# DESIGN AND CHARACTERIZATION OF ISFET BASED DEVICE FOR BIOMEDICAL APPLICATIONS

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**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

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**This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours**

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# DEDICATION

Special thanks to my parents, my love ones and supervisor for the guidance all the way.

# ABSTRACT

The use of chemical sensor for biomedical field in-field is gaining interest due to their advantages over conventional sensors. Among them chemical sensor ISFET based on semiconductor technology offer additional advantages such as small size, robustness, low output impedance and rapid response make it suitable for biomedical application. Nowadays, diabetes arises as a major public health concern in Malaysia since the prevalence of diabetes have been escalated throughout the years. Glucose monitoring has become an integral part of diabetes care but has some limitations in accuracy. While conventional blood glucose monitoring meter requires the use of disposable blood glucose test strip with the need for routine finger pricks. The project is carried out to design an Ion-Selective Field Effect Transistor (ISFET) based biosensor that is able to detect pH concentration using Silvaco software. The work is based on simulation study using Silvaco ATHENA and Silvaco ATLAS. The ISFET designed is characterized and the performance is analysed based on the critical parameter namely pH value and threshold voltage. Effect of the gate channel length and sensing layer's thickness on the pH sensitivity is discussed in this study. The sensitivity of ISFET designed is the highest when the thickness of tantalum oxide sensing layer is 0.55nm and the gate channel length is 100nm.

# ABSTRAK

Penggunaan sensor kimia dalam bidang bioperubatan semakin ditambah minat kerana kelebihannya berbanding dengan sensor konvensional. Antaranya sensor kimia ISFET berdasarkan teknologi semikonduktor menawarkan kelebihan tambahan seperti saiz kecil, ketahanan, impedans keluaran yang rendah dan tindak balas pantas menjadikannya sesuai untuk aplikasi bioperubatan. Hari ini, penyakit kencing manis adalah kebimbangan kesihatan awam utama di Malaysia sedangkan kelaziman diabetes telah meningkat sepanjang tahun. Pemantauan glukosa telah menjadi bahagian penting dalam penjagaan diabetes tetapi mempunyai batasan ketepatan. Manakala meter pemantauan glukosa konvensional juga memerlukan penggunaan jalur ujian glukosa darah sekali pakai dengan keperluan untuk jari telunjuk rutin. Tujuan projek ini adalah untuk merekabentuk biosensor glukosa berasaskan Ion-Selective Field Transistor yang dapat mengesan kepekatan pH dengan menggunakan perisian Silvaco. Kerja ini berdasarkan kajian simulasi menggunakan Silvaco ATHENA dan Silvaco ATLAS. Reka bentuk ISFET dicirikan dan prestasi dianalisis berdasarkan parameter kritikal iaitu nilai pH dan voltan ambang. Kesan panjang saluran dan ketebalan lapisan mendalam terhadap kepekaan pH dibincangkan dalam kajian ini. Kepekaan ISFET yang direka adalah yang tertinggi apabila ketebalan lapisan penderiaan tantalum oksida adalah 0.55nm dan panjang saluran pintu adalah 100nm.

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# LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| ISFET | : | Ion-Selective Field Effect Transistor |
| pH | : | Concentration of hydrogen ion ($H^+$) |
| $V_{ref}$ | : | Reference voltage of ISFET |
| $V_{TH}$ | : | Threshold voltage |
| $I_D$ | : | Drain current |
| $SiO_2$ | : | Silicon Dioxide |
| $pO_2$ | : | Partial pressure of oxygen |
| $pCO_2$ | : | Partial pressure of carbon dioxide |
| $Ta_2O_5$ | : | Tantalum oxide |
| Na+ | : | Sodium ions |
| K+ | : | Potassium ions |
| Ca2+ | : | Calcium ions |
| Cl- | : | Chloride ions |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

This chapter explained about the introduction of this project following by the background and the problem statement. For the project background, an explanation about the ISFET has been described. Project objectives, scopes and expected results from this project also discussed in this chapter. All the details for each section of the project have been discussed in this chapter.

## 1.1 Background of Project

Over the past thirty-five years astounding progress has been made on multifold applications of chemical sensing technology. The field of chemical sensor mainly includes electrochemical sensor and optical sensor, while the concept of biosensing gives a new leap to it. Ion Sensitive Field Effect Transistor (ISFET), which is basically a chemical sensor, was first reported by Bergveld in 1970 [1]. ISFET bears the potential of fast response, smaller size and low cost due to the well-established metal oxide semiconductor (MOS) technology. Initially silicon dioxide was used in ISFET as its sensing surface. It was sensitive to hydrogen ions, an inherent property of inorganic oxide. The circuit is completed by using one reference electrode. This concept was developed by Matsu and Wise [2] in 1974. Structurally ISFET is almost similar to metal oxide semiconductor field effect transistor (MOSFET) barring the metal gate electrode and adding a reference electrode immersed in the electrolyte solution. In this structure the gate insulator is exposed to the electrolyte solution and the reference electrode which is also inside the solution, completes the circuit.

Kensall D.Wise used silicon as substrate for micro electrodes for electrophysiological measurement. But a systematic progress started with the inception of the ISFET. Since then several researchers carried out various studies on ISFET and other field effect transistor (FET) based devices. Most of them described ISFET as future tools for electrophysiological measurement [3].

The Ion Sensitive Field Effect Transistor (ISFET) is a device which has gained much popularity for use as a pH sensor. Being robust, cheap and small in size, it has rapidly become competitive with conventional ion selective glass electrodes. The device consists of a transistor similar to a traditional MOSFET but with the gate left exposed to form an ion sensitive area. ISFET was initially actualized using a standard metal–oxide–semiconductor FET (MOSFET) by replacing the gate metal with a remote gate to set a steady potential or gate bias to the fluid bearing a chemical-sensitive membrane insulator to the electrolyte. The rest of the transistor is encapsulated to isolate the device from the electrolyte. The sensing membrane used silicon dioxide ($SiO_2$) exposed to an electrolyte solution. The sensitivity is explained partly by the site binding theory and also by a fast-dynamic electrochemical exchange component occurring at the surface of the ISFET. The equilibrium between the binding and unbinding of charged ions at the gate surface becomes a function of analyte concentration which is measured as a change in the voltage drop (flatband voltage) across the insulator layers [4].

## 1.2 Problem Statement

Bioreceptors are natural transducers that convert all types of chemical and physical signals from the environment into electrical signals, resulting in action potential which can be processed by the natural computer consisting of nerve or brain tissue. As our industrial computers need electrical signals to operate, the artificial bioreceptors that are at present developing will have to contain a conversion to an electrical signal. It is known however the contact between living systems and non-living material is very hard to achieve. In other words, the development of biosensors has been sought in the use of an intermediate layer where one side should be biocompatible with the living surroundings, while the other side should be biocompatible with the attached sensor [5].

The accuracy of glucose monitoring systems may be limited due to strip manufacturing variances, strip storage, and aging. As with any manufactured product, there is a small amount of strip-to-strip variation, which will therefore lead to some inaccuracy in blood glucose readings. Changes in enzyme coverage may also influence accuracy. Generally, excess enzyme is used in strips, thus small decreases in enzyme amount do not alter glucose values. On the other hand, a thinning of the enzyme will not cause an error, but loss of enzyme coverage, with bare spots, will lead to underestimation of the glucose values. They may also be due to limitations on the environment such as temperature or altitude. Glucose oxidase biosensor strips are often sensitive to oxygen concentration. The mediator and oxygen can both compete to take electrons from the reduced form of the glucose oxidase enzyme. Since the electrode will only pick up mediator, if the oxygen content of the sample is high, the active mediator will be lower and the value underestimated. Similarly, if the oxygen is low, the meter may report a value higher than the true value. Most meters also have a temperature sensor and will report errors at extreme temperatures [6].

## 1.3 Objectives

The purposes of this project are:

1. To design an Ion-Selective Field-Effect Transistor (ISFET) which is able to detect pH concentration using Silvaco software.
2. To characterize and analyze the performance of the SOI ISFET based on the critical parameter namely pH value and threshold voltage.

## 1.4 Scope of Project

The scope of this project is to design and characterize the ISFET structure using Silvaco software without fabrication of the product. This project will be designed by utilizing Silvaco ATHENA and Silvaco ATLAS software. Silvaco ATHENA is utilized for developing and optimizing semiconductor manufacturing processes and withal to design the physical structure of the device while Silvaco ATLAS is utilized for enabling simulating the electrical behaviour of semiconductor devices and to obtain the electrical characteristic of the device. The design opportunely accounts for the variation of channel length, drain current and threshold voltage. The design is expected to analyze the performance of ISFET designed through the electrical characteristics obtained.

## 1.5 Project Significance

pH-ISFET-based biosensors (BioFET) have many advantages over conventional biosensors, namely small size, rapid response, the possibility of mass production and more importantly, the possibility of manufacturing one chip multifunctional biosensors that can be implanted within the human body. In addition, it has higher sensitivity and accuracy in measuring blood glucose concentration. Compared to conventional blood glucose monitoring meter which requires the need for routine finger pricks and the use of disposable blood glucose test strip, ISFET based glucose biosensor is more user-friendly and environmentally friendly.

## 1.6 Project Outline

This project is organized into five chapters to cover the research work that is related to ISFET based device for DNA detection application. The outlines of the project are described as follows. Chapter 1 is the introduction of the project. This chapter will explain the objectives of the project, the problem statement and the scope of the project. Chapter 2 presents the literature review of project. It discusses the background