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Directional coupler design based on coupled cavity waveguides in photonic crystals

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ABSTRACT

We propose a directional coupler design based on coupled cavity waveguide in photonic crystals. The plane wave expansion is used to give the dispersion of the coupled cavity waveguides and two parallel such waveguides. The couple length is got from the dispersion curves. Based on the research of the dispersion, we present a directional coupler and the transmission property is given. This structure is potentially important for highly efficient directional coupler in integrate optical circuit.

1. Introduction

Photonic crystals (PCs) [1,2] have attracted great interest because of the potential ability to control light propagation. The PCs has provided a new means for incredible properties due to the PBG. Many functional devices utilizing PCs have proposed and are expected to play an important role in future optical circuit. Compare to traditional PCs waveguides [3–7], a new type waveguide that comprises a periodic array of isolated structural elements called coupled cavity waveguides (CCW) [8–10] rendered special attention due to fantastic dispersion. The dispersion of the structure is narrow in the frequency domain and is in the neighborhood of the resonance frequency of the cavity. Correspondingly, light in a CCW propagates with small group velocity and group velocity dispersion (GVD) in the defect chain because of interactions between the neighboring evanescent cavities modes. The most features of CCW are the feasibility of tuning the central frequency of the CCW by modifying the cavities and 100% transmission of light through sharp bends over their entire bandwidth if the cavity modes have a proper symmetry.

Since a directional coupler (DC) [11] plays an important role in optical communication systems and can be used in wavelength de-multiplexing [12,13], optical switches [14] and optical filters [15], several theoretical and experimental studies have been carried out in recently. Furthermore, various designs of DC have been proposed to attain shorter coupling lengths and better performance. The coupling length of a DC composed of dielectric pillars in air can be reduced by decreasing the radii or the number of rows of dielectric rods separating transmission channels in the coupling region [16–18].

In this paper, we proposed a directional coupler design based on coupled cavities waveguide. The relationship between coupler length and the parameters of the structures is given. Based on the structures we investigate, a 2×2 optical switching is proposed. The plane wave expansion (PWE) is employed to investigate the dispersion of the DC and the finite difference time domain (FDTD) is used to simulate the distribution of the filed. The total length of the coupling length is $8a$.

2. Description of the design system and principle of operation

A two dimensional PC composed of a square lattice of cylinders with refractive index of $n = 3.4$ (corresponding to the relative dielectric constant of InGaAsP-InP semi-conductor material system at a 1.55 μm wavelength) in vacuum is considered. The radius of cylinders is $R = 0.18a$, where a is the lattice constant of the PC. For TM polarization (electric field parallel of the cylinders), which has widen band-gap in the normalized frequency rang from $a/\lambda = 0.3042$ to $a/\lambda = 0.444$ (λ is the wavelength in free space), the plane wave expansion method is used to calculated the band-gap.

A coupled cavities waveguide shown in Fig. 1(a) is constructed by removing line cavity with a unit cell comprising one missing

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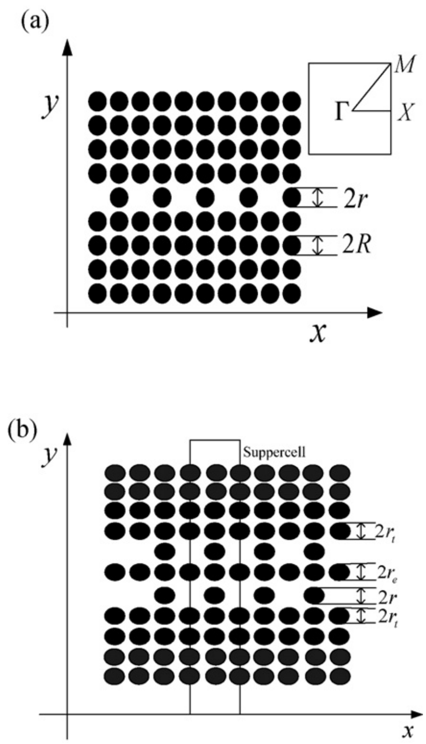

Fig. 1. (a) Schematic of an CCW with periodic r consisting of defect cavities embeded-ded in a 2D square lattice photonic crystals straight waveguide with R, the insert is the first Brillouin zone. (b) PCs DC structure used in the calculations. Radius (edge) = r_t, radius (defect) = r, radius (center) = r_e.

cylinder with one spacer hole. To create the waveguide directional coupler, two such parallel waveguides are set along the ΓX direction which is shown in Fig. 1(b). The parameters are shown in the Fig. 1. The dispersion of Fig. 1(a) for difference r is shown in Fig. 2.

The whole structure is simulated using the plane expansion method. Fig. 2 shows the dispersion relation of the CCW guided modes of the proposed structure inside the PBG for different r. It is observed that the parameter of the defect can effect on the dispersion of the structure. The low group velocity and GVD can be obtained. From the literature of the direction coupler, we know that the low group can enhance the interaction of the two waveguides and the couple length can be reduced. Next we would investigate the properties of the DC make up of this kind of CCW.

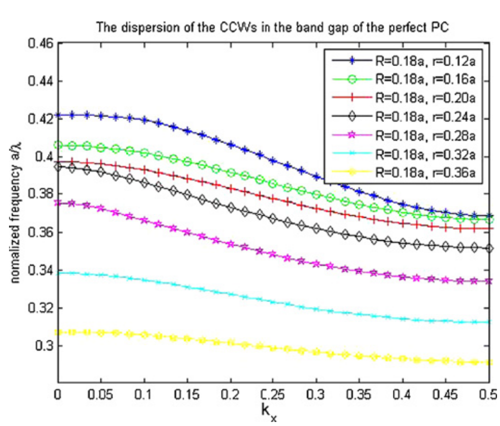

Fig. 2. Dispersion relation of the TM CCW guided modes of the proposed 2D PCs shown in Fig. 1(a) for different r.

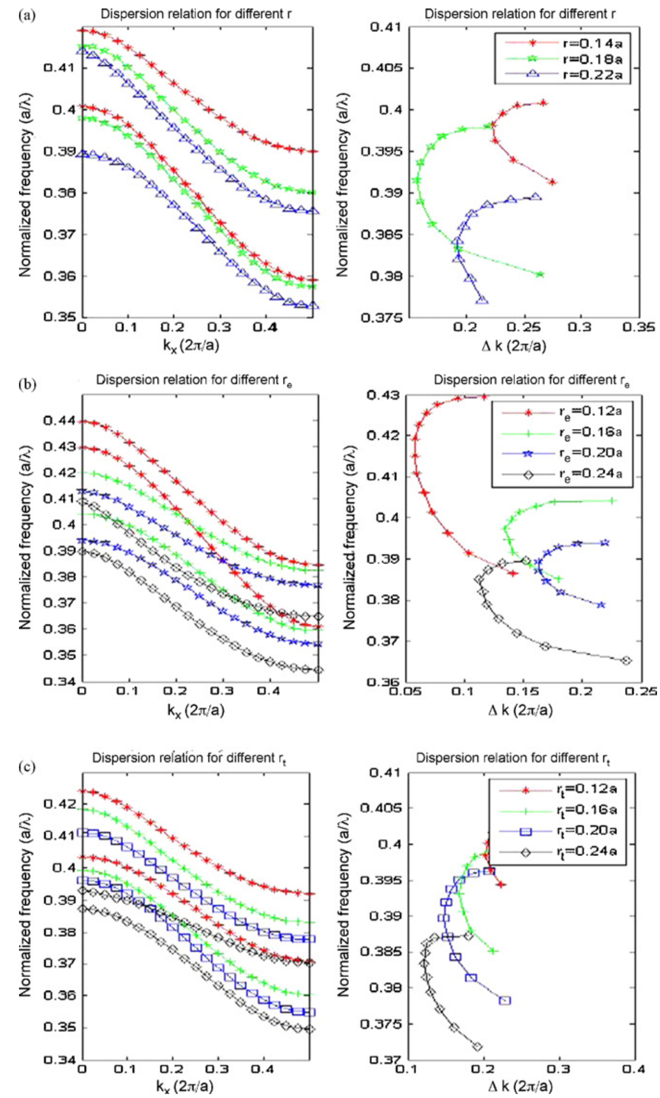

Fig. 3. PWE simulations results of the dispersion and Δk for different parameters of the structure we proposed.

Left column of Fig. 3 shows dispersion relation for even and odd. Due to the presence of the DC shown in Fig. 1(a), the even mode further splits into even–odd and even–even modes. In order to maintain the single mode condition, the dispersion for $r \in (0.14a, 0.22a)$, $r_e \in (0.12a, 0.24a)$ and $r_t \in (0.12a, 0.24a)$ is given. The dispersion of odd and even modes always appear in pairs. The distribution of electric field is simulated by FDTD method, hereafter we get that the up one is even–even modes and the other is even–odd modes. In the left column of Fig. 3, by decreasing the radii of the dielectric cylinders next to the waveguides and defect cylinders, the dispersion curves of both even–odd and even–even modes shift up. The difference of wave numbers is shown in the right of Fig. 3(b) for the two modes at the frequency of interest. These modes, named even–odd and even–even have difference propagation constants for every frequency, as the mismatch between the propagation constants of both modes is large, the coupling length, defined as $L_c = 2\pi/\Delta k$, can become significantly small, and the coupling length can be very large. From right of Fig. 3(a) and (b), we get the Δk larger, even for r and r_e smaller or larger than 0.18a. This is significantly because of the mismatch of the electric field propagate constant. In Fig. 3(c), with r_t decreasing, Δk becomes larger in particular frequency range.