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Simulation and Comparison of Current Voltage Characteristics of Si and Ge based Bio Field Effect Transistor by Varying Oxide Thickness to Get Better Sensitivity

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Abstract

Aim: *The current voltage characteristics of Silicon based BIOFET and Germanium based BIOFET are simulated by varying their oxide thickness ranging from 1nm to 100nm.*

Materials and Methods: *The electrical conductance of Silicon based BIOFET (n=320) was compared with Germanium based BIOFET (n=320) by varying oxide thickness ranging from 1nm to 100nm in the NanoHub© tool simulation environment.* ***Results:*** *Germanium based BIOFET has significantly higher conductance than Silicon based BIOFET. The optimal gate oxide thickness for maximum conductivity was 1nm for Silicon based BIOFET and 35nm for Germanium based BIOFET.* ***Conclusion:*** *Within the limits of the study, Germanium based BIOFET with oxide thickness of 35nm offers the best conductivity.*

Key-words: BIOFET, Silicon, Germanium, Oxide Thickness, Novel BioFET, NanoHub Simulation Tool, Nanotechnology, Conductance.

1. Introduction

Current voltage characteristics of Si based BIOFET and Ge based BIOFET were explored through simulation by varying the oxide thickness of the device. Ion Sensitive Field Effect Transistor (ISFET) is potentially the most well known semiconductor biosensor, and has been introduced as the first nanosized bio-synthetic sensors (Park et al. 2019)(Makhlouf and Barhoum 2018). ISFET development will be beneficial in developing many bio-electronic applications (Gasparyan et al.

2019) (Morales and Morales, n.d.). BIOFET is a semiconductor gadget with a bio-sensitive layer that can explicitly distinguish bio-particles such as nucleic acids and proteins. The results from the simulation can be used to determine the current and voltage characteristics of BIOFET structure to obtain good sensitivity and it can be widely used for cancer diagnosis, DNA detection, and toxicity detection (Kanungo 2018) (Demelas et al. 2011).

Several research articles were published on BIOFET in the past 5years. 10 research articles were published in IEEE explore and 28 research articles were published in science direct. The majority of the study discusses the sensitivity of BIOFET. In this work the focus is on two significant materials of BIOFET namely Silicon based BIOFET and Germanium based BIOFET. Hyung Youl Park et.al had discussed that a Bio-FET framework comprises a semiconducting field-impact semiconductor that goes probably as a transducer separated by a insulator layer (for example SiO2) which are specific to the objective molecule called analyte (Shim et al. 2017). Nawaz Shafi et.al had discussed that the BIOFETs have an ability of being used as label free sensors for quick discovery of microorganisms, proteins with enough high affectability and little limitations of lower recognition (Saha and Sarkar 2021; Shafi, Sahu, and Periasamy 2020). Mudita Pant et.al had synthesized reduced graphene oxide by which nano-film of RGO a FET- biosensor was developed and tested for the rapid detection of Rota-virus (Pant et al. 2017)(Foo, Kashif, and Hashim 2010). Lusine Gasparyan et.al had discussed that the current affectability regarding convergence of DNA particles linearly relies upon the source-channel voltage (Gasparyan et al. 2019) (Nehra and Singh 2015).

Previously our team has a rich experience in working on various research projects across multiple disciplines (Sathish and Karthick 2020; Varghese, Ramesh, and Veeraiyan 2019; S.R. Samuel, Acharya, and Rao 2020; Venu, Raju, and Subramani 2019; M. S. Samuel et al. 2019; Venu, Subramani, and Raju 2019; Mehta et al. 2019; Sharma et al. 2019; Malli Sureshbabu et al. 2019; Krishnaswamy et al. 2020; Muthukrishnan et al. 2020; Gheena and Ezhilarasan 2019; Vignesh et al. 2019; Ke et al. 2019; Vijayakumar Jain et al. 2019; Jose, Ajitha, and Subbaiyan 2020). Now the growing trend in this area motivated us to pursue this project.

Optimizing conductance of BIOFET is an important parameter that needs to be taken into consideration while simulating the BIOFET. Carrie Haslam et.al showed profoundly sensitive label-free detection of deoxyribonucleic acid (DNA) atoms using silicon nanowire (SiNW) FETs and also different uses of ISFETs (Pachauri and Ingebrandt 2016; Haslam et al. 2018) (Wroblewski et al. 2003). Comparison of conductance of Silicon based BIOFET and Germanium based BIOFET is carried out to explore the current voltage characteristics of BIOFET for gate oxide thickness ranging from 1 nm to 100nm to optimize conductance.

2. Materials and Methods

In the research work there are two groups. group 1 refers to Silicon based BIOFET and the other group refers to Germanium based BIOFET. The pre-test analysis was done using clinicalc.com by keeping g-power at 80%, threshold at 0.05%, confidence interval at 95% (Passeri et al. 2015) (Windbacher et al. 2008). For each group sample size is 320 and total sample size is 640.

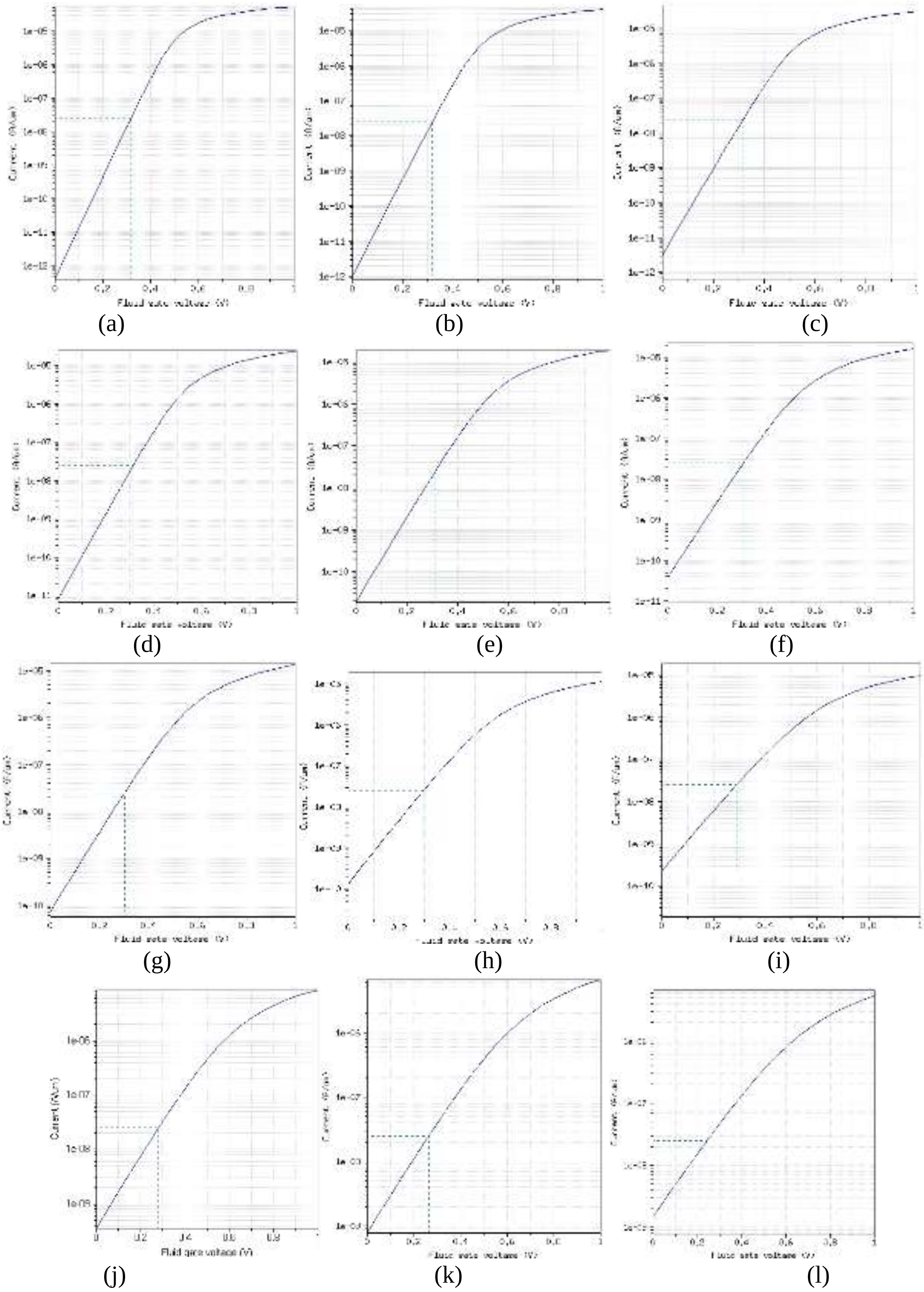
In sample preparation for group 1, Current voltage characteristics of Silicon based BIOFET were simulated for different gate oxide thickness from 1nm to 100nm. Open Nano-Hub simulation tool and select resources and choose tools. In tools select BIOFET and choose ENBIOS 2D lab and launch the tool. Simulator window gets open then select semiconductors and choose the material (Silicon) and vary the gate oxide thickness from 1nm to 100nm. Select simulate to get results. For sample preparation of group 2, germanium is selected instead of silicon as semiconductor in BIOFET and then the same process is repeated for the same gate oxide thickness.

Nano Hub© is an open-source software tool. It is a science and engineering gateway comprising several resources that are useful for educational and research purposes. Nano Hub© consists of predefined simulation tools for nanotechnology that are used to perform simulations instead of doing experiments physically. The testing procedure measures the current and voltage characteristics of BIOFET. Keep gate voltage as constant (0.4 V) and measure drain current. Similarly simulate for remaining values and measure drain current by keeping gate voltage as constant (0.4 V) and tabulate them. Conductance of Silicon based BIOFET and Germanium based BIOFET is obtained by dividing the respective drain current with gate voltage (0.4 V) i.e. conductance = I_d/V_g. The statistical software used in this research work are origin and SPSS. Origin is used to plot graphs for the given values and compare the variables and SPSS is used to calculate the mean, standard deviation and significance difference of the results obtained through simulation. In this research work gate oxide thickness and gate voltage are the independent variables because they are inputs and remain constant even after changing other parameters, whereas drain current and conductance are dependent variables because they depend on the inputs and vary for every change in the input. The analysis of the research work is done using Independent T-Test which is used to compare conductance and drain current of Silicon based BIOFET and Germanium based BIOFET.

3. Results

As the oxide thickness is varied in silicon based BIOFET the corresponding change in current and voltage are measured (Fig1(a-p)).Corresponding current and conductance of silicon based BIOFET are calculated and tabulated (Table 1). As the gate oxide thickness increase from 1nm(low) to 100nm(high) current appears to decrease and conductance also decreases since current is inversely proportional to conductance. This appears to be gradually decreasing (Fig 2(a-p)), Since conductance is inversely proportional to current. As the oxide thickness is varied in germanium based BIOFET the corresponding change in current and voltage are measured (Fig 3). Similarly, current and conductance of germanium based BIOFET are tabulated (Table 2). As the gate oxide thickness increases from 1nm(low) to 100nm(high) current appears to decrease and conductance also decreases since current is inversely proportional to conductance. This appears to be gradually decreasing and suddenly the conductance raises and gradually decreases (Fig 4), Since conductance is inversely proportional to current. Conductance of both silicon and germanium based BIOFET is compared and it appears to be germanium have high conductance (Fig 5), Since potential barrier in germanium material is less compared to silicon material. T-test comparison of conductance of silicon based BIOFET and germanium based BIOFET is tabulated (Table 3) which shows there is a statistically significant difference in conductance of silicon based BIOFET and germanium based BIOFET. Conductance of germanium based BIOFET has the highest mean(1.17312) over silicon based BIOFET(0.43031).The mean, standard deviation and significant difference of current and conductance of silicon based BIOFET and germanium based BIOFET is tabulated(Table 4) which shows there is significance difference between the two groups since $p<0.05$(Independent Sample T Test).Bar graph is comparing the mean(+/- 1SD) conductance of silicon based BIOFET and germanium based BIOFET (Fig 6) and there is a significance difference in current and conductance of silicon and germanium based BIOFET $p<0.05$(Independent Sample T-Test).

Fig. 1 - (a-p) Simulated current voltage characteristics of Silicon based BIOFET for varying gate oxide thickness with drain voltage of 0.4 V (a) 1 nm (b) 5 nm (c)10 nm (d) 15 nm (e) 20 nm (f) 25 nm (g) 30 nm (h) 35 nm (i) 40 nm (j) 45 nm (k) 55 nm (l) 65 nm (m) 75 nm (n) 85 nm (0) 95 nm (p)100 nm. Current increases as the gate oxide thickness increases.



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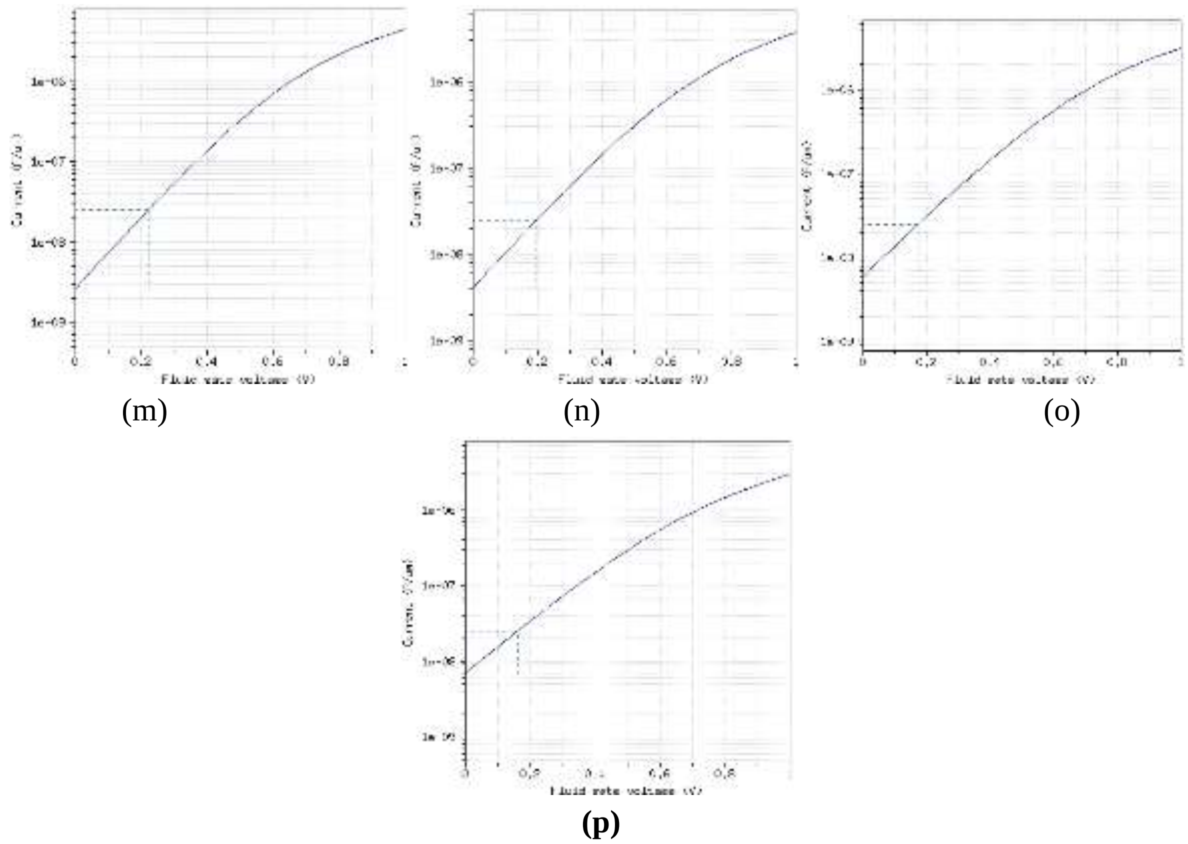


Fig. 2 - Graphical representation of conductance of silicon based BIOFET. Conductance of silicon material based BIOFET is inversely proportional to oxide thickness

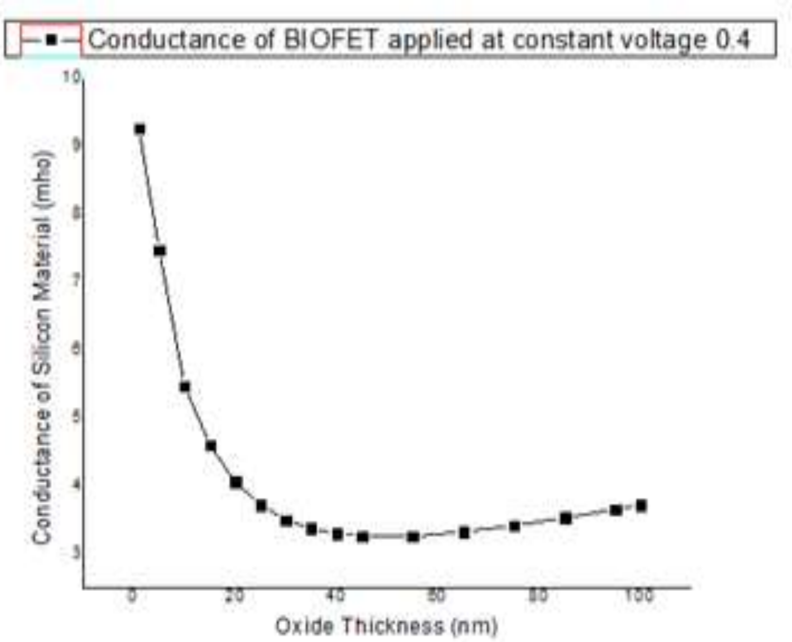
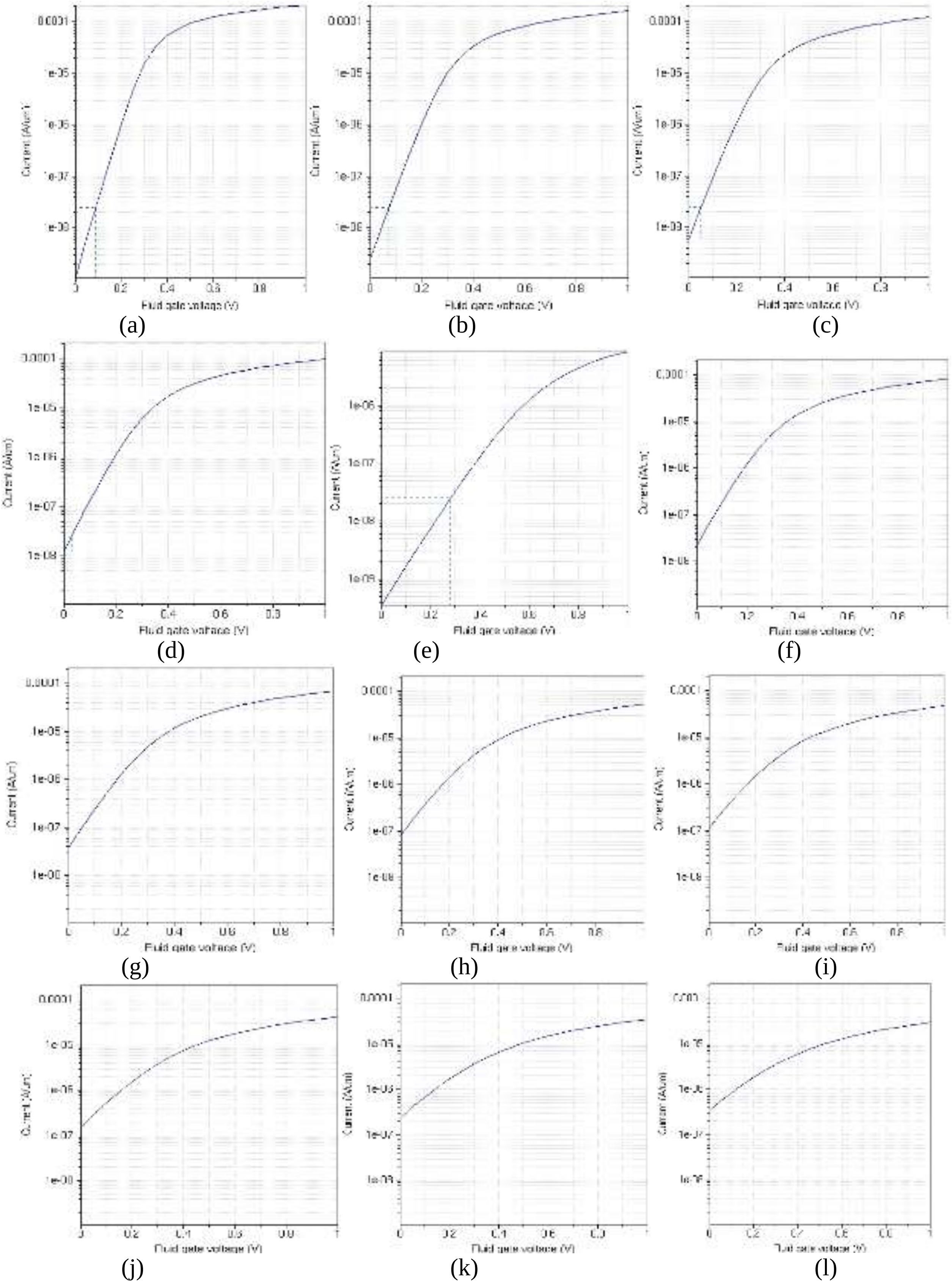


Fig. 3(a-p) - Simulated IV characteristics of Germanium based BIOFET, varying gate oxide thickness with drain voltage of 0.4v (a)1 nm (b) 5nm © 10 nm (d)15 nm (e) 20 nm (f) 25 nm (g) 30 nm (h) 35 nm (i) 40 nm (j) 45 nm (k) 55 nm (l) 65 nm (m) 75 nm (n) 85 nm (o) 95 nm (p)100 nm. Current decreases as the gate oxide thickness increases.



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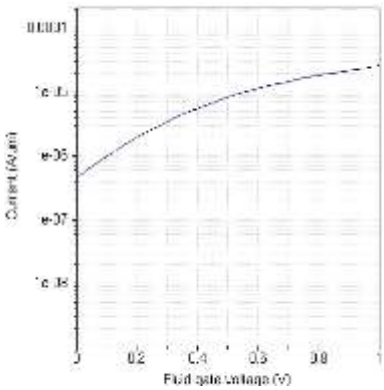
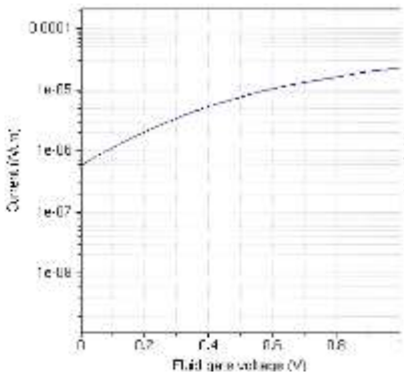
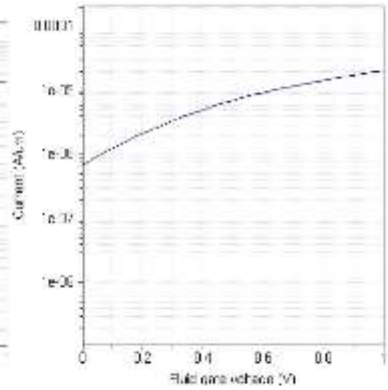


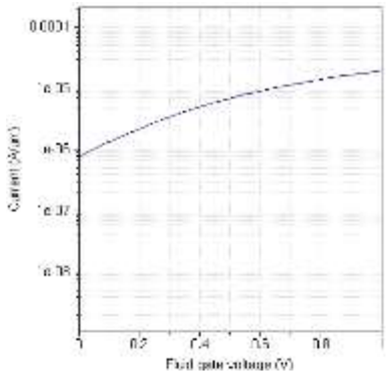
(m)



(n)



(o)



(p)

Fig. 4 - Graphical representation of conductance of germanium based BIOFET. Conductance and oxide thickness are found to be inversely proportional to each other.

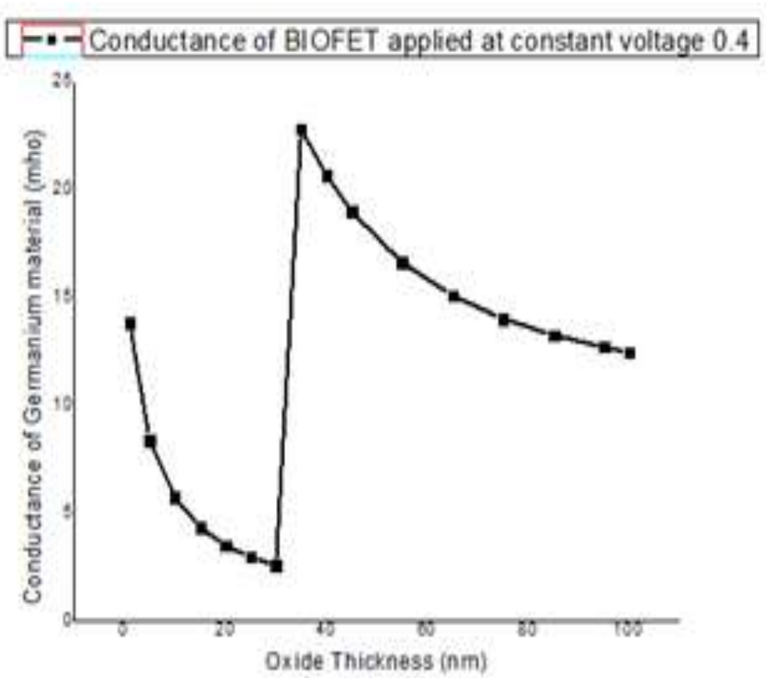


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Fig. 5 - Comparison of conductance of Si and Ge based BIOFET from 1nm to 100nm applied at constant voltage 0.4v. Conductance of Germanium based BIOFET is found to be significantly better than Silicon based BIOFET.

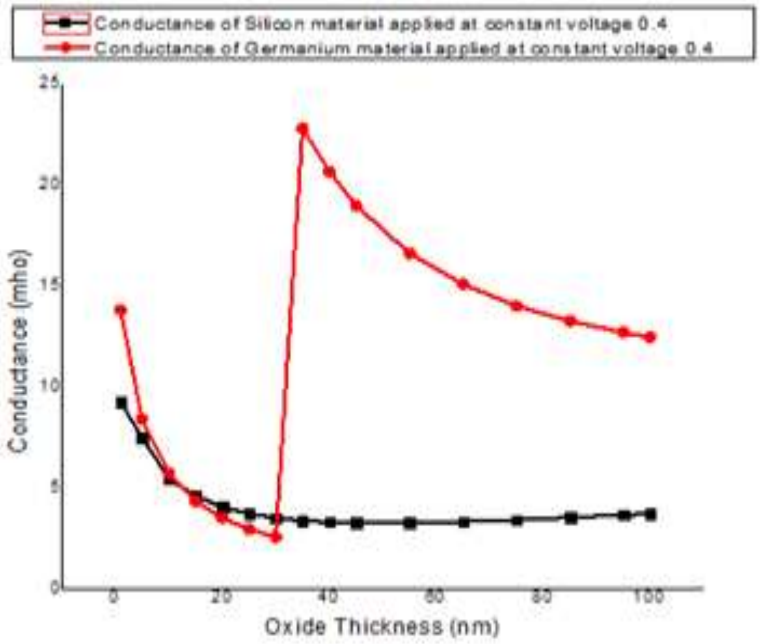

Fig. 6 - Bar chart comparing the mean(+/- 1SD) conductance and drain current of Silicon based BIOFET and Germanium based BIOFET by varying oxide thickness. There is a significant difference between two groups $p<0.05$ (Independent Sample T-Test). X Axis: Silicon based BIOFET vs Germanium based BIOFET. Y Axis: Mean of Current and conductance

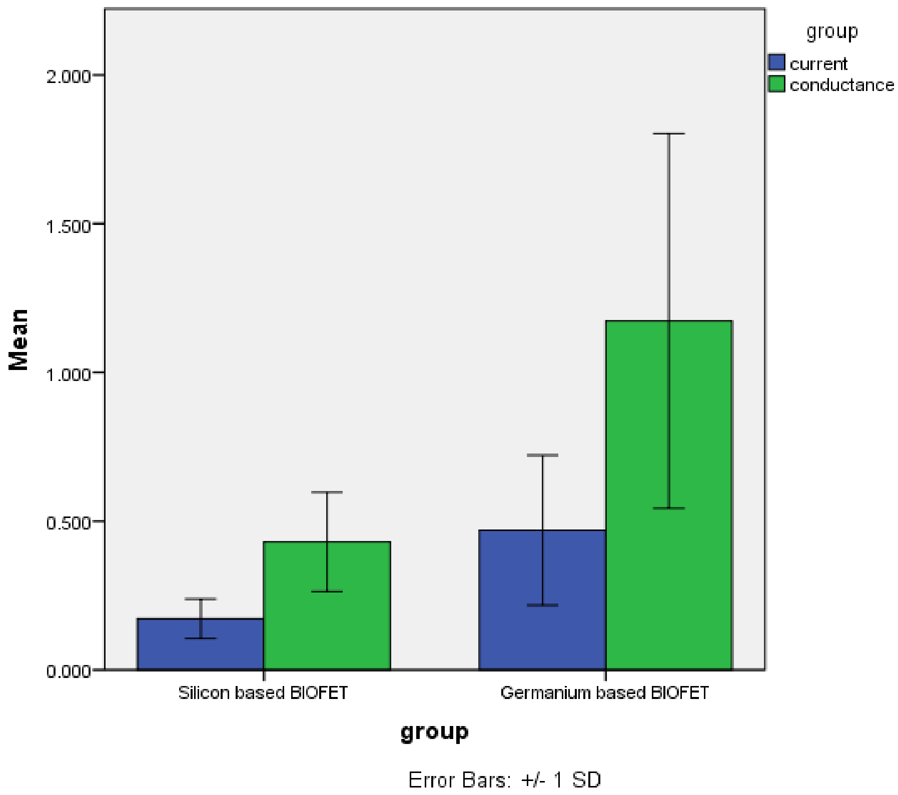

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Table 1 - Drain Current and Conductance Values for Silicon based BIOFET

Oxide Thickness(nm)	Drain Current(A)	Conductance (mho)
1	3.70464e-07	9.266e-07
5	2.98699e-07	7.4674e-07
10	2.1909e-07	5.4772e-07
15	1.84096e-07	4.6024e-07
20	1.62356e-07	4.0589e-07
25	1.48909e-07	3.7227e-07
30	1.40178e-07	3.50445e-07
35	1.3511e-07	3.37775e-07
40	1.31987e-07	3.2996e-07
45	1.30658e-07	3.2664e-07
55	1.30335e-07	3.2583e-07
65	1.33123e-07	3.32807e-07
75	1.36644e-07	3.4161e-07
85	1.41336e-07	3.5334e-07
95	1.46318e-07	3.65795e-07
100	1.48674e-07	3.71685e-07

Table 2 - Drain Current and Conductance of Germanium based BIOFET

Oxide thickness(nm)	Drain Current(A)	Conductance(mho)
1	5.5182e-07	13.7955e-07
5	3.3554e-07	8.3885e-07
10	2.28731e-07	5.7182e-07
15	1.73876e-07	4.3469e-07
20	1.4033e-07	3.5082e-07
25	1.18123e-07	2.9530e-07
30	1.02513e-07	2.5628e-07
35	9.11288 e-07	22.7822e-07
40	8.25583e-07	20.6395e-07
45	7.59284e-07	18.9821e-07
55	6.64673e-07	16.6168e-07
65	6.03313e-07	15.0828e-07
75	5.60309e-07	14.0077e-07
85	5.29992e-07	13.2498e-07
95	5.07717e-07	12.6929e-07
100	4.98522e-07	12.4630e-07

Table 3 - T-test Comparison of Silicon based BIOFET and Germanium based BIOFET by varying the gate oxide thickness ranging from 1nm to 100 nm. Statistically significant difference of conductance in Silicon based BIOFET and Germanium based BIOFET. Conductance of based BIOFET has the highest mean (1.17312) over Silicon based BIOFET (.43031). Drain current of Germanium based BIOFET has a mean of (.46894) which is higher and Silicon based BIOFET has the lowest mean (.17194).

	Group	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Gate oxide thickness	silicon	320	43.81	31.212	1.745
	germanium	320	43.81	31.212	1.745
Current	silicon	320	.17194	.066597	.003723
	geanium	320	.46894	.251996	.014087
Conductance	silicon	320	.43031	.166600	.009313
	germanium	320	1.17312	.629986	.035217

Table 4 - Mean, standard deviation and significance difference of conductance and drain current for Silicon based BIOFET and Germanium based BIOFET. There is a significant difference between the two groups since $p<0.05$ (Independent Sample T Test)

		Levene's test for Equality of variances		T-test for Equality of means						
		F	Sig.	t	df	Sig.(-tailed)	Mean Difference	Std.Error Difference	95% Confidence interval of the difference	
									Lower	Upper
current	Equal variances assumed	459.074	.000	-20.383	638	.000	-.297000	.014571	-.325612	-.268388
	Equal variances not assumed			-20.383	363.344	.000	-.297000	.014571	-.325653	-.268347
conductance	Equal variances assumed	459.554	.000	-20.391	638	.000	-.742812	.036428	-.814346	-.671279
	Equal variances not assumed			-20.391	363.400	.000	-.74812	.036428	-814449	-.671176

4. Discussion

Germanium based BIOFET have better conductance compared to silicon based BIOFET as gate oxide thickness ranges from 1nm to 100nm using Independent Sample T-test. Some of the past studies (Heitzinger et al. 2008) had simulated the BIOFET by analyzing the drain source characteristics. BIOFETs have the poor conductance comparing to present results. In the present study, the germanium based BIOFET has higher conductance.

Current and voltage characteristics of Silicon based BIOFET and Germanium based BIOFET were analyzed by varying the oxide thickness of the device. Drain current vs. gate voltage characteristics have been simulated for different gate oxide thickness of the device ranging from 1nm to 100nm. After analyzing the simulation curves, it has been observed that lowering the oxide thickness of the device will result in an increase of drain current which ultimately increases the conductivity for both Silicon and Germanium based BIOFET. Germanium have higher collector cutoff current due to the presence of more free electrons. The energy gap for germanium is high compared to silicon. Potential barrier in germanium material is less compared to silicon material that results in higher conductance of germanium material. (Babarada et al. 2010) (Ravariu, Podaru, and Manea 2009).

The factor that affects the conductance of Silicon based BIOFET and Germanium based BIOFET in this research work is gate oxide thickness (Deen et al. 2006). As oxide thickness of Silicon based BIOFET and Germanium based BIOFET increases the conductivity and drain current decreases. Coming to the modifications, gate oxide thickness is varied between 1nm and 100nm for both Silicon based BIOFET and Germanium based BIOFET (Schöning and Poghossian 2002).Conductivity and drain current of Germanium based BIOFET appears to be higher compared to Silicon based BIOFET. Increasing the oxide thickness affects the drain current. In geometry the channel length is kept constant and cannot be changed throughout the completion of simulation. Temperature of ISFET is kept as constant at 290.12K,it affects the conductance when temperature is changed. Gate oxide thickness is varied between 1nm to 100nm.

Our institution is passionate about high quality evidence based research and has excelled in various fields ((Vijayashree Priyadharsini 2019; Ezhilarasan, Apoorva, and Ashok Vardhan 2019; Ramesh et al. 2018; Mathew et al. 2020; Sridharan et al. 2019; Pc, Marimuthu, and Devadoss 2018; Ramadurai et al. 2019). We hope this study adds to this rich legacy.

Due to the limitations such as short channel effects, narrow channel effects, sub-threshold conduction and channel length modulation the power passing through the devices is dissipated in the form of current leakage which decreases the conductance and performance of Silicon based BIOFET (Papakonstantinopoulos 2016). Simulation of BIOFET can be done by varying the gate oxide thickness within the limited range from 1nm to 100nm for both Silicon and Germanium based BIOFETs. Beyond 100nm the gate oxide thickness cannot be changed. In future BIOFET can be developed in novel biomedical applications like cancer diagnosis, DNA detection and toxicity detection (Vu and Chen 2019).

5. Conclusion

Germanium based BIOFET has better conductance and performance when compared with silicon based BIOFET. After analyzing the results it is clear that the conductance of both Silicon based BIOFET and Germanium based BIOFET decreases as oxide thickness increases. To improve conductivity of Silicon based BIOFET and Germanium based BIOFET the oxide thickness should be minimum.

Declarations

Conflict of Interests

No conflict of interest in this manuscript.

Author Contribution

Author S.LAYASREE was involved in data collection, data analysis, manuscript writing. Author Dr. A. Deepak was involved in conceptualization, guidance and critical review of manuscript.

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All the simulations used in this research paper were carried out in NanoHub© and the data was processed in the tool and graphs were generated. We would like to take this opportunity to express our gratitude to Saveetha School of Engineering's administration for providing the requisite support and motivation to complete this project.

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References

Babarada, F., C. Ravariu, A. Bajenaru, and E. Manea. 2010. “From Simulations to Masks for a BioFET Design.” *CAS 2010 Proceedings (International Semiconductor Conference)*. https://doi.org/10.1109/smicnd.2010.5650502.

Deen, M., M. Shinwari, Dolf Landheer, and Gregory Lopinski. 2006. “High Sensitivity Detection of Biological Species via the Field-Effect.” *International Caribbean Conference on Devices, Circuits and Systems*. https://doi.org/10.1109/iccdcs.2006.250891.

Demelas, Monia, Stefano Lai, Massimo Barbaro, and Annalisa Bonfiglio. 2011. “DNA Hybridization Detection Based on an Organic Charge Modulated Field Effect Transistor.” *IEEE SENSORS Proceedings*. https://doi.org/10.1109/icsens.2011.6127414.

Ezhilarasan, Devaraj, Velluru S. Apoorva, and Nandhigam Ashok Vardhan. 2019. “Syzygium Cumini Extract Induced Reactive Oxygen Species-Mediated Apoptosis in Human Oral Squamous Carcinoma Cells.” *Journal of Oral Pathology & Medicine: Official Publication of the International Association of Oral Pathologists and the American Academy of Oral Pathology* 48 (2): 115–21.

Foo, K. L., M. Kashif, and U. Hashim. 2010. “Design and Fabrication of Nano Biologically Sensitive Field-Effect Transistor (Nano Bio-FET) for Bio-Molecule Detection.” *2010 International Conference on Enabling Science and Nanotechnology (EsciNano).*

https://doi.org/10.1109/escinano.2010.5700931.

Gasparyan, Lusine, Ilya Mazo, Vahan Simonyan, and Ferdinand Gasparyan. 2019. “ISFET Based DNA Sensor: Current-Voltage Characteristic and Sensitivity to DNA Molecules.” *Open Journal of Biophysics*. https://doi.org/10.4236/ojbiphy.2019.94017.

Gheena, S., and D. Ezhilarasan. 2019. “Syringic Acid Triggers Reactive Oxygen Species-Mediated Cytotoxicity in HepG2 Cells.” *Human & Experimental Toxicology* 38 (6): 694–702.

Haslam, Carrie, Samar Damiati, Toby Whitley, Paul Davey, Emmanuel Ifeachor, and Shakil A. Awan. 2018. “Label-Free Sensors Based on Graphene Field-Effect Transistors for the Detection of Human Chorionic Gonadotropin Cancer Risk Biomarker.” *Diagnostics (Basel, Switzerland)* 8 (1). https://doi.org/10.3390/diagnostics8010005.

Heitzinger, C., R. Kennell, G. Klimeck, N. Mauser, M. McLennan, and C. Ringhofer. 2008. “Modeling and Simulation of Field-Effect Biosensors (BioFETs) and Their Deployment on the nanoHUB.” *Journal of Physics: Conference Series*. https://doi.org/10.1088/1742-6596/107/1/012004.

Jose, Jerry, Ajitha, and Haripriya Subbaiyan. 2020. “Different Treatment Modalities Followed by Dental Practitioners for Ellis Class 2 Fracture – A Questionnaire-Based Survey.” *The Open Dentistry Journal* 14 (1): 59–65.

Kanungo, Sayan. 2018. “Introduction to Dielectrically Modulated Biological Field Effect Transistor.” *2018 International Symposium on Devices, Circuits and Systems (ISDCS)*. https://doi.org/10.1109/isdcs.2018.8379627.

Ke, Yang, Mohammed Saleh Al Aboody, Wael Alturaiki, Suliman A. Alsagaby, Faiz Abdulaziz Alfaiz, Vishnu Priya Veeraraghavan, and Suresh Mickymaray. 2019. “Photosynthesized Gold Nanoparticles from Catharanthus Roseus Induces Caspase-Mediated Apoptosis in Cervical Cancer Cells (HeLa).” *Artificial Cells, Nanomedicine, and Biotechnology* 47 (1): 1938–46.

Krishnaswamy, Haribabu, Sivaprakash Muthukrishnan, Sathish Thanikodi, Godwin Arockiaraj Antony, and Vijayan Venkatraman. 2020. “Investigation of Air Conditioning Temperature Variation by Modifying the Structure of Passenger Car Using Computational Fluid Dynamics.” *Thermal Science* 24 (1 Part B): 495–98.

Makhlouf, Abdel Salam Hamdy, and Ahmed Barhoum. 2018. *Fundamentals of Nanoparticles: Classifications, Synthesis Methods, Properties and Characterization*. William Andrew.

Malli Sureshbabu, Nivedhitha, Kathiravan Selvarasu, Jayanth Kumar V, Mahalakshmi Nandakumar, and Deepak Selvam. 2019. “Concentrated Growth Factors as an Ingenious Biomaterial in Regeneration of Bony Defects after Periapical Surgery: A Report of Two Cases.” *Case Reports in Dentistry* 2019 (January): 7046203.

Mathew, M. G., S. R. Samuel, A. J. Soni, and K. B. Roopa. 2020. “Evaluation of Adhesion of Streptococcus Mutans, Plaque Accumulation on Zirconia and Stainless Steel Crowns, and Surrounding Gingival Inflammation in Primary ….” *Clinical Oral Investigations*. https://link.springer.com/article/10.1007/s00784-020-03204-9.

Mehta, Meenu, Deeksha, Devesh Tewari, Gaurav Gupta, Rajendra Awasthi, Harjeet Singh, Parijat Pandey, et al. 2019. “Oligonucleotide Therapy: An Emerging Focus Area for Drug Delivery in Chronic Inflammatory Respiratory Diseases.” *Chemico-Biological Interactions* 308 (August): 206–15.

Morales, and Morales. n.d. “DNA-Based Nanosensors for Small Molecules and Proteins.” https://doi.org/10.17760/d20294438.

Muthukrishnan, Sivaprakash, Haribabu Krishnaswamy, Sathish Thanikodi, Dinesh Sundaresan, and Vijayan Venkatraman. 2020. “Support Vector Machine for Modelling and Simulation of Heat Exchangers.” *Thermal Science* 24 (1 Part B): 499–503.

Nehra, Anuj, and Krishna Pal Singh. 2015. “Current Trends in Nanomaterial Embedded Field Effect Transistor-Based Biosensor.” *Biosensors and Bioelectronics.*

https://doi.org/10.1016/j.bios.2015.07.030.

Pachauri, Vivek, and Sven Ingebrandt. 2016. "Biologically Sensitive Field-Effect Transistors: From ISFETs to NanoFETs." *Essays in Biochemistry* 60 (1): 81–90.

Pant, Mudita, H. Kharkwal, K. P. Singh, and H. C. Joshi. 2017. "Detection of Rota Virus with the Help of Nanomaterial Based Field Effect Transistor (BIO-FET)." *Biosensors Journal*. https://doi.org/10.4172/2090-4967.1000149.

Papakonstantinopoulos, Charalampos. 2016. *Fabrication and Testing of Silicon Nanowire Field Effect Transistors for Sensing Applications*.

Park, Chanoh, Wonyoung Choi, Donghoon Kim, Bo Jin, and Jeong-Soo Lee. 2019. "Highly Sensitive Detection of Influenza A (H1N1) Virus With Silicon Nanonet BioFETs." *IEEE Sensors Journal*. https://doi.org/10.1109/jsen.2019.2936216.

Passeri, Daniele, Arianna Morozzi, Keida Kanxheri, and Andrea Scorzoni. 2015. "Numerical Simulation of ISFET Structures for Biosensing Devices with TCAD Tools." *Biomedical Engineering Online* 14 Suppl 2 (August): S3.

Pc, J., T. Marimuthu, and P. Devadoss. 2018. "Prevalence and Measurement of Anterior Loop of the Mandibular Canal Using CBCT: A Cross Sectional Study." *Clinical Implant Dentistry and Related Research*. https://europepmc.org/article/med/29624863.

Ramadurai, Neeraja, Deepa Gurunathan, A. Victor Samuel, Emg Subramanian, and Steven J. L. Rodrigues. 2019. "Effectiveness of 2% Articaine as an Anesthetic Agent in Children: Randomized Controlled Trial." *Clinical Oral Investigations* 23 (9): 3543–50.

Ramesh, Asha, Sheeja Varghese, Nadathur D. Jayakumar, and Sankari Malaiappan. 2018. "Comparative Estimation of Sulfiredoxin Levels between Chronic Periodontitis and Healthy Patients - A Case-Control Study." *Journal of Periodontology* 89 (10): 1241–48.

Ravariu, C., C. Podaru, and E. Manea. 2009. "Design and Technological Characterization Aspects of a Gluco-Detector BioFET." *2009 International Semiconductor Conference*. https://doi.org/10.1109/smicnd.2009.5336544.

Saha, Priyanka, and Subir Kumar Sarkar. 2021. "Drain Current Characterization of Dielectric Modulated Split Gate TFET for Bio-Sensing Application." *Materials Science in Semiconductor Processing*. https://doi.org/10.1016/j.mssp.2020.105598.

Samuel, Melvin S., Jayanta Bhattacharya, Sankalp Raj, Needhidasan Santhanam, Hemant Singh, and N. D. Pradeep Singh. 2019. "Efficient Removal of Chromium (VI) from Aqueous Solution Using Chitosan Grafted Graphene Oxide (CS-GO) Nanocomposite." *International Journal of Biological Macromolecules* 121 (January): 285–92.

Samuel, Srinivasan Raj, Shashidhar Acharya, and Jeevika Chandrasekar Rao. 2020. "School Interventions-Based Prevention of Early-Childhood Caries among 3-5-Year-Old Children from Very Low Socioeconomic Status: Two-Year Randomized Trial." *Journal of Public Health Dentistry* 80 (1): 51–60.

Sathish, T., and S. Karthick. 2020. "Wear Behaviour Analysis on Aluminium Alloy 7050 with Reinforced SiC through Taguchi Approach." *Journal of Japan Research Institute for Advanced Copper-Base Materials and Technologies* 9 (3): 3481–87.

Schöning, Michael J., and Arshak Poghossian. 2002. "Recent Advances in Biologically Sensitive Field-Effect Transistors (BioFETs)." *The Analyst*. https://doi.org/10.1039/b204444g.

Shafi, Nawaz, Chitrakant Sahu, and C. Periasamy. 2020. "Analytical Modeling of Surface Potential and Drain Current for Virtually Doped Symmetrical Dielectric Modulated BioFET." *IEEE Sensors Journal*. https://doi.org/10.1109/jsen.2020.2964625.

Sharma, Parvarish, Meenu Mehta, Daljeet Singh Dhanjal, Simran Kaur, Gaurav Gupta, Harjeet Singh, Lakshmi Thangavelu, et al. 2019. "Emerging Trends in the Novel Drug Delivery Approaches for the Treatment of Lung Cancer." *Chemico-Biological Interactions* 309 (August): 108720.

Shim, Jaewoo, Hyung-Youl Park, Dong-Ho Kang, Jin-Ok Kim, Seo-Hyeon Jo, Yongkook Park, and Jin-Hong Park. 2017. "Electronic and Optoelectronic Devices Based on Two-Dimensional Materials: From Fabrication to Application." *Advanced Electronic Materials.*

https://doi.org/10.1002/aelm.201600364.

Sridharan, Gokul, Pratibha Ramani, Sangeeta Patankar, and Rajagopalan Vijayaraghavan. 2019. "Evaluation of Salivary Metabolomics in Oral Leukoplakia and Oral Squamous Cell Carcinoma." *Journal of Oral Pathology & Medicine: Official Publication of the International Association of Oral Pathologists and the American Academy of Oral Pathology* 48 (4): 299–306.

Varghese, Sheeja Saji, Asha Ramesh, and Deepak Nallaswamy Veeraiyan. 2019. "Blended Module-Based Teaching in Biostatistics and Research Methodology: A Retrospective Study with Postgraduate Dental Students." *Journal of Dental Education* 83 (4): 445–50.

Venu, Harish, V. Dhana Raju, and Lingesan Subramani. 2019. "Combined Effect of Influence of Nano Additives, Combustion Chamber Geometry and Injection Timing in a DI Diesel Engine Fuelled with Ternary (diesel-Biodiesel-Ethanol) Blends." *Energy* 174 (May): 386–406.

Venu, Harish, Lingesan Subramani, and V. Dhana Raju. 2019. "Emission Reduction in a DI Diesel Engine Using Exhaust Gas Recirculation (EGR) of Palm Biodiesel Blended with TiO2 Nano Additives." *Renewable Energy* 140 (September): 245–63.

Vignesh, R., Ditto Sharmin, C. Vishnu Rekha, Sankar Annamalai, and Parisa Norouzi Baghkomeh. 2019. "Management of Complicated Crown-Root Fracture by Extra-Oral Fragment Reattachment and Intentional Reimplantation with 2 Years Review." *Contemporary Clinical Dentistry* 10 (2): 397–401.

Vijayakumar Jain, S., M. R. Muthusekhar, M. F. Baig, P. Senthilnathan, S. Loganathan, P. U. Abdul Wahab, M. Madhulakshmi, and Yogaen Vohra. 2019. "Evaluation of Three-Dimensional Changes in Pharyngeal Airway Following Isolated Lefort One Osteotomy for the Correction of Vertical Maxillary Excess: A Prospective Study." *Journal of Maxillofacial and Oral Surgery* 18 (1): 139–46.

Vijayashree Priyadharsini, Jayaseelan. 2019. "In Silico Validation of the Non-Antibiotic Drugs Acetaminophen and Ibuprofen as Antibacterial Agents against Red Complex Pathogens." *Journal of Periodontology* 90 (12): 1441–48.

Vu, Cao-An, and Wen-Yih Chen. 2019. "Field-Effect Transistor Biosensors for Biomedical Applications: Recent Advances and Future Prospects." *Sensors*, 19(19).

https://doi.org/10.3390/s19194214.

Windbacher, Thomas, Viktor Sverdlov, Siegfried Selberherr, Clemens Heitzinger, Norbert Mauser, and Christian Ringhofer. 2008. "Simulation of Field-Effect Biosensors (BioFETs)." *2008 International Conference on Simulation of Semiconductor Processes and Devices*. https://doi.org/10.1109/sispad.2008.4648270.

Wroblewski, Wojciech, Artur Dybko, Michal Chudy, and Zbigniew Brzozka. 2003. "New Ion-Sensitive Field Effect Transistors (ISFETs) with Backside Contacts for Flow Analysis." *Optoelectronic and Electronic Sensors V*. https://doi.org/10.1117/12.517058.