Design and Analysis of All-Optic Circuits Using 2D Photonic Crystal

Submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

In

ELECTRONICS AND COMMUNICATION ENGINEERING

by

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Vellore Institute of Technology

(Deemed to be University under section 3 of UGC Act, 1956)

April, 2019

DECLARATION

I here by declare that the thesis entitled “**Design and Analysis of All-Optical Circuits using 2D Photonic Crystal**" submitted by us, for the award of the degree of *Bachelor of Technology in* Electronics and Communication Engineering to VIT is a record of bonafide work carried out by us under the supervision of **Dr. A. Rajesh**.

We further declare that the work reported in this thesis has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or University.

Place: Vellore

Date:

Signature of the Candidates

CERTIFICATE

This is to certify that the thesis entitled "**Design and Analysis of All-Optical Circuits using 2D Photonic Crystal**" submitted by Amanjot Singh (15BEC0452), Sumanth Munnangi (15BEC0451), Anuj Chandan Gurbaxani (15BEC0294), SENSE, VIT University, for the award of the degree of *Bachelor of Technology in* Electronics and Communication Engineering, is a record of bonafide work carried out by him under my supervision during the period, 01. 12. 2018 to 30.04.2019, as per the VIT code of academic and research ethics.

The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university. The thesis fulfills the requirements and regulations of the University and in my opinion meets the necessary standards for submission.

Place :Vellore

Date : **Signature of the Guide**

Internal Examiner **External Examiner**

PROF. THANIKAISELVAN V

ELECTRONICS AND COMMUNICATION ENGINEERING

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We owe our deep gratitude to our project guide **Dr. RAJESH A** who took keen interest on our project work and guided us all along, until the completion of our project work by providing all the necessary information for developing a good system. We are extremely thankful to him for providing support and guidance.

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Executive Summary

In recent years, optical logic circuits have been attracting wide attention because of their potential application in fields of optical computing systems, optical signal processing and optical interconnection networks. Because as the conventional electronic technology would reach its speed limit in computation and communication of information in future, all optical Integrated circuit will become the most promising alternative to face this problem.

The deployment of all-optical digital processing is dependent upon being able to add functionality directly at the optical layer. Electrical to optical and optical to electrical conversion limit the speed of optical networks. In order to overcome the electronic bottlenecks and fully exploit the advantages of fibers, it is necessary to move towards networks where the transmitted data will remain exclusively in the optical domain without optical electrical optical (OEO) conversions.

Photonic crystals are the periodic structure in one, two or three dimensions that introduce photonic band gaps the range of frequencies within which propagating electromagnetic wave does not exist. Photonic bandgaps provides the ability of guiding and engineering the flow of light. It offers new platform for all optical switching networks due to low energy loss and small structure dimension. Using these properties of photonic crystals, we have proposed designs of an all-optic encoder, flip-flop and decoder. In following proposed designs core of encoder is made of two T-type resonators, core of flip flop is made of two nor gates with feedback and core of decoder is made two circular resonators.

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List of Abbreviations

PC/PhC	Photonic Crystals
OEO	Optical Electrical Optical
IC	Integrated Circuit
PBG	Photonic Band Gap
LED	Light Emitting Diode
1D	One dimensional
2D	Two dimensional
3D	Three dimensional

1 INTRODUCTION

1.1 OBJECTIVE:

In the recent decade, researchers are concentrating more on the development of optical based logic designs to improve the high-speed activities in telecommunication systems and networks. Not only the telecom sector but also the electronic computing systems which may not satisfy the demand of high speed computing due to their limiting capabilities too needs the replacement with optical means because of high speed nature of light. Information processing at terahertz speed is possible with optics due to the realisation of the terahertz optical signals. Towards this approach, researchers have explored the optical devices stimulated by the development of non-linear materials and other semiconductor based technologies.

Semiconductor optical amplifier based technique is the cutting edge in the evolution of optical based logical and arithmetic designs. However, power consumption and speed remain the major limitation in these designs apart from inevitable spontaneous emission of noise. Logic devices with non-linearity are affected with high power consumption though they have many other applications. In order to overcome all of these limitations and as a part of challenging research, scientists have dedicated their time and efforts towards the implementation of the logic functions on photonic crystal platform due to its unique optical characteristics.

Photonic crystal is such a promising area, which can provide a recognisable space for the realisation of logic devices due to the unparalleled advantages like high speed, low power consumption and compactness. They can control, guide and limit the light in nanometre scale. These structures have found many applications in wavelength optical switches, logic gates. The design of these all-optic devices based on photonic crystal waveguides is much smaller than the conventional design due to large dispersion in photonic crystals. In this paper, a basic flip-flop, 4-2 Encoder and 2-4 Decoder design is proposed using two-dimensional photonic crystal (2D PhC). Encoder has four input and two output waveguides as the ports, Decoder has three input(including one reference input) and four output waveguides as the ports, and flip-flop has four input (including two reference inputs) and two output waveguides as the ports.

1.2 MOTIVATION:

Nowadays the demand for high-speed telecommunication systems has increased intensively. An all-optical switching takes its position as a remarkable candidate by representing dramatically fast and extremely low energy switching operation .All optical logic gates are the key elements of optical network systems. In recent years so many studies have been done on basic logic gates, AND, NAND, OR, and XOR . Combining and constructing more complex structures with these basic elements are common in electronic circuits.

In order to cope the ever increasing demand for high speed, high bit rate and wide band width communication links, we need to immigrate from current microwave networks toward optical communication networks and systems. For gaining the full advantages of all optical networks and systems we need all optical devices.

A solution using photonic crystal structure is proposed. This solution offers a certain number of advantages: it can provide small power loss due to the use of photonic crystal platform. In addition, there is no need for any external light or electrical current for biasing.

Keeping this in mind, we have proposed an all optic Flip-Flop, encoder and decoder design in which all the inputs and outputs are completely optical. The deployment of all-optical digital processing is dependent upon being able to add functionality directly at the optical layer. In order to overcome the electronic bottlenecks and fully exploit the advantages of fibers, it is necessary to move towards networks, where the transmitted data will remain exclusively in the optical domain without optical electrical optical (OEO) conversions. Electrical to optical and optical to electrical conversion limit the speed of optical networks.

1.3 BACKGROUND

What is Photonic Crystal?

- Photonic crystals are the periodic structure in one ,two or three dimensions that introduce photonic band gaps (i.e.)the range of frequencies within which propagating electromagnetic wave does not exist.
- Photonic band gaps provides the ability of guiding and engineering the flow of light.
- Total compactness obtained by the use of PC structures makes it suitable for optical integrating.

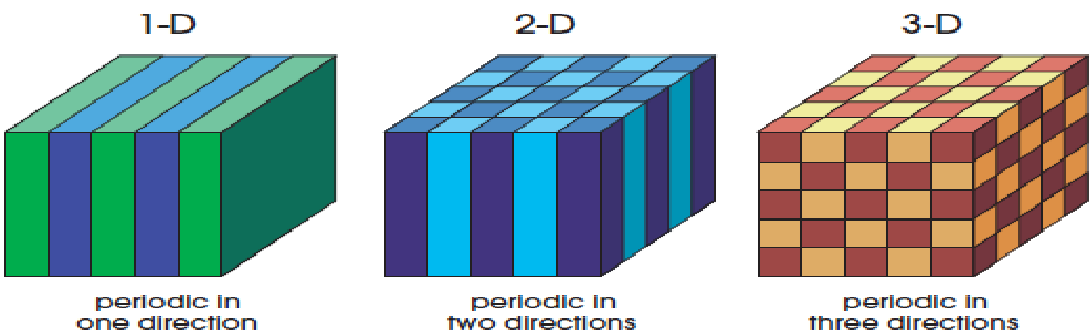
Types of photonic crystals:

- The fabrication method depends upon the number of dimensions that the Photonic band gap must exist.
- Depending on geometry of the structure, PhCs can be divided into three broad categories, as shown in the fig(1.1).

I. One dimensional (1D)

II. Two dimensional (2D)

III. Three dimensional (3D)



Fig(1.1)- Types of photonic crystals.[Source: John D.Joannopoulos,Steven G.Jonson,Joshua N.Winn,Robert D.Meade. 'Photonic crystal –Molding the flow of light']

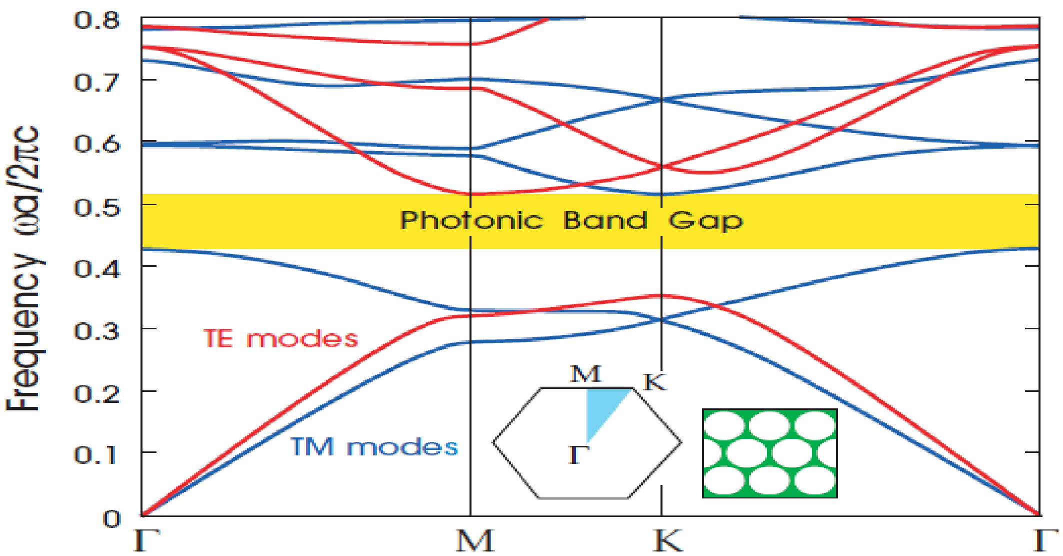
- In 1D PhCs, the periodic modulation of the permittivity occurs in one direction only, while in two other directions structure is uniform.

- 2D PhCs can have comparatively large variety of configurations, because it possesses periodicity of the permittivity along two directions, while in the third direction the medium is uniform.

- 2D PhCs attracted more attention because of their fabrication process is similar to that used for planar electronic integration circuits.
- These structures are used in the implementation of fast devices such as waveguides, resonators, logic gates and switches.
- 3D PhCs has permittivity modulation along all three directions.

Photonic Band Gap:

- In photonic crystals, perforation are analogous to the atoms in the semiconductor. Light entering the perforated material will reflect and refract off interfaces between glass and air.
- The complex pattern of overlapping beams will lead to cancellation of band of wavelength in all directions leading to prevention of band into the crystal.
- The resulting photonic band structure can be modified by filling in some holes and creating some defects in periodic systems.

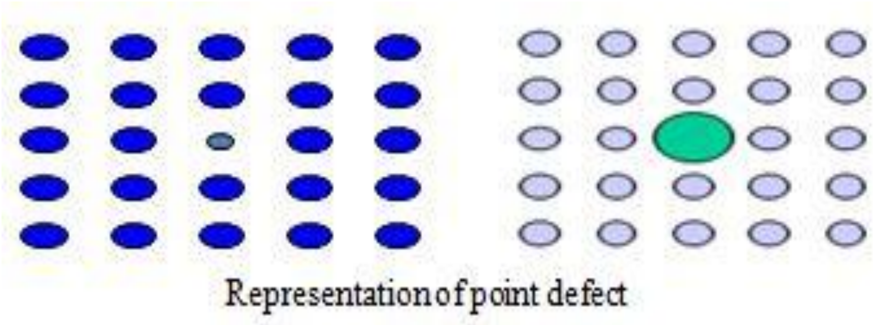


Fig(1.2) – Photonic bandgap.[Source: John D.Joannopoulos,Steven G.Jonson,Joshua N.Winn,Robert D.Meade. 'Photonic crystal –Molding the flow of light']

Defects in 2D photonic crystals:

- Point defect:

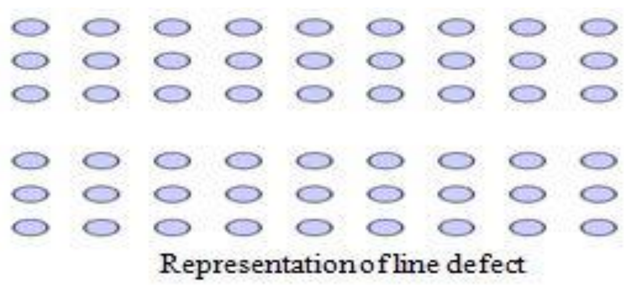
A point defect involves a alteration of a single lattice in the crystal structure. The hole can be modified in size, properties or even it can be deleted.



Fig(1.3) – Point defect[3]

- Line defect:

In this case the defect is created by removing the rods from the whole row in structure. This can be act as a waveguide.

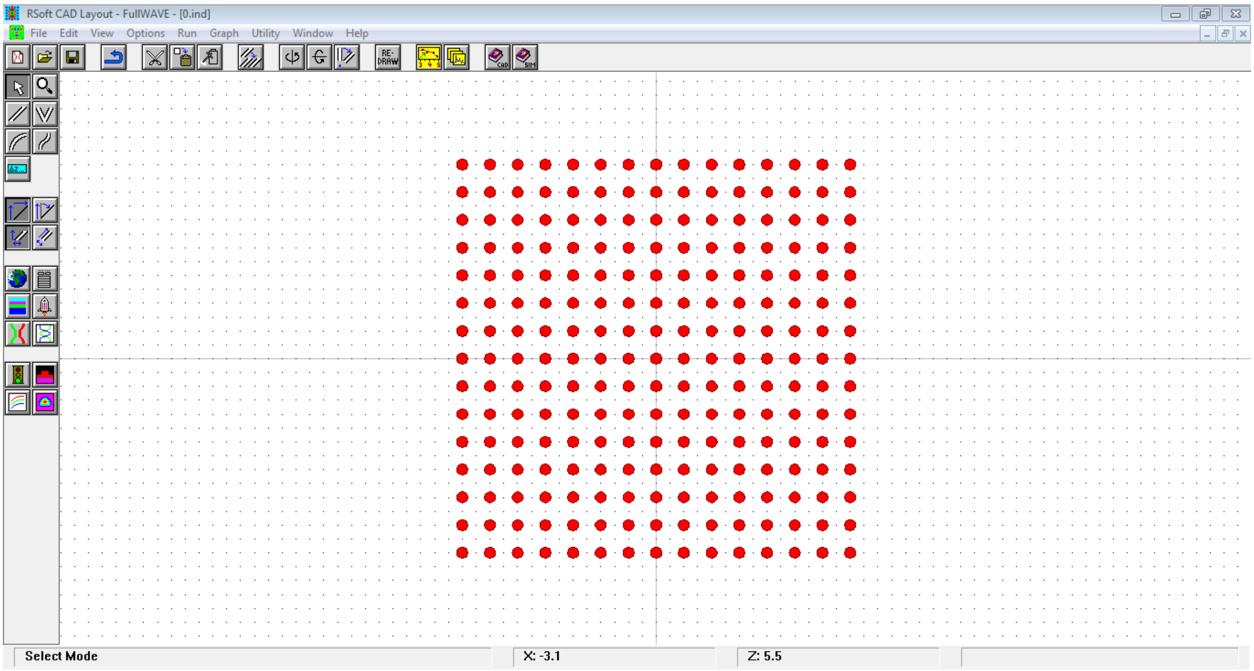


Fig(1.4) – Line defect[3]

About the Software

- RSoft products are used to design and analyze optical telecommunication devices, optical components used in semiconductor manufacturing, and nano-scale optical structures. They enable engineers to design and optimize the optical components and systems found in products such as fiber optic networks, semiconductor lithography equipment, silicon optical chips and LEDs.

- Within the physical layer, the Photonic component design suite allows users to design and simulate both passive and active photonic optoelectronic components and subsystems.
- The Photonic component design suite allows users to design and simulate current and next-generation optical communication systems and photonic integrated circuits at the signal propagation level.



Fig(1.5) – 15a x 15a crystal lattice

Applications

- Communications
- Photonic crystals
- Displays and imaging
- Photonic Integrated Circuits
- Coherent Fiber optics system
- Optical Networks
- Waveguide sensors
- Transmission Impairments in Fiber
- Optical Amplifiers

LITRATURE SURVEY

Title:An ultra-fast all-optical flip-flop based on nonlinear photonic crystal structures
Publisher:The Optical Society of Japan 2018
Description: A square lattice photonic crystal with lattice constant equal to 575 nm was used for designing an all optical RS flip-flop. The proposed structure consists of two ring resonator-based switches with different resonant modes that are connected to a core section.

Title: All optical XOR and OR gate based on line and point defects in 2-D photonic crystal
Publisher: Optics and Laser technology, 2015
Description:

- Studying of phase difference between beams responsible for constructive and destructive interference of light in optical logic gates and control the light by defects .
- Device for optical switch and gates with low power consumption based on line and point defect. Speed isnear to velocity of light.

Title: All optical SR flip flop in 2D PhC
Publisher: Springer Science+Business Media New York 2015
Description:

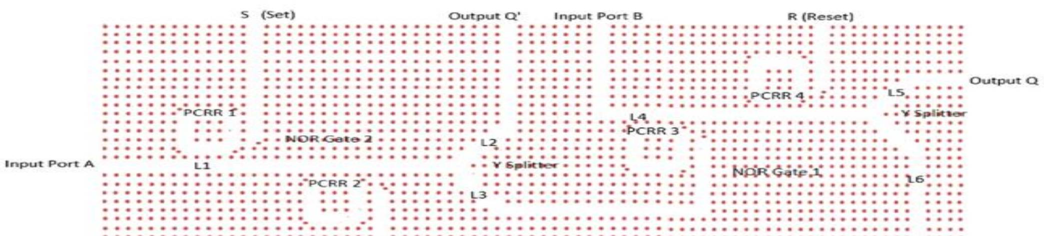


Figure (1.a) SR flip flop in 2D PhC

- The photonic crystals (PhC) draw significant attention to build all optical logic devices and considered one of the solutions for the opto-electronic bottleneck via speed
- The PhC structure has a square lattice of silicon rod with refractive index of 3.39 in air.
- Response time is also calculated.

Title:Reconfigurable design of flip flops based on a switch.

Publisher:The Optical Society of Japan 2018

Description:

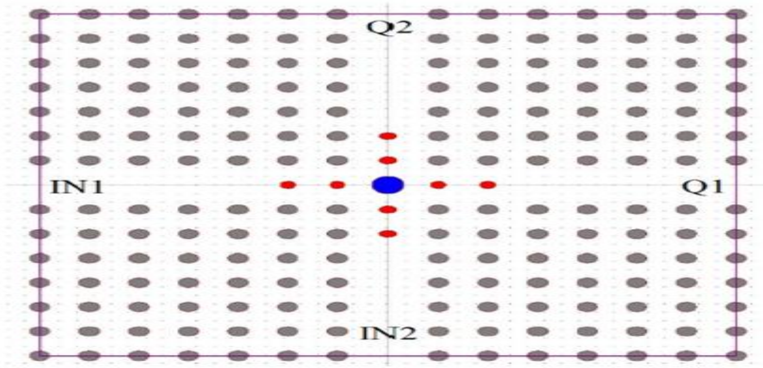


Figure (1.b) Flip-flop switch

- All-optical RS flip-flop was proposed using nonlinear Kerr effect in photonic crystals.
- The proposed structure is composed of a core section and two optical switches.
- The core section consists of two cross-connected resonant cavitieswhose resonant mode are at wavelengths 1586 and 1620 nm.

Title:All optical 1 to 2 decoder based on photonic crystal ring resonator

Publisher:Iranian Solar EnergyScientific Society,2017

Description:

- Controlling the optical behaviour of the resonant ring via optical power intensity
- The resonant wavelength of the photonic crystal ring resonator is very sensitive upon the refractive index of dielectric rods, on the other hand the refractive index of dielectric materials depend on the optical power intensity.

1 PROJECT DESCRIPTION AND GOALS

We have proposed designs of an encoder, a flip-flop and a decoder made in optical simulation software 'Rsoft', on Photonic crystal platform with goal to introduce circuits with relatively smaller dimensions and less response time.Photonic crystals (PhC) are optical material represented with periodic modulation of the permittivity. Multiple interference of light on a periodic lattice leads to a photonic band gap and anomalous dispersion because light with a wavelength close to the period of modulation cannot propagate in certain directions.

The structure of PhC can be classified into one-dimensional (1D), two dimensional (2D) and three-dimensional (3D) structures. The 2D photonic crystals are widely used and attractive because of the ease of fabrication and mathematical analysis. The optical devices are fabricated in the photonic crystals by either adding or removing dielectric material in a certain area. The dielectric materials then act as a defect region that can be used to localize and guide the electromagnetic waves. A single defect in a photonic crystals acts like a resonant cavity, and a line defect in the structure acts like a waveguide. So, these defects are used to design all optical logic gates and flip flops. The proposed design are of small size and for encoder has been designed such that no bias wave is required to operate it whereas our flip-flop design uses two and decoder uses one reference wave, which has to be given continuously throughout the working of that circuit, following has been explained in detail in section (4) and section (6).

GOAL: To successfully design an all-optical encoder, a flip flop and a decoder on 2 Dimensional photonic crystals with smaller footprint, good response time and minimal leakage.

3 TECHNICAL SPECIFICATION:

3.1 Parameters and specifications of all-optic encoder:

An Encoder is a combinational circuit that performs the reverse operation of Decoder. It has maximum of 2^n input lines and 'n' output lines. It will produce a binary code equivalent to the input, which is active High. Therefore, the encoder encodes 2^n input lines with 'n' bits. It is optional to represent the enable signal in encoders. Here we are making 4 to 2 Encoder, it has four inputs D0, D1, D2 & D3 and two outputs Q0 &Q1.At any time, only one of these 4 inputs can be '1' in order to get the respective binary code at the output.

We can write the Boolean functions for each output as

Q0 = D0 + D1 and

Q1 = D0 +D2.

Table(1.1) - Parameters of design Encoder

PARAMETER	VALUE
Lattice constant(a):	556nm
Dimensions:	24a×34a
Material used:	Silicon
Refractive index:	3.39
Rod type:	Circular
Lattice arrangement:	Cubic
Operation wavelength:	1.56µm
Frequency range(a/λ):	0.32167-0.4403
Wavelength range(a=0.56):	272nm<λ<1717nm

3.2 Parameters and specifications of all-optic Decoder:

Decoder is a combinational circuit that has ‘n’ input lines and maximum of 2^noutput lines. One of these outputs will be active High based on the combination of inputs present, when the decoder is enabled. That means decoder detects a particular code. The outputs of the decoder are nothing but the **min terms** of ‘n’ input variables (lines), when it is enabled.2 to 4 Decoder has two inputs A_1 & A_0 and four outputs Y_3, Y_2, Y_1 & Y_0. One of these four outputs will be ‘1’ for each combination of inputs when enable, E is ‘1’.

We can write the **Boolean functions** for each output as:

Y3=E.A1.A0

Y2=E.A1.A0′

Y1=E.A1′.A0

Y0=E.A1′.A0′

Each output is having one product term. So, there are four product terms in total.

(In Rsoft Simulation Enable will be bias input)

Table(1.2) - Parameters of design Decoder

PARAMETER	VALUE
Lattice constant(a):	523nm
Dimensions:	25a x 25a
Material used:	Silicon
Refractive index:	3.39
Rod type:	Circular
Lattice arrangement:	Cubic
Operation wavelength:	1550nm
Frequency range(a/λ):	0.32129-0.43992
Wavelength range(a=0.56):	188nm<λ<1634nm

3.3 Parameters and specifications of all-optic Flip flop

A typical Flip-flop has two input ports, namely reset (or R) and set (or S)(in our all-optic circuit we also have two reference ports) and two output ports, namely Q and Q′ . If S = 1 and R = 0, we should have Q = 1 and Q′ = 0. When S = 0 and R = 1, we should have Q = 0 and Q = 1. If both input ports are inactive the output ports should keep their previous states. R = S = 1 case is invalid in Flip-Flop.

Table(1.3) - Parameters of design Flip flop

PARAMETER	**VALUE**
Lattice constant(a):	582nm
Dimensions:	35a×20a
Material used:	Silicon
Refractive index:	3.39
Rod type:	Circular
Lattice arrangement:	Cubic
Operation wavelength:	1.55µm
Frequency range(a/λ):	0.27558-0.4465
Wavelength range(a=0.56):	1.29899-2.10465 µm

4. DESIGN APPROACH AND DETAILS

Constraints:-

We cannot change the inputs simultaneously while running the simulation in following designs and there is no memory element used in optical-design of circuits which can save the previous value to facilitate it’s use in future input processing.

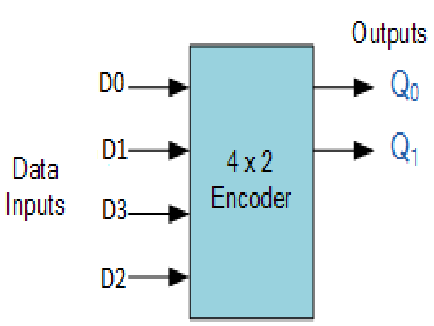
Trade-off"s:

We have kept dimensions small to decrease operating time and power usage, as wave has to travel less distance, but it is at cost of increased leakage.

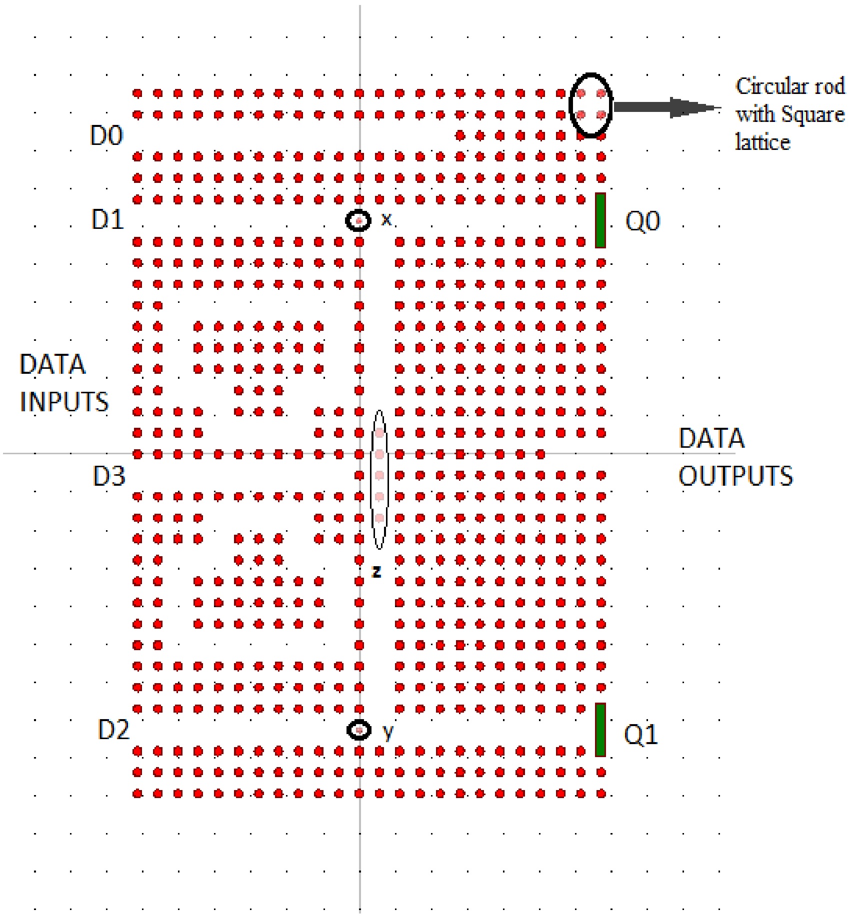
4.1 T-shaped resonator based encoder design on 2D photonic crystal

Proposed Logic circuit of encoder using waveguides:

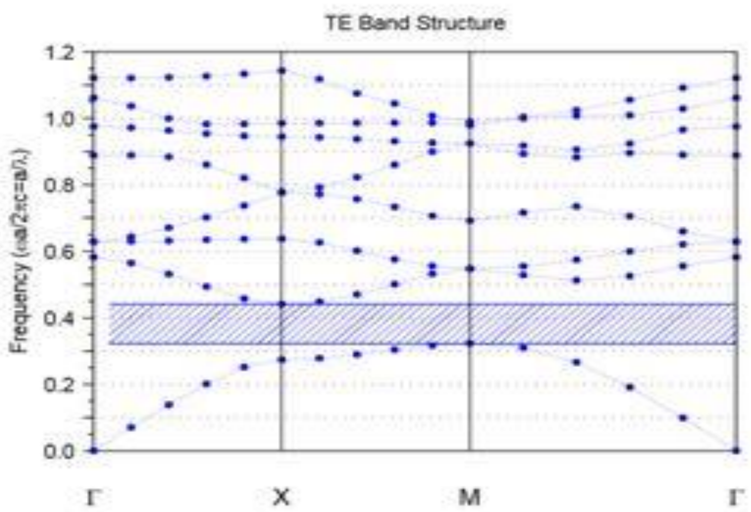
Table (1.4) Truth table of Encoder [www.electronics-tutorials.ws/]



Inputs				Outputs	
D_3	D_2	D_1	D_0	Q_1	Q_0
0	0	0	1	0	0
0	0	1	0	0	1
0	1	0	0	1	0
1	0	0	0	1	1
0	0	0	0	x	x



Fig(4.1) -Design in T-resonator based Encoder



Fig(4.2) -Region of photonic band gap.

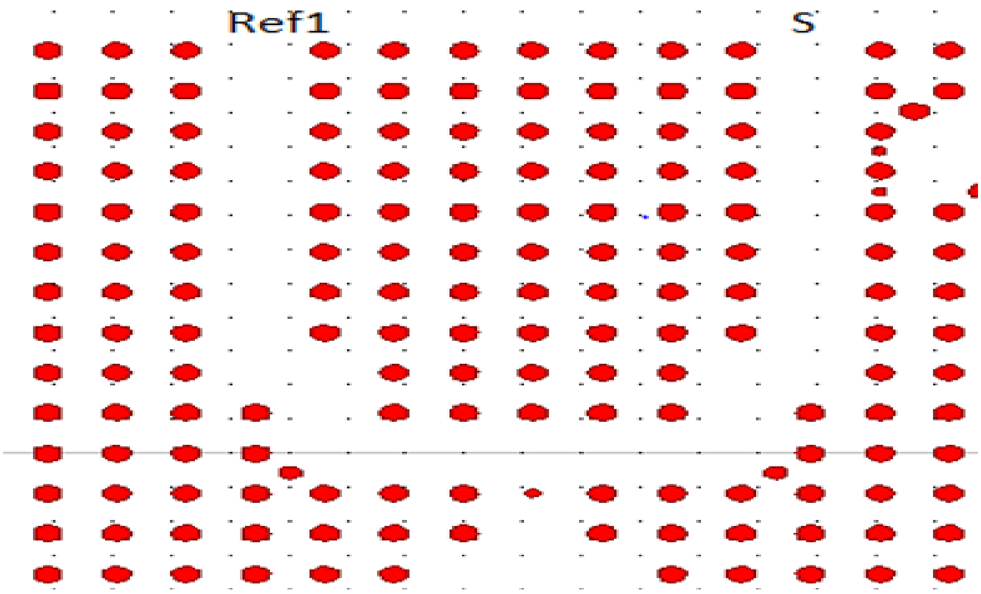
In figure 4.1 we have shown proposed design of encoder, It has 24a×34a square lattice silicon rods at air(used as background)with the refractive index of 3.39 and the radius r (of rod) is 0.2a, where 'a' is the lattice constant of the photonic crystal structure. The fundamental Phc has one PBG(the range of frequencies within which propagating electromagnetic wave does not exist) and it is suitable for designing the logic structure.

The frequency range of this PBG is at $0.32167<a/\lambda<0.4403$(from Y-coordinates of fig.(4.2) which is equal to the wavelength range of $1272nm<\lambda<1717nm$ where lattice constant a(0.5018nm-0.6869nm) is 560nm.The operating wavelength for this structure is 1560nm.

Here in fig.(1.6),at x and y radius of Phc rod has been kept 67% of original radius (or 0.134a), this has been calibrated such that they will allow waves coming from D1 and D2 to pass but would block waves coming from D3 to some extent, to avoid leakage, although leakage can also be avoided by increasing the size of this circuit, but then it's operating time will also increase, so it is a trade-off for faster operating circuit.

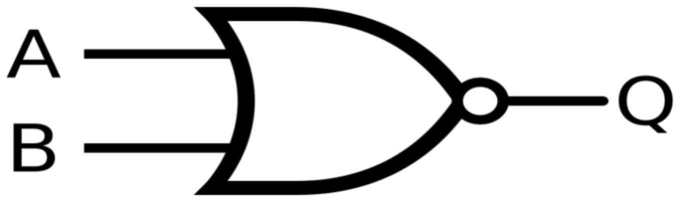
As seen in fig. 4.1 two T shaped resonators are used in the circuit to switch direction of wave towards the required output when D3=1(required output is 'high' at both Q1 and Q2), for required coupling in both directions with the resonators the lattice constant. operating wavelength, circuit material(for certain refractive index) are calibrated for maximum coupling of waves towards output and minimum leakage, here we took operating wavelength as 1560nm, and material as silicon and varied lattice constant to get the required output. Output is considered 'high' when at output the power is greater than or equal to 0.5 units. In fig.4.1, z is used to avoid leakage back into D3, and differentiate output towards Q1 AND Q2.

4.2 Feedback based Flip-Flop design on 2D photonic crystal



Fig(4.3) – NOR gate crystal structure, used as a basic element in all optic SR flip flop

The above figure show the design of NOR gate, on which our flip-flop is based. Here one of the input is Reference and the other is Logic input.

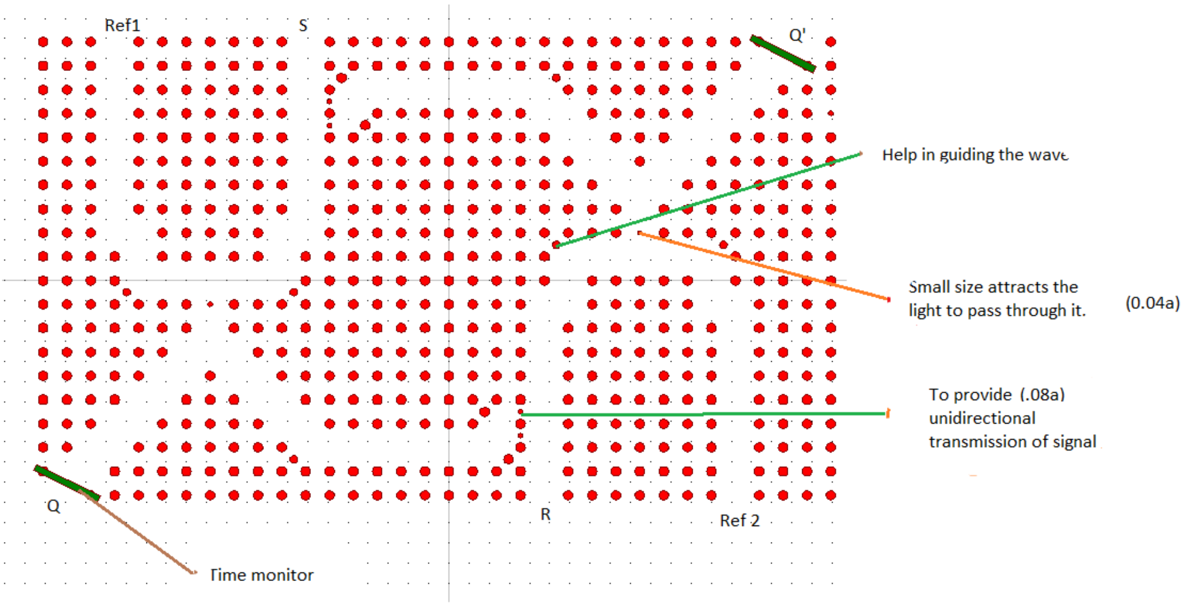


Fig(4.4) : NOR Gate

The truth table(4.2) is implemented according to the design represented above.

Table(4.2) :- Truth table of NOR gate.

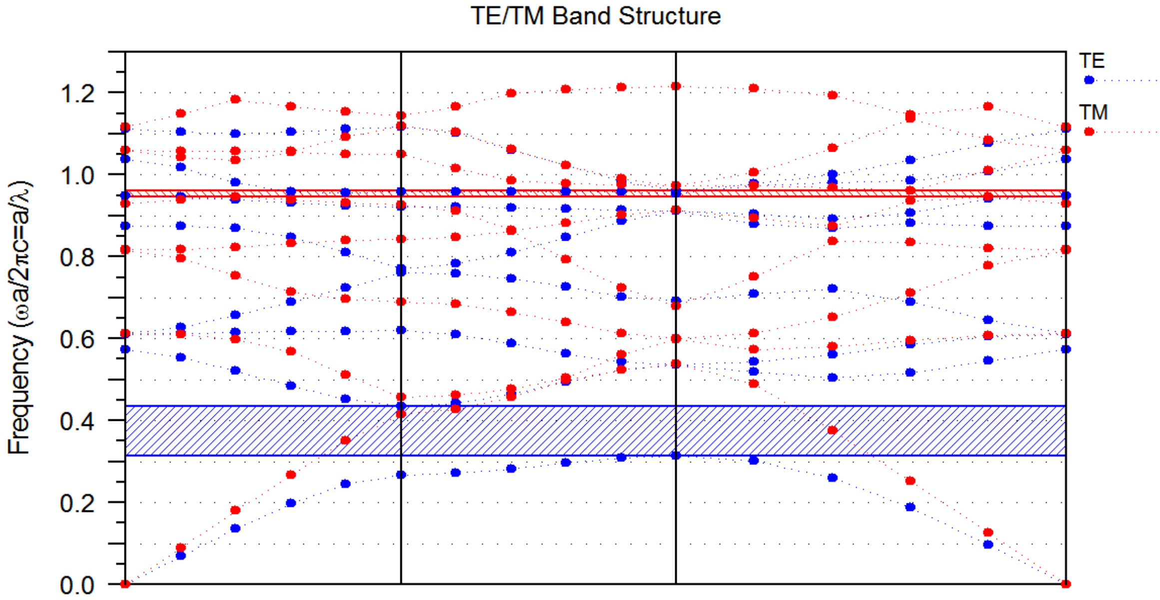
Inputs		Outputs
X	Y	Z
0	0	1
0	1	0
1	0	0
1	1	0



Fig(4.5) -Design of Waveguide based all optic SR Flip- Flop

The permittivity of the dielectric Silicon rods in the structure is equal to e = 10.1 9 10-11 farad/m(er = 11.49), and the refractive index of n = 3.39, where the overall circular Si rods are surrounded by air. The bandgap range of this structure is equal to a/k = 0.32 to a/k = 0.44 at operating wavelengths k1 = 1550 nm and k2 = 1560 nm, which is derived by the plane wave expansion (PWE) method. The bandgap range of the overall structure is approximately equal to a/k = 0.32 to a/k = 0.44 at operating wavelength k = 1550 nm, which is derived by the plane wave expansion (PWE) method to obtain the band diagram of the PC along the most symmetrical lines. Based on the structure of photonic crystals flip flop and bandgap diagram, we consider the polarization type is the transverse electric (TE) polarization of electromagnetic (EM) wave.

There are two different methods for a vertical confinement schemes based on the refractive index scheme to confine the light in high refractive index. In our flip flop, the supported membrane scheme is used with the Rode type PhC, where the semiconductor rods in air is supported by a lower refractive index material (SiNx, SiOx, polymers. The optical flip flop is excited from ports S and R with optical signal, and exit from ports Q and Q0. The inputs S-R of flip flop are applied to one of the control ports of NOR gates, and the other control port for each NOR gate is obtained from feedback of outputs Q and Q0 respectively through the optical y splitters. The wavelength of optical sources for port B and Set S is k1 = 1550 nm, while the wavelength of port A and reset R is k2 = 1560 nm.



Fig(4.6) -Region of photonic band gap for Waveguide based SR Flip- Flop

PBG structure is a periodic array of varying permittivity forming a lattice of scatterers of EM radiation. PBGs have been extensively studied and have demonstrated a range of novel physical phenomena leading to many applications, particularly in lasing where defects in the lattice are used to produce highly-intense coherent radiation. For certain lattice configurations, EM waves with specific frequencies are not able to propagate through the lattice. Figure shows the band structure (wavenumber versus frequency) for a triangular 2D lattice of sapphire rods with the frequency normalized to the speed of light. A 'band gap' in propagating frequencies is clearly present. It follows that PBG structures containing a defect in the periodic lattice can behave analogously to a conventional microwave resonant cavity. Wave propagation in this periodic structure is governed by Bloch–Floquet theory. If an EM wave has a half-wavelength comparable to the size of the defect region and a frequency that lies inside the band gap, the 'mode' becomes spatially localized at the defect site.

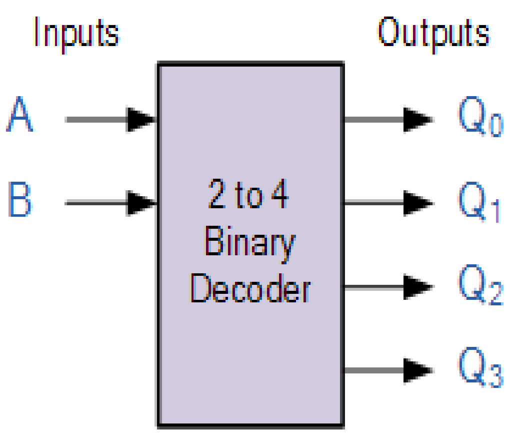
The frequency dependence of the localization effect makes it possible to create a structure where a specific mode is confined, but all other modes propagate away from the defect site through the PBG lattice. The ability of the lattice to confine an EM field by virtue of the periodicity of the lattice alone, means the structure can confine EM modes to the defect regions without the need for any external waveguide or cavity to support the mode. These parameters define the propagation of EM waves in the photonic structure, the frequency and size of the band gap, and the frequency/Q of the confined EM state.

The choice of materials is determined by the thermal and mechanical properties, the frequency stability of the permittivity, and the permittivity contrast between the materials. In this case, sapphire is chosen as people have demonstrated that microwave sapphire PBG structures of the form discussed here can operate at powers over 2 MW if required, and the high permittivity contrast creates a well-defined band gap ideal for the experiment we propose.

4.3 Circular-resonator based decoder design on 2D photonic crystal:

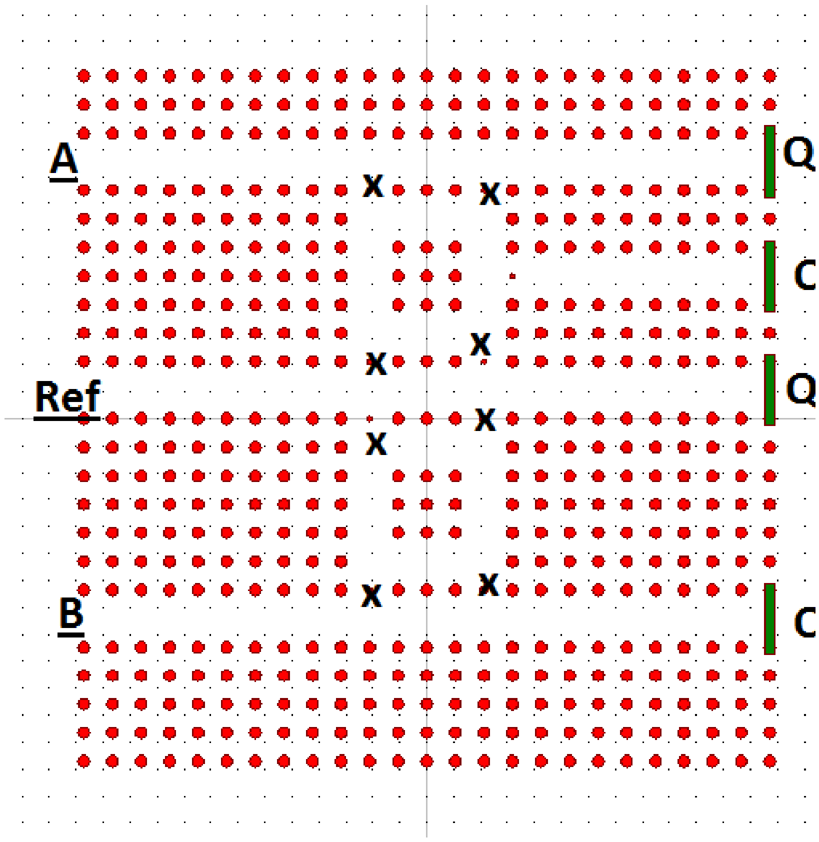
Proposed Logic circuit of decoder using waveguides:

Table(1.6) -Truth table, data input and output ports of Decoder.[www.electronics-tutorials.ws]

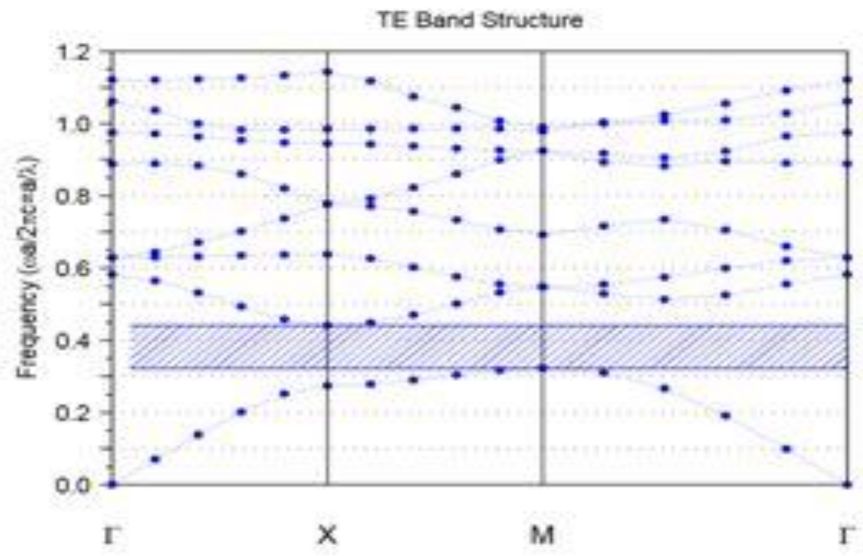


Truth Table

A	B	Q_0	Q_1	Q_2	Q_3
0	0	1	0	0	0
0	1	0	1	0	0
1	0	0	0	1	0
1	1	0	0	0	1



Fig(4.7) -Decoder design with Silicon crystal



Fig(4.8) - Region of photonic band gap.

In figure 4.7 we have shown proposed design of decoder, It has 25a×25a square lattice silicon rods at air(used as background)with the refractive index of 3.3 and the radius r is 0.2a, where ‘a’ is the lattice constant of the photonic crystal structure.

The fundamental Phc has one PBG(the range of frequencies within which propagating electromagnetic wave does not exist) and it is suitable for designing the logic structure .

The frequency range of this PBG is at $0.32129<a/\lambda<0.43992$(from Y-coordinates of figure Fig(4.8) which is equal to the wavelength range of $1188nm<\lambda<1634nm$ where lattice constant a(0.5018nm-0.6869nm) is 523nm.The operating wavelength for this structure is 1560nm.

Here in Fig(4.7) - at x radius of Phc rod has been kept 50% of original radius , this has been calibrated such that it will allow waves from A, Ref and B to merge into the resonator and avoid leakage.

When there is no input (reference input is always high), output Qo=1

When A=1,B=0 : Q2=1

When A=0,B=1 : Q1=1

When A=1,B=1 : Q4=1

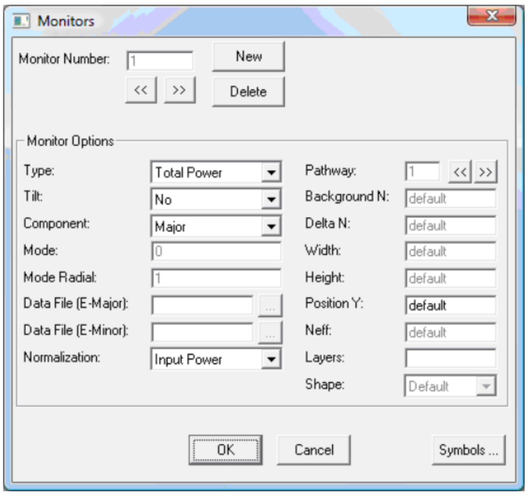
5. SCHEDULE, TASKS AND MILESTONES

Table(1.7) –Schedule

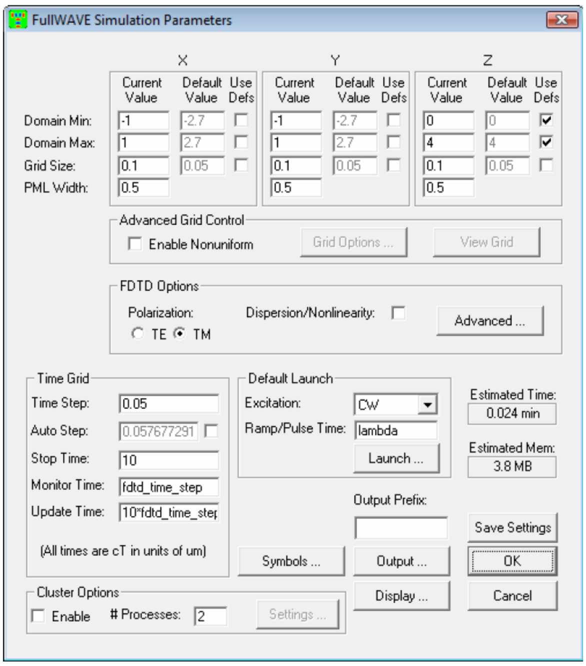
	RESEARCH TARGETS	DURATION
1	• Literature Survey • Study of Simulating tool • Analysis of existing structures • Modifying the existing structure	1 Month (Dec 2018-Jan 2019)
2	• To design all-optical flip flop, encoder and decoder on 2D photonic crystals.	2 Months (Jan 2019-Mar 2019)
3	• Interpretation of results and documentation	1 month (Mar 2019-April 2019)

6. PROJECT DEMONSTRATION

At the output, a time monitor is installed to observe the normalized output for the corresponding input. We are in need to achieve 0.5 as it the threshold for the output to be 'high'. Using the Fullwave application in the R Soft software, we simulate the results.



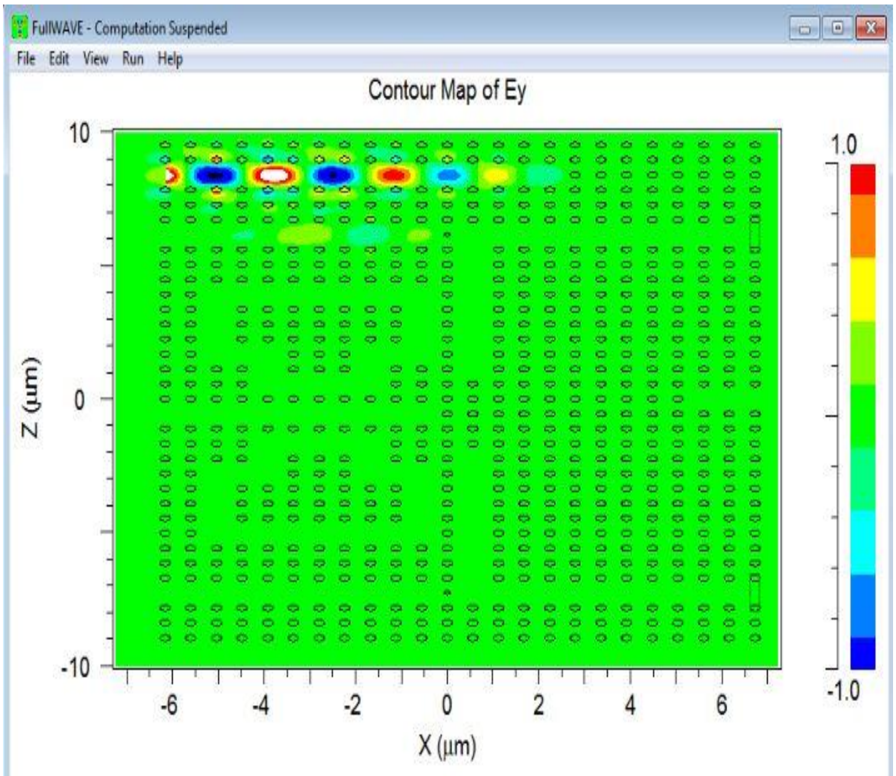
Fig(6.1) -Bandsolve parameters(Bandsolve will give the simulation results for bandgap.)



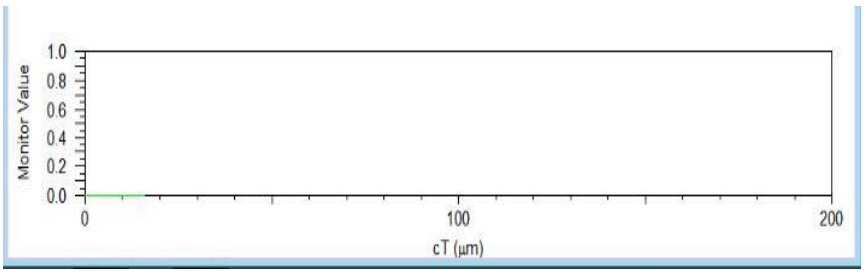
Fig(6.2)- Example of Fullwave simulation parameter

6.1 Working of all-optic encoder:

Field Distribution of Encoder(according to different inputs) :



Fig(6.3) Transmission diagram of Encoder for input Do=1



Fig(6.4) – Output of Encoder for input for D0=1

(a) Here, D0=1, D1=D2=D3=0, which gives output as Q0=Q1=0 which is in line with Truth Table given in table 1.4.

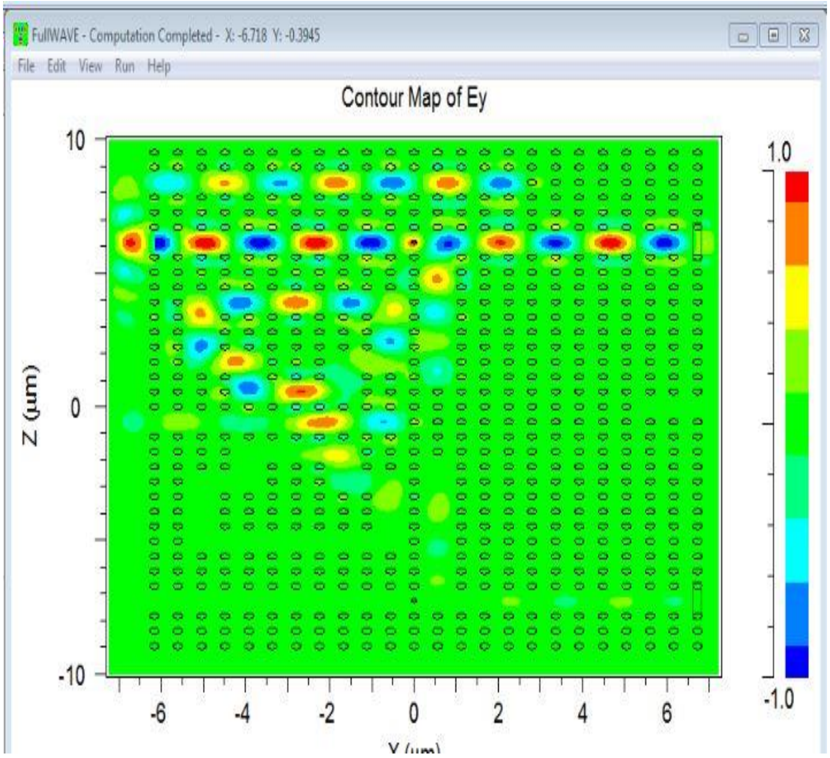


Fig (6.5) - Transmission diagram of Encoder for input D1=1

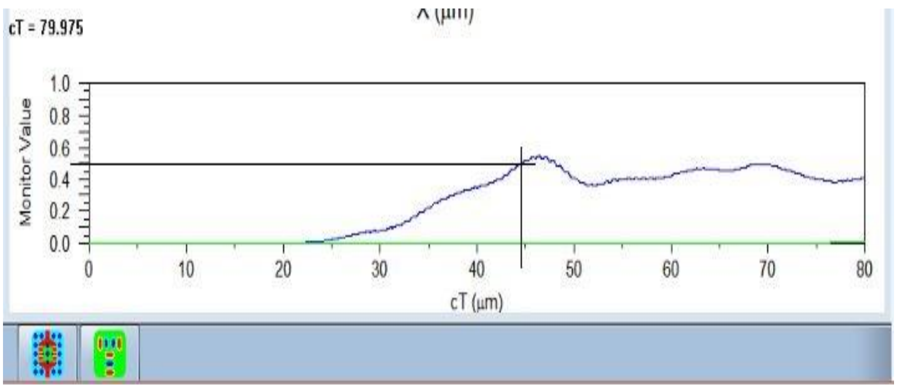


Fig (6.6) - Output of Encoder for input for D1=1

(b)Here D1=1, D0=D2=D3=0, which gives output as Q0=1, Q1=0 which is in line with Truth Table given in table 1.4. As visible from output graph (Fig. 6.5), we get required 'high' output at 45 microsecond (when output is greater than or equal to 0.5), as no leakage through Q1 in other cases, so it is easy to detect, but it is at cost of leakage from D0 and D3.

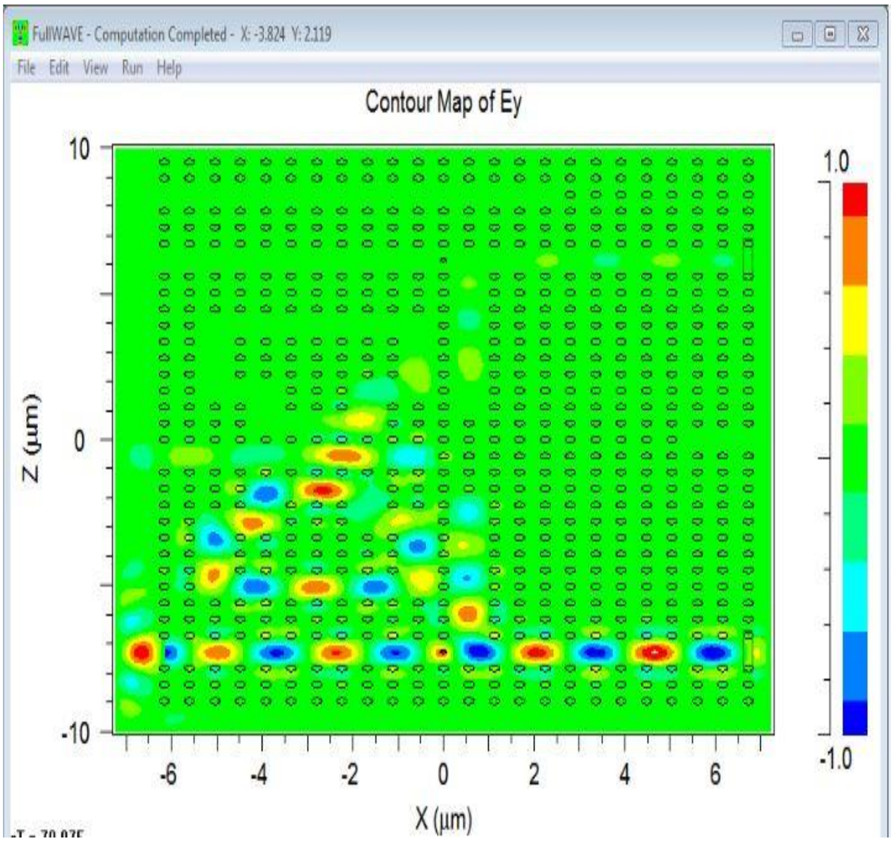


Fig (6.7) -Transmission diagram of Encoder for input D2=1

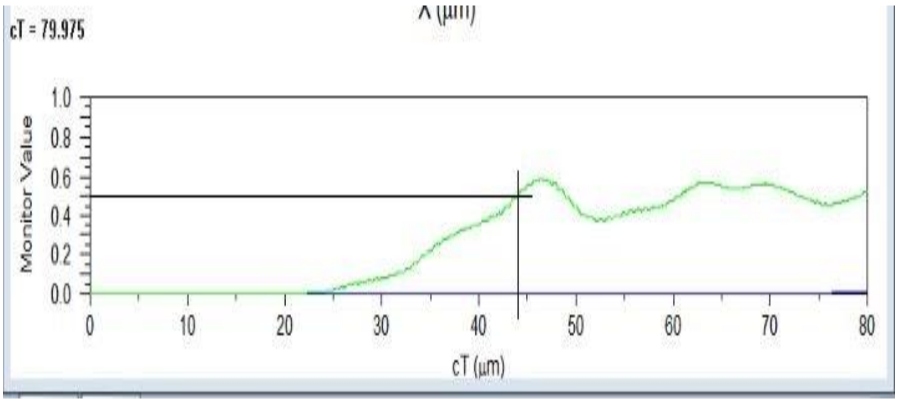


Fig (6.8) - Output of Encoder for inputforD2=1

(c) Here D2=1, D0=D1=D3=0, which gives output as Q0=0, Q1=1 which is in line with Truth Table given in table (1.4). Here we get required 'high' output at 44 microseconds(when output is greater than or equal to 0.5)and output is also easy to detect, as there is almost zero output at Q0, but again it is possible at the cost of leakage from D3.

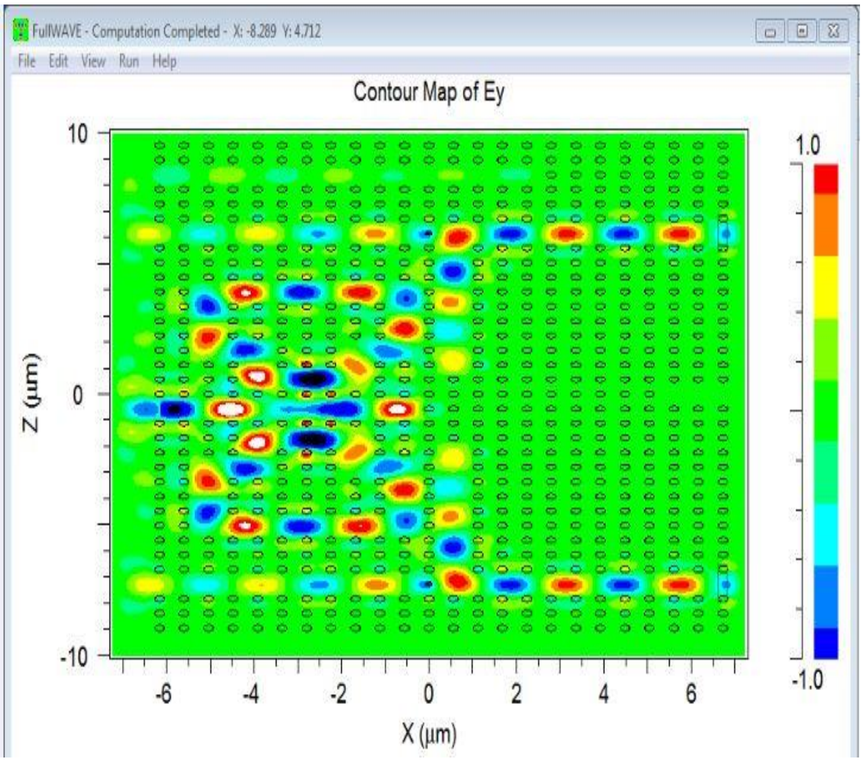


Fig (6.9) -Transmission diagram of Encoder for input D3=1

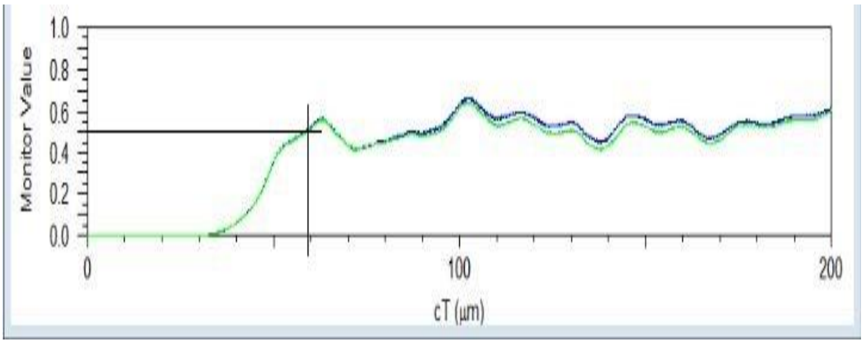


Fig (6.10) - Output of Encoder for inputfor D3=1

(d)HereD3=1, D0=D1=D2=0, which gives output as Q0=1, Q1=1 which is in line with Truth Table given in table (1.4).

Here in fig. 6.10, Output from Q0 of green color and output from Q1 is of Blue color. As visible from fig. 6.9 here two T-resonators are used to get identical output at Q0 and Q1. Here time taken is 60 millisecond, there is leakage from D0 and D2.

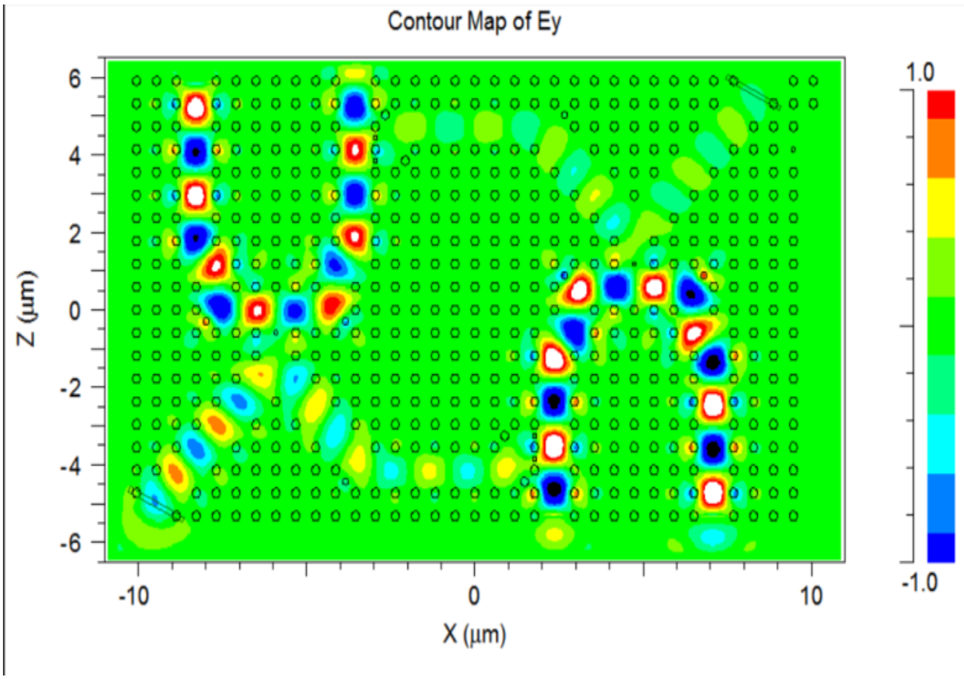
6.2 Working of all-optic flip-flop:

In the given circuit, the reference inputs are always high. In addition, the Set - Reset inputs are given accordingly.

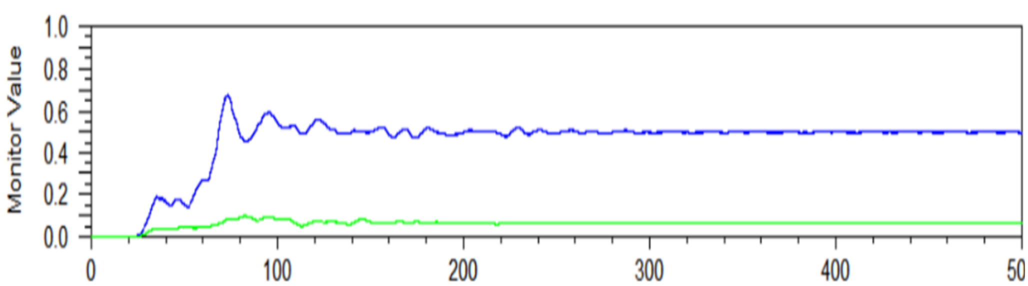
PROJECT DEMONSTRATION

Case 1:-

Set is high and Reset is low, as per the truth table, the output q is high as represented in the simulation screenshot below.



Fig(6.11) -Field Distribution for Waveguide based all optic SR Flip- Flop



Fig(6.12)– Normalized output for Waveguide based all optic SR Flip- Flop

Clearly in the above normalized power graph we can observe that it is taking 100 microseconds to give the stable output. This phenomenon is due to the circuit feedback loops.

Case 2:-

Set is low and Reset is high, as per the truth table, the output q is high as represented in the simulation screenshot below.

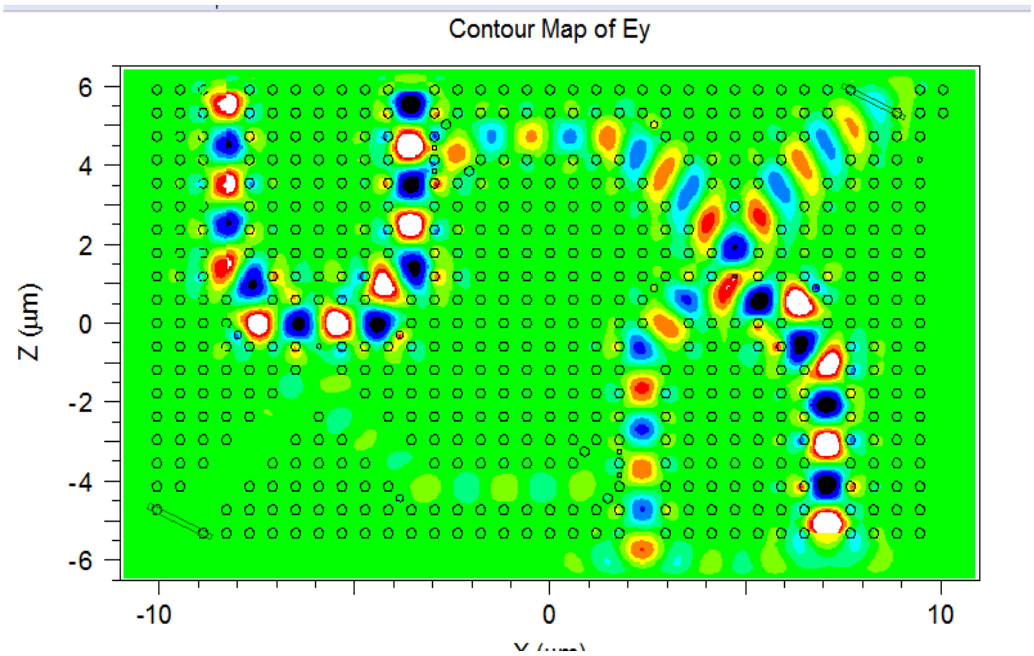


Fig (6.13) -Field Distribution for Waveguide based all optic SR Flip- Flop (Case 2)

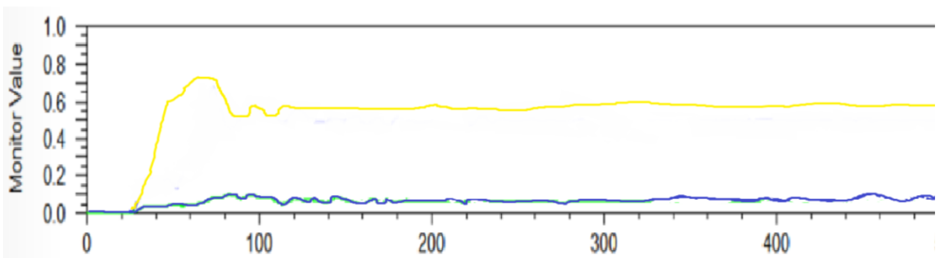


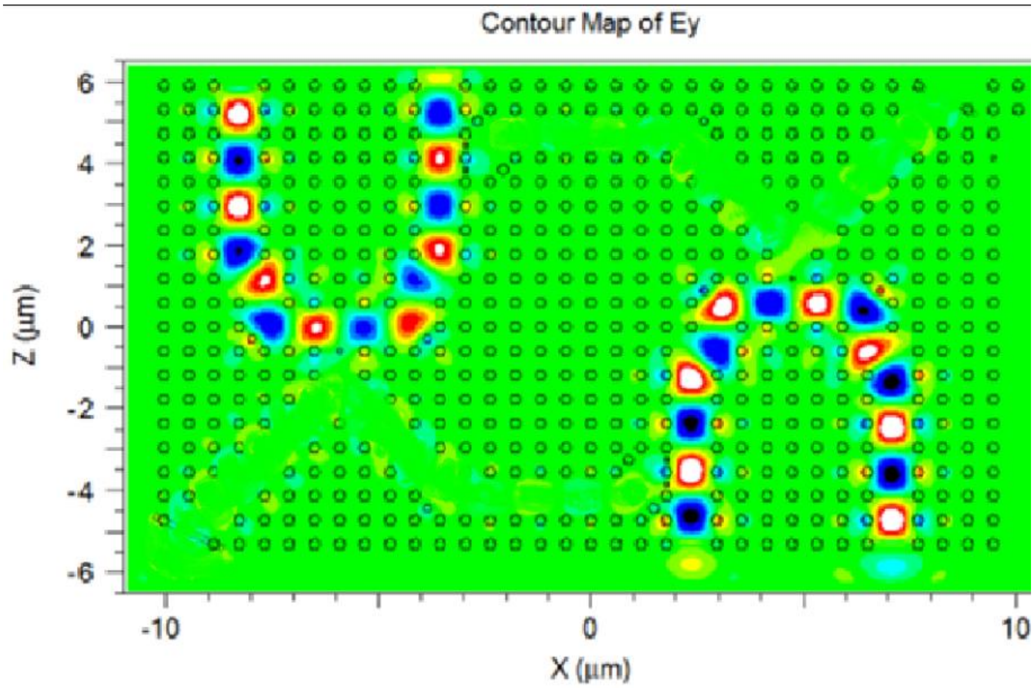
Fig (6.14) - Normalized output for Waveguide based all optic SR Flip- Flop (Case 2)

Contrary to the first case, the q1 output is high and q is low. This satisfies our output as a SR flip-flop

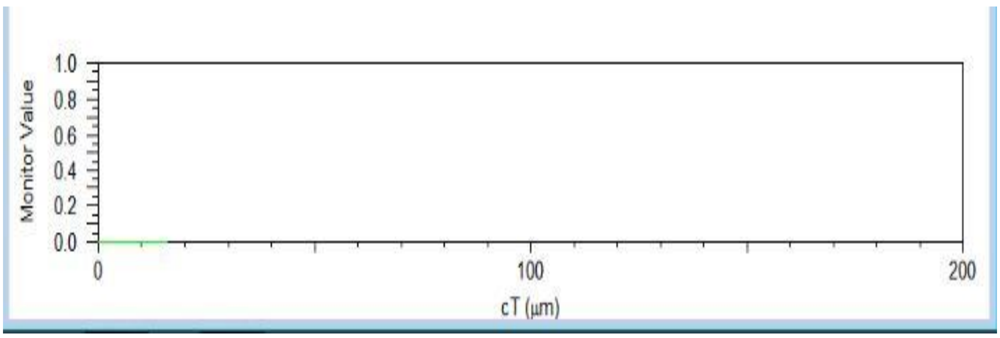
Clearly in the above normalized power graph we can observe that it is taking 100 microseconds to give the stable output. This phenomenon is due to the complexity in the circuit feedback loops.

Case 3 :-

Set is high and Reset is high, as per the truth table, the output q is high as represented in the simulation screenshot below.



Fig(6.15) - Field Distribution for Waveguide based all optic SR Flip- Flop (Case 3)



Fig(6.16) -Normalized output for Waveguide based all optic SR Flip- Flop (Case 3)

The input and the reference is perfectly cancelled for one – one condition representing the output as zero.

6.3 Working of all-optic decoder:

CASE 1 : When A=0, B=0

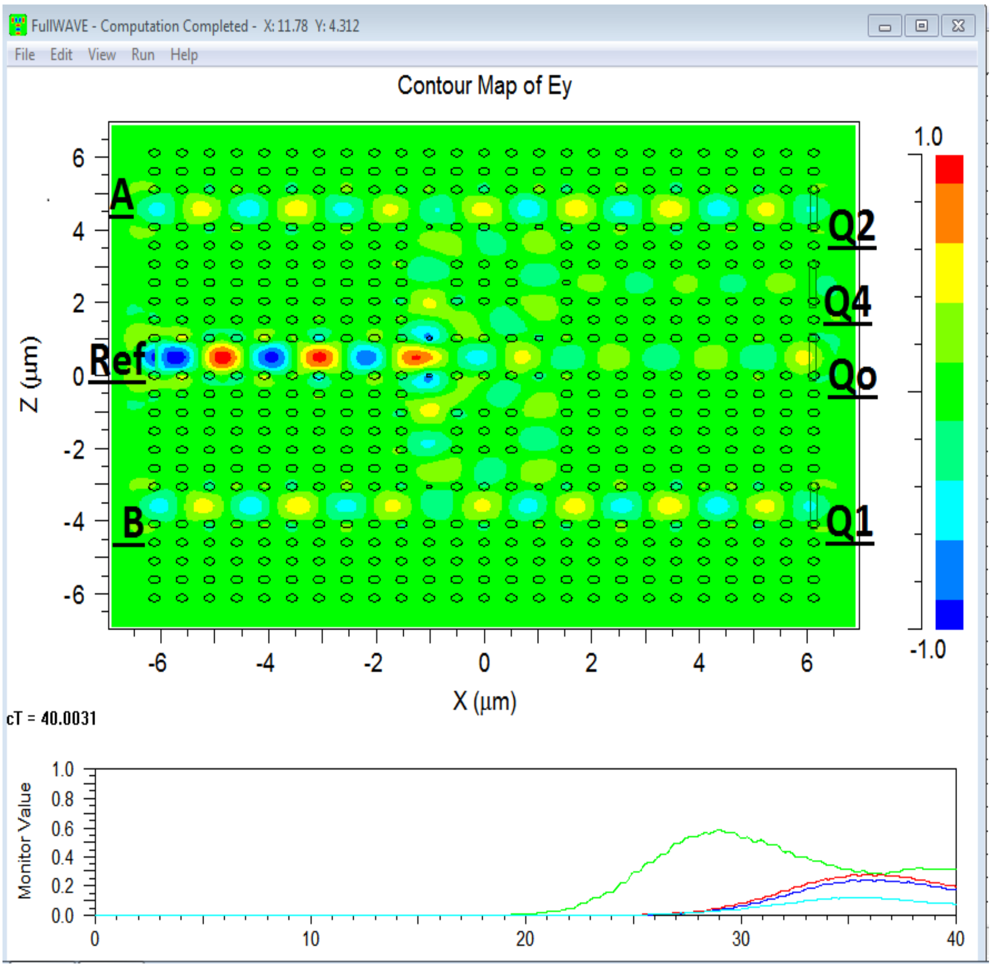
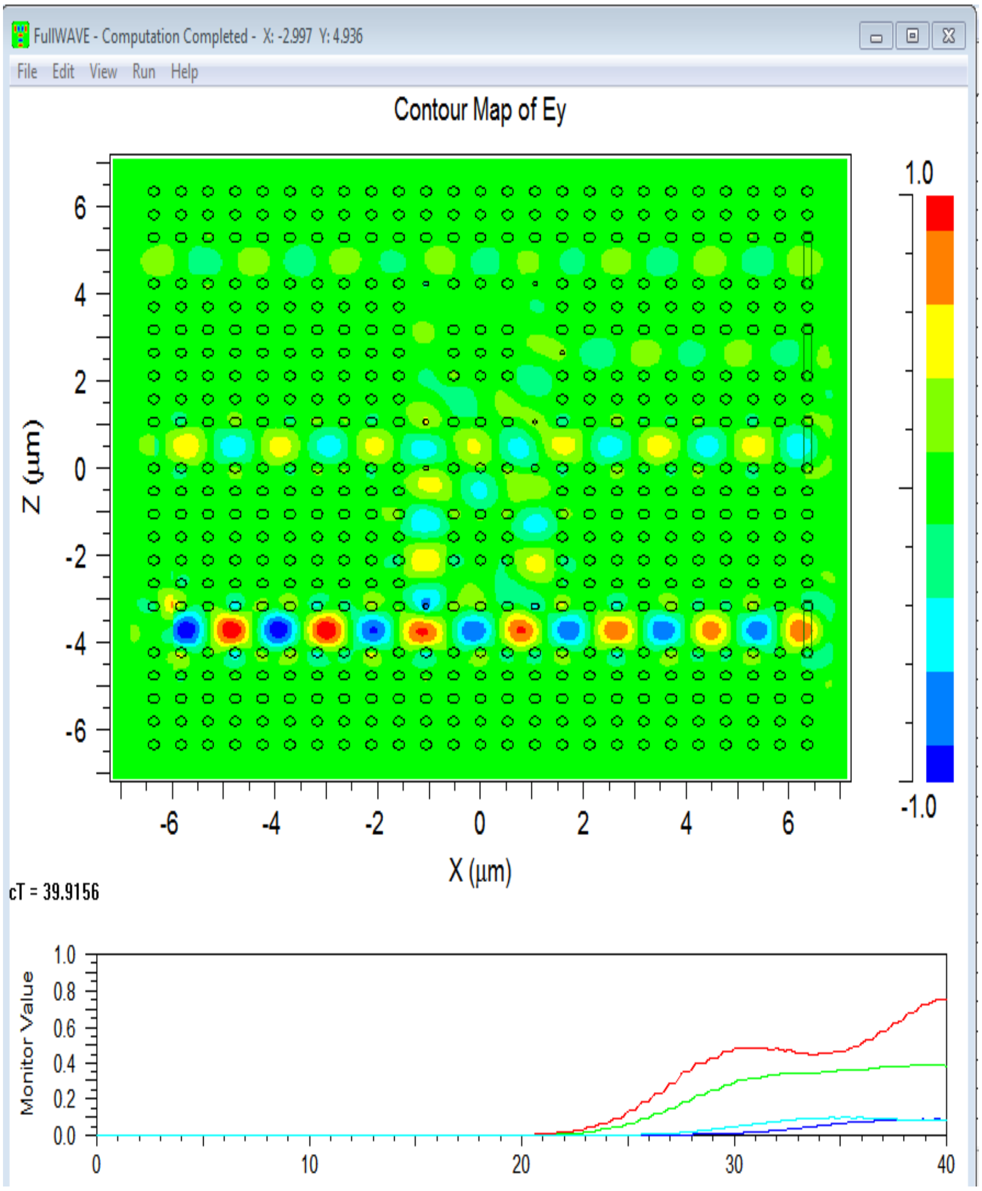


Fig (6.17) – Decoder result with no input

As we can see that when A=0, B=0 then we have Qo=1 because its monitor value is above 0.5 (shown by green color) and hence is considered 1 in binary

Here due to small dimensions, so as to get smaller response time, there is visible leakage through A, B and also in resonators. Here response time is 28.5 microsecond.

Case 2 : When A=0, B=1



*

Fig (6.18) – Decoder output with only one input(i)

As we can see that when A=0, B=1 then we have Q1=1 because its monitor value is above 0.5 (shown by red color) and hence is considered 1 in binary.

Here again due to small dimensions, so as to get smaller response time, there is visible leakage through Ref and Q0. Here response time is 38 microsecond.

Case 3 : When A=1, B=0:

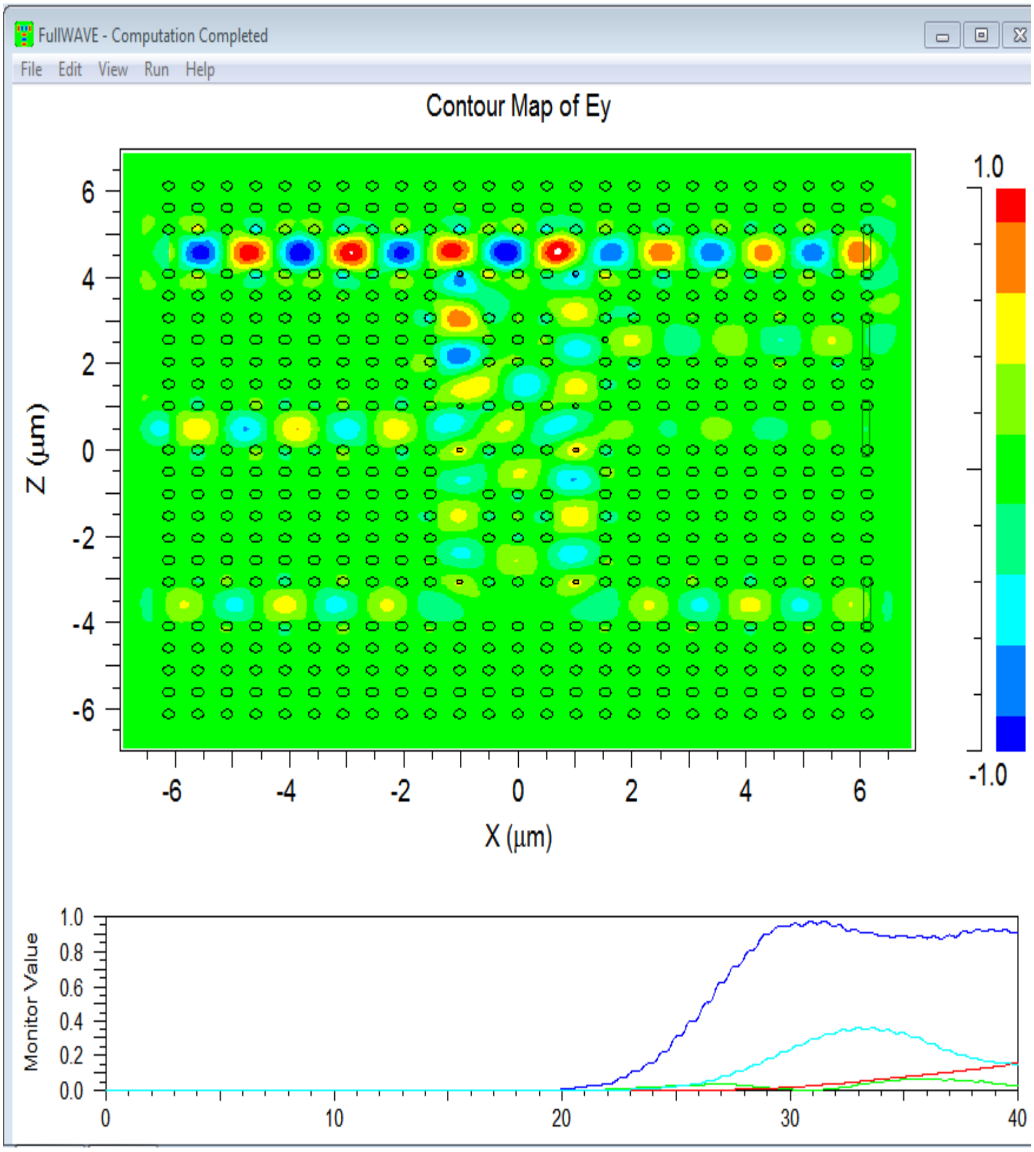


Fig (6.19) – Decoder output with only one input(ii)

As we can see that when A=1, B=0 then we have Q2=1 because its monitor value is above 0.5 (shown by blue color) and hence is considered 1 in binary.

Here again due to small dimensions, so as to get smaller response time, there is visible leakage through Ref , B , Q0 and resonators. Here response time is 27 microsecond

Case 4 : When A=1, B=1

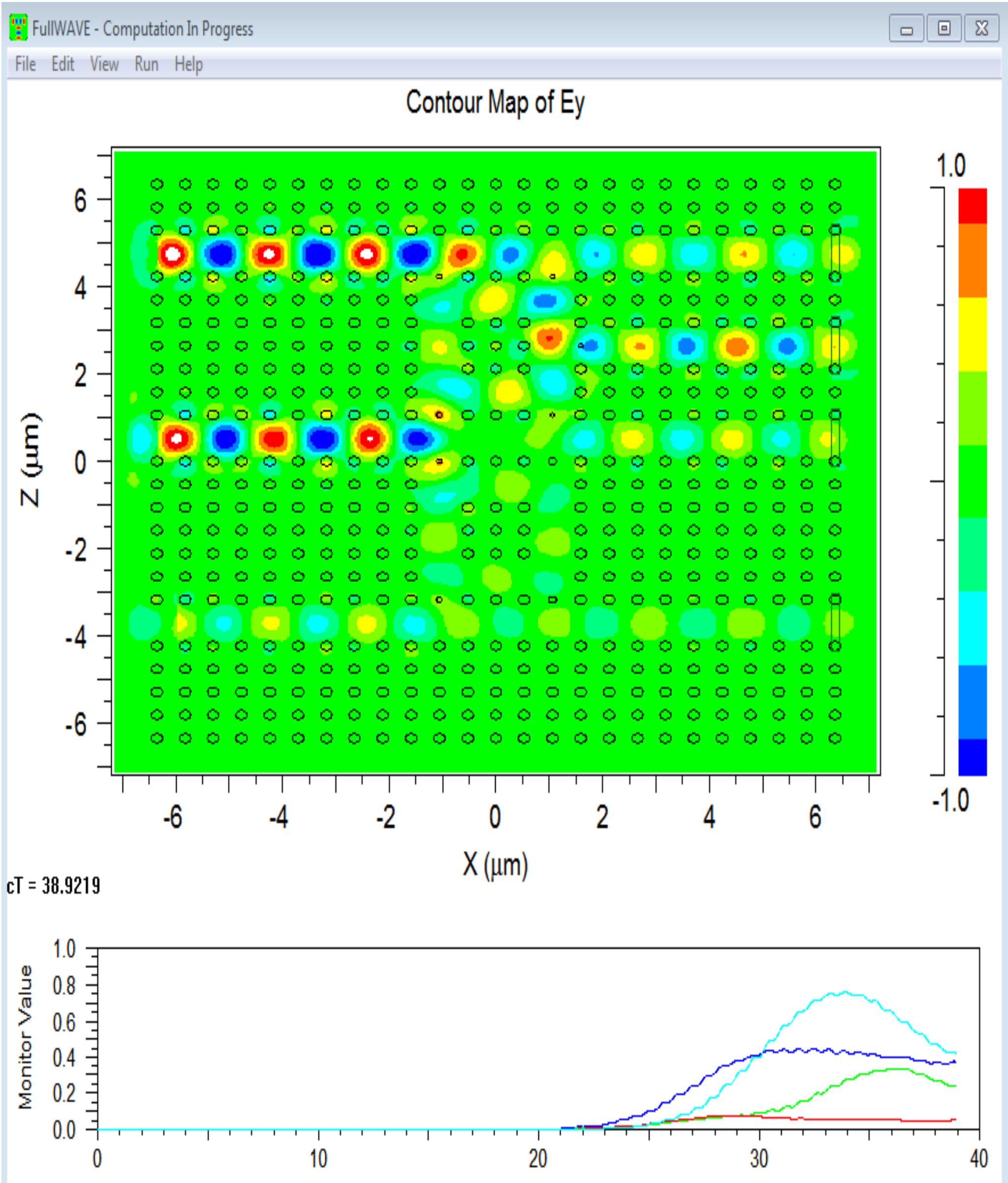


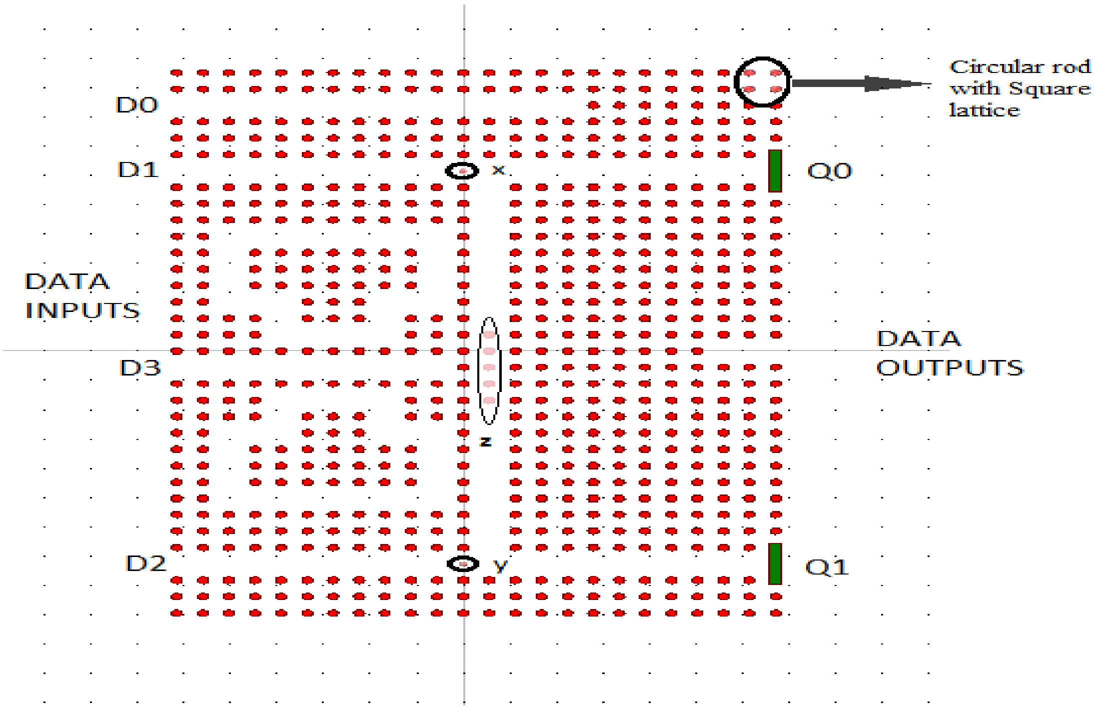
Fig (6.20) –Decoder output with two inputs

As we can see that when A=1, B=1 then we have Q3=1 because its monitor value is above 0.5 and hence is considered 1 in binary. Here also due to small dimensions, so as to get smaller response time, there is visible leakage through B and Q2. Here response time is 34 microsecond. Hence, we get the required truth table similar to conventional truth table of a 2-4 decoder.

7 RESULT

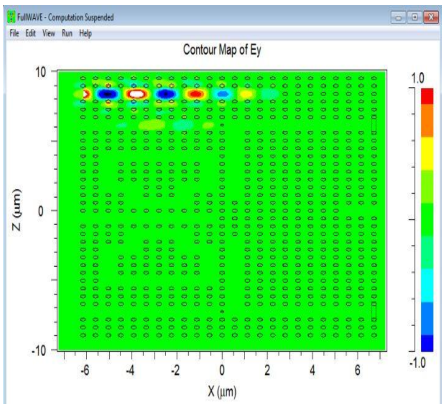
The proposed three circuits in the Rsoft software i.e Encoder, Flip flop and Decoder are designed precisely to match the expected results of that of those of their corresponding electronic circuits.

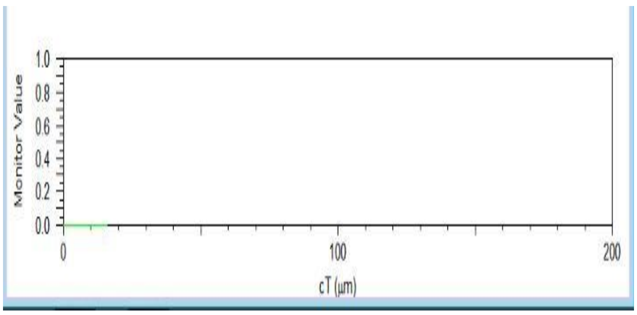
ENCODER



Fig(7.1) – Design of T-resonator based encoder

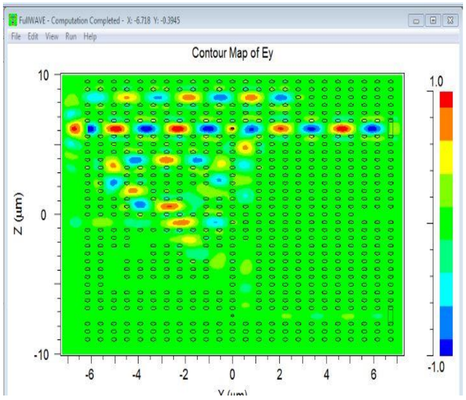
The above circuit made in Rsoft software with silicon crystal lattice provides the desired output for correspondinginputs as given in Truth Table (table 1.4), as shown in following figures:



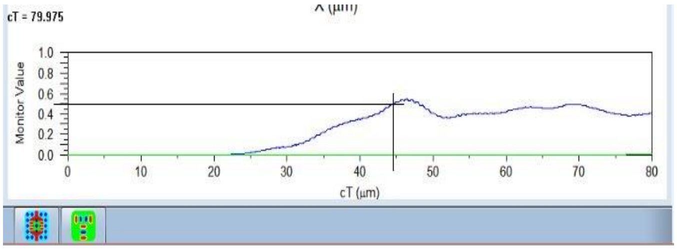


Fig(7.2) Fullwave response for D0=1

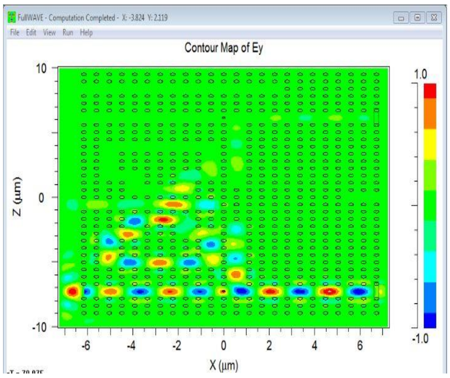
Fig(7.3) Output response for D0=1



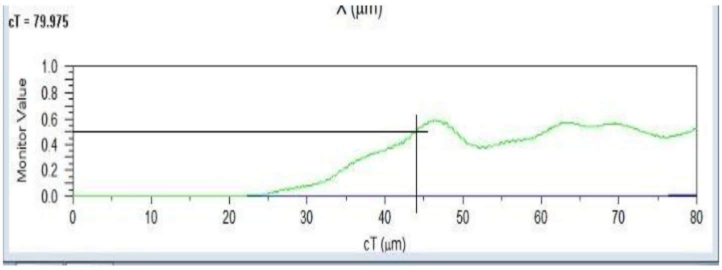
Fig(7.4) - Fullwave response for D1=1



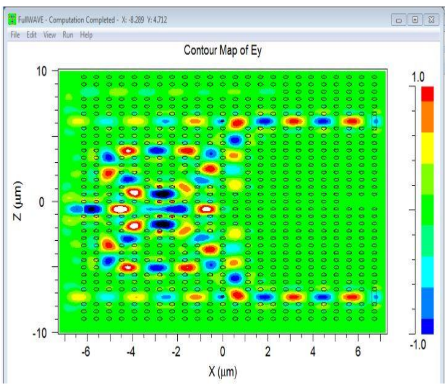
Fig(7.5) Output response for D1=1



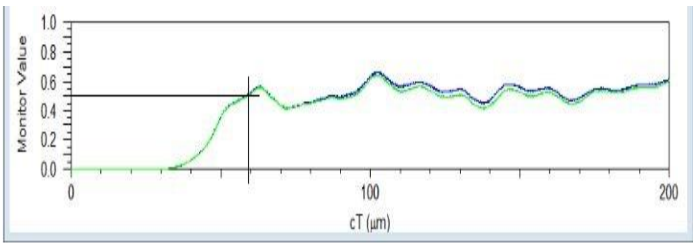
Fig(7.6)– Fullwave response for D2=1



Fig(7.7)– Output response for D2=1

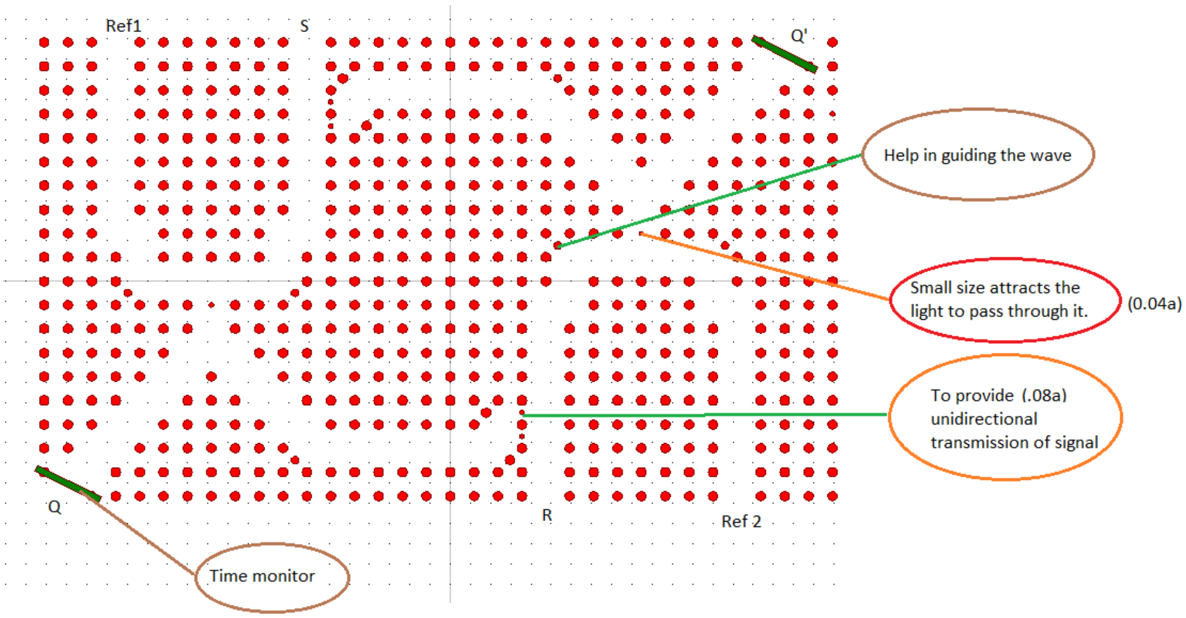


Fig(7.8) - Fullwave response for D3=1



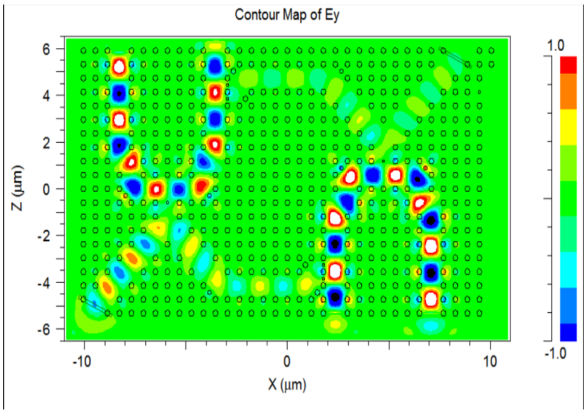
Fig(7.9) - Output response for D3=1

FLIP-FLOP

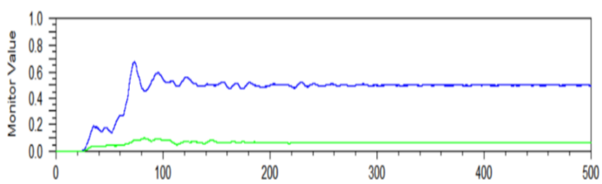


Fig(7.10) – Design of waveguide based all optic SR Flip- Flop

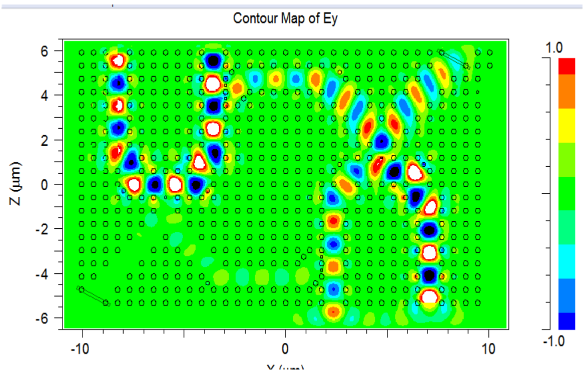
The above circuit made in Rsoft software with silicon crystal lattice provides the desired output for corresponding inputs, as shown in following figures:



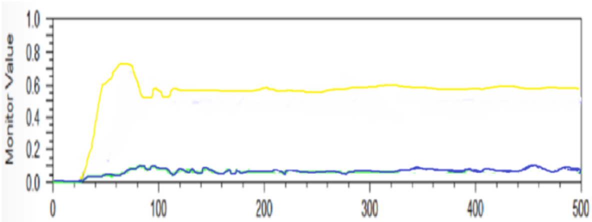
Fig(7.11) - Field Distribution for waveguide based all optic SR Flip- Flop (Case 1)



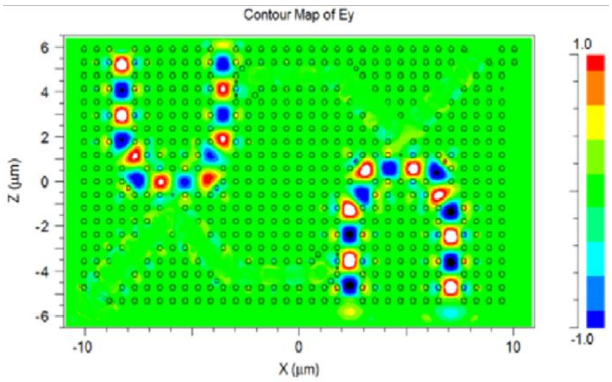
Fig(7.12) - Normalized output for waveguide based all optic SR Flip- Flop (Case 1)



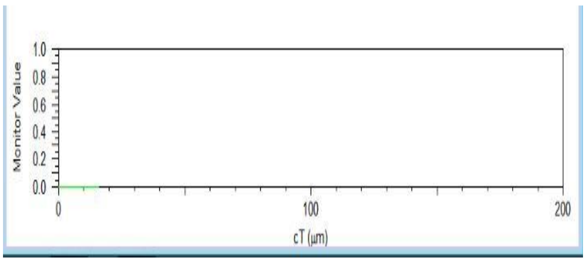
Fig(7.13) - Field Distribution for waveguide based all optic SR Flip- Flop (Case 2)



Fig(7.14) - Normalized output for waveguide based all optic SR Flip- Flop (Case 2)

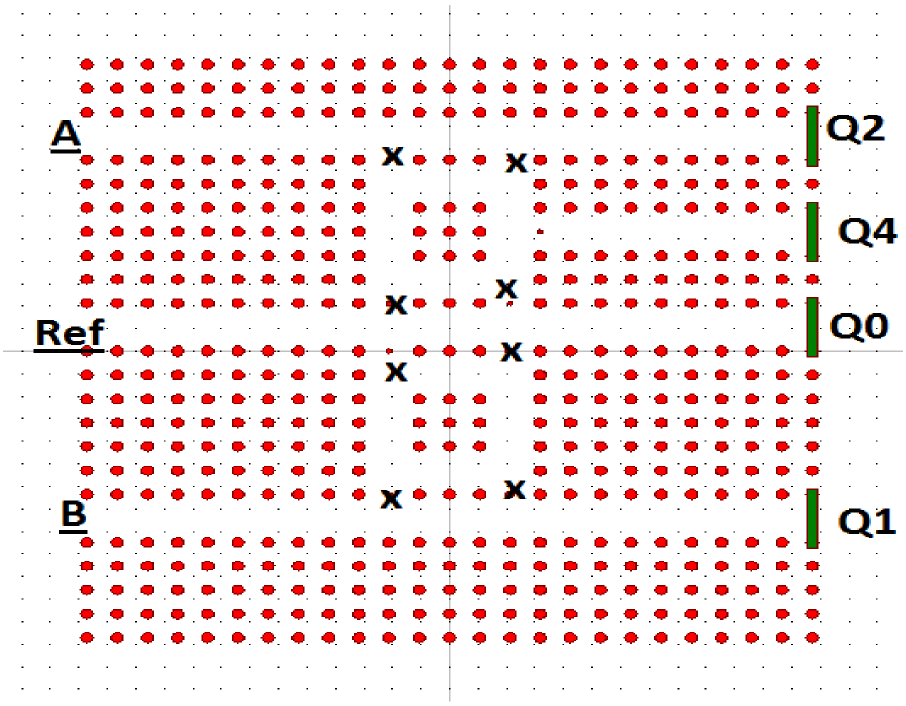


Fig(7.15) – Field Distribution for waveguide based all optic SR Flip- Flop (Case 3)



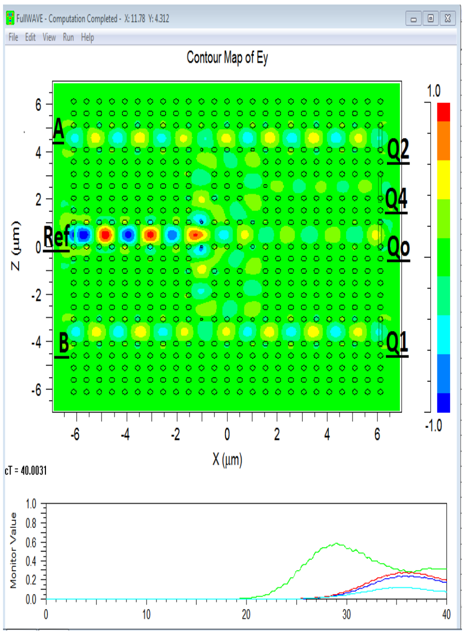
Fig(7.16) - Normalized output for waveguide based all optic SR Flip- Flop (Case 3)

DECODER

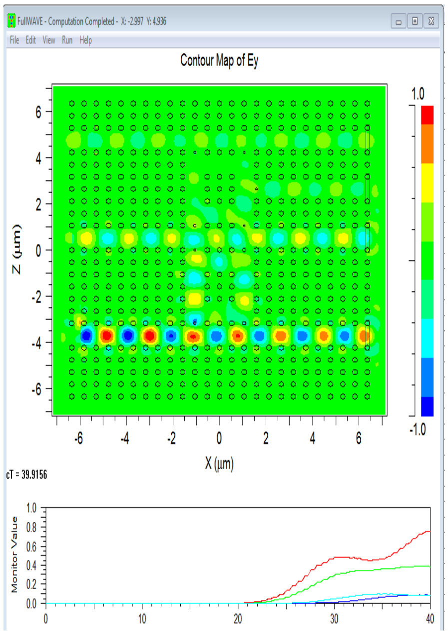


Fig(7.17) – Design of 2-4 decoder

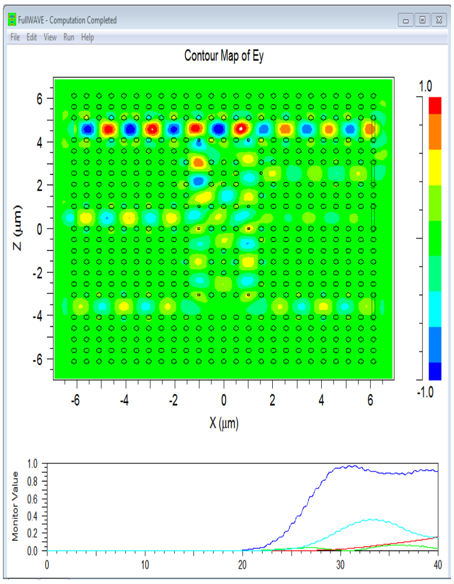
The above circuit made in Rsoft software with silicon crystal lattice provides the desired output for corresponding inputs as given in Truth Table (table 1.6), as shown in following figures:



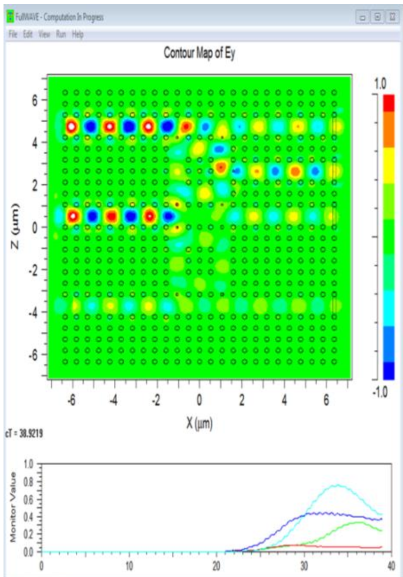
Fig(7.18) – Decoder result with no inputs



Fig(7.19) – Decoder result with one input



Fig(7.20) – Decoder result with one input(ii)



Fig(7.21) – Decoder result with two inputs

8 SUMMARY

In the recent decade, researchers are concentrating more on the development of optical based logic designs to improve the high-speed activities in telecommunication systems and networks. Not only the telecom sector but also the electronic computing systems which may not satisfy the demand of high speed computing due to their limiting capabilities too needs the replacement with optical means because of high speed nature of light. Information processing at terahertz speed is possible with optics due to the realization of the terahertz optical signals. Towards this approach, researchers have explored the optical devices stimulated by the development of non-linear materials and other semiconductor based technologies. Semiconductor optical amplifier based technique is the cutting edge in the evolution of optical based logical and arithmetic designs. However, power consumption and speed remain the major limitation in these designs apart from inevitable spontaneous emission of noise. Logic devices with non-linearity are affected with high power consumption though they have many other applications. In order to overcome all of these limitations and as a part of challenging research, scientists have dedicated their time and efforts towards the implementation of the logic functions on photonic crystal platform due to its unique optical characteristics. Photonic crystal is such a promising area, which can provide a recognizable space for the realization of logic devices due to the unparalleled advantages like high speed, low power consumption and compactness. They can control, guide and limit the light in nano-metre scale. Many more concepts have been introduced in the design of logic devices (like compactness). These structures have found many applications in wavelength optical switches , logic gates. The design of these all-optic devices

Based on photonic crystal waveguides is much smaller than the conventional design due to large dispersion in photonic crystals. Here, a basic flip flop, 4*2 Encoder and 2*4 Decoder design is proposed using two-dimensional photonic crystal based (2D PhC). Encoder has four input and two output waveguides as the ports, Decoder has three input (including one reference input) and four output waveguides as the ports, and flip-flop has four Input(including two reference inputs) and two output waveguides as the ports.

A flip-flop, decoder and encoder are designed and simulated. The results are documented with all the outputs and graphs. The advantages and trade-offs are mentioned in section (4) & (6). It has been proved many times that the all-optical systems are better in manyways. They are fast with a huge bandwidth enabling us to push ourselves in the fieldof optical communication and all-optic equipment. In the coming future the work wehave done is hoped to act as a reference to the researchers for the further development of the all-optic devices.

9 References

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