Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 5, Issue 01, January -2018

Analysis of All Optical Feynman and Majority Reversible gates Using 2D Photonic Crystals

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Abstract: *This paper presents the two reversible logic gates on 2D photonic crystal with optical power as an inout. Reversible logic is one of the solutions for ever demanding increase in density of future electronics based on quantum computation with almost zero energy dissipation. Optical simulation of Feynman gate with output efficiency ≥ 30% is considered to be logic '1' and logic '0' and logic '1' for Majority gate with transmission efficiency ≤ 20% and ≥ 50% respectively. The 2D FDTD simulation of Feynman gate with contrast ratio 3.01 dB and Majority gate 10.37 dB is achieved.*

Keywords: *Reversible logic gates, Photonic crystal, Feynman gate, Majority gate, Contrast ratio.*

I. INTRODUCTION

Reversible logic operations based on the quantum computation is one of the demanding field in designing miniaturized optoelectronic devices. In 1973, C. H. Bennett has demonstrated different computing technology which does not erase information of inputs after processing the outputs hence virtually proved zero dissipation of energy [9]. Reversible system means it has to operate in both the direction and this property will reproduce the inputs form the output. A logic gate or circuit is said to be reversible if and only if there is a one-to-one mapping between its input and output assignment hence the number of outputs is equal to the number of inputs [6].Optical technology is one of the alternative method for designing low power dissipation and high speed devices. Photonic crystal (PhC) light controlling waveguides are the great platform for designing all optical devices. PhC's are the materials with low absorption and periodic refractive indices. The periodicity will be in 1D, 2D and 3D out of these 2D PhC's have received great attention towards designing all optical photonic crystal based devices. Photonic bandgap is preventing light from propagating in certain directions with specified wavelengths this phenomenon is known as photonic crystal waveguide [2].The optical power transmission expressed as a ratio of power output at logic '1' to the logic '0' and is known as contrast ratio(CR) expressed in dB.

$$CR= 10 \log (P_1/P_0) \qquad \text{.....(1)}$$

Where 'P_1' represents logic 1 power output and 'P_2' logic 0 power output of PhC structure.

In this paper we have analyzed all-optical Feynman and Majority gates using 2D silicon PhC's. The Feynman gate is a logic reversible gate with 2 inputs A & B and two outputs P & Q. The outputs are defined by the following Boolean expressions.

$$P = A \qquad \text{..... (2)}$$

$$Q= A \oplus B \qquad \text{..... (3)}$$

Where '$\oplus$' represents logic XOR.

A majority gate is a combinational circuit with an odd number of inputs and only one output. Output determines the Boolean value of the majority of inputs other inputs can be at any value (including unknown, or X). The smallest majority gate can be described by the following Boolean expression.

$$R = (A * B) + (B* C) + (C * A) \qquad \text{..... (4)}$$

Where '*' represents logic AND, and '+' logic OR.

II. DESIGN ASPECTS OF STRUCTURES

The reversible all optical Feynman and Majority gates are designed on 2D photonic crystal platform shown in figure 1 and figure 2.

Structure with hexagonal lattice of utility array dimension of 30 unit cell width of Si rod and 31 unit cell heights of Si rod with air as a background medium. Lattice constant (a) is of value 0.558μm and radius(r) is of value 0.118 μm.

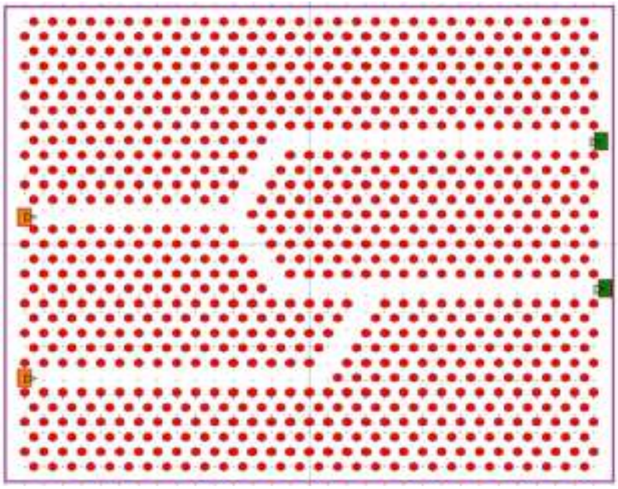

Fig. 1 Lattice structure of optical Feynman gate

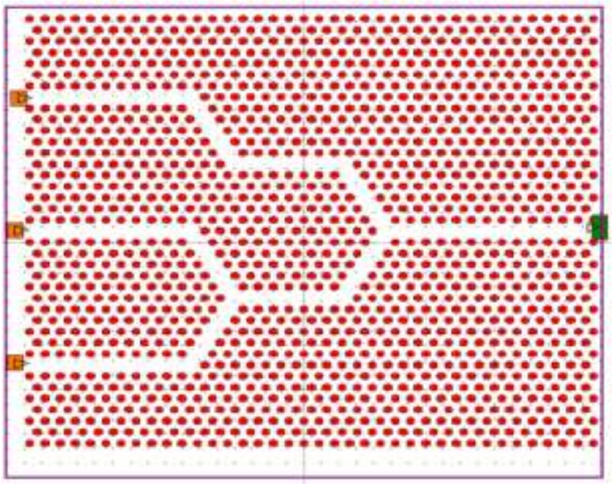

Fig. 2 Lattice structure of optical Majority gate

Figure 3 shows Feynman gate with two inputs and two outputs and figure 4 shows reversible Majority gate with three inputs and three outputs the last output is computed based on majority logic function.

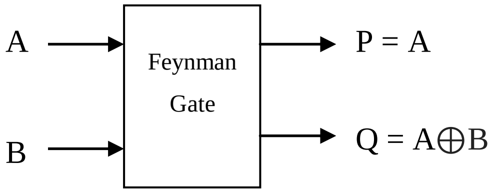

Fig. 3 Reversible Feynman gate

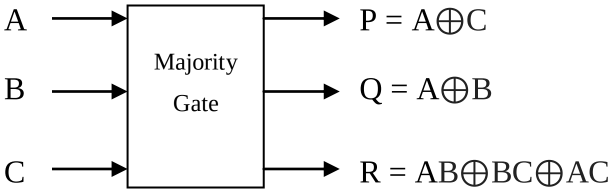

Fig. 4 Reversible Majority gate

The operating wavelength (λ) can be calculated by plane wave expansion method (PWE). The execution of lattice structure using BandSOLVE software provides Band diagram shown in figure 5. For a particular structure operating wavelength is determined by the range $0.21 \leq a/\lambda \leq 0.40$ obtained by band diagram. The wavelength range 1450nm to 2150nm is obtained in that 1550nm is used in most of the telecommunication applications because of low attenuation.

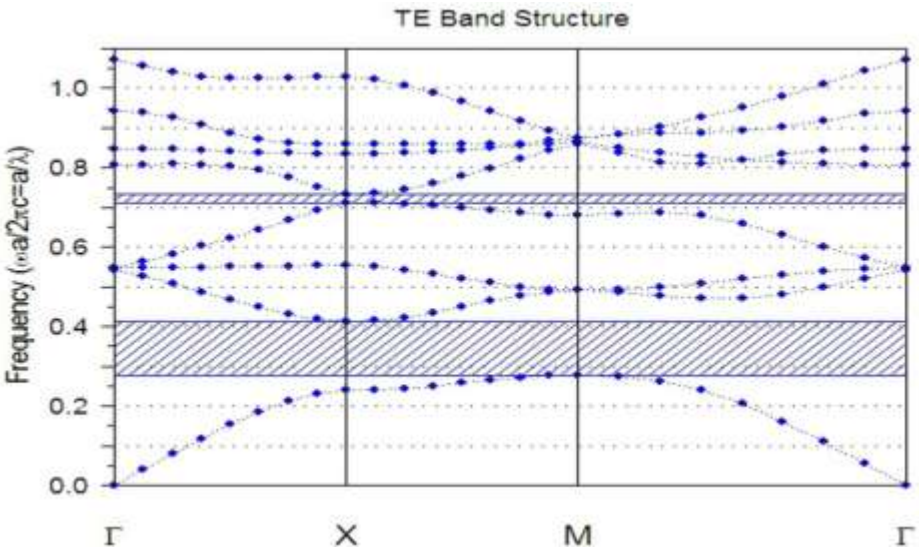

Fig. 5 Band diagram of 2D PhC lattice structure

The optical simulations are carried out using licensed RSoft FullWAVE software based on 2D Finite Difference Time Domain (FDTD) method. Figure 6, 7 and 8 shows simulation results of Feynman gate with different input combination obtained power transmission output at two output port monitor and simulation results with contrast ratio is shown in table 1.

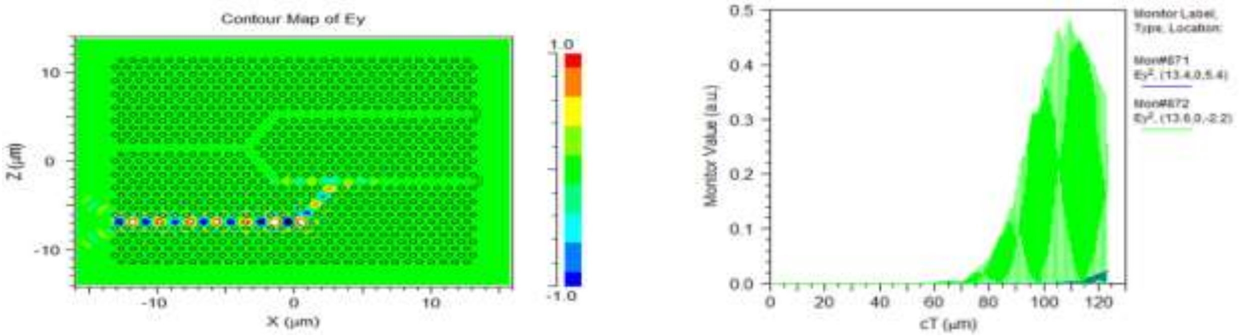

Fig. 6 2D FDTD simulation result of Feynman gate with A=0 and B=1

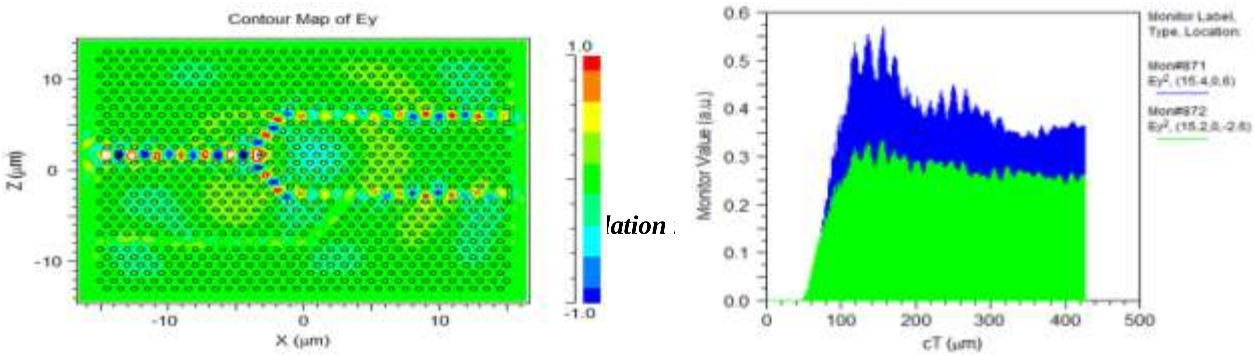

Fig. 7 2D FDTD simulation result of Feynman gate with A=1 and B=0

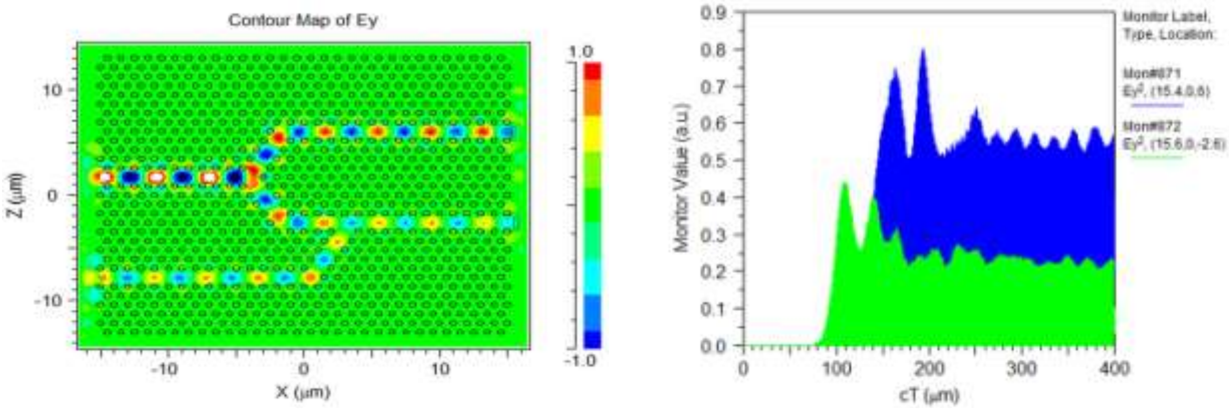

Fig. 8 2D FDTD simulation result of Feynman gate with A=1 and B=1

Inputs (Power in a.u.)		**Theoretical Outputs**		**FDTD Simulation Results (Power in a.u.)**		**Contrast ratio**
A	**B**	**P**	**Q**	**P**	**Q**	**CR_Q**
0	1	0	1	0.05	0.48	
1	0	1	1	0.57	0.37	3.01dB
1	1	1	0	0.82	0.24	

Figure 9, 10, 11 and 12 shows simulation results of Majority gate with different input combination obtained power transmission output at only third output(R) monitor and simulation results with contrast ratio is shown in table 2.

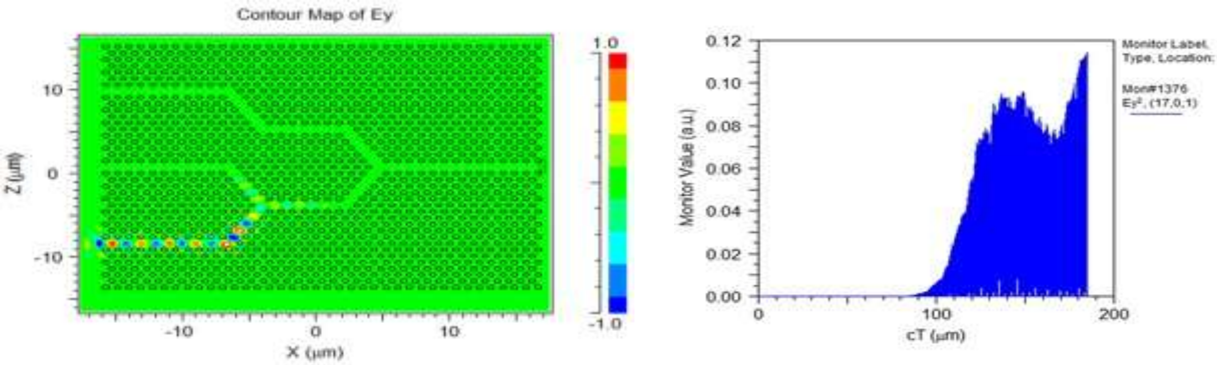

Fig. 9 2D FDTD simulation result of Majority gate with A=0, B=0 and C=1

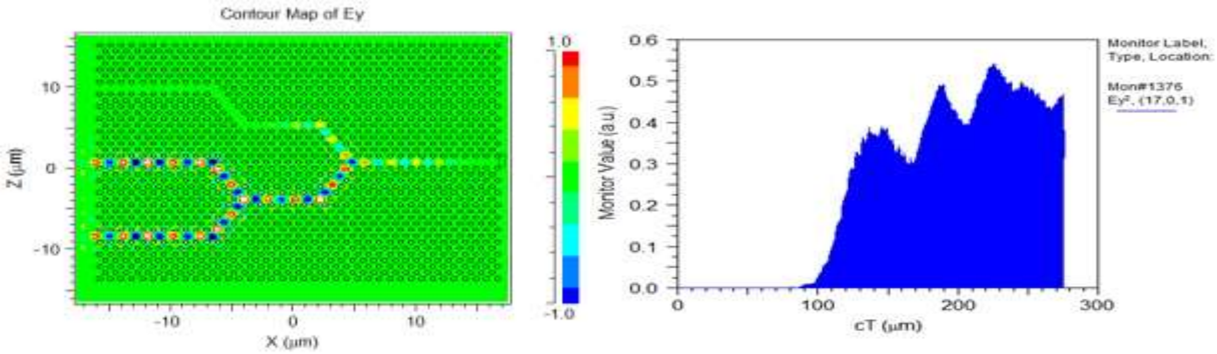

Fig. 10 2D FDTD simulation result of Majority gate with A=0, B=1 and C=1

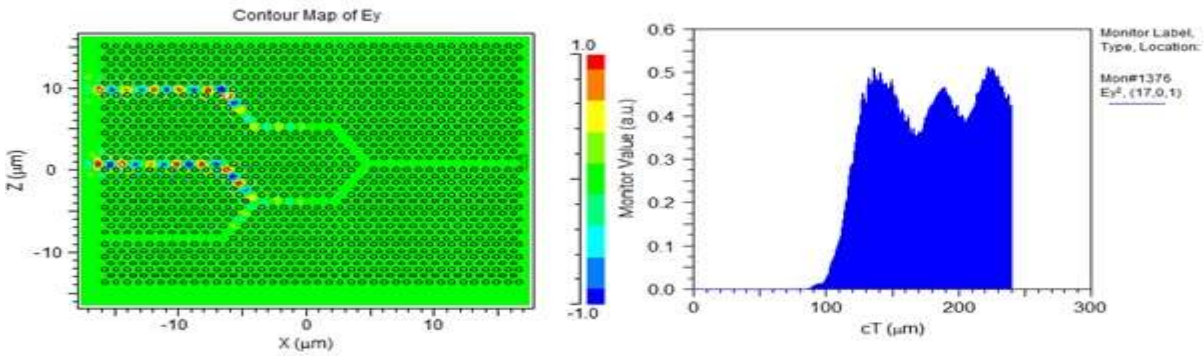

Fig. 11 2D FDTD simulation result of Majority gate with A=1, B=1 and C=0

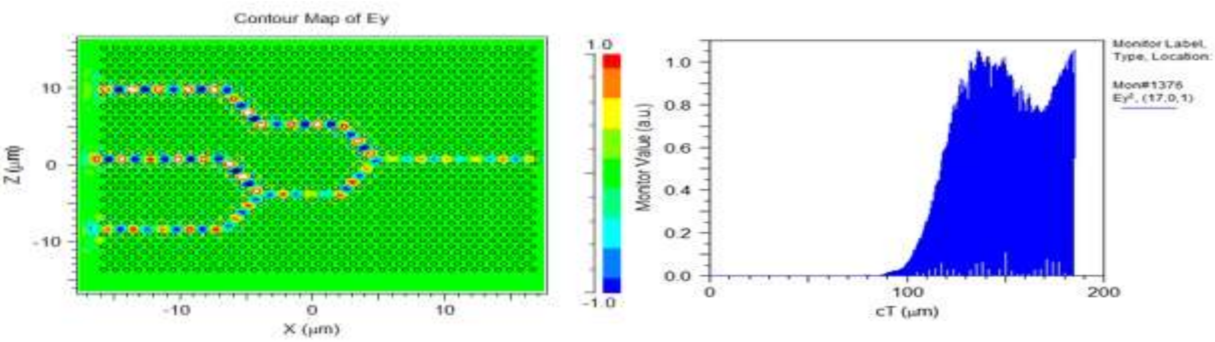

Fig. 12 2D FDTD simulation result of Majority gate with A=1, B=1 and C=1

Inputs (Power in a.u.)			Theoretical Outputs			FDTD Simulation Results (Power in a.u.)	Contrast ratio
A	**B**	**C**	**P**	**Q**	**R**	**R**	$\mathbf{CR_R}$
0	0	1	1	0	0	0.11	10.37 dB
0	1	1	1	1	1	0.55	
1	1	0	1	0	1	0.55	
1	1	1	0	0	1	1.2	

Table 2 FDTD Simulation results of Majority gate

IV. CONCLUSION

This paper has presented a different approach for reversible gates in 2D PhC's to achieve best contrast ratio of 3.01dB and 10.37 dB for both Feynman and Majority gates. Licensed RSoft FullWAVE software based on finite difference time domain (FDTD) method is used for simulation of the 2D PhC's structure. Licensed RSoft BandSOLVE software based on plain wave expansion (PWE) method is used for calculating the operating wavelength. Optical simulation of Feynman gate with output efficiency ≥ 30% is considered to be logic '1' and logic '0' and logic '1' for Majority gate with transmission efficiency ≤ 20% and ≥ 50% respectively. Major drawback of photonic crystal structure is cascading is not allowed because of weak transmission of power from input to output that leads to a issue for photonic integrated circuit.

ACKNOWLEDGMENTS

This work is supported by Vision Group on Science & Technology, Bangalore, Karnataka State under Award no.VGST/K-FIST (L1) (2014-15)/2015-16/373

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