SIMULATING THE EFFECTS OF INSULATOR AL2O3 AND ITS COMPARING HFO2 IN ION SENSITIVE FIELD EFFECT TRANSISTOR TO PREDICT THE CONDUCTANCE USING ENBIOS 2D

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Abstract

Aim: The aim of this research work is to predict the conductance of insulators Al_2O_3 and HfO_2 based ISFET are simulated by varying their oxide thickness ranging from 3nm to 22nm using Enbios 2D lab.
Material and Methods: The dataset for this study collected via nanoHub simulation. Samples were considered (N=20) for Al_2O_3 and (N=20) for HfO_2 using clinicalc.com by keeping alpha error-threshold value 0.05, enrollment ratio as 1, 95% confidence interval, power as 80% , total sample size calculated. The conductance of the insulator is done by independent sample t-test SPSS software.
Result: Comparison of conductance is done by independent sample T test using SPSS software. The statistical significant difference was observed between insulator Al_2O_3 and HfO_2. Significantly Al_2O_3 (80%) showed better conductance results in comparison to HfO_2 (78%) with p=0.007, p<0.05 using independent sample T test
Conclusion: Al_2O_3 insulator showed higher conductance than HfO_2

Keywords: ISFET, Al_2O_3, HfO_2, Oxide Thickness, Insulators, Conductance, Novel Simulation ENBIOS 2D Lab Tool, Biosensor.

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1. Introduction

ISFET (Ion sensitive field effect transistor) is used for measuring ion concentration, pH and biologically sensitive field effect transistors and also used for clinical applications of FET-based biosensors devices, including cardiovascular diseases, malignancies, diabetes, HIV, and DNA sequence (Syu, Hsu, and Lin 2018),(Lai, Yang, and Lu 2006). Nowadays ISFETs have been produced using a variety of biological recognition elements, ranging from enzymes and immune species to DNA molecules and even actual cells and creatures (Chou, Weng, and Tsai 2002). Moreover ISFET stands for the basic structural key element that is most commonly utilised in BioFETs and BioFETs can be easily made from an ISFET by modifying the gate or linking it with various biological recognition components (Schöning and Poghossian 2002).The pH of raindrops can be measured using an ISFET application and also used for determination of nitrate in rainwater (Poghossian et al. 2001).ISFET-based biosensors and its applications for reliable measurement of biomolecules such Genes, different proteins, digestive enzymes, and cells(Pachauri and Ingebrandt 2016). ISFET is used in pH sensors and bioelectronic sensors used for medical, environmental, food safety, military, and biotechnology applications have also been made (Dutta 2012).

Based on ISFET, several research articles on ISFET have been published in the last 5 years. 130 research articles were published in google scholar and 70 research articles were published in sciencedirect. The majority of the research is based on the potential of the ISFET. This research focuses on two key insulator materials: Al_2O_3 based ISFET and HfO_2 based ISFET. A comprehensive identification of sensitive and stable ISFET sensing layer high-k gates was performed, There are reports on Ta_2O_5 that has a strong surface potential response at around 59mV/pH and is also very stable in diverse electrolyte concentrations (Dinar, Zain, and Salehuddin 2019). (Fredj et al. 2021) have proved that different Hafnium Dioxide (HfO_2) thicknesses capacitance electrochemical pH sensor has better pH sensor performances at 15 nm HfO_2 thickness. Some researchers discussed that development and construction of a nanostructured ion sensitive field effect transistor based pH Sensor for micro Solution with a sensitivity of 88.125 mV/pH and hydrogen peroxide oxidation reaction with a sensitivity of 144.26 pA mol/L (Yiqing Wang, Yang, and Wu 2020). High-k dielectric materials of Fin-FET electrochemical sensors have surface sensitivities of 54.2 ± 1.9mV/pH for Al_2O_3 (Rollo et al. 2020). When compared to other study efforts (Fredj et al. 2021) have proved Hafnium dioxide (HfO_2) thicknesses capacitance of electrochemical pH sensor performances of 15 nm HfO_2 thickness is thought to be a better result and best study .

Our institution is passionate about high quality evidence based research and has excelled in various domains (Vickram et al. 2022; Bharathiraja et al. 2022; Kale et al. 2022; Sumathy et al. 2022; Thanigaivel et al. 2022; Ram et al. 2022; Jothi et al. 2022; Anupong et al. 2022; Yaashikaa, Keerthana Devi, and Senthil Kumar 2022; Palanisamy et al. 2022). The major key point that motivated us to work on this project is to predict the conductance of insulators Al_2O_3 and HfO_2. The authors were expertised in the field of Novel Simulation ENBIOS 2D Lab Tool and able to conduct studies in comparison of Al_2O_3 and HfO_2 Insulator in the biomedical aspect. The aim of the proposed study is to compare conductance of Aluminium oxide (Al_2O3) and Hafnium oxide (HfO_2) by investigating gate oxide thicknesses varying from 3nm to 22nm using Novel simulation Enbios 2D Lab tool.

2. Material and Methods

The study was performed in the Saveetha University, Simulation lab, Saveetha School of Engineering at Biomedical Department and ethical approval is not necessary for our proposed study. Group 1 refers to Al_2O_3 based ISFET and group 2 refers to HfO_2 based ISFET. The sample size calculation was done using previous study results (Kumar and Tripathi 2021). using clinicalc.com by keeping g-power at 80%, threshold at 0.05%, confidence interval at 95%, Enrollment ratio 1, For each group sample size is 20 and total sample size is 40.

Sample preparation for two groups is done by collecting 40 dataset from nanoHub. In sample preparation for group 1, current voltage characteristics of Al_2O_3 based ISFET were simulated for different gate oxide thickness from 3nm to 22nm and the same sample preparation for group 2, current voltage characteristics of HfO_2 based ISFET were simulated for different gate oxide thickness from 3nm to 22nm. There are 20 samples for each group for each category of the parameter from nanoHub. In this work the proposed parameters are Al_2O_3 and HfO_2.

Testing setup is done by selecting resources and tools in the nanoHub simulation. select ISFET from the tools menu, then choose Novel Simulation ENBIOS 2D Lab Tool and launch the tool. From the tool select insulators, choose the material of insulators, and select the ambient temperature in the environment setting

then change the gate oxide thickness from 3nm to 22nm by keeping a current as a constant in the simulator window. To get results, select the current voltage characteristics of insulators and run the simulation to obtain outcome of conductance

Statistical Analysis

Statistical analysis was performed using IBM-SPSS Software to validate the results of both parameters. The conductance(mho) was measured using current (A/μm) as an independent variable and gate oxide thickness(nm) as a dependent variable. Independent sample t test was performed.

3. Results

In this research work, simulating the effect of both the insulators appear to produce the same variable results with conductance ranging from 78% to 80%. Figure 1 represents the mean conductance of Al_2O_3 and HfO_2 and it represents conductance is more for Al_2O_3 when compared to HfO_2. Fig. 2 and Fig. 3 show the outcome of Al_2O_3 and HfO_2 insulator by using Novel Simulation Enbios 2D lab Tool in nanoHub. Table 1 demonstrated the gate voltage and conductance Values for Al_2O_3 based ISFET. Table 2 demonstrates the gate voltage and conductance Values for HfO_2 based ISFET.

Al_2O_3 insulators have the highest conductance 80% in comparison to HfO_2 insulators 78%. The descriptive statistics Table 3 demonstrated T-test Comparison of Al_2O_3 based ISFET and HfO_2 based ISFET Al_2O_3 Table 4 demonstrates Independent sample t-test in predicting the conductance of insulators

There appears to be a statistically significant difference ($P=0.007, p<0.05$) using Independent sample T test. This result shows that Al_2O_3 insulators are higher conductance than the HfO_2 insulators.

4. Discussion

To stimulate the effect of insulators Al_2O_3 and HfO_2 in ISFET by finding the conductance. From obtaining the conductance of Al_2O_3 and HfO_2 insulators, there appears to be a statistically significant difference ($P=0.007, p<0.05$) using Independent sample T test.

Some researcher discussed electrical properties of metal oxide semiconductor (MOSFET) field effect transistors on InP medium with high k dielectric (ALD) atomic layer deposition that focuses on the interfacial Al_2O_3 layer to provide better oxide results, which shows good interface quality of Al_2O_3/InP (94mV/sec) when compared to HfO_2/InP layer(Yanzhen Wang et al. 2011). Zhao et al analyzed applications of atomic layers deposition of nanostructures in energy storage and sensing which proves Al_2O_3 and HfO_2 membranes can be deposited and regulated in the ALD process by selecting the right precursors with Al_2O_3-ISFET has a sensitivity of 57.8 mV/pH and HfO_2 ISFET has a sensitivity of 52.35 mV/pH.(Zhao et al. 2020). Lai, Yang, and Lu discussed rapid thermal annealing which improves thickness effects on pH response of HfO_2 sensing dielectric which demonstrate HfO_2 sensor dielectric's minimum thickness of 4 nm and attained sensitivity at 59.6 mV/pH (Lai, Yang, and Lu 2006). Lu et al have proved hafnium oxide HfO_2 deposition by atomic layer absorption and sputtering method which is used for pH sensor application and the results shows when compared to sputtering, atomic layer absorption has effectively increased pH sensitivity of 59.6 mV/pH at 900 degree celsius (Lu et al. 2011).

Al_2O_3 and HfO_2 Insulators are used in biomedical applications as medical implants. ISFET has limits of Long-term drift, thermal drift, and hysteresis are all present. As a result, an increase in the number of samples in the dataset , may yield further better conductance (100%) in future.

In the future work, if the sampling size and proportion of the training data set are increased then outcomes also increase as well. In the near future ISFET will be used for DNA hybridization, blood biomarker, antibody detection, glucose measurement, and pH sensing.

5. Conclusion

In this study when compared to conductance of Al_2O_3 (80%) and HfO_2 (78%) insulators based ISFETs , the insulator Al_2O_3 based ISFETs appeared to give greater results and good performance. The results show that the conductance of Al_2O_3 and HfO_2 based ISFETs increases as the oxide thickness increases. Al_2O_3 insulator has higher conductance than the HfO_2 insulator.

Declaration

Conflict of Interests

No conflict of interest in this manuscript.

Authors Contribution

Author MS was involved in data collection, data analysis, and manuscript writing.Author SCK was involved in conceptualization, data validation, and critical review of manuscript.

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Figures and Tables

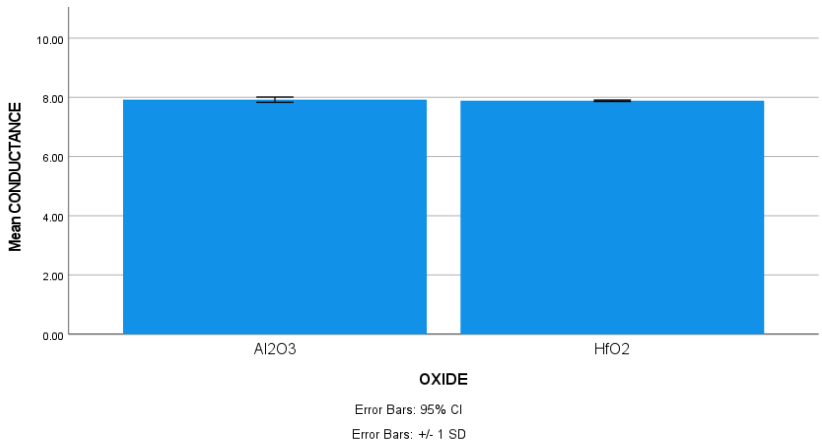

Fig. 1: Bar chart comparing the mean(+/- 1SD) conductance of Al_2O_3 based ISFET and HfO_2 based ISFET by varying oxide thickness. There is a significant difference between two groups $p<0.05$ (Independent Sample T-Test). X Axis Al_2O_3 based ISFET vs HfO_2 based ISFET. Y Axis: Mean of conductance

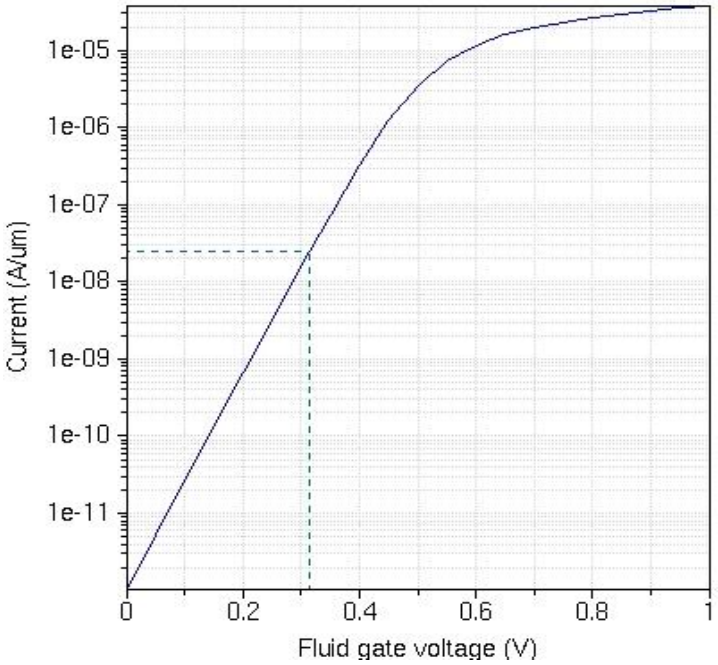

Fig. 2: Simulated current voltage characteristics of Al_2O_3 based ISFET for varying gate oxide thickness of (3nm) with drain voltage using Novel Simulation ENBIOS 2D Lab Tool. It is the output graph representation of Al_2O_3.

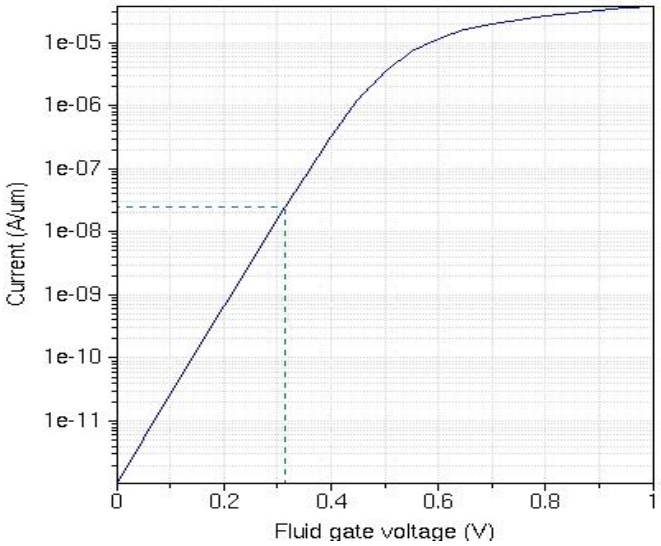

Fig. 3 Simulated current voltage characteristics of HfO_2 based ISFET for varying gate oxide thickness of (3nm) with drain voltage using Novel Simulation ENBIOS 2D Lab Tool.It is the output graph representation of HfO_2

Table 1:Gate voltage and Conductance Values for Al_2O_3 based ISFET using Novel Simulation ENBIOS 2D Lab Tool

GATE OXIDE THICKNESS (nm)	**GATE VOLTAGE(v)**	**CONDUCTANCE(mho)**
3	0.318338	7.9280
4	0.318319	7.8537
5	0.318281	7.8546

6	0.318182	7.8571
7	0.318102	7.8591
8	0.318001	7.8616
9	0.317857	7.8651
10	0.317635	7.8706
11	0.317432	7.8757
12	0.317192	7.8816
13	0.316965	7.8873
14	0.316662	7.8948
15	0.316301	7.9038
16	0.315493	7.9152
17	0.315265	7.9241
18	0.315265	7.9298
19	0.314851	7.9402
20	0.309479	8.0780
21	0.308273	8.1096
22	0.306548	8.1553

Table 2:Gate voltage and Conductance Values for HfO_2 based ISFET using Novel Simulation ENBIOS 2D Lab Tool

GATE OXIDE THICKNESS (nm)	**GATE VOLTAGE(v)**	**CONDUCTANCE(mho)**
3	0.318154	7.8578
4	0.318304	7.8541
5	0.318246	7.8555
6	0.317937	7.8631
7	0.317865	7.8649
8	0.317784	7.8669
9	0.317683	7.8694
10	0.317531	7.8732
11	0.317405	7.8763

12	0.317256	7.8800
13	0.317123	7.8833
14	0.316946	7.8877
15	0.31674	7.8929
16	0.316484	7.8992
17	0.316292	7.9040
18	0.316178	7.9069
19	0.315961	7.9123
20	0.31572	7.9184
21	0.313493	7.9241
22	0.315104	7.9202

Table 3: T-test Comparison of Al_2O_3 based ISFET and HfO_2 based ISFET. Statistically significant difference of conductance in Al_2O_3 based ISFET and HfO_2 based ISFET. Conductance of Al_2O_3 based ISFET has the highest mean (7.9223), standard deviation (0.08808) and standard error mean (0.01969) over HfO_2 based ISFET mean (7.8862), standard deviation (0.02419), and standard error mean (0.00541).

	GROUP	**N**	**MEAN**	**Std. Deviation**	**Std. Error Mean**
Conductance	**Al2O3**	20	7.9223	.08808	.01969
	HfO_2	20	7.8862	.02419	.00541

Table 4: Independent sample t-test in predicting the conductance of insulators. There appears to be a statistically significant difference ($p<0.05$) and standard error difference , 95% confidence Interval of the difference in lower and upper and mean difference of Conductance Al_2O_3 based ISFET and HfO_2 based ISFET

Parameter		**Levene's Test For Equality of Variances**		**t-test for Equality of Means**				**95% Confidence Interval of the Difference**	
		F	**Sig**	**t**	**df**	**Mean Difference**	**Std error difference**	**lower**	**upper**
Conductance	**Equal Variance assumed**	8.225	0.007	1.766	38	.03607	.02042	.02042	.07742
	Equal variance not assumed			1.766	21.850	0.3607	.02042	-.00630	-.00630