NOVEL DESIGN OF PHOTONIC CRYSTAL STRUCTURE BASED ON A COUPLED MICROCAVITY-WAVEGUIDES FOR ALL-OPTICAL AND LOGIC GATES

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ABSTRACT:
In this study, the transmission of the all-optical AND logic gate using a structure connected with a triangular photonic crystal lattice is improved. The proposed logic gate consists of a photonic crystal nano-resonator formed by changing the size of the air holes. In addition to the simplicity, the response time is very short and the designed nano-resonator increases the bit rate of the logic gate. The two-dimensional finite difference time domain (2D-FDTD) method is used to simulate the structure, the transmission obtained is about 98% with very negligible losses. The proposed photonic crystal AND logic gate are widely used in future integrated optical microelectronics.

Keywords: *logic gates, photonic crystals, optical integrated circuits. Interferences effect, resonant cavities*

INTRODUCTION:

Photonic crystals (PhCs) are the best platforms for designing all optical devices suitable for all optical integrated circuits. The periodic distribution of refractive index in these artificial structures results in a forbidden wavelength region for propagation of light; this forbidden wavelength region is called photonic band gap (PBG) [1-2]. By use of PBG, we can control the behavior of light inside PhCs in very small spaces. For this reason, designing ultra-compact devices based on PhC suitable for optical integrated circuits is feasible. Optical reflectors [3]. Optical band rejection filters [4] are some examples of proposed devices using PBG property of PhCs.

Optical logic devices play important roles in optical calculation and high-speed information processing [5]. In addition, the need of all-optical logic designs increases day by day to cope up with the demand of high-speed telecommunication networking and computing systems. [6]. Lack of the need of Optical-Electrical-Optical (O-E-O) conversion as well as the data processing in optical means [7]. All-optical logic gates are major unit of all-optical signal processing and optical communication [8]. Both of these need a lot of complex combination of all-optical logic gates. Every all-optical logic gate needs to be operated fast and functional as a critical and essential part of bigger structure [9]. Furthermore, we can improve the entire system to work faster and more reliable by optimizing an all-optical logic gate. [10] All-optical logic gates can be based on semiconductor optical amplifiers [11], quantum-dot semiconductor optical amplifiers [12.13], and photonic crystals [14].

Many structures have been proposed to introduce all-optical photonic crystal logic gates [15-16]. New structures for all-optical photonic crystal logic gates have been increasingly optimized [17-18]. In addition, different structures have been reported for logic gates to obtain high contrast ratios in all-optical photonic crystal logic gates [19.20.21]. Mohebzadeh and Olyaee reported a novel structure for photonic crystal NOT and XOR logic gates with high contrast ratio [19]. In their study, the contrast ratios of 20.53 dB and 19.95 dB were obtained for NOT and XOR logic gates, respectively, at the wavelength of 1550 nm. In addition, the XOR and XNOR logic gates were reported based on the Fano resonance in a plasmonic ring resonator with a contrast ratio of about 23 dB [21]. Muthu and al are recently reported XOR/OR logic gates with a response time of 120 fs [22]. More recently, an ultra-compressed structure has been reported for XOR/NOT/OR logic gates with a response time around 100 femtoseconds [23].

Another particularity of these structures is the Multifunctionality of this logic gate, which simultaneously provides a logic multiplexer and an AND logic gate using a 2D photonic crystal structure [24]. Kumar and Medhekar designed and simulated all-optical photonic crystal NOR and NAND gates using silicon rods in air [25]. In this structure, we design a logic gate to provide the AND logic gate function. The AND gate is formed by the Y junction and two microcavities with a triangular array of silicon air holes. The two holes were located in the right waveguide. Their size was changed in order to optimize the transmitted power and to reduce the losses. To validate our results numerically, we use a finite-difference time-domain method (FDTD-2D) to simulate the wave propagation inside the Y-junction in a two-dimensional photonic crystal. The studied device is widely used in future integrated optical microelectronics.

DESIGN AND STRUCTURE:

The photonic crystal structure used in the design is a triangular array photonic crystal of air holes in a silicon substrate. The refractive index of silicon 3.42. The hole radius is chosen as r = 0.4*a, where (a) is the lattice constant and (r) is the radius of the air holes were chosen for a triangular lattice in order to obtain a photonic band gap (PBG) around 1.55 µm existing for telecommunication wavelengths. This crystal is illuminated by a Gaussian wave under normal incidence with a transverse electrically polarized (TE) mode. The length of the photonic crystal is 19*a and the time step is chosen to be 0.01. Note that it may be necessary to reduce the time step below the stability limit when simulating the materials.

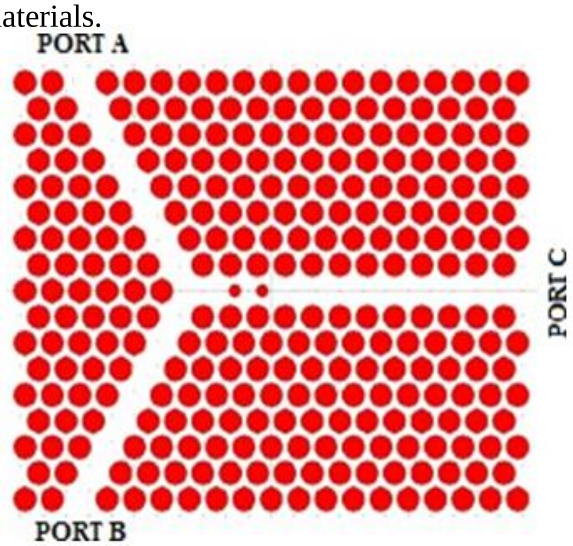

Figure 1: Design of the optimized All-optical AND logic gate

We chose this structure because triangular array can have large band gaps and silicon is expected to be a good platform for integrated photonic circuits and ultra-compact optical devices. [26, 27]. Figure 2 shows the band gap diagram who is obtained using the FDTD method. The band gap means that light in this range is not allowed to pass through the photonic crystal structure [28]. This band diagram and the primary photonic crystal structure are shown in Fig. 2. For this structure, in TE mode, there is a band gap between 0.293 a/λ and 0.428 a/λ, which is equivalent to the wavelength range of 1269 nm to 1890 nm. In our simulation, the wavelength 1550 nm is used.

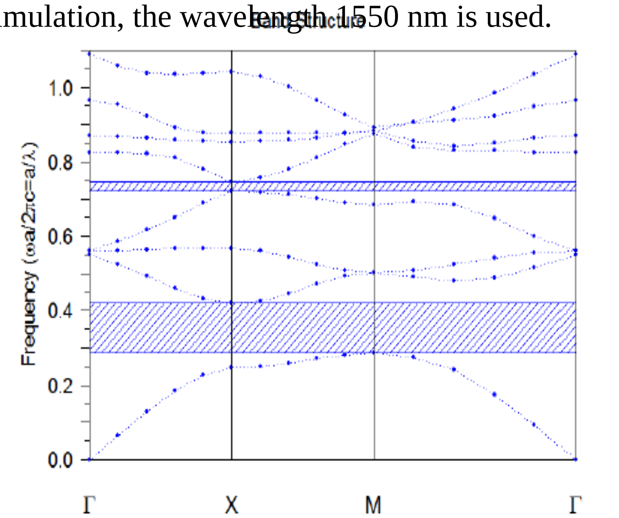

Figure.2 the band Band of the structure in TE mode.

RESULTS AND DISCUSSION:

In theory the AND gate is a device whose output is logical (1) if both inputs are logical (1). The logical AND function of two variables is represented either by writing a point between the two variables, or by writing the adjacent letters without a point. For example X. Y = Z or XY = Z reads, "X AND Y is equal to Z". The AND gate symbol and its timing diagram are shown in Figures (3-a) and (3-b) respectively, with two inputs marked A and B and one output marked X [29].

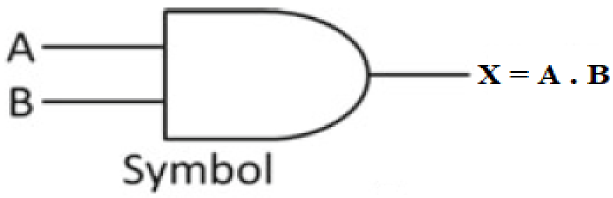

Figure 3-a: symbol of the AND logic gate.

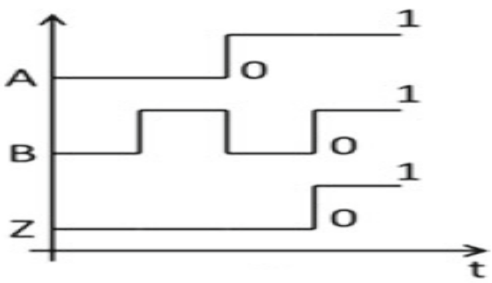

Figure 3-b: Timing Diagram

A continuous light source is used to verify the correct operation of the logic gate. This source is located in ports A and B. at port C a time monitor is provided to receive the light output. According to the truth table, the operation of the logic gate has been studied in three modes.

TABLE1 :

Port A	Port B	Port C	Logical output
0	0	0	0
0	1	0.015	0
1	0	0.015	0
1	1	0.982	1

Table1: The truth table for AND logic gate, where the output signal is as a function of input power Pi

In the first mode, the source on port A is active and the source on port B is inactive. In this case, most of the light is captured in the microcavities and a very small part of the light reaches the output port. The corresponding electromagnetic field is shown in Figure 4.a; the ratio of the received optical power to the input power in the proposed logic gate is 0.015, which is considered equal to the logic level of “zero”.

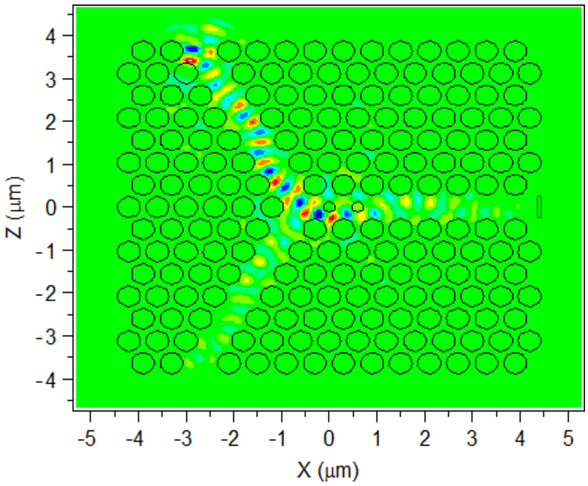

Figure 4.a: the electromagnetic field in the structure when A=1 and B=0

In the second mode, the light source on port B is active and the other light source is inactive. The function of the logic gate presented by the electromagnetic field representation is shown in Figure 4.b. The output power is 0.015. This optical power is equal to the logic level of “zero”.

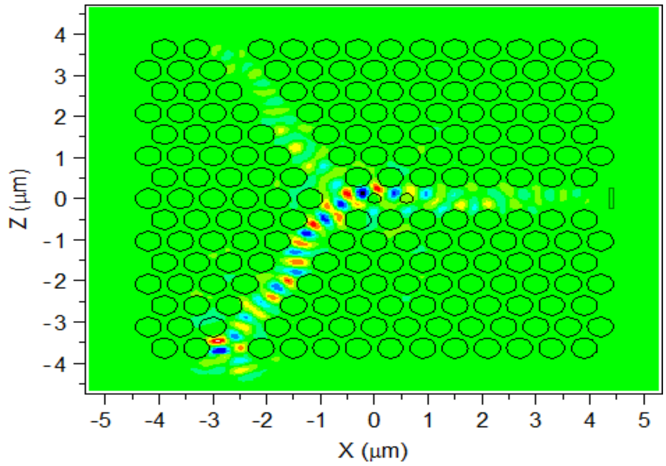

Figure 4.b: the electromagnetic field in the structure when A=0 and B=1

In the third mode, both optical sources are active. This means that from both ports A and B, light reaches the microcavities with high optical power. The two lights are merged in the microcavities and the high power light reaches the output port.

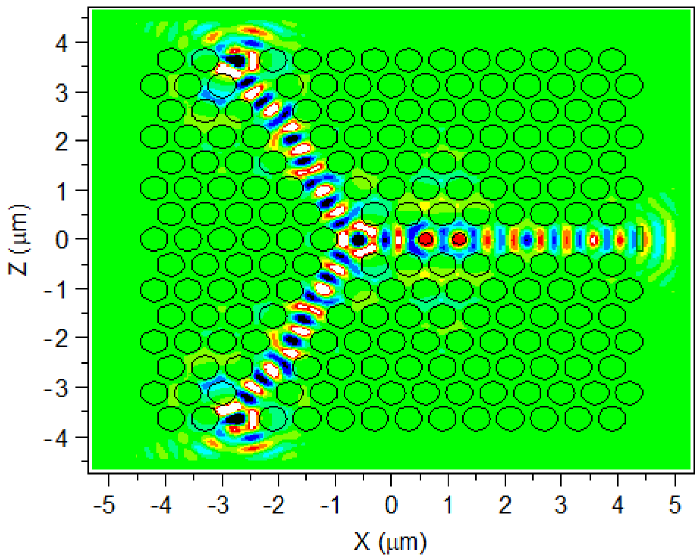

Figure 4.c: the electromagnetic field in the structure when A=1 and B=1.

Figure 4.c, shows the electromagnetic field of the logic gate in this state. The ratio of output power to input power is 2.9. This value is considered equal to logic level "one".

Figure 5 shows the power transfer diagram when both input ports are set to 1.

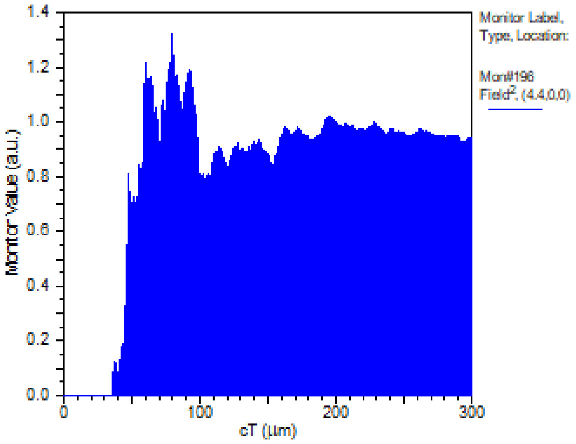

Figure 5: the power transfer diagram in the proposed AND logic gate

The contrast ratio can be calculated by the logic levels "one" and "zero" of the output power as

$$CR = 10\, log\, \frac{PL}{PH}$$

Where P_L and P_H are the lowest optical power at logic level "one" and the highest value of output power at logic level "zero [30].

Table 2 shows the comparison of the proposed structure with other similar structures proposed in previous works. The performance of the proposed logic gate is compared with four similar logic gates, it is very clear that our structure has much more compact dimensions compared to the other structures and that the use of microcavities allows to amplify the transmission in the output port. The performance of this structure is optimal in terms of contrast ratio.

TABLE2 :

Power intensity (µm)		Contrast ratio (dB)	Lattice type
REF [31]	33%	6.93	Square
REF [32]	36%	13.93	Square
REF [33]	73%	9.29	Square
REF [34]	80%	11.03	Square
THIS WORK	98%	22.98	Hexagonal

Table2: The comparison of the results of the proposed structure with other structures

The contrast ratio for the proposed photonic crystal AND logic gate is 23 dB

CONCLUSION

In this paper, a new connected structure is proposed and demonstrated by simulation in the telecommunication wavelength range (1.55 µm). Our structure is very compact with low power consumption and simplicity of operation compared to other compound structures logic gates. For the proposed all-optical AND logic gate the transmission is amplified and the contrast ratio (22.98 dB) is very satisfactory compared to other structures studied. The two-dimensional finite difference method (2D-FDTD) demonstrates the optical performance of the proposed structure and its dispersion diagram is presented using the PWE method. The studied structure provides a basis for the optimal design of the integrated circuit and has an important application perspective in all fields.

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