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Comparison of Planar (ISFET) And Extended Gate Field-Effect Transistors (EGFET) for Biosensor Applications by Varying The Length of The Sensing Area To Improve Drain Current

Phani Venkata Kumar[1], K.Vidhya[2]

[1]Research ScholarDepartment of Electronics and Communication Engineering,Saveetha School of Engineering,Saveetha Institute of medical and Technical Sciences,Saveetha University, Chennai, Tamilnadu, India. Pincode: 602105
[2]Project Guide, Corresponding Author,Department of Electronics and Communication EngineeringSaveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences,Saveetha University, Chennai, Tamilnadu, India. Pincode: 602105

Abstract

Aim: The present research aims to simulate and compare the drain current of Ion Selective Field Effect Transistor (ISFET) and Extended Gate Field Effect Transistor (EGFET) for biosensor application by varying the length of the sensing area from 1µm to 0.0001cm and by keeping the other parameters as constant. **Materials and Methods:** Two nano biosensors were analyzed in which ISFET (N=20) was the sensing element in one biosensor and EGFET (N=20) was the sensing element in the second biosensor. The total number of samples for the two groups is 40, twenty each, and simulated using a nanoHUB simulation tool with a G-power of 80%. **Results:** From the nanoHUB simulation tool, the drain current for both the ISFET and EGFET were analyzed. The simulation results obtained from the biosensor provide the conductance with a significant drain current. The study has a significance value of $p<0.05$ i.e, ($p=0.006$) for hybridized mode and ($p=0.009$) for unhybridized mode. The ISFET gives a higher drain current (1.82574E-9mA, $p<0.05$) than EGFET (8.52684E-10mA, $p<0.05$). **Conclusion:** ISFET based nano biosensors show significantly higher performance than EGFET nano biosensors.

Keywords: EGFET, Novel ISFET, Nano biosensor, Drain current, Length, Sensing Area, Hybridized Mode, Unhybridized Mode.

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INTRODUCTION

The current and voltage properties of Novel Ion-Selective Field Effect Transistor (ISFET) and Extended Gate Field Effect Transistor are being analyzed using simulation by changing the device's sensing length. From the past 20 years, great attention has been paid to the investigation of semiconductor-based sensors because of the various properties and advantages exhibited by transducing materials and semiconductor devices (Pullano et al. 2019). A sensor is a device that detects changes in the physical environment and converts them into some electrical, optical, mechanical, or other signals depending on the applications. A sensor needs target materials and a transduction signal. Based on these characteristics sensors are classified as acoustic, electrical, biological, Thermal, mechanical, chemical, and others. Among them, biological sensors are sensors that use biochemical reactions of enzymes, DNA, organic molecules, or whole cells to detect the changes in the sensing materials through electrical, thermal, or optical signals (Naresh and Lee 2021). Among the various biosensing techniques, FET-based nano biosensors are more effective because of their attractive properties such as low-cost manufacturing, the capability of mass production, and ultra sensitivity detection (Rao et al. 2020) As most biomolecules carry electrostatic charges and bioactivities involve potential electrical changes, FET-based biosensors become promising for applications that require greater sensitivity and faster response time. In addition, modern production Metal-Oxide-Semiconductors (MOS) offers the benefits of miniaturization, parallel sensing, as well as integration capabilities with electrical circuits and systems. This can be of great help for the biosensors to compete with other bio-hearing systems in the future. Among these, the ion-sensitive field-effect transistor is one of the most prominent electrical biosensors and has been introduced as the first chemical sensor made of silicon. These sensors are found in different fields like medical for diagnosis and detection, the food industry for quality control and analysis, agriculture for sensing soil properties (Malhotra and Ali 2017). The major application of EGFET and ISFET biosensors is the detection of ion species, and other specific molecules through functionalizing materials like urea, glucose (Lin et al. 2013).Our team has extensive knowledge and research experience that has translate into high quality publications(Bhansali et al. 2021; Jayanth et al. 2021; Sudhakar, Ravel, and Perumal 2021; Sathiyamoorthi et al. 2021; Deepanraj et al. 2021; Raju et al. 2021; Arun Prakash et al. 2020; Kamath et al. 2020; Shanmugam et al. 2021; Rajasekaran et al. 2020; Adhinarayanan et al. 2020; Rajesh et al. 2020; Aurtherson et al. 2021)

Several articles were published on ISFET and EGFET in the past five years. 340 journals were published in Google Scholar and 258 journals in IEEE explore and science direct. The first enzyme-electrode biochemical-based biosensor was introduced by Clark and Lyons (Clark and Lyons 2004). Based on this work, a variety of sensing mechanisms and different types of sensing materials were developed. Analysis of mechanical, chemical, and electrical properties of various electrochemical sensors such as DGFET, EGFET, and ISFET was discussed by (Hashim, Chong, and Liu 2013). ISFET sensitivity with the stable sensing higher-k materials by (Dinar, Mohd Zain, and Salehuddin 2019) stated that Ta_2O_5 has a high surface potential response at around 59mV/pH, and also exhibits high stability in different electrolyte concentrations. Ion sensitive field-effect transistor fabricated using Silicon Nitride (Si_3N_4) as the sensing membrane for pH measurement was reported by (Hashim, Chong, and Liu 2013) ISFET device was tested with pH buffer solutions of pH2-pH9 with the I-V characteristic of the ISFET device and is directly proportional to the device’s sensitivity of 43.13 mV/pH. Among all the studies Santhosh's work has more advantages because it describes all electrical and mechanical properties of the sensor, which is useful in designing and analysis of biosensors with utmost efficiency.

As sensor performance is such a high priority for biosensors in today's technology. It depends on various properties of sensors like sensitivity, efficiency, size, drain current In all the research works there is less significance to the drain current of the device for different sensing materials. In Field-effect biosensors as the sensing devices dimension varies the drain current changes which affect the sensor characteristics and it is not efficient. The main objective of this research is to design and analyze the drain current of biosensors with Novel ISFET and EGFET by varying the length of the sensing area for better electrical and thermal efficiency.

Materials And Methods

The project was done in the nanoHUB simulation tool in the Nanoelectronics Laboratory at Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai. In this study, two groups are used for comparison. The sample size for the research is 20 for each group. A total of 20 samples of nano biosensors using novel ISFET and 20 samples using EGFET were collected for analysis. Simulations of the groups were based on the FET-biosensor with a pre-test power of 80%used for testing (P. R. Nair and Alam 2006).

The ion-selective field-effect transistor as a sensing element for the sensor is used in the initial sample preparation. For this sample, the DNA is used as the analyte with 12 as the base pair strand length of the DNA. A diffusion coefficient of 1e-06 is considered as the diffusion parameter. The simulation is done considering a temperature of 300 degrees Kelvin and an incubation time of 60 minutes as the ambient conditions for the simulation (Pradeep R. Nair and Alam 2010).

The Extended Gate Field effect membrane is used as the sensing element for the sensor for the second sample. Similar to the first sample, DNA is taken as the analyte with a base-pair strand length of 12 with a diffusion coefficient of 1e-06 as a diffusion parameter. The sensitivity simulation is done considering the temperature of 300 degrees Kelvin and an incubation time of
60 minutes the ambient conditions for the simulation (Pradeep R. Nair and Alam 2010).

The simulation is carried out using the BiosensorLab simulation tool in the nano HUB. Nano HUB is an open-source simulation tool. This tool helps to evaluate and predict the performance parameters of the biosensors. The results of the software tool are accurate and precise (Klimeck et al. 2011). Through this tool, you can now analyze the performance of a wide variety of sensors like Planar ISFETS, cylindrical NWs, Nanosphere, magnetic particle-based schemes, and Double gate FETs. Based on the inputs given such as device parameters, type of analyte, ambient conditions, type of simulation to be done the output transfer characteristics are obtained. select the resources and select the sensors module. In that select biosensor and launch the tool.

Select the type of sensor in the change the length of the sensing area from 1μm to 0.0001cm. Then all the device, biological, parameters, and ambient conditions can be changed sample requirements and simulated. Collect the data samples of transfer characteristics from the output log and tabulate them. Repeat the simulation for different length values.

Statistical Analysis

In this study, Origin, and SPSS were used as statistical software. For plotting graphs of given values, Origin is used, while SPSS is used for calculating the mean, standard deviation, and significance of the differences between variables obtained through simulation (Landau 2017). For this study, the oxide thickness and width are independent variables because they are inputs and remain constant regardless of changes to other parameters, whereas the drain current and efficiency are dependent variables because they are affected by changes to inputs. The Independent T-Test is used to analyze the readings.which is used for comparing the efficiency and drain current of DGFET and EGFET.

Results

Although thesensing element is an important part of high efficient nano biosensors, the length of the sensing area must also be considered. The Drain current is inversely proportional to the length of the sensing membrane. For any biological sensor, Efficiency indicates the number of biological materials it can sense on the sensing membrane.

The relationship between the length of the sensing membrane and the average drain current obtained from I-V characteristics for different length variations(1µm to 0.0001cm) for the Ion-selective field-effect transistors is shown in Fig. 1 length is plotted on the x-axis and drain current is plotted on the y-axis. Similarly, Fig. 2 illustrates the relation of drain current concerning the length of the sensing area (1µm to 0.0001cm) to the drain current for the Extended gate field effect transistor. Width is plotted along the x-axis and drain current is plotted along the y-axis.

The comparison of novel ISFET and EGFET is shown in Fig. 3, It is plotted between drain current and the length of the sensing area in both hybridized mode and unhybridized mode. Fig. 4: SPSS graphical representation of Ion-selective field effective transistor and Extended gate field effect transistor drain current in comparison between the hybridized model and unhybridized mode. Unhybridized mode in both ISFET and EGFET produces more drain current compared to hybridized mode.

Table. 1 gives the drain current of novel ISFET in both Hybridized and unhybridized modes. Correspondingly, Table. 2 gives the drain current of EGFET in both hybridized and unhybridized modes Table. 3 gives theGroup statistics of independent sample T-test for novel ISFET and EGFET efficiency. It provides the mean, standard deviation, and standard error mean of the drain current of both the Ion-selective field effect transistor and extended gate field effect transistor by varying the length of the sensing area. Table. 4 gives the data of the Independent Sample T-test As inferred from the SPSS statistical report for ISFET and EGFET in hybridized mode as well as in unhybridized mode.

Discussions

The drain current for both the ISFET and EGFET were analyzed. The simulation results obtained from the biosensor provide the conductance with a significant drain current. The study has a significance value of $p<0.05$ i.e, ($p=0.006$) for hybridized mode and ($p=0.009$) for unhybridized mode. The ISFET gives a higher drain current (1.82574E-9mA, $p<0.05$) than EGFET (8.52684E-10mA, $p<0.05$).

The current and voltage characteristics of novel ISFET and EGFET are analyzed by varying the sensing length of the device. The drain characteristics have been simulated for different sensing lengths of the device ranging from 1µm to 0.0001cm. Based on the simulation curves, The length of the sensing area is one of the elements that have an effect on the drain current of the field-effect transistors which are used as sensing elements for biosensing (Hung et al. 2014). The length of the sensing area is indirectly proportional to the drain current. So, as the length increases the drain current is decreasing. It has been observed that an increase in the sensing part length causes a decrease in the drain current for both devices, and ISFET based biosensor has better conductivity than the EGFET based biosensor. From the existing reports, the drain current of ISFET and EGFET are 1.82574E-9mA and 8.52684E-10mA respectively with a significance of $p<0.05$. These drain currents achieved is similar to the (Kim and Jeong 2013) which is around 1.7e-9mA (Passeri et al. 2015). Under their conditions of simulations. This novel ISFET and EGFET are simulated under an ambient temperature of 300^0 With constant width of sensing areas (Jahanmir, n.d.), with an incubation time of 60 minutes whereas other research works were processed at a temperature $> 400^0$(Pullano et al. 2019).

The main limitation of this work is that the sensing length can be increased up to a limit. If it is further increased the size of the device will also increase. This makes the sensor big and large which is not appreciable in the present trend. This work can be further extended by replacing the sensing channel with different field-effect transistors with better efficiency and small in size.

Conclusion

To conclude, FET-based nano biosensors have been designed and simulated using the biosensor simulator tool in nanoHUB. It is inferred that novel Ion-selective field-effect transistor-based nano biosensors have a greater drain current (1.82574E-9mA, $p<0.05$) than the extended gate field-effect transistor-based nano biosensor (8.52684E-10mA, $p<0.05$). Furthermore, optimization of the device should be carried out for the improvement of the performance of the biosensor

Declaration

Conflicts Of Interest

No conflicts of interest in this manuscript.

Author Contributions

Author PVK was involved in data collection, data analysis, and manuscript writing. Author KV was involved in conceptualization, data validation, and critical review of the manuscript.

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Tables And Figures

Table. 1: The drain current of Novel ISFET in both Hybridized and unhybridized modes.

S.NO	Length of the sensing area(cm)	ISFET (Hybridized)	ISFET (Unhybridized)
1	1e-06	4.92951E-7	7.84058E-7
2	2e-06	2.46475E-7	3.92029E-7
3	3e-06	1.64317E-7	2.61353E-7
4	4e-06	1.23238E-7	1.96014E-7
5	5e-06	9.85901E-8	1.56812E-7
6	6e-06	8.21585E-8	1.30676E-7
7	1e-05	1.64317E-8	2.61353E-8
8	3e-5	5.47723E-9	8.71176E-9
9	5e-5	3.28634E-9	5.22705E-9
10	9e-5	1.82574E-9	2.90392E-9

Table. 2: The drain current of EGFET in both Hybridized and unhybridized modes.

S.NO	Width of the sensing area(cm)	EGFET (Hybridized)	EGFET (Unhybridized)
1	1e-06	2.3E-7	3.45262E-7
2	2e-06	1.15112E-7	1.72631E-7
3	3e-06	7.67415E-8	1.15087E-7
4	4e-06	5.75561E-8	8.63154E-8
5	5e-06	4.60449E-8	6.90523E-8
6	6e-06	3.83707E-8	5.75437E-8
7	1e-05	7.67415E-9	1.15087E-8
8	3e-5	2.55805E-9	3.83624E-9
9	5e-5	1.53483E-9	2.30175E-9
10	9e-5	8.52684E-10	1.27875E-9

Table. 3: Group statistics of independent sample T-test for Novel ISFET and EGFET efficiency. It provides the mean, standard deviation, and standard error mean of the efficiency of both the Ion-selective field effect transistor and extended gate field effect transistor by varying the length of the sensing area. It is inferred that the efficiency of ISFET is higher than EGFET.

Group	**Length**	**N**	**Mean**	**Std. deviation**	**std.Error Mean**
Drain current (hybridized)	ISFET	20	.0000000801	.0000001235	.0000000291
	EGFET	20	.0000000374	.0000000576	.0000000291
Drain current (unhybridized)	ISFET	20	.0000001273	.0000001964	.0000000291
	EGFET	20	.0000000561	.0000000865	.0000000291

Table. 4: The statistical calculations for independent sample test between the novel Ion-selective field effective transistor (ISFET) and Extended gate field-effect transistor biosensors.An Independent sample T-test is applied with a confidence interval of 95%. This independent sample test consists of significance as 0.001, significance level (2-tailed).

	Levene's test for equality of variance						**T-test for equality means**		**Differ Ence of interval**	
		F	**Sig p**	**t**	**Df**	**Sig(tailed)**	**Mean Diff**	**Std. Error diff**	**Lower**	**Upper**
Efficiency (hybridized)	**Equal variance assumed**	3.295	0.006	1.329	34	.000193	.0000000427	0000000321	-.000000023	0000001080
	Equal variance assumed			1.329	24.069	<0.001	.0000000427	0000000321	.000000024	.0000001090
Efficiency (unhybridized)	**Equal variance assumed**	3.702	0.009	1.409	34	<0.001	.0000000713	0000000321	-.000000032	.0000001741
	Equal variance assumed			1.409	23.354	<0.001	.0000000713	0000000321	-.000000033	.0000001758

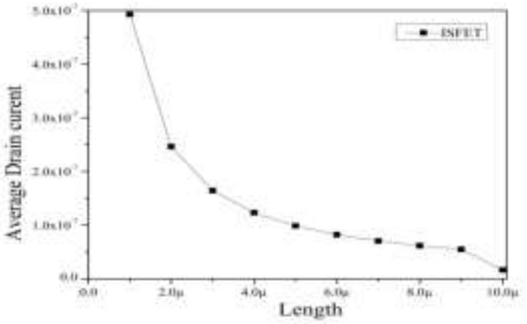

Fig. 1: Length of the sensing area vs average drain current of the Ion-selective Field Effect Transistor.

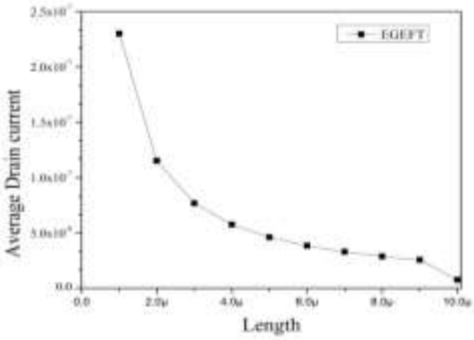

Fig. 2: Length of the sensing area vs Average drain current of the extended gate field effect transistor.

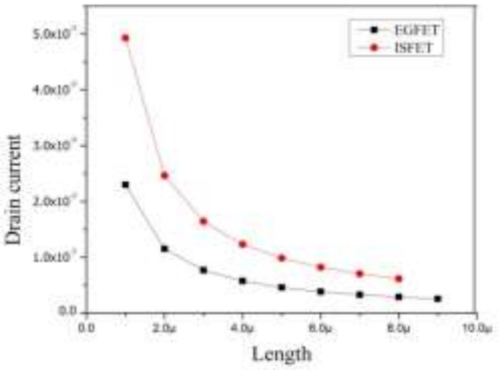

Fig. 3: Length of the sensing area vs drain current produced for both Ion-selective field-effect transistor (Red - ISFET) and extended gate field-effect transistor (Black-EGFET).

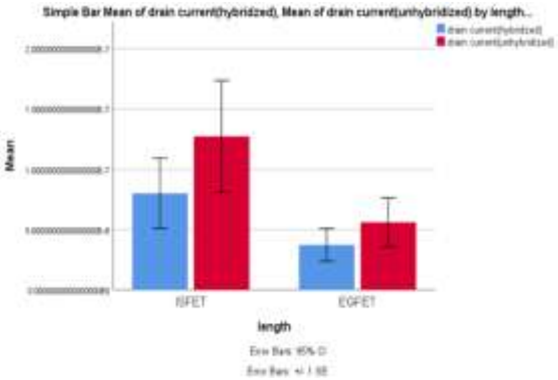

Fig. 4: SPSS graphical representation of Ion-selective field effective transistor and Extended gate field effect transistor drain current in both Hybridized mode (BLUE) and unhybridized mode (RED). The mean drain current of the Ion-selective field-effect transistor biosensor is better than the Extended gate field effect transistor. The Mean value of the drain current is ± 1SD.