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T-shaped channel-drop filters using photonic crystal ring resonators

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ABSTRACT

In this paper, we demonstrate a new type of 2D photonic crystal T-shaped channel-drop filters based on ring resonators with high normalized transmission; we investigate parameters which affects resonant frequency in these channel-drop filters. These parameters include dielectric constant of inner rods, coupling rods and whole rods of the structure as well as radius of the coupling rods and scatterer rods. At dropping case, the power transferred to the drop waveguide and the power remaining in the bus waveguide are found by finite difference time domain (FDTD) method to be over 95% and less than 5%, respectively.

1. Introduction

Photonic crystal structures are considered for using in integrated nanophotonic circuits. One of the most important devices for ultra-dense integrated circuits is channel-drop filter (CDF). CDFs, which extract one channel from wavelength multiplexed signals and pass through other channels undisturbed, are useful and essential elements for photonic integrated circuits. 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 [1,2]. One kind of resonant CDFs is T-shaped CDF utilizing the resonant coupling between the two T-shaped waveguides and one cavity. In this paper, such a CDF is devised in two-dimensional photonic crystal with a ring resonator instead of point-defect cavity, where the ring used realizes channel drop operation. In this paper, we report a new idea for a CDF. Its operation principle is based on resonance of the ring resonator and coupling mechanism between waveguide and ring resonator. It is obvious that the resonant modes in the ring resonators are supported by the photonic band-gap which is more efficient in optical confinement, especially for the wavelength-scale ultra-compact ring resonators [3,4]. For various applications, choice of the ring size is determined by the desired resonant wavelength and the tradeoff between the ring quality factor and the ring modal volume [3]. Compared to point-defect or line-defect PC cavities, ring resonators offer scalability in size and flexibility in mode design due to their multi-mode nature. Also design parameters for this ring resonator can be the dielectric constant of the scatterer rods, coupling rods and whole rods of the structure. As it will be shown later in this case, design parameters of the rings are much more that of point-defect cavities. We used this element to achieve a new type of T-shaped CDF with high normalized transmission (over 95%) in third communication window.

2. Photonic crystal ring resonators

A typical ring resonator obtained by removing a ring shape of columns from a rectangular lattice of dielectric rods in air host is shown in Fig. 1. The four extra rods which have the same properties as other rods are located at each corner of the ring resonator at half lattice constant and act like a right-angled reflector that reduce the back-reflection at the ring corner. These scatterer rods are shown in Fig. 1. For further improvement the radius of the coupling rods is chosen to be 0.8r in order to achieve more coupling.

Due to trade-off between the ring quality factor and the ring dropping efficiency, choosing higher dropping efficiency, great

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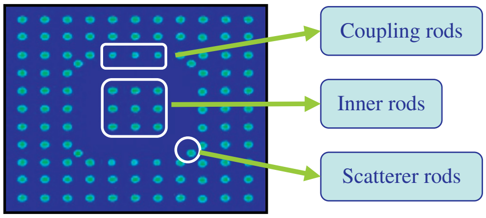

Fig. 1. A typical photonic crystal ring resonator.

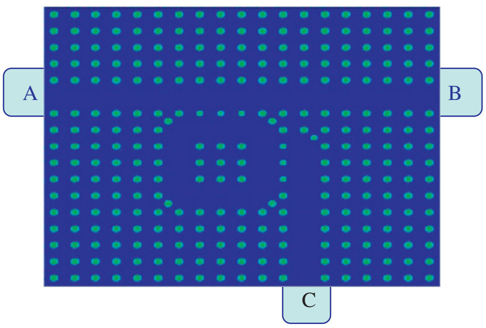

Fig. 2. A new T-shaped channel-drop filter with ring resonator.

quality factor would be lost. But this quality factor is still acceptable for our application. By putting this ring resonator next to the waveguide formed by removing one row of rods, it can be evanescently coupled to the waveguide at its resonant frequency to trap the electromagnetic energy propagating in the waveguide and localize its energy [5].

3. A new T-shaped CDF based on ring resonators

Here, we design a T-shaped CDF with excellent power transmission as shown in Fig. 2. An optimized ring resonator in rectangular lattice of dielectric column in air host is used in our structure. By putting the ring resonator and the waveguide next together, the electromagnetic energy propagating in the waveguide will be trapped in a ring resonator. This phenomenon occurs because of coupling between the waveguide and ring resonator at resonant frequency [6–8]. For improving the performance of this filter, end of the vertical waveguide is closed and also it is smoothened by adding the extra scatterer rod to the top of the vertical waveguide at half lattice constant. In ordinary case when the ring does not resonate, whole of power remains in the horizontal bus waveguide and goes through port B. At dropping case, most of the power transfers to the vertical drop waveguide and goes through port C. The structure and its three ports (labeled as A, B, and C) are shown in Fig. 2. As it will be shown later, the ring resonator drops the light from the horizontal waveguide and sends it to the vertical waveguide.

4. Simulations

The structure used in this paper is 2D rectangular lattice photonic crystal of Si rods in air host. Refractive index of Si is 3.66, the radii of the rods is 18.5% of the lattice constant, radius of three coupling rods is $0.8r$ and radius of four scatterer rods is r while r is the radius of typical rods. The polarization of the signal in our simulation is TM. The spectrum of the power transmission is obtained with finite difference time domain (FDTD) method [9] in our *MATLAB* code. Perfect matched layers (PMLs) [10] are used around the CDF structure. The power transmission spectra are computed by taking the FFT of the fields (during 30,000 time step, 45 min running time) that calculated by FDTD incorporating with integrating the poynting vector over the cells of the output ports. The computer used in this simulation is P4 3.00 GHz and has 4 GB of RAM.

The result of the FDTD processing for this new CDF that shows the normalized transmissions of the structure over the third communication window is shown in Fig. 3. Switching wavelength is the wavelength that both ports have equal nonzero value. As shown in Fig. 3, normalized transmission power of port B or C at desired region in third communication window is above 95%. In next section, the effect of changing five parameters on ring resonator performance will be studied. Section 4.1 describes effect of changing dielectric constant of rods in filter performance, while Section 4.2 describes effect of changing radius of rods in filter performance.

4.1. Changing dielectric constant of rods

One of the most important features of any filter is tunability. Here we investigate parameters which affect resonant frequency

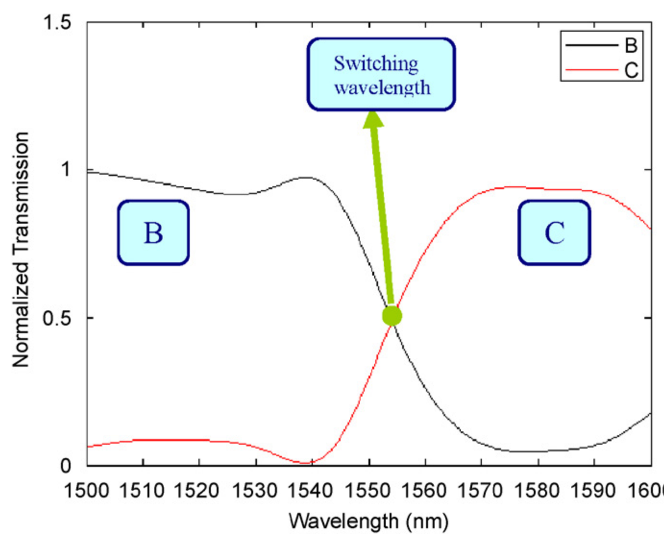

Fig. 3. Optical power transmission characteristics of T-shaped CDF.

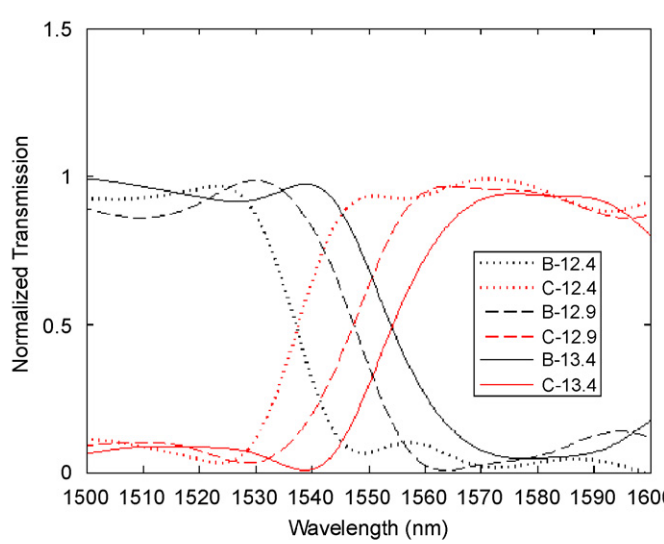

Fig. 4. Optical power transmission characteristics of T-shaped structure for different dielectric constant of whole rods.