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Performance Analysis of 2D Photonic Crystal Optical Not Logic Gate

Gloria Joseph *, Mrs. Vijaylaxmi Kalyani
* Digital Communication, Govt. Women Engineering College,Ajmer , India

Abstract

The work presented in this paper potrays the working of NOT logic gate which is implemented using the 2D photonic crystal instead of using conventional semiconductor devices. The gate fabricated is implemented on a air wafer of 12µm x 12µm.The dielectric used is silicon to fabricate the rods of the radius =0.2a where 'a' is the lattice constant taken as 0.11886µm.The refractive index of silicon= 3.39.The square lattice of gate implemented is simulated on the wavelength of 1.7µm using finite difference time domain method using the tool opti FDTD.

Keywords: NOT logic gate, PCRR(photonic crystal ring resonator), FDTD, quality factor and contrast ratio.

Introduction

Semiconductor materials and devices have always dominated the world of electronics in the form of gates, diodes, transistors, etc.. In today's world rapidly growing technologies we require advancements in every field specially electronics. So we move in the context of this advancement form electronics to the world of optics. Our effort through this work is to make the semiconductor devices work in the optical field. Hence, we use the most promising optical structure of photonic crystals by implementing optical logic gates instead of analytical electronic gates. Various gates have been implemented using different techniques such as SOA's(semiconductor optical amplifier), PPLN(periodically poled lithium noibate), multimode interference, MZI(mach zhender interferometer), nonlinear effects of SOI waveguide. As against the disadvantages of these methods which are like low power transmission, high input power, complex designs, heavy cost and complex stuctures etc. we use photonic crystals overcoming all the short comings. So the PhC optical NOT logic gate presented here is highly advantageous with high transmitting power and simple design.

The performance of this gate is evaluated numerically by taking into considerations two fators: quality factor and contrast ratio.

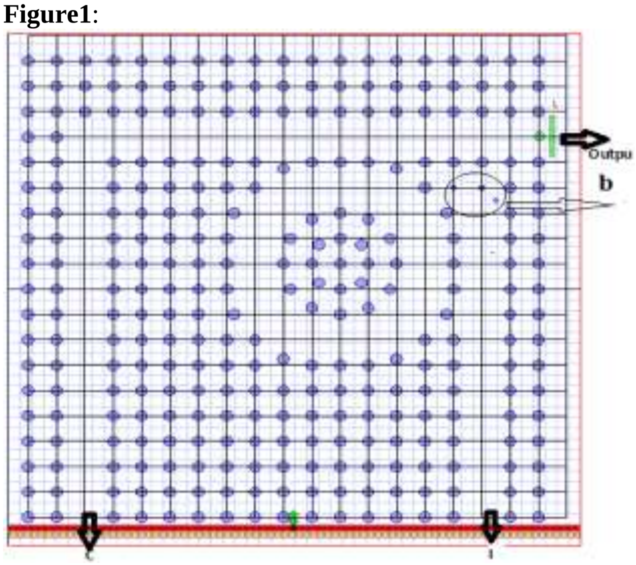
The paper is summarized as follows: section II deals with the designing, followed by section III of results and the discussion of the principles involved. Section IV of conclusion.

Materials and methods

Structure designing

Dielectric rods:	silicon
Refractive index:	3.39
Wavelength:	1700nm
Lattice constant 'a':	.5943µm
Radius of rods:	.11886µm
Wafer size:	12 µm x 12µm.

Figure1:



Silicon square lattice of optical NOT logic gate

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The figure 1 shown above is the implemented optical NOT logic gate structure.Circular ring of PCRR ia a microcavity is made by varying rods in the corner from centre by 0.2a in XZ directions. So accordingly inner and outer rods are adjusted giving rise to circular rings. One input waveguide is marked as control signal (c) which is shown by upper horizontal waveguide. This channel waveguide is made by removing the required no. of si dielectric rods called as line defects. An observation point is placed at end of waveguide Another waveguide is the main input marked as 'I' connected vertically to the PCRR. This vertical waveguide is made by creating line defect of 12 si rods.The output signal is calculated from output port marked as 'output' by observing the power transmitted through the upper waveguide. In the end of the input waveguide a scatter rod is placed, shifted by a .707a through which input wavelength propagates inside PCRR. The three si rods marked as 'b' in the figure 1. are of the radius 0.05µm which creates point defects. They are responsible for the light confinement property.For the performance analysis we need to study the electric field propagation calculated by finite difference time domain method.

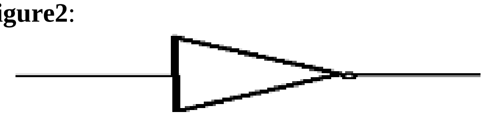
Basic principle involved

Photonic crystals are artificial periodic dielectric structures to confine light passing between the dielectric material. Many application of photnic crystals are couplers, add drop filters, multiplexers, demultiplexers, photonic integrated circuits, logic gates etc. Here the switching property between logic 1 and logic 0 of gate is achieved by the light confinement property of PhCs silicon rods. In logic 1 state there should be maximum power transmitted as compared to the power transmitted in case of logic 0. So the switching nature of NOT gate is proved also giving us an idea of inverting behaviour of the gate hence called as inverter when our structure obeys the truth table shown in table 1. The digital structure shown in figure2.

Table I. Truth Table

Control(C)	Input(I)	output	P
1	1	0	.03
1	0	1	.74

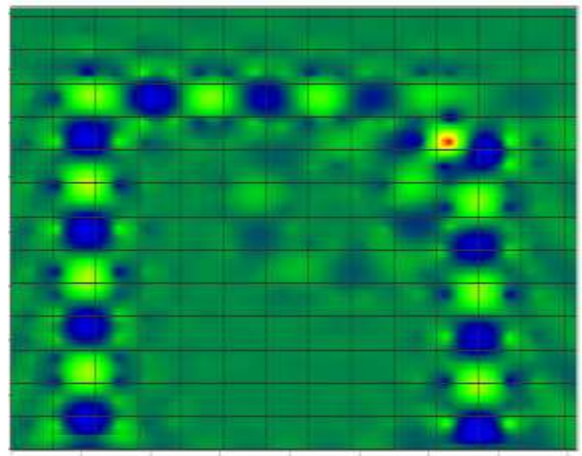
Figure2:



Digital Stucture

In figure 1 the microcavity shown permits a single wavelength to pass with single peak to propagate from input to output. When two input wavenlengths each of 1.7µm from control port and from input port ia active together the electric field interfere with each other destructively and we get no signal at output which cab be understood by beam interference theory. This is shown in figure 3 depicting the electric field propagation in OFF state or logic 0. The poin defects introduced by changing the radius allows for trapping of the continuous wave since it leads to change in the refractive index of rods.

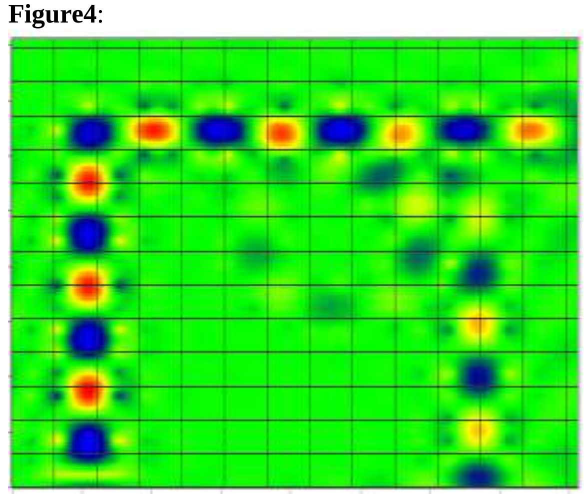
Figure3:



Electric field propagation when I and C are "ON" output = OFF.

When only one control signal is applied, it directly passes through the control waveguide and there is no interference. In this state there is maximum power transmission and this is logic 1 or 'ON' state as shown below in figure 4.

Figure4:



Electric field propagation when I is' OFF. Output= O

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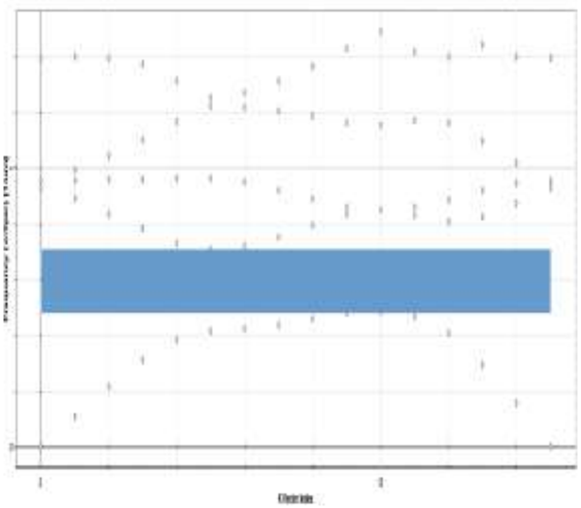
Hence, we can say that electric field propagation results show and prove the switching capability.

The band gap is the state which can be considered same as the energy band gap in which no electrons are present. So in the photonic band gap no wavelength of light propagates or we can say that density of optical states is zero. This is calculated by plane wave expansion method. Band gap is different in TE and TM modes. The stucture presented here produces a TE band gap as shown in figure 5.

Figure5:



Photonic band gap of optical NOT logic gate at TE mode.

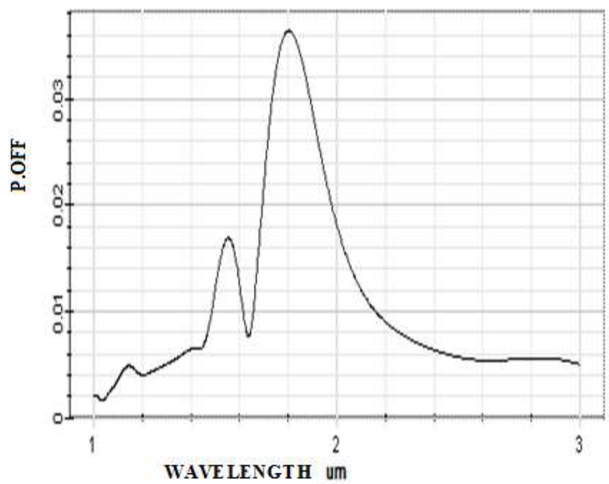
Results and discussion

The truth table and electric field has been already shown. Next, we have plotted power transmission graphs according to discrete fourier transforms for the same simulated results shown above. For the first state, in case of interference, power transmitted is very low for OFF condition. This is shown in figure 6 below.

Similarily when power transmitted for ON state is calculated it is known to have large power transmission shown in figure 7. Now for analysing the high performance of the implemented gate the ratio between these two power levels is calculated which is higher than the previous calculated results. This power transmission factor is called as contrast ratio defined as ratio of average power in ON state to average power in OFF state given as in formula 1:

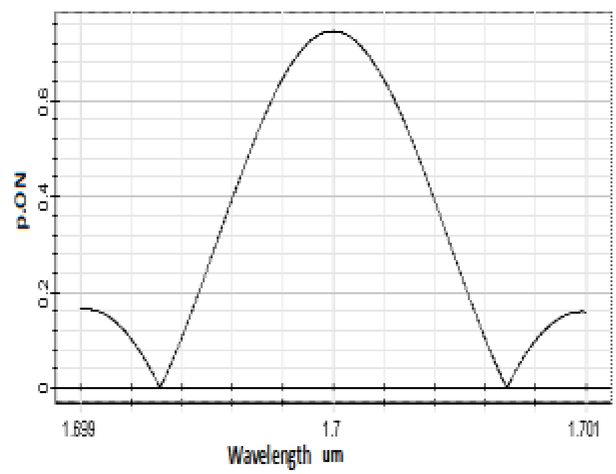
P.ON = 0.74
P.OFF= .03
So. C.R.= 10 log(P.ON/ P.OFF) (1)
= 10 log(0.74/.03)
= 13.92 dB ~14dB

Figure6:



Power transmission in OFF state

Figure7:



Power transmission in ON state

Next. We calculate the figure of merit for the proposed gate called as quality factor for the circular cavity defined as ratio of resonance wavelength to the difference in wavelength given by the relation 2:

$$Q = \lambda/\Delta\lambda \quad (2)$$
$$= 2428$$

Quality factor above 800 is considered as highly beneficial because PCRR plays an important role in switching capability of optical NOT gate.

Conclusion

In the proposed work we can say that light can be controlled by light. We have designed and analysed high performance optical NOT logic gate on

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2D photonic cryrstal. This is proven by quality factor and high contrast ratios i.e. 2428 and nearly 14dB respectively. These performance parameters allows it to be beneficial and promising for applications in optical computing, cryptography, digital processing systems etc

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Author Biblography

Gloria joseph
Passed b.tech form Maharishi Arvind Institute Of Engineering & Technology, Rajasthan, India(2011).Pursuing m.tech from Govt. Women Engineering College , Rajasthan
Email: glrjsph@gmail.com