A waveguide reflector based on hybrid one-dimensional photonic crystal waveguides with a semi-cylinder defect

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Abstract: A hybrid one-dimensional photonic crystal waveguide—a slab waveguide surrounded by one-dimensional photonic crystal with omnidirectional reflection bands, is presented; the transmission/reflection characteristics of the hybrid waveguides with a semi-cylinder defect are investigated by numerical simulation. Calculated results indicate that, as long as the semi-cylinder radius is appropriately adjusted, the high reflectance of 96.7%, nearly zero transmittance and low loss of 3% can be observed. The hybrid waveguide with a semi-cylinder defect can be used as a waveguide reflector. The simple and compact waveguide reflector is expected to be applied to highly dense photonic integrated circuits after further research.

OCIS codes: (130.3120) Integrated optics devices; (130.5296) Photonic crystal waveguides

References and links

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1. Introduction

In a bulk two-dimensional photonic crystal (2D PC), if the radii of a row of rods/holes are adjusted, a line-defect two-dimensional photonic crystal waveguide (2D PCW) can be formed, and light is confined within and transmitted along the defect channel by photonic band gaps (PBGs). However, there is the flat band edge of defect modes due to periodicity along the guided-wave direction, so the guided-wave band available is usually narrow. To obtain a larger guided-wave bandwidth, through a row of rods/holes in defect channel replaced by a

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slab waveguide (SW), a hybrid 2D PCW is proposed [1]. The hybrid 2D PCW has a large enough bandwidth of guided-wave mode. The dispersion curves of hybrid 2D PCW are close to those of SW, so the 2D PC surrounding SW is only regarded as a perturbation [2]. However, the existence of PBGs can effectively inhibit scattering loss from surface roughness caused by manufacture in SW [3].

The omnidirectional reflection bands (OFBs) of one-dimensional photonic crystals (1D PCs) is presented [4]; both dielectric mirrors [5] and Bragg fibers [6,7] based on OFBs have already been manufactured. Recently, a one-dimensional photonic crystal waveguide (1D PCW) is proposed [8,9], and light can be confined within and transmitted along defect channel full of air by OFBs.

Inspired by these points, a hybrid 1D PCW is proposed in this paper, and its dispersion characteristics are studied. The transmission/reflection characteristics of hybrid 1D PCW with a semi-cylinder defect are investigated, and a simple and compact waveguide reflector is constructed. These numerically computed results are discussed and some important conclusions are drawn.

2. Waveguide structures and their dispersion characteristics

Fig. 1(a) is a schematic drawing of symmetrical SW; the refractive index of its clad and core are n_0 and n_2, respectively; its core width is h. If the SW is surrounded by 1D PC with OFBs, a hybrid 1D PCW is formed, as shown in Fig. 1(b), where h_0 is the total width of defect channel. 1D PC consists of alternating layers of material with different index/width: n_1/h_1 and n_2/h_2, where is $h_1 + h_2 = a$, and a is lattice constant. Here, take $n_0 = 1$ (air), $n_1 = 1.6$ (polystyrene), $n_2 = 4.6$ (tellurium), $h_0 = 1.75a$, $h_1 = 0.75a$ and $h_2 = 0.25a$.

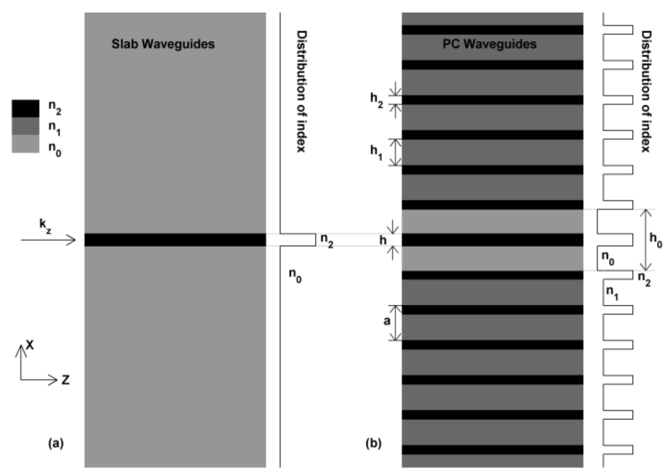

Fig. 1. (a). A schematic drawing of symmetric slab waveguides; the index and width of waveguide core is n_2 and h, respectively; the index of clad is n_0. (b) A schematic drawing of hybrid one-dimensional photonic crystal waveguide—a slab waveguide surrounded by one-dimensional photonic crystals; One-dimensional photonic crystal consists of alternating layers of material with different index/width: n_1/h_1 and n_2/h_2, where is $h_1 + h_2 = a$, and a is lattice constant. h_0 is the total width of defect channel.

When a light beam is incident into a periodical multilayer stack with alternative indices of n_2-n_1-n_2-n_1-n_2-n_1……from a medium with a lower index n_0 ($n_0<n_1<n_2$), the omnidirectional reflection will occur [4,5]. For the parameters used in this paper, the frequency range of OFB for TE modes, 0.151-0.282 [$\omega a/2\pi c$], is marked in Fig. 2. In the following studies on dispersion and transmission characteristics of the hybrid 1D PCW, the frequency range is focused on, and the influence of OFB on SW is considered.

As an example for TE modes, the dispersion curves of SW and hybrid 1D PCW are calculated by using plane wave expansion method based on a super-cell [10]. The results for

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h = 0.15a and 0.35a are shown in Fig. 2, respectively. It can be seen that, in frequency range less than 0.282 [$\omega a/2\pi c$], there is only zero-order TE mode (TE_0) in the two waveguides; TE0 mode difference between the two waveguides with identical h is decreasing with the increase of frequency, because the light confinement in SW is stronger and stronger, and the influence of 1D PC on isolated SW is smaller and smaller. Figs. 3(a), 3(b), 3(c) and 3(d) are E_y field distributions at A, B, C and D points of the dispersion curves in Fig. 2, respectively. It can be observed that Ey difference between A (PCW) and B (SW) points at the propagation constant 0.4 [$2\pi/a$] is obvious, while E_y difference between C (PCW) and D (SW) points at 0.9 [$2\pi/a$] is very little /negligible.

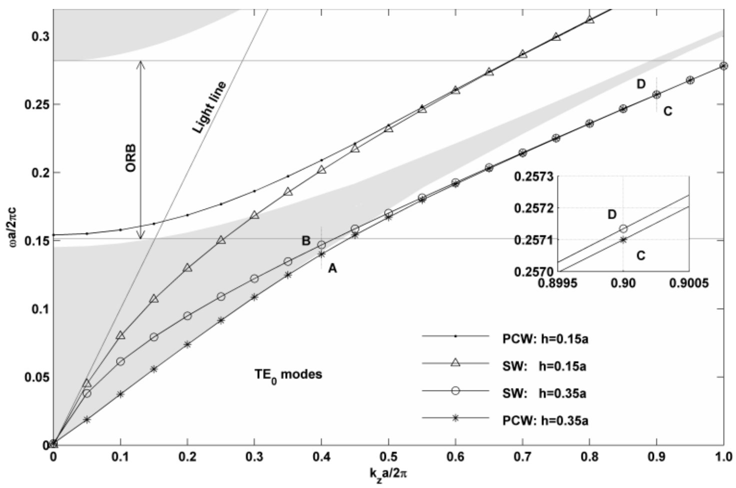

Fig. 2. The dispersion curves of TE_0 mode for slab waveguide (shown in Fig. 1(a)) and hybrid one-dimensional photonic crystal waveguide (shown in Fig. 1(b)) with h = 0.15a or 0.35a. Here, take n_0 = 1 (air), n_1 = 1.6 (polystyrene), n_2 = 4.6 (tellurium), h_0 = 1.75a, h_1 = 0.75a and h_2 = 0.25a.

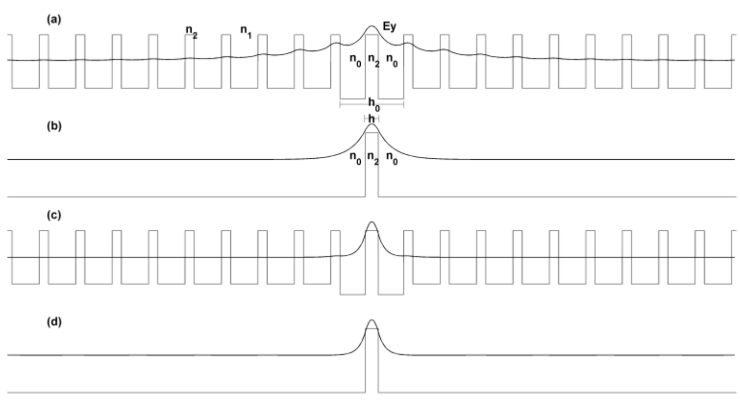

Fig. 3. The comparison of E_y field distribution between slab waveguide and hybrid one-dimensional photonic crystal waveguide with h = 0.35a; (a), (b), (c) and (d) are corresponding to A, B,C and D points in Fig. 2, respectively.

3. A semi-cylinder defect in hybrid one-dimensional photonic crystal waveguides

A semi-cylinder defect with radius r and index n_2 is introduced into a sidewall of the SW with h = 0.35a and that of the hybrid 1D PCW with h = 0.35a, as shown in Figs. 4(a) and 4(b), respectively. The influences of defect radius r on transmission characteristics of the two waveguides are studied by using definite-difference time-domain method [11].

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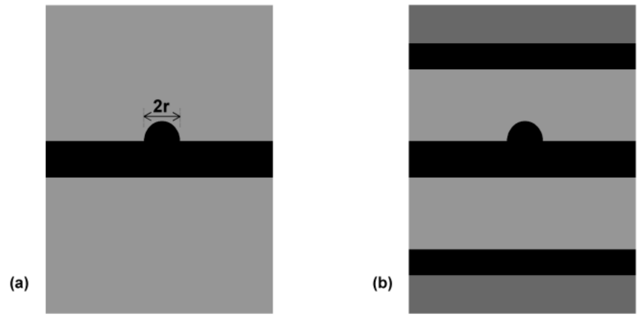

Fig. 4. A semi-cylinder defect with index n_2 and radius r is introduced into a sidewall of in slab waveguide core (a) and hybrid one-dimensional photonic crystal waveguide core (b), respectively.

For the SW with a semi-cylinder defect shown in Fig. 4(a), Figs. 5(a), 5(b), 5(c) and 5(d) are transmission(T), reflection (Γ) and loss spectra, corresponding to r = 0.19a, 0.21a, 0.29a and 0.34a, respectively. It can be seen that, with the increase of r, the transmittance is decreasing and the radiation loss is increasing, while the reflectance is always low. Furthermore, the valley frequency of transmittance spectrum exactly correspond the peak frequency of loss spectrum, and this means larger radiation loss will occur when there is a larger disturbance in a sidewall of SW.

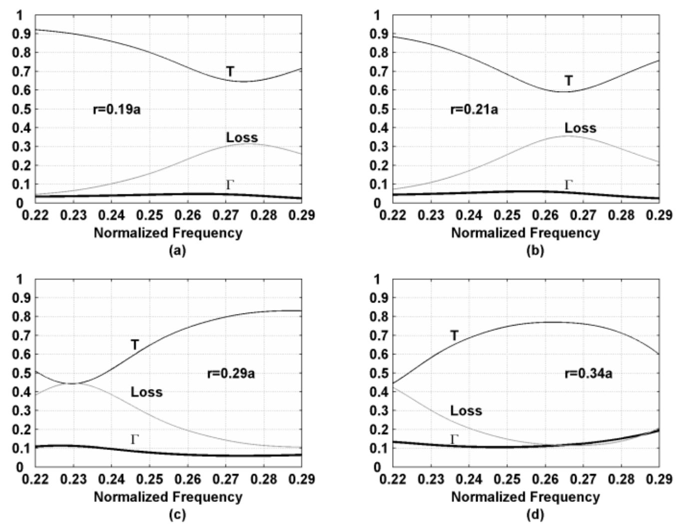

Fig. 5. For the slab waveguide with a semi-cylinder defect shown in Fig. 4(a), the influence of defect radius r on transmission (T), reflection (Γ) and loss spectra.

For the hybrid 1D PCW with a semi-cylinder defect shown in Fig. 4(b), Figs. 6(a), 6(b), 6(c) and 6(d) are transmission (T), reflection (Γ) and loss spectra, corresponding to r = 0.19a, 0.21a, 0.29a and 0.34a, respectively. It can be observed that there are a sharp transmission valley and a sharp reflection peak, and the minimum transmittance is always nearly zeros regardless of r, while the maximum reflectance is changed with r due to radiation loss. With the comparison between Fig. 5 and Fig. 6, it can be seen that the radiation loss is well inhibited by introducing 1D PCW with OFBs.

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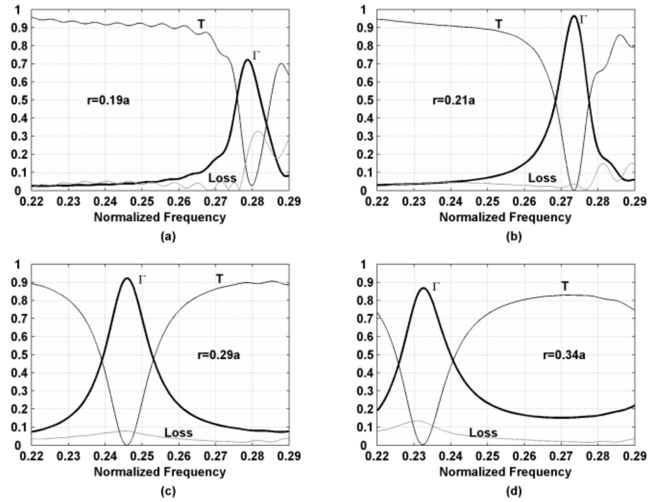

Fig. 6. For the hybrid one-dimensional photonic crystal waveguide with a semi-cylinder defect shown in Fig. 4(b), the influence of defect radius *r* on transmission (T), reflection (Γ) and loss spectra.

The relation curve between maximum reflectance and defect radius *r* is given in Fig. 7, where there is 0.967 of the maximum reflectance for $r = 0.21a$. According to Fig. 6(b), at reflection peak frequency 0.2734[c/a], radiation loss and transmittance are 0.03 and nearly zero, respectively.

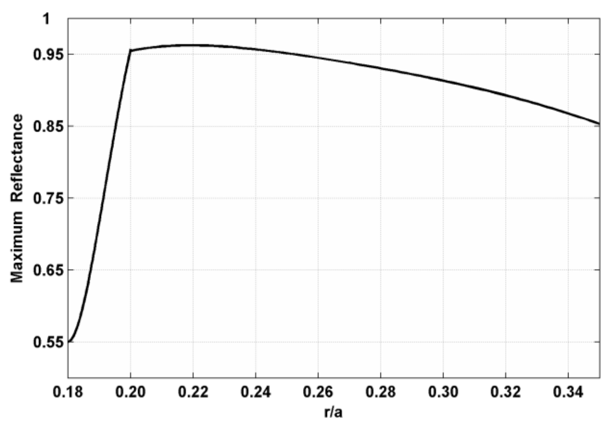

Fig. 7. The relation curve between maximum reflectance and defect radius *r*, for the defect waveguide shown in Fig. 4(b)

4. A waveguide reflector

Base on the reflection/transmission characteristics of hybrid 1D PCW with a semi-cylinder defect, a waveguide reflector is constructed and shown in Fig. 8(a). The waveguide reflector has good performances such as high reflectance, nearly zero transmittance and low loss. Moreover, the waveguide reflector is simple and compact: a semi-cylinder with appropriate radius can be located in any necessary position, only if its circular center is located at either sidewall of SW; the width of reflection layer on each side of SW is only 4*a*.

The distributions of E_y field component in the waveguide reflector with defect radius r = 0.21*a* at 0.2735 [*c/a*], is given in Fig. 8(b). If the optical communication wavelength of 1.55 μm is located at the frequency 0.2735 [*c/a*], the required lattice constant *a* is 0.4239 μm,

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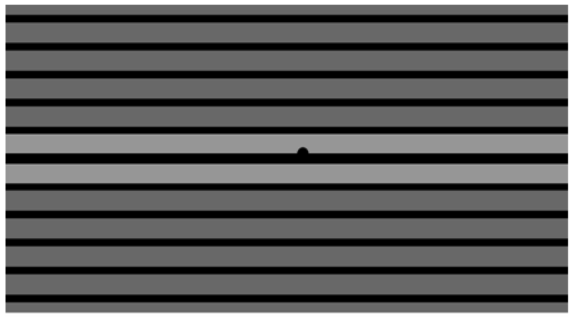
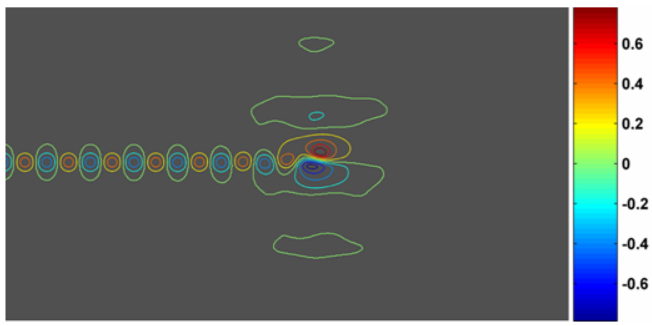
the radius of semi-cylinder *r* is 0.0890 µm, the width of waveguide core *h* is 0.1484 µm, the total width of device is 4.6629 µm.



(a)



(b)

Fig. 8. A schematic drawing of the waveguide reflector based on a semi-cylinder defect in hybrid one-dimensional photonic crystal waveguide; (b) the distributions of E_y field component in the waveguide reflector with r = 0.21*a* at 0.2735 [*c/a*].

5. Conclusions

A hybrid one-dimensional photonic crystal waveguide is presented, and this waveguide with a semi-cylindrical point defect can be used as a waveguide reflector, whose good performances such as high reflection, nearly zero transmission and low loss are demonstrated. The simple and compact waveguide reflector in flattened form will be studied further, and it is expected to be applied to highly dense photonic integrated circuits.

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