Realization of All Optical Half Subtractor using 2-D Photonic Crystal Waveguides

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Abstract: In this paper, we have reported an All-Optical Half Subtractor using 2-D photonic crystals of T shaped waveguides with square lattice and silicon dielectric rods in air background. The design is based on the principle of Beam interference mechanism. The performance of the proposed structure has been simulated and verified by using finite difference time domain method and the design having compact size, this design can be used in photonic integrated circuits and all optical signal processing. The model having a contrast ratio of 8dB and 13dB with optimized silicon rod radius that is 0.6a and has a refractive index of 3.36 and is operated at a wavelength of 1500nm.

KEY WORDS: Photonic Crystal, Half Subtractor, Defects, T-Shaped Waveguide, Beam Interference.

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INTRODUCTION

In the last decade, semiconductor technology is a versatile platform used in various integrated circuits is falling back due to response time, power dissipation, operational speed and switching time. To overcome these optical devices came into origin. These optical devices are having some superior properties like higher capacity, low power dissipation, compactness. All optical logic gates are the basic elements for optical communication and several methods have been proposed for designing of these optical logic gates.

Optical logic gates accomplished by photonic crystals satisfy all these properties. In photonics [1] information is carried out with help of photons so data is always safe and secure. PhC's have some unique features like high speed, low power consumption [2]. In PhC's light [3] is manipulated by creating defects in the design. Point defect for resonators and line defects for waveguides. So far, distinct techniques came into existence for designing of optical logic gates used for optical networks. Semiconductor optical amplifier (SOA) [4] suffers from spontaneous emission of noise and operational speed depends mostly on the carrier recovery time. Mach Zehnder interferometer [MZI][5] are highly sensitive to random phase changes and are of complex integration. PhCRRs [6] they have complex structures. In Self collimation [7] there is a difficulty in controlling the dispersion. Semiconductor ring resonators, consume low input signal power but in large dimensions they are limited and low speed. To overcome these photonic crystals came into domain. Photonic logic gates such as AND, OR, NAND, NOR, XOR, XNOR [8] are the keystones for both combinational and sequential circuits. Many researchers come up with different designs of Multiplexer/Demultiplexer [9-10], Encoder/Decoder [11], half adder/Full adder [12], comparator by using 2-D photonic crystals that are used in high-speed telecommunication and optical arithmetic logic gates.

Problem Formulation

In this paper, to our finest knowledge on photonic devices we proposed a half subtractor using beam interference mechanism with silicon dielectric rods in air background. Prior, many models of half subtractor are introduced by using PhC's as follows Parandin et al which was designed by using cross connected optical waveguides [13], Moradi designed optical half subtractor in which three nonlinear ring resonators [14] are used, Askarian et al designed optical half subtractor by beam interference [15]. The design proposed is compact in size, high speed and having good contrast ratio with less reflection is obtained and this was analysed and optimized by using Finite Difference Time Domain (FDTD) [16] method. This inside work is scheduled as Section 1 Introduction. Section 2 deals with design proposed, mode of functioning and working principle. Section 3 defines simulation results and discussion. Section 4 arrival of the conclusion of proposed mode.

DESIGN AND WORKING OF ALL OPTICAL HALF SUBTRACTOR

A Half Subtractor is a major element in designing of complex integrated and feedback circuits is simple in structure. Operation of half subtractor is when XOR operation applied on input binary bits the output is termed as subtrahend and when NOT, OR operation is applied that output is minuend.

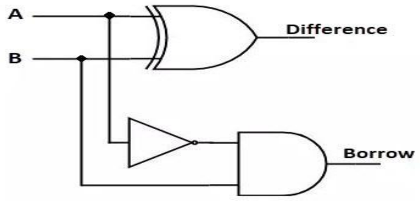

Fig. 2: Block diagram of Half subtractor

A	B	DIFF	BORROW
0	0	0	0
0	1	1	1
1	0	1	0
1	1	0	0

Table 2: Truth table of Half Subtractor

The structure made from the dimension of 7.8*7.8 μm with a Refractive index (RI) of 3.46 and the silicon rod radius is 0.2a where a is lattice constant (0.6) the distance between adjacent silicon rods and operated at a wavelength of 1500nm. These contains two T shaped waveguides [17] those are creating by removing the dielectric rods. These created with square lattice with silicon dielectric rods in air background. The radius of the junction rods is optimized to 0.12 having less reflections to the input. Here three input ports named as A, B, Ref are used and two outputs ports such as Diff, Borrow. In structure left side horizontal waveguide represents input port 'B', upper side of vertical T-shaped waveguide represents output port 'Borrow', lower left side of vertical T-shape waveguide represents reference port 'A', right side horizontal waveguide represents output port 'Diff' and lower side of vertical waveguide represents input port 'Ref' as shown in fig. 2.1

The operating principle of the Proposed model is Beam interference mechanism which has dual type of interferences those are constructive or destructive. Depending on the phase and path difference in the structure one of this interference occurs. As explained by wave optics theory, when the phase difference between the light beams is even integral or 0^0 then constructive interference occurs and destructive occurs when the phase difference is odd integral or 180^0.

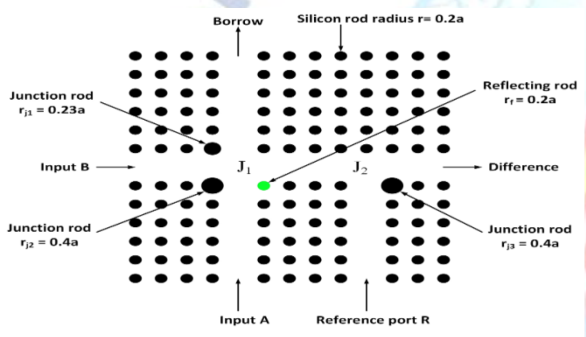

Fig. 2.1: Proposed model of all optical half subtractor structure

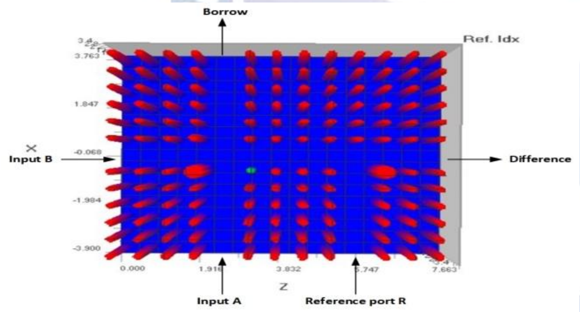

Fig. 2.2 Layout Design of Half Subtractor Structure

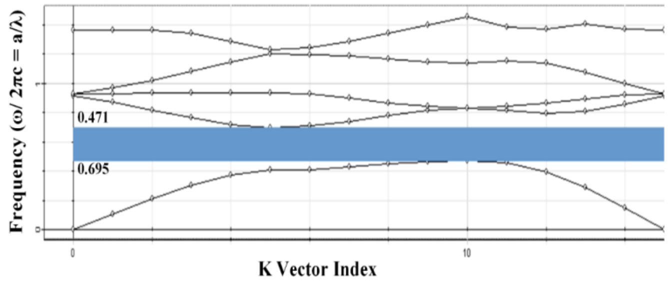

Fig. 2.3: PBG structure of all-optical half subtractor for TE mode

The photonic band gap (PBG) is a special phenomenon in photonic crystal waveguides [18] in which optical signal propagation is being controlled by selecting required operational frequencies that is simulated using planar wave expansion. Prior in electronics energy band gap that exists between the conduction and valance band here in PBG the propagation does not exist between the two spectral ranges.

These spectral ranges of proposed half subtractor are between λ= (0.471, 0.695) calculated from a/λ where a is lattice constant and λ is continuous wavelength. So, light could not propagate and reflected back with in this ranges (1.273, 0.863) as shown in

Optimization of Refractive index (RI)

This model of half subtractor is verified and analysed under different refractive indexes and out of this a better refractive index of 3.46 that has satisfied all the conditions of half subtractor truth table with maximum output power >0.5 and minimum power of 0.2>

OUTPUT POWER											
A	B	3.40		3.42		3.44		3.46		3.48	
		D	B	D	B	D	B	D	B	D	B
0	0	0.26	0.02	0.20	0.02	0.17	0.02	0.21	0.02	0.21	0.05
0	1	0.52	0.36	0.42	0.37	0.47	0.40	0.56	0.46	0.46	0.37
1	0	0.96	0.03	0.88	0.05	0.78	0.04	0.72	0.06	0.91	0.05
1	1	0.07	0.13	0.02	0.11	0.04	0.16	0.14	0.18	0.03	0.17

Table 2.1: Intensity at output port for different RI

SIMULATION RESULTS AND DISCUSSION

3.1 Case: 00 (Input 'A' low, Input 'B' low)

In this combination both the input ports are in off state that is input 'A' input 'B' are low and reference signal 'R' that is always high in any input combination. The required output, low state in both the conditions of difference and borrow is observed. The delivery of reference input light to the output ports is reduced by placing junction rods, reflecting rods. No interference occurs because of only one active signal. So, this satisfied the condition of half subtractor, low states in both the inputs and outputs and the phase of the reference is 0.

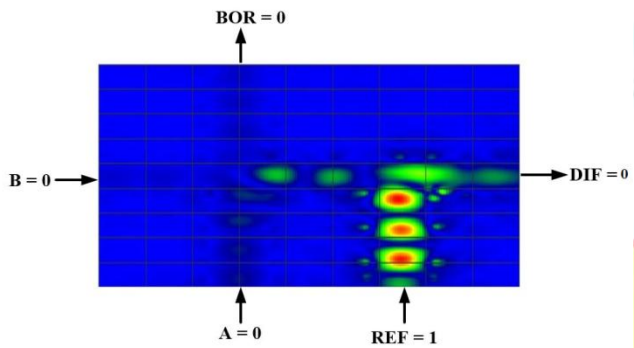

Fig.3.1: Output power intensity for input combination of 00

3.2 Case: 01(Input 'A' low, Input 'B' high)

In this combination of inputs of low and high an output that satisfying the condition of half subtractor having an extra output of borrow is observed. So, both the outputs that are in high states. The junction j1 is followed by constructive interference and junction j2 also has a constructive interference because of their properties satisfying beam interference having an adjacent junction rod, reflecting rods and this condition satisfied the beam interference principle of phase and path difference.

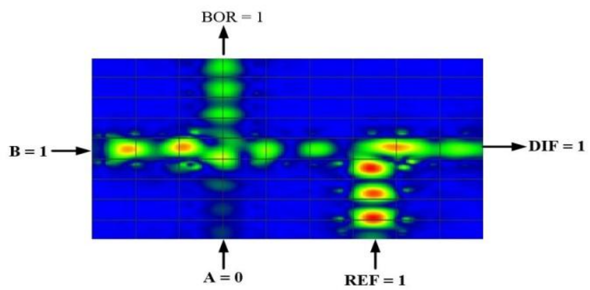

Fig.3.2: Output power intensity for input combination of 01

3.3 Case:10(input 'A' high, input 'B' low)

In this condition of high and low inputs from the ports of A and B which satisfy the condition of half subtractor in which borrow is 0 and output present at the port difference. The output that is constructive at only the junction j2 and because of the presence of reflecting rod the input travels towards the junction j2. The conditions satisfied the principle of beam interference with path and phase difference.

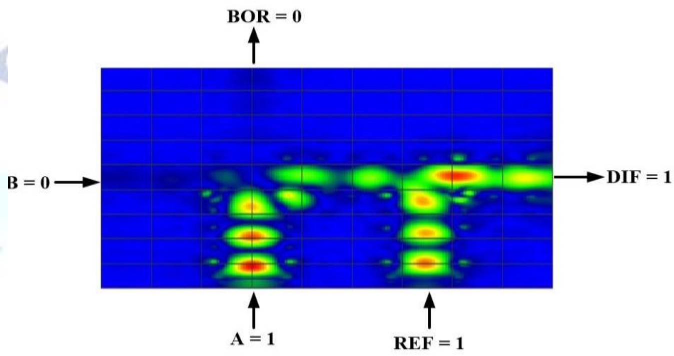

Fig.3.3: Output power intensity for input combination of 10

3.3 Case:11 (input 'A' high, input 'B' high)

In this condition both the inputs ports are high and the reference port that is always high. So, a high signal that is present at each of the input ports and due to destructive interference, that is seen at both the junction. So, no signal that is present at that junction j1 and junction j2 because of destructive interference. This satisfied the condition of subtracting between two high inputs is zero and also satisfied the beam interference of phase and path difference.

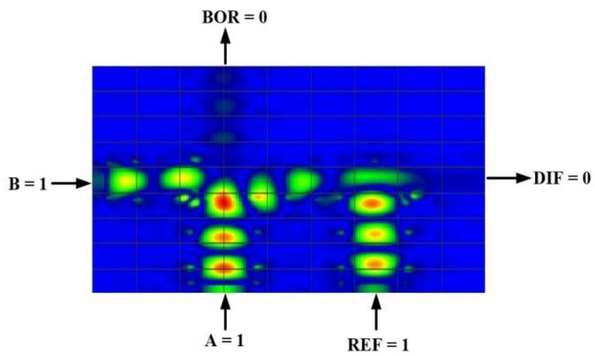

Fig.3.4: Output power intensity for input combination of 11

Normalized values of All optical half subtractor is shown in below table

INPUTS			OUTPUTS		NORMALIZED VALUE	
A	B	REFERENCE	DIFFERENCE	BORROW	DIFFERENCE	BORROW
0	0	1	0	0	0.21	0.02
0	1	1	1	1	0.56	0.46
1	0	1	1	0	0.72	0.06
1	1	1	0	0	0.14	0.18

Table 3.1: Normalized output power

These design of half subtractor that is verified by varying the Refractive Index and calculation of the output parameters. These model gives a better output at a RI of 3.46. The design is operated as an all-optical Half Subtractor for the wavelength range from 1.52 µm to 1.56 µm. The functionality of this design is verified for wavelength ranging from 1.52µm to 1.56µm and we analysed that design, it provides the best Contrast Ratio (CR) at a wavelength of 1.55µm.

By, changing the RI the CR that is been calculated. At the RI of 3.46 that gives the optimized contrast ratio.

$$\mathbf{CR = 10 \log_{10}\left(P_1/P_0\right)}$$

Where p1 is the high-power level and p0 is the low power level.

INPUT		OUTPUT	
A	B	DIFF	BORROW
0	0	021	0.02
0	1	0.56	0.46
1	0	0.72	0.06
1	1	0.14	0.18
CONTRAST RATIO (CR)		**8dB**	**13dB**

Table 3.2: Calculation of Contrast Ratio (CR)

Apart from contrast ratio this proposed model that is good in both Transmission Ratio and Insertion Loss compared with the previous models.

Transmission Ratio that is determined by

$$\mathbf{TR = (P_y/(P_a+P_b+P_r)) * 100\%}$$

Where, P_y is the output power and $(P_a+P_b+P_r)$ is the total input power that is obtained from each input port. A good transmission ratio that is seen from it for the proposed design.

Table below compares the proposed model with existing model of half subtractor.

Material	RI	Lattice constant	Wafer dimensions(µm²)	CR	Model
Silicon	3.4	0.6	12*10.5	--	19
Silicon	3.46	0.6	18*44.4	--	20
Silicon	3.46	0.6	7.8*7.8	13dB	Proposed

Table 3.3: Comparison of different proposed model

The table below illustrates the comparison of Refractive Index (RI) and Contrast Ratio (CI)

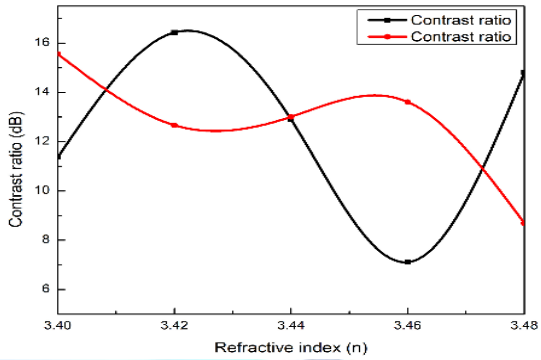

Fig. 3.5: Comparison of RI and CR

CONCLUSION

In this work, a Half Subtractor is been proposed by using 2-D photonic crystals by creating T shaped waveguides. A reference signal been used to obtain the exact functionality of difference and borrow. The parameters like reflecting and junction rods are optimized in the proposed model to avoid back reflections at the input port and no other nonlinear materials or optical switches are used. The model is compact in size is advantageous can be used in photonic integrated circuits. The optimization of RI and silicon rods to 3.46 and 0.2a. The mechanism here is well explained by beam interference and been simulated by using FDTD. A good Contrast Ratio and Transmission Ratio is observed and less Insertion Loss which functions at a wavelength of 1550nm. So, this design can be used for conventional operations.

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