Design of a T-shaped wavelength division de-multiplexer based on 2D photonic crystal

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We design a T-Shaped wavelength division de-multiplexer in two-dimensional (2D) photonic crystal based on the coupling resonance characteristics. In this structure, three high effective and relative narrow bandwidths optical wavelengths (1 310, 1 440, and 1 550 nm) are obtained by changing the radius of the ring and cavity rods. The method of the finite-difference time-domain is used to investigate the characteristics of the coupling resonance characteristics of the ring and the cavity. The calculation results show that transmission rates of these three wavelengths are all reach up to 95% and achieve with 5-nm mean value of bandwidth.

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Since Yablonovithch *et al.* proposed the concept of photonic crystals (PCs) in 1987[1,2], the PCs have attracted intensive interests in sciences and technologies. Due to their capability of controlling electromagnetic (EM) waves in a very small area, PCs are very suitable for realization of future passive and active optical devices. Optical filters[3], optical switches[4,5], couplers[6], and power splitters[7,8], are some examples based on PCs.

One of the most important applications of PCs is the realization of devices for use in wavelength division de-multiplexing, which is useful to divide and combine different wavelength channels each carrying an optical data signal in order to meet the demand of the optical transmission bandwidth in optical communication networks.

So far, people desired several structures of wavelength division de-multiplexer (WDDM) based on two-dimensional (2D) PCs. WDDM based on waveguide coupled theory, like line defect waveguide[9−11], can get a wide bandwidth wavelength with a high effective. And a WDDM based on resonant or ring cavity[12−14] has been widely applied in the photonic circuit because of their high quality factor.

In this letter, we designed a T-shaped WDDM based on the coupling resonance characteristics. In this structure, we used a resonant cavity to select a channel with a 5-nm bandwidth, and by changing the radius of rods as defects to change the propagation modes. As a result, we can get the wavelengths 1 310, 1 440, and 1 550 nm, and the transmission rates of these three wavelengths are all reach up to 95%.

By means of discussing a filter structure supporting only one resonant state, we perform the principle where we excite a propagating state in the bus waveguide and study how it is affected by the resonant state.

Plane wave expansion (PWE)[15] and multiple scattering theories are used to discuss the EM behavior in this PCs structure. For a triangular lattice of PCs below, the band gap is between 0.28 and 0.5, when radius of the rods are 0.18a with a dielectric constant of 11.56 on an air background. (Where a is the lattice constant).

As is shown Fig. 1, the resonant cavity is divided into two parts, a cavity defect and four rods besides it. These four rods can be treated as two groups, and their radii are $R1=0.18a$ and $R2=0.14a$ respectively.

According to the coupling resonance characteristics, the curves of the modes in the waveguide and the resonant can be intersected at point. And it is the point whose frequency can be energized. Thus, we can get the wavelength at that frequency.

Figure 2(a) gives the transmission rates and the dispersion curves for the waveguide and the resonant cavity while Fig. 2(b) shows the transmission rate of the structure. From Fig. 2(a), the intersection frequency is $a/\lambda=0.426$ and it is the frequency which is energized as we see in Fig. 2(b). The comparison between these two figures tells the resonant frequency which agrees with the coupling resonance characteristics. And the transmission rate of the frequency 0.426 reaches to 97%.

The WDDM in a 2D PC with a triangular lattice of air holes is designed as shown in Fig. 3. By contrast, the structure is similar to the single one above. The radius in the PC is $R=0.18a$, on an air background. And the dielectric constant is still 11.56. The 2D PC has a TM band gap between 0.28 and 0.45.

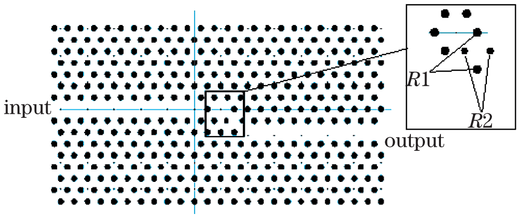

Fig. 1. Structure of single resonant cavity.

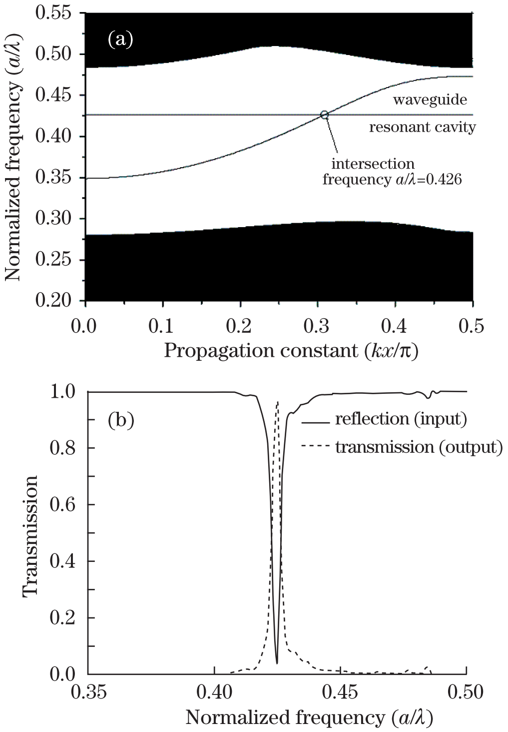

Fig. 2. (a) Dispersion curves for the waveguide and the resonant cavity and (b) transmission characteristics of the single structure.

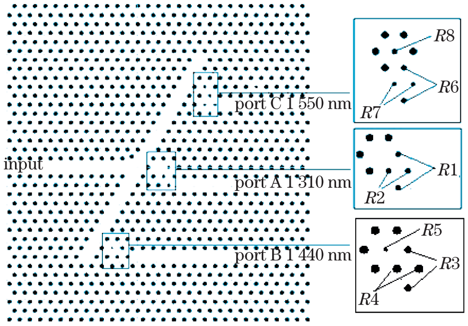

Fig. 3. Structure of the three port T-shaped WDDM.

Like the single resonant cavity structure, each port is composed of two parts, a cavity defect and four rods besides it. And these four rods can be treated as two groups as well. For port A, we remove the center rod in the cavity, and the radius besides it are $R1=0.13a$, and $R2=0.13a$, respectively. For ports B and C, we change the center rod's radius $R5=0.065a$ and $R8=0.13a$. The radius close to the cavity are $R3=0.145a$, $R4=0.18a$ and also for port C $R6=0.135a$, $R7=0.1a$.

Based upon the coupling resonance characteristics, we give the dispersion curves in Fig. 4. In Fig. 4, three almost straight lines and a waveguide curve cut at three points. And these points of intersection are the resonant frequencies.

When the input light coming from the input port encounter the resonant region, the photons with the resonant frequency feeding into the cavity will build up the mode amplitude of the resonator, then radiating energy goes into the surrounding three waveguide ports. Figure 5 shows the wavelength response of the structure which satisfies the coupling resonance characteristics we have discussed above.

According to Table 1, we can easily tell the peak value of each port. The transmission spectrum through port A is close to 95.9%, and the selecting wavelength is 1310 nm. The transmission spectrum through port B is close to 95.4% over the entire spectrum, with the selecting wavelength 1 440 nm. And for port C is 98.9% which selects 1 550 nm. High effective and relative narrow bandwidths optical wavelengths are obtained with 5-nm mean value of bandwidth.

In conclusion, by changing the radius of resonate rods, three high effective and relative narrow bandwidths optical wavelengths with 5-nm mean value of bandwidth (1 310, 1 440, and 1 550 nm) are obtained. And the transmission spectrum through wavelength of 1 310 nm achieves nearly 95.9% while the transmission spectrum through wavelength of 1 440 nm reaches to 95.4% over the entire spectrum. And for 1 550 nm is 98.9%. Thus, we verify that it can content with the demands of the optical transmission bandwidth.

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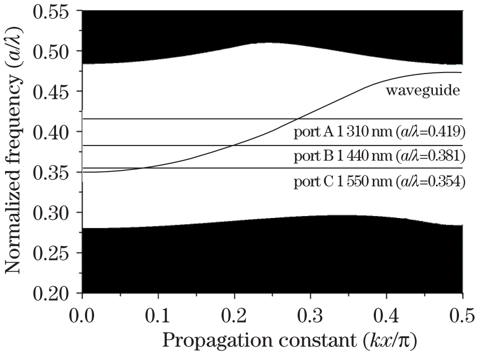

Fig. 4. Dispersion curves for the waveguide and the resonant cavity de-multiplexer.

Table 1. Peak Value of the Transmission of Ports A, B and C

Port	1 310 nm	1 440 nm	1 550 nm
A	95.9%	0	1.1%
B	0	95.4%	0
C	0	0	98.9%

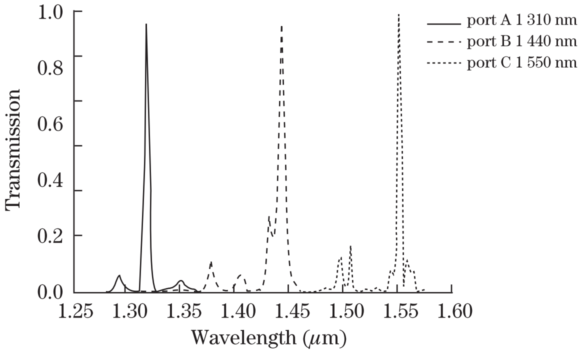

Fig. 5. Wavelength response of the structure. The transmission spectra de-multiplexer through port A is shown as solid line while ports B and C are shown as thin dotted lines.

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