A photonic crystal L-shaped bend based on ring resonators

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We propose a new type of two-dimensional (2D) photonic crystal L-shaped bent waveguides based on ring resonators with an acceptable bandwidth. The proposed structure mechanism is based on coupling between a waveguide and a ring resonator. This structure is designed and verified by finite-difference time-domain (FDTD) computation. Our simulation using this method gets over 90% output.

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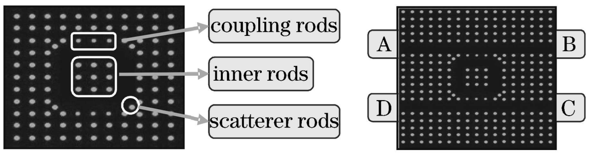
Great interests have been given to the photonic crystal whose photonic band gap has attracted considerable possibility[1,2]. By using the strong confinement of the light by the photonic bandgap, it is expected that waveguide devices whose size is of the order of the wavelength of light can be realized. One of the key elements of integrated optical devices is bent waveguide. Many papers have investigated different geometries of bent waveguides in order to improve their transmission characteristics[3]. Ring resonators are another useful elements especially in channel-drop filters. Because of high quality factor of the ring resonators and the ring's intrinsic single mode nature, very high spectral selectivity could be achieved[1,2]. We use this element to achieve a new type of L-shaped bent waveguide with acceptable bandwidth ranges from 1537 to 1600 nm in the third communication window.

A typical ring resonator in a rectangular lattice photonic crystal of dielectric column in air host is shown in Fig. 1(a). Trapping behavior is realized by removing a ring shape of columns from a rectangular lattice of dielectric rods.

In this structure, choosing the refractive index of 3.46, the lattice constant a of 540 nm and the rods' radii r of 99.9 nm. The bandgap opens for the normalized frequency a/λ ranges from 0.31 to 0.46 for TM polarization (electric field parallel to the rod axis), where λ is the wavelength in free space. The photonic crystal waveguides are formed by removing one row of rods. Adding the four extra scatterer rods which are the same as other rods at each corner of the ring resonator at half lattice constant improves the performance of the ring resonator. These scatterer rods are shown in Fig. 1(a). This work minimizes the effect of propagating mode which results from back-reflections at the sharp corners of the ring. These additional rods at each corner act like a right-angled reflector reducing the back-reflection at the corresponding corner. During an optimization process, the radii of the coupling rods are chosen to be $0.8r$ for more coupling. By putting a ring resonator next to the waveguide, it could be coupled to the waveguide at its resonant frequency to trap the electromagnetic energy propagating in the waveguide and localized its energy[3]. In another word, the ring resonator drops the light from the top waveguide and sends it to the bottom waveguide at resonant wavelength of the ring, as shown in Fig. 2(b). Optical power transmission characteristic of structure in Fig. 1(b) is depicted in Fig. 2(a). Figure 2(c) shows snapshots of electric field pattern through the channel (off-resonance of $\lambda_2 = 1500$ nm).



(a) (b)

Fig. 1. (a) Photonic crystal ring resonator (PCRR); (b) coupling two waveguides by ring resonator.

A typical right-angle bent waveguide is shown in Fig. 3(a). Many papers have worked on this kind of bend and optimized its topology for high transmission[3]. In this letter, we design an L-shaped bent waveguide with excellent power transmission as shown in Fig. 3(b). An optimized ring resonator in rectangular lattice photonic crystal of dielectric column in air host is used in our structure. By putting the ring resonator next to the waveguide, the electromagnetic energy propagating in the waveguide will be trapped in a ring resonator. This phenomenon occurs because of coupling

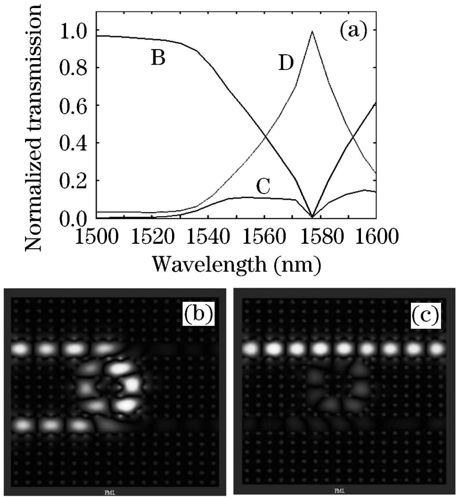


Fig. 2. (a) Optical power transmission characteristics of structure in Fig. 1(b); Electric field intensity of this filter achieved by FDTD (b) for dropping the channel ($\lambda_1 = 1577$ nm) and (c) through the channel ($\lambda_2 = 1500$ nm).

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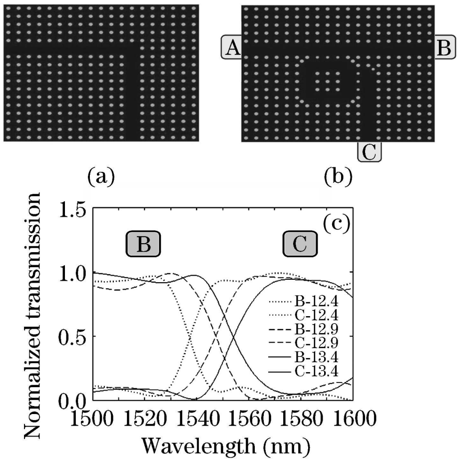

Fig. 3. (a) A typical L-shaped bent waveguide; (b) a new bend structure based on ring resonators; (c) optical power transmission characteristics of bend structure for different dielectric constants of whole rods.

between the waveguide and ring resonator at resonant wavelength[4−7].

First we use the structure described in previous section and replace the bottom horizontal waveguide with an end closed vertical one. By closing the top of the vertical waveguide and adding a scatterer to the top of it at the corner, the performance of the bend is improved and the radii of coupling rods are optimized separately. In this case, the electromagnetic energy which is trapped in the ring resonator couples to the vertical waveguide and goes through the output. The structure and its three ports (labeled as A, B, and C) are shown in Fig. 3(b). As it will be shown later, the ring resonator drops the light from the horizontal waveguide and sends it to the vertical waveguide. Then we investigate the parameter such as dielectric constant which has the most effect on changing frequency spectra in this structure. We change this parameter εr of the whole rods for three different values 12.4, 12.9, and 13.4. Results of this investigation are depicted in Fig. 3(c). As shown in Fig. 3(c), curves are shifted to left as dielectric constant decreases. So during an optimization process this parameter is chosen to be 12 for more drop bandwidth. Transmission characteristic for this value is depicted in the next section.

The spectrum of the power transmission is obtained with finite-difference time-domain (FDTD) method in our MATLAB code. A perfect matched layer (PML) is used around the structure. The power transmission spectra are computed by taking the fast Fourier transform (FFT) algorithm of the fields that calculated by FDTD incorporating with integrating the Poynting vector over the cells of the output ports.

The result of the FDTD processing for structure with dielectric constant of 12 is shown in Fig. 4 that shows the normalized transmissions of the structure over the third communication window. As shown in Fig. 4, normalized transmission power in the range of 1537 – 1600 nm is above 80% and in the range of 1549 – 1595 nm is above 90%, therefore the acceptable frequency range is achieved. So based on the previous results, a new L-shaped bend is presented. In this structure, the end of the top waveguide is closed and an extra rod as scatterer is added to its corner for better performance. It should be noted that transmission spectra of this new L-shaped bend is the same as transmission spectra of port C in previous structure. At last, the results of time domain simulation are depicted. Figure 5 shows the electric field intensity of L-shaped bend at one of the ring resonator resonant wavelengths between 1537 to 1600 nm.

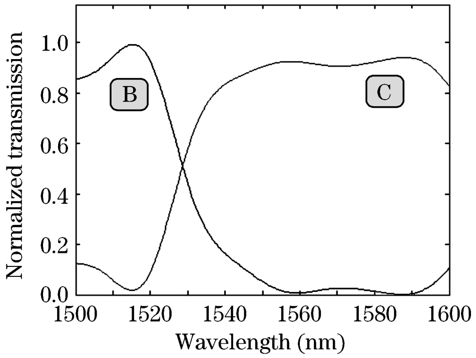

Fig. 4. Optical power transmission characteristics of the L-shaped bend.

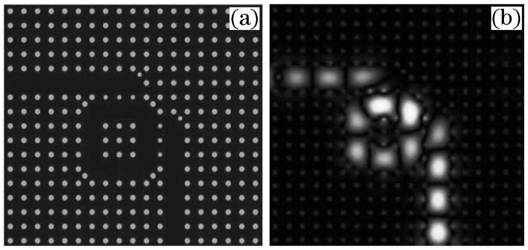

Fig. 5. (a) Final pattern of our L-shaped bend with ring resonator and (b) electric field intensity of L-shaped bend waveguide at one of the ring resonator wavelengths in 1537 – 1600 nm.

In conclusion, we propose an excellent L-shaped bent waveguides based on ring resonator composed of a two-dimensional photonic crystal and analyze its characteristics using the FDTD method. We get the acceptable frequency range over the third communication window and show that the normalized transmission of this frequency range is above 90%.

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