

# A Novel Asymmetric Structure for Photonic Crystal Based All Optical Silicon Logic OR Gate

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**Abstract**—In this paper, a novel simple structure for all optical photonic crystal based logic gate is presented. The structure is based on coupling the input signals to a combiner and thresholding the output signal of the combiner. The unit cell of the structure is designed to achieve band gap around the communication wavelength (i.e., 1.5  $\mu\text{m}$ ). The presented structure reveals low cross couple between gate inputs. The structure has no symmetry between inputs, which enables realization of the gate on small footprint photonic crystal. The structure offers 0.1  $\mu\text{m}$  bandwidth around the communication wavelength. The footprint of the structure is 25.59  $\mu\text{m} \times 25.31 \mu\text{m}$ .

## 1. INTRODUCTION

In recent years, the application of optical computers has been considered to increase processing power. Although there seem to be technical and economic problems to reach commercial optical computers, this is still a hot topic, and there are still many researchers working in various fields. For this purpose, we need processors as well as all-optical memory components [1]. The main bottleneck in the implementation of optical processors is the construction of elementary logic gates. In the initial research, nonlinear optical fibers as well as semiconductor optical amplifiers were used for this purpose. However, these devices are bulky and also require optical pump or DC bias voltage, which causes unwanted loss and nonlinear effects in the equipment. In recent decades, the application of photon crystals based circuits has been considered. Generally, linear and nonlinear circuits have been considered in this regard. Most of the circuits considered are based on the doping the photon crystal by the nonlinear materials. These types of circuits often require bias, which increase the size of the circuit, and the nonlinear impurities are material other than silicon compounds, which makes them difficult to construct and implement.

However, in recent years, the implementation of undoped logic gates has been considered. In this type of gates, the defect in the photon crystal is embedded to perform the desired logical operation at the output. Obviously, there must be a nonlinear element in logical operations. In this type of circuit, a nonlinear element is embedded in the output of the circuit, assigning logical 0 or 1 to the output signal [2–6].

This paper presents a linear structure for a logic OR gate. The structure is based on coupling the input signals to a combiner and thresholding the output signal of the combiner. In the following section, the unit cell and its dispersion diagram are introduced. Then, the proposed structure and its working mechanism are introduced. By performing several simulations, the efficiency of the structure is examined, and the desired threshold is determined. At the end, the conclusion of the article is provided.

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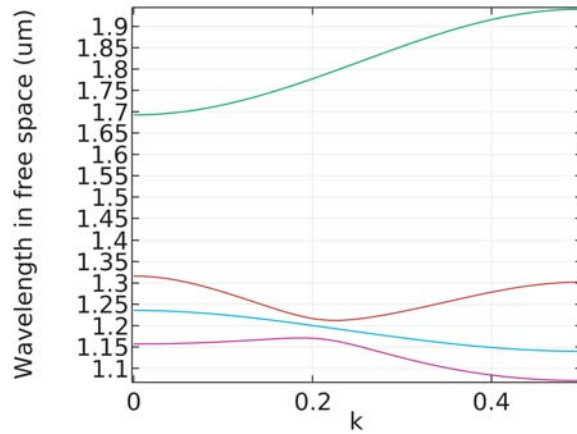
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## 2. THE PROPOSED STRUCTURE

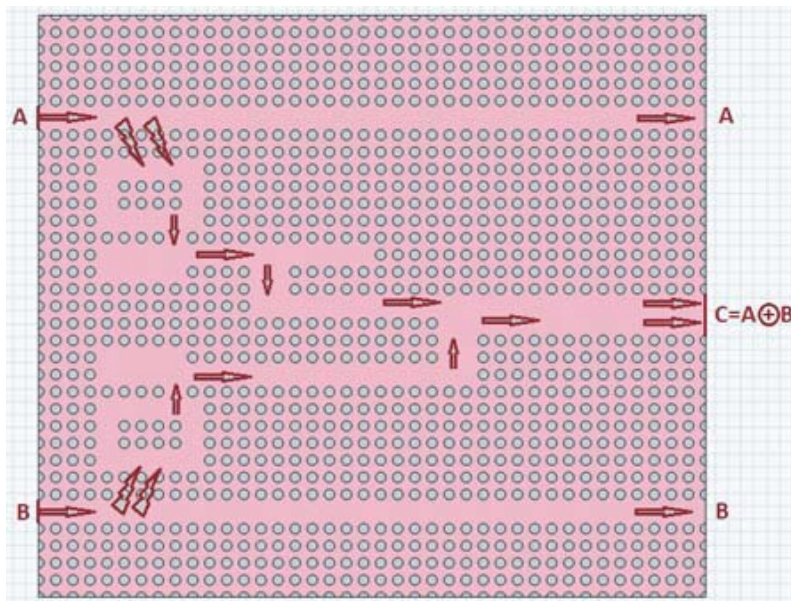
A periodic lattice with a square unit cell is considered in this structure. In the center of the unit cell, a silicon rod with refractive index and radii of 3.59 and 197 nm is assumed. The spatial period of the unit cell is 656 nm.

Figure 1 shows the dispersion diagram of the photonic crystal at the  $X$  direction for TM polarization. With due attention to wave propagating direction, only dispersion diagram in the  $X$  direction is necessary for the structure analysis. The diagram for the TM polarization is calculated. The photonic crystal dispersion diagram has been engineered to achieve band gap around the communication wavelength (i.e., 1.5  $\mu\text{m}$ ) with 24.8% bandwidth.

On the photonic crystal with the above mentioned dispersion diagram, a set of defects is created to implement OR gate, as shown in Fig. 2. The structure is composed of 3 coupled parts. The bottom and top parts are logical inputs. The fields from the bottom and top parts are gradually coupled to the middle part of the circuit. The role of the middle part is to combine the coupled fields. The whole footprint of the OR structure is 25.59  $\mu\text{m} \times 25.31 \mu\text{m}$ .



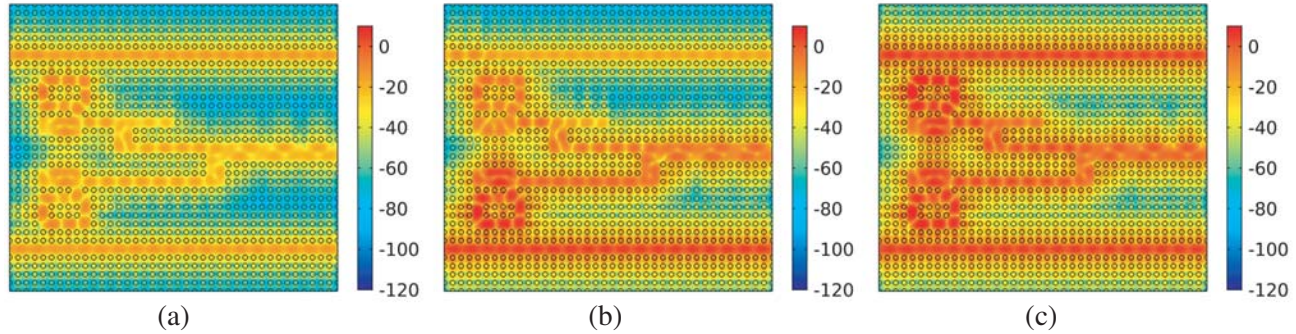
**Figure 1.** This dispersion diagram of the periodic lattice.



**Figure 2.** The proposed OR structure and its operation mechanism.

### 3. RESULTS AND DISCUSSIONS

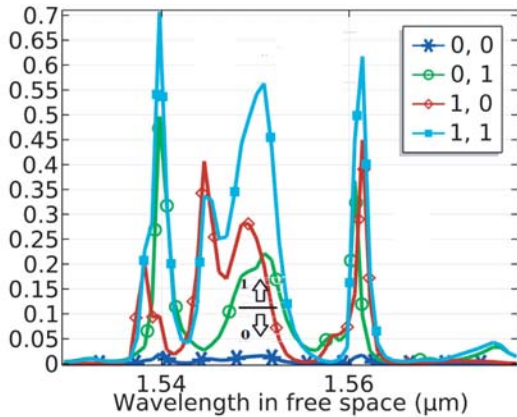
All simulations are performed in COMSOL software. Fig. 3 depicts the field pattern in the structure for three cases of truth table of the OR gate (i.e., (a):  $A = 0, B = 0$ , (b):  $A = 0, B = 1$ , and  $A = 1, B = 1$ ). A threshold of 0.5 is assumed to discretize the amplitude of the input field. In the figure for the simulation, the values of 0.125 and 0.75 are intended for logical “0” and “1”, respectively. Simulations are carried out for 193 THz. It is seen that for all cases the field is fully confined to the defect. Also field is coupled to the combiner structure. The output field amplitude is minimum in case (a) and maximum in case (c).



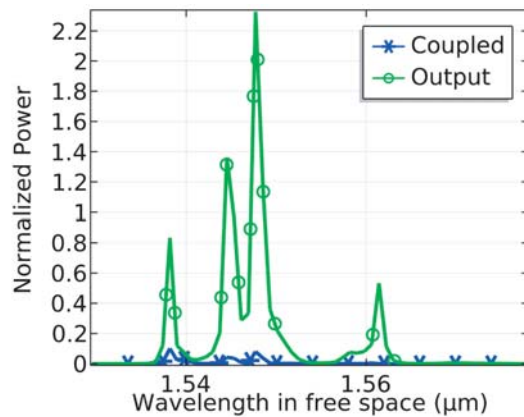
**Figure 3.** Field distribution in the structure for three cases. (a)  $A = 0$  and  $B = 0$ . (b)  $A = 0$  and  $B = 1$ . (c)  $A = 1$  and  $B = 1$ .

For better interpretation of the results, Fig. 4 depicts the integral of the output fields versus the wavelength. In the telecommunication band ( $\lambda = 1.55 \mu\text{m}$ ), it is observed that the output for logical zero case is very far from that for the other case, and with a threshold of 0.125, logical 0 is easily distinguishable from a logical 1. This offers a bandwidth of  $0.1 \mu\text{m}$  around the free space wavelength of  $1.55 \mu\text{m}$ . Cross coupling from one input to the next can cause systematic malfunctions. Fig. 5 examines the cross-coupling phenomenon. In this regard in the B and A inputs, logical 1 and 0 are applied, respectively. All powers are normalized to that of output port of B. It is observed that the cross coupling is negligible, and the proposed OR gate can be used without any concerns about the destructive effect of cross coupling. It can also be concluded that the output power of the gate is stronger than that of the output ports, the major part of the field is coupled to the combiner.

According to the authors, the footprint of the structure is in the order of previous structures.



**Figure 4.** Normalized output power for the truth table of or gate for different wavelengths.



**Figure 5.** Comparison of the output power with the cross coupled power for different wavelengths.

Table 1 compares the footprint of the structure with those of some references.

**Table 1.** Comparison of footprint of the structure with some references.

Ref.	Footprint
[2].	$26.46 \mu\text{m} \times 21.6 \mu\text{m}$
[3].	$50 \mu\text{m} \times 45 \mu\text{m}$
[4].	$20 \mu\text{m} \times 20 \mu\text{m}$
[5].	$12.5 \mu\text{m} \times 16 \mu\text{m}$
[6].	$72 \mu\text{m}^2$
This work	$25.59 \mu\text{m} \times 25.31 \mu\text{m}$

#### 4. CONCLUSION

A logical all optical OR gate structure was introduced, and its properties are examined by the simulation experiments. The structure consists of 2 input and three output ports. At the middle output port by suitable thresholding the OR logical operation can be implemented. Simulation results reveal 0.125 percent of the input power for proper OR operation. Also the cross coupling from one input to the other input is investigated, and it is seen that the cross-coupled power at the ports can be neglected.

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