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Slow Light Properties of 2D Photonic Crystal Waveguide for Optical Storage in Optical Computers

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Key words: Photonic Crystal; Line-defect Waveguide; Guided Mode; Slow Light; Group Velocity Dispersion

Abstract. Slow light properties of the photonic crystal line-defect waveguide are researched with the plane wave expansion method. The structure of the waveguide is adjusted with several methods mentioned above at the same time and the slow light properties get better. For the structure of dielectric rods, central frequency and the group velocity of the guided modes decrease with the increase of the radii of the defected rods as well as the dielectric constant. Effects on the slow light from the change of the defected rods' position are also studied, through moving the rods up and down; we get the almost linear guide mode which has flat slow light curve and smaller group velocity. In a word, group velocity of the slow light is mainly affected by the radii and dielectric constant of the defected rods, and group velocity dispersion is decided by the change of the defected rods' location.

Introduction

All optical switching is the crucial support technology in the field of optical interconnection. During all the solutions for realizing the all optical switching, all optical storage is one of the most dominant schemes. All optical switching can temporarily storage the optical information to solve the congestion problem when multiple roads light signal routing. And it can distribute the light signal according to the need of information to light path. The existing all optical storage is general through the passive Fiber Delay Line (FDL) or active fiber loop to simulate the light storage function. However, the memory devices are large, obviously can't be used in On-Chip light exchange.

Photonic crystal [1-3] provides a better choice for people to design high performance all optical integration device. Photonic crystal is also called PBG materials, which cannot be through by the light of band frequency range. For the 2D photonic crystal, if introduce defects into it, light would be completely limited in the defect inside and go forward in the direction of the defects due to PBG exists on both sides of optical model. So as to form the photonic crystal defect waveguide, light cannot only efficient transmit in photonic crystal waveguide efficient transmission, because the photonic crystal structure of the internal waves produce Prague scattering effects, also makes the speed of light to slow, form the photonic crystal slow light [4-8]. Through optimizing design, the smaller volume memory device can be used to achieve the better Storage property.

Slow light properties of photonic crystal waveguide are general realized through line-defected waveguide or Coupled Cavity Waveguide, CCW. For the CCW structure, it is mainly through the feebleness coupling effects of adjacent micro cavity to achieve the slow light effect. Though this

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result is small, it also brings a lot of the group velocity dispersion, which is against the practical application. Although the speed of slow light group is smaller than CCW, after being optimizing design the defects and the nearby structural parameters, line defect waveguide of photonic crystal can get the smaller slow light result and ensure the group velocity dispersion is in the normal light signal transmission range. Based on the 2D photonic crystal defect waveguide line, this paper analyzes the waveguide slow light changes.

Slow Light Waveguide of 2D Air Hole-type Photonic Crystal

There are two types' 2D photonic crystals: air hole-type and dielectric cylinder type. Take the air hole-type 2D photonic crystal as the object of study firstly.

Photonic crystal waveguide, the light group velocity can be made by the media of dispersion curve, which is also called $\omega - k$ relation curve. As follows:

$$v_g = \frac{d\omega}{dk} = \frac{c}{n_g} \tag{1}$$

Second order group velocity dispersion (GVD) coefficient β_2 is seriously influence the waveguide transmission in a photonic crystal. And it would lead to pulses of light distortion before the wave. β_2 is given by the equation:

$$\beta_2 = \frac{d^2k}{d\omega^2} = \frac{dn_g}{d\omega}\frac{1}{c} = \frac{dn_g}{dk}\frac{1}{n_g} = \frac{d(1/v_g)}{dk}\frac{1}{v_g} \tag{2}$$

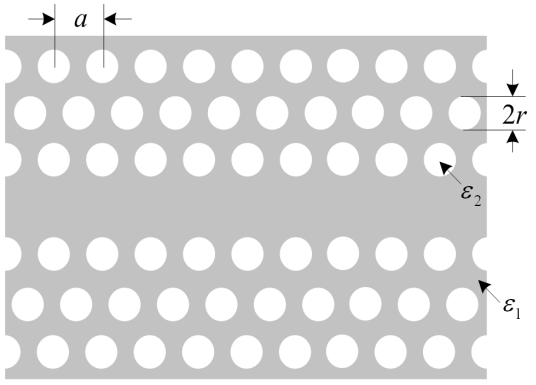
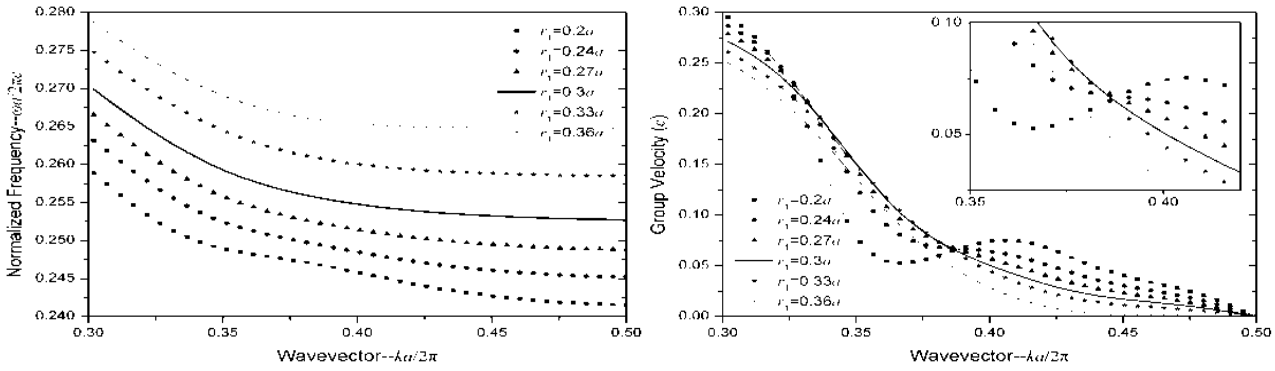


Fig.1. The structure of triangular lattice air hole-type photonic crystal.

The structure of triangular lattice air hole-type photonic crystals is as the figure 1. The equivalent refractive index of the background medium (corresponding to the typical a SOI flat structure) is 2.9; just as $\varepsilon_1 = 8.41$; dielectric coefficient of air $\varepsilon_1 = 1$; lattice constant is a; air hole radius is defined as r; line defect the triplex row which distribute on both sides to outside in the line defect is r_1,r_2,r_3. The several points, by using the plane wave expansion method for the numerical simulation, discuss effects which the defect waveguide structure makes on slow light.

Affects that Air Hole Defect Radius Takes on Slow Light. Firstly study on the effects Which Air Hole Defect Radius Makes on Slow Light. Suppose r = 0.3a, just change the size of the r_1, the changes of guide model can be given as figure 2.

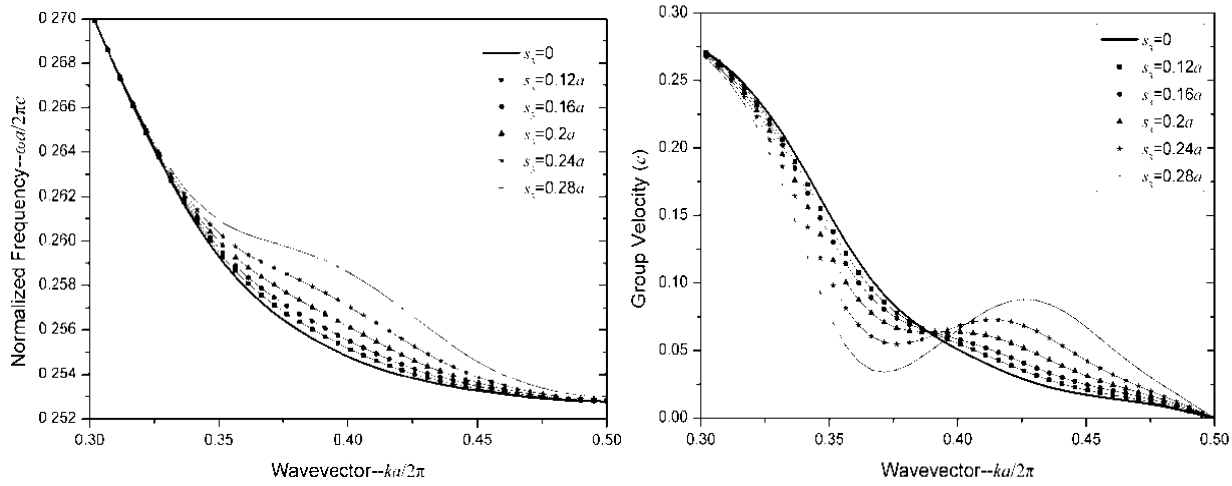


(a) (b)

Fig. 2. The changes of Photonic crystal waveguide corresponding (a) guide mode curve and (b) group of speed curve (Illustrations for slow flat area light amplification)

The present model of linear characteristics can be found in the figures. From equation (1), we can judge that this limits the group velocity value should be more smoothly and have little change. For all the speed of the model calculation can get figure 2. The conclusion can be given that GVD of slow light of flat area is smaller and the light signal transmission efficiency. However, we can see that, from compare, $r_1 <$ r structure than $r_1 >$ r structure are more likely to achieve slow light flat area. If just change the size of r_2, as the change of r_1, the guide model moves to the high frequency follows the increasing radius.

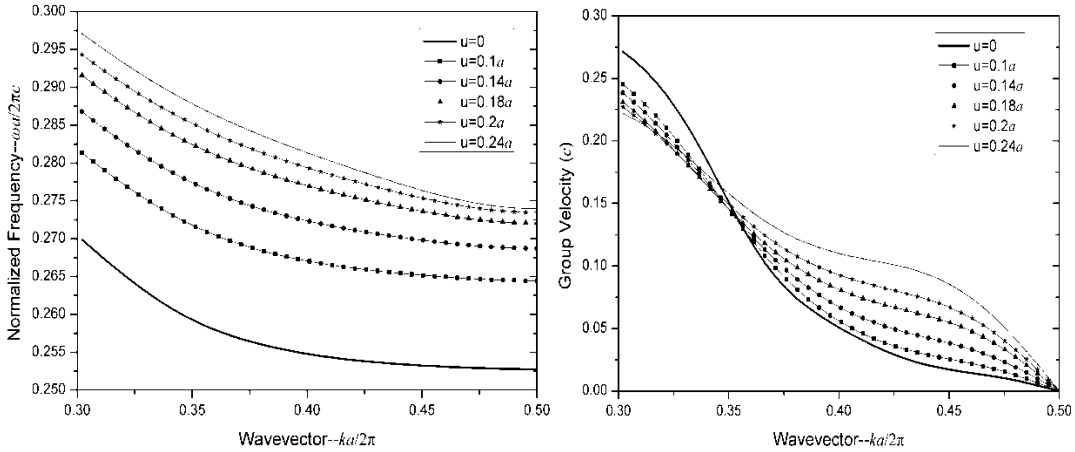
Affects Which Air Hole Left-right Movement Takes on Slow Light. The analysis of change slow light is through changing the position of air holes around the line defects. Firstly, define r_1, r_2, r_3's light translation amount as s_1,s_2,s_3. If $s_1 = r_1$, the guide mode frequency increases, while the group velocity reduces. When $s_2 = r_2$, the result is similar with r_1. And if $s_3 = r_3$, we can get the corresponding guide mode curve and group of speed curve respectively as shown in figure 3 (a), (b) as shown. Then we can get a conclusion that when s3= r3, effects which air hole left-right movement makes on slow light is more obvious, especially when s_3=0.2a, 0.24a, 0.28a.



(a) (b)

Affects Which Air Hole up-down Movement Takes on Slow Light. Line on both sides of the air hole defects will move up and down to slow light characteristics effect.

From calculation, we can get the result as figure 4: when r1=u, the frequency of guide model increases. When the wave vectors reach 0.35, the group velocity also increases. Curve of the flatness has been improved. However the change is not big.



(a) (b)

Fig.4. Guide mode curve and group speed curve of photonic crystal when air hole up-down movement

Combining with the above law, we can design a new photonic crystal slow light structure with better properties, as shown in figure 5. We can see that, if r1=0.2a, and adjust the right side movement as 0.2a, the group speed decline.

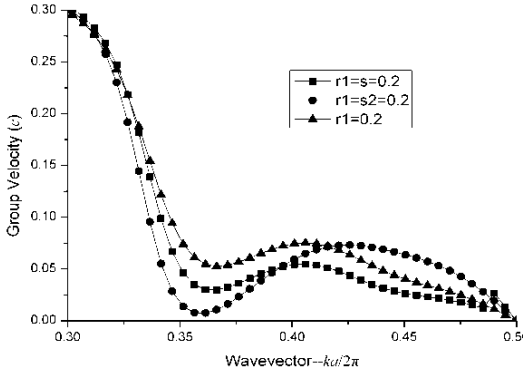
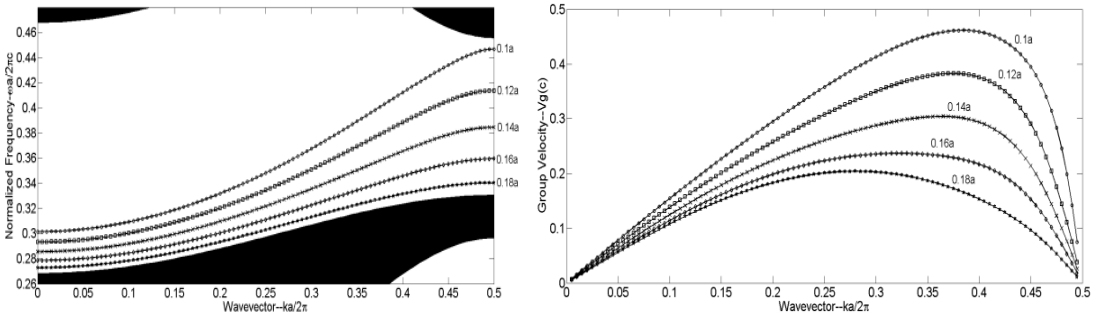


Fig.5. Group speed curve when the Air hole parameters mixed changes

Slow Light Waveguide of 2D Dielectric Cylinder Type Photonic Crystal

By using plane wave expansion method, the effects, which structure of dielectric cylinder type 2D photonic crystal change takes on the slow light, can be given. Set the lattice constant to be a; and the dielectric constant is 8.9; r=0.2a; the Defects column's radius dimension is rd.

Affects Which Defect Column the Radius Takes on Slow Light. When rd=0.1a/0.2a/0.12a/0.16a/0.18a, the guide model curve is as the figure 6 (a). It can be seen that, as the rd increases, the guide model moves down. And when rd=0.2, it is submerged in the conduction band. The guide model gradient is also becomes more and more small. According to the formula (1), guide model's group speed equals slope value of every spot. Therefore, when rd increases, guide model's group speed declines which is shown in the figure 4 (b).

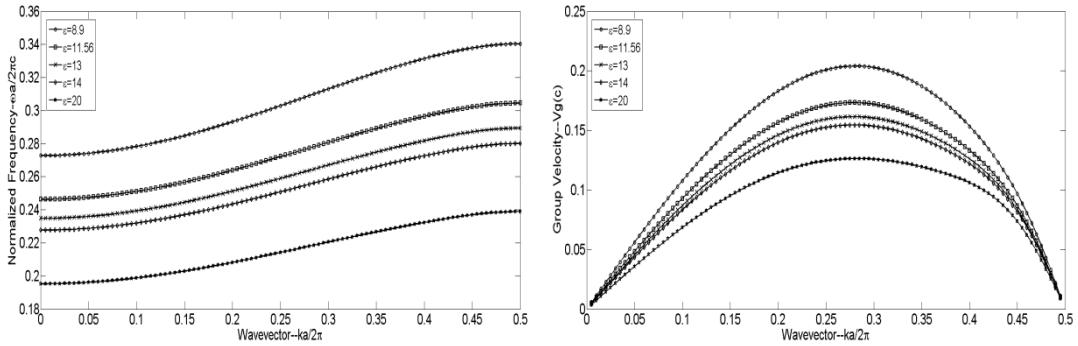


(a) (b)

Effects That Dielectric Constant of Defects Column Takes on Slow Light.

Set rd=0.18a, ε=8.9，11.56，13，14，20. The results are shown as the figure 7. From comparing, a conclusion can be given that when ε increases, just as to enlarge the dielectric constant, the guide model will moves down to the low frequency. Therefore, the group speed will decline.

From calculation, it can be found that when $\varepsilon = 20$; the guide mode has a smallest value of 0.126c. The guide model bandwidth, as well as the lattice constant, declines as the group speed.



(a) (b)

Fig. 7. (a) Guide model of line defect waveguide; (b) group speed changes as dielectric constant

Conclusion

This paper analyzes the slow light of line defect 2D photonic crystals. The structure of the waveguide is adjusted with several methods mentioned above at the same time and the slow light properties get better. For the structure of dielectric rods, central frequency and the group velocity of the guided modes decrease with the increase of the radii of the defected rods as well as the dielectric constant. Effects on the slow light from the change of the defected rods' position are also studied, through moving the rods up and down; we get the almost linear guide mode which has flat slow light curve and smaller group velocity.

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