# VARIATION OF DOPING TYPE FOR SIGE OPTICAL MODULATOR WITH NPN CONFIGURATION

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This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Wireless Communication

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UNIVERSTI TEKNIKAL MALAYSIA MELAKA

FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN PENERIMAAN LAPORAN PSM II

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Date :

The project and research work is dedicated to my beloved parents for their devoted caring throughout my life, my beloved sibling and my friends for their encouragement and assistance.

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# ABSTRACT

This project proposed the design of SiGe optical modulator with NPN configuration by using Silvaco application. The accurate design is required to develop the best performance of optical modulator device The designs are develop using instruction in DECKBUILD. The doping type for the design will be chance using 3 different type of material which is Boron, Aluminum and Indium for P+ doping while Antimony, Phosphorus and Arsenic for N+ doping. The performance of each doping type will be determine using the beam propagation method (BPM). A different performance when varying doping material is expected to be developed. The parameter which has been analysis is refractive index and absorption loss. From the simulation and analysis, it was observed that doping material using Antimony as N+ and Indium as P+ give the highest reflection index change compare to other material. While doping material using Phosphorus as N+ and Boron as P+ give the lowest absorption loss compare to other material.

# ABSTRAK

Projek ini mencadangkan rekabentuk SiGe pemodulat optik dengan konfigurasi NPN menggunakan aplikasi Silvaco. Rekabentuk pemodulat optik yang tepat diperlukan untuk membina peranti dengan prestasi yang terbaik. Reka bentuk ini adalah dibangunkan dengan menggunakan kod arahan dalam DECKBUILD. Jenis dopan untuk rekabentuk akan diubah menggunakan 3 jenis bahan iaitu Boron, Aluminum dan Indium untuk P+ dopan manakala Antimony, Phosphorus dan Arsenic untuk N+ dopan. Prestasi setiap jenis dopan akan ditentukan menggunakan kaedah penyebaran pancaran (BPM). Prestasi yang berbeza akan diperoleh apabila menggunakan bahan dopan yang berbeza. Parameter yang telah dianalisis adalah indek biasan dan kehilangan penyerapan. Berdasarkan hasil simulasi dan analisa, didapati bahawa Antimony sebagai N+ dopan and Indium sebagai P+ dopan memberi nilai indek biasan tertinggi berbanding bahan lain. Manakala bahan dopan menggunakan Phosphorus sebagai N+ dopan dan Boron sebagai P+ dopan memberi nilai kehilangan penyerapan terendah berbanding bahan lain.

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| Content | |
|---|---|
| | |
| SiGe | = Silicon Germanium |
| BPM | = Beam Propagation Method |
| 2D | = Two Dimension |
| RC | = Resistance Capacitance |
| | |
| | |
| | |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Optical modulator is a device which is used to modulate a beam of light. Optical modulators may be categorized into amplitude modulators, phase modulators or polarization modulators. For all type of modulator, the performance is an important parameter for example the performance of optical modulator is depending on doping material. Therefore, in this project SiGe (Silicon Germanium) optical modulator with NPN configuration is design and the performance using varies doping type is investigate. The scope of this project limited to 3 type of doping material which are Boron, Aluminum and Indium for P+ doping while Antimony, Phosphorus and Arsenic for N+ doping for SiGe optical modulator with NPN configuration. The development of this project is include of designing metal contact, doping material and SiGe layer. The device has an NPN structure where three side doping regions are joined as a common anode or cathode. A different performance when varying doping material is expected to be developed.

## 1.2 Problem Statement

Optical modulator is a device which is used to modulate a beam of light. Optical modulators itself may be categorized into amplitude modulators, phase modulators or polarization modulators. As other optical device, the performance of modulator is very important in order to improve the signal transmitted. As for optical modulator, the performance is depend on doping material. Each doping material has different doping level to each other. Improving the doping level for N+ and P+ will increase the speed as well as increasing the performance of device.

## 1.3 Objective

The objectives of this project are listed below:

a. To develop SiGe optical modulator with NPN configuration
b. To analyze the performance of SiGe optical modulator with NPN configuration
c. To study the effect of doping materials variations on SiGe optical modulator
d. To determine the best doping material

## 1.4 Scope of Project

The scope of this project is limited to 3 type of doping material for SiGe optical modulator with NPN configuration. The development of project consists of designing metal contact, doping material and SiGe layer. The device has an NPN structure where three side doping regions are joined as a common anode or cathode. The doping material for P+ is Boron, Aluminum and Indium while for N+ is Antimony, Phosphorus and Arsenic.

### 1.4.1 Study & Research

All information related to the project are been search through article, journal or conference papers. The action is taken to develop knowledge and understanding about the project.

### 1.4.2 Software Design

The development of SiGe optical modulator with NPN configuration is done using Silvaco application. The process involves ATHENA module for structure design and ATLAS module for measurement result.

## 1.5 Summary of Thesis

Chapter 1 is an introduction of SiGe optical modulator. Chapters 2 explain the literature review of the SiGe optical modulator. Chapter 3 discuss about the methodology of the project. Chapters 4 explain the result of the project. Chapter 5 discuss about conclusion and recommendation of the project.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Literature Review

This chapter explain the literature review on theoretical and practical concepts applied in this project. It contains all related background study and information gathering in order to complete this project. It give information regarding of process design, Silvaco application and module involve in the project.

## 2.2 Optical Modulator

Optical interconnects need a light source, a modulator, a passive distribution of the optical signal from one point to several points and integrated photodetectors at each end. Except for the source, which is supposed to be external, physical properties of silicon are not advantageous for the conception of such devices due to the indirect bandgap and to the crystal symmetry. So reaching the target frequency operation is a real challenge that needs advanced optimizations. The effective bandwidth can be strongly limited by RC constants.

The doped regions of the PIN diode and the metallic contacts have to be optimized to reduce the RC (Resistance Capacitance) constants while maintaining low optical losses for the guided wave. At zero bias, free carriers (holes) generated from the doped layers are trapped in the wells. Under reverse bias applied to the PIN diode, holes are extracted from the wells and swept out of the structure, leading to a refractive index variation. The phase of the optical wave getting out of the active region depends on the refractive index.

Therefore the refractive index variation created in this structure by the electrorefractive effect, under a reverse bias polarization, induces a phase modulation of the optical guided wave propagating through the structure.

## 2.3 Optical Loss

The optical losses cause by carrier absorption can be determined using the beam propagation method (BPM). The total of the hole and electron concentration need to be measured based on NPN structure. The absorption coefficient variations and refractive index can be determine using formula as below, [2] ;

$$\Delta n = \Delta n_e + \Delta n_h$$
$$= -[8.8 \text{ x } 10^{-22}.\Delta N_e + 8.5 \text{ x } 10^{-18}.(\Delta N_h)^{0.8}]$$
$$\Delta\alpha = \Delta\alpha_e + \Delta\alpha_h$$
$$= 8.5 \text{ x } 10^{-18}.\Delta N_e + 6.0 \text{ x } 10^{-18}.\Delta N_h$$

Which

$\Delta n$ = change in refractive index

$\Delta n_e$ = change in refractive index cause by change in electron concentration

$\Delta n_h$ = change in refractive index cause by change in hole concentration

$\Delta N_e$ = change in refractive index cause by change in electron concentration at point

$\Delta N_h$ = change in refractive index cause by change in hole concentration at point

$\Delta\alpha$ = change in absorption

$\Delta\alpha_e$ = change in absorption cause by $\Delta N_e$

$\Delta\alpha_h$ = change in absorption cause by $\Delta N_h$

The estimate length of optical device can be measure using formula as below:

$L_\pi = \lambda/2\ \Delta n$ Where Δn is change in refractive index

The phase shift can be measure using formula as below:

$\Delta\theta = 2\pi\Delta nL/\lambda$ Where

Δn is change in refractive index

L is length of optical device

λ is wavelength

The absorption loss can be measure using formula as below:

$\alpha_\pi = 10 \log (\exp[- (\Delta\alpha) L_\pi ])$ Where

Δα is change in absorption

$L_\pi$ is estimate length of optical device

## 2.4 Silvaco Module

This project only involves software application or simulation using Silvaco. There are two modules that are used during this project which are ATHENA and ATLAS. ATHENA is one of software application that specifically builds to design the fabrication process of optical modulator. ATHENA has advantage of capability to create impressive simulation analysis which can be implementation as real fabrication as in industry.

ATHENA use a simple framework by joining all design processes such as impurity diffusion and oxidation, topography simulation, and lithography simulation to make sure the application is easy to use hence user friendly. There are several modules that can be categorize under ATHENA which were listing in Table 2.1.

Table 2.1: ATHENA Module Description

| Module | Description |
|---|---|
| ATHENA | Simulate structure initialization and manipulation, and supply basic deposition and etch process |
| SSUPREM4 | Need in order to design, analysis, and optimization of optical modulator structures. Involve in fabrication process which is ion implantation, diffusion and oxidation. |
| ELITE | Use to provide 2D view simulator that explain some of process such as deposition, etch and reflow that used in Integrated Circuit |
| OPTOLITH | Simulate based on optical lithography process |
| FLASH | Need in the design, analysis and optimization of compound semiconductor structures. |

ATHENA is designed to be used in conjunction with the VWF INTERACTIVE TOOLS which includes DECKBUILD, TONYPLOT, DEVEDIT, MASKVIEWS, and OPTIMIZER. Table 2.2 shows the ATHENA facility description.

Table 2.2: ATHENA Facility Description

| Facility | Description |
|---|---|
| Bake | Time and temperature bake specification<br>Models photoresist material flow<br>Models photo-active compound diffusion |
| C-Interpreter | Allows user access to diffusion coefficient calculation<br>Allows user access to activation calculation<br>Allows user access to segregation calculation |
| Deposition | Conformal deposition model<br>Hemispherical, planetary, and conical metallization models<br>Unidirectional or dual directional deposition models<br>CVD model |

| | |
|---|---|
| | Surface diffusion/migration effects<br>Ballistic deposition models including atomistic positioning effects<br>User-definable models<br>Default deposition machine definitions |
| Development | Five different photoresist development models |
| Diffusion | Impurity diffusion in general 2D structures including diffusion in all material layers<br>Fully coupled point defect diffusion model<br>Oxidation enhanced/retarded diffusion effects<br>Rapid thermal annealing<br>Models simultaneous material reflow and impurity diffusion<br>Impurity diffusion in polysilicon accounting for grain and grain boundary components. |
| Epitaxy | 2D epitaxy simulation including auto-doping |
| Etch | Geometric etch capability<br>Wet etching with isotropic profile advance<br>RIE model that combines isotropic and directional etch components<br>Microloading effects<br>Angle dependence of etchant source<br>Default etch machine definitions<br>Monte Carlo plasma etching<br>Dopant Enhanced etching |
| Exposure | Exposure on substrates with arbitrary topography<br>Defocus and large numerical aperture effects |
| Implantation | Pearson, dual Pearson, and Gaussian analytical models<br>Extended low energy and high energy implant parameter tables<br>Fast Monte Carlo implant simulation for amorphous materials<br>Monte Carlo calculations for Crystalline materials<br>Universal tilt and rotation capability for both analytic and Monte Carlo calculations<br>Secondary recoil calculation for Monte Carlo damage calculation |

| | |
|---|---|
| Oxidation | Compressible and viscous stress dependent models<br>Separate rate coefficients for silicon and polysilicon materials<br>HCL and pressure-enhanced oxidation models<br>Impurity concentration dependent effects<br>Ability to simulate the oxidation of structures with deep trenches, undercuts<br>Accurate models for the simultaneous oxidation and lifting of polysilicon regions |

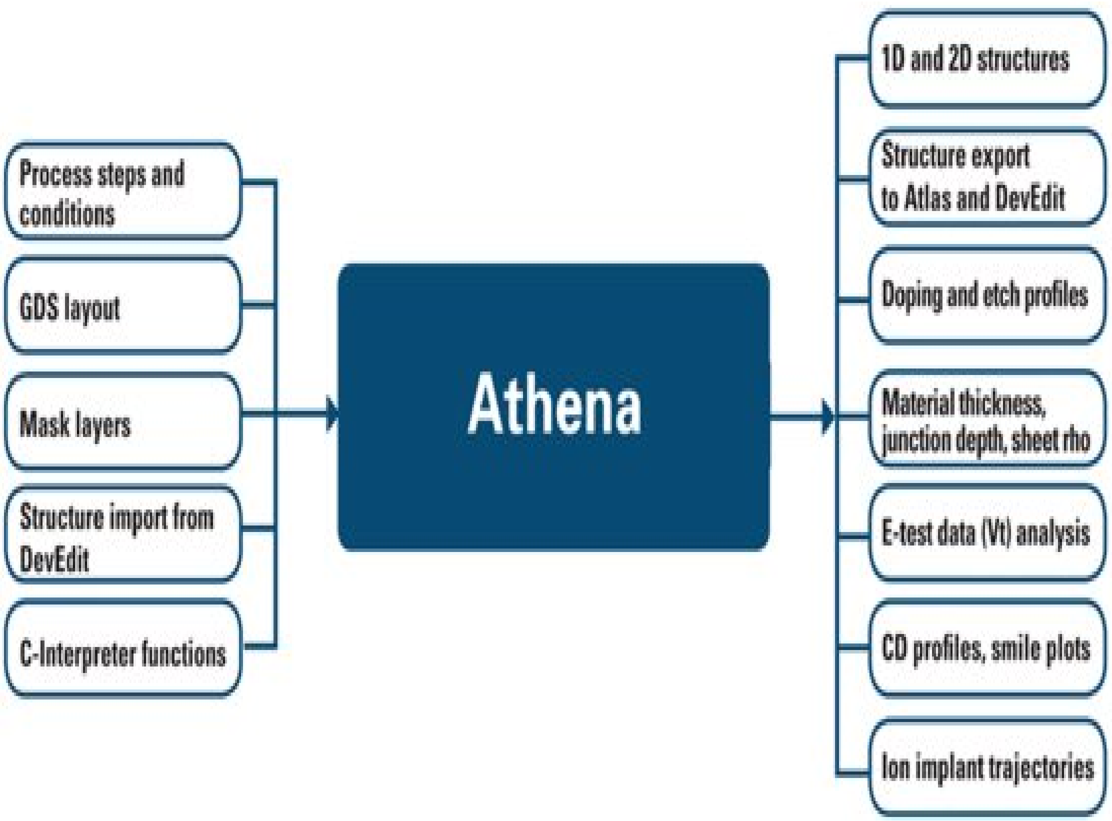


Figure 2.1: The Input and Output of ATHENA

**ATLAS** is a modular and extensible framework for one, two and three dimensional semiconductor device simulation. It is implemented using modern software engineering practices that promote reliability, maintainability, and extensibility.