

Design and Simulation of an Improved ISFET using Si_3N_4 Sensing Layer

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Abstract: This paper describes the design of an improved ISFET. A detailed 2D process simulation of ISFET and its electrical characterization has been done using TCAD Tools. Using oxide thickness, t_{ox} of 0.04 μm and silicon nitride thickness (Si_3N_4) of 0.03 μm , the threshold voltage V_t for the ISFET and previously made ISFET is 0.25V and 0.5V respectively. This indicates lower power consumption, more drain current i.e 5.29 μA and better performance.

Keywords: ISFET (Ion sensitive Field Effect Transistor), Ph Sensor, TCAD Tools.

I. INTRODUCTION

Ion Sensitive FETs (ISFETs) are based on a standard FET structure but with an insulating layer on top of the gate oxide. The ISFET was first demonstrated by Bergveld in 1970. Ion-Sensitive Field Effect Transistor (ISFET) is a device in which the gate oxide is in direct contact with an analytic solution. The contact to the electrolyte gate is provided by a reference electrode [3]. This type of device is advantageous over the conventional electrodes due to its high sensitivity, fast response time, micro-size and on-chip circuit integration. ISFETs have been of great interest for the application in chemical and biological sensing devices. The ion-sensitive field-effect transistor (ISFET), is one of the most popular electrical biosensors, it is referred as a pH sensor. ISFET has been used to measure ions concentrations (H^+ or OH^-) in a solution, causing an interface potential difference on the gate insulator. The ISFET is a potentiometric type device that operates in a similar way as the MOSFET (Metal Oxide Semiconductor Field-Effect Transistor) works. ISFETs are realized by removing the metal gate electrode of a Metal Oxide Field Effect Transistor (MOSFET). Therefore, the metal becomes a remote gate. The silicon dioxide (SiO_2) layer of ISFET is exposed to an ionic solution (electrolyte), due to interaction of solution and oxide layer, interfacial potential difference is devolved which modulates the threshold voltage, V_T of the transistor [3]. ISFET sensing principle is based on the charge adsorption at the ion-solid interface between the sensing layer which contains hydroxyl groups and the electrolyte, from which hydroxyls may donate or accept protons. In this process a double-layer capacitance is created with a potential drop, which influences the threshold voltage of the transistor depending on the value of H^+ protons concentration (pH). The pH sensitivity that is observed during the exposure to the electrolyte makes ISEFT a highly useful tool for obtaining measurements in various fields of applications: agricultural, environmental, food, etc. Most important applications are in biomedical engineering, for which the ISFET was initially developed. 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].

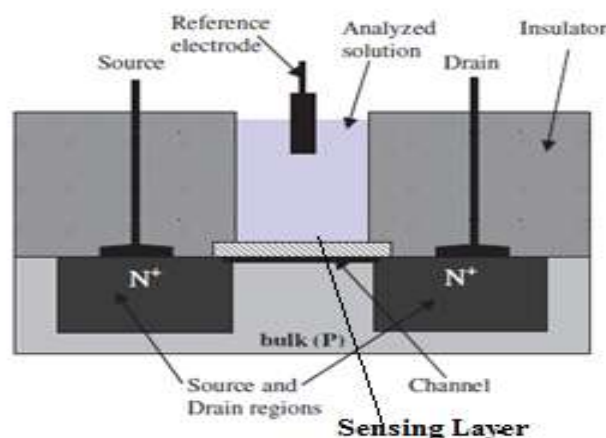


Figure. 1: Structure of an Ion sensitive Field Effect Transistor (ISFET)

In the above figure 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

This paper gives a comparison between existing and proposed device. The process simulation of ISFET and its electrical characterization is done using Silvaco Tcad tools [14].

The process simulations are done using Athena environment and the device electrical characterization is done using Atlas environment. The following equation gives the relation between different parameters such as drain current depends upon β , gate voltage (V_{gs}), Threshold voltage V_T .

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

Where, β : - $\mu C_{ox} W/L$

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. So that it can be find out the better value of drain current and threshold voltage by which we can obtain better sensitivity.

III. ISFET DESIGN

I. Process Simulations and Parametric Analysis

A P type silicon wafer (boron doped) is implanted with the $1.3 \times 10^{15} \text{ cm}^{-3}$ doping concentration. The resistivity orientation and thickness of the silicon wafer are taken as $10 \Omega \text{ cm}$, 100 and 525 microns respectively [1]. Now an oxide layer of thickness $0.04 \mu\text{m}$ 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 $1.0 \times 10^{21} \text{ cm}^{-3}$ is done and a layer of silicon of $0.04 \mu\text{m}$ is made. After this oxide layer from gate is completely remove and a layer of oxide (SiO_2) of $0.04 \mu\text{m}$ thickness is grown again on gate. A layer of nitride (Si_3N_4) of $0.3 \mu\text{m}$ thickness is deposited. 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 aluminium is deposited on the whole region. After this layer of aluminium is etched to make source and drain as contact. Finally, the final structure of ion sensitive field effect transistor (ISFET) is shown in Figure 2 &3.

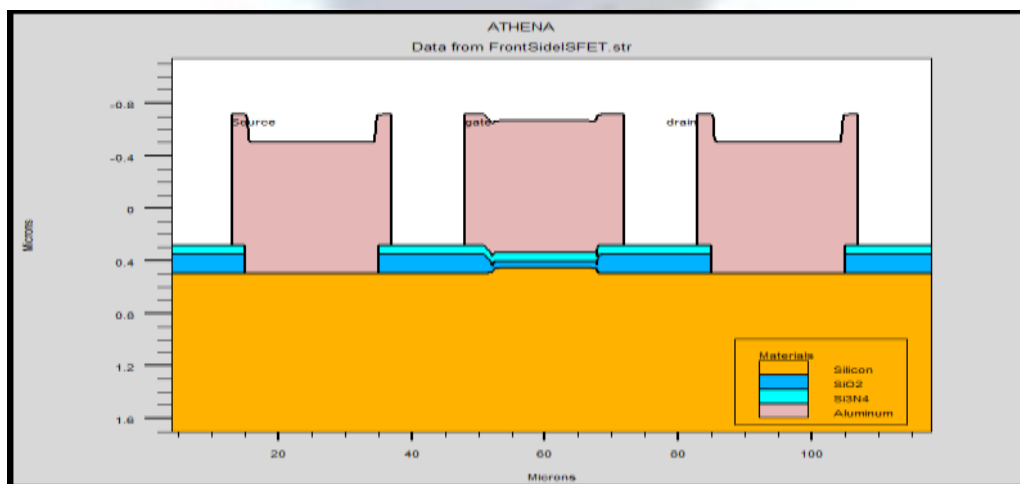


Figure: 2: Ion sensitive Field Effect Transistor (ISFET) showing various regions/layers

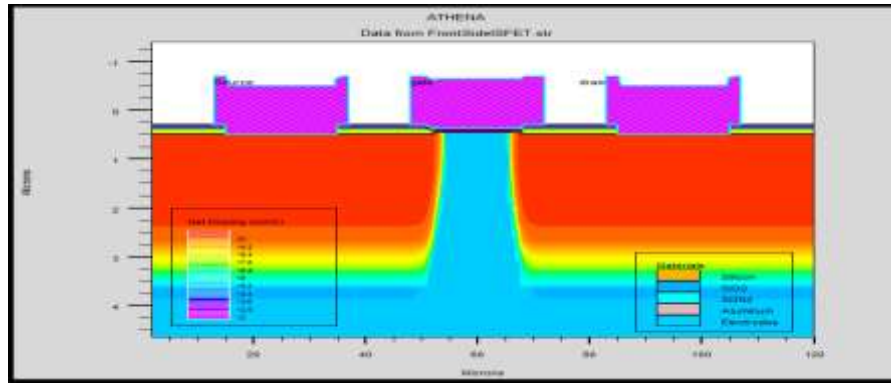


Figure:3 Ion sensitive Field Effect Transistor (made using Athena)

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, V_{gs} curve with a constant drain voltage for ISFET device is shown in figure 4. From the figure 4 the threshold voltage can be easily extruded which is **0.25 V** and the peak drain current is **5.29 μ A**. In previous paper the value of threshold voltage is 0.5V and the peak drain current is 1.97 μ A. [1] This indicates that the simulated results are different to the result extruded from previous paper. It also indicates that as reduces the channel length, threshold voltage also reduces.

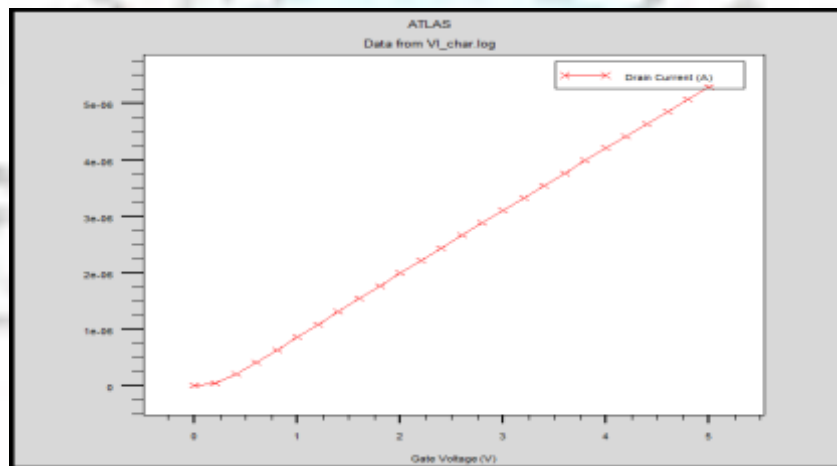


Figure: 4: I_d v/s V_{gs} (input characteristic)

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 represents the graph of drain current versus drain voltage.

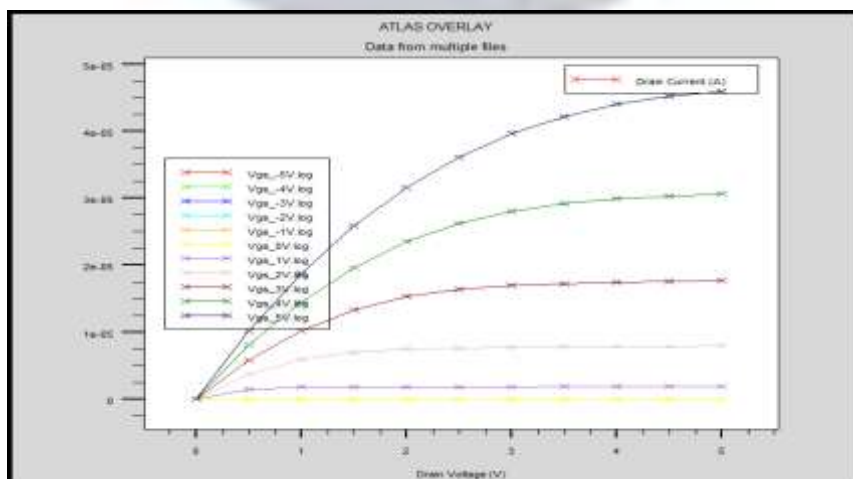


Figure: 5: I_{ds} v/s V_{ds} (Output Characteristic)

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

CONCLUSION

The design, simulation and design parameters comparison of ISFET-based structures were presented in this paper. From above results, it is concluded the new device has better performance than previously simulated device. Obtained Characteristics of ISFET are also similar to the characteristics of conventional MOSFET.

TCAD tools can be applied and each technological process step simulated in order to predict the behaviour of the designed structure. The improved results can be improved the P_H sensitivity of the ISFET to electrolyte solution.

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