PERFORMANCE OF PIPIN CARRIER INJECTION SOI MODULATOR

NUR RASYIDA ADILA BINTI ZULKIFLI

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I would like to dedicate this study to my beloved families especially my parents Mr. Zulkifli bin Haji Ali and Mrs Asmah binti Haji Abdul Halim. Then, to my supervisor, I'm grateful to know you.

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ABSTRACT

Silicon photonics has been a fast growing subfield of integrated optics and optoelectronic in the previous decade and is currently considered an established technology. The main thrust behind the evolution is its compatibility with the established and low-cost microelectronic integrated circuits fabrication process. In recent years, a number of active and passive photonic devices have been demonstrated on silicon.

In this project, a number of diode structure of P-I-P-I-N on Silicon-On-Insulator (SOI) are proposed and demonstrated. Simulation and experimental results to produced higher refractive index change. The Silicon-On-Insulator (SOI) used in this project to observe the performance of P-I-P-I-N carrier injection in forward biased. The modulator device based on P-I-P-I-N diode structure has been designed using ATHENA and ATLAS in TCAD Silvaco Software. The scope of this project only focus on wavelength at 1.55 µm for long distance transmission and the results is present the performance of P-I-P-I-N carrier injection for three different structure. The gap/ distance from the rib waveguide sidewall used for structure 1 is 4.4 µm, structure 2 is 3.5 µm and structure 3 is 2.0 µm.

The parameter and analysis obtain from this project are refractive index change,Δn, phase Shift, $\Delta\theta$, modulation efficiency, $L_\pi V_\pi$, absorption Coefficient, $\Delta\alpha$, and absorption Loss, α_π (dB). At the end of the work, the results proved that the difference gap/distance of the doping region from rib waveguide sidewall lead the changing of refractive index change that will affect the performance of other parameters.

ABSTRAK

Fotonik silikon telah berkembang dengan kadar yang cepat dalam bidang optik dan optoelektronik dan kini di iktiraf. Teras utama di sebalik evolusi ini adalah keserasian dengan proses penghasilan litar dan mikroelektronik dengan kos yang rendah. Sejak kebelakangan ini, silicon menghasilkan dan mempamerkan aktif and pasif peranti struktur.

Bagi projek ini, beberapa struktur diod P-I-P-I-N di Silikon-kepada-penebat (SOI) telah dicadangkan dan dihasilkan. Hasil dapatan daripada simulasi menunjukkan dan perubahan indeks biasan yang lebih tinggi. Silikon-kepada-penebat (SOI) yang digunakan dalam projek ini ialah untuk meninjau prestasi struktur diod (positif). Struktur P-I-P-I-N diod struktur telah dihasilkan menggunakan ATHENA dan ATLAS dalam TCAD Silvaco Software. Skop projek ini hanya memberi tumpuan kepada panjang gelombang 1.55 µm di untuk penghantaran jarak jauh dan focus kepada tiga struktur PIPIN diod yang berbeza. Jurang / jarak dari sisi pandu gelombang yang digunakan untuk struktur 1 adalah 4.4 µm, struktur 2 3.5 µm dan struktur 3 adalah 2.0 µm.

Hasil daripada analisis projek ini adalah perubahan indeks biasan, Δn, perubahan fasa, Δθ, kecekapan modulasi, $L_{\pi}V_{\pi}$,, penyerapan Pekali, Δα, Rugi penyerapan, α_{π} (dB).

Hasil dapatan daripada kajian ini membuktikan bahawa perbezaan jurang / jarak dari pandu gelombang sisi membawa perubahan perubahan indeks biasan yang akan memberi kesan kepada prestasi parameter yang lain.

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LIST OF ABBREVIATION

SOI	-	Silicon-On-Insulator
P-I-N	-	Positive Intrinsic Negative
P-I-P-I-N	-	Positive Intrinsic Positive Intrinsic Negative
CMOS	-	Complementary Metal-Oxide semiconductor
MEMS	-	Microelectromechanical System
TCAD	-	Technology Computer Aided Design
Si	-	Silicon
Si_2O	-	Silicon Oxide

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Optical modulator are used in optical communication systems which is to convert electrical signals into modulated optical signals. As traffic in network increase, the usage of optical modulation in data transmission is more suitable. The modulation may be imposed on the phase, frequency, amplitude or polarization of modulated beam but this project focuses to the phase modulation where silicon as a medium of transmission. The function of phase modulator are used to convert the data signal from electrical data signal to optical data signal. [1]

The fabrication of optoelectronic used Silicon-On-Insulator (SOI) as a medium due to high index contrast between the silicon core and the sil-ica cladding. The increasing of the usage of silicon optical modulator in photonic research based on their good performance in order to achieve high speed optical link. The carrier injection of PIPIN diode will produced high refractive index change in Silicon-based materials. The best way to modulate the signal in silicon-based materials by free dispersion effect. [1] This is due to the facts that unstrained pure crystal silicon does not have electro-optic effect such as Pockelseffect, Kerr effect and Franz–Keldysh effect. [2] Silicon medium also allowing much faster the electrical data signaling [3].

In this project, the performance of PIPIN carrier injection SOI modulator is analyzed. The purpose of this project is to design and simulate the PIPIN structure on SOI (silicon-on-insulator) and to analyze the performance of PIPIN SOI optical modulator. The structure of the device will be implemented using two-dimensional (2-D) device simulation package SILVACO which are ATHENA and ATLAS [4].

The performance of PIPIN carrier injection SOI modulator are analyzed using difference values of voltage and doping distance from waveguide which is to find the value of parameters like refractive index change, modulation efficiency, absorption coefficient and absorption loss.

1.2 Motivation

Silicon photonic has high potential in photonic research of optical communication system as it allows optical devices to minimize the cost and easy to produced using standard semiconductor fabrication techniques. Other than that, it is to overcome the critical bottleneck due to the advantages of optical interconnects. Silicon photonic in phase modulation helps in order to achieve the best characteristic in fabrication technology like low-cost, high-volume and reliable manufacturing with nanoscale precision.

The purpose of this project is to produce a good performance of the PIPIN silicon-on-insulator (SOI) optical modulator by brought closer the gap/distance of the doping region to the rib waveguide sidewall. This is because when the distance between the doped region and waveguide wall is reduced, it will decreased the distance for the injected free holes and free electrons to move for the doping region to the optical waveguide. Then, it will produced a good performance of the PIPIN SOI optical modulator.

Modulators are developed based on silicon platform can achieve excellent optical modulation originating from the strong electroabsorption effect and electrorefractive effect. Therefore, the expected result can be seen before the fabrication is done. The benefit from this ways is to save time and to avoid the complication in the design and fabrication.

1.3 Problem Statement

In recent years, Optical fibers becomes most important for high speed transmission in communication system compared others system in the communication field. The Silicon photonics in optical fiber may replace a computer chip's semiconductor transistors with optical equivalents for greater computing performance.

Over the previous decade the performances of silicon optical modulators has been dramatically improving with the most impressive devices being from those based upon the plasma dispersion effect methods. One of the methods is carrier injection which used in PIN structure. When this device is forward biased carriers are injected into the intrinsic region, changing the refractive index. The carrier is injected into the intrinsic region, changing refractive index and phase of propagating light as a forward biased. This injection process will directed the modulation to produced is relatively very phase efficient.

1.4 Objectives

1. To design and simulate PIPIN structure on SOI modulator.
2. To analyze the performance of PIPIN SOI optical modulator.

1.5 Scope

Scope of work is to review the performance of PIPIN carrier injection SOI modulator. The purpose of PIPIN structure is to employ the forward biased PIPIN diode performance. The phase modulator of PIPIN using telecommunication wavelength at 1.55 µm for long distance transmission. Afterwards, analyze the PIPIN performance based on the different value of gap/distance of the doping region from the rib waveguide sidewall. The carrier injection effect of SOI modulator under different value of voltage investigate by using two-dimensional (2-D) design simulating package SILVACO.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a review of the background topics that are related to this report. Firstly, this report review on the optical modulator. A brief discussion on the structure of the diode, the substrate used, the carrier concentration method chosen and the comparison of the research on the gap/distance of the doping region from the rib waveguide sidewall and carrier depletion effect of SOI modulator under different value of voltage.

2.2 Optical Modulator

An optical modulator is a device used for manipulating the characteristic of light [20]. The modulation may be imposed on the phase, frequency, amplitude or polarization of modulated beam. Optical modulator usually used in optical fiber communications, mode locking of laser, image processing and optical metrology. One of the application of optical modulator used in optical fiber communication is photonic systems for data communication application [7]. Optical modulator consist of two types which are electro-absorption modulator and electro-refractive modulator.

2.2.1 Types of Modulator

There are two types of optical modulator known as electro-absorption modulator and electro-refractive modulator. Electro-absorption modulator is a semiconductor device used to modulate the light beam from an electric voltage. It is also known as intensity modulator. The operation principle of this modulator is depending on Franz-Keldysh effect [21] [22]. This is because the absorption spectrum change because the changes of the band gap energy when the electric field is applied. The function of electro-absorption modulator as a data transmitters in optical fiber communication.

Electro-refractive modulator is depends on the types of material used. There are two types of electro-refractive modulator which are electro-optic modulator and acousto-optic modulator. The application of the acousto-optic modulator for switching or laser beam amplitude adjusting and optical frequency shifting where it is based on the acousto-optic effect. While, electro-optic modulator used to modulate the power, phase or polarization of a light beam with an electrical signal. Basically, it is contains one or two Pockels cell. The types of Pockels cell shown in figure 2.1. The changes of the refractive