Design and Simulation of ISFET Using Si_3N_4 as the Sensing Layer for Biomedical Applications

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***Abstract*— The present paper describes the comparison between simulated views of ISFET (Ion sensitive Field Effect Transistor).A comparison of better result between conventional, previously made ISFET and an improved ISFET design is presented in this report. This paper gives the improve valve of designing parameters. By which the performance of the ISFET can be improved.**

The pH sensing properties and drift behaviour of the ISFET improved greatly with the introduction of other insulating materials. Commonly used pH-sensitive membrane on top of the gate is Si_3N_4. This layer has higher pH sensitivity, selectivity, and long term stability. Si_3N_4 layer has another advantage that it has better diffusion barrier against water molecules and sodium ions which are major sources of corrosion and instability in microelectronics. This device has advantage over the conventional electrodes due to its high sensitivity, fast response time, micro size.

***Index Terms*— ISFET (Ion sensitive Field Effect Transistor), TCAD Tool.**

I. Introduction

The Ion Sensitive Field Effect Transistor (ISFET) is a chemical sensitive device based on structure of Metal-Oxide-Semiconductor (MOSFET). The ISFET was first demonstrated by Bergveld in 1970. The sensitivity to ions is derived by eliminating the metal gate contact of the MOSFET and exposing the gate insulator to an electrolyte solution [12]. The contact to the electrolyte gate is provided by a reference electrode. ISFETs have been of great interest for the application in chemical and biological sensing devices. A common method to measure Ph is the well-known glass membrane electrode. Glass membrane electrode has some limitations in order to measure the pH of solution in biomedical application such as the inability to operate at high temperatures, being a bulky device, manufacturing difficulties, and low durability. So ISFET has advantages over a conventional device such as small size, low power consumption, robustness, and fast response time, so ISFET is using for various purposes in biomedical, medicine, and chemical applications The basic idea of an ISFET is to remove the metal gate electrode from a MOSFET, and to expose the oxide directly to an electrolyte, whose concentration of certain ions is wished to be determined. Instead of the fixed gate, a reference potential V_{Ref} is applied

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to the electrolyte – oxide – semiconductor system via a reference electrode, which is dipped into the electrolyte? [3]

The first ISFET (Ion Sensitive Field Effect Transistor) device introduced was for the measurement of in and effluxes around the nerve [4] which later were indeed measured as illustrated [5].

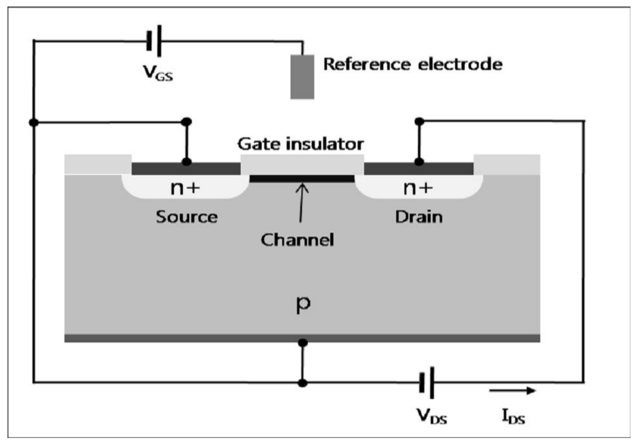

Figure- 1: Structure of ISFET with source, drain, gate insulator, and reference electrode.

In the above fig. one electrode pair is used. One as the measuring electrode and other as reference electrode. As reference electrode hydrogen electrode is used because its potential is 0 volt [2].The amount of the current flow in ISFET is sensitive to pH also. Normally it is determined by the charges of molecular interacting on the gate dielectric.

II. EXPERIMENTAL CONSIDERATIONS AND OBSERVATIONS

The report gives a comparison between existing and proposed device. The process simulation of ISFET and its electrical characterization is done using SILVACO Tcad tool [14]. The process simulations are done using Athena environment and the device electrical characterization is done using Atlas environment. The report gives the different value of current and threshold voltage as compare to my base paper. The following equation gives the relation between different

parameter such as drain current depends upon β, gate voltage (V_{gs}), Threshold voltage V_T.

$$I_d = \beta (V_{gs} - V_T - \tfrac{1}{2} V_{ds}).V_{ds} \quad (1)$$

Where, β: - μ C_{ox} W /L
μ :- Mobility of the e^- in the inversion layer
C_{ox}: - The gate insulator capacitance per unit area
W /L: - Aspect ratio of the channel which affects the transconductance
Here β is sensitivity factor describes the resulting response of the ISFET to change in the P_H of the electrolyte. The response of the sensor depends on β: the higher value of β, thus leading to higher pH sensitivity and the more linear the response [6].Experiment consideration is to improve the value of β and threshold voltage, by changing some designing parameter of the ISFET.Sothat it can be find out the better value of drain current and threshold voltage by which we can obtain better sensitivity.

III. ISFET DESIGN

A. Process Simulations and Parametric Analysis

A P type silicon wafer (boron doped) is used 1.3e15cm-3. The resistivity orientation and thickness of the silicon wafer are taken as 10 Ω cm, 100 and 525 microns respectively [1].
Now an oxide layer of thickness 0.05μm is deposited on the silicon wafer for this the diffusion process is carried out for different time interval in different condition and at a certain temperature after this the oxide layer is etched from both the axis X and y for making the channel.
Now for making Source and Drain, N-type of doping is done. For that phosphorus doping/diffusion of 1.0e21cm-3 is done and a layer of silicon of 0.05 μm is made.
After this oxide layer from gate is completely remove and a layer of oxide (Sio2) of 0.05 μm thickness is grown again on gate.
A layer of nitride (Si_3N_4) of 0.05 μm thickness is deposited [15]. After this the nitride layer is etched from both the axis x and y for defining source and drain region. For making contacts etching of oxide is done on source and drain region both.
Now a layer of aluminum is deposited on the whole region. After this layer of aluminum is etched to make source and drain as contact. Finally, the final structure of ion sensitive field effect transistor (ISFET) is shown in Fig. 2and 3. In Device simulation ISFET is simulated in Atlas. The device is simulated to obtain the Electrical characteristics. From the simulation, the drain current I_d versus gate voltage, Vgs curve with a constant drain voltage for ISFET device is shown in figure 4.

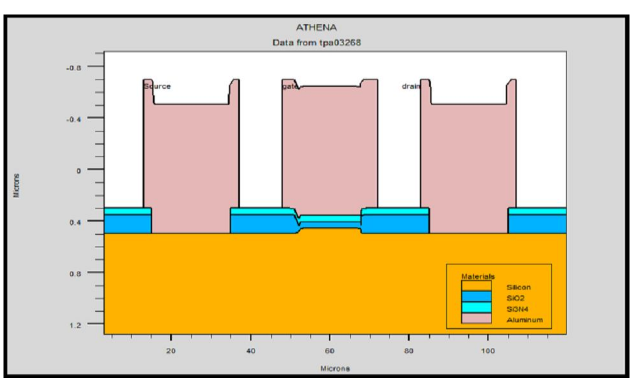

Figure-2: ISFET showing various regions/layers

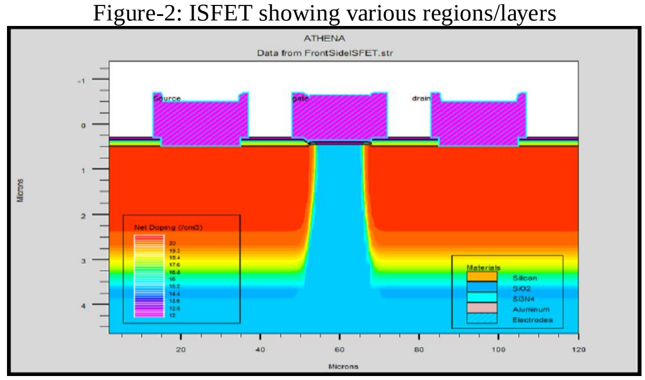

Figure-3: Structure with Doping Electrical Characterizations and Comparisons

From the figure 4 the threshold voltage can be easily extruded which is 0.28 V and the peak drain current is 4.5μA. This result is different to my base paper. In my base paper the value of threshold voltage is 0.5V and the peak drain current is 1.97μA [1].This indicates that the simulated results are different to the result extruded from my base paper. It also indicates that as reduces the channel length, threshold voltage also reduces.

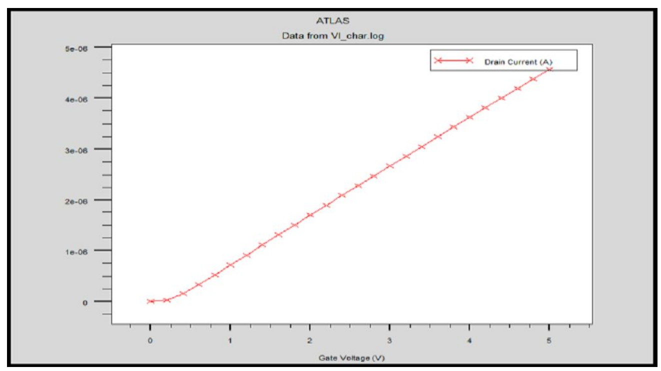

Figure-4: I_d v/s V_{gs} (input characteristic)

Besides that, structure is also simulated to ramp the drain voltage V_{ds} to 5V when gate voltage V_{gs} is bias to 1V, 2V, 3V and 4V. The simulation results are shown in fig 5 which represent the graph of drain current versus drain voltage.

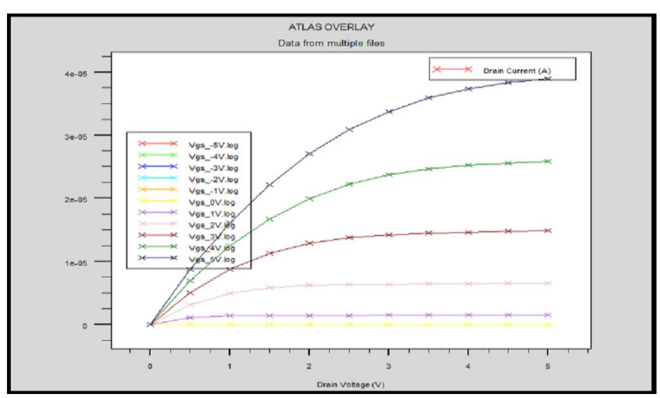

Figure-5: I_{ds} v/s V_{ds} (Output Characteristic)

The family of curve from atlas for I_d versus V_{ds} is also is observe in figure 5.Figure 5 shows the different curve for different value of V_{gs} between drain current and drain voltage. Figure 5 also show that new ISFET has higher current compared to previously designed ISFET.

IV. CONCLUSIONS

From the above results, it is worth considering some general features of the ISFET devices simulated. The general enhancement can be observed in the drain current and threshold voltage of ISFET. Obtained Characteristics of ISFET are also similar to the characteristics of conventional MOSFET.

The improvement in the values of drain current and threshold voltage can be improved the P_H sensitivity of the ISFET to electrolyte solution.

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