B. TECH. PROJECT REPORT

On

Design And Analysis Of On-Chip Photonic Switch

for

Optical Fiber Communication

BY

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Guided by:

Dr. Mukesh Kumar

DISCIPLINE OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY INDORE

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Design And Analysis Of On-Chip Photonic Switch For Optical Fiber Communication

A PROJECT REPORT

Submitted in partial fulfilment of the
requirements for the award of the degrees

of
BACHELOR OF TECHNOLOGY
In

ELECTRICALENGINEERING

Submitted by:
Dilip Kumar Meena
Guided by:
Dr. Mukesh Kumar

INDIAN INSTITUTE OF TECHNOLOGY INDORE

CANDIDATE'S DECLARATION

I hereby declare that the project entitled **"Design And Analysis Of On-Chip Photonic Switch For Optical Fiber Communication"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Electrical Engineering' completed under the supervision of
Dr. Mukesh Kumar (Associate Professor) IIT Indore is an authentic work.

Further,

I declare that I have not submitted this work for the award of any other degree elsewhere.

Signature and name of the student with date

CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the students is correct to the best of my knowledge.

Dr. Mukesh Kumar (Associate Professor)

Preface

This project report on “ Design and analysis of on chip photonic device for optical fiber communication " is prepared under the guidance of Dr.Mukesh Kumar.

This report is about optical switch its applications in optical fiber communication being the focused device.

I have tried to the best of our abilities and knowledge to explain the content in a lucid manner. I have added figures and experimental results to make it more illustrative.

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Acknowledgement

I wish to thank Dr. Mukesh Kumar for his kind support and valuable guidance. This work has been done in the framework of the IIT Indore project. I would like to acknowledge Swati Rajput, Vishal Kaushik and Sourabh Jain for providing their sincere cooperation and guidance to carry out this research. It is their help and support, due to which I was able to complete the design and technical report. Without their support, this report would not have been possible.

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Abstract

Photonic Integrated Circuit (**PIC**) or we can say **integrated optical circuit** is a circuit that combine several function (at least two) photonic functions on a single chip as similar to any conventional electronic integrated circuit. The main difference between the traditional integrated circuits and Photonic integrated circuits is that a photonic integrated circuit provides the function for information signals imposed on optical wavelengths usually in the visible spectrum or we can say near infrared 850 nm-1650 nm. A photonic integrated circuit have many components like laser, photonic diode , coupler, modulator etc. form them one of main component is optical switch And there are several advantages of a good optical switch it will help in multiple connection ,provide optical protection also a good switch should operate on wide range of wavelength and produce very low loss however, in order to make a good optical switch one cannot rely only on silicon because silicon have low electro-optic switching coefficients so , to overcome these limitation of silicon we should some other semiconductor along with silicon

one of the most commercially used material platforms for photonic integrated circuits is indium phosphide (InP), it allows the integration of multiple optically passive or active functions on the single chip at a same time interference are required. This type of communication can transmit, text, voice, video, and telemetry through local area networks, computer networks, or across very long distances. Currently main application of photonic integrated circuits is in the area of fiber-optic communication, internet though applications in other fields such as computing, defense biomedical .

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CHAPTER 1

1.1) Introduction to Integrated photonics

Photonic integrating circuits have numerous benefits over conventional circuit faster speed, higher bandwidth, and very less energy consumption. Hybrid technologies used Photonics integrated circuit and Integrated circuits as well as purely photonic circuits are advancing technology and science left behind the electronics age and look into the future, pushing the boundaries of what is possible for large data processing, communications, computing, defense, and consumer technology [1]. Present integrated circuits work on conducting electricity, or flow of electrons to flow easily in the circuit. Electrons are subatomic charged particles having negative charge that interact with other electrons as well as other particles. due to These interactions slow speed get electrons down as they move through integrated circuits, control the amount of data or information which can be transmitted, and generate heat which increase the temperature and also causes height energy losses. A heat sink or may be a cooling device is sometime required to regulate heat generation, otherwise the electrical components or whole device become irreversibly damaged and become useless .In Photonic integrated circuits photons, are used for transferring information which is massless particles representing a quantum or packet of light, instead of electrons and no extra heat generate

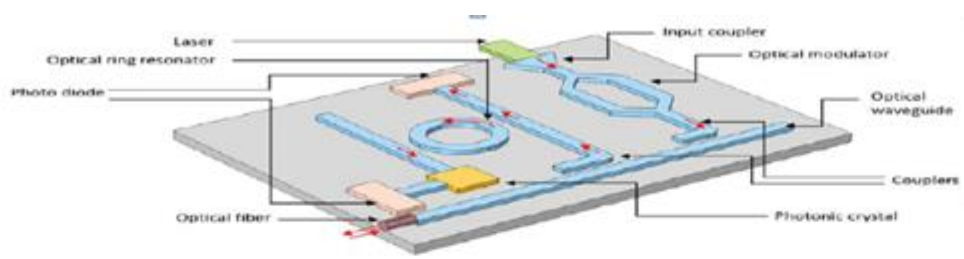


Fig 1.1 Photonic components on a single chip [3]

Photons move faster than electron moves in informal integrated circuit almost at the speed of light through the optical transmitting Medium without interacting with other photons. This way greatly increases the bandwidth and speed of the circuit moreover at the same time drastically reducing the large amount of energy loss, making Photonic integrated circuit much more power efficient [2-5]. With modern technique such as multiplexing techniques, a large number of signals can be sent with the help of a single-mode fiber that is orders of magnitude larger much larger than the number of electrical signals that copper or iron wire can transmit. A single optical fiber strand in a submarine transatlantic fiber optic cable can carry millions of phone calls at the same time at almost 100 km before requiring any amplification, and the amplifiers itself are optically pumped lasers: no electronics involved. However, one of the biggest drawbacks of Photonics integrated circuits is their size. The current transistor density on integrated circuit is about a million transistors per millimeter.

1.2) Objective and Motivation

silicon is largely used semiconductor in C-mos. industries and most of the Integrated circuits made of this material also in silicon provide very low loss at 1550nm wavelength at the same time silicon cannot widely use in active phonics circuits due to its poor electro optics charters tics at the other hand conventional integrated circuits are very small and compact so its a challenge in . Photonic integrated circuits to make device compact try to shrink it size ,as small as possible .however, Photonics has papers as one of the interesting field because of its ability for low-cost optical components integrated along with electronic functionality also. In the last decades, there is enormous growing interest in photonic devices based on Si-compatible materials in the field both of the optical communications and of the optical inter-connect.

In this contest, tremendous progresses is achieved in the technological processes mainly based on the use silicon-on-insulator (SOI) substrates that allowed obtaining reliable and effectiveness of fully complementary metal-oxide semiconductor (CMOS) compatible optical components such as, very low loss waveguides, high-Q resonators, photonic diode, high speed modulators, optical switch, laser, couplers, . All these devices have been developed to operate in the special wavelength range that very from (1528–1561 nm) to (1561–1620 nm). However, at the same time one of the crucial steps toward the integration of photonics with electronics resides in the development of highly efficient chip-scale photodetectors (PD) integrated on Si. Bulk and large photodetectors are perhaps the oldest and best understood silicon optoelectronic devices.so, our aims is to develop a photonics switch that can operate in wide rang of wavelength and aslo have enery efficiency at the same time we try to use silicon along with some new semiconductors that have good electo-optic properties. For the realization of photodiodes integrated in photonics circuits operating at wavelengths beyond 1100 nm silicon is not the right material due its transparency.

Chapter 2

2.1)Optical switch

An optical switch is a device that selectively allows to switches optical signals from on state to off state or from off sate to on or one can say switches the signal from one channel to any another. The former is called as an optical switch (time domain) or an optical modulator, while the latter is called an optical router. Since the switching can be temporal for short period of can be longer time of period, such switches are similar to two-way or one -way switches in conventional integrated circuits. In general, optical switch are consume very less power then normal switches however optical switches are not that much common to use as conventional electric circuits .

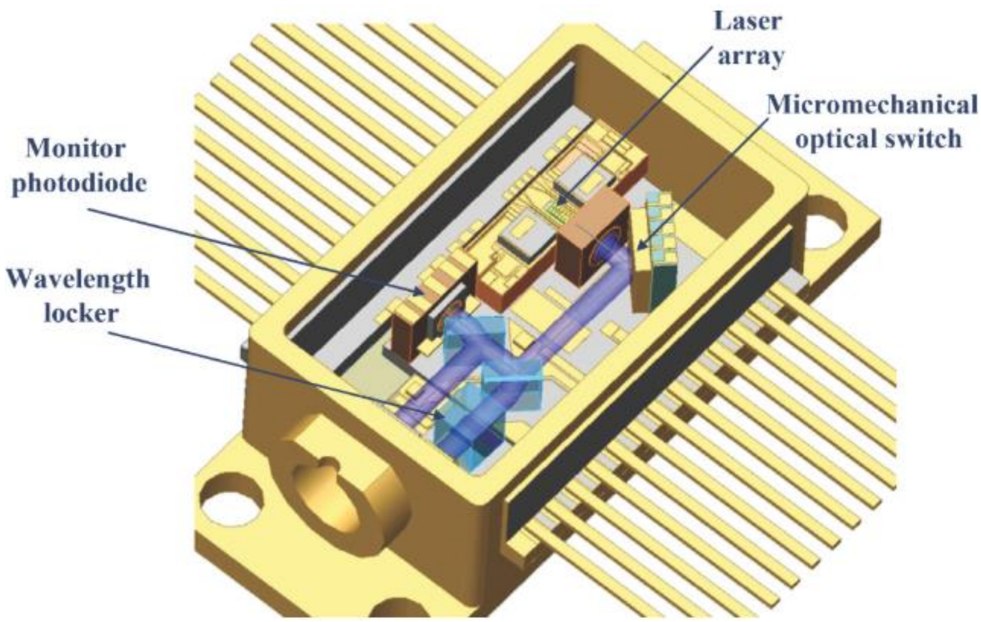


Fig 2.1 optical switch[16]

One can operate optical switch by mechanical means, like physically shifting an optical fiber cable to drive one or more alternative fibers cables, or by other method like magneto-optic effects, electro-optics effect or by some other technique or methods. Slow optical switches, like those using moving fibers, may be used for different routing of an optical switch transmission path, such as routing around a fault. On the other hand, Fast optical switches, like those using magneto-optic effects or electro-optics may be used to perform logic operations or for fast switching applications also involve in this category are semiconductor optical amplifiers, which are optoelectronic devices that can be used as optical switches and be integrated with discrete or integrated microelectronic circuits several parameters are defined and specified to measure the performance of optical switches like operating frequency range, loss etc. The steady state operation of an optical switch (or optical switching matrix) helps in determining its ability to effectively transmit optical power from an input port(source) to any one of output(destination) ports over the "on" state transmission path, and its ability to effectively isolate input power sources from all non-active ports over the "off" state transmission paths**.**

2.2) characteristic of optical switch

In PICs we have to select a switch that operate a very low losses moreover we can use on wide range of wave length there are few parameter the helps us to selectivity choose a good switch like a good optical switch In conventional integrated circuit to turn on and turn off we use normal electric switch but in provide Flexibility in optical network connectivity[11-13] ,it help in optical protection, optical cross connection etc. theses parameter helps to choose a good switch apart from these a good switch helps to provide connection between multiple paths so that we can easy inter-connect multiple device on single chip moreover a good optical switch must also have low switching loss and less transient time so that we can get fast on –off switching

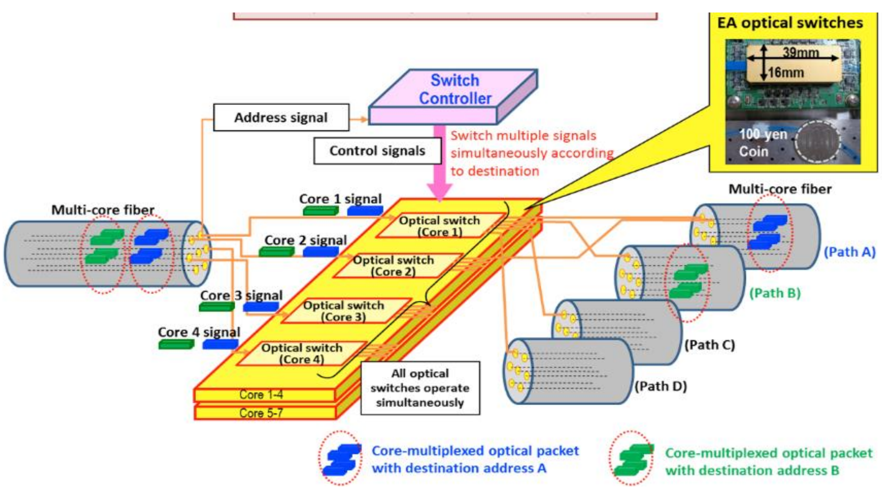


Fig 2.2 function of optical switch[18]

CHAPTER 3

Hybrid silicon based Photonic Switch

Development in optoelectronics is often led by the discovery and development of materials having special properties. Recently, the special class of material knows as transparent conductive oxides (TCO) has attractive choice for active photonic on-chip device. In particular, indium tin oxide (ITO) one the member of TCO family have refractive index changes on the unity oder[7]. That property makes it possible to achieve electro optic modulation of sub-wavelength device scales, when thin ITO layer interfaced with optical light confinement techniques like we found in plasmonics; optical modes are compressed and create strong light-matter interactions[3,4]. TCOs are largely used for their optically transparent yet electrically conductive properties. apart from that, TCO's found increasing interest in many optoelectronic technologies such as for panel displays and energy conversion Here we try to used this special material for high performance switching. With the advancement of Technology we are tried to make optical modulation efficient and more accurate process

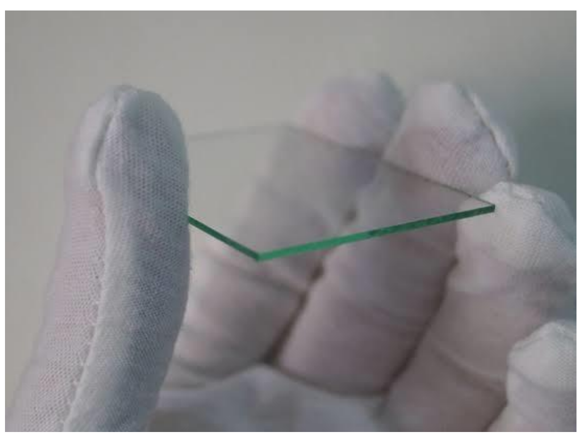


Fig 3.1 ITO slab[9]

A vast research is going on in order to find the material which suits best for the electrical optical modulation sum of them are V02 , polymer and TCO family .vV02 and polymer appears to be attractive because there optical electric property. Can be widely change by changing the temperature ,at the same time They have temperature limitation after certain temperature They are failed to perform as our requirement .when we are look at the TCO family like ITO,AZO, etc. we found that they are also have good optical electrical property and can be used in optical modulation. ITO (10%sno2 and 90%in2o3) from TCO family have amazing electrical tunability permeability which can also be explained by drude model. According to drude Lorentz model when charge concentration in a semiconductor material change by any means it's permittivity also get change that ultimately leads to change in its refractive index. And the best part of ITO is that its refractive index can be changed by large amount by changing career concentration in it . this features of IOT make it good choice for optical modulation.   In order to justify and analysis, the amazing optical electrical property of ITO. Moreover For ITO, electrons are the majority carriers that originating mainly from the doping donor oxygen and Sn vacancies.

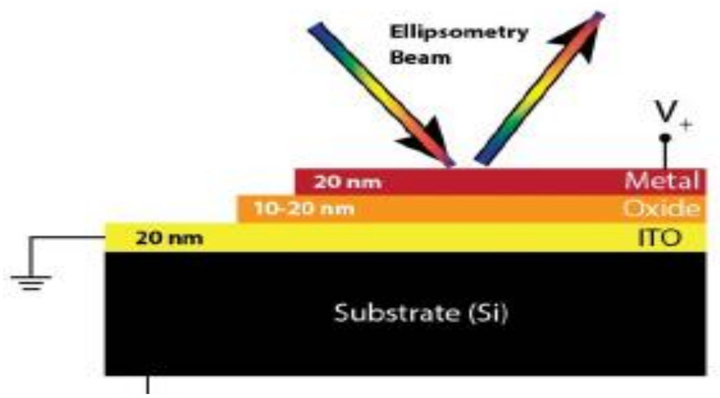


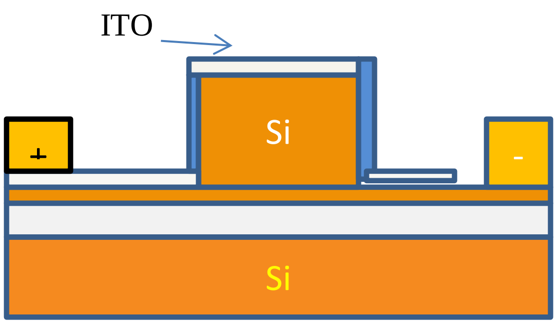
Fig 3.2 Indium-Tin-Oxide based High-performance Electro-optic Modulators[3]

before utilize ITO in photonic devices, a piece of detailed knowledge and dependencies of one parameter on another and how they relating to the optical and electrical properties must be well known. generally, the optical properties were previously modeled by a Drude–Lorentz mode[12], due to the high carrier concentration .here we are mainly Focusing on the electrical properties, the carrier concentration and mobility of ITO has been found to vary widely with process conditions for the deposition method such as sputtering power, oxygen flow, and temperature because of that one should very carefully handle ITO during processing.

CHAPTER 4

Device Design

Before design of optical switch we should remember that ITO have good opto-electric tunablility so ,we have to use that property of ito now silicon is widely use in c-mos. fabrication due to its widely acceptance also having impressive passive optical property moreover silicon have very less transmission loss at the wavelength so, our prime aim is to use property of both ITO and silicon tin ode rot achieve our objective SO, Good electro-optic properties of ITO and



<u>Device Parameters</u>
Si Rib thickness =150nm to 1050nm
Si Rib Width= 1µm
ITO thickness= 50nm
Refractive index of silicon= 3.48
Refractive index of ITO=1.827
Operating Wavelength: 1550nm
Simulation tools: Mode & Charge

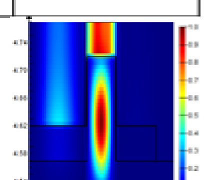
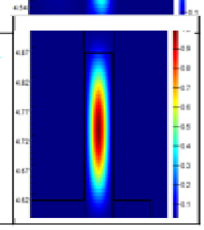
Figure 1.1 Design of optical switch

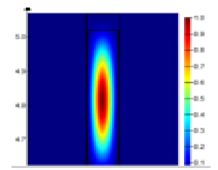
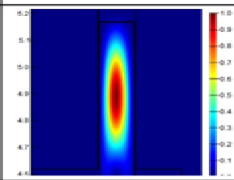
impressive passive optical properties of Silicon inspired us to make a optical switch so, for make optical switching we use silicon wafer as base of 50nm and a layer on insulator on that ,now we have taken rib height of 150 nm and width of 1 micro and it is a covered with a thin layer of ITO of 50 nm when we try to pass 1550 nm wavelength light throw it will be found that there are some mode which strongly confined in near ITO-silicon junction basically we chosen silicon as optical waveguide because it has good passive optical property also we know that An optical waveguide or rib is a rectangular structure that guides electromagnetic waves in the optical spectrum. Some very common types of optical waveguides involving optical fiber and transparent dielectric waveguides made of plastic and glass. We also provide two metallic contact so that we can easily operate our device is carrier depletion mode carrier accumulation mode on contact is connected with silicon and other with ITO .in for simulation of this device we are use lumeric software .

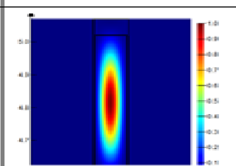
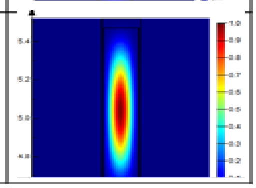
CHAPTER 5

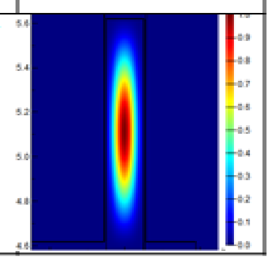
Computation of Optical Characteristics

Initially, we have taken rib height of 150 nm it is a covered with a thin layer of nm when we try to pass 1550 nm wavelength light throw it will be found that there are some mode which strongly confined in near ITO-silicon junction so our firm aim is to find the optical mode which highly confined in silicon rib but also intact with silicon-ITO because if mode is not interact with junction the carrier concentration at junction or more specifically at near junction ITO the carrier concentration will not change much so when we simulate at 1550nm wavelength then some optical mode are confined with silicon-ITO junction as one can see from the table also when we increase rib height to 300nm and check optical mode for same wavelength then we found that optical modes not that much interact with junction and mainly confined only in silicon rib also at 300nm rib height we can see from table that loss are very less as compare to 150nm on further increase rib height to 450nm then 750nm ,900nm and finally 1050nm we found that at higher rib height optical optical modes mainly confined only in silicon rib and on interact with junction secondly as rib height increase loss are very less at higher rib heights other parameter like dispersion, group index, group delay , are not change much as one can see from table also

S.NO	Rib height (nm)	Effective index	Loss (dB/cm)	Dispersion (ps/nm/km)	Group index	Group delay	Mode
1	150nm	1.359681 + i0.00127469X10^{-5}	448.79	410773	4.76871	1.59067 x 10^{7}	
2	300nm	2.538355 + 7.555439 X10^{-5}	26.602	8884.97	4.95504	1.6528X10^{7}	

S.NO	Rib height (nm)	Effective index	Loss (dB/cm)	Dispersion (ps/nm/km)	Group index	Group delay	Mode
3	450nm	3.009224 + 3.669466 X10^{-5}	12.90	2327.01	4.19992	1.40094X10^{7}	
4	600nm	3.175458 + 2.637422 X10^{-5}	9.2863	653.453	3.97342	1.32539	

S.NO	Rib height (nm)	Effective index	Loss (dB/cm)	Dispersion (ps/nm/km)	Group index	Group delay	Mode
5	750nm	3.251225 + 2.148863 X10^{-5}	7.5661	437.556	3.89346	1.29872X10^{7}	
6	900nm	3.293718 + 2.009463 X10^{-5}	7.0753	186.45	3.84491	1.28253	

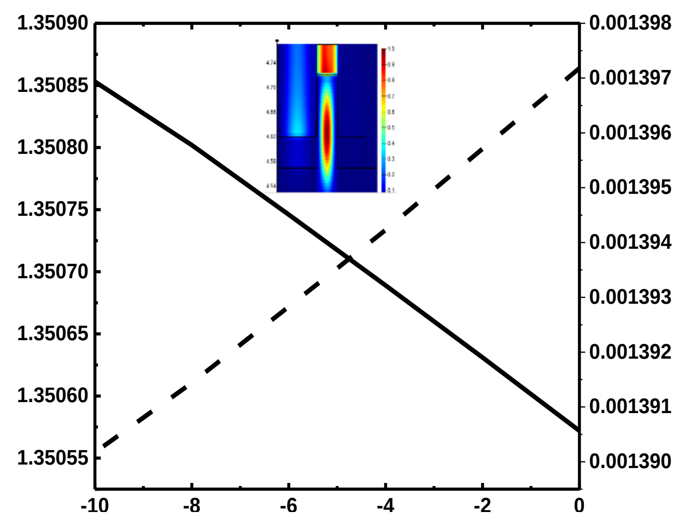
S.NO	Rib height (nm)	Effective index	Loss (dB/cm)	Dispersion (ps/nm/km)	Group index	Group delay	Mode
7	1050nm	3.319731 + 1.932297 X10^{-5}	6.8036	37.2767	3.81555	1.2727 X10^{7}	

Stronger and enhanced interaction of optical mode with Si-ITO interface at 150nm rib height at other rib height optical model confined only in silicon on but not interact with Si-ITO junction from this we can conclude the 150nm rib height is best suitable of elect-optical switching more-over

CHAPTER 6

Carrier depletion mode

we know that the from previous that rib at height 150nm we got maximum change now we are try to operate our switch in reverse bias mode carrier depletion mode basically we are try to follow drude Lorentz model which say as the carrier concentration of a semiconductor change their permittivity of material as change which ultimately change in effective index of material as ITO is member of TCO family it has good electro optic property or ITO is n type device and silicon is P type device if we apply reverse biasing to this device. that is negative voltage on the ITO[17] and positive on Silicon. then , we can successfully able to change ionic concentration at the Silicon junction Reason by doing so we can also use model here. initially when we apply -2 then -4 we have observed slight change in reflective index near the junction on further increasing the negative voltage up to - 10 volt. We are able to get significant amount of the change in reflective index now to understand the result in better way. We repeat this whole process but this time rib height is 300 nm we did this process for the different height of the reply 450 , 600, 750, 900nm and finally 1050nm on analysing the data we can prove that the maximum change occur at the 150 nm height. And the graph we got as follow.



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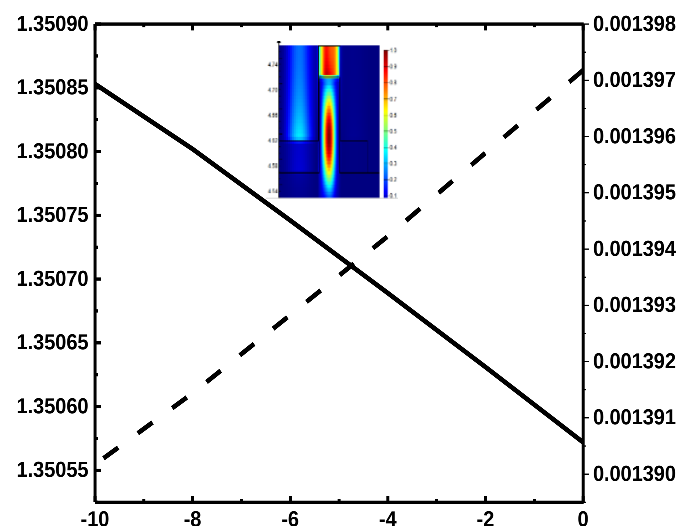

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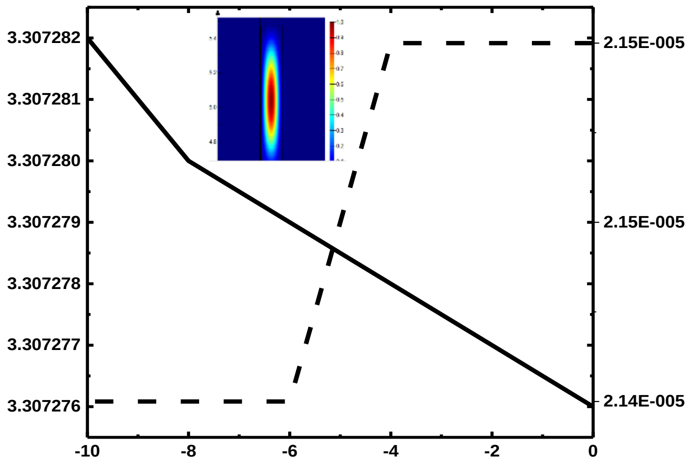

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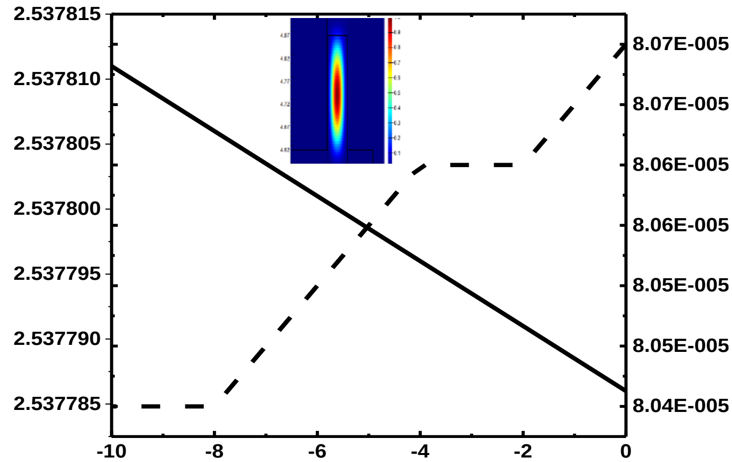

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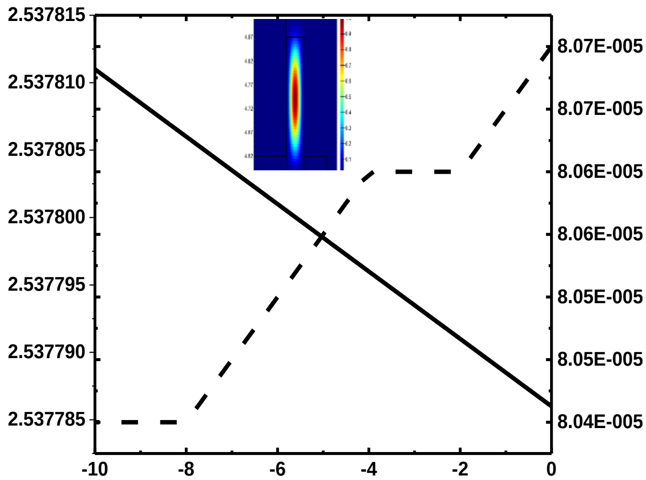

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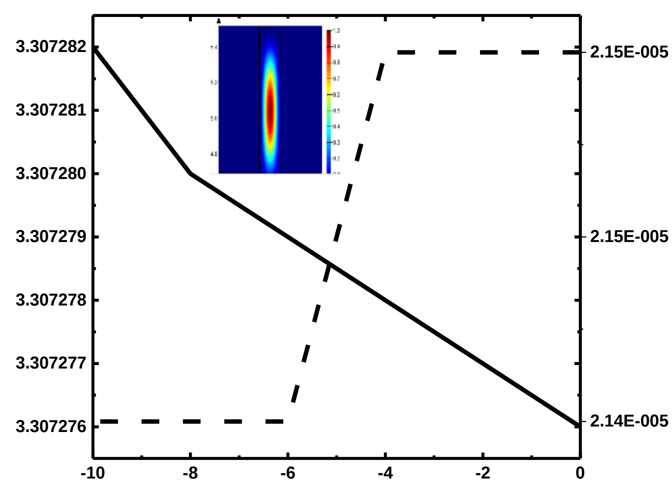

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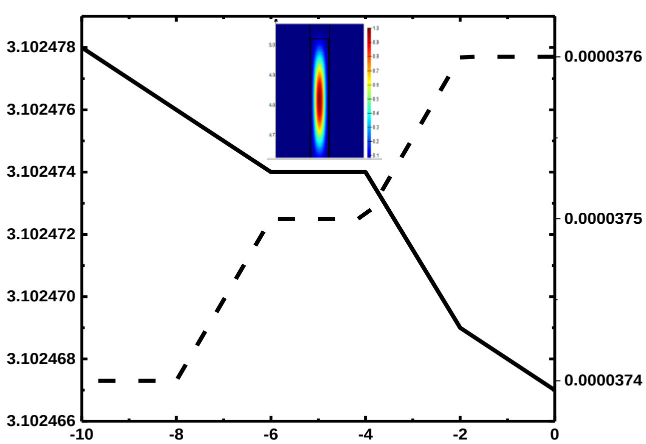

g

Fig 6.1(a tog) Effective index (img and real) vs Voltage for rib height 150 nm,300 nm,450 nm,600 nm,750 nm,900 nm and 1050 nm from a to g respectively

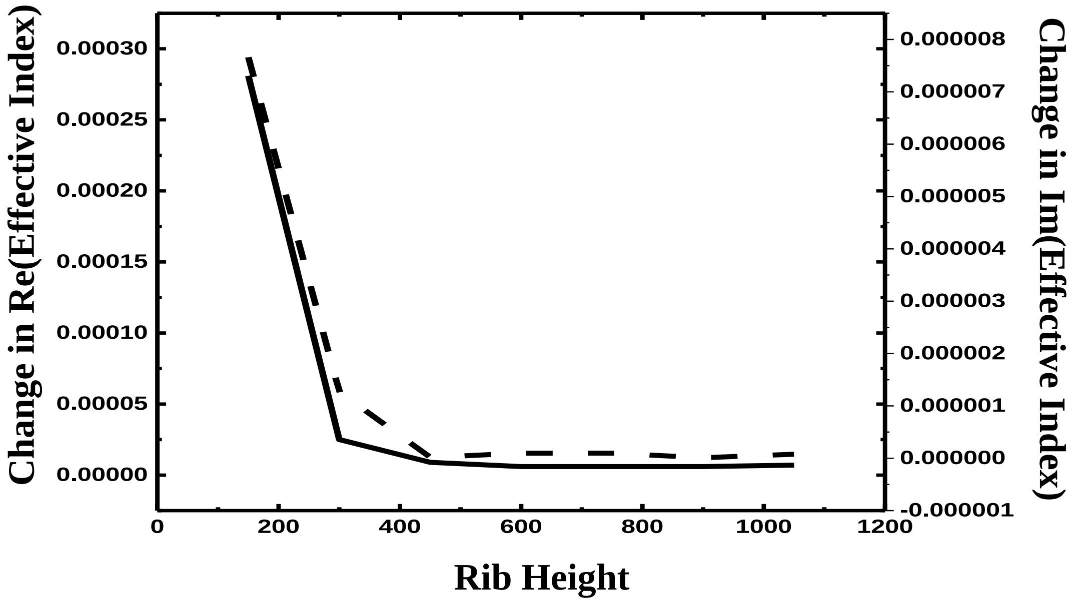

Fig 6.2 Effective index (img and real)Vs Voltage at different rib height

from fig 6.2 we can observe that there is large change in effective index(img and real) both at rib height of 150nm and as we increase the rib height from 150nm to 300nm we observe that change are less on further increasing rib height change become very less almost constant from 600nm to 1050 nm and from fig 6.3 one can observe that on increase wavelength form 1200nm to1700nm large change observe at higher rib height (rib height is constant at 150nm) .

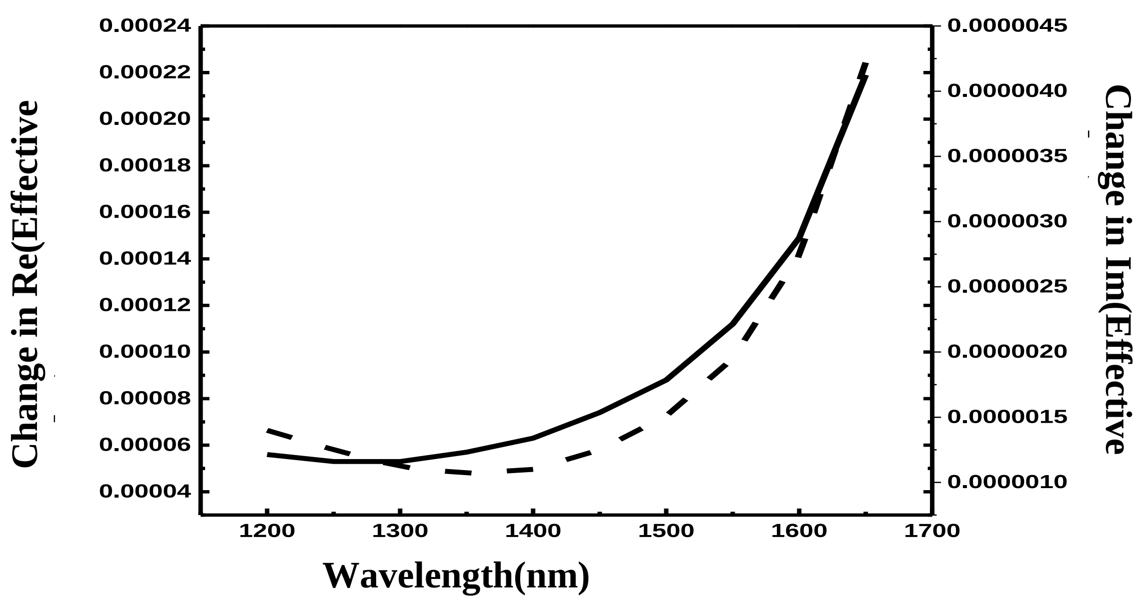

Fig 6.3 Effective index (img and real)Vs Voltage at different wavelength

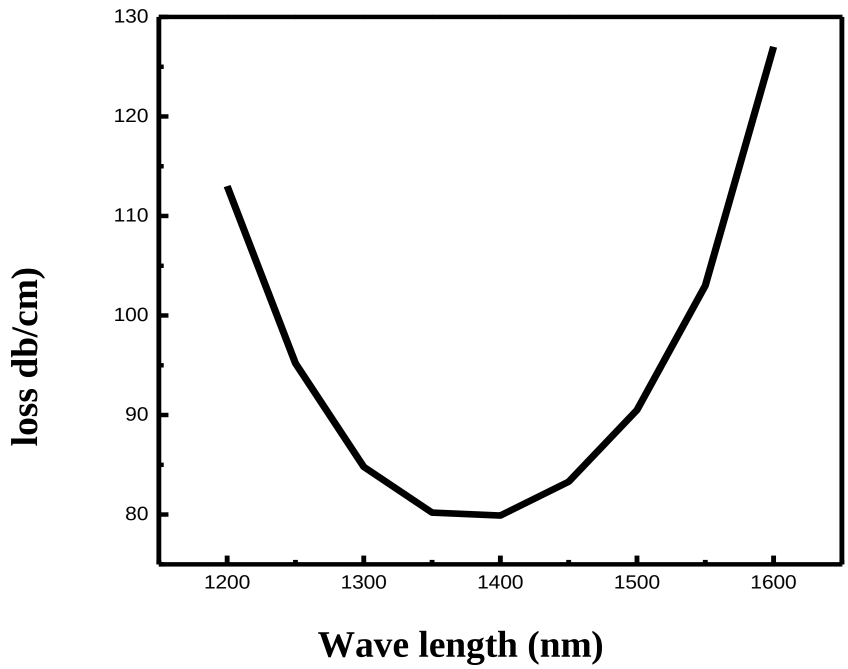

Fig 6.4 Loss vs. wavelength (at rib height 150nm)

Before coming to the graphs we first see what Drude-Lorentz model says. It say that whenever there is charge carrier concentration change in any semiconductor there is change in permittivity of material change which ultimately change is effective index of material. Form the below equation we can conclude the same

$$\boxed{\Delta n = \Delta \varepsilon / (2\sqrt{\varepsilon})}$$

$$\boxed{\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_p^2}{\omega(\omega + i\gamma)};\ \omega_p^2 = \frac{n_c e^2}{\varepsilon_0 m^*}}$$

From above simulation result we found the there is good change in electro-optical property of at Si-ITO junction at rib height of 150nm moreover our device good result at height wave length so, known in order to check how loss varies in our device at different wavelength

We varies wavelength for 1200nm to1650nm at measure loss at the difference of 50nm wavelength and the final

CHAPTER 7

Carrier accumulation type photonic switch

we know that the ITO is "n" type device and silicon is P type device if we apply forward biasing to this device. that is positive voltage on the ITO and negative on Silicon. then , we can successfully able to change ionic concentration at the Silicon junction Reason by doing so we can also apply drude lornez model here. initially when we apply 1 then 2 we have observed slit change in effective index(both in real and img) near the junction on further increasing the negative voltage up to 5 volt. We are able to get significant amount of the change in reflective index now to understand the result in better way. We repeat this whole process but this time rib height is 300 nm we did this process for the different height of the reply 450 ,600,750, 900nm and finally 1050nm on analysing the data we can prove that the maximum change occur at the 150 nm height. And the graph we got as follow large change occurs at rib height because 150nm because of good optical mode interaction at Si-ITO junction as expected he got good change in carrier accumulation type photonic switch but at the same time we have speed limitation in this type switch due to slow diffusion of minority charge carriers secondly, we observe the losses are also high relative to carrier depletion type switch due to flow of current

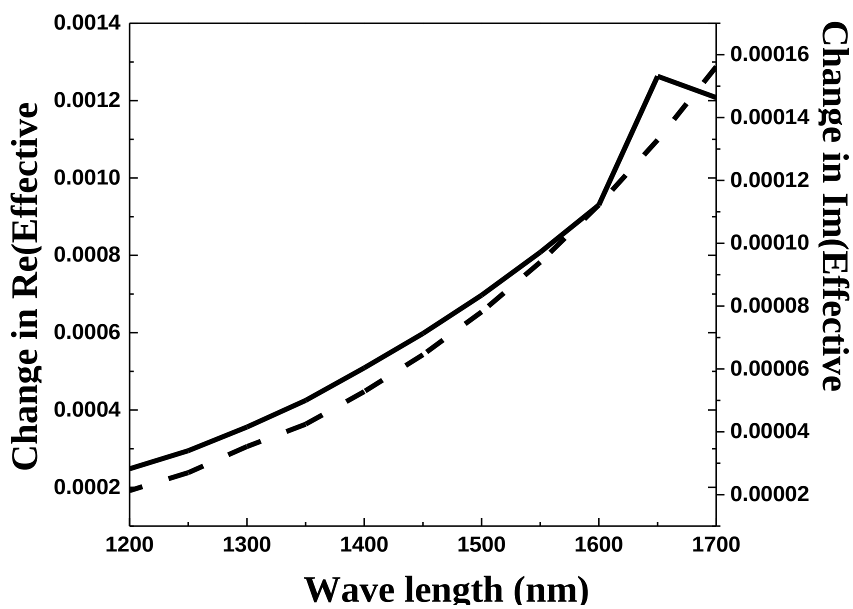

Fig 7.1 Effective index (img and real)Vs Voltage at different wavelength

Chapter 8

Conclusion

from the simulation result and the graph we can make several conclusion the very first thing we observer that rib height of 150 nm is best suitable for our optical switch because at that height we got maximum optical mode confinement and mode is also interact with silicon-Ito junction also at other rib height like 300nm ,450nm..etc optical mode is not interacting with si-ito junction and modes is only confined in silicon rib apart from that , our second observation is that we can our device is works as good optical switch at height wavelength because we found good change in effective index at higher wavelength moreover we can also say that our device is Low loss broad bandwidth aswe found that loss is very less in our device for larger part of wave length . our device is not just made of silicon but a hybrid of silicon as ITO .so, we can also say that presence of ITO lead our device to be electrically driven .

we are successfully able to achieve Electro-optic switching in carrier depletion type structure and are carrier accumulation type structure both and we got better change is carrier accumulation type mode but here speed limit of switch is a problem because of that carrier depletion type switch is prefer and last conclusion that we can made is that our that are able to tune elect- optical property with the help of apply voltage as we expect same result from Drude-Lorentz model.

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