OPTIMIZATION OF THE FABRICATION PROCESS PARAMETERS OF AN OPTICAL MODULATOR

MOHAMMAD AZWAN SAFWAN BIN HARUN

This Report Is Submitted In Partial Fulfilment of Requirements for the Bachelor Degree of Electronic Engineering (Computer Engineering)

Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka

June 2015

UNIVERSTI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek	:	**OPTIMIZATION OF THE FABRICATION PROCESS PARAMETERS OF AN OPTICAL MODULATOR**
Sesi Pengajian	:	**1 4 / 1 5**

Saya **MOHAMMAD AZWAN SAFWAN BIN HARUN** mengaku membenarkan Laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (√) :

[ ]	**SULIT***	*(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
[ ]	**TERHAD****	**(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
[/]	**TIDAK TERHAD**	

Disahkan oleh:

(TANDATANGAN PENULIS)

(COP DAN TANDATANGAN PENYELIA)

HAZURA BINTI HAROON
Pensyarah
Fakulti Kejuruteraan Elektronik & Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya
76100 Durian Tunggal Melaka

Tarikh: 16 / 6 / 2015

Tarikh: 16 / 6 / 2015

DECLARATION

"I hereby declare that this report is the result of my own work with the exception of the quotes as cites in the references."

Signature :...
Name : MOHAMMAD AZWAN SAFWAN BIN HARUN
Date : JUNE 16, 2015

APPROVAL

"I hereby declare that I have read this report and in my opinion this is enough in terms of the scope and quality for the award of Bachelor of Electronic Engineering (Computer Engineering) With Honours."

Signature : ....

Supervisor's Name : DR. HAZURA BINTI HAROON

Date : JUNE 16, 2015

Specially dedicate to my father, Allahyarham Harun Bin Abdullah, my lovely mother, Pn. Gayah Binti Che Seman, my supervisor, Dr. Hazura Binti Haroon and also thanks to my siblings, for their supports, guides and advices. Also, not to forget my friends and people around me who always supporting me through this whole times.

ACKNOWLEDGEMENT

Praise to Allah S.W.T for helping me to get an idea and give me strength to overcome all the difficulties and letting me to finish my Final Year Project I and Final Year Project II. Next, I would like to thank to my beloved and respected supervisor Dr. Hazura Binti Haroon for all the guidance and motivation she gave to me during the process of the project. Without her support, I will not be able to achieved the goals of the project and also difficult to complete my thesis.

Besides, I also want to thank to all the people around me such as families and friends for their moral support and always stands behind me whenever I need them. I will not forget all of their kindness to me. Thank you very much and may Allah bless all of you always.

ABSTRACT

The purpose of this project is to optimize the fabrication process parameters of an optical modulator. An optical modulator is an optical device which can manipulated the optical signal controlled by light source. The basic formation of optical modulator is based on optical waveguides. The main function of optical modulator is to convert the electrical signal to an optical signal. The L_9 orthogonal array of Taguchi Method was employed in this project to optimize the performance of modulation efficiency and absorption loss. The optimized silicon-based waveguide designs are aimed to be implemented in future photonic devices such as optical modulators. The project created simple process of modeling, optimization and characterization of silicon optical waveguides using Silvaco software. The dry etching are considered to evaluate the effect of etching techniques on the waveguide structure. The project involved both N-type and P-type dopants using silicon waveguide with the orientation of <100>. The silicon optical waveguide fabrication process has been done through multilevel fabrication process with the use of Silvaco software and the optimization of the silicon optical waveguide based on modulation efficiency and absorption loss have been analyzed.

ABSTRAK

Tujuan projek ini adalah untuk mengoptimumkan parameter proses fabrikasi peninggirendahan optik. Modulator optik adalah alat optik yang boleh dimanipulasi isyarat optik dikawal oleh sumber cahaya. Pembentukan asas modulator optik berdasarkan pandu gelombang optik. Fungsi utama modulator optik adalah untuk menukar isyarat elektrik kepada isyarat optik. The L_9 tatasusunan ortogon daripada Taguchi Kaedah telah digunakan dalam projek ini untuk mengoptimumkan prestasi kecekapan modulasi dan kehilangan penyerapan. Dioptimumkan reka bentuk pandu gelombang berasaskan silikon yang bertujuan untuk dilaksanakan dalam peranti fotonik masa depan seperti modulator optik. Projek ini diwujudkan proses yang mudah pemodelan, pengoptimuman dan pencirian silikon pandu gelombang optik menggunakan perisian Silvaco. Punaran kering dianggap menilai kesan teknik punaran pada struktur pandu gelombang. Projek melibatkan kedua-dua bahan dop jenis-N dan jenis-P menggunakan silikon pandu gelombang dengan orientasi <100>. Silikon pandu gelombang optik proses fabrikasi telah dijalankan menerusi proses fabrikasi bertingkat dengan menggunakan perisian Silvaco dan pengoptimuman pandu gelombang optik silikon berdasarkan kecekapan modulasi dan kehilangan penyerapan telah dianalisis.

TABLE OF CONTENT

LIST OF TABLES

NO TITLE **PAGE**

LIST OF FIGURES

LIST OF APPENDIX

LIST OF ABBREVIATION

PIN – Positive-Intrinsic-Negative

SOI – Silicon – On – Insulator

UV – Ultraviolet

CMOS – Complementary metal–oxide–semiconductor

MOS – Metal–oxide–semiconductor

DOE – Design of Experiment,

SNR – Signal-to-noise ratio

ANOVA – Analysis of Variation,

MZI – Mach-Zehndar interferometers

CHAPTER 1

INTRODUCTION

The introduction of the project discussed in this chapter includes the problem statement, the main objective and the scope of the project. The important of the project is described based on the sustainable development and potential commercialization.

1.1 INTRODUCTION

An optical modulator is an optical device which can manipulated the optical signal controlled by light source such as optical beam and laser beam. The basic formation of optical modulator is based on optical waveguides. An optical waveguide is basically a physical structured used in the transmission of the optical signal. The main function of optical modulator is to convert the electrical signal to an optical signal. Optical modulator can be applied in optical fiber communication, display, switching function, mode locking of laser and in optical metrology [1]. Figure 1.1 shows the example of Positive-Intrinsic-Negative (p-i-n) junction of an injection-type modulator [2]. The injection modulators are based on the injection of carriers (holes and electrons) in the waveguide core. The modulation speed is limited by the recombination lifetime and by the physical dimensions of the waveguide which requires the resistive contacts (highly doped regions) to be only a few hundred nanometers away from each other to avoid limiting the bandwidth and Figure 1.2 shows the Silicon-On-Insulator (SOI) Mach Zehnder interferometer with an optical modulator [2]. The high-speed interferometers based on concept with a bandwidth of 1GHz were first proposed in 2004, followed in 2005 by a design featuring a much reduced waveguide size and significant bandwidth increase (24GHz), achieved by insertion of ”lifetime killers” (impurities) in the waveguide area.

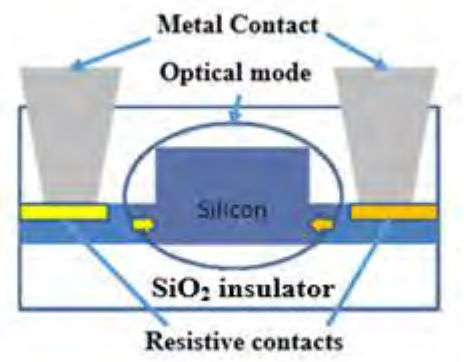

Figure 1.1: p-i-n junction of an injection-type modulator.

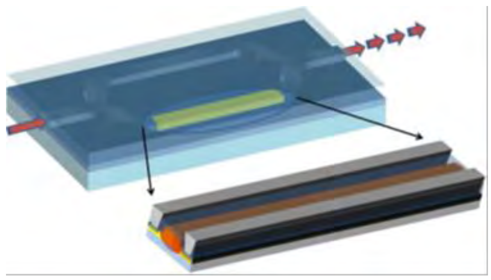

Figure 1.2: SOI Mach Zehnder interferometer with an optical modulator.

The microelectronics circuits nowadays has given huge impact in development of the new world technology. The microelectronics circuits have been applied or implemented in many devices such as computers, smartphone and with the main materials used is silicon. The silicon in optical application has been known in its oxidized form and silicon dioxide. In the silicon optical waveguide, there are many types of waveguide structure can be formed. For example, strip waveguide, slab waveguide, rib type SOI waveguide, and many more. The simplest waveguide structure is the slab waveguide and it has a consistent high index layer on a low index cladding layer. This type of waveguide structure will be employed in this project. The silicon in microelectronics field has been important and preferable based on its performance or capability. The capability to combine with low cost raw materials, simple processing and useful temperature range has made it as the one of the best materials among the others. Also, the improvement and development of technologies has increase the advancement and the efficiency of the cost of the silicon based fabrication technology.

The project involved the process of modelling and optimizing the fabrication process of an optical modulator by using Silvaco software. By using Athena from Silvaco software, it provides us with all the process needed in wafer fabrication such as oxidation, lithography and etching process. For this project, the optimization will focus on the fabrication parameters such as oxidation time, resist stripping time, ultraviolet (UV) exposure time and others to meet the stringent requirements in the actual fabrication process [3]. The dry etching process is selected in the etching process, in order to evaluate the effect of etching techniques on the waveguide structure. The project involved diffusion of N-type and P-type materials waveguide structured with the silicon orientation of <100>. Besides that, the optimization will be carried out by the Taguchi method. The Taguchi method is the technique to reduce the variation in a process throughout tough design of experiment and this method is capable to produce a good quality of product at a lower cost. Therefore, the research on development and the process of fabrication cost time can be further reduced.

1.2 PROBLEM STATEMENT

The fabrication process can be easily done by using Silvaco software to model and optimize the fabrication process of an optical modulator. In addition, the Silvaco software mostly important to predict various characteristics of the silicon such as etch selectivity, etch rate and others in wafer fabrication due to the costly and complicated process in a real fabrication. Athena software can provides us with all the process needed in wafer fabrication such as oxidation, lithography, and etching process. Hence, it can minimized the time needed for the fabrication process and optimized parameter for fabrication can be estimated. The Taguchi method help to reduce the variation in a process throughout the tough design of the experiment and to produce a good quality of product at a lower cost. Therefore, the project should be cutting the costs and the researches of development time can be further reduced.

1.3 OBJECTIVES OF PROJECT

The main objective of this project is to optimize the fabrication process parameter of an optical modulator. The goals of this project are;

- To model simple, cost-effective and scalable fabrication process of an optical modulator by using Silvaco software.
- To investigate the influence of fabrication parameter variations on optical modulator performance.
- To obtain the optimal fabrication process of an optical modulator by using Taguchi method.

1.4 SCOPE OF PROJECT

The scope of this project is to model an optical modulator by using Silvaco software simulation tools. The silicon orientation of <100> is considered. Silvaco software simulation tools is employed in the fabrication modelling and taking into account the phosphorus diffusion temperature, boron diffusion temperature, silicon orientation and oxide thickness. The simulation modelling is important to estimate the optimum fabrication parameters in order to meet the stringent requirements in the actual fabrication process. The dry etching was selected for the etching process in the fabrication process. The p-i-n diode structure is choose to be operated at λ =1.55 optical wavelength. Besides that, the Taguchi method will be used for the silicon parameter optimization.

1.5 IMPORTANT OF PROJECT

1.5.1 Sustainable Development

The project focuses on the semiconductor industry because of its reliability and accuracy in the development of silicon or semiconductor devices. The project enhanced the development of optical devices. However, the designer can test the fabrication process and analyze the result without having to create or fabricate the actual silicon wafer and this will give a lot of benefits for the designers or for the industry in terms of reduced fabrication times and costs. The optimizing of the fabrication process is not applied on optical modulator, but can also be accounted for any of waveguide based on optical devices. Example: waveguide filter, switching, amplification, multiplexing and etc.

1.5.2 Potential Commercialization.

The project potential commercialization is aimed to be implemented in the sectors of microelectronics, microphotonics or semiconductor devices. In addition, this project can been further implemented in the industry company such as in telecommunication companies.

1.6 PROJECT OUTLINE

This report consists of five chapters. Chapter 1 discusses about the introduction of the project which includes the objective of the project, problem statements, scope of project, important of project and project outline. In Chapter 2, it focused more on literature review of project. Otherwise, discussed about the theoretical, background knowledge and methodological approaches in silicon waveguide fabrication. Meanwhile, the next Chapter 3 discussed about the project methodology and software implantation. In this chapter, the flow chart will be provided to show the process of whole project. Chapter 4 includes the result and discussion of the project. The results will be discussed based on the simulation and calculation from the simulation of Silvaco and Minitab. Last but not least, the final chapter is Chapter 5. In this chapter explain about conclusions and recommendation for future work related to this project.

CHAPTER 2

LITERATURE REVIEW

The literature review on the project will briefly discussed based on theoretical, background knowledge and methodological approaches in silicon waveguide fabrication.

2.1 OPTICAL MODULATOR

Optical modulator is a device that can modulate the amplitude of the optical signal. Besides that, the function of the optical modulator is used to modulate the emission of light. An optical waveguide is basically a physical structured used in the transmission of the optical signal. The optical waveguides as a medium to propagate beam that carried by free space. Parameters that can be used to change the optical modulator are transmission factor, index of refraction, reflection factor, the deflection and coherence light [1]. The high speed of optical transmission links require high performance optical modulators to convert electrical data into an optical format. Although, the devices based in silicon offer the attractive prospect of integration with Complementary metal–oxide–semiconductor (CMOS) electronics on the same substrate. This has cost benefits and in turn can result in optoelectronic integrated circuits with a high level of functionality. For example, Figure 2.1 shows the Metal-oxide-semiconductor (MOS) capacitor-type modulators are accumulation devices in which only majority carriers are accumulated on both sides of an insulating layer of silicon dioxide. This layer, placed in the wave guiding region, limits the bandwidth of the device to the resistance-capacitance cut-off frequency [2].

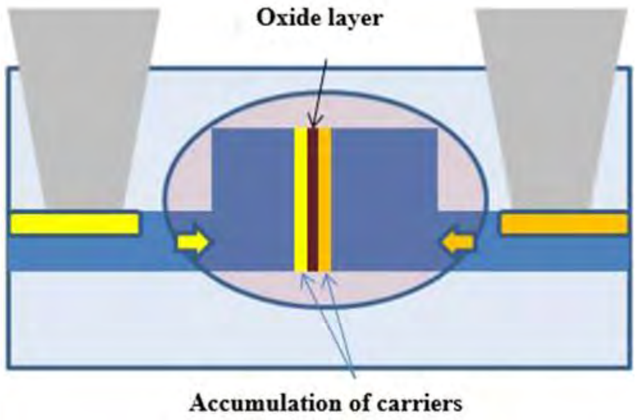

Figure 2.1: MOS capacitor of an accumulation-type modulator.

2.2 THE SILICON WAVEGUIDE STRUCTURE

In the silicon photonic, there are a lot of applications silicon waveguides types that can be chosen. For example, rib waveguide, hollow-core waveguide, free standing waveguide and etc. Apart from that, many materials can be used to realize a waveguide on silicon such as silicon dioxide, silicon oxynitride, polymers, phosphorus, boron and the silicon itself. A rib structures exist on the top layer of the silicon acts as guidance to guide the optical power in the silicon plane. Figure 2.2 shows an example of the silicon optical waveguide structure [4].

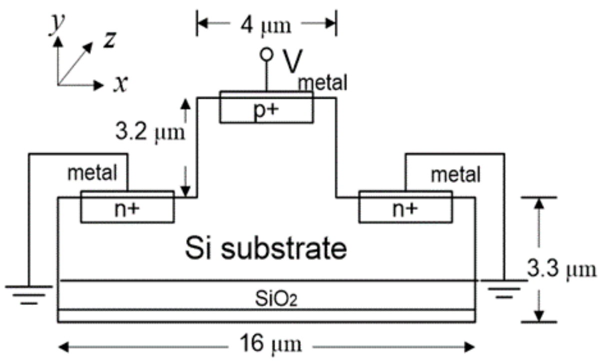

Figure 2.2: The silicon waveguide with p-i-n diode structure integrated on SOI.