratings, Fabry–Perot filters, and arrayed waveguide gratings. Resonant CDFs, which involve waveguide-cavity interaction, are other attractive applicants for this intention [3–5]. Significant progress has been made on CDF based devices in the areas of compactness, high spectral selectivity, wide spectral tunability, fast switching, and low-power switching [6, 7]. Fan et al. [3] reported channel drop filters based on square-lattice 2D PCs. The resonators are consisted of one or two point defects inside the 2D PCs. The size and the refractive index of scatters are varied to match the desired resonance condition. The quality factor of forward and backward drop filters in their results is approximately 1000 and 6000, respectively.

The first report of a photonic-crystal ring resonator (PCRR) was in a hexagonal waveguide ring laser cavity [8], where flexible mode design and efficient coupling were discussed. Later, the spectral characteristics of the waveguide-coupled rectangular ring resonators in photonic crystals were investigated by Kumar et al. [9], where a large single quasi-rectangular ring was introduced as the frequency selective dropping elements. Qiang et al. [10] studied add-drop filters based on square-lattice PCs, thus the resonator comprises a square trace defect in 2D PCs. The quality factor of single square ring filter is enhanced from 160 to over 1000 by increasing the coupling sections between waveguide and ring. They also proposed a dual square ring filter in order to achieve forward dropping. Recently Monifi et al. [11] presented a three output-ports channel drop filter based on the ring structure introduced by Qiang et al. in Ref. [10]. By manipulating the refractive index and radius of some scatters in PCs, they achieved a high transmission, three wavelengths channel drop filter in double-ring configuration. The estimated quality factor based on the reported data is about 100. PCs based ring resonators provide very well optical confinement due to ultra low bending loss. In addition, Bai et al. [12] reported a new 45° PCRR based on square lattice silicon rods. They obtained a quality factor of more than 830 and dropped efficiency of 90% at 1550 nm. It is helpful to overcome the challenge aforementioned by reducing the radius of ring to achieve a resonator with high-Q, high wavelength selectivity, and ultra small footprint size [13].

In this paper, we propose and investigate a new type of optical CDF based on PCRRs. The symmetrical filter consists of a single or dual-PCRRs laterally coupled to a bus waveguide and a drop waveguide using resonant tunnelling process. Its performance is investigated by the 2D FDTD method with the perfectly matched layer (PML) absorbing boundaries conditions at all boundaries. The proposed device provides a possibility of optical channel drop filter and can be used in the future photonic integrated circuits.

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2. Single ring photonic crystal ring resonators

All the designs in this paper are based on two-dimensional (2D) triangular lattice of silicon rods (refractive index $n_{Si}=3.46$) in an air background ($n_{air}=1.00$). As shown in Fig. 1(a), the W1 bus waveguide is formed by removing a single line defect (one line of rods removed) along ΓK direction. If the height of the rods is more than two investigated wavelengths, the structure can be considered infinite on the vertical direction, that is, a two-dimensional model instead of practical three dimensional one, which is typically computational time and memory consuming. In addition, it can offer the design trade-offs and guidelines before the real structure design based on a completely 3D FDTD technique [10].

In this investigation, the ratio of the rod radius r to the lattice constant a, is 0.2. The photonic band gap and the dispersion curve for the guided defect mode in the single line-defect waveguide (W1) were simulated with the free MIT Photonics-Bands (MPB) package [14]. This program computes definite-frequency eigenstates (harmonic modes) of Maxwell's equations in periodic dielectric structures for arbitrary wavevectors, using fully-vectorial and three-dimensional methods. It is especially designed for the study of photonic crystals, but is also applicable to many other problems in optics, such as waveguides and resonator systems. As shown in Fig. 1(b), a photonic band gap (PBG) is found only for the TM polarization. In other words, the proposed structure does not have PBG for transverse electric (TE) modes. Thus, all of simulations are done in TM mode. In addition, there exists a single-mode frequency (normalized) ranging from 0.337 a/λ to 0.442 a/λ below the light line.

For the 1550 nm communication window, the lattice constant a, is set at 607.6 nm.

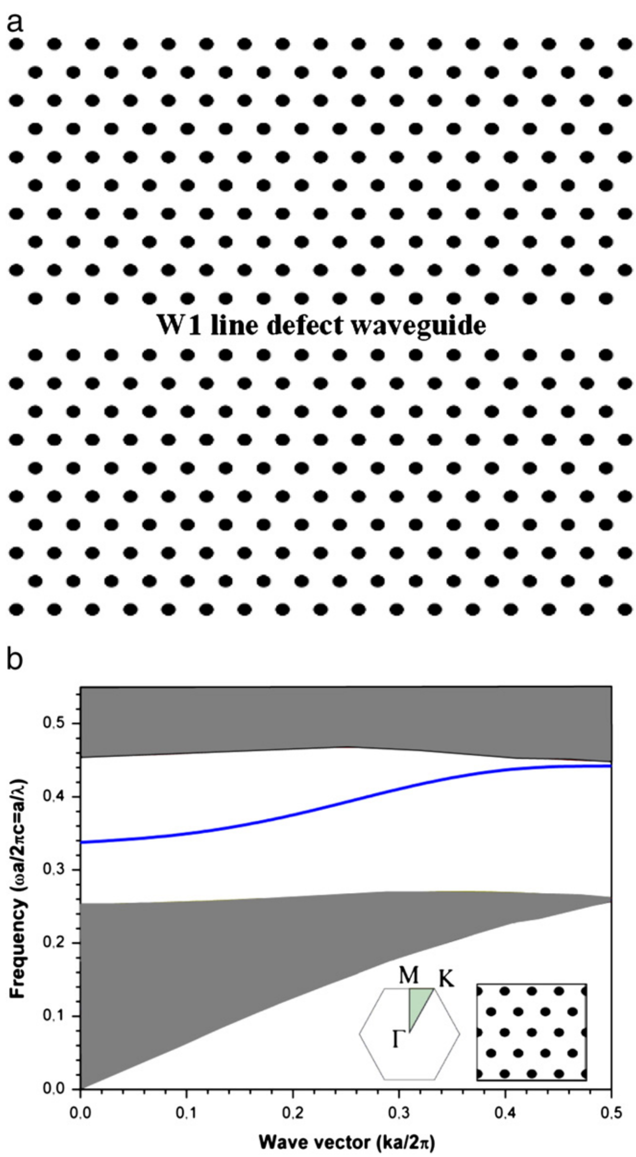

Fig. 1. (a) Single line-defect (W1) photonic crystal waveguide, (b) Dispersion plot for TM polarization and the corresponding guided mode shown as a blue line in the photonic bandgap region.

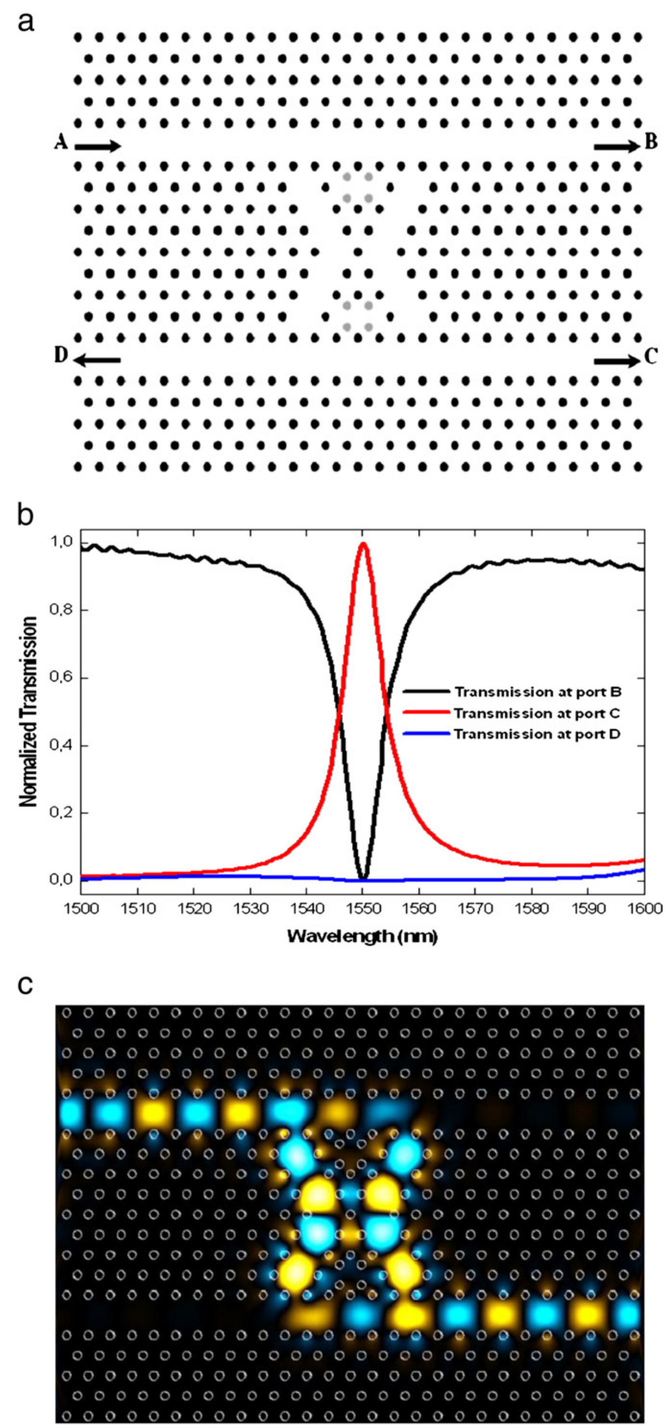

Fig. 2. (a) Schematic of single-ring PCRR based CDFs, (b) Normalized transmission spectra at B, C and D, (c) The electric field pattern at resonant wavelengths of 1550 nm.