Design and Performance Assessment of Split Gate Dielectric Modulated Junction less TFET Variation of Hfo_2 by the Divided Gate Insulator for High Sensitivity Using Tcad Simulation

Rajkumar Mandal[1], Debasis Mukherjee[1, *]
[1]Department of Electronics & Communication Engineering, Brainware University, Barasat, Kolkata-700125, India
[*] Corresponding author: debasismukherjee1@gmail.com

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Abstract
A number of more recent discoveries in microbiology have made reliable identification of nano-biomolecules and extensive analyses of them necessary. A variety of proteins, including DNA, biotin-streptavidin, amino acids, as well as many types of bacteria and viruses, must be found and analyzed in order to fully comprehend any odd behavior occurring inside of live cells. Rapid testing and detection are essential steps in preventing undiscovered biohazards from eradicating the human race and other terrestrial living things. Since many decades ago, developing an accurate, affordable biosensor has been a struggle for scientists [1]. When compared to pricey laboratory-based sensors and detection methods, FET-based lab-on-chip nano biosensors appear to be a promising substitute. It is significantly more dependable than conventional bulk sensors because of its size, affordability, low power consumption, resilience, faster response time, and better sensitivity [1]. Due to their precision, adaptability, and compatibility with embedded systems, dielectrically modulated FET biosensors with Nano cavities are emerging as a promising research area that can yield useful data on bio-analyses. As an alternative to conventionally doped TFET devices, using a charge plasma SiGe-heterojunction double gate TFET, a label-free biosensor can be produced, bypassing the need for conventional semiconductors, which require a large thermal budget and are susceptible to random dopant fluctuations (RDFs). The effect of changing the dielectric constant (k), the positive and negative charge density, the gate work function, and the cavity size has been investigated to better understand how these factors affect the performance of the proposed biosensor. These parameters modify the biosensor's electric characteristics, improving detection [2]. There is also discussion of how these factors influence the device's drain current, electric field, surface potential, sub-threshold swing (SS), insulator-to-metal film (ION/IOFF) ratio, and electron tunneling rate (ETR). The sensitivity of the drain current in the proposed biosensor is also investigated. There is no restriction on whether or whether the proposed structure is used for charged or neutral molecules.Under lower supply voltages, it is discovered that the SG

-DM
current JLFET's sensitivity is high, measuring 1.2 *10^3, with a pot ential sensitivity of 1.4 V. A result, the SG-DM [2] JLFET exhibits good application potential while consuming little po wer and having ahigh sensitivity.

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1. Introduction

To recognize the requirement of generating high sensitivity biosensors in medical science, many types of biological sensors are developed employing nanomaterials. A biosensor is a research tool that detects neutral/charged biological molecules like proteins, catalysts, and nucleotides in numerous contexts, such as in the medical field [1], the food industry [2], the “ISOMAP” process [3], the “examination of bio-molecules” [4], the “examination of medicinal molecules” [5], the observation of the environmental field [6], and the “inspection of criminal activity” [7]. “Biosensors based on contemporaryField Effect Transistors include, but are not limited to, the "ion-sensitive Field Effect Transistor (ISFET)", the "dielectric modulated Field Effect Transistor (DM-FET)", the "ARINC structure" [8, 9], the radio frequency Sip [10], and the "tunnel field effect transistor (TFET)".

The original transistor design by "Lilienfeld" [14] has been successfully expanded upon to create a new type of device called a "Junctionless Field Effect Transistor (JLFET)." It is simpler to manufacture and has better electrical properties than the standard ""MOSFET device arrangement [11, 12, 13-16].

Similar to MOSFET, the JLFET is still constrained by the subthreshold slope (SS). “Tunnel Field E ffect Transistors (TFETs)”, alternative transistors with minimum power consumption and lowest SS (<60 mV decade^-1), have been developed [17, 18]. In order to tackle these obstacles in fabrication and SS, a new device termed a "Junctionless Tunnel Field Effect Transistor (JLTFET)" has been designed. This research presents a "Dielectric Modulated JLTFET (DMJLTFET) biosensor" that can detect neutral and charged bimolecular species. To provide bimolecular contact with the component, a cavity is carved out from under the gate electrode. Electrical parameters such as potential, threshold voltage, and drain current will vary when bio-molecules become trapped in the nanogap region of the proposed structure.Wet etching [19] is used in JLTFETs to make a nanogap cavity. Physical TFET doping also causes a number of other issues, such as making the fabrication process more complicated and raising the overall thermal budget [9].SiliconRandom dopant variations are another issue with the physical doping of TFETs (RDFs). As a result, the TFET biosensor uses the charge plasma (CP) based approach. Metals with the appropriate work-function are employed to create the source and drain regions in CP-TFET-based biosensors [8]. For the charge plasma procedure, two requirements must be met.

i. First, the silicon body's thickness can't be greater than "Debye's length". The "Debye length", or the range over which the "band structure" of a semiconductor material responds to rapid doping changes, $L_D = \sqrt{\frac{\epsilon_{Si} \times V_T}{q \times N}}$ Here N is the density of bimolecular in the cavity, "V_T is thermal voltage", and ∈si is silicon's dielectric constant.

ii. The source and drain electrode work-function values should correspond to Equations.

$$\Phi_{source} > \left(\chi_{Si} + \frac{E_g}{2 \times q}\right)$$

$$\Phi_{drain} < \left(\chi_{Si} + \frac{E_g}{2 \times q}\right)$$

Where □si is silicon's electron affinity, which is around 4.17 eV, and Eg is silicon's energy band ga p.In the biological field, it aids in the early diagnosis of several conditions like Alzheimer's, ovarian cancer, and a few other diseases. A sensor node can be used in multiple locations if it is properly co nfigured [20]. Different kinds of biosensors, such as nanomechanical devices [2], optical devices [3], piezoelectric and electrochemical devices [8], are also built, but their production requires pricey machinery, which raises the costs of their formulation. It consequently exposes people to semicondu ctor-based biosensors. The FET-
based biosensors are chosen over these structures for the simplest feasible biomolecule detection [9, 10] without the need for an explicit transducer. Technology advancements have resulted in smaller devices [21, 22] and more leakage current [23–24], both of which require attention. Furthermore, thanks to their more affordable mass production, JLFETs as biosensors offer significant advancements in the field of fabrication. The assumption of a dry environment is used to carry out the detection process. Evidently, The SiO2 in the gate region is pulled out to produce a hole in the material on either side of the device for sensing bio-molecules in "JLFETs", which use the advanced fragmented gate topologies [25].The transistor characteristics differ from an empty cavity when bio-molecules are present inside [26]. When a cavity is empty, since air has a unit dielectric constant, it is presumed that it is filled with air. The cavity is found to be made of materials with a distinct dielectric constant when the cavity is filled with bio-molecules. This change in permittivity value alters the device's electrical properties [27], [20], [28], [29]. A split-gate DM JLMOSFET is created in the current study as an under lap gate bio-transistor.

Table 1 displays the values of several variables.

Variables	**Values**
Hafnium(IV) oxide Dielectric value	25nm
Thickness of HfO2 dielectric Region	5 nm
Silicon di-oxide Dielectric value	3.9
Doping concentration	10^{19}cm^{-3}

Width of gate oxide (t_{ox1} and t_{ox2})	0.5 nm and 2.69 nm
Length of Spacer(L_{GS})	3 nm
Width of the hollow area	2.69 nano meter
Gate work-function (ϕ_m)	5 Electron Volt
Gate metal Work Function at source side	1 3.8 eV
Distance of split hollow area (L_{cavity})	92 nano meter
Gate metal Work Function at drain side	2 5.1 eV
Length of gate or channel area (L_g)	100 nano meter

Table.1. Different Variables of SG-DM-JLFET

2. Proposed Structure of the Device

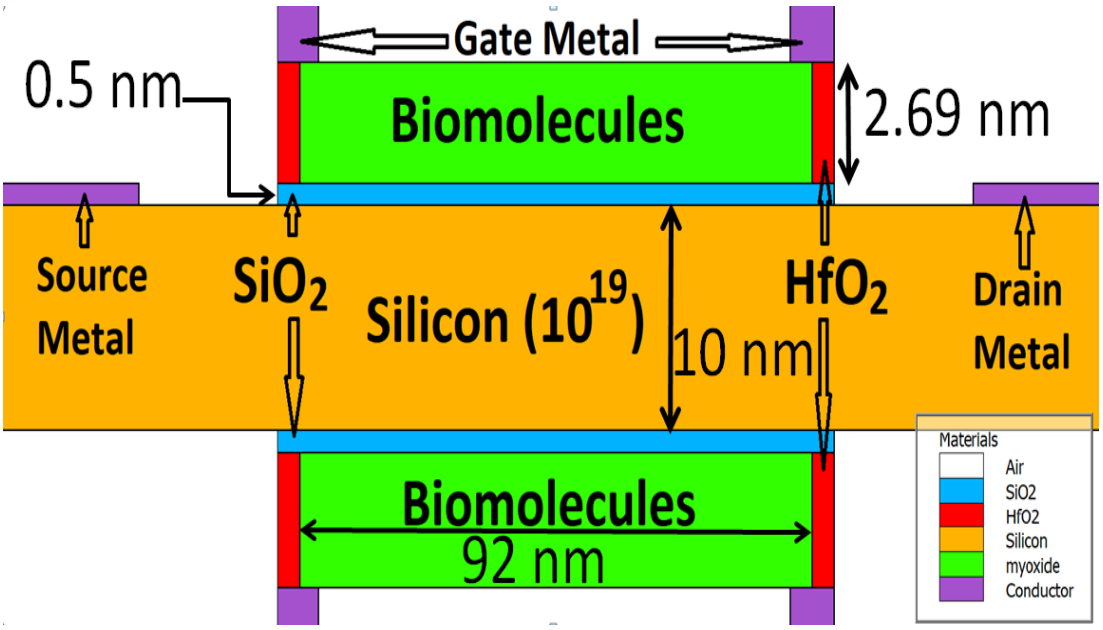


Fig.1. Junctionless "FET's" performance was tempered by the divided gate insulator schematic design structure (SG-DM-JLFET)

"Highly doped substrate" with "ni = 1 *10^19 cm3", "silicon film thickness of 5 nm", "gate silicon dioxide thickness of 2 nm", "channel length of 20 nm", and gate work function are the factors used to simulate the "JL TFET" standard [15].(4.3 eV).

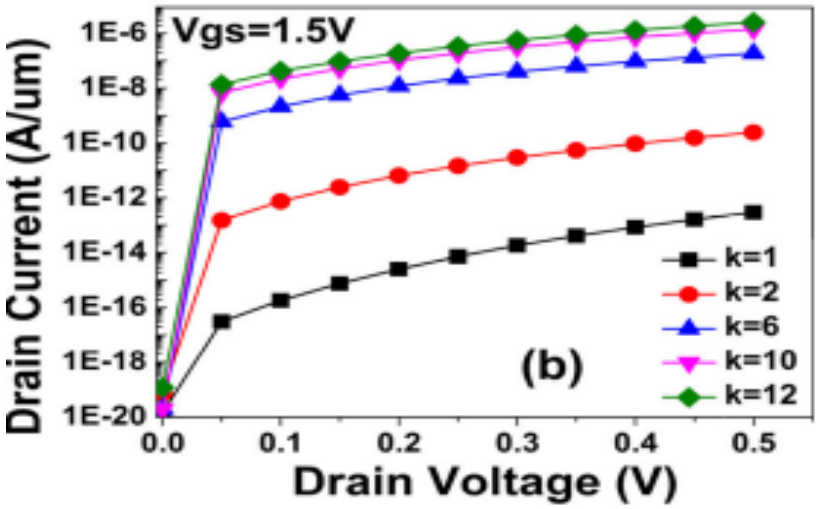
Platinum metal is employed to induce charge carriers with a proportionate concentration of 1* 10^2 0 cm3 in the source. Figure 1 depicts the suggested device design, a biosensor based on DM-JLTFET. Table 1 includes a list of several device parameters that were utilised to simulate the sugg ested structure. Despite the construction of a nanocavity region that is meant for the immobilisation

of biological molecules, DM-

JLTFET has the same model properties as regular JLTFET.Despite the creation of a nanocavity zon e for immobilising biological molecules, the SG-DM-
JLFET metrics are consistent with those of ordinary JLFET devices [30]. For simulations, TCAD [3 1] is the simulator of choice. The behaviour of the device is simulated for a number of basic physica l models. A few of the models that have been used to comprehend the proposed biosensor include the "Field Reliant on Constant Mobility Model", the "Drift Diffusion prototypical for carrier transport", the "SRH and Auger Recombination Model, the Doping Dependent Mobility Deprivation Model, and the Statistical Fermi Dirac Model". The value of the gate metal work function should allow “thermionic emission” to happen when bio-molecules gather inside the cavity in order to show a variance in “device sensitivity”. With a metal work function = 5 eV, this is possible. The suggested biosensor can recognise four different bio-molecules, including "air, protein, Bacteriophage T7", "keratin, and gelatin", at dielectric constants of "1, 2.5, 6.2, 8, and 12". It also contains a 92 nm nanogap cavity.

3. Results and Discussions

In our research, theTCAD tool is used to assess an ntypemoderatedof“split gate insulator FET” junc tionless (SGDMJLFET) [37]. The permittivity (K>1) value increases dramatically as K=1 when biomolecules are contained within the nanocavity. The relative permittivity value also varies (K>1) when suffering immobilisation inside t he hollow, indicating changes in the electrical quantities [28]. A suggested four-
gate SGDMJLFET biosensor is shown schematically in Figure 1. It is comparable to a standard DG -MOSFET, with the exception of an “uncovered gate-
portioncreated by etching and using an insulating layer” (“HfO2 with a permittivity 21”)



In order to account for native oxide formation on the “exposed area that silicon is exposed to ambie nt air”, a SiO2 layer with a 0.5 nm thickness is created on top of the exposed.

3.1Effect of Changes in Density on Device Efficiency

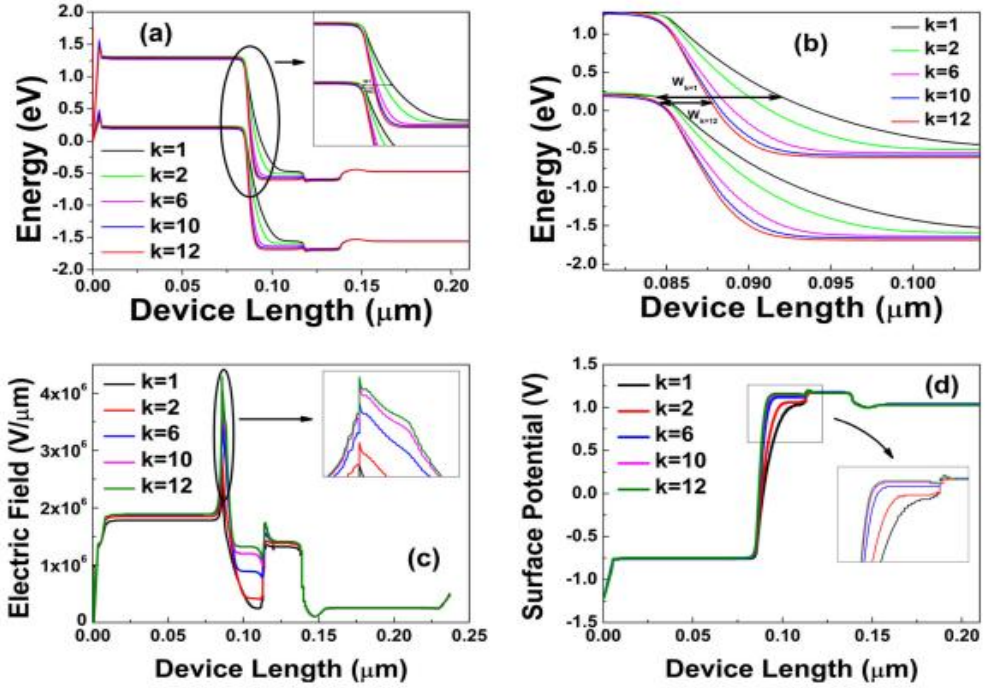


Fig. 2 Dielectric constant variation's effects on the energy band diagram, the tunnelling barrier widt h, and the electric field (d) Surface Potential when neutrally charged biomolecules are present in the cavity at Vgs = 1.5V and Vds = 0.5V.

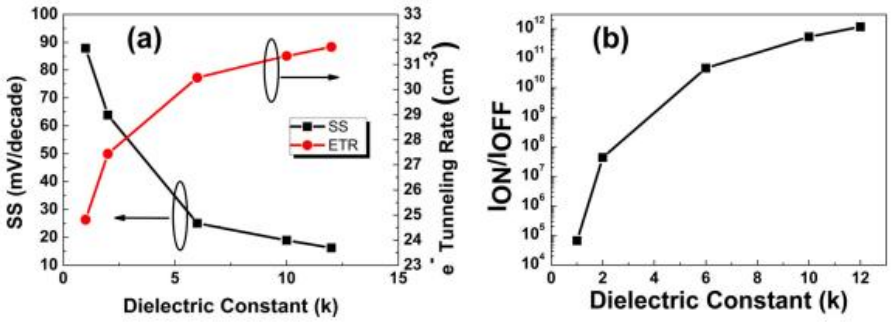


Fig.3 Ion/Ioff ratio and Electron Tunnelling Rate (ETR) at 1.5 volts and 0.5 volts, respectively, are affected by variations in the dielectric constant (k).when neutrally charged biomolecules fill the cav ity

Dielectric Constant	SS (mv/decade)	ION /IOFF	Reference	Electron Tunneling Rate (cm−3)
k=12	16.237	10^12	[2]	31.712
k=10	18.959	10^11	[2]	31.344

k=6	25.046	10^10	[2]	30.475
k=2	63.879	10^7	[2]	27.441
k=1	87.936	10^5	[2]	24.816

Table 2: Effect of variation in dielectric constant (k) on SS, ION /IOFF ratio and ETR.

3.2 Surface potential

As can be seen in Fig. 3, the DMJLTFET structure without a cavity under the gate electrode has a surface potential divide in the channel area. When all of the hollow area in figure 1 is covered by oxide, we say that the structure has "no cavity" (SiO2). By eliminating the oxide layer (K = 1), a presumed air-filled void is created. When "neutral biological molecules" are present in the "nanogap region", "DMJLTFET devices" can perform better, that improves nanogap permeability (K > 1) Variations in nanogap flat band voltage affect the device's surface potential [29, 30]. Figure 4 shows possible biological molecule dispersion in the nanogap region. The potential changes when positively or negatively charged biological molecules are added to the nanogap. Positive-charged biomolecules reduce the depletion barrier, while negative-charged ones raise it [22]. Because capacitance below the cavity zone depends on dielectric constants [31], the location of the energy band is governed by flat band voltage fluctuations near to the cavity zone.

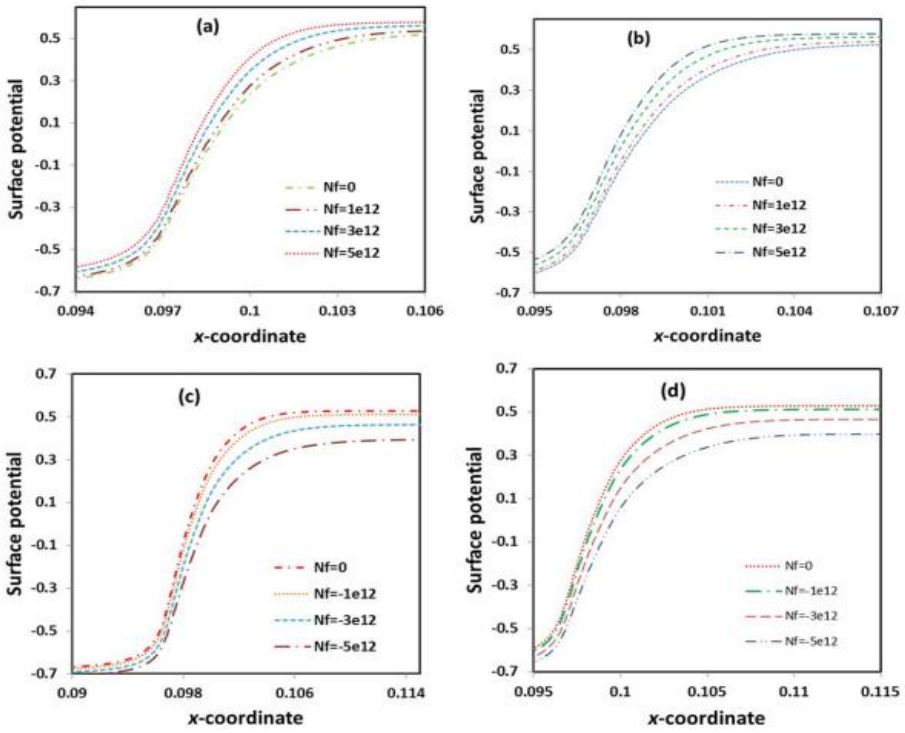


Figure 4 shows potential changes to the “horizontal axis”. (a)for “positively charged biological mol ecules at cavity” lengths of “7 nm, 12 nm, and 7 nm”, respectively; (b) for positively charged biolog ical molecules at cavity lengths of 12 nm, 12 nm, and 7 nm, respectively; (c) for negatively charged

biological molecules at cavity lengths of “7 nm”, and (d) for negatively charged “biological molecul es at cavity” lengths of “12 nm”, respectively; for “tSi = 10 nm”,

3.3. Surface potential sensitivity

The potential increase in sensitivity to the presence of “biological molecules” is shown in Figures 6(a) and (b). It is discovered that many “biological molecules” are confined in the “nano cavity region” when the permeability in the region fluctuates from the lowest value, K = 1, to the “highest value”, “K > 1”, and the current sensitive rises to an obviously high value.Additionally, it has been found that positively charged biological molecules' potential affectability dramatically rises in the cavity area whereas negatively charged biological molecules' potential affectability sharply falls [20, 28].Increases in positively charged biological molecules cause flat band voltage to decrease, which enhances potential sensitivity to a higher degree.

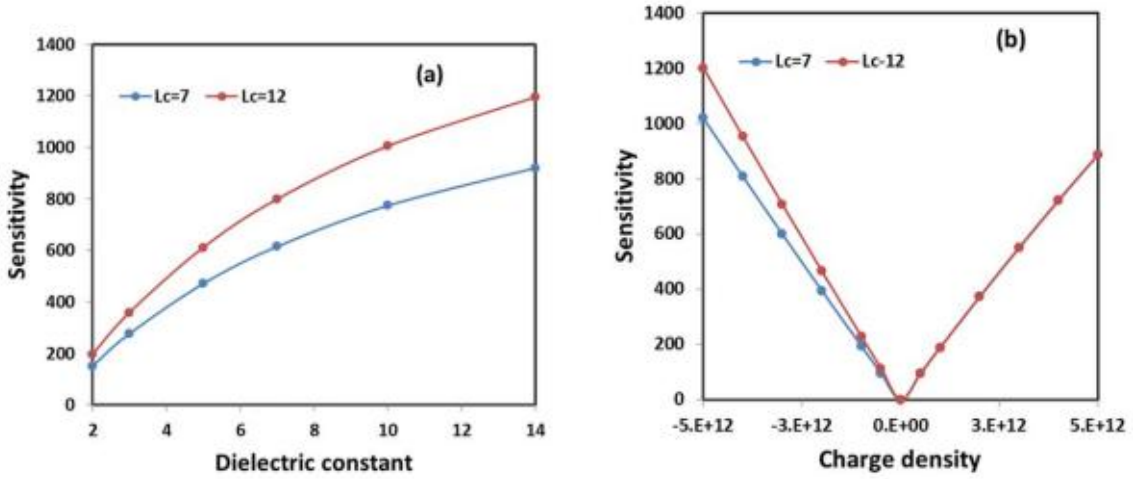


Figure 5 shows how surface potential sensitivity varies for various “cavity lengths” (“LC = 7 nm, 1 2 nm”). (a) For “biological molecules” that are neutral, (b) for “biological molecules” that are charg ed, and (c) for “tSi = 10 nm, ND = 1 1019 cm3, and Vds = 0 V”.

3.4 Neutral biomolecule threshold voltage sensitivity is described as follows:

The threshold voltage is one of the distinguishing characteristics utilised to identify distinct analytes in DMJLFETbased biosensors.When the permittivity in the achieve regiondeviates from unity “(K = 1)”, the threshold voltage for neutral bio-molecules rises in a positive direction.This is depicted in Figure 5. Positively charged analytes have a smaller threshold voltage than negatively charged bio-molecules, and vice versa [29]. Equations (1) and (2) of [32] are used to compute the threshold voltage sensitivity for charged and neutral bio-molecules, respectively.Neutral bio-molecule “threshold voltage sensitivity” is describedas follows:

$$Sn=\frac{Vth(k=1)-Vth(k>1)}{Vth(k=1)}$$

The following definition of threshold voltage sensitivity for charged biomolecules:

$$Sn=\frac{Vth(neutralbiomolecules\ )-Vth(chargebiomolecules\ )}{Vth(neutralbiomolecules\ )}$$

3.4 Electrical Field Strength as Affected by Charged and Neutral Biotic Particles

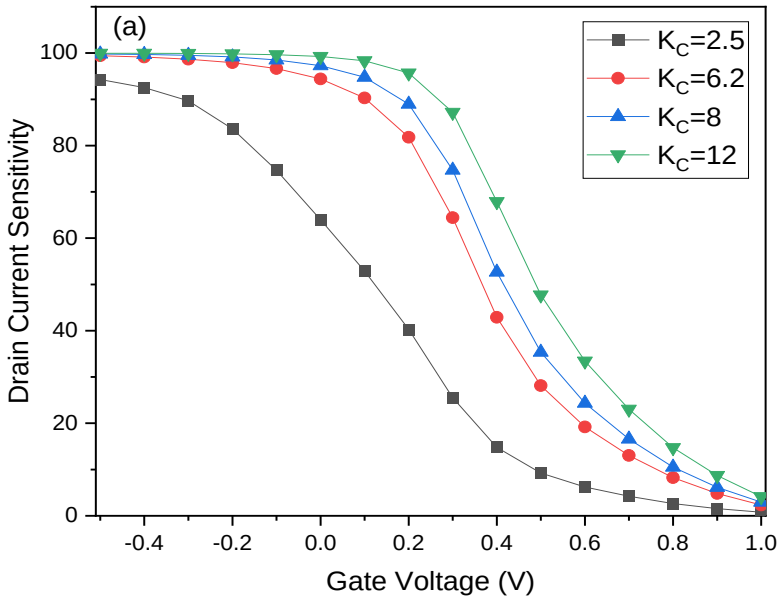


Fig.6. Dependence of the output current on the dielectric constant: Increases in gate-to-source voltage (Vgs) and improvements in output current sensitivity.

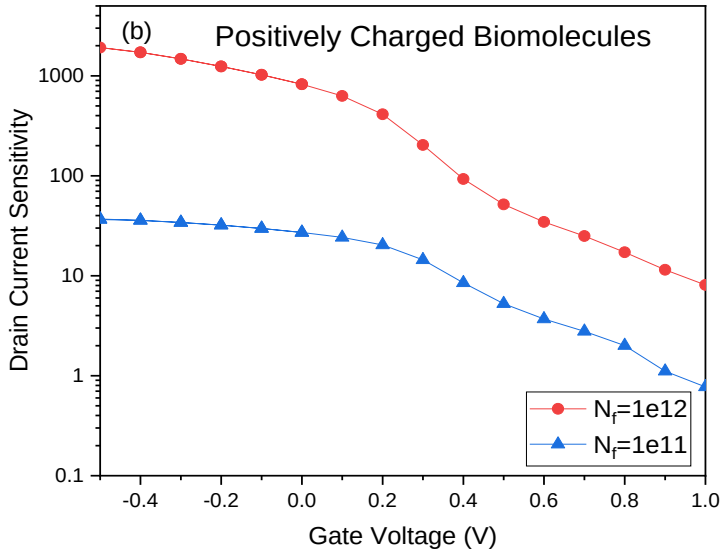


Fig.7. Output current in response to many positively charged bio-molecules, an increase in "gate-to-source voltage (Vgs)" sensitivity.

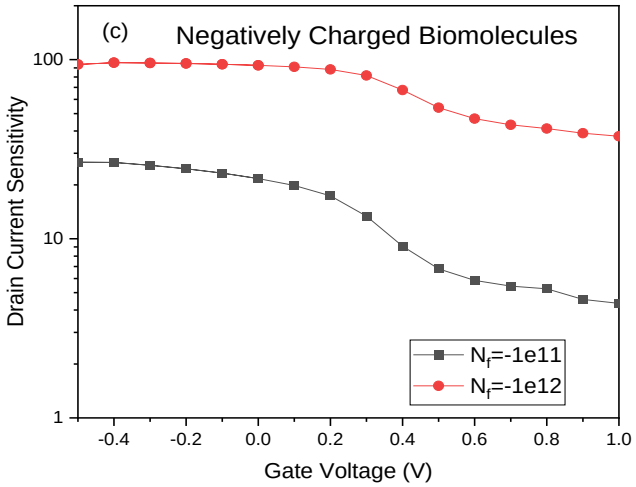


Fig. 8. Gain in Gate –to- **S**ource voltage (Vgs) sensitivity together with output current sensitivity: Drain current in relation to various "–ve biotic particles in exposed area".

The device channel electric field profile has no peak before the cavity forms. However, a huge magnitude peak develops across the source-channel interface when a cavity forms in the channel region at empty (K=1) state. As can be shown in Figure 6, the insulator constant increases to K > 1 and the slope elevation of the cavity-gate oxide interface decreases when uncharged biotic particles are immobilized.The effect of biological molecules with positive and negative charges on the electric field is depicted in Figure 7. In contrast to biotic particles that aren't charged in a hollow with K=12,the peak's magnitude changes with positively and negatively charged molecules. Figure 8 depicts the drain current in relation to different biotic -ve particles in an exposed location.

The ability of the proposed biosensor device to identify the presence of biological molecules in a cavity is linearly related to the "drain current, potential, and threshold voltage" sensitivity. The presence of neutral and charged bio-molecules causes a shift in the drain current and potential, as seen in Figures 4 and 5, respectively. If "positively charged biological molecules" are present, the drain current will be more sensitive.
The examination of Published "Biosensor's Performance" is shown in Table III

Table- IIIPerformance Evaluation of published biosensors.

SI.No.	Biosensors	References	Sensitivity
1.	SiGe Source DM PNPN TFET with 20% Ge	[4]	1×10^{3}
2.	DM FET	[3]	1×10^{2}
3.	SG-DM-JLFET	[5]	1.05×10^{2}
4.	SG-DM-JLFET	Present Work	6.5×10^{2}

4. Conclusion

In conclusion, the performance enhancements over various parameters are explored for a device spli tgate dielectric modulated junctionless transistor used in biosensing applications. For sensing purposes, we investigate how bio-molecules influence electric field strength, "surface potential, drain current, and threshold voltage". It's well-known that the Vth fluctuation is reduced with increasing channel length [1]. The variation in drain current and potential is also calculated for use as a sensing metric. Instead, the sensitivity of the "SG-DM-JLTFET" gadget is tested by seeing how different neutral and charged bio-molecules affect the device's output current, potential, and threshold voltage. With its label-free molecular recognition, the "SG-DM-JLTFET" device increases detection sensitivity for both charged and neutral molecules, as well as bio-molecules, with only a minor reduction due to leakage currents and short channel effects. Results from this structure may influence the development of high-sensitivity, low-cost electronics. Permittivity, voltage sources, as well as electric field values for charged bio-molecules fluctuate more for positively charged bio-molecules than for negatively charged bio-molecules.

Author Declarations

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

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Not applicable

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