The Designs of 4×2 Encoder Based on Photonic Crystals

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ABSTRACT

All-optical logic gate is a basic and crucial element for optical signal processing. In this paper, we propose a 4×2 encoder based on two dimensional triangular lattice photonic crystals composed of cylindrical silicon rods. The main structure of the device is a combination of both line defect Y branch and coupler photonic crystal waveguides. The computational simulation is carried out by using a finite-difference time-domain (FDTD) method. The simulation results show that the proposed all-optical photonic crystal waveguide structure could really function as a 4×2 encoder logic gate. In addition, the distance between coupler photonic crystal waveguides, the length of coupler waveguides and the distance between line defect Y branch waveguide structure are optimized for achieving the optimal performance for the proposed encoder logic gates. This device is potentially applicable for photonic integrated circuits.

Keywords: All-optical logic gate, encoder, photonic crystal

1. INTRODUCTION

As all-optical communication is the solution "electronic bottleneck" of the most fundamental way, all-optical telecommunication networks can greatly improve the node throughput capacity to adapt to future high-speed broadband communications requirements, so all-optical signal processing techniques are rapidly increasing [1-4]. All-optical logic gates are key elements in all-optical signal processing techniques, the use of photons to replace the electronics, which shows digital computing, information storage and processing, encryption and other functions. Much of the research reported in the literature has focused on performing various optoelectronic logic operations have been successfully completed recently. [5-8]. These approaches have showed some advantages, however, the foregoing approaches are difficult to operate at very high speed data rate. The inevitable spontaneous emission noise affects the operation performance. Furthermore, logic implementation techniques are usually limited to Mach-Zehnder interferometer and fiber-based devices. The 4×2 encoder together with other logic gates can create advanced all-optical processing circuits. The optical encoder can also be used in the optical mouse, and all-optical high-speed counting module of all-optical Programmable Logic Controller (PLC).

Photonic crystal (PhC) structures have been extensively studied recently [9-10]. In photonic crystal waveguide devices, photons with wavelength within the bandgap cannot propagate through the crystal, and destroy the periodic arrangement to make some defects in the crystal with possible to build a waveguide to guide light along certain path. It advantageous characteristics such as the device sizes are drastically reduced to a scale of a few tens of micrometers, curves angle, photorefractive materials selections, etc. Owing to the ability of photonic crystals (PhCs) to manipulate photons in the wavelength-dimension, various PhC devices such as micro-resonators [11-13], waveguides [14-15], channel-drop filters [16-20], and optical switches [21,22] have been developed as building blocks for integrated photonic systems. Furthermore, 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 [23-25], which suffered from certain fundamental limitations, such as power

Passive Components and Fiber-based Devices VI, edited by Perry P. Shum,
Proc. of SPIE-OSA-IEEE Asia Communications and Photonics, SPIE Vol. 7630,
76300I · © 2009 SPIE-OSA-IEEE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.852155

consumption and narrow operating frequency range. Base on the above reasons, in this paper, we propose an encoder 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 combination of both line defect Y branch and line defect coupler waveguides. Initial experimental results show that the proposed all-optical photonic crystal waveguide structure could really function as a 4×2 encoder logic gate.

2. OPERATION PRINCIPLE AND STRUCTURE ANALYSIS

In this paper, we propose an encoder 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 encoder optical logic gate is shown in Figure 2. The main structure of the device is a combination of both line defect Y branch and line defect coupler waveguides. It is expected that there should be several phase shift between these line defect input waveguide structures. Hence, if an appropriate initial phase is introduced, these light signals between these waveguide structures 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 $\varepsilon = 11.56$, 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 propagate along certain path.

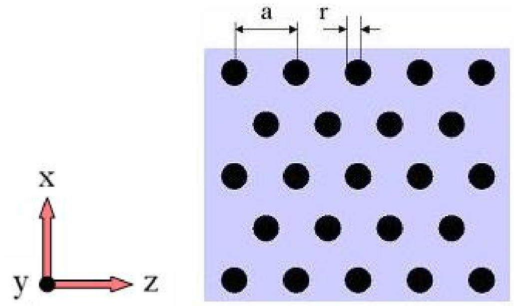


Figure 1 A array of two dimensional triangular lattice photonic crystal composed of cylindrical silicon rods in air, where r is the radius and a is the lattice constant of the silicon rods, respectively.

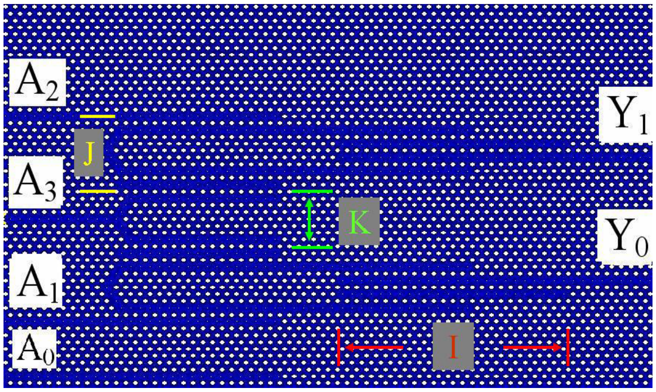


Figure 2 Schematic diagram of the proposed optical encoder, where J is the distance between coupler photonic crystal waveguides, I is the length of coupler waveguides and K is the distance between line defect Y branch waveguide structure, respectively.

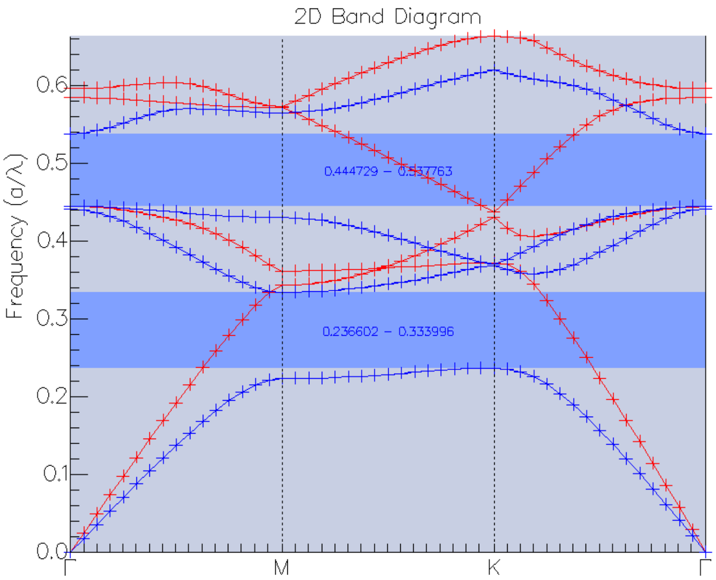


Figure 3 Band diagram of the photonic crystal structure for both E-polarized and H-polarized modes.

3. RESULT AND DISCUSSION

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.

Table 1 shows the truth table for our 4×2 encoder. 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 encoder is (00), (01), (10), (11) depending on the four input signals indicated by the pairs (0001), (0010), (0100), (1000). The behavior of the encoder for input (0010), (0100) and (1000) is shown in Figure 4, Figure 5, and Figure 6. In the frequency 0.491(*a/*λ), the intensity of output signal for logic 1 is above 90% of the input ones and the output intensity for logic 0 is below 5% of the input ones. The simulation results confirm our encoder can show their capabilities.

Table 1 Truth table for the 4×2.

INPUT				OUTPUT	
A_3	A_2	A_1	A_0	Y_1	Y_0
0	0	0	1	0	0
0	0	1	0	0	1
0	1	0	0	1	0
1	0	0	0	1	1

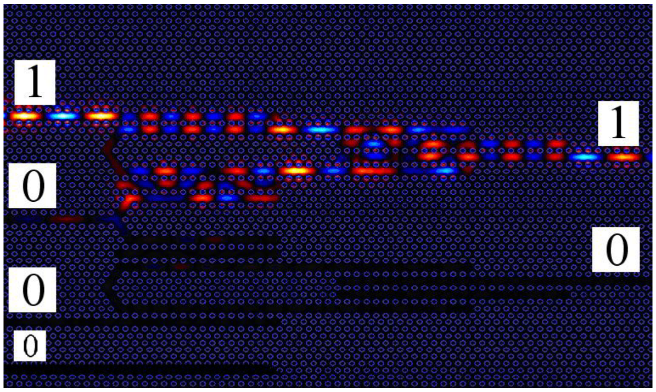


Figure 4 The behavior of the proposed 4×2 encoder for input (1000).

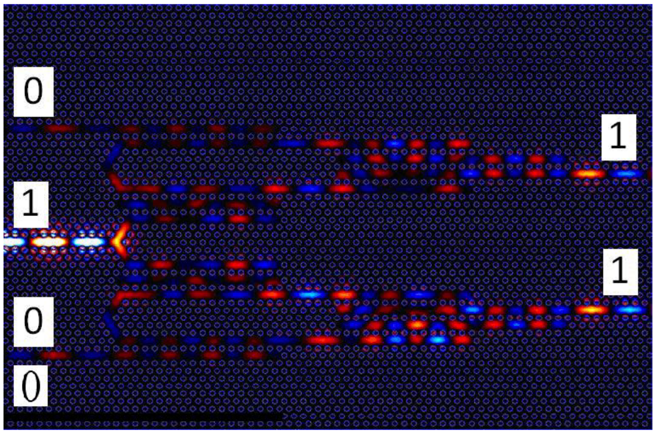


Figure 5 The behavior of the proposed 4×2 encoder for input (0100).

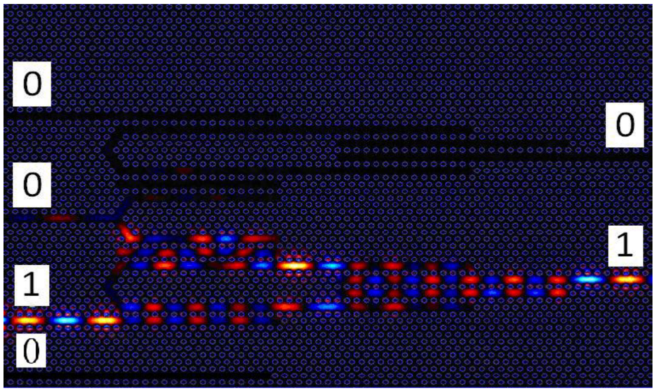
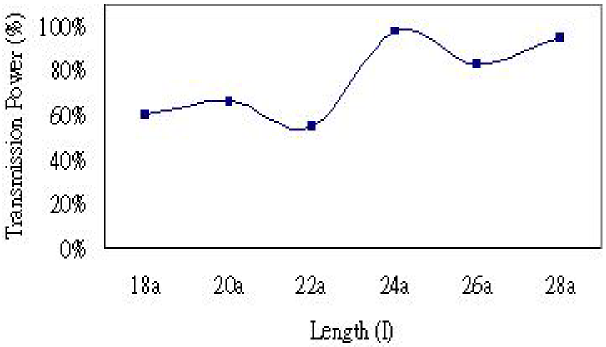
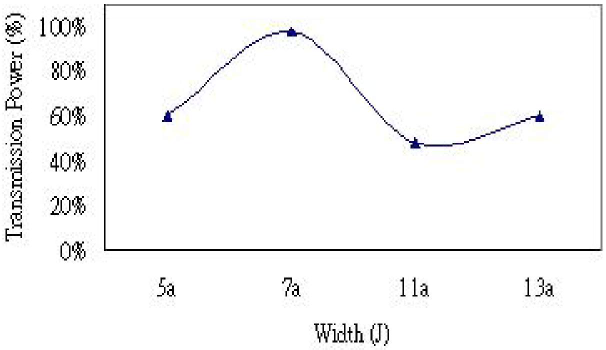


Figure 6 The behavior of the proposed 4×2 encoder for input (0010).

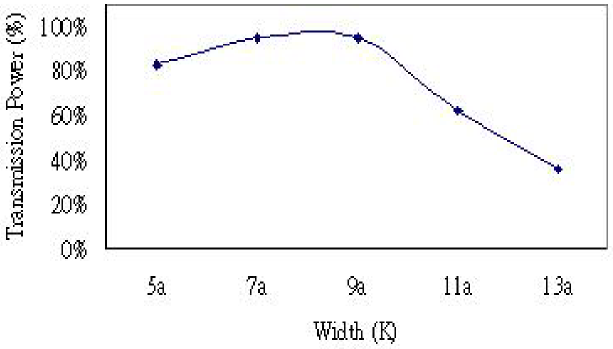
In order to achieve the optimal performance for the proposed encoder logic gates, the distance (J) between coupler photonic crystal waveguides, the length I of coupler waveguides and the distance K between line defect Y branch waveguide structure as shown in Figure 2 are optimized. Figure 7(a), 7(b) and 7(c) plots the factor for the proposed encoder as a function of the output transmission power under different length I of line defect coupler waveguides, different distance J between coupler photonic crystal waveguides, and different distance K between line defect Y branch waveguide structures, respectively. It is found that there exists an optimized output transmission power value, more than 90% and below 5% of the input ones, for a given waveguide length I equal to 24a, a given distance width J equal to 7a, and a given distance K equal to 8a, where a is the lattice constant of the silicon rods.



(a)



(b)



(c)

Figure 7、The factor for the proposed encoder as a function of the output transmission power under different (a)length I of line defect coupler waveguides, (b)different distance J between coupler photonic crystal waveguides, and (c)different distance K between line defect Y branch waveguide structures, respectively.

4. CONCLUSION

In this paper, a 4×2 encoder logic gate, based on the array of two dimensional triangular lattices photonic crystal composed of cylindrical silicon rods in air, is proposed and demonstrated. The main structure of the device is a combination of both line defect Y branch and coupler photonic crystal waveguides. The simulation results show that the proposed all-optical photonic crystal waveguide structure could really function as 4×2 encoder logic gates. Devices parameters are optimized for achieving the optimal performance for the proposed encoder logic gates. The proposed device has simple geometric structure and clear operating principle. The device sizes are expected to be drastically reduced to a scale of a few tens of micrometers and the device can be utilized to construct photonic integrated circuits systems in the future.

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