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Analysis of a Proposed Multi Channel Drop Photonic Crystal Filter by the FDTD

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ABSTRACT

We have derived the general condition to achieved 100% drop efficiency in the resonant tunneling-based channel drop filters of a three port system with reflection feedback. Based on these theoretical analysis, a six- channel drop filter and some other multi-channel filters are designed in two-dimensional photonic crystals (2D PCs) with square lattice of dielectric rods in air. The performance of the designed filter has been numerically calculated using the finite-difference time-domain (FDTD) method. In the designed filter, drop efficiencies larger than 95% in all channels have been achieved

KEYWORDS: photonic crystal. Channel drop filter, Photonic crystal multi/de multi planer FDTD method.

I. INTRODUCTION

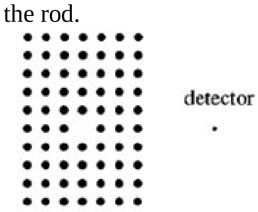
Channel drop filter plays a key role in the integration of photonic circuits. It is used in the area of optical communication and sensor systems. Various functional elements, such as, multiplexers, switches, and directional coupler can be realized by channel drop filters.

A range of energies which the photonic crystal does not allow photons to propagate, regardless of their direction and polarization is called a complete photonic band gap (PBG) [1]. If a defect is introduced to a perfect photonic crystal, a mode (or group of modes) may be appeared at a frequency (or several frequencies) within the PBG [2].

In this paper, the numerical methods for analysis and simulation of photonic crystals are reviewed. The wave propagation in photonic crystal cavities, waveguides and several channel add-drop filters are simulated by the two-dimensional (2D) finite difference time-domain (FDTD) method. The analysis areas are surrounded by the perfectly matched layer (PML) to simulate the unlimited analysis boundaries.

II. BAND GAP OF 2D-PC

The photonic crystal under study consists of a perfect array of infinitely long dielectric rods arranged in a square lattice. Each rod has a radius of 0.20a, where a is the lattice constant and a refractive index of 3.4, which is related to Si(Silicon). We investigated the propagation of electromagnetic fields in the plane normal to the rods. Since the rods have translational symmetry along their axes, the waves can be decoupled into two transversely polarized modes, of TE and TM. There is a large photonic band gap for the TM polarization between frequencies of 0.29 ($2\pi c/a$) and 0.42 ($2\pi c/a$). A defect is now introduced into the perfect array of rods. The defect can possess any shape or size; it can be made by changing the refractive index of a rod, modifying its radius, or removing a rod altogether. The defect could also be made by changing the index or the radius of several rods. Here we modify the radius of a single rod. The modes in the crystal are derived using a super cell approximation, which consists of placing a large crystal with a defect into a super cell and repeating it periodically in space. The considered super cell crystal contains 7×7 rows. We begin with a perfect crystal, where every rod has a radius of $0.2a$, and gradually reduce the radius of a single rod. Initially, the perturbation is too small to localize a mode in the crystal. When the radius reaches $0.15a$, a resonant mode appears in the vicinity of the defect. Since the defect involves removing dielectric material in the crystal, the mode appears at a frequency close to the lower edge of the band gap. As the radius of the rod is further reduced, the frequency of the resonance mode sweeps upward across the gap, and eventually reaches f=0.38c/a when the rod is completely removed. Figure 1 depicts the frequency of the mode for several values of the rod radius. The frequency of the mode can be tuned by simply adjusting the size of the rod.



(a)

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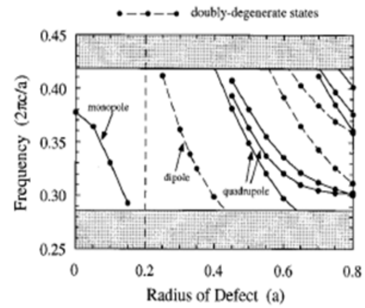
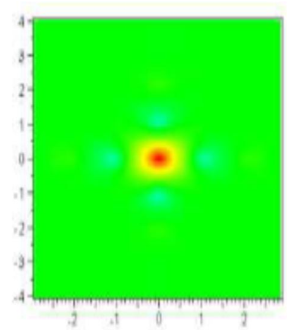


(b)

Figur. 1: Frequency of the defect states in an array of dielectric rods with radius 0.20*a*. The defect is introduced by changing the radius *R* of a single rod. The case where *R*=0.20*a* corresponds to a perfect array, while the case of *R*=0 corresponds to the removal of a rod. The shaded regions indicate the edges of the band gap.

The electric field distribution of the resonance mode is shown in Fig. 2(a) for the specific case which defect rod the radius is to 0.10a. The electric field is polarized along the axis of the rods and decays rapidly away from the defect. Since the field does not have a node in the azimuthally direction, it is labeled a monopole. Instead of reducing the size of a rod, it would also have been possible to increase its size. Again, starting from a perfect photonic crystal, we gradually increase the radius of a rod. When the radius reaches 0.25a, one doubly degenerate modes appear at the top of the gap. Since the defect involves adding material, the modes sweep downward across the gap as the radius increases. The modes eventually disappear into the continuum below the gap when the radius becomes larger than 0.40a (see Fig 1). The field distribution of the one doubly degenerate mode is shown in Figs 2(b) for the case where R= 0.33a. The modes are labeled dipoles since they have two nodes in the plane. By increasing the radius further, a large number of resonant modes can be created in the vicinity of the defect. This is shown again in Fig 1. Several modes appear at the top of the gap: first a quadruple, then another (no degenerate) quadruple, followed by a second-order monopole and two doubly degenerate hexa poles. These modes also sweep downward across the gap as the defect is increased. The modes are shown in Figs 2(c)–2(d) and 2(e) for the case which R = 0.60a.

A line defect within a photonic crystal can guide photons through the system. If the frequency of light lies within the PBG, it will be confined to the defect line, since propagation is forbidden through the rest of the photonic crystal. The advantage of such a system compared to the conventional optic- al fibers or waveguides is that in this case the light confinement does not rely on total internal reflection.



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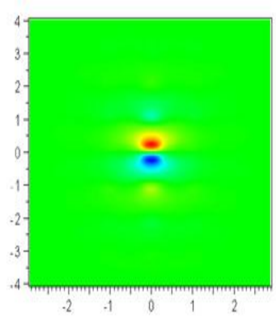

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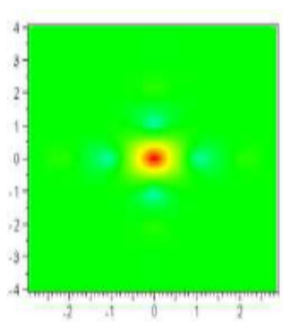
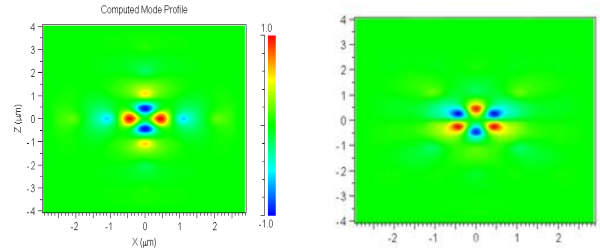


(c)



(d) (e)

Fig. 3: The electric field distributions of the defect modes for a square array of dielectric rods in the air. (a) Monopole, R=0.10a (b) Doubly degenerate dipoles, R=0.33a. (c) monopole, R=0.60a (d) Second-order, R=0.60a. and (e) Doubly degenerate hexapoles, R=0.60a.

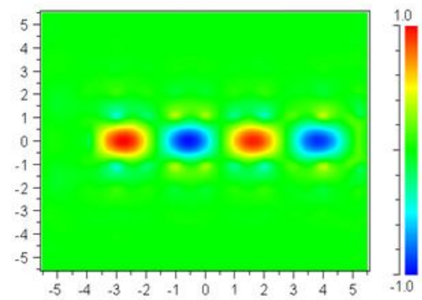
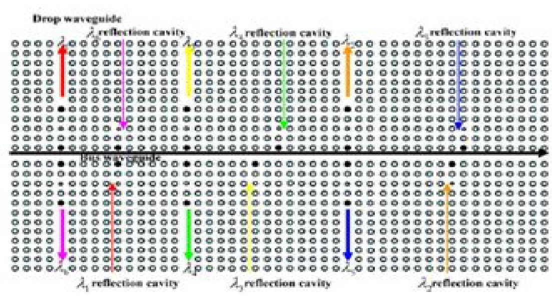


Fig. 4: Electric-field distribution of TE line defect (waveguide).

III. Six Channel Drop Filter

Fig.4(a) is the structure, the six drop channels are put on the two sides of bus waveguide, and corresponding wavelength selective reflection cavity are put on the other sides. The distance between the neighboring drop channel and reflection cavity should be 5a in order to avoid the coupling between them, where a is the lattice constant. As seen in Fig.4(b), channel drop efficiencies larger than 95% are achieved in all channels. If the lattice constant a is 542nm, the six channel- drop wavelengths from λ_1 to λ_6 are 16552, 1575, 1550, 1529, 1517, and 1468 nm, respectively , which cover the larger section of optical communication wavelength ranges.



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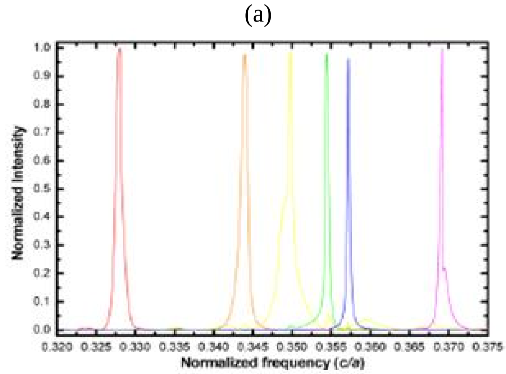

(b)

Fig. 4: (a) Schematic view of the proposed 5 channel drop filter, where channels are located on both sides of the bus waveguide the bus waveguide is terminated with another channel, in order to use the space more efficiently. The dielectric constant of all rods is 11.56. (b) Transmission spectrum of the proposed filter, which has been calculated using the 2D-FDTD method.

IV. CONCLUSION

In this paper, a channel drop filter, an important component in the optical wavelength division multiplexing (WDM) systems in a two dimensional photonic crystal has been proposed. Line defect waveguide and point defect cavities near a two dimensional photonic crystal the structure which can be used for the trapping and emission of photons, and perform as a six channel drop filter .also Based on the theoretical modeling, a six-channel drop filter with a simple structure has been designed.

The performance of the designed filter has been demonstrated by using the 2D FDTD method. It has been shown that for all channels in the designed filter, channel drop efficiencies higher than 96% have been achieved**.** In practical filters, the proposed structure should be realized in different forms, such as PC slabs, in which vertical confinement is provided and 3D calculation is required for design. In such practical structures, performance of the channel drop filter will be degraded by imperfect vertical confinement.

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