The Designs of XOR Logic Gates based on Photonic Crystals

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ABSTRACT

All-optical logic gate based on photonic crystal waveguides is a promising technique in future high-speed all-optical signal processing. In this paper, we propose a XOR logic gate based on two dimensional triangular lattice photonic crystals composed of cylindrical silicon rods in air. The main structure of the device is a line defect asymmetric Y branch waveguide. It is expected that there should be a phase shift between the two input beams. Hence, if an appropriate initial phase is introduced, the two input beams may interfere constructively or destructively to realize the logical functions. The simulation results show that the proposed all-optical photonic crystal waveguide structure could really function as XOR logic gates. The interference section length and width of photonic crystal waveguide structure are optimized for achieving the optimal performance for the proposed XOR logic gates. This device is potentially applicable for photonic integrated circuits.

Keywords: logic gate, all-optical signal processing, photonic crystal, photonic integrated circuit

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1、INTRODUCTION

As the development of high-speed and high-capacity telecommunication systems, the demands for all-optical signal processing techniques are rapidly increasing[1-4]. All-optical logic gates are key elements in all-optical signal processing techniques such as addressing, switching, header recognition, data encoding, and encryption. So far, several schemes have been investigated to realize various all-optical logic functions[5-8]. These approaches have showed some advantages, but which are difficult to operate at very high speed data rate. The inevitable spontaneous emission noise affects the operation performance. In addition, logic implementation techniques are usually limited to mach-zehnder interferometer and fiber-based devices.

The all-optical exclusive-OR (XOR) is one of the common and basic logic operations required in data processing and label switching networks[9-10]. In addition, XOR gate together with other logic gates can construct advanced all-optical processing circuits, such as half-adder, full-adder, etc. [11]. Formerly, all-optical XOR gate was demonstrated using a nonlinear optical loop mirror. However, its bulky size and poor power efficiency hindered its practicality. In addition, it could be realized by utilizing cross-gain modulation and cross-polarization modulation in a semiconductor optical amplifier (SOA), at 10- and 5-Gb/s signal speeds, respectively. [12-14]. However, the data patterning effect in SOA always induced severe system degradations when the input signals were in on–off keying (OOK) format.

In recent years, photonic crystal based optical devices have attracted significant research efforts [15-16]. The ability to interact with light on a wavelength scale promises ultra-compact structures for optical integrated circuits. In photonic crystal waveguide devices, photons with wavelength within the bandgap cannot propagate through the crystal. Due to the periodic arrangement is destroyed so placing some defects in the crystal and it is possible to build a waveguide to guide light along certain path.

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Photonic crystal based optical logic gates are considered as key components in future photonic integrated circuits and such optical devices have attracted significant research efforts in recent years. However, most of the reported works were based on nonlinear optics [17-19], which suffered from certain fundamental limitations, such as power consumption and narrow operating frequency range. In this paper, we propose and discuss a XOR logic gate based on two dimensional triangular lattice photonic crystals composed of cylindrical silicon rods in air. The main structure of the device is a line-defect-induced asymmetric Y branch waveguide. The simulation results show that the proposed all-optical photonic crystal waveguide structure could really function as XOR logic gates. By appropriately choosing the interference section length and width of photonic crystal waveguide structure, the optimal performance for the proposed XOR logic gates is achieved.

2、OPERATION PRINCIPLE AND STRUCTURE ANALYSIS

In this paper, we propose a XOR logic gate based on two dimensional triangular lattice photonic crystals composed of cylindrical silicon rods as shown in Figure 1. The schematic diagram of the proposed XOR optical logic gate is shown in Figure 2. The main structure of the device is a line defect asymmetric Y branch waveguide. It is expected that there should be a phase shift between the two input beams. Hence, if an appropriate initial phase is introduced, the two input beams may interfere constructively or destructively to realize the logical functions.

To verify our conjecture, we consider a two dimensional triangular lattice photonic crystals composed of cylindrical silicon rods in air. The radius and the dielectric constant of the silicon rods are r = 0.35a and ε= 11.56, respectively, where a is the lattice constant. According to the band diagram of our structure as shown in Figure 3, the bandgap opens for the frequency range of 0.4447-0.5378(a/λ) for the ***E***-polarized mode (electric-field is parallel to the rod axes), where λ is the wavelength in free space. The width and the central width of bandgap are 0.093 and 0.491, respectively. The results are same in three ΓK, MK, and KΓ directions of the band diagram mentioned above. So, a line defect is created and the photons with wavelength within the bandgap can propogate along certain path.

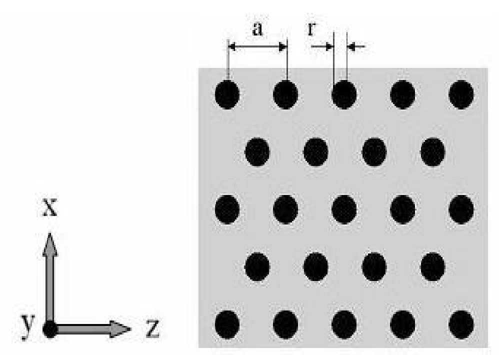


Figure 1、A array of two dimensional triangular lattice photonic crystal composed of cylindrical silicon rods in air, where r is the radius and a is the lattice constant of the silicon rods, respectively.

3、RESULTS AND DISCUSSIONS

The computational simulation is carried out by using a finite-difference time-domain (FDTD) method and an ***E***-polarized Gaussian wave with full width at half maximum 4a is used. A monochromatic wave of the frequency 0.491(a/λ) is launched into the photonic crystal device along the three ΓK, MK, and KΓ directions.

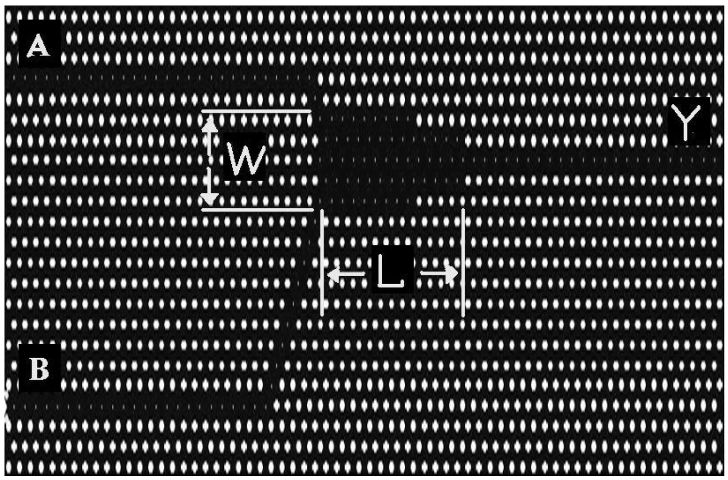


Figure 2、Schematic diagram of the proposed XOR optical logic gate.

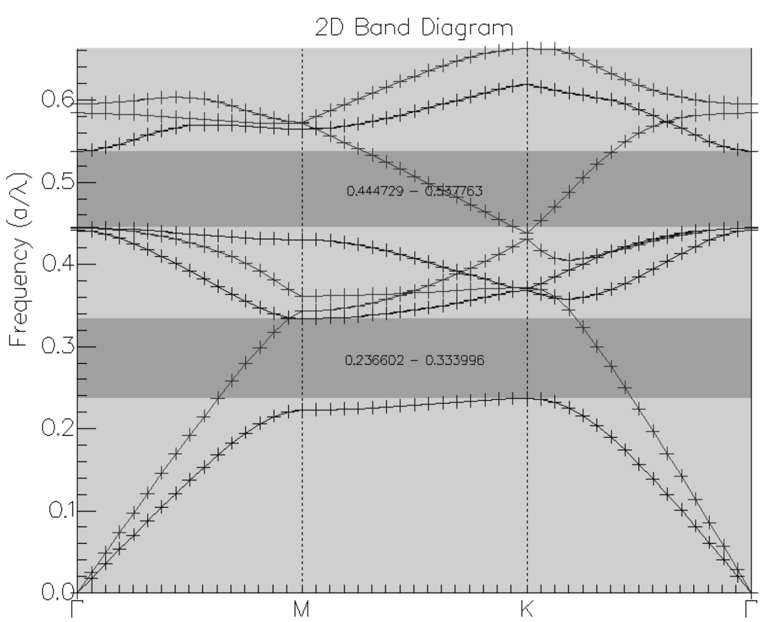


Figure 3、Band diagram of the photonic crystal structure for both E-polarized and H-polarized modes.

Table I shows the truth table for XOR logic gates. The logic 0 and 1 in the truth table indicate without and with input/output signal, respectively. From the computational simulation, it is clear that, whether the output signal of XOR is high (1) or low (0) depending on the two input signals indicated by the pairs (00), (01), (10), (11). The behavior of the XOR for input (01), (10) and (11) is shown in Figure 4, Figure 5 and Figure 6. In the frequency 0.491(a/λ), the output intensity for logic 1 is more than 90% of the input ones and the output intensity for logic 0 is less than 15% of the input ones. The simulation results show that the proposed all-optical photonic crystal waveguide structure could really function as XOR logic gates.

Table 1 Truth table for XOR logic gates.

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

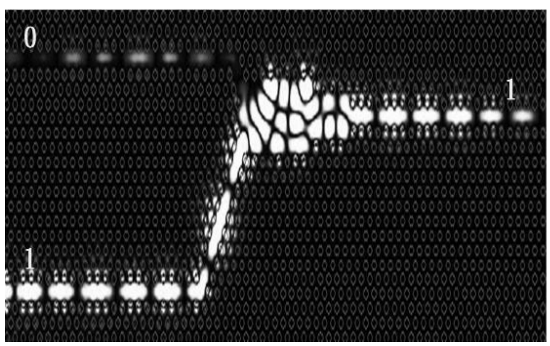


Figure 4、The behavior of the proposed XOR optical logic gate for input (0,1)

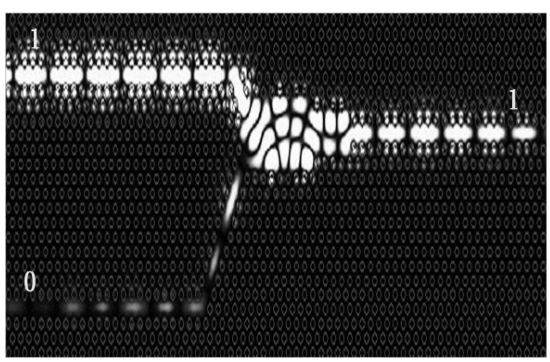


Figure 5、The behavior of the proposed XOR optical logic gate for input (1,0)

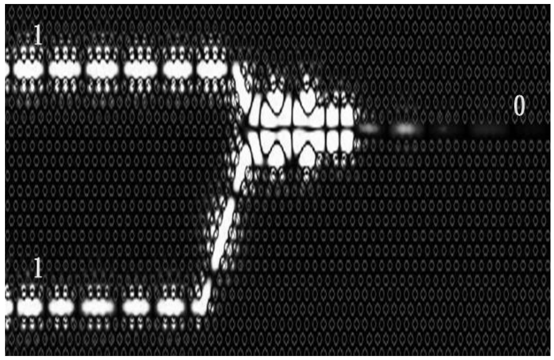
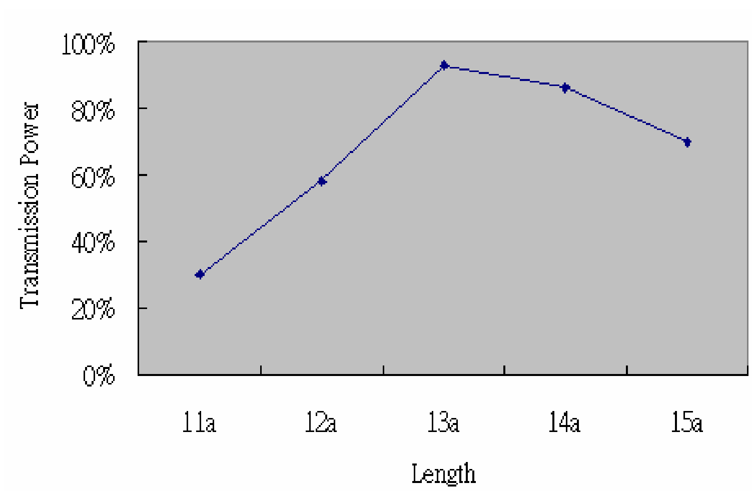
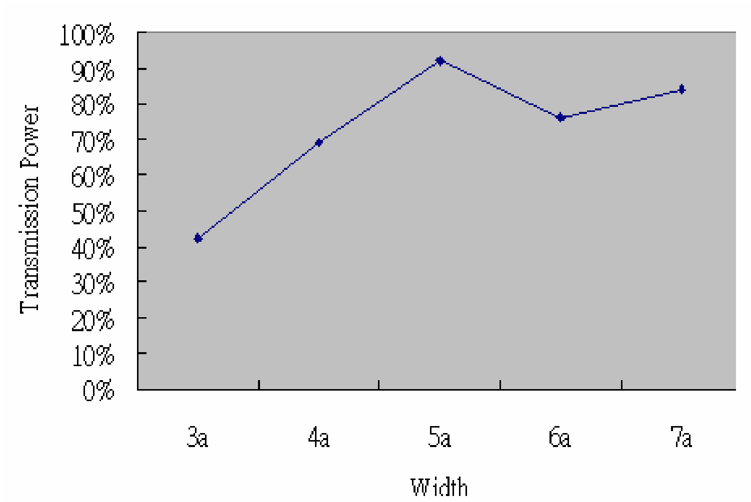


Figure 6、The behavior of the proposed XOR optical logic gate for input (1,1)

In order to achieve the optimal performance for the proposed XOR logic gates, the effect of interference section length(L) and width(W) of photonic crystal waveguide structure as shown in Figure 2 are investigated. Figure 7(a) and (b) plots the -factor for XOR logic gates as a function of the output transmission power for logic 1 signal under different interference section lengths and widths, respectively. It is found that there exists an optimized output transmission power value, more than 90% of the input ones, for a given waveguide length 13a and a given waveguide width 5a. Figure 8(a) and (b) plots the -factor for XOR logic gates as a function of the output transmission power for logic 0 signal under different interference section lengths and widths, respectively. It is found that there exists an optimized output transmission power value, less than 15% of the input ones, for a given waveguide length 13a and a given waveguide width 5a. It is obvious that the optimal interference section length and width of photonic crystal waveguide structure can be obtained.

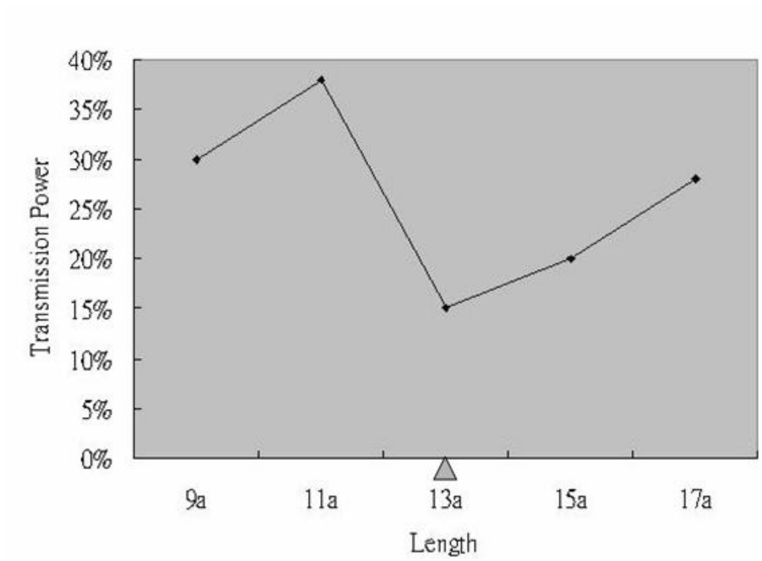


(a)

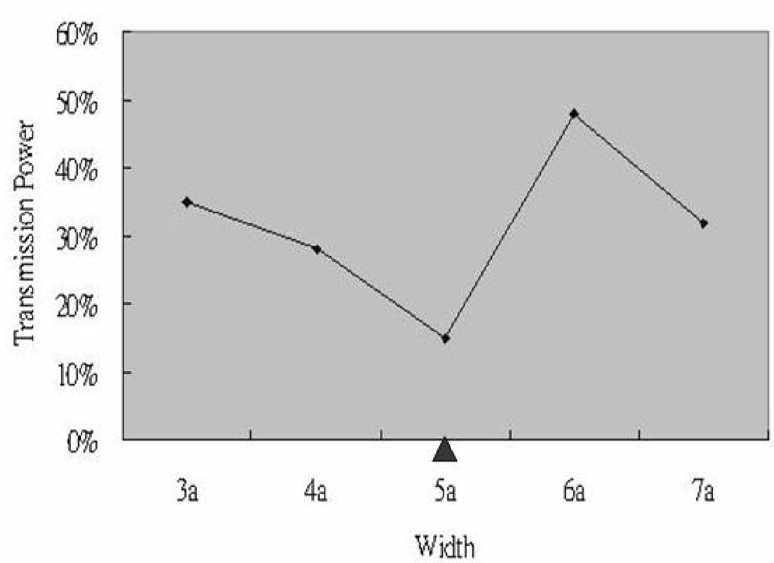


(b)

Figure 7、The -factor for XOR logic gates as a function of (a) the output transmission power for logic 1 signal under different interference section lengths and (b) the output transmission power for logic 1 signal under different interference section lengths widths.



(a)



(b)

Figure 8、The -factor for XOR logic gates as a function of (a) the output transmission power for logic 0 signal under different interference section lengths and (b) the output transmission power for logic 0 signal under different interference section lengths widths.

4、CONCLUSIONS

In this paper, a all-optical XOR gate based on two dimensional triangular lattice photonic crystals composed of cylindrical silicon rods in air has been proposed and demonstrated. The main structure of the device is a line defect asymmetric Y branch waveguide. The simulation results show that the proposed all-optical photonic crystal waveguide structure could really function as XOR logic gates. The interference section length and width of photonic crystal waveguide structure are optimized for achieving the optimal performance for the proposed XOR logic gates. The device sizes are expected to be drastically reduced to a scale of a few tens of micrometers and the device can constructe advanced all-optical processing circuits, such as half-adder, full-adder, etc.

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