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Design and Implementation of Optical Half-Adder for Switching Purpose

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Abstract:

In this paper, we are proposing Design and implementation of two-dimensional photonic crystal based Optical Half-Adder using T-shaped and Y-shaped waveguides with silicon dielectric rods in air substrate. The performance of this design is verified and simulated by Finite Difference Time Domain (FDTD) method. The design of this Optical Half-Adder circuit is based on the Beam Interference Principle. It has two inputs A, B and two outputs Sum and Carry, which will be obtained by changing the phases of the inputs.

Keywords: Half-Adder, Photonic crystal, T and Y-shaped waveguides Beam Interference principle, FDTD.

1.Introduction:

In present days it has been shown that photonic crystals have the ability to play key role in the future generation of optical systems. This photonic crystal has the significant properties of small size, large bandwidth and reduced power dissipation. Hence these are going to be future technology in telecommunication. Many techniques have been used in recent time to realize the optical devices such as optical fibers, demultiplexers, switches, logic gates. Before the development of two-dimensional photonic crystals, many of the researchers were concentrated on design of optical devices using semiconductor optical amplifier, logic gates, flip-flop. But these designs have some small limitations of having high latency, less compatibility compared to other devices and it is somewhat difficulty to carry optical integrations on a small chip. So, these photonic crystals highly replace those semiconductor-based designs. These photonic crystals work based on the “Beam Interference principle”.

Beam Interference Principle: When two waves reflected from a media collides each other two types of interferences will takes place. When the two waves are in-phase then it leads to “**Constructive interference”.** When the two waves are out of phase then it leads to “**Destructive interference”, i**n this case the signal will get cancelled.

The photonic crystals can also be called as photonic Band Gap materials because, the photonic band gaps in the band structure gives them the ability to combine and control the propagation of the light beams inside desired waveguides. Due to an important property of the photonic band gap (PBG), light could not propagate through the PBG within the spectral range of wavelength. To overcome the behaviour of the substrate the periodic variation of the dielectric constant will be used to control the flow of light.

These PhC structures were mostly designed and studied due its properties such as high speed, high compatibility compared to semiconductor designs, compactness, simple structures, low diffraction losses and high speed. We know that Half-Adder is one of the key elements of the ALU (Arithmetic and Logic Unit).

Structure of paper:

In section 1, the introduction of the paper is given. The operating principle and design of Optical Half-Adder are illustrated in Section 2. Simulation Results of Half-Adder and Calculation of Contrast Ratio are discussed in Section 3 and Section 4 has the conclusion.

2. Design and Working of All optical Half-Adder:

A half adder is a combinational circuit which performs the addition of numbers. The half adder is able to add two single binary digits and provide the output and a carry value. It has two inputs A and B and two outputs Sum and Carry. A general Half-Adder representation has an XOR gate and an AND gate.

$$\text{Sum} = A \text{ xor } B$$

$$\text{Carry} = A.B$$

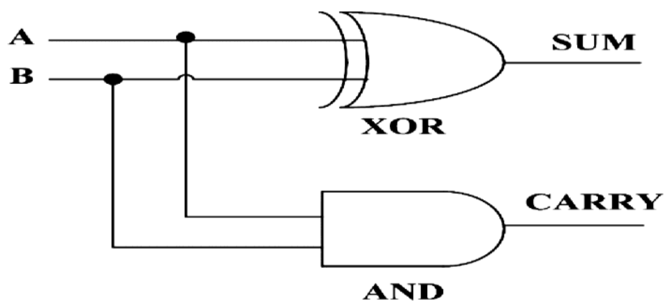

Fig. 1: Logic circuit of Half-Adder

A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Table.1: Truth Table of Half-Adder

2.1 Operating Principle and Design of Proposed All-Optical Half-Adder:

The innovative arrangement of All-optical Half-Adder is shown in fig.3(a). Our proposed structure is designed using a Y-shaped waveguide and two T-shaped waveguides with the dimensions of 16a*15a array. of Silicon dielectric rods with air as the substrate. we are using phC's here so there is need to use semiconductor optical amplifiers. coming to its design we have used a Y-shaped waveguide and two T-shaped waveguides and its lattice structure is of size 9.6µm*9µm. Silicon rods (Refractive index=3.46) are taken with Radius of 0.2a. Y-shaped waveguide is taken at 'A' input side, it means power from 'A' input source will goes through this Y-shaped waveguide. Two T-shaped waveguides were established to take outputs and to give remaining two inputs 'B' and 'Reference'. The full design with rods information is shown in below Fig.3(a).

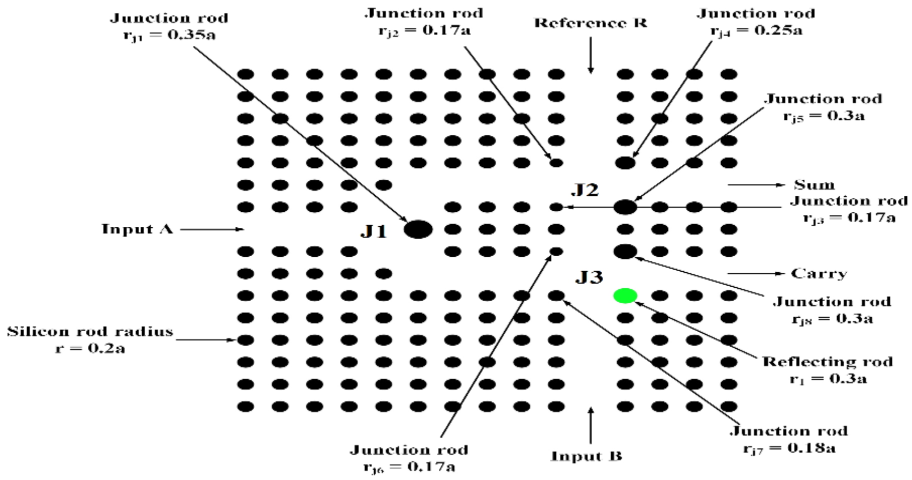

Fig.3(a) Proposed Model of Half-Adder

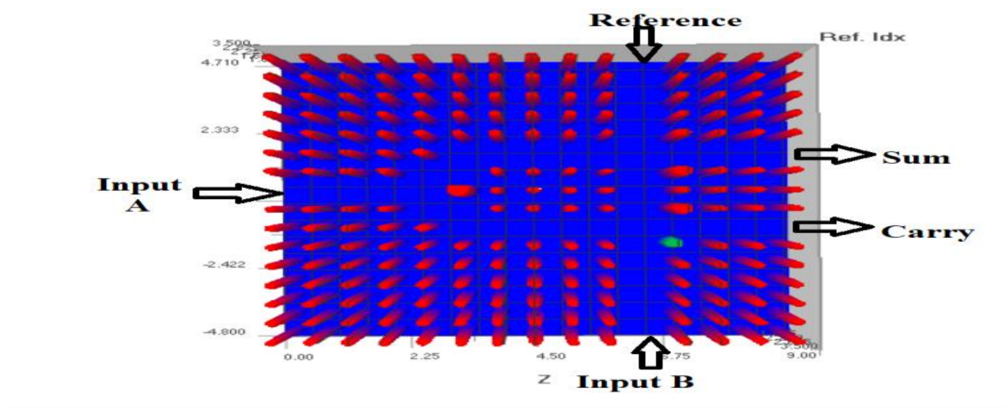

Fig.3(b) Refractive index profile of half adder

The above fig.3(a) shows our proposed design stricture of all-optical half-adder with rods radius and Fig3(b) shoes the Refractive Index Profile of the design where we can clearly observe the rods information and rods refractive index. A Reflecting rod has placed at the ‘A’ input side where the waveguide is splitting to form a Y-shape with the radius of 0.35a and refractive index =3.46. The working of Reflecting rod is it splits light wave into two means it splits the light wave. That’s why we have placed the Reflecting rod at the splitting point of waveguide. All the junction rods at the Sum side are having different radius (J1=0.25a, J2=0.3a, J3=0.17a, J4=0.17a; Refractive index=3.46) not like other silicon rods. And also junction rods at Carry side are also having different refractive index and also having different radius (Refractive index of J5, J7 and J8 =3.46, Refractive index of J6=1.92; Radius of J5=0.3a, J6=0.3a, J7=0.18a and J8=0.17a). Fig.4 shows the Refractive Index profile of our proposed design in which we can clearly observe its properties.

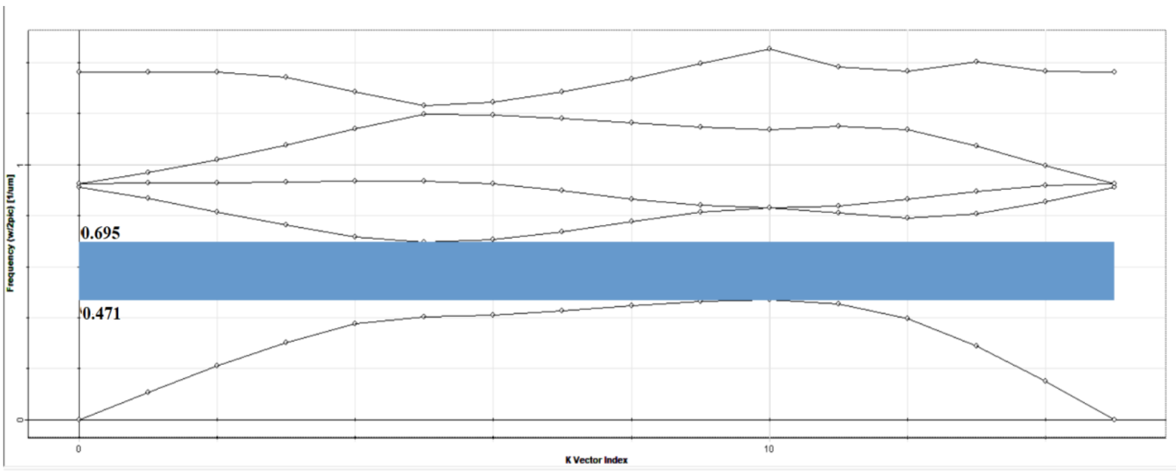

Fig.4 PBG Structure of Half-Adder

Fig. 4 shows the PBG structure of the Half-Adder. PBG (Photonic Band Gap) is a phenomenon in which the optical wave propagation is controlled by selecting required operational frequencies. It is simulated using Planar Wave Expansion.

For our proposed Half-Adder, the spectral ranges are between (0.471, 0.863).

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3. Simulation Results of Proposed Optical Half-Adder:

3.1 Case 1: A=0; B=0 (A is low, B is low)

In this case both the ports A and B are in off state that is A and B inputs are low and Reference input is high. The Reference input which will always be in active state in all cases. In this case according to its working the output must be zero. We have given initial phase angle of the reference input is 0^o.

At Sum port we have got the output power of 0.28mw and at Carry port 0.01mw both the powers are very low, so the condition is satisfied. In this design we got no output power at both the outputs Sum and Carry. This happens because no interference occurs at both the junctions so the signal gets cancelled at the junction. . Fig 5(a) shows the optical field propagation.

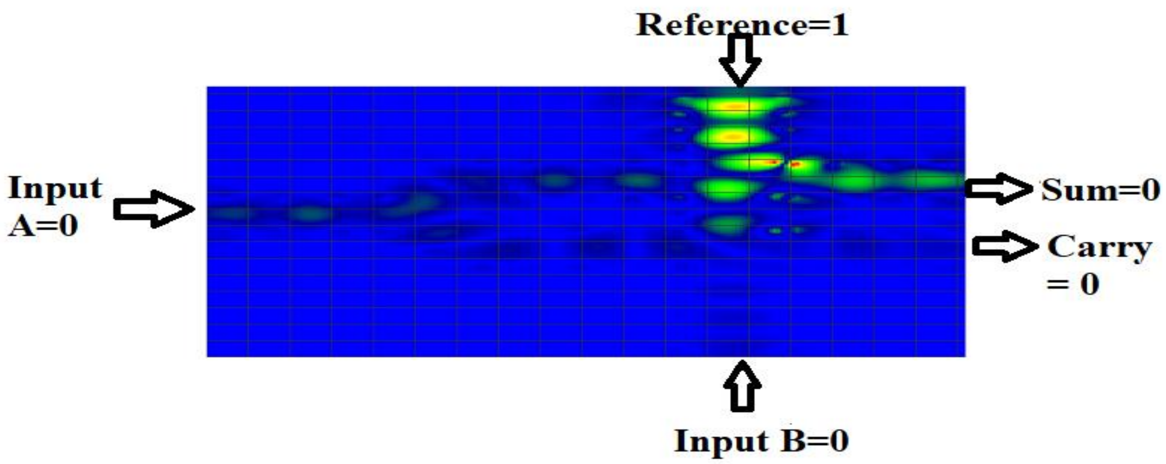

Fig.5(a) optical field propagation of Half-adder for condition of logic 0, 0

3.2 Case 2: A=0; B=1 (A is low, B is high)

In this case port A is in off state, port B and Reference ports are in ON state. In this condition we have to get output logic 1. To get this we had gave the input B with phase angle of 180^o and Reference input with 0^o phase difference is odd and according to design path difference between is also odd so, Construction interference occurs at the junction of sum side and we got the outpower at Sum port. We do not get power at Carry because path difference between B and Reference at carry junction is odd so, Destruction interference occurs and gets cancelled.

At Sum port we have got the output power of 0.49mw this power can be considered as logic '1' and at Carry port 0.18mw this power is very low so this is considered as logic '0'. Hence the condition is satisfied. Fig5(b) shows the Optical field propagation for 0,1 condition.

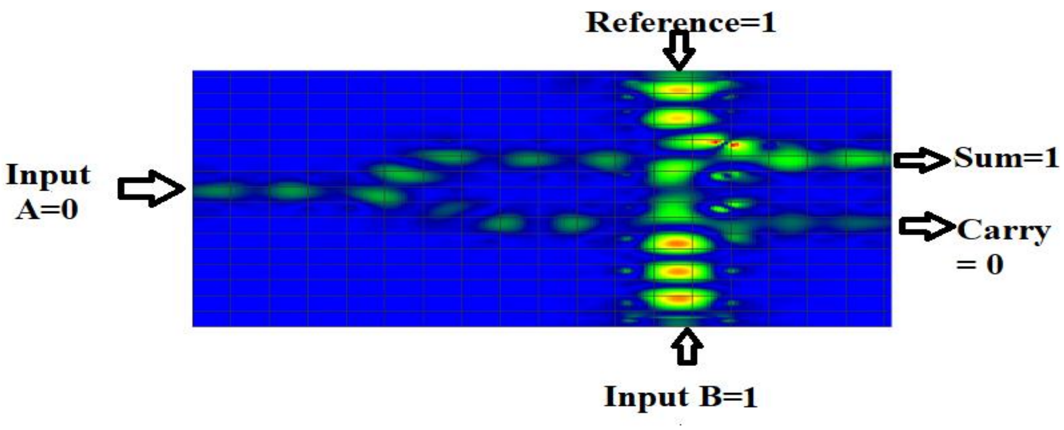

Fig. 5(b) optical field propagation of Half-adder for condition of logic 0,1

3.3 Case 3: A=1, B=0 (A is high, B is low);

In this condition B input is low, input A and Reference inputs are in on state. It means A and Reference inputs are High, B input is low. In this condition we have to get the output logic 1. To achieve this input A and Reference both the inputs were given with initial phase of 180^{o}. There is no phase difference between them and path difference is odd but we got the output at Sum port, this is happened because of our design. At the carry port both phase difference and path difference were Even but due to our design the light cannot be appeared at Carry port.

At Sum port we got power 0.79mw this can be considered as logic '1' and at Carry port we got power of 0.01mw this is very low so it is considered as logic '0'. Hence the condition is satisfied. Fig.5(c) shows the optical field propagation for condition 1,0.

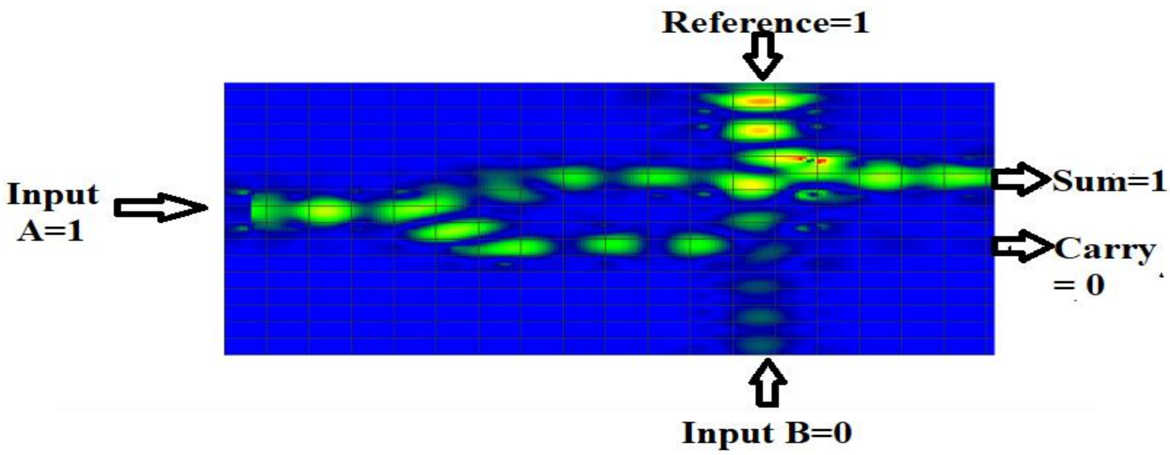

Fig.5(c) optical field propagation of Half-adder for condition logic 1,0

3.4 Case 4: A=1, B=1 (A is high, B is high)

In this condition inputs A, B and Reference all three are in ON state means all three inputs are High. In this condition we have to get the Sum output zero and Carry output 1. So here we want Sum 0 and Carry 1. In our design A is given with 0° phase, B with 180° and Reference also with 180° phase. Construction interference occurs at junction J2 but due to design very less power 0.21mw at Sum port so it is considered as zero. Phase difference and path difference between B and Reference input is Even So Construction interference happens and light appears at Carry port. We got power of 0.505mw at this carry port. Hence the condition is satisfied. Fig.5(d) shows the optical field propagation in condition 1, 1.

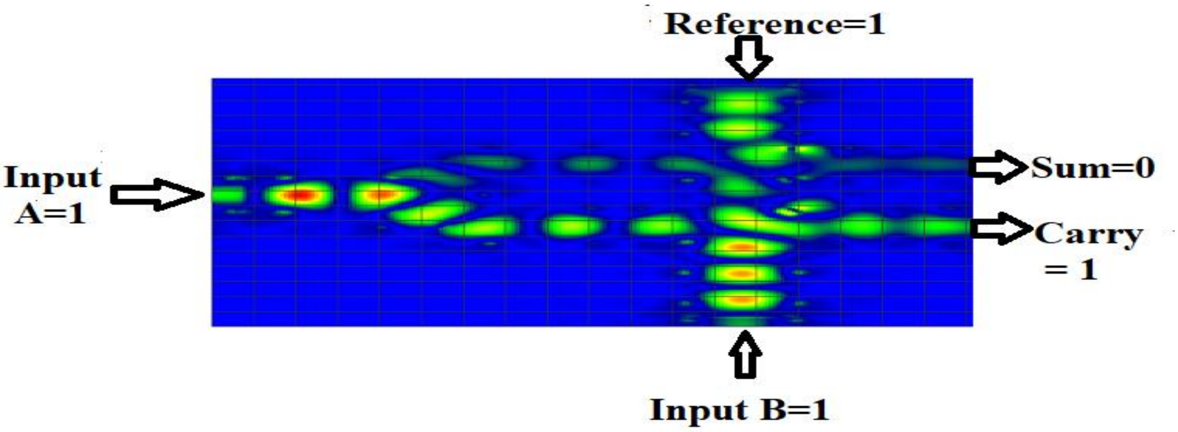

Fig5(d) optical field propagation of half-adder for condition logic 1, 1

Inputs						Outputs			
Logic Inputs			Phase Inputs			Logic Outputs		Normalized values	
A	B	Ref	A	B	Ref	Sum	Carry	Sum	Carry
0	0	1	-	-	0°	0	0	0.28mw	0.01mw
0	1	1	-	180°	0°	1	0	0.49mw	0.17mw
1	0	1	180°	-	180°	1	0	0.79mw	0.01mw
1	1	1	0°	180°	180°	0	1	0.25mw	0.505mw

Table.2 Truth Table Half-Adder along with Initial Phase angles of Inputs

Table. 3 shows the Comparison of output power values for different Refractive Index Values raging from 3.4 to 3.48.

		3.4		3.42		3.44		3.46		3.48	
A	B	S	C	S	C	S	C	S	C	S	C
0	0	0.19mw	0.1mw	0.21mw	0.05mw	0.33mw	0.03mw	0.28mw	0.02mw	0.2mw	0.02mw
0	1	0.27mw	0.16mw	0.25mw	0.16mw	0.35mw	0.42mw	0.49mw	0.18mw	0.2mw	0.23mw
1	0	0.4mw	0.15mw	0.27mw	0.08mw	0.61mw	0.03mw	0.79mw	0.01mw	0.28mw	0.02mw
1	1	0.03mw	0.19mw	0.45mw	0.53mw	0.2mw	0.6mw	0.21mw	0.5mw	0.53mw	0.46mw

Table. 3 Comparison of Normalized power values with Different Refractive Index values

3.4 Contrast Ratio

→ Contrast Ratio can be calculated by using the formula,

$$CR = 10\log_{10}\left(P_1/P_o\right)$$

Where P_1 is the high-power and P_0 is the low power ratio:

A	B	Sum	Carry
0	**0**	**0.28**	**0.02**
0	**1**	**0.46**	**0.18**
1	**0**	**0.79**	**0.01**
1	**1**	**0.21**	**0.505**
CR		**6dB**	**17dB**

Table.4 Calculation of CR

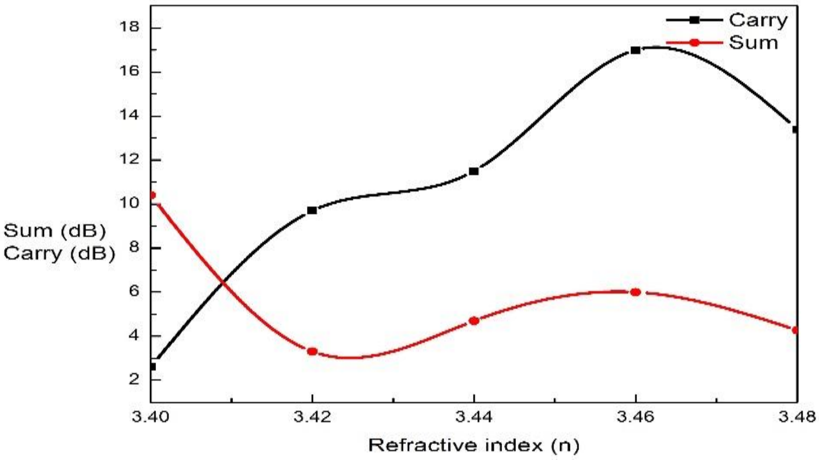

Fig. 6 Comparison of RI and CR

Above Fig.6 which shows the graph of comparison of Contrast Ratio for different Refractive index values.

4. Conclusion;

In this work, we have proposed Half-Adder using 2-D photonic crystals by using T-shaped and Y-shaped Waveguides. We have got the Contrast Ratio of 17dB. By the use of a Reference signal, we have got the Sum and Carry outputs. Reflecting and Junction rods are used in this proposed design. This model is compact in size so we can use it in optical integrations. Here this design is Simulated by using the FDTD platform. It has good contrast ratio which works at wavelength 1550nm.

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