Optimization of all optical photonic crystal half adder in two dimensional structure

Priyanka Pathak, Yazusha Sharma and Rukhsar Zafar
Department of Electronics and Communication, Swami Keshvanand Institute of Technology, Management and Gramothan, Jaipur-302017 (INDIA)
Email- **priyanka.pathak1994@gmail.com**
Received 15.08.2019 received in revised form 09.10.2020, accepted 09.10.2020

Abstract:The photonic crystal waveguides is quite significant in designing the optical integrated circuits. Half Adder is the important part of any ICs. Here, we have designed an all optical half adder. This adder is designed with T-shaped square lattice photonic crystal. The structure is optimized with the line and point defect to act as Adder. These structure yields output at sum and carry port using phase interference method. Contrast ratio is used to measure the performance. The contrast ratio for sum is 6.50 dB and for carry is 10.47 dB. The footprint of proposed structure is 56 µm². The design is viable to open a way in designing future optical integrated circuits.

Keywords: Photonic crystal, Optical half adder, Interference method, contrast ratio.

1. INTRODUCTION

Now a day's, the photonic technology is swapping the electronics technology. It offers better functionality in terms of speed as it uses light as photon carrier [1,2]. The integrated photon technology needs microstructure photonics materials for adjusting propagating state of photons. The photonic crystal has photonic band gap structure which restrains air band and dielectric band. Photonic band gap stops light coming from some particular directions with identified frequencies [3]. The photonics communication is widely used in digital integrated circuits. The large amount of data can be transferred from one location to another with use of photonics with very low loss of information [4]. This property of photonics is widely used in optical integrated circuits. Combinational and sequential circuits are needed in digital integrated circuits. For designing combinational and sequential circuits; logic gates, adders, multipliers, dividers etc. are used. Plane wave expansion (PWE) [5] , Finite difference time domain(FDTD) method is used for simulating such type of circuits.

Half adder is used in many digital integrated circuits. Several designs of all-optical half adder are proposed by researchers. Earlier in 2016, Sandip Swarnakar an all optical half adder is proposed which uses T-shaped square lattice with silica dielectric rods in air background [6,7]. In 2017, Mona Neisy et. al, proposed all optical half adder with square lattice structure. The photonic crystal resonant cavities technique is used. The footprint of this design is 303 µm² [8]. In 2018, Sonth et. al. proposed optical half adder using T- waveguide. It works as beam splitter at input side and power combiner at output side. This design has large footprint [9]. In 2017, Mohammad Mehdi suggested an all optical half adder by using defects rods in hexagonal lattice. The contrast ratio for SUM and CARRY is obtained as 6.11 dB and 3.52dB [10,11]. We have proposed all optical half adder which offers ultra small footprint. Twisted optical waveguide method is employed for devise AND gate. Standing waves are produced at the meddling of incident light and reflected light. Immense changes are notified in the refractive index of defect rods by changing the radius of dielectric rods. These rods are made up of dielectric material Si. Intersection method is used for XOR gate. By using the AND and XOR gate, optical half adder is designed. This design have decent contrast ratio. Small area designs are always preferred in terms of speed [12]. The compact design which has smallest area, very high speed and very low loss of information is always demanded.

2. DESIGN AND OPERATING PRINCIPLE

The schematic of suggested half adder design is as shown in fig. 1. The grid size is 11×10. Unit area (1×1) of grid includes an area of a2, where 'a' is the lattice constant and is equal to 560 nm. Silicon rods having refractive index of 3.47 and background medium is air having refractive index 1. Periodically arrangement of rods with square lattice are used so that less footprint area is acquired by propound design . The radius of Si rods is 0.2a. The radii of defect rod Re1 =0.284a and R2e =0.313. We design the structure in such a manner so that the desired photonic band gap lie in the C band. The band gap, which spans from 0.50(1/λ) to

0.74 (1/λ) that means proposed structure restrict the light of wavelength from 1.35μm to 2μm in perfect photonic crystal. This range of photonic crystal can be used for propagation of waves.

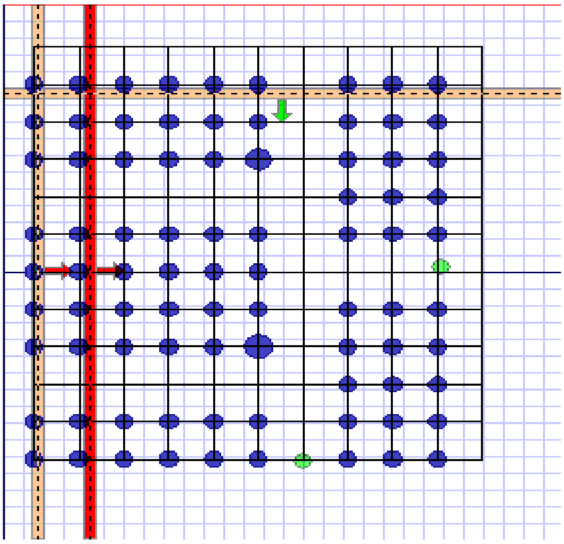

Figure 1: Optical half adder structure

The proposed half adder structure has three inputs named input 'A' input 'B' and reference input C. The reference input is used to bus the output into sum and carry. Sum and carry is obtained by using the operation of XOR and AND gate respectively. The radius of edge rod Re1 and Re2 is altered for obtaining desired result of proposed design [10,12]. The rod Re1 acts as a hole which take up some amount of input signal. The reasonable amounts of input power is obtained at sum and carry output due to rod Re2. These rods are also called reflecting rods. There are four possible states in optical half adder i.e. 00, 01, 10, 11.The ON state is represents as '1'and OFF state is represents as '0'. When both the input is OFF, there is no output signal generated. When the input A or B=1 and reference input has zero degree angle is applied, then constructive interference is occurred due to phase interference [5]. In this case the sum S is high and carry C is low. The rod Re1 does not allow the signal to propagate in unwanted path i.e. towards B input. When input A =B=1 i.e. both inputs are ON state having angle of zero degree intersect with reference input 'C' having 180 angle, then destructive interference is occurred . In this case, sum is low and carry is high.

3. RESULTS AND JUSTIFICATIONS:

Proposed structure is analyzed using plane wave expansion method to calculate the dispersion properties of photonic crystals. The dispersion relation is drawn between 1/λ and k-vector. Photonic band gap can be gained by dispersion relation. When dielectric rod type structured is selected, band gap is obtained in TE mode [4].For every wave vector, there exists some ranges of frequencies through which electromagnetic waves cannot passed. For simulation process of proposed half adder, the radius and lattice constant of rods of half adder structure is set.

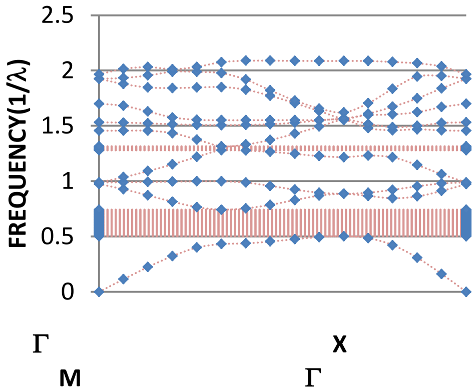

Figure 2: Dispersion relation for perfect photonic crystal; the photonic band gap ranges from 0.50(1/λ)to 0.74(1/λ)

3.1 When logic input '01' applied:

In the condition of '01', input signal 'A' is not applied i.e. 0 which can be represent as OFF condition and input signal 'B' is applied i.e. 1 which can be represent as ON condition. The reference input 'C' is also in ON condition. The input 'A', 'B' and reference input 'C' has zero degree phase angle. When the waves come from input 'B', the rod R_{e1} forbid waves to go into input 'A'. The waves coming from reference input combine with waves of input 'B'. The light pulse will reflect at the sum port due to reflecting rod R_{e2} which prohibit waves to go towards carry. The sum output is considered as logic output '1' and carry is considered as output '0'.

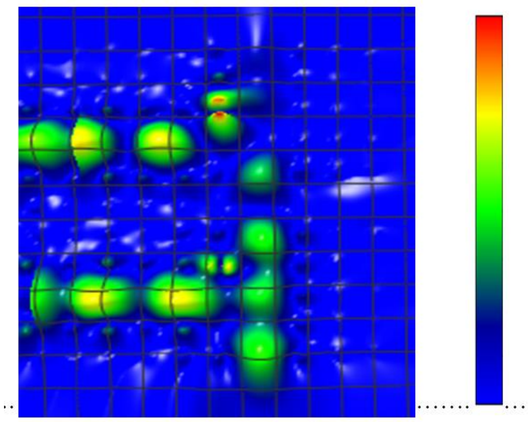

Figure 3: Electric field profile of proposed adder for logic " 01"

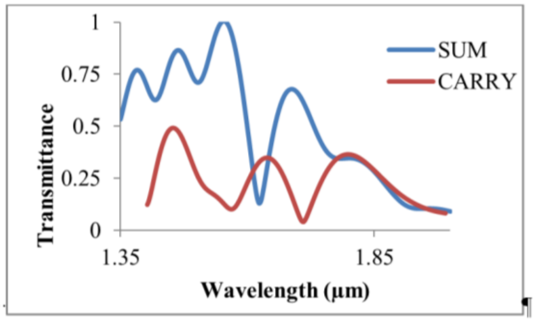

Figure 4: Normalized transmittance spectrum for sum and carry input A=0

3.2 When logic input '01' applied:

In the condition of '10', input signal 'A' applied i.e. 1 which can be represent as ON condition and input signal 'B' is not applied i.e. 0 which can be represent as OFF condition. The reference input 'C' is also in ON condition. The input 'A', 'B' and reference input 'C' has zero degree phase angle. When the waves come from input 'A', the rod R_{e1} forbid waves to go into input 'B'. In this case too, waves coming from reference input combine with waves of input 'A'. The signal will reflect at the sum port due to reflecting rod R_{e2} which prohibit waves to go towards carry. The sum output is considered as logic output '1' and carry is considered as output '0'.

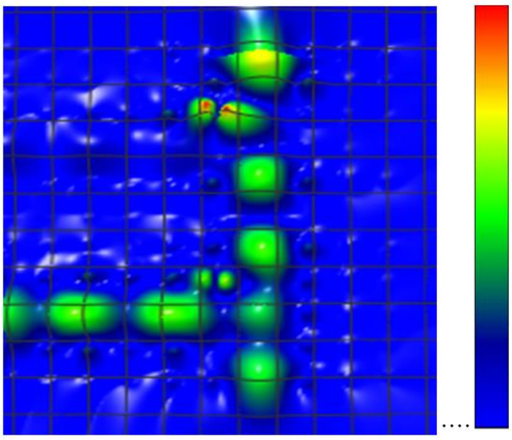

Figure 5: Electric field profile for logic " 10 "

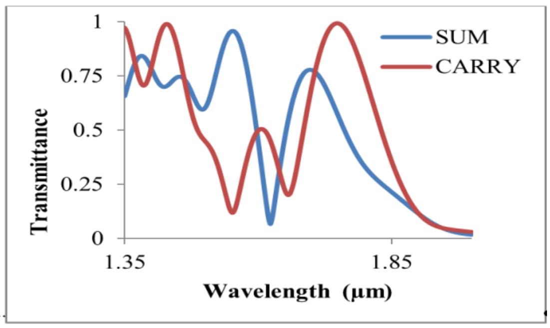

Figure 6: Normalized transmittance spectrum for sum and carry input A=1 and B=0

3.3 When logic input '11' applied:

In the condition of '11', both the signal input signal 'A' and input signal 'B' is applied i.e. 1 which can also be represent as ON condition. The reference input 'C' is also in ON condition. The input 'A' and 'B' has zero degree phase angle and reference input 'C' has 180 degree phase angle. When the waves come from input 'A' and 'B', the waves combine together. Rod $R_{e\,2}$ forbid waves to go towards sum port. The light pulse will reflect at the carry port due to reflecting rod R_{e2} which prohibit waves to go waves in sum port. The sum output is considered as logic output '1' and carry is considered as output '0'.

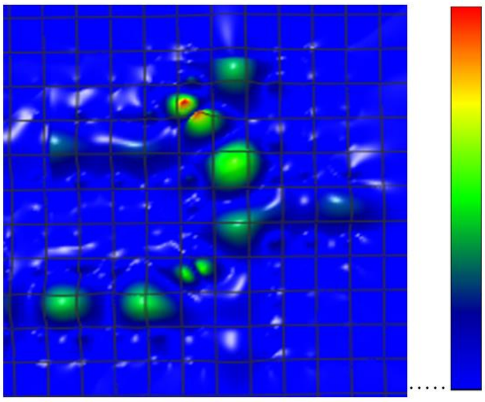

Figure 7: Electric field profile for logic " 11"

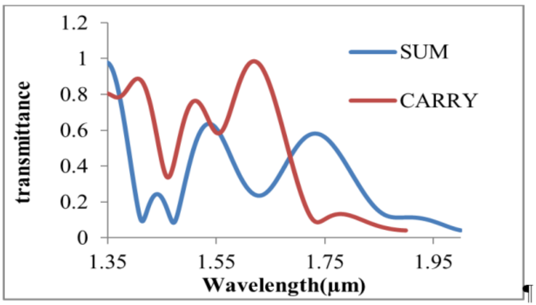

Figure 8: Normalized transmittance spectrum for sum and carry input A=1 and B=1

Contrast ratio: Contrast ratio can be defined as the ratio of power level when output is ON to the power level when output is OFF .

$$C.R. = 10\,log\,\frac{P_{on}}{P_{off}}$$

Contrast ratio (Sum) = 6.50 dB

Contrast ratio (Carry)= 10.47dB.

Footprint of lattice structure can be defined as area required for implementation of photonic crystal waveguide. It is measured in μm^2.

Footprint = 56 μm^2

This optical half adder design with ultra-small footprint and very good contrast ratio which can be utilized in designing of full adder, multiplexer, demultiplexer and many more digital designs. The proposed adder offers minimum footprint and large contrast ratio. As it's based on photonic crystal, so it can be used in optical ICs. Table 2 summarizes a comparative analysis with the different adders proposed in the literature [15-18]. Although the contrast ratio of the proposed adder is not so good, but the footprint offered by our design is minimum as compared to other adders [15-18]

Table 1: Summary of optical half adder

S.NO.	LOGIC INPUTS		PRATICAL RESULTS	
	SUM	CARRY	SUM	CARRY
1.	0	0	0	0
2.	1	0	1.52	0.12
3.	1	0	1.40	0.18
4.	0	1	0.34	1.34

Table 2: Comparative Analysis

Ref	**Contrast Ratio**	**Footpint**
[15]	5.29 dB	-
[16]	17.98 dB	$19.8 \times 12.6\ \mu m^2$
[17]	16 dB	$158\ \mu m^2$
[18]	9.77 dB	$1056\ \mu m^2$

4. CONCLUSION:

We have proposed a new design of 2D photonic crystal half adder. Phase differences produces sum and carry outputs. Through, the contrast ratio is comparatively less with that of existing half adder designs, but footprint is minimized having dimensions of 7 × 8 μm2. . The contrast ratio for sum is 6.50 dB and for carry is 10.47 dB of optical half adder. As the footprint is very small, it can be potentially applied in the various digital integrated circuits.

REFERENCES

[1] J. D. Joannopoulos, R. D. Meade, and J. N. Winn, Photonic Crystals: Molding the Flow of Light. Princeton, NJ: Princeton Univ. Press, 2002

[2] C.G. Bostan and R.M de Ridder "Design of photonic crystal slab structures with absolute gaps in guided modes", J. Opt. Adv. Mat., vol. 4, pp.921-928, 2002.

[3] C. Jamois, R.B. Wehrspohn , L.C. Andreani, C. Hermannd, O. Hess & U. Gosele, "Silicon-based two-dimensional photonic crystal waveguides", Sciencedirect, Photonics and Nanostructures Fundamentals and Applications , pp 1 -13,2003.

[4] J. D. Joannopoulus, Pierre R., & Shanhui Fan, "Photonic Crystal: Putting a new twist on light" Nature Vol. 386, pp 3787-3790, 1996.

[5] Swarnakar S, Kumar S, Sharma S. All-optical half-adder circuit based on beam interference principle of photonic crystal. Journal of Optical Communications, 39(1), pp 7-13, 2017.

[6] Neisy M, Soroosh M, Ansari-Asl K. All optical half adder based on photonic crystal resonant cavities. Photonic Network Communications, 1;35(2):245-50 , April 2018.

[7] Sonth MV, Soma S, Gowre SC, Biradar N. Modeling and Optimization of Optical Half Adder in Two Dimensional Photonic Crystals. Journal of Electronic Materials, 47(7):4136-9, Jul 2018.

[8] Shaik EH, Rangaswamy N. Design of photonic crystal-based all-optical AND gate using T-shaped waveguide. Journal of Modern Optics, 63(10):941-9, May 2016.

[9] Karkhanehchi MM, Parandin F, Zahedi A. Design of an all optical half-adder based on 2D photonic crystals. Photonic Network Communications, 33(2):159-65, April 2017.

[10] Liu Q, Ouyang Z, Wu CJ, Liu CP, Wang JC. All-optical half adder based on cross structures in two- dimensional photonic crystals. Optics express, 16(23): 8992-9000 , Nov 2008.

[11] 11.Jiang YC, Liu SB, Zhang HF, Kong XK. Realization of all optical half-adder based on self-collimated beams by two-dimensional photonic crystals. Optics Communications, 348:90-4, Aug 2015.

[12] 12.Serajmohammadi S, Alipour-Banaei H, Mehdizadeh F. Proposal for realizing an all-optical half adder based on photonic crystals. Applied optics, 57(7):1617-21 , , March 2018.

[13] Sharma, Shivani, Rukhsar Zafar, Mohammad Hossein Mahdieh, Ghanshyam Singh, and Mohammad Salim. "High Contrast Ratio Based All-Optical OR and NOR Plasmonic Logic Gate Operating at E Band." In Optical and Wireless Technologies, pp. 325-332. Springer, Singapore, 2020.

[14] Zafar, Rukhsar, Sarfaraz Nawaz, and Mohammad Salim. "Fano resonance excited all-optical XOR, XNOR, and NOT gates with high contrast ratio." Plasmonics 13, no. 6 (2018): 1987-1994

[15] Anagha, E.G. and Jeyachitra, R.K., An investigation on the cascaded operation of photonic crystal based all optical logic gates and verification of De Morgan's law., Optical and Quantum Electronics volume 52, Article number: 293 (2020).

[16] Mostafa, Tamer S., Nazmi A. Mohammed, and El-Sayed M. El-Rabaie. "Ultra-High bit rate all-optical AND/OR logic gates based on photonic crystal with multi-wavelength simultaneous operation." Journal of Modern Optics 66, no. 9 (2019): 1005-1016.

[17] Naghizade, Saleh, and Hamed Saghaei. "A novel design of all-optical half adder using a linear defect in a square lattice rod-based photonic crystal microstructure." arXiv preprint arXiv:2002.04535 (2020).

[18] Serajmohammadi, Somaye, Hamed Alipour-Banaei, and Farhad Mehdizadeh. "Proposal for realizing an all-optical half adder based on photonic crystals." Applied optics 57, no. 7 (2018): 1617-1621.