

A PH SENSOR USING GALLIUM NITRIDE BASED SEMICONDUCTOR WITH
GATELESS FIELD EFFECT TRANSISTOR TYPE STRUCTURE

MASTURA SHAFINAZ BINTI ZAINAL ABIDIN

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Universiti Teknologi Malaysia

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ABSTRACT

GaN-based wide bandgap semiconductors have become one of the most extensively studied materials and rapid progress has been demonstrated in both optical and electronic devices. Due to their wide bandgap, good thermal and chemical stability, GaN-based semiconductor materials are also very promising for high temperature pH sensor devices. The purpose of this project is to fabricate GaN based pH sensor and characterize the sensing characteristics with different pH values. This project is mainly concerned on fabricating the pH sensor using n-AlGaIn/GaN HEMT with gateless FET structure. The sensor must have high performance for Intelligent Quantum (IQ) chip application in order to follow the circulation of epoch. IQ chip is required to develop a new device for Ubiquitous Network Society (UNS). It is a smart chip with nanometer scale quantum processors and memories are integrated on chip with capabilities of wireless communication, wireless power supply and various sensing functions. The discussion in this project report focuses on the device and material structure of fabricated sensor, the fabrication process, the measurement setup and the results of device characterization and measurement. Based on results obtained, the FET behavior was observed from the I_{DS} vs. V_{DS} of device fabricated. The potential of the AlGaIn surface at the sensing area can be effectively controlled by the solution. Thus, good gate controllability was observed. Moreover, it was observed in that current collapse normally in AlGaIn based FET device. From the experiment, the drain-source current decreases with the pH level as expected. Therefore, it can be concluded that the gateless AlGaIn/GaN HEMTs shows significant change in current as exposure to different pH solutions.

ABSTRAK

Separa pengalir lebar jalur luas berasaskan GaN menjadi salah satu bahan kajian secara meluas dan perkembangan pesat telah ditunjukkan dalam kedua-dua bidang peranti optik dan elektronik. Disebabkan lebar jalur luas serta kestabilan suhu dan kimia, bahan separa pengalir berasaskan GaN adalah meyakinkan untuk peranti sensor pH suhu tinggi. Tujuan projek ini adalah untuk menghasilkan sensor pH berasaskan GaN dan mencirikan sifat pengesanan terhadap pelbagai nilai pH. Pada dasarnya, projek ini menumpukan penghasilan sensor pH menggunakan n-AlGaIn/GaN HEMT dengan struktur transistor kesan medan tanpa get. Sensor mestilah mempunyai keupayaan yang tinggi untuk aplikasi *Intelligent Quantum* (IQ) cip selari dengan peredaran era. Cip IQ diperlukan untuk membangunkan peranti baru untuk pertubuhan rangkaian yang menyeluruh. Ia merupakan sebuah cip pintar dengan pemproses kuantum berskala nanometer dan memori diintegrasikan dalam satu cip berserta keupayaan komunikasi tanpa wayar, sumber kuasa tanpa wayar dan pelbagai fungsi pengesanan. Perbincangan dalam laporan projek ini merangkumi struktur bahan dan peranti sensor yang dihasilkan, proses fabrikasi, konfigurasi pengukuran dan hasil keputusan pencirian serta pengukuran peranti. Berdasarkan keputusan yang diperolehi, ciri transistor kesan medan dapat dilihat daripada I_{DS} vs. V_{DS} peranti. Beza upaya permukaan AlGaIn dapat dikawal dengan berkesan oleh larutan. Dengan itu, keupayaan kawalan get yang baik diperolehi. Tambahan pula, pengurangan arus secara normal dapat dilihat dalam peranti transistor kesan medan berasaskan AlGaIn. Daripada eksperimen, I_{DS} berkurang dengan kenaikan pH seperti yang dijangkakan. Oleh yang demikian, dapatlah disimpulkan bahawa AlGaIn/GaN HEMTs tanpa get menunjukkan perubahan yang ketara dalam arus apabila didedahkan kepada larutan pH yang berbeza.

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CHAPTER 1

RESEARCH BACKGROUND

1.1 Introduction

Gallium Nitride (GaN) is a III-V compound semiconductor composed of element Gallium (Ga) from column III and the element Nitrogen (N) from column V of the periodic table of the elements. GaN- based wide bandgap semiconductors have become one of the most studied materials and rapid progress has been demonstrated in both optical and electronic devices. Due to their wide bandgap and good thermal and chemical stability, GaN based semiconductor materials are very promising for high temperature pH sensor device.

Recently, AlGaN/GaN high electron mobility transistor (HEMT) structure has been used widely to fabricate sensor to sense pH level, hydrogen and hydrocarbon species. The device structure that has been tested is gateless field effect transistor (FET) type. These devices were found to operate in similar way that sensors operate on Silicon (Si) and Silicon Carbide (SiC). In sensors of these types, atoms or ions are absorbed at the semiconductor interface where they cause electrical polarization, which then changes the electrical properties of these devices. It is well known that the AlGaN/GaN interface has a large polarization field related to piezoelectricity and spontaneous polarization that causes a high density two

dimensional electron gas (2DEG) to be formed at the AlGa_N/Ga_N interface. The intrinsic polarization fields on the AlGa_N/Ga_N surface are accepted to play an important role in determining the pH sensitivity and response speed.

The III-V compound semiconductor such as GaN is an excellent material platform on a contribution to a development of new smart chemical sensor chip called an intelligent quantum (IQ) chip. An IQ chip is an III-V semiconductor chip with sizes of millimeter square or below where nanometer scale quantum processors and memories are integrated on chip with capabilities of wireless communication, wireless power supply and various sensing functions.

IQ chip which consists of four parts namely central processing unit (CPU) / memory, communication circuits, rectenna and sensors. This concept is shown schematically in Figure 1.1. Basically, it is an attempt to endow ‘more intelligence’ chip than simple identification (ID) like radio frequency identification (RFID) chips to semiconductor chips so that they can be utilized as versatile tiny ‘knowledge vehicles’ to be embedded everywhere in the society or even within bodies of human beings and other living species to fulfill the ubiquitous network society.

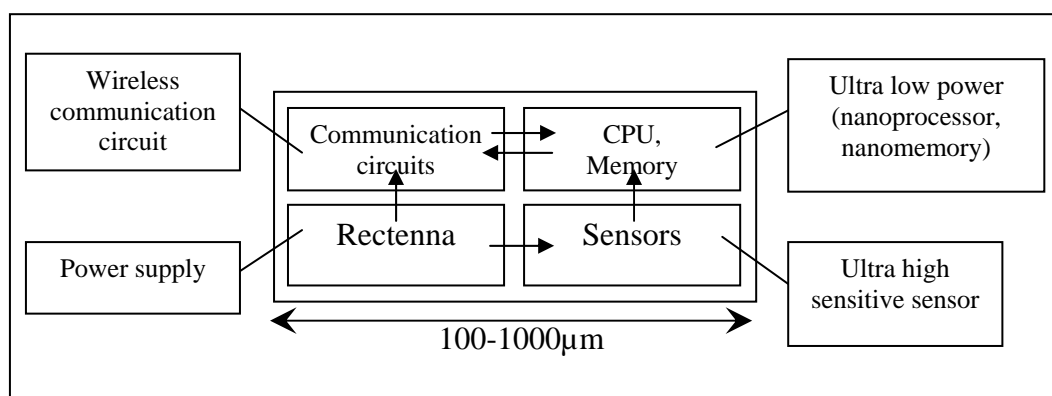


Figure 1.1: Element of the IQ Chip

This study will focus on a development of the GaN-based pH sensor by using the open gate (gateless) field effect transistors (FETs) structure. It will focus on the fabrication and characterization of the suitable pH sensor structure that should be implemented in the IQ chip.

1.2 Objectives

The objective of this project is to fabricate a pH sensor by using GaN-based semiconductor with gateless FET structure and characterize the sensing characteristics at different pH values. In order to evaluate the performance of fabricated sensing device, the dependence on the exposure to different pH was investigated. Besides, the sensing mechanism and the dependence on physical properties of used materials also were investigated.

1.3 Scope of Project

Sensor is one of the most potential devices to be integrated on the IQ chip to form the ultra high sensitivity sensor. Therefore, this study is carried out to fabricate and characterize the optimal design of the pH sensor in order to perform such applications. This study will encompass all the things and knowledge related to the pH sensor and material that will be used.

1.4 Organization of Project Report

This project report is organized in 6 chapters.

Chapter One gives an overview of the project that gives the introduction of the project including objectives and scope of study.

Chapter Two covers literature review on general background and theory needed on the topic as well as the previous researches related to this study.

Chapter Three covers the methodology that consist the specification and design, fabrication process and measurement configuration. The fabrication processes of the device have been explained in detail in this chapter.

Chapter Four discuss about the results of the project. Here, the sensing response of device fabricated was presented. It was found that current changes while exposing to various pH solutions.

Chapter Five contains the conclusion of project and the suggestion for further enhancement.

PUBLICATION LIST

Conference/Symposium/Exhibition:

- 1) **Mastura Shafinaz Zainal Abidin**, Abdul Manaf Hashim, “Fabrication Technique of pH Sensor with Open Gate n-AlGa_N/Ga_N Structure”, 2009 IEEE Regional Symposium on Micro and Nano Electronics (IEEE-RSM2009), Renaissance Hotel, Kota Bharu, 10- 12 August, 2009

- 2) Maneea Eizadi Sharifabad, **Mastura Shafinaz Zainal Abidin**, Mazuina Mohamad, Shaharin Fadzli Abd Rahman, Abdul Manaf Hashim, Abdul Rahim Abdul Rahman, “Fabrication and Characterization of AlGa_N/Ga_N-based HEMT for pH Sensing”, Nanotech Malaysia 2009, Putra Kuala Lumpur Convention Centre (KLCC), Kuala Lumpur, 27 - 29 October 2009.

- 3) Abdul Manaf Hashim, **Mastura Shafinaz Zainal Abidin**, Maneea Eizadi Sharifabad, Mazuina Mohamad, Shaharin Fadzli Abd Rahman, Abdul Rahim Abdul Rahman, Anisah Abdullah, “Novel Ga_N-based On-Chip pH Sensor”, Bronze Medal, Industrial Art and Technology Exhibition 2009 (INATEX 2009), Universiti Teknologi Malaysia

- 4) **Mastura Shafinaz Zainal Abidin**, Maneea Eizadi Sharifabad and Abdul Manaf Hashim, “Fabrication and Measurement Technique for Ga_N-Based pH Sensor with Open Gate Structure”, International Advanced Technology Congress 2009 (ATCi 2009), Putra World Trade Center (PWTC), Kuala Lumpur, 3 - 5 November 2009.

- 5) Maneea Eizadi Sharifabad, **Mastura Shafinaz Zainal Abidin**, Mazuina Mohamad and Abdul Manaf Hashim, “Undoped-AlGa_N/Ga_N HEMT Structure for pH sensor”, International Advanced Technology Congress 2009 (ATCi 2009), Putra World Trade Center (PWTC), Kuala Lumpur, 3 - 5 November 2009.
- 6) **Mastura Shafinaz Zainal Abidin**, Maneea Eizadi Sharifabad, Abdul Manaf Hashim, Shaharin Fadzli Abd Rahman, Abdul Rahim Abdul Rahman and Nurul Afzan Omar, “AlGa_N/Ga_N HEMT Based pH Sensor”, ESciNano Annual Symposium 2009, The Zon Regency Hotel, Johor, Malaysia, 30 November – 1 December 2009
- 7) **Mastura Shafinaz Zainal Abidin**, Maneea Eizadi Sharifabad, Abdul Manaf Hashim, Shaharin Fadzli Abd Rahman, Abdul Rahim Abdul Rahman and Mohd Nizam Osman, “Fabrication of Open Gate Structure on Ga_N-Based HEMT for pH Sensing”, International Semiconductor Device Research Symposium 2009 (ISDRS 2009), College Park, MD, USA, 9 – 11 December 2009