SIMULATION OF SINGLE EVENT UPSET ON SILICON-ON-INSULATOR (SOI) SPACE RADIATION DETECTOR

BY

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ABSTRACT

High radiative environment in space remains as one of the greatest challenges to any space mission especially those beyond the earth magnetosphere. After human, the reliability of microelectronics components is of paramount importance when radiation is concerned. The concern for space electronics performance has increased in recent years due to Single Event Upset (SEU) phenomenon. This research is intended to address the SEU impinging threat by characterizing planar Silicon-on-Insulator (SOI) PIN diode electrical behavior to be used as SEU radiation detector in space. ATLAS and ATHENA, two dimensional simulation softwares by Silvaco Inc. are used to achieve the research objective. Simulation method in device characterization is an advantage due to its design flexibility and safety assurance against hazardous radiative particles. The detector is designed to have a structure of 2500 µm x 22 µm planar SOI PIN diode with 500 µm intrinsic length. Similar device of bulk and planar SOI are characterized before and after proton radiation and their performance are compared. The radiative proton particle is represented by Linear Energy Transfer (LET) value up to 34 $MeV.cm^2/mg$ which is equivalent to 500 MeV proton energy in space. It is found that at room temperature the planar SOI detector shows better performance with four orders of magnitude lower leakage current, higher multiplication rate and better linearity in its current-energy relationship. It has been proven that the planar SOI detector superiority against bulk detector is attributed to its well-defined charge collection region. However, under temperature variation of –40 ^0C to 120 ^0C, planar SOI detector I-V characteristic shows unfavorable behavior with inconsistency of current observed. Under zero Celsius, current in SOI detector fluctuates with voltage increment. From this study, it can be concluded that planar SOI PIN diode has high potential to be used as SEU space radiation detector but proper insulator design needs to be implemented to address its thermal sensitivity issue.

ملخص البحث

المحيط الإشعاعي العالي في الفضاء لا يزال واحدًا من أكبر التحديات التي تواجه أي مهمة فضائية خاصة تلك التي تتجاوز المغنطيسية الأرضية. وبوجود الإنسان أصبحت دقة العناصر المايكروالكترونية أمرًا بالغ الأهمية خاصة عندما نعني الإشعاع. وقد زاد الاهتمام بأداء الكترونيات الفضاء في السنوات الأخيرة نتيجة لظاهرة حادثة أحادي الاضطراب (SEU). إن البحث الحالي يهدف إلى معالجة تهديد تأثير (SEU) بواسطة مميّز السلوك الكهربائي للصمام الثنائي المستو سيليكون على عازل PIN (SOI) حتى يمكن استخدامه ككاشف إشعاعي لل SEU في الفضاء. وقد استخدمت محاكاة برنامج ثنائي الأبعاد (2D) لتحقيق هذا البحث. وقد تميزت طريقة المحاكاة في تخصيص مميزات الجهاز نظرًا لمرونة تصميمها وضمان السلامة ضد الجسيمات الإشعاعية الخطرة حيث تمّ تصميم جهاز الكشف على أن يكون له هيكل بأبعاد 2500 ميكرون X 22 ميكرون على صمام ثنائي مستو PIN SOI مع 500 ميكرون كطول ذاتي. إضافة إلى أن جهازاً مماثلاً من حيث الكتلة الجسمية والمستو SOI قد تمّت دراسة مميزاته قبل وبعد، الإشعاع البروتوني وكذلك مقارنة أدائهما. الجسم الإشعاعي البروتوني الممثل عن طريق التحويل الخطي للطاقة (LET) بقيمة تصل إلى 34 Me V.cm2 /mg أي ما يعادل 500 إلكترون فولت طاقة البروتون في الفضاء. ووجد أن في درجة حرارة الغرفة إن كاشف مستو SOI يظهر أداء أفضل مع أربعة رتب أقل من حجم التسرب الحالي، وارتفاع معدل التضاعف والعلاقة طاقة – تيار خطية أفضل. وقد ثبت أن تفوق كاشف مستو SOI يعود إلى االتحديد الجيد لمنطقة التراكم الشحني له. ومع ذلك، وفي ظل اختلاف درجة الحرارة من 40- C إلى 120 C ، فإن مميزات I-V لكاشف مستو SOI تظهر سلوك غير مواتي مع التناقض في التيار الملحوظ. ومن هذه الدراسة فإنه يمكن استنتاج أن الصمام الثنائي مستو PIN SOI لديه إمكانات عالية لاستخدامه ككاشف للإشعاع الفضائي SEU لكن يحتاج إلى تصميم عازل سليم ذلك للتنفيذ ومعالجة قضية الحساية الحرارية.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Electronics Engineering.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigation, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Zuraidah binti Zainudin

Signature…………………. Date …..............................

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In the name of Allah, the Most Gracious, the Most Merciful

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In the name of Allah, the Most Gracious, the Most Merciful.

Praise be to Allah, the Cherisher and Sustainer of the worlds, and peace and blessings be upon our Prophet Muhammad Sallallahu Alaihi Wassalam, and upon his family and companions.

All praise be to Allah for His mercy upon me in completing this journey, the patience He gave me and in the sustenance He have provided me. There is no power except in Allah. Praise be to Allah by Whose blessing good things happen.

To my parents, I pray that Allah bestow His mercy on them in this world and the hereafter, grant them goodness and make them among the people that are close to Him. "My Lord, have mercy upon them as they brought me up when I was small."

To my supervisor, Dr. Nurul Fadzlin, jazakillahi khairaa. May Allah reward you, may He give you all the goodness in this world and the hereafter and may He make you among those who are patient.

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Praise be to Allah in all circumstances.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
BOX	Buried oxide layer
FB	Forward Bias
I-V	Current – Voltage
LET	Linear Energy Transfer
RB	Reverse Bias
SEB	Single Event Burnout
SEE	Single Event Effects
SEL	Single Event Latchup
SEU	Single Event Upset
SOI	Silicon-on-Insulator
TCAD	Technology Computer Aided Design
TEPC	Tissue Equivalent Proportional Counter
TID	Total Ionizing Dose

LIST OF SYMBOLS

As	Arsenic
B	Boron
Ec	Conduction band energy level
Ev	Valence band energy level
GaAs	Gallium Arsenide
InP	Indium Phospide
Qcrit	Critical charge value
Si	Silicon
Vbi	Build-in potential
Vsupply	Supply voltage

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The realization of Moore's Law has made microelectronics devices more susceptible to high energetic particles. This miniaturization of devices has caused the critical charge value (Q_{crit}) of every microelectronics device to decrease (Oldham, 2003). This is because when devices become smaller, their capacitance also reduces. And from charge-capacitance direct relationship equation, the reduction of capacitance value causing smaller number of charge to be stored. Due to this, probability of ionizing radiation to occur will increase (Irom, Nguyen, Underwood, & Virtanen, 2010). From semiconductor perspective, ionizing radiation is a phenomenon in which enough energy imparted into a material causing generation of electron-hole pairs. These free carriers will change devices electrical characteristics and may also lead to possible overall electronics system degradation and performance. Although problem related to device miniaturization has started to become a concern for terrestrial and daily electronics application, it is more apparent in the case of space electronics. Existence of energetic particles in space —especially in the Van Allen belts —makes electronics devices more vulnerable and prone to failure (Dodd, Shaneyfelt, Schwank, & Felix, 2010; Gonçalves, Pimenta, & Tomé, 2006). This has led many research projects in the radiation assurance field (Artola et al., 2011; Asai et al., 2011; Ferlet-Cavrois, Massengill, & Gouker, 2013).

In general, space radiation effects on microelectronics components are divided into two categories: i) Total Ionizing Dose (TID), and ii) Single Event Effects (SEE). The first type is charge buildup effects on the devices after being exposed to continuous radiation for a certain period of time. The charge buildup is a result of free carriers' generation when radiative particle interacts with device materials and transfer energy to it. When the accumulated charges exceed device Q_{crit}, its electrical characteristics will change and may lead to other serious issues. However, data collected in real space experiences show that, problems attributed to this effect has started to decline in recent years. One of the reasons to this is because devices intended to be used in space have underwent stringent designing process to become harden to radiation.

On the other hand, the second type of radiation, SEE has shown an increment in the number of cases observed in these past few years (Kastensmidt & Reis, 2007). This is due to the device miniaturization trend discussed previously. In contrast to TID, ionizing radiation in SEE occurs due to a single particle interaction with the device material at an instant of time. It means that a mere single strike from a highly energetic particle may result in device failure. SEE can be further classified into three categories: i) Single Event Upset (SEU), ii) Single Event Burnout (SEB), and iii) Single Event Latchup (SEL). Details explanation on all these events can be found in (Srour, 1988; Oldham, 2003; Gaillard, 2011). The first effect, SEU will be the focus of this study. When SEU happens, the resultant current from electron-hole pairs generation may change a state of memory cell from bit 1 to bit 0 and vice versa. Although this event can be observed in other type of devices, it is most prominent in memory-type devices.

Due to devastating problems SEU may cause, many ongoing research projects are being conducted in this area. The methods used to prevent, if not mitigate SEU can generally be categorized into two approaches. The first method is by designing space electronics using materials or technologies that are harden to radiation. Examples of the materials used are GaAs, InP, and most of III-IV compound. Apart from using more resistant materials, other researchers also reported about the success of using Silicon-on-Insulator (SOI) technology as replacement for conventional bulk silicon. The technology has been shown to perform better in radiative environment. Some space electronics devices that have benefitted from this technology are MOSFET, photodiodes and bipolar transistor (Menon, Tasirin, Ahmad, & Abdullah, 2013; Roy & Kumar, 2006).

Another approach that can be taken is by placing a radiation detector onboard of the space mission. The main function of this detector is to detect any impinging energetic particle that may harm the satellite electronic system. Current commonly used detector is made of conventional PIN photodiode fabricated using conventional bulk technology. Although it gives advantages in terms of simplicity and lightweight, this device suffers from several issues. One of the most critical issues is the poorly defined sensitive volume. This causes inaccurate incident particle energy conversion in conventional bulk detector. Bradley, Rosenfeld, Lee, Jamieson, Heiser, and Satoh (1998) reported that the use of SOI technology may resolve this issue. Until now, three generations of SOI PIN diode have been proposed to be used as a radiation detector focusing mainly for biomedical application. Given the similarity between biomedical detector and SEU detector, this research aims to investigate the performance of Silicon-on-Insulator space radiation detector for SEU using Technology Computer Aided Design (TCAD). This is done by comparing conventional bulk detector performance to that SOI detector.

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

Radiation detector is used to protect vulnerable space electronics components from being affected by hostile space radiative environment. The addition of radiation detector in any space mission may determine the success or failure of the mission. Early radiation detector used proportional gas counter but had become obsolete due to its weight and large voltage requirement. For some time, silicon based radiation detector (diode) had successfully addressed the shortcomings and replacing proportional gas counter. However, diode radiation detector suffers from (i) unwanted diffusion current, (ii) funneling effect, and (iii) inaccurate charge confinement region (Bradley et al., 1998). One of the suggested methods in addressing these disadvantages is by using Silicon-on-Insulator (SOI) technology. Until date, many efforts are being made on improving SOI radiation detector but few are using Technology Computer Aided Design (TCAD) in investigating SOI potential.

Hence, given the flexibility and deep-analysis function TCAD has to offer, this research is intended to investigate the potential of SOI PIN diode detector for space application using 2D simulation.

1.3 RESEARCH OBJECTIVES

The main goal of this research is to explore the potential of planar SOI PIN diode as radiation detector for space application. This goal can be divided into the following tasks:

1. To characterize electrical behavior of planar SOI PIN diode as Single Event Upset (SEU) radiation detector intended for space environment using process and device simulation software (ATLAS/ATHENA).
2. To investigate the effect of space temperature variation on planar SOI PIN diode radiation detector electrical characteristics.

1.4 RESEARCH SCOPE

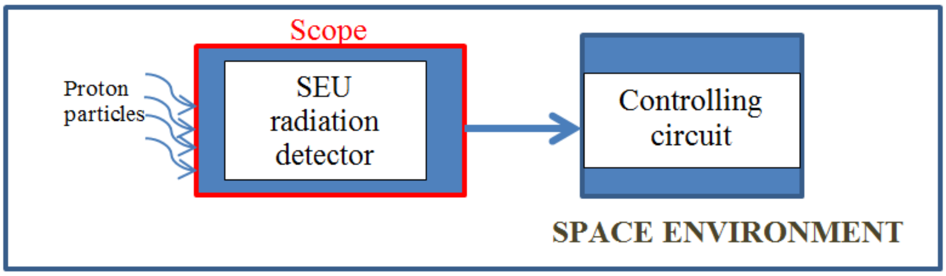

Figure 1.1. Research scope.

The research will focus only on the investigation of Single Event Upset (SEU) radiation detector for space application. Although there are other particles in space that may contribute to SEU, this research will only study the effect of proton particle interaction with the detector. Also, this research will only study about the incident particle detection mechanism and will not cover the subsequent controlling circuit mechanism after detection.

1.5 RESEARCH METHODOLOGY

In order to achieve the stated objectives, this research is conducted following the steps outlined below. Detailed flowchart of this research can be referred in Figure 1.2.

1. Study of various literatures on radiation detector basic mechanism, space environment and effects of space radiation on microelectronics devices. Also, during this stage related literature on ongoing research projects in this area and their limitations are highlighted.
2. Designing process of SOI detector for SEU detection in space. The design is based on various literature uncovered in step 1.
3. Process simulation of both conventional bulk detector and SOI detector using two dimensional process simulator, ATHENA by Silvaco Inc. This virtual fabrication is done to mimic real fabrication process.
4. Simulation of conventional bulk detector and SOI detector electrical characteristics before radiation. This is done using ATLAS device simulation software by Silvaco.
5. Simulation of conventional bulk detector and SOI detector electrical characteristics after exposure to proton particle radiation at 300 K ambient temperature.
6. Simulation of conventional bulk detector and SOI detector electrical characteristics after exposure to proton particle radiation at various ambient temperatures.
7. Analysis of simulation results and discussion on the findings.
8. Report writing on the research all about.

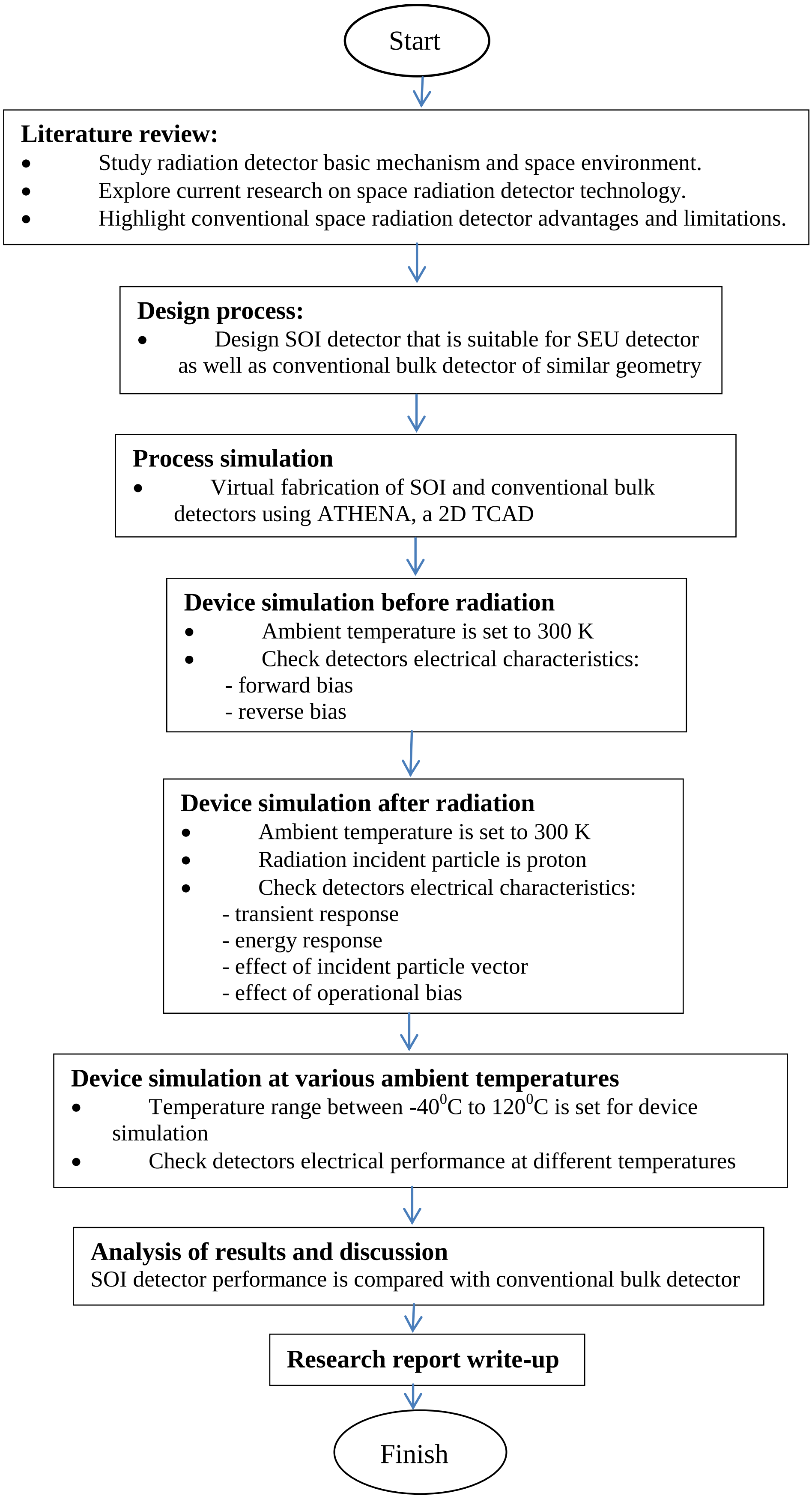

Figure 1.2. Research flowchart.

1.6 DISSERTATION OUTLINE

The dissertation organization is shown in details in the Table of Contents and is described briefly as follow:

Chapter 1: This chapter introduces research background, the motivation leading to this research, research aims and approach taken to address current technology problems in space radiation detector.

Chapter 2: Details of literature pertaining to this research are discussed in this chapter. This includes basic theory of semiconductor radiation detector, past and recent works, as well as key researchers in this field.

Chapter 3: The design and research methodology are described along with simulation process used in this research. Reference and explanation on approaches taken in conducting this research are also included.

Chapter 4: The simulation results and discussion on detectors performance at 300 K are presented. It contains conventional bulk detector and SOI detector electrical characteristics analyzed before radiation, after radiation, at different incident angle vector and at different operational bias.

Chapter 5: This chapter is intended to analyze both detectors electrical characteristics at various ambient temperatures. This is to address temperature variant in space environment and its effect on microelectronics components.

Chapter 6: This chapter will conclude the research findings and gives indication on the research accomplishment based on research aims outlined at the beginning of the research study. Also, limitations of the conducted study and recommendations for further research improvement can be found here.