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A proposal for all optical decoder using PSK technique

A. MOVAHEDZADEH, A. ANDALIB*
Departement of Electrical Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran

In this paper we proposed an all optical decoder based on photonic crystals. Unlike most of the previous structures in this work we used a purely linear structure for creating the proposed optical decoder. This decoder works based on optical beam interference phenomena. Therefore it does not require any high power optical waves for implementing the logic operations. The rise time of the proposed structure is 0.2 ps.

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Keywords: Photonic crystals; Optical decoder, PSK, rise time

1. Introduction

Photonic crystals (PhCs) [1] are made of periodic arrangement of dielectric materials with different refractive indices. This periodic refractive index creates photonic band gap (PBG) regions inside the band structure diagram of these structures [2,3]. PBG helps PhCs to confine the optical waves [4]. PhCs can be used for designing a large variety of optical devices like filters [5–11], demultiplexers [12–18], logic gates [19–24], coders [25–32], adders [33–39], subtractors [40–42], comparators [43–46], multiplexers [47], and converters [48–52].

Optical decoders are one of the useful devices required for designing all optical digital systems. The first optical decoder was proposed by Serajmohammadi et al [53]. This structure was designed using a nonlinear ring resonator. The second structure which was a 2*4 decoder was proposed by Alipour-Banaei et al [54], using 3 nonlinear ring resonators. These structures required optical intensities as high as 1 kW/μm^2. Mehdizadeh et al [55] proposed another 2*4 decoder using 5 nonlinear ring resonators which requires optical intensities equal to 1 kW/μm^2. Daghooghi et al [56–59] presented similar structures for designing optical decoders too. They succeeded to reduce the working optical intensity down to 13 W/μm^2. The time delay of their structures was about 2 ps. Recently 3*8 optical decoder was proposed using 7 nonlinear ring resonators. For this structure the time delay was about 6 ps [60].

All of the above mentioned works are based on nonlinear resonators, which require high amounts of optical intensities for correct operation of the proposed structures. The other disadvantage of these structures is their very limited working wavelength. All of these works can only operate at a certain wavelength which is determined by the resonant mode of the resonators. In this paper we are going to design and propose an optical decoder without using any nonlinear resonators. Due to using purely linear structure the proposed decoder is not sensitive upon the variation of optical intensity and does not require high amount of optical intensities. The proposed structure operates based on optical beam inference, which recently has become popular for designing PhC based optical logics. Phase shift keying (PSK) technique is used for implementing the required logic operation. In this technique the initial phase of the input signals determine the logic state of the input ports, however the logic state of the output ports are determined based on the level of the optical signal at the output port.

2. Basic optical gates

For designing the proposed 1*2 optical decoder we require two basic optical gates namely an optical NOT gate and a buffer gate. The required structure are designed inside a 2D PhC structure made of Silicon rods inside air background. As we know the refractive index of Si is 3.46. The radius of these rods is 116 nm and the lattice constant of the overall structure is 580 nm. For such a PhC structure two PBGs are obtained at TM mode like Fig. 1. The main PBG is at 1380-2071 nm.

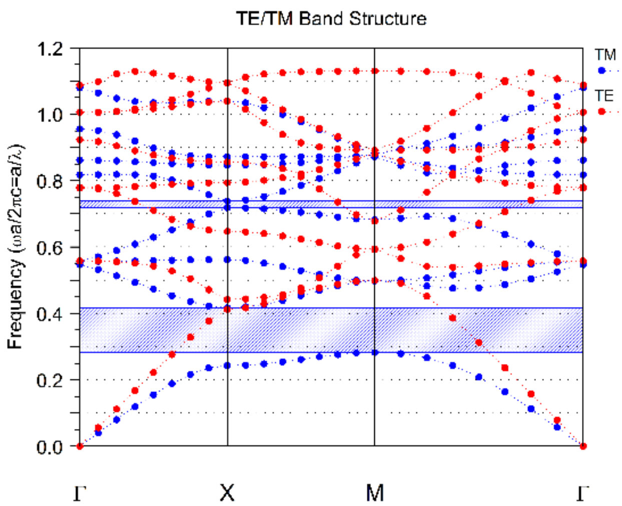
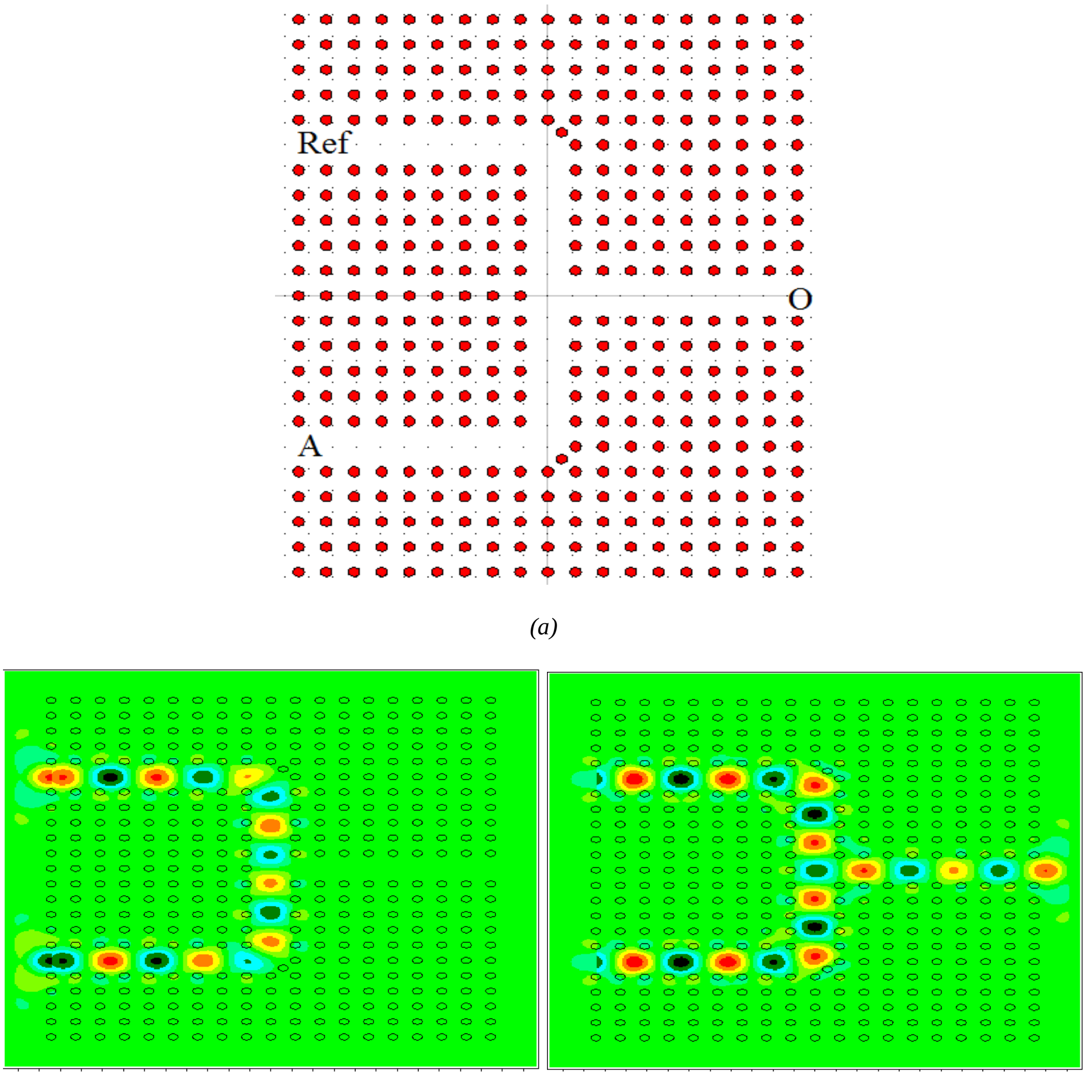


Fig. 1. The band structure diagram of the PhC (color online)

The first basic logic gate which designed before designing the final structure is an optical buffer. As far as we know an optical logic buffer is an optical gate which sends the value of input port directly to the output port. The optical buffer was designed using three optical waveguides, two input and one output waveguides. All of these waveguides were connected to each other at a certain joint point. Both input waveguides have the same lengths (Fig. 2a). In this structure the Ref is for the reference signal whose amplitude and initial phase are 0.5 and 0 respectively. Also A is the input port of the structure, whose amplitude is 0.5. The initial phase of A can be either 0 or 180 degrees for logic 1 and 0 respectively. When the initial phase of A is 180 degrees (i.e. A is at logic 0), the optical waves will have a destructive interference at the joint point of the waveguides, because they have a phase difference of 180 degrees when they reach this point. As a result no optical signals reach the output port so the output ports is OFF (Fig. 2b). When the initial phase of A is 0 degrees (i.e. A is at logic 1), the optical waves will have a constructive interference at the joint point of the waveguides, because they have similar phases when they reach this point. As a result optical signals with the amplitude of 1 can reach the output port so the output ports is ON (Fig. 2c).

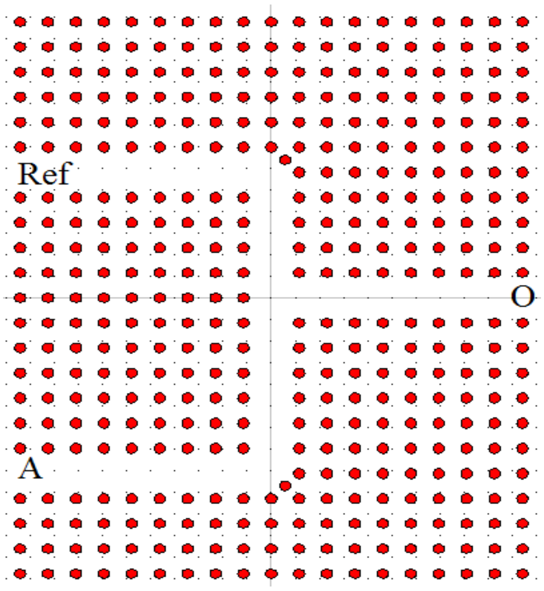


(a)

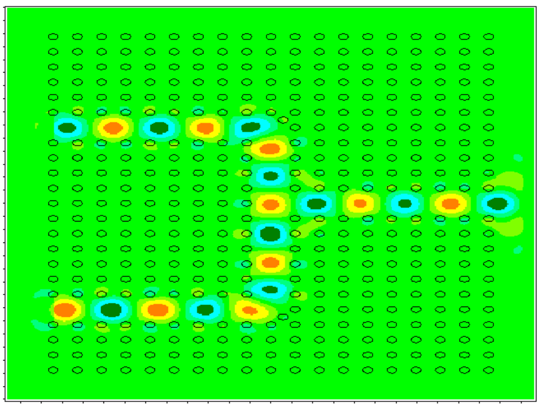
(b) *(c)*

Fig. 2. (a) The optical buffer and its optical behavior when A is at logic (b) 0 and (c) 1 (color online)

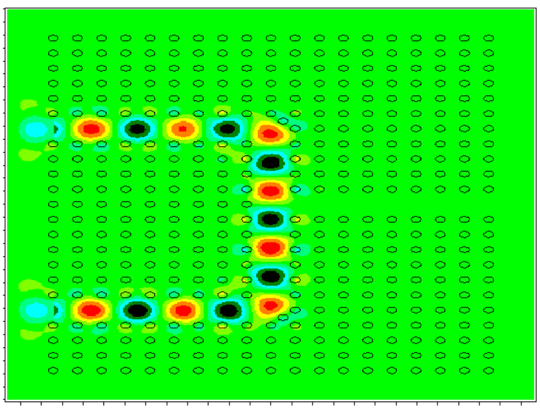
For designing the NOT gate we used a similar structure. The only difference is different lengths of the input waveguides connected to Ref and A ports of the structure (Fig. 3). Similar to the buffer structure amplitude and initial phase of Ref are 0.5 and 0 respectively. When the initial phase of A is 180 degrees (i.e. A is at logic 0), the optical waves will have a constructive interference at the joint point of the waveguides, because they have similar phases when they reach this point. As a result optical signals with the amplitude of 1 can reach the output port so the output ports is ON (Fig. 3b). When the initial phase of A is 0 degrees (i.e. A is at logic 1), the optical waves will have a destructive interference at the joint point of the waveguides, because they have a phase difference of 180 degrees when they reach this point. As a result no optical signals reach the output port so the output ports is OFF (Fig. 3c).



(a)



(b)



(c)

Fig. 3. (a) The optical NOT and its optical behavior when A is at logic (b) 0 and (c) 1 (color online)

3. Optical decoder

Finally by combining the basic gates the final structure was realized like Fig. 4. The proposed structure consists of 3 input and 2 output waveguides. The input waveguides were labeled as W1, W2 and W3 also the output waveguides were labeled as W4 and W5. W1, W2 and W4 are connected to each other at J1. Similarly W2, W3 and W5 are connected to each other at J2. The length of W1 and W2 are different but W2 and W3 have the same length. Ref1 and Ref2 are for the reference signals of the structure and A is for the logic input of the proposed decoder. The output ports are shown with O0 and O1.

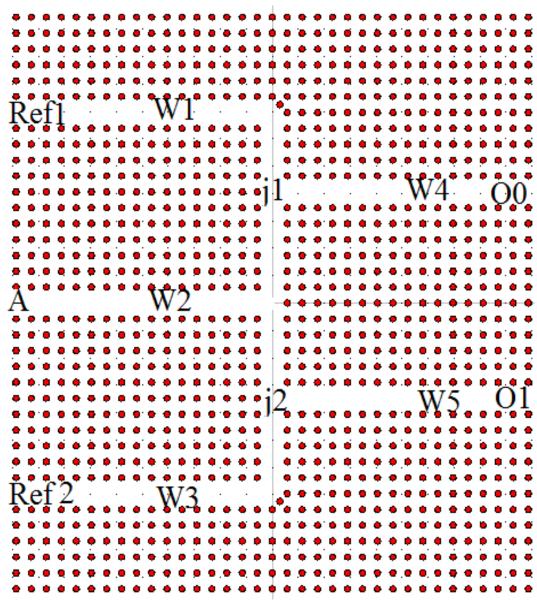
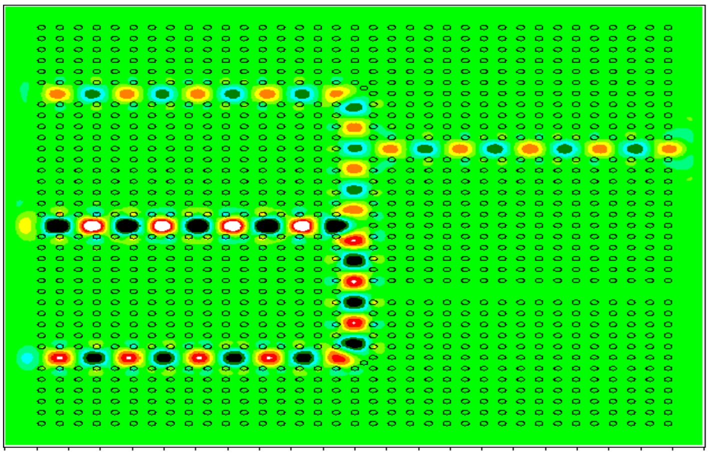
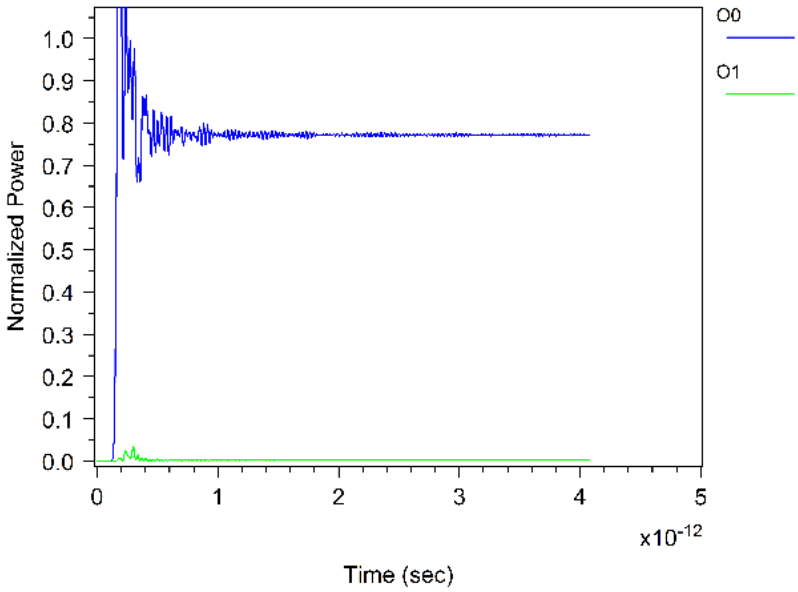


Fig. 4. The proposed optical decoder (color online)

The optical signal launched at Ref1 and Ref2 have similar phase and amplitude, which are 0.5 and 0 degrees respectively. A is the input port of the structure, whose amplitude is 1. The initial phase of A can be either 0 or 180 degrees for logic 1 and 0 respectively. One part of the optical waves coming from A propagates toward J1 and the other part propagates toward J2. When the initial phase of A is at 180 degrees (i.e. A is at logic 0), there will be constructive and destructive interferences at J1 and J2 respectively. As a result the amplitude of the optical waves coming from A will be added to the amplitude of the optical waves coming from Ref1 and O0 will be ON. But the optical waves coming from A and Ref2 will cancel each other and O1 will be OFF (Fig. 5a). In this case the amount of normalized power at O0 and O1 will be 75% and 2% respectively. Also the rise time for O0 is about 0.2 ps (Fig. 5b).



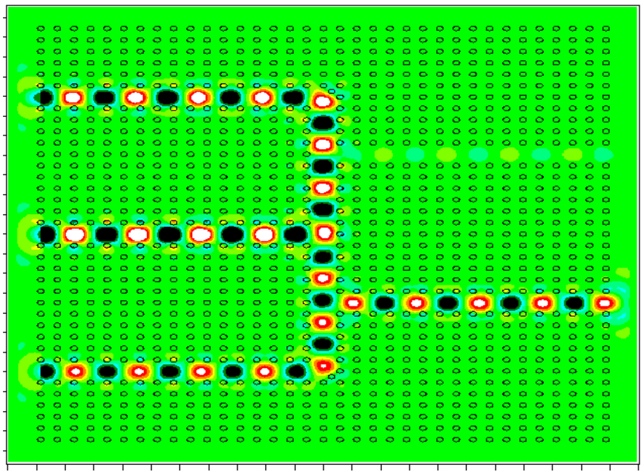
(a)



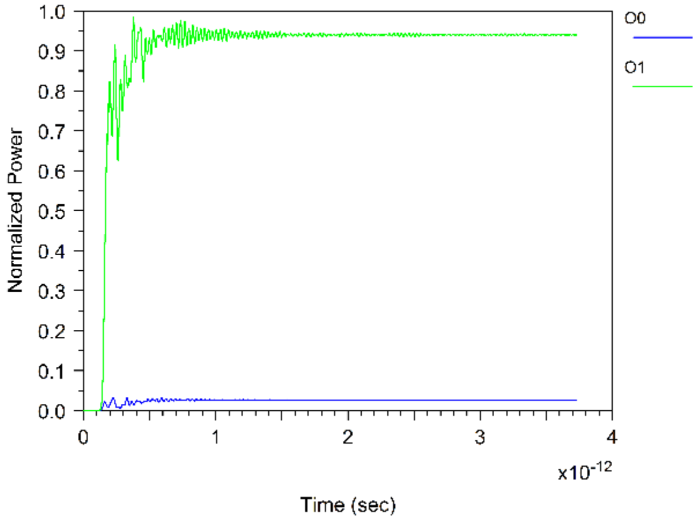
(b)

Fig. 5. (a) The optical behavior and (b) the time response diagram of the decoder when A is at logic 0 (color online)

When the initial phase of A is at 0 degrees (i.e. A is at logic 1), there will be destructive and constructive interferences at J1 and J2 respectively. As a result the amplitude of the optical waves coming from A will be added to the amplitude of the optical waves coming from Ref2 and O1 will be ON. But the optical waves coming from A and Ref1 will cancel each other and O0 will be OFF (Fig. 6a). In this case the amount of normalized power at O0 and O1 will be 4% and 95% respectively. Also the rise time for O1 is about 0.2 ps (Fig. 6b).



(a)



(b)

Fig. 6. (a) The optical behavior and (b) the time response diagram of the decoder when A is at logic 1 (color online)

As the simulation results show the proposed structure can work as an all optical decoder. The logic state of the input port was determined by the initial phase of A and the logic state of the output ports were determined with amplitude of the optical waves at O0 and O1. The maximum rise time for the proposed structure is 0.2 ps.

4. Conclusion

To basic logic gates were designed based on PSK technique. The working mechanism of the proposed gates are based on the beam interference. Then the proposed gates were combined to implement the final all optical decoder. The proposed device is a pure linear structure therefore its functionality does not depends on the optical power and does not requires high amounts if optical intensities for optical threshold switching. The final structure has a rise time as low as 0.2 ps.

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*Corresponding author: andalib@iaut.ac.ir