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Photonic Crystal Slab Add-Drop Filter

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ABSTRACT

A new type of optical add drop filter (ADF) based on slab photonic crystals resonant cavities is proposed. ADF operation is based on coupling between the photonic crystal waveguides. Using the finite difference time domain (FDTD) method and plane wave expansion (PWE) method, the ADF characteristics and band structure of the filter, respectively are obtained. The proposed structure is optimized to work as an ADF. Dropping efficiency at 1560*nm* and quality factor (*Q*) of our proposed structure are 90% and 195, respectively. The quantities of quality factor and transmission efficiency are suitable for optical applications. This structure is highly attractive for photonic integrated circuits (PICs).

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1. INTRODUCTION

In 1978 Yablonovitch [1] and john [2] first proposed the idea that periodic dielectric structures are able to provide photonic band gap (PBG) for distinct regions in the frequency spectrum, just like that of electronic band gap (EBG) in solid-state crystals behavior. Owing to features like compactness, electromagnetic wave emission controllability, high rate of performance speed, long life period and property for integrating on optical circuit, the photonic crystals (PhCs) has been used for designing optical devices since 1978. PhC is a structure in which the optical refractive index shows a periodic modulation with a lattice constant in wavelength performance. Defects in photonic crystals can be of point, linear or surface type. Each of mentioned defects concludes designable attributes and features with a specific usage. For instance, the point defect could act as a cavity with a very low mode volume [3]. The allowed modes that appeared in PBG make possible the propagation of wavelength in the structure [4].

So far, many optical devices have been designed based on photonic crystals such as optical switches [5], [6], filters [7], [8], power splitter [9] and wavelength demultiplexer [10]. These devices are being used mainly in optical communication systems, like a wavelength Division multiplexing (WDM) system. As an essential element of such systems, add drop filter (ADF) is being used for selecting a channel with a specific wavelength. The cavities which are coupled to the waveguides can be used as wavelength selecting devices. Cavities in a specific wavelength, which is the cavity resonant wavelength, localize electromagnetic energy from an input waveguide into the cavity and then transmit it to drop waveguide.

In this paper, an ADF structure has been designed by slab PhC cavity for selecting desired wavelength. A slab PhC of triangular lattice of air holes has a large transverse electric (TE) band gap and it is expected to serve as a good platform for Photonic integrated circuits and ultra-compact optical devices. In this structure, power transmit efficiency is 90% while full width at half maximum (FWHM) is about 8*nm*.

These characteristics are highly appropriate for devising a cavity based ADF. The overall size of the proposed device is about 85.37μm^2 which is appropriate for photonic integrated circuits.

2. DESIGN AND SIMULATION OF PHC ADF

In this paper, as shown in Fig. 1, our goal is designing a compact structure for ADF based on photonic crystals air holes. The configuration is composed of three layers of Sio_2 (top cladding), Si (slab), Sio_2 (lower cladding), with thickness of 100, 200, 1000*nm*, respectively. The air holes have a radius r=0.3a where a is denoted as the lattice constant and equal to a=420*nm*. In this structure, band gap opens for the normalized frequency $0.2555<a/\lambda<0.3236$ for TE polarization (in which the electric field is in propagation plane and the magnetic field is perpendicular), where λ is the wavelength in free space. Since this type of hole-array PhCs slab favor photonic band gap (PBG) mainly for TE polarization, we focus on the TE-like polarization in this work. This cavity structure has a central air hole with radius R_0, and four periods of air holes with decreasing radii towards the outside direction with radius R_1, R_2, R_3, and R_4 respectively. The radii of the air holes R_0 ~ R_4 equal to 0.38a, 0.372a, 0.360a, 0.354a and 0.343a [8]. To increase the transmission power of port B we can shape the cavity as pseudo-circular. As shown in Fig. 1, the air holes with radiuse R_2 of the cavity are shifted towards the center up to quarter of lattice constant, allowing the cavity to be shaped like a circle.

The spectrum of the power transmission is obtained with finite difference time domain (FDTD) method. FDTD is a time domain simulation method for solving Maxwell's equations in arbitrary materials and geometrics [11]. Berenger's perfectly matched layers (PML) are located around the whole structure as absorbing boundary condition [12].

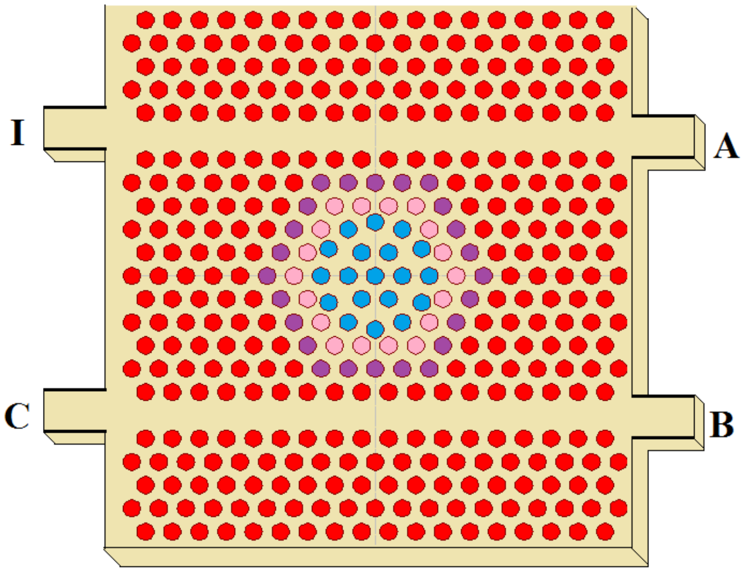
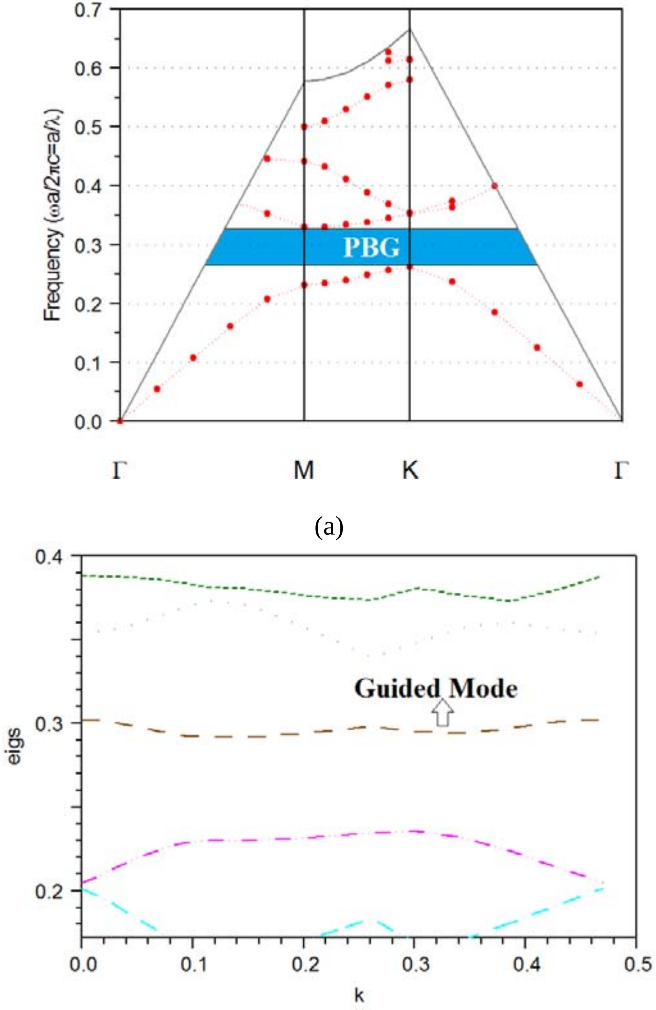


Figure 1. Schematic of a photonic crystal based ADF

Fig. 2(a) sketches the band diagram of the structure without any defects. When the line defect is introduced in the structure, the PBG is broken and the guided modes are allowed to propagate inside the PBG region as shown in Fig. 2(b). Both point and line defects are introduced for designing the filter. The guided modes are regulated by controlling the defect size and shape. In general, a cavity is positioned between two optical waveguides provides an ideal basic structure for ADF such that power in one waveguide is transferred into the other through the resonance of the cavity, which is used to add or remove a channel from the multiplexed input/output signals.

A Gaussian pulse input signal is launched into the input port with lable 'I' and its output is detected at the ports 'A', 'B' and 'C' using power monitor. The normalized transmission spectrum is obtained by taking Fast Fourier transform (FFT) of the fields that are calculated by FDTD method. The normalized transmission spectra for three output ports (A, B and C) in the ADF are displayed in Fig. 3 as blue, green and red lines, respectively. It can be seen that the spectral selectivity is significantly improved, 90% dropping efficiency can be obtained at the resonant wavelength of 1560*nm*. The quality factor (Q) of dropping peak is 195. Such Q and dropping efficiency values are enough for optical communication applications. It can be seen that high power transfer from the input to the drop port through the resonant cavity is possible in our ADF. On the other words, the power in the input waveguide is extracted by using resonant tunnelling process and coupled into port B. The coupled mode in the resonant cavity rotates in the counter-clockwise direction with the propagating waveguide mode, which leads to the forward dropping.



(a)

(b)

Figure 2. Band diagram of structure, (a) before and (b) After introducing line defect

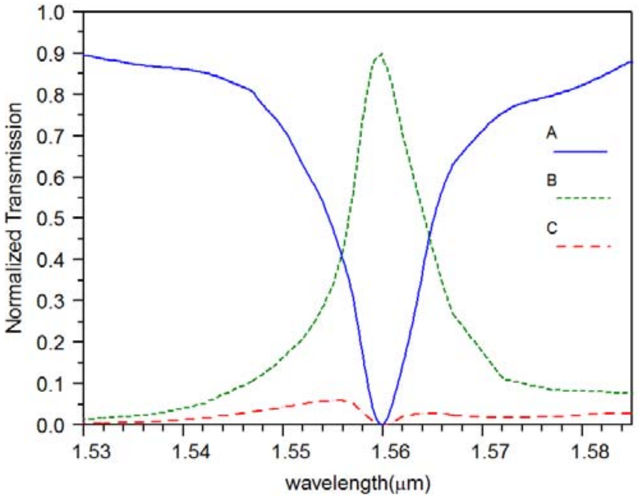


Figure 3. Normalized optical power transmission characteristic of ADF

In compared with other work, the design of the ADF presented in this paper seems to be more appropriate for actual fabrication and application. The proposed structure provides a possibility of ADF and has the ability to be highly suitable for integration.

3. CONCLUSION

A slab photonic crystal ADF had been presented and investigated through FDTD method in triangular lattice of air holes in *Si* slab. We have shown that there is flexibility in design of the ADF with photonic crystal. 90% drop efficiency and quality factor of 195 can be obtained at 1560*nm* that this is an important advantage for ADF is proposed than the ADFs already reported in the literature. The most important characteristic of this structure is it's easily to fabrication and integration. Such structure may offer promising applications for photonic integrated circuits based on PhCs and other nanophotonic structures.

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