DESIGN AND FABRICATION OF N-ISFET USING SI_3N_4 AS A SENSING MEMBRANE FOR PH MEASUREMENT

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ABSTRACT

This project is about the development of n-type ISFET using silicon nitride (Si_3N_4) as a sensing membrane for pH measurement in biomedical applications. The theory, design, and fabrication methods, along with the experimental results are presented in this report. The gate of the ISFET is replaced by the Si_3N_4 sensing membrane layer that has been deposited using PECVD system to cover the gate area. Both exposed membrane of ISFET and reference electrode were immersed in pH buffer solution to measured electrical I_DV_D (drain current-drain voltage) and I_DV_G (drain current-gate voltage) characteristic in order to identify the ISFET behavior. The best pH sensitivity achieved from the experimental testing is 40.35 mV/pH.

KEYWORDS: *ISFET, Si_3N_4, pH measurement and pH sensitivity.*

1.0 INTRODUCTION

This research paper presented the development of n-type Ion Sensitive Field Effect Transistor (ISFET) based sensor for pH measurement. Sensors play an important role in almost all fields of science and technology including engineering, medical, industrial control, aerospace, food and beverage production, security and defense and environmental applications.

ISFET was first explored by P. Bergveld in 1972 (Bergveld, 1972). In recent years, many researchers have done to characterize ISFET based on MOSFET technology up until now. ISFET is an integrated device that is similar to Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) except the gate part. Unlike MOSFET, metal gate of MOSFET is replaced by a pH sensing membrane which is Silicon Nitride (Si_3N_4) in ISFET design. Si_3N_4 as a sensing membrane is use to detect ion response in pH buffer solution by exposed the membrane layer to the solution.

The pH sensitivity is one of the most important characteristic parameters of ISFET devices. The response of an ISFET is generally determined by the type of the sensing membrane used. Therefore the sensing membrane material plays a significant role.

The pH sensitivity can be determined by extracting the threshold voltage (V_{TH}) of ISFET device in various pH solutions. The V_{TH} of MOSFET is usually defined as the gate voltage where an inversion layer forms at the interface between the insulating layer (oxide) and the substrate (body) of the transistor (Wikipedia, 2009). As for ISFET device, V_{TH} refer to the minimum gate voltage required to induce a conducting channel at the surface of ISFET.

In addition, the ISFET cannot operate alone by himself. The best way to improve the operation of ISFET is by adding reference electrode (Gracia *et.al.*, 1992)(Moinpour *et.al.*, 1989). ISFET can operate well with a present of reference electrode as to establish the electrolyte potential with respect to the semiconductor substrate.

This paper presents a complete n-ISFET device involving mask layout design, fabrication process, pH testing preparation and characterization. Firstly in mask layout design, it consists of designing four masks layout. Then, there were 28 process steps need to be done in fabrication process of ISFET device. Next, pH testing preparation includes dicing, mounting, wire bonding and encapsulation process and also preparation of experimental setup to characterize the n-ISFET device.

2.0 ISFET FABRICATION PROCESSES

The research methodology involves are designing four masks layout, fabrication process flow, testing and characterize the ISFET device. There are four mask levels and each mask level is designed to be precisely aligned with the previous mask. Transparency masks are sufficient when the features being generated are of 50 μm size or larger (Dotson *et.al*., 2004). The procedure for developing transparency masks is simple, inexpensive, saves time and straightforward. This procedure consists of two steps: computer design and high resolution printing. First, layout of the masks is designed using AutoCAD software in a computer. After completed, all design will be printed using standard inkjet printer with high resolution (Hashim *et.al*., 2007).

The typical layout of ISFET was designed as in Figure 1. The length of channel (sensing membrane) L1, of the ISFET is typically between 10 μm and 50 μm to ensure a good contact with the solution. Unfortunately, because of the limitation of laboratory printer in order to print micron size, the channel length decided size is 200 μm.

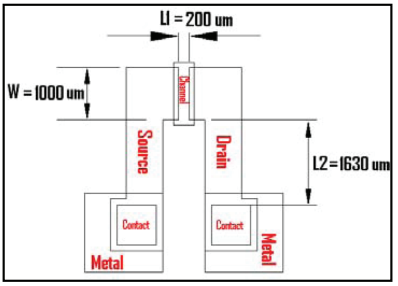

Figure 1 Typical layout design of an ISFET

The first mask is N+ source/drain mask. This mask is used to control the heavily phosphorus doped and create the source and drain region of the transistors. The second mask is gate mask. This mask is used to remove the thick oxide layer and grow a very high quality of thin oxide. Moreover, this mask also being use to define membrane area of the n-ISFET. The third mask is contact mask. This mask is used to pattern the contact holes. The etching process will opens the holes. The last mask is metal mask. This mask is used to pattern the connection of the device and the evaporated aluminum film is defined onto it. The entire mask design is shown in Figure 2.

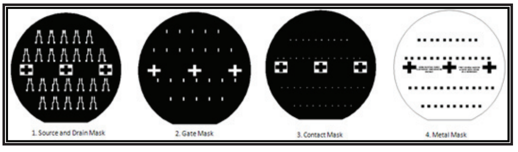

Figure 2 Four mask design by using AutoCAD

The fabrication sequence includes the same processing steps as standard MOS processing but with one extra step for sensing membrane as shown in Figure 3.

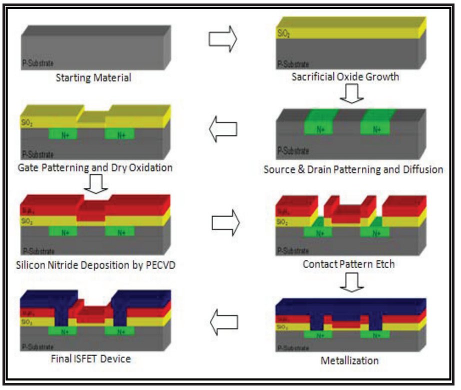

Figure 3 ISFET fabrication process flow

3.0 ISFET PH TESTING

The I-V Characteristic which consists of I_D-V_D measurement and I_D-V_G measurement has been done by using Keithley Semiconductor Parametric Analyzer. I_D-V_D and I_D-V_G are measured in acidic, neutral and base solutions (pH 4, pH 7 and pH 10 respectively) as in Figure 4.

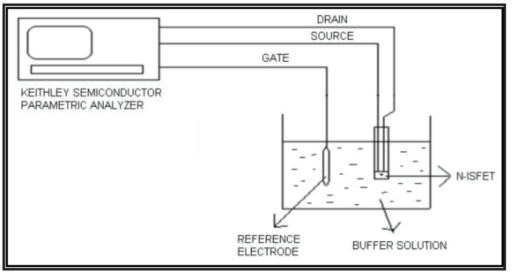

Figure 4 Experimental setup

The I_D-V_D and I_D-V_G measurements were carried out in order to measure the threshold voltage of the ISFET devices in various pH buffer solutions as shown in Figure 5 below. In addition, another purpose is to investigate the suitable operating point of ISFET (Rani *et.al*., 2008) and to inspect the pH sensitivity of ISFET. Afterward, the I-V (current vs voltage) curves are measured to investigate the pH sensitivity.

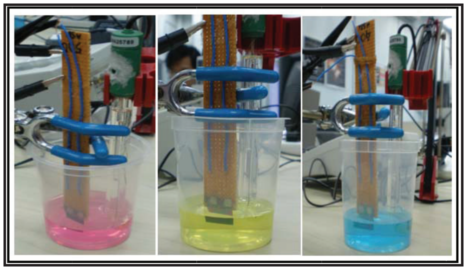

Figure 5 ISFET and Reference Electrode immersed in various pH range

The ISFET device and reference electrode is thoroughly rinsed with De-Ionized (DI) water as it is transferred from one pH to another. This action will lead to gain more precise of collected data.

4.0 RESULTS

The Figures below show the results obtained after finishing the experiment of immersing ISFET and reference electrode in various pH range.

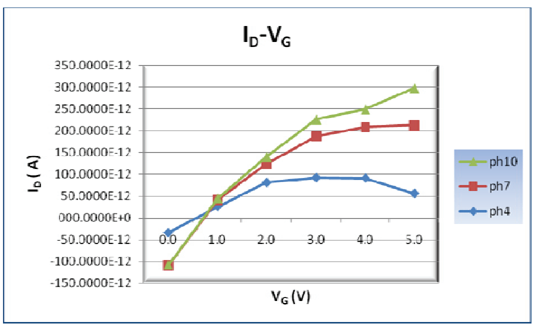

Figure 6 I_D-V_G curves of n-ISFET

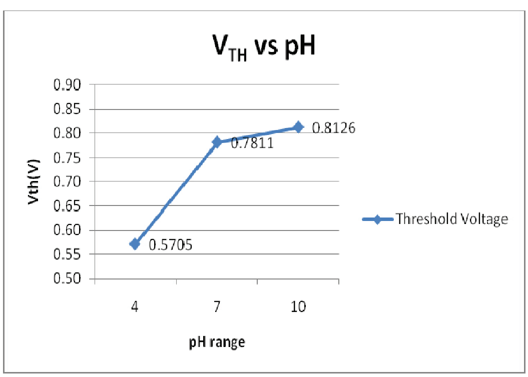

Figure 7 V_{TH} value vs pH range

According to the result of I_D-V_G curves and V_{TH} value vs pH range of n- ISFET in Figure 6 and 7, the experiment is tested in three levels of pH buffer solutions which is extracted to make the samples. From Figure 6, the curves show that n-ISFET response toward different buffer solutions.

Based on Figure 7, the response of n-ISFET towards three levels of pH buffer solution is not linear. These results condition cannot give the right sensitivity value for the n- ISFET. The sensitivity of n-ISFET is 40.35 mV/pH.

5.0 DISCUSSION

The n-ISFET based sensor for pH measurement in biomedical applications with Si_3N_4 as a sensing membrane was successfully designed, fabricated and tested. The entire 28 process steps of fabrication did not give the actual size of designated ISFET device due to some over developed or over etch the patterns. Proper performance of ISFET sensors in biomedical is strongly related to the process conditions of fabricating the device. Based on the experimental results obtained, the ISFET device did not have an appropriate procedure of fabricating and testing. It is important to have an appropriate procedure to make sure the sensor can function well. Failure of ISFET device to function well in pH buffer solution might be due to the errors done in fabrication process. Another reason is due to our equipment limitation which is the smallest size that can be printed onto mask design is 400 μm.

6.0 CONCLUSION

As a conclusion, the in-house fabricated ISFET have high sensitivity; 40.35 mV/pH in a range of pH4 to pH10 which is near to the Nernstian potential.

7.0 ACKNOWLEDGEMENT

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