Design and Optimization of ISFET for Health Care Applications

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May 9, 2023

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Abstract

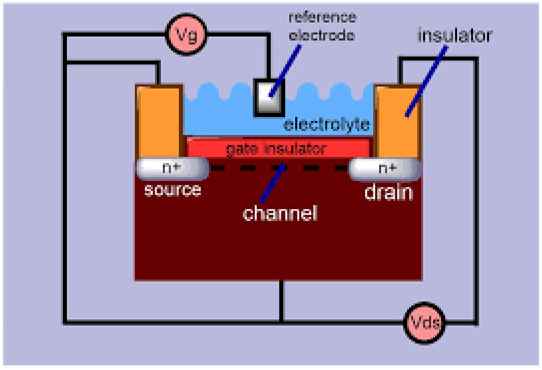
ISFET is known as Ion Sensitive Field Effect Transistors. By considering measurement of sensitivity, simple integration process we can say that ISFET is very much used for medical applications. Some of the features of ISFET are rapid reaction rate, small size, single integration process and rapid reaction time. It is fabricated with the help of the CMOS technology. ISFETs are developed by refining the layout of MOSFET. Some medical applications of ISFET are detection of DNA hybridization, biomarker detection from blood, antibody detection, glucose measurement and pH sensing. The ISFET is also the basis for later Bio FETs, such as the DNA field-effect transistor (DNAFET), used in genetic technology. Here, we design two dimensional ISFET and measuring sensitivity by considering two different electrolytes. And identifying best oxide in case of both the electrolytes when different oxides are taken into consideration.

1 Introduction

An integrated circuit, ISFET is a tiny sensor. These type of sensors are the choice for pH measurement. Medical applications need high accuracy and high performance these features can be matched by ISFET. So they can be used. Electrolyte properties are very much Important and plays a key role in controlling the sensitivity. ISFET is manufactured by CMOS process because it is a form of MOSFET. Limitations of Normal or conventional FET are they have less sensitivity, delay in response time and have high leakage current. Both acidity and alkaliness can be managed by ISFET. Few features of isfet they are fast and have high sensitivity, light in weight ans small. Applications which needs good performance and portable these features are useful. Some of those applications are

- Monitoring beer fermentation.
- Manufacturing dairy products likecheese, milk, and yogurt
- Analysing soil for herbicides.chemicals, and other toxic chemicals
- Handheld drug detection devices

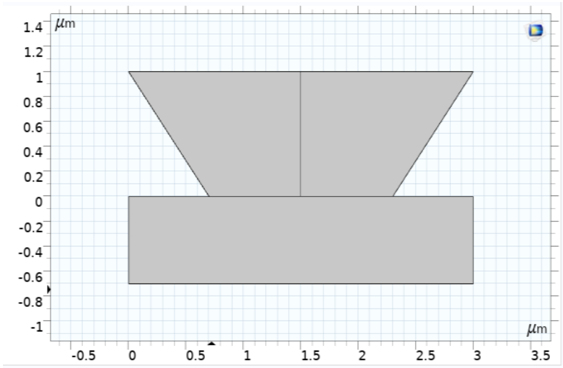
The structural difference between these two FETs is the gate position. In the general case any transistor comprises of source, gate and drain. These three are present on substrate.



But instead of gate depositing on the surface in ISFET gate is separated from the structure and it is known as reference electrode. When a MOSFET with the metal gate removed and the underlying gate oxide inserted in an aqueous solution along with a reference electrode could be used detect ions. In this study four different oxides namely Hfo2, Al2o3, Sio2, Ta2o3 are considered and deposited when two different electrolytes are considered. Here to obtain the best oxide two electrolytes are taken. The ISFET model is build and stimulated in COMSOL Multiphysics software. A simulation environment is provided by COMSOL. This software is used in some domains such as fluid flow, electromagnetics, chemical reactions. The model build in 2D because ion concentration level will be easy from front view. The aim is to get electrolyte potential and features of Id vs Vd of the modelled ISFET, to observe Drain Current (Id) vs. Gate Voltage (Vg), Comparing the Id vs Vg at different pH levels for different oxides, Choosing the best oxide based on the sensitivity of ISFET 2D model.

2 Modelling

The process of isfet Designing is comparable and parallel to metal-oxide-semiconductor field-effect transistors (MOSFETs). This model comprises of contiguous domains they are semiconductor domain and an electrolyte domain. The physics involved in the semiconductor domain are similar to those in the MOSFET but instead of metal gate in MOSFET in ISFET there is electrolyte. Few details are needed for executing this ion transistor. From the Figure of ISFET we can observe that on the surface of oxide electrolyte is present. The applied voltage at the drain is 10mv. So the sensitivity is measured by adding urime into the electrolyte tank. By varying pH and maintaining drain voltage constantly gives the electric potential. In the source and drain region, when there is change in pH then there is a proportional change in doping concentrations. For design of 2D-ISFET COMSOL Multiphysics software is used. First step for designing the model is setting the geometry of the model. For building the substrate width and the height is 3 and 0.7µm respectively. The source and drain lengths are considered as 0.5µm. For the electrolyte tank chosen shape is trapezoid. The dimensions of electrolyte tank is 3µm in width and 1.5µm in height.



The electrolyte domain is selected by specifying the relative permittivity of the solution taken. So when urine is considered as electrolyte relative permittivity is 81 and when blood is considered it is 60.5. Different oxides are considered in case of both the electrolytes are SiO_2, Al_2O_3, Ta_2O_3 and HfO2. Doping concentration varies along with electrolyte potential(pH). At source and drain regions there is change in doping concentration. In case of all oxides there is a slight change in drain side but at source all oxides have same level of concentration. For SiO_2, both source and drain side have less concentration. Both source and drain have variations in case of Ta_2O_3 and HfO_2. And for Al_2O_3 there is a disturbed concentration.

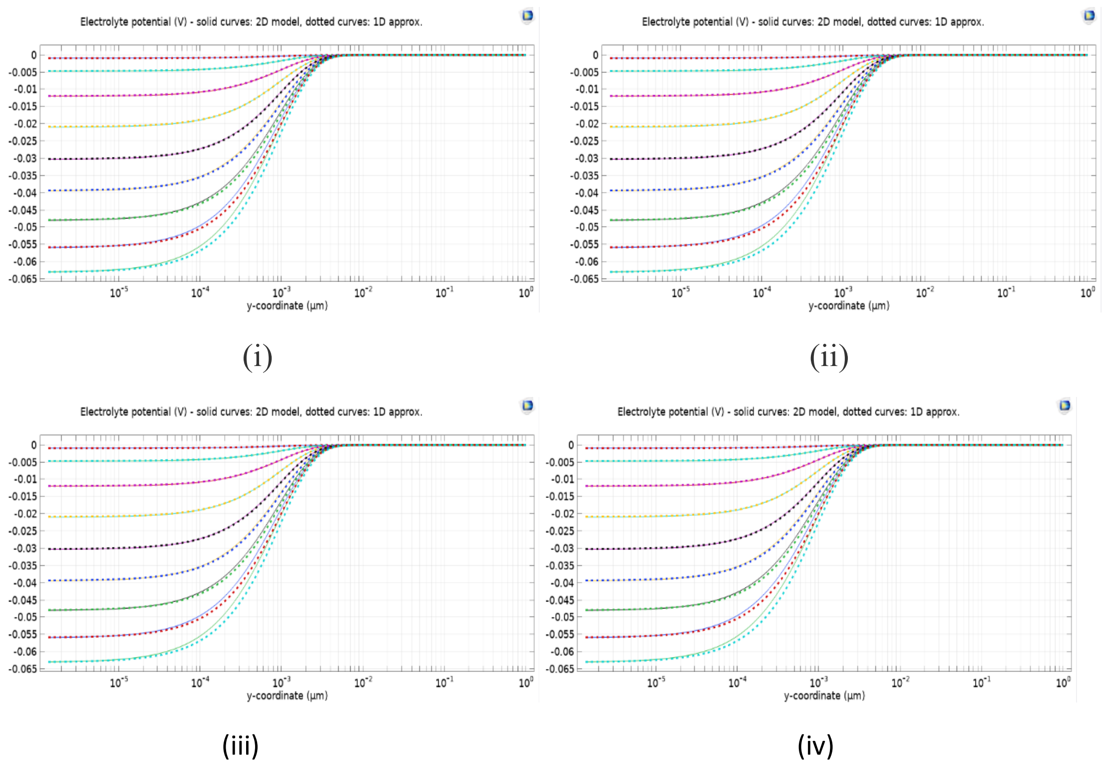


Fig.1 Electrolyte potential curves for all the four oxides when electrolyte is urine.

(i)SiO_2 (ii)Ta_2O_3 (iii)Al_2O_3 (iv)HfO_2

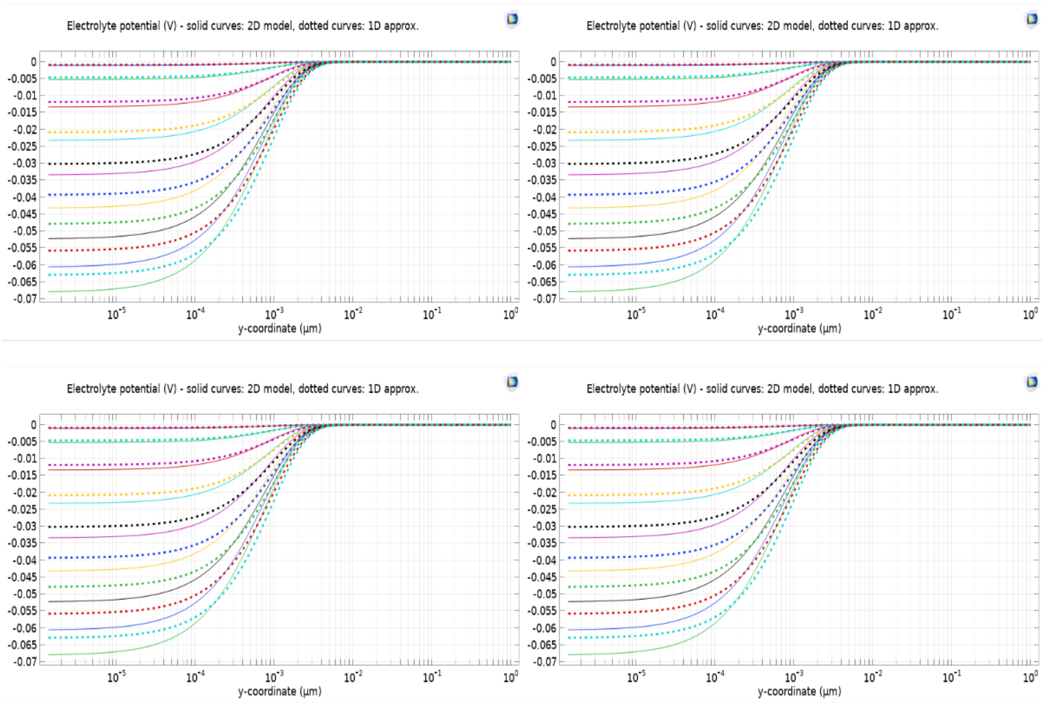


Fig. 2 Electrolyte potential curves for all the four oxides when electrolyte is urine.

(i)SiO_2 (ii)Ta_2O_3 (iii)Al_2O_3 (iv)HfO_2

3 Results

3.1 Id Vs Vg characteristics

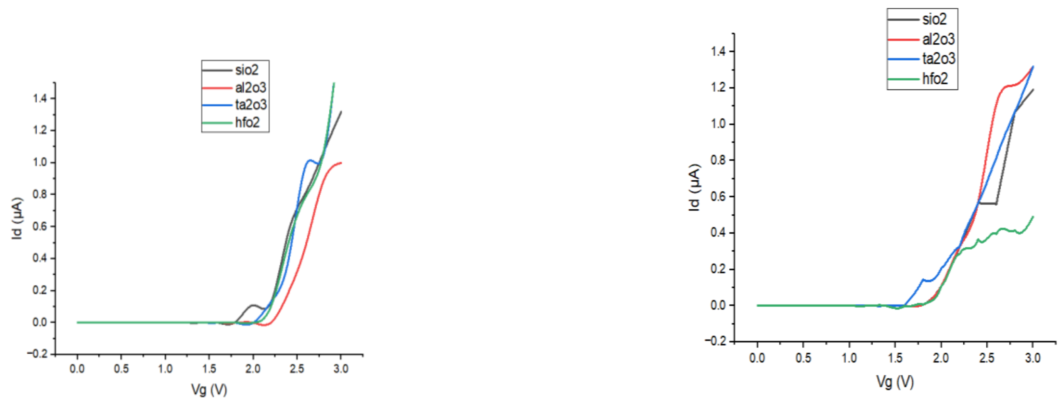
The applied voltage and the pH of the electrolyte functions the gate voltage in ISFET. Coupled system is defined as the system in which the equations are formulated by structure and fluid equations and integrated with time. This type of system express the relation between drain current and gate voltage. Actions of Id vs Vg curve are comparable to MOSFET. This is because to transmit the voltage to the oxide surface, electrolyte reacts as conductor. Fig.3 shows the characteristics between Id and Vg for different electrolytes. From Fig.3(i) we can conclude that for blood as electrolyte there is rapid increase in current in case of SiO_2 oxide. Similarly in Fig.3(ii) we can see that for urine as electrolyte Ta_2O_3 oxide has more drain current .

3.2 Electrolyte potential curves

At the centre Electrolyte potential of the model is observed. There are two types of curves in plot. These curves represents both 2D and 1D model. Fig1 and Fig2 describes the electrolyte potential of the ISFET model which is indicated by solid curves and 1D approximation indicated by dotted curves.

3.3 The sensitivity of ISFET

By varying oxide sensitivity also varies. The typical method for determining sensitivity is to look at how the pH level affects the distributions of charges and potentials above the gate insulator. The significant of finding the best oxide which has better sensitivity is to use them in medical applications. In sensitivity curves the resulting gate voltage is function of pH value. And it is defined as the slope of the curve and it determines the performance. And sensitivity is inversely proportional to pH value of the electrolyte. At very high pH small value of Vref gives high sensitivity. From sensitivity curves we observe that Ta_2O_3 has more sensitivity in both the case when it is urine and blood as electrolyte . So we can conclude that ISFET device is more sensitive in case of Ta_2O_3.



(i) (ii)

Fig. 3 plot between Id vs Vg for different electrolytes (i)blood (ii) urine.

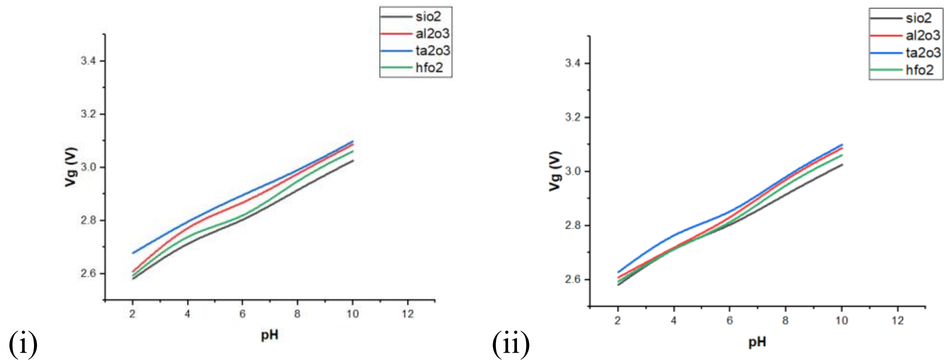


Fig.4 Sensitivity curves for four oxides in case of (i)urine (ii)blood

4 Conclusion

In this learning of ISFET, Id vs Vg is characterised by considering oxides as SiO_2, Ta_2O_3, Al_2O_3 and HfO_2 .Electrolytes are urine and blood. As ISFET is used for medical applications for accurate results the sensitivity of the device is most important. And in this study it is proved that in both the electrolyte cases Ta_2O_3 gives the better sensitivity for isfet model when compared to all the other oxides.

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