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Performance improvement of wavelength division multiplexing based on photonic crystal ring resonator

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ABSTRACT

In this paper, an ultra-narrow band channel drop filter (CDF) based on two-dimensional photonic crystal ring resonator (2D PCRR) with hexagonal lattice of silicon rods is proposed and designed. For this purpose, the influences of variation of the radius of the quad rods on corners of X-shaped PCRR, on the performance characteristics of channel drop filter such as drop efficiency, and quality factor have been investigated. Calculation results show that the efficiency of 100% and quality factor of nearly 1500 at operating wavelength of 1550 nm can be achieved. Consequently the channel bandwidth and channel spacing are reduced to 1 nm and 10 nm respectively, which will be suitable for coarse wavelength division multiplexing (CWDM) optical network systems with 10 nm channel spacing. Simulations have been performed using 2D finite difference time-domain (2D FDTD) calculations.

1. Introduction

Photonic crystals (PhCs) have the ability to control propagation light waves, which have many applications in optical integrated circuits and optical telecommunications. Foundation of the design and manufacturing of the majority of optical devices such as waveguides, high quality factor resonant cavities, optical switches and channel drop filters (CDFs) are photonic crystals [1]. Photonic crystals (PhCs) which have the photonic band gap (PBG) because of their periodic structures have been much focussed in fabrication technologies [2]. Recently, channel drop filters based on 2D photonic crystals with square and hexagonal lattices have attracted much attention [3–6]. In this regard, several kinds of CDF based on 2D photonic crystal ring resonator (PCRR) have been presented by using the quasi-square PCRR [7,8], square PCRR, dual square PCRR [9], dual curved PCRR [10], hexagonal PCRR [11], 45° PCRR [12], circular PCRR [3,4] and X-shaped PCRR [5].

The wavelength division multiplexing (WDM) devices are fundamental components for improving bandwidth of optical communication. In fact, the wavelength division multiplexer is a device that merges the multiple light signals of a set of wavelengths into compound signal, which are directed from several fibers for input and conversely the wavelength division de-multiplexer is a device that separates the received compound signal into multiple light signals of a set of wavelengths, which are directed to several fibers for output. Moreover, people have tremendous interests in developing device that is more compact [13].

In this paper, a new scheme of CDF based on 2D PCRR is proposed and designed that leads to the trade-offs between quality factor and drop efficiency that is reduced and inhibited. The performance of filter with hexagonal lattice of silicon rods in air background is investigated by using two-dimensional finite-difference time-domain (2D FDTD) numerical method. The proposed filter can be used as either multiplexer or de-multiplexer such that the channel spacing is very small so this filter is very suitable for CWDM multichannel systems. In continuation, this paper is arranged as follows:

In Section 2.1, the description of the structure and its photonic band structure with created line defect for designing the CDF based on 2D-PhC is discussed. MUX/DEMUX design for CWDM systems and also, simulation results are described in Section 2.2. Eventually, Section 3 will conclude the paper.

2. Design and numerical results

2.1. Design

The proposed structure consists of 2D photonic crystal with hexagonal lattice which consists of silicon dielectric rods with refractive index of 3.46 and radius of 0.2*a* (126 nm) that are embedded in the air background with refractive index of 1. Fig. 1(a) shows the W1 line defect (waveguide 1) that has been created by removing

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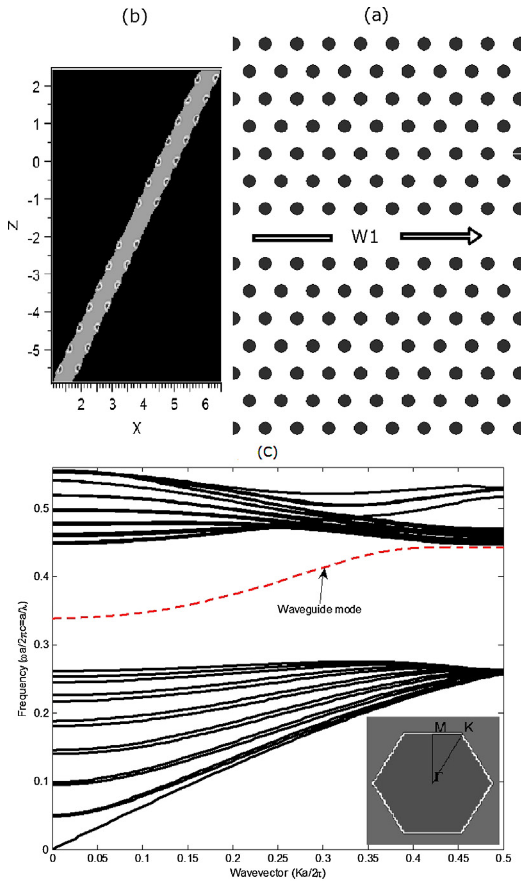

Fig. 1. (a) PhC waveguide created with line defect, (b) 2D Super-cells with a defect, (c) dispersion curves for TM polarization; waveguide transmission components are marked as red color which are located in the photonic band gap. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

a row of dielectric rods along the direction of ΓK. The approximation of two-dimensional super-cell is shown in Fig. 1(b). According to Fig. 1(c), waveguide supports single-mode frequency in range of $0.337a/\lambda$ to $0.442a/\lambda$, where "λ" is the wavelength of light in free space and "a" is lattice constant (the distance between two adjoining rods). The lattice constant is approximately 632 nm for optical communication systems (1550 nm). In fact, by adjusting the lattice constant of this structure, W1 waveguide has the capability of propagating the wavelengths of 1437–1885 nm that behaves as a single-mode waveguide.

The proposed structure consists of two waveguides and an X-shaped PCRR which has been placed between two waveguides [5].

Considering Fig. 2, the upper waveguide is called bus waveguide and lower waveguide is called dropping waveguide. The input port is labeled as "A", forward transmission output port as "B" and the

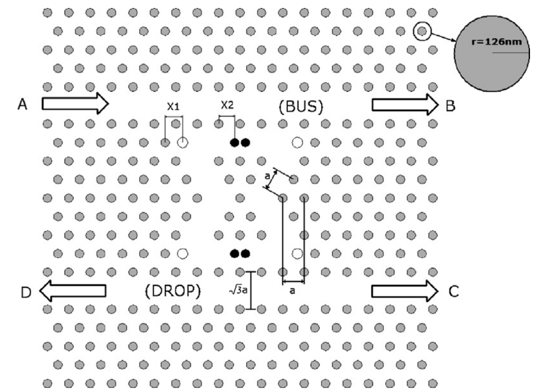

Fig. 2. The proposed CDF based on 2D PCRR ($X_1 = 0.82a$, $X_2 = 0.748a$).

forward- and backward-dropping output ports are labeled as "C" and "D" respectively.

To increase drop efficiency, the black rods without changing its radius have been shifted as $0.248a$ in opposite direction relative to each other along the ΓK and also to increase the quality factor of the filter, white rods have been shifted as $0.18a$ in the ΓK direction. Once again to improve the quality factor, we increase the radius of these rods up to $1.2a$; this change leads to the drop efficiency being reduced. So for inhibition of trade-offs between quality factor and drop efficiency, we assume the drop waveguide as in Fig. 5(c). The transmission characteristics of proposed CDF are calculated with FDTD method.

A light source of Gaussian distribution with TM polarization is applied to the input port that records the transmitted power spectral density. Time monitors are placed in each of the B, C and D output ports. All the transmitted power densities are normalized to the light power density of an input port. Normalized transmission spectrum of the output ports of B, C and D are shown in Fig. 3. There is no backward-dropping transmission at resonance state while the

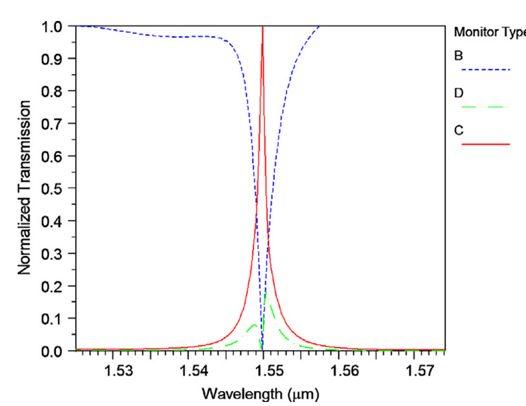

Fig. 3. Normalized transmission spectrum of the output ports.

Table 1
Comparing devices based on PCRRs available in a variety of papers.

Reference	Dropping efficiency (%)	Quality factor	PCRR type
This paper	100	1500	Improved X-shaped (Direct-dropping)
This paper	100	1500	Improved X-shaped (Indirect-dropping)
Youcef Mahmoud et al. [5]	100	1000	X-shaped
Robinson and Nakkeeran [3,4]	100	114.6	Circular
Ma and Ogusu [6]	95	775	Diamond
Bai et al. [12]	90	840	45°
Hsiao and Lee [11]	55	423	Hexagonal
Andalib and Granpayeh [10]	68	153.6	Dual curved
Djavid et al. [7,8]	99	52.7	Quasi-square
Qiang et al. [9]	>98	160–1000	Quasi-square