Designing a Circuit for High-Speed Optical Logic Half Subtractor

Fariborz Parandin[1,*], Arezoo Sheykhian[1]
[1]Department of Electrical Engineering, Eslamabad-E-Gharb Branch,
Islamic Azad University, Eslamabad-E-Gharb, Kermanshah, Iran

Received: March 13, 2021. Revised: February 14, 2022. Accepted: March 13, 2022. Published: March 28, 2022.

***Abstract:* - In this paper, a high-speed optical subtractor has been designed and simulated. This circuit is based on a photonic crystal structure with silicon rods embracing a circular cross-section in the air platform. This structure was performed based on the photonic band gap. The best performance of this subtractor is in the highly-usable telecommunication wavelength of 1550, laying in the range of the photonic band gap of this structure. To design the circuit, two inputs with optical sources and two outputs have been used for difference and borrow bit. The features of this logic half subtractor encompassed simple structure, small dimensions, and appropriate level of the outputs 1 and 0.**

***Key-Words:* - Half subtractor; Photonic crystals; Photonic band gap; Logic gate; FDTD.**

I. INTRODUCTION

Nowadays several microwave components and circuits such as filters, diplexers, power dividers, couplers, and amplifiers are designed based on microstrip substrates. However, this technology has a limitation for upper microwave frequency range because of high losses at this frequency range. Therefore, the other technologies such, photonic crystal technology or optical structures should be used in this frequency range [1-7].

Photonic crystals are intermittent dielectric structures whose refractive index changes intermittently in one, two, or three dimensions. Each structure prevents the transmittance of a certain wavelength regarding the dielectric material, structure's form, rod radius, and lattice constant identified as a photonic band gap [8-13].

The photonic band gap is used in designing a variety of optical devices and logic gates. The simplicity of designed gates, high speed, and small dimensions are significant features of photonic crystals. In fact, photonic crystals have revolutionized the optical device industry, just as the invention of the transistor did in the electronics industry in the last century and became the platform for the design of integrated circuits and the expansion of electronic devices. Today, photonic crystals are widely used in designing optical fibers, amplifiers, filters, various sensors and biosensors, logic gates (AND, OR, NOT, NAND,…), multiplexers, and optical collectors. One of the essential and practical fields of photonic crystals is the design of all-optical processors, which, in addition to possessing small dimensions, dramatically increases the speed of information processing. A high-quality half adder and Subtractor can play an influential role in the design of a processor. One of the quality indexes of the logic gate is the approximation of the logic 1 output to logic 1 input value, and the approximation of the logic 0 output to the input value in the off mode [14-34].

Another index is the acceptable and detectable distance between the actual values of the outputs at 1 and 0. The greater gets the distance, the lower becomes the chance of error. This paper attempted to propose a half subtractor that output level of 1 be approximate to the input value and the output level of 0 shows a value close to the off source. Considering the fact that telecommunication devices are mainly performable at 1550 wavelength, this half subtractor has been designed to work at the same wavelength.

II. HALF SUBTRACTOR CIRCUIT

Photonic crystals are intermittent structures of materials with various refractive indexes that prevent the transmission of optical waves of a certain wavelength through their structure. This range is called the photonic band gap. The photonic band gap depends on the characteristics such as the material and, thus, the refractive index of the components, the rods' shape and dimensions, or holes of the crystal structure.

Given that the intermittence of refractive index extends at one, two, or three directions in the crystal, one, two, or three dimensional crystals are defined in which the photonic band gap in all directions will be available in one, two, or three dimensions.

The proposed half subtractor in this paper uses two-dimensional photonic crystals with dielectric rods and a refractive index of 3.4 in the air platform (refractive index of 1). In this structure, embracing lattice constant is as $a = 0.64$ and the radius of each rod as $r = 0.18a$. The wavelength used in this simulation is $\lambda = 1550nm$, defined as a highly usable telecommunication wavelength. This square lattice structure has dimensions of $12.36\mu m \times 12.36\mu m$, involving two waveguides and a ring resonator. The waveguides are cross-sectional, and the X and Y input optical sources are placed at the input of each waveguide. At the end of the waveguides, the outputs of D and B are the result of subtraction and borrow bit, respectively. In the simulations, monitors are placed to control and check the output level. The simulation time and the sampling steps were considered to be 180 and $Period/16 = 0.1$, respectively. In designing this circuit, receiving outputs were attempted to be appropriate, small dimensioned, and simply structured.

The wavelength of half subtractor input sources, i.e., $\lambda = 1550$, is also involved in the photonic band gap range. All calculations were performed in TM mode using the finite difference time domain method (FDTD). Figure 1 shows the proposed structure of optical half subtractor.

As represented in Figure 1, the radius of the four rods in the center of the ring resonance was reduced to $0.5 \times r$, as did the radius of common rods between the waveguides and the ring resonator to the same rate. On the sides of the second waveguide output, the radius of two rods on each side was reduced by half, increasing the efficiency and output level of 1.

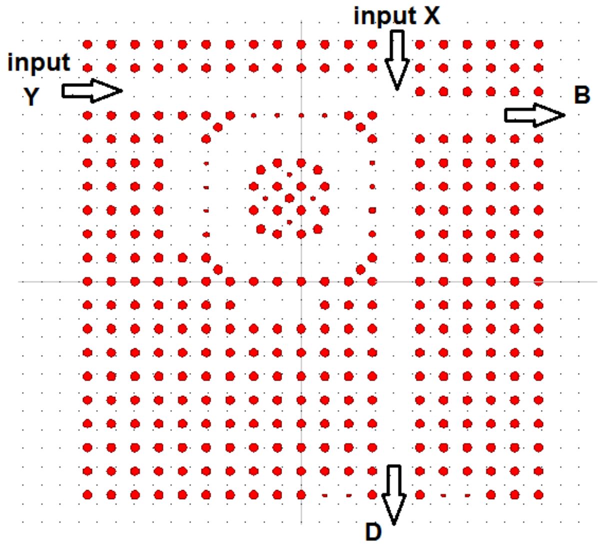

Fig. 1. Proposed structure of optical half subtractor

The considerable distance between the acceptable outputs for logics of 1 and 0 is one of the features of this half subtractor, reducing the error in the outputs and increasing the accuracy of the logic circuit.

According to Figure 1, input Y is located on the left side of the circuit and input X at the top, while the output of D, the difference, is reachable at the bottom of the circuit, demonstrating its output wave level as green in the figure. Additionally, in the figure, the output of B (borrow bit) on the right side of the circuit was shown in blue.

According to accuracy table of half subtractor, for the input mode of $XY = 01$ the output should be as $BD = 11$. Also when the input is $XY = 10$, the output should be $BD = 01$. For two state of $AB = 00$ *and* $AB = 11$, the output should be $DB = 00$.

The presence of a ring resonance has a significant effect on the output of 0 in this case. Also, by creating a phase difference of 100 between the input optical sources, the outputs were tried to be approximated to 0. Creating phase difference between two input sources has no effect in $AB = 10$ and $AB = 01$, but rather very effective in the input of $AB = 11$. The phase difference of 100 is calculated as the optimal state that results in the minimum output level by performing many simulations.

Figure 2-5 show the distribution of optical power for different input modes in the optical half subtractor.

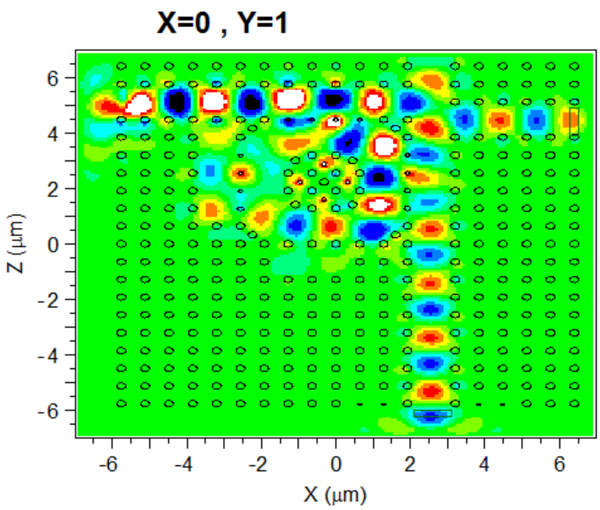

Fig. 2. Optical power distribution in output paths

for x=0 , y=1

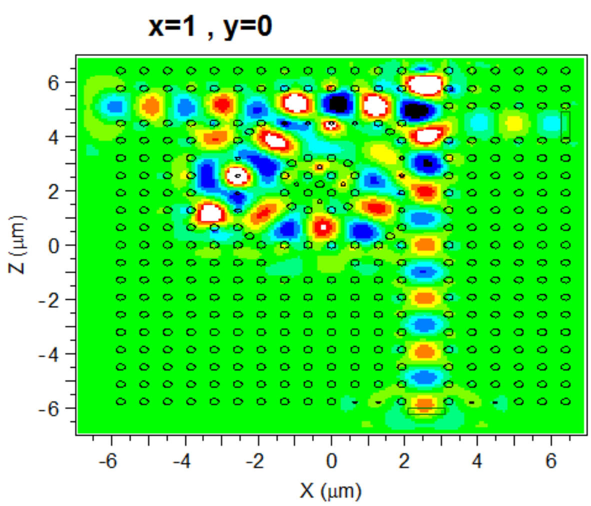

Fig. 3. Optical power distribution in output paths

for x=1 , y=0

As shown in Figure 2, in case a where the inputs are XY = 01, the power of the input source is divided by both outputs and it can be said that both outputs are in logical case 1 (BD = 11).
Figure 3 shows that when the inputs are XY = 10, the power is high at output D but very low at output B. That is, the outputs are set to BD = 01.
Figures 4 and 5 show that when both inputs are equal, ie A = B = 0 and A = B = 1, the power in both outputs is very low and can be considered zero. That is, in these two cases, the outputs are in the state BD = 00. These results are consistent with the accuracy table of half-subtractor.

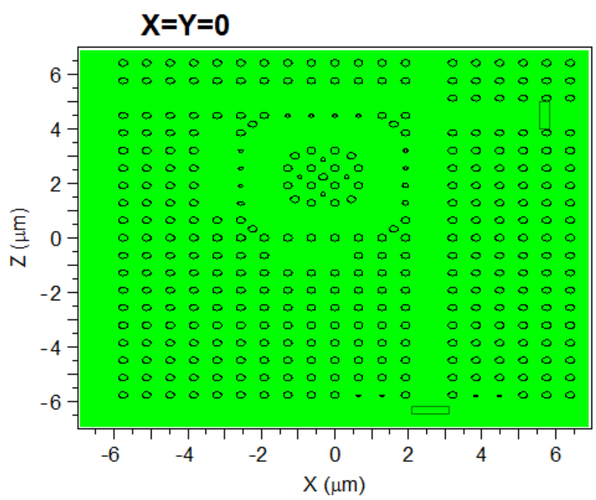

Fig. 4. Optical power distribution in output paths

for x=0 , y=0

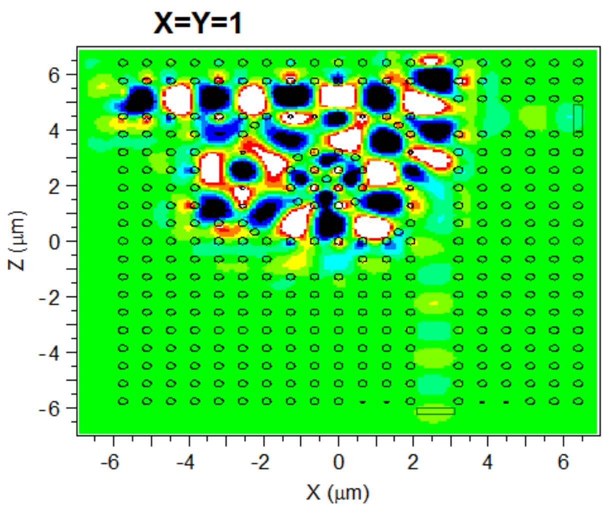

Fig. 5. Optical power distribution in output paths

for x=1 , y=1

III. CONCLUSION

In this paper, an optical half subtractor is designed to be applied in digital circuits. A two-dimensional photonic crystal structure was used for this circuit. To reach a half subtractor circuit, a ring resonator was utilized, which has been used to adjust the wavelength. The simulation results implied that the outputs corresponded to the half subtractor accuracy table. One of the advantages of the proposed design was the simplicity of the structure and the acceptable values for the logic values of 0 and 1.

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