FIELD-EFFECT TRANSISTOR (FET) FAILURE ANALYSIS

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DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE BACHELOR OF SCIENCE WITH HONOURS

PHYSICS WITH ELECTRONICS PROGRAMME
SCHOOL OF SCIENCE AND TECHNOLOGY
UNIVERSITY MALAYSIA SABAH

April 2007

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS@

JUDUL: FET Failure Analysis

Ijazah: Sarjana Muda Sains (Fizik dengan Elektronik)

SESI PENGAJIAN: 2006/2007

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ACKNOWLEDGEMENT

Praise is to God upon His permission I could complete this thesis smoothly. Words are hardly adequate to express my gratitude to a number of persons for their kind and generous help during the times that this study was in the making.

I take this opportunity to thank my supervisor, Dr. Haider F. Abdul Amir for his endless advices and tireless support for the crucial progress of this thesis.

Many thanks also go to Mr. Kamaruddin Buyong and Mr. Ayub B. Muhamad who are the staffs at the ALURTRON laboratory at the Malaysian Institute of Nuclear Technology (MINT). I am indebted to them for conducting the radiation part of this project. I also would like to acknowledge Mr. Rahim and Mr. Nazri who are the laboratory assistants at the School of Science and Technology (SST) in Universiti Malaysia Sabah.

My utmost gratitude has to go to my family for their invaluable support and motivation to finish this project.

To the many individuals whose names are not mentioned, your efforts are not forgotten and are acknowledged. Your help, even in the tiniest way, certainly has a big impact on the completion of this project.

Working on this project has been a journey of faith for me; for this experience, I thank God.

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14 April 2007

ABSTRACT

This research is a failure analysis of the metal-oxide-semiconductor field effect transistor (MOSFET) where the change of the threshold voltage value, V_{TH}, with the increase of radiation dosage on the transistor is observed. In this research, the MPF990 *n*-channel enhancement mode MOSFET is used. These transistors are first tested to confirm their good conditions before being irradiated with beta radiation. After the irradiation, these transistors are reconnected to the circuit and a multimeter is also connected to obtain a measurement of the drain current, I_D which is recorded 10 times. This process is repeated for the other transistors. The average value of the drain current, I_D, that has been recorded is then used to calculate the value of the threshold voltage, V_{TH} of the transistor according to the dosage of radiation received. The V_{TH} value obtained is then used to plot a graph of threshold voltage versus radiation dosage. From the analysis done on the data and the graph, it is found that the transistor is already slightly damaged at 0.5 KGray and the threshold voltage value increases as the radiation dosage increases. From this, it is deduced that the increase of radiation dosage can cause failure in the enhancement mode *n*-channel MOSFET (MPF990). This is because, according to theory, that when the threshold voltage, V_{TH} increases and becomes larger than the gate-source voltage, V_{GS}, then the drain current, I_D, will gradually decrease to zero.

ANALISIS KEGAGALAN TRANSISTOR KESAN MEDAN (FET)

ABSTRAK

Kajian ini merupakan satu analisis kegagalan transistor (MOSFET) di mana pemerhatian nilai voltan ambang, V_{TH}, terhadap kesan peningkatan dos radiasi pada transistor dibuat. Dalam kajian ini, transistor yang digunakan adalah MPF990 iaitu transistor jenis MOSFET perluasan saluran-*n*. Transistor-transistor yang diuji terlebih dahulu untuk dipastikan berkeadaan baik. Kemudian, setiap transistor dikenakan dos radiasi beta yang berbeza-beza. Selepas proses radiasi, transistor disambung balik kepada litar dan multimeter disambungkan pada litar untuk mendapatkan nilai arus salir, I_D, di mana nilai tersebut direkod sebanyak 10 kali. Proses ini diulang untuk transistor lain. Nilai purata arus salir, I_D, yang telah direkod kemudian digunakan untuk mengira nilai voltan ambang, V_{TH}, setiap transistor mengikut tahap dos radiasi yang dikenakan. Nilai V_{TH} yang diperolehi dari pengiraan digunakan untuk memplotkan graf voltan ambang melawan dos radiasi. Daripada analisis graf dan data yang dibuat, transistor sudahpun mengalami kerosakan pada 0.5 KGray (dos radiasi) dan nilai voltan ambang meningkat apabila dos radiasi semakin meningkat. Daripada keputusan ini, kesan daripada radiasi dengan dos yang mencukupi akan mengakibatkan kegagalan transistor MOSFET perluasan saluran-*n* (MPF990) untuk berfungsi dengan baik kerana teori mengatakan bahawa apabila voltan ambang,V_{TH} meningkat dan menjadi lebih besar dari voltan get-sumber, V_{GS}, arus salir pula akan menjadi sifar.

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LIST OF SYMBOLS

V_{TH}	Threshold Voltage, in Volts, V
V_{GS}	Gate-Source Voltage, in Volts, V
V_{DS}	Drain-Source *Voltage,* in Volts, V
I_D	Drain Current, in Amperes, A
V_P	Pinch-off Voltage in Volts, V
I_S	Source Current, in Amperes, A
I_{DS}	Drain-to-Source Current, in Amperes, A
Φ	Neutron Fluence
Si	Silicon
SiO_2	Silicon dioxide
K	Transistor Constant

CHAPTER 1

PREFACE

1.1 INTRODUCTION

Device failure analysis has become increasingly important especially in this era of cutting-edge technology, where optimum reliability of a device or an electronic component is most needed. This means, there can be no room for error. Faulty devices could make an electronic equipment go haywire. For example, a computer that loses all its data on its hard disk.

This project is focused on Field-Effect Transistor (FET) failure analysis. It intends to determine the cause and provide reason and suggestion for the identified failure from beta radiation. An analysis of the FET failure will further enhance our comprehension on the component's behaviour and characteristics, notably its performance and limitations. The information gathered from this analysis will greatly benefit manufacturers of such electronic components in terms of enhancing the capabilities and the longevity of these components. This would translate into better and higher quality products for the masses.

Enhancement-mode *n*-channel Metal-oxide-semiconductor-field-effect transistors (MOSFET) will be used throughout this project.

1.2 PURPOSE OF STUDY

The purpose of this study is to find out the effects of beta radiation on the enhancement-mode *n*-channel MOSFET.

1.3 OBJECTIVES OF THE STUDY

The objectives of this study are as follows:

1) To irradiate the enhancement-mode n-channel MOSFET with different beta radiation dosage.
2) To obtain the electrical measurements of the enhancement-mode n-channel MOSFET before and after beta irradiation.
3) To observe the change of the values of the electrical measurement of the enhancement-mode *n*-channel MOSFET before and after beta irradiation.
4) To study the mechanism of failure in the enhancement-mode n-channel MOSFET based on the above measurements.

1.4 RATIONALE

Enhancement-mode *n*-channel Metal-oxide-semiconductor-field-effect transistors (MOSFET) are chosen among others because most electronic gadgets these days utilize them in their components build. The use of FET is very widely applied in today's modern high-tech gadgets such as notebook computers and ultra-thin mobile phones. Information on the cause of its failure can be vital to developing better and higher quality FET. This would mean the availability of better and higher quality gadgets. There could be higher-resistant notebooks and thinner mobile phones than what we have today. In this light, it is therefore worth the while for the researcher to undertake this study.

1.5 SIGNIFICANCE OF THE STUDY

This study seeks to determine the cause and provide explanation of failure on effect of beta radiation in the MOSFET. This in turn, helps device engineers to better understand its limitations. It is hoped that with the enhancement of their understanding, engineers will be able to design and eventually produce better MOSFET which will perform better with reduced limitations.

1.6 RESEARCH SCOPE

This research will be done at two locations. The testing and mechanism of failure analysis of the MOSFET will be done at the Electronic Physics Postgraduate Lab of the School of

Science and Technology in Universiti Malaysia Sabah. These processes involve the measurement of certain parameter values on the MOSFET.

The part where the MOSFETs are exposed to beta radiation will be done at the Malaysian Institute of Nuclear Technology (MINT). Equipment called Electron Beam Accelerator will be used to perform the beta radiation on the MOSFET.

The scope of this research involves the measurement of the drain current, I_D, generated in the pre-radiation condition and its post-radiation condition.

1.7 HYPOTHESIS

Every research done is based on learnt theories. These theories are meant as guides in the undertakings of a scientific experiment. Hypothesis is an expectation or assumption of results or outcomes before the research or experiment is done.

For this research, the hypothesis is that when the MOSFET receives beta radiation, it will start to malfunction. The extent of the damage in the MOSFET is directly proportional to the radiation dose. The damage is more extensive in the MOSFET when it receives higher dose of radiation.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Field-effect transistors (FET) are one of the most commonly used electronic components in today's gadgets and electronic appliances. They are implemented in the build of the living room television set to the sophisticated Automated Teller Machine (ATM) in the banks. Its predecessors, the typical transistor which was created and developed by the employees of Bell Telephone Laboratories in 1948, ushered in the computer revolution.

2.1.1 Review of Related Literature

Perhaps one of the most important milestones in the history of electronics was the invention of the transistor in 1948 by John Bardeen, Walter Brattain and William Schockley, all of whom worked for Bell Telephone Laboratories at the time. The transistor (also called a solid-state or semiconductor) eventually replaced the vacuum tube in radios and televisions. The transistor is much more efficient than the vacuum tube since it does not have a heater. Other solid-state devices include diodes and integrated circuits. The development of solid-state devices has led to the continued miniaturization of all types of electronic equipment. Each month we learn of new technological advances that produce increasingly sophisticated circuitry in ever smaller integrated circuits. The primary reasons for this trend are improved reliability, lower costs and increased speed due to the reduction in the length of the interconnecting wires (Grob and Schultz, 1999).

2.2 FIELD-EFFECT TRANSISTOR (FET)

Field-effect transistors (FET) is developed in a way that the flow of electrons from terminal S (the source) to terminal D (the drain) can be controlled by an electric field set up within the device by a suitable electric potential applied to terminal G (the gate). Hence, the name field-effect transistor which comes from the electric field mentioned above.

In the input circuit, the gate and channel act like two plates of a capacitor. A charge of one polarity on the gate induces an equal and opposite charge in the channel. As a result, the conductivity of the channel can be increased or decreased by the gate voltage. With an *n* channel, positive voltage at the gate induces negative charges in the channel to allow more electron flow from source to drain (Halliday *et al.*, 2001).

Transistors are available in many types; in this study however, we shall discuss only 2 types of FET called the JFET (Junction Field-Effect Transistor) and the

MOSFET, or metal-oxide-semiconductor-field-effect transistor. The MOSFET has been described as the workhorse of the modern electronics industry.

2.2.1 Junction Field-Effect Transistor (JFET)

To produce a Junction Field-Effect Transistor (JFET), a manufacturer diffuses two areas of *p*-type semiconductor into the *n*-type semiconductor, as shown in Figure 2.1.
When a manufacturer connects a separate lead to each gate, the device is called a dual-gate JFET. The main use of a dual-gate JFET is with a mixer, a special circuit used in communications equipment. Most JFETs have two gates connected internally to get a single external gate. These JFETs are called single-gate JFET. Single-gate JFET is more widely used than the dual-gate JFET.

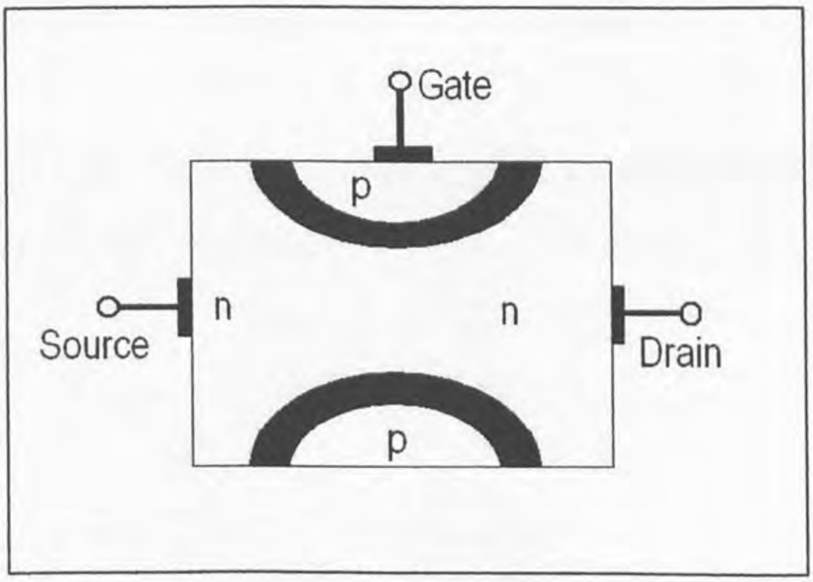

Figure 2.1 The JFET (Floyd, 1996).

In Figure2.1, the gate is a *p* region, while the source and the drain are *n* regions. Because of this, a JFET is similar to two diodes. The gate and the source form one of the diodes, and the gate and the drain form the other diode.

The term *field-effect* is related to the depletion layers around each *p* region as shown in Figure 2.1. The junctions between each *p* region and the *n* regions have depletion layers because free electrons diffuse from the *n* regions into the *p* regions. The recombination of free electrons and holes then creates the depletion layers shown by the shaded areas in Figure 2.1. When electrons flow from the source to the drain, they must pass through the narrow *channel* between the two depletion layers. The more negative the gate voltage is, the tighter the channel becomes (Malvino, 1989). In other words, the gate voltage can control the current through the channel. The more negative the gate voltage, the smaller the current between the source and the drain. Almost all the free electrons passing through the channel flow to the drain. Because of this,

$$I_D = I_S \tag{2.1}$$

where I_D is the current through the drain and I_S is the current through the source.

To analyze a JFET, these formulae apply:

$$V_P = -V_{GS(off)} \tag{2.2}$$

$$R_{DS} = \frac{V_P}{I_{DSS}} \tag{2.3}$$

$$K = \left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2 \tag{2.4}$$

$$I_D = K\, I_{DSS} \tag{2.5}$$

2.2.2 Metal –Oxide Semiconductor Field-Effect Transistor (MOSFET)

The Metal-Oxide Semiconductor Field-Effect Transistor (MOSFET) consists of a metal electrode for the gate separated from the channel by a thin layer of silicon oxide. This material is an insulator, like glass. However, by electrostatic induction of a voltage applied to the gate can induce charges in the channel to control the current from source to drain. There is no PN junction. MOSFET is also known as IGFET which stands for Insulated-Gate Field-Effect Transistor.

MOSFETs come as either depletion or enhancement types, depending on the amount of doping used for the channel construction. The depletion-mode MOSFET is a normally on device. Meanwhile, the enhancement-mode MOSFET is a normally off device (Grob and Schultz, 1999).

For many applications, the MOSFET is operated in only two states: with the drain-to-source current I_{DS} ON (gate open) or with it OFF (gate closed). The first of these can represent a 1 and the other a 0 in the binary arithmetic on which digital logic is based, and therefore MOSFETs are widely used in digital logic circuits.

a. The Depletion-Mode Metal-Oxide Semiconductor Field-Effect Transistor

Depletion-mode MOSFET is a piece of *n* material with a *p* region on the right and an insulated gate on the left, as shown in Figure 2.2. Free electrons can flow from the source to the drain through the *n* material. The *p* region is called the substrate (or body). Electrons flowing from source to drain must pass through the narrow channel between the gate and the *p* region.

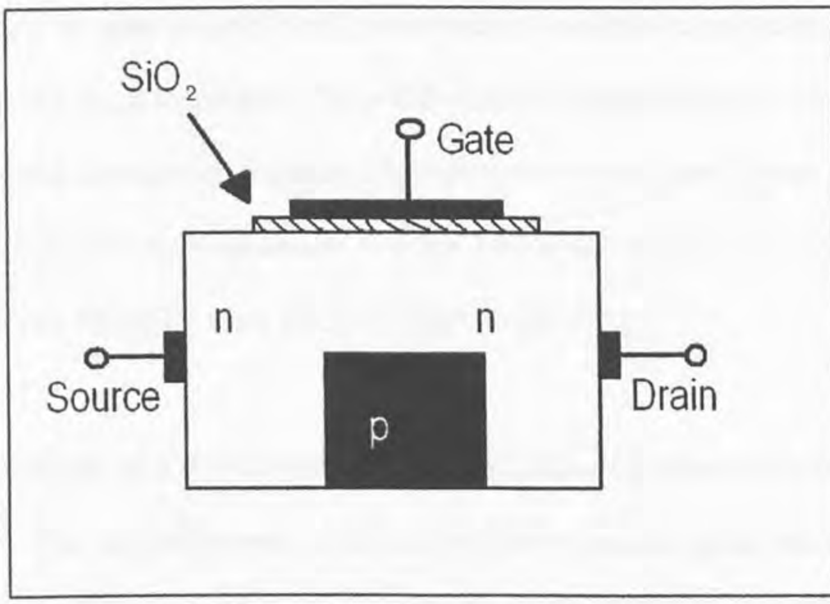

Figure 2.2 The depletion-mode MOSFET (Floyd, 1996).

A thin layer of silicon oxide (SiO_2) is deposited on the top side of the channel. Silicon oxide is the same as glass, which is an insulator. In a MOSFET, the gate is metallic. Because the metallic gate is insulated from the channel, negligible gate current flows even when the gate voltage is positive (Grob and Schultz, 1999). In other words, the gate-source diode and the gate-drain diode of the JFET have been eliminated in the MOSFET.

In the depletion-mode MOSFET, for a negative gate operation, the V_{DD} supply forces free electrons to flow from source to drain. These electrons flow through the narrow channel on the left of the *p* substrate. The gate voltage controls the width of the channel (Malvino, 1989). The more negative the gate voltage, the smaller the drain current. When the gate is negative enough, the drain current is cut off.

Because the gate of a MOSFET is electrically insulated from the channel, we can apply a positive voltage to the gate. The positive gate voltage increases the number of free electrons flowing through the channel. The more positive the gate voltage becomes, the greater the conduction from the source to drain. Being able to use a positive gate is what distinguishes this MOSFET from the JFET (Giret *et al.,* 2002).

The analysis of a depletion-mode MOSFET circuit is almost identical to that of JFET circuit. The only difference is the analysis for a positive gate, but even here the same basic formulae are used to find the drain current, gate-source voltage.Therefore, these formulae apply (similar to JFET's formulae):

$$V_P = -V_{GS(off)}$$

$$R_{DS} = \frac{V_P}{I_{DSS}}$$

$$K = \left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2$$

$$I_D = K\, I_{DSS}$$

$$V'_P = I_D R_{DS}$$

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