DESIGN AND CHARACTERIZATION OF VERTICAL STRAINED SILICON MOSFET INCORPORATING DIELECTRIC POCKET BY USING TCAD TOOLS

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Dedicated to my beloved family
To my father and mother
To my respected lecturer/supervisor
To all my friends
And thanks to Allah for nurturing me spiritually and helping me see the world in the right perspective.

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ABSTRACT

This project is about to design and characterize the Vertical Strained Silicon MOSFET Incorporating Dielectric Pocket (SDP-VMOSFET) by using SILVACO Technology Computer Aided Design (TCAD) tools. SILVACO TCAD tool is a program, which allow for creation, fabrication, and simulation of semiconductor devices. The structure of the vertical MOSFET leads to a double channel width that is increasing the packaging density. The strained silicon MOSFET is introduced to modify the carrier transport properties of silicon in order to enhance transport of both electrons and holes within strained layer. Dielectric pocket is act to control encroachment of the drain doping into the channel and reduce short channel effects (SCE). Overall, SDP-VMOSFET, which is combining Vertical MOSFET, Strained Silicon and Dielectric Pocket can overcome the short channel effect in term of leakage current, threshold voltage roll-off also Drain Induce Barrier Lowering (DIBL). As a result, SDP-VMOSFET produces a better threshold voltage and DIBL compared to related structures. Meanwhile, it gives slightly increased for leakage current compared to Vertical MOSFET Incorporating Dielectric Pocket. The characteristics of the SDP-VMOSFET are analysed in order to optimize the performance of the device and leading to the next generation of IC technology.

ABSTRAK

Projek ini adalah untuk mereka dan mengenal pasti ciri-ciri MOSFET Menegak Terikan Silikon Mengandungi Poket Dielektrik (SDP-VMOSFET) menggunakan perisian SILVACO TCAD. Perisian SILVACO TCAD adalah program yang membolehkan rekacipta, fabrikasi dan simulasi peranti semikonduktor. Struktur MOSFET Menegak membawa kepada saluran yang lebih lebar untuk meningkatkan ketumpatan dalam pembungkusan. MOSFET Terikan Silicon diperkenalkan untuk mengubahsuai ciri-ciri pengangkutan pembawa silicon dalam usaha untuk meningkatkan pengangkutan kedua-dua elektron dan lubang di dalam terikan lapisan. Pocket Dielektrik pula bertindak untuk mengawal pencerobohan ke dalam saluran dan mengurangkan Kesan Saluran Pendek (SCE). Secara kesuluruhannya, SDP-VMOSFET, hasil gabungan MOSFET menegak, Terikan Silikon dan Poket Dielektrik boleh mengatasi SCE seperti kebocoran arus, voltan ambang dan juga *Drain Induce Barrier Lowering* (DIBL). Keputusannya, SDP-VMOSFET menghasilkan nilai voltan ambang dan DIBL yang lebih baik banding struktur yang berkaitan. Ciri-ciri SDP-VMOSFET dianalisis untuk mengoptimumkan prestasi peranti dan seterusnya membawa kepada generasi IC teknologi yang mendatang.

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SDP-VMOSFET	-	Vertical Strained Silicon MOSFET Incorporating Dielectric Pocket
MOSFET	-	Metal-Oxide Semiconductor Field Effect Transistor
TCAD	-	Technology Computer Aid Design
SiGe	-	Silicon Germanium
DIBL	-	Drain-Induced Barrier Lowering
SCE	-	Short Channel Effects
FET	-	Field Effect Transistor
FILOX	-	Fillet local oxidation
I_D	-	Drain Leakage
I_{off}	-	Leakage Current
L_g	-	Channel Length
t_{Ox}	-	Oxide Thickness
V_{DS}	-	Drain-Source Voltage
V_{GS}	-	Gate-Source Voltage
V_{TH}	-	Threshold Voltage
HDD	-	Highly Doped Junctions
IC	-	Integrated Circuit

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CHAPTER I

INTRODUCTION

1.1 Background

The metal oxide semiconductor field effect transistor (MOSFET) is a transistor used for amplifying or switching electronic signals. The MOSFET consist of four-terminal device with source (S), gate (G), drain (D), and body (B) terminals. The MOSFET has common transistor in both digital and analogue circuits. The relatively small size of the MOSFET causes thousands of devices that can be fabricated into a single integrated circuit design.

Moore's law is the observation that over the history of computing hardware, the number of transistors on integrated circuits doubles approximately every two years. The period often quoted as 18 months is due to Intel executive David House, who predicted that period for a doubling in chip performance. The law is named after Intel co-founder Gordon E. Moore, who described the trend in his 1965 paper. In 1958 until

1965, the paper noted that the number of components in integrated circuits had doubled every year from the invention of the integrated circuit and predicted that the trend would continue for at least ten years. His prediction has proven to be uncannily accurate, in part because the law is now used in the semiconductor industry to guide long-term planning and to set targets for research and development [1].

Nowadays, research is focused on obtaining higher speed, low power consumption and low cost devices as the MOSFET undergoes scaling down of the size. Due to this specifications, possible solutions and new devices structure like Vertical Strained Silicon MOSFET Incorporating Dielectric Pocket has been discovered.

1.2 Problem Statement

An integrated circuit (IC) consist of passive and active components including transistor, diode, capacitor and resistor. Since the transistor could be made much smaller so that it was much more convenient to use. As a result, the transistor became the main amplifying devices in almost all electronic devices. The recent development of MOSFET has reached the progress that channel length goes shorter into nanometre scale.

Scaled MOSFETs must simultaneously satisfy following performances requirement such as suppression of the short-channel effect, small threshold voltage and increasing packaging density. As a result the improvement of MOSFET, Vertical Strained Silicon MOSFET Incorporating Dielectric Pocket has been created to satisfy this requirement.

1.3 Objectives

The objectives of this project are:

(i) To design SDP-VMOSFET device by using TCAD tools (ATHENA, DevEdit and ATLAS).
(ii) To characterize the current-voltage of SDP-VMOSFET.
(iii) To compare the performance of SDP-VMOSFET with other MOSFET devices.

1.4 Scope of Project

Today much of the development of semiconductor devices and processes is done by computer modelling. The approach is called TCAD (Technology-Computer Aided Design). Use of TCAD tools reduce the development cost and shorten the development time. In a teaching environment, TCAD tools present unique possibilities in term of visualization of processing steps, description of the physical changes and understanding of the interrelation of the process variables as shown in Figure 1.1. Modelling of processes provides a way to interactively explore the fabrication process and study the effects of process. This tool will help to understand the semiconductor physics.

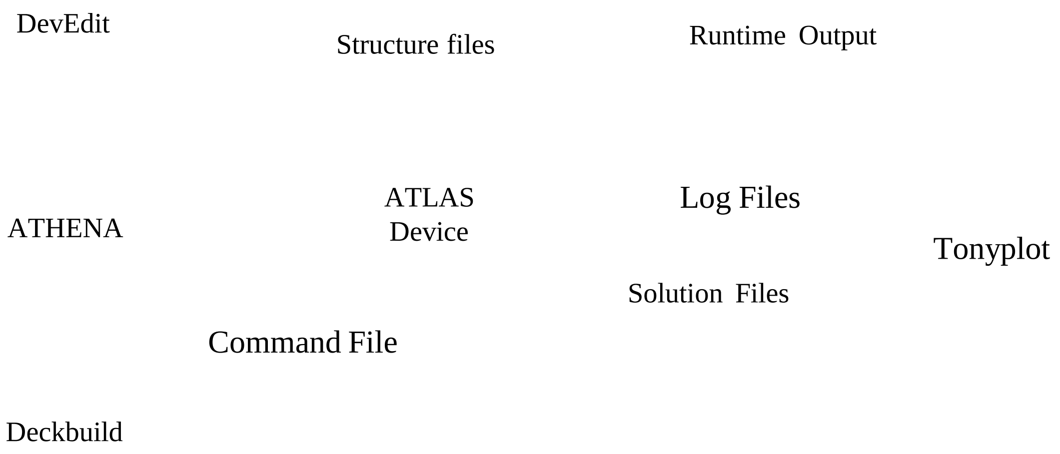

Figure 1.1: Figure Scope of Project Work

1.4.1 Introduction to TCAD

TCAD (Technology Computer Aided Design) is a branch of electronic design automation that models semiconductor fabrication and semiconductor device operation. The modelling of the fabrication is termed Process TCAD, while the modelling of the device operation is termed Device TCAD. Included are the modelling of process steps (such as diffusion and ion implantation) and modelling of the behaviour of the electrical devices based on fundamental physics.

1.4.2 ATHENA

ATHENA is a group of process simulation products that enables process and integration engineers to develop and optimize semiconductor manufacturing processes. ATHENA provides a platform for simulating ion implantation, diffusion, etching, deposition, lithography, oxidation, and silicidation of semiconductor materials.

1.4.3 ATLAS

ATLAS is a group of device simulation products enables device technology engineers to simulate the electrical, optical, and thermal behaviour of semiconductor devices. It provides a physics-based, modular, and extensible platform to analyse DC, AC, and time domain responses for all semiconductor based technologies in 2 and 3 dimensions.

1.4.4 DevEdit

DevEdit can be used to either create a device from scratch or to remesh or edit an existing device. DevEdit creates standard Silvaco structures that are easily integrated into Silvaco 2D or 3D simulators and other support tools.

1.5 Methodology

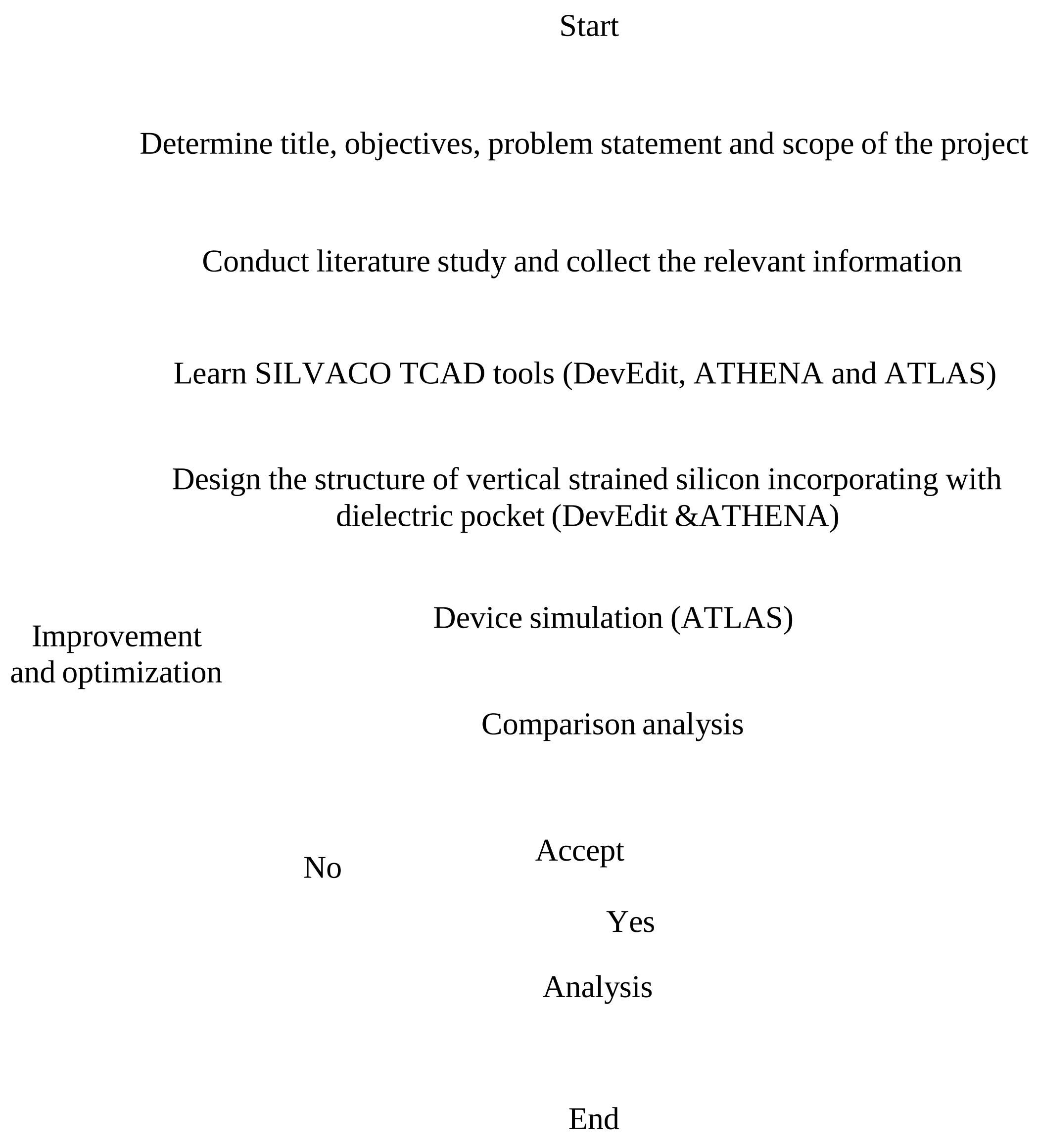

Figure1.2: Flow Chart of the Project

1.6 Project Structure Overview

This thesis consists of five chapters. The first chapter provides an introduction to this project to readers. This includes the objectives and importance of this project. The second chapter contains theories and information about other relevant researches conducted by research institutes and universities around the world.

The research activities and methods employed in this project will be discussed in detail in Chapter III. This chapter shows the flow of this project from the very beginning of the data collection until the acceptable results. It also introduced the TCAD tools to readers. Step by step explanations on the development of the Vertical Strained Silicon MOSFET Incorporating Dielectric Pocket device structure are provided for extra information and knowledge.

Chapter IV shows the results that obtained from the process simulation of the device structure using the ATLAS tools. The data and results from the process are analysed and discussed in this chapter. The effects of the tested parameters are discussed and opinions are brought forward in this chapter. Comparison of various structures which is Vertical MOSFET, Vertical Strained Silicon MOSFET and Vertical MOSFET Incorporating Dielectric Pocket are also discussed.

Finally, Chapter V is the conclusion for this project and incorporates the overview of the results in this project. More importantly, this chapter compares the results analysis with the objectives of this research in order to determine the achievement of this research. Some suggestions to improve the MOSFET are discussed in this chapter for future improvement.