# Investigation of Structural Parameter Variation on Extended Gate TFET for Bio-Sensor Applications

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***Abstract*—Traditional Gate engineered Metal Oxide Semiconductor (MOS) technology faced serious challenges in terms of greater sensitivity for target biomolecules and to be utilized as the state-of-the-art Nano-recognition tool. Research on a tunnel field-effect transistor (TFET) started with the aim to achieve fast detection, low power consumption, and its potential for on-chip integration capability. Dielectric Modulated TFET (DMTFET) has established itself to be a primary candidate for sensing both charged and charge-neutral species with volumetric sensitivity. As extended gate DMTFET happens to be inferior to its short gate counterpart, we have devised ways to achieve superior performance only by making variations over structural electrostatics. With the incorporation of most possible ways of modulation, we present two orders of magnitude on-current increment and a considerable percentage of sensitivity improvement over the conventional one. Future scopes having noteworthy diversifications have also been analyzed with proper justification.**

**Keywords— Bio-Sensor; FG-DMTFET; SG-DMTFET; BTBT; Label-free Detection; On-current Improvement; Sensitivity; Structural Parameter Variation.**

## I. INTRODUCTION

Biosensors are integrated devices which can give quantitative information on some biological element employing some biorecognition element which is in direct contact with the transducer element [1,8]. Good biosensors must have the following four characteristics: linearity, sensitivity, selectivity, and response time. Applicability of any biosensors must be judged based on those four principle parameters. Now, high substrate concentration requires the linearity of the sensor to be higher as well. Sensitivity means the amount of response per unit substrate concentration. Selectivity denotes response on any particular substrate; high selectivity means lesser interference of other elements and more accurate sensing [8,9]. The response time of the sensor should be high to provide fast detection. The main component of biosensors is the analyte, sample handling, detection, and signal. The analyte is the bio-element that we want to detect. It can be any biomolecules like protein, toxin, peptide, glucose, DNA, or any metallic ions found in the living body. Sample handling is the procedure to send the molecules to the sensor. Detection is to specifically recognize the analyte. The signal is the output from the sensor that tells about the presence of the specific analyte [8]. The signal can also quantify analyte concentration. There are myriad sensing techniques for sensing, for example, fluorescence, surface plasmon resonance, DNA microarray, variable impedance, scanning probe microscopy, surface-enhanced Raman spectroscopy, and several others. Depending upon sensing techniques [7-12] biosensors can be categorized into following different types: potentiometric, calorimetric, piezoelectric, and optical. Important and challenging aspects of biosensor research are bio-compatibility and calibration. Biosensors should be safe psychologically and environmentally. It should be properly calibrated with extensive field testing. There is not an iota of doubt that biosensor research has a very bright future. There is a huge commercial demand for portable biosensors which can give important medical information or monitor certain important health parameters continually. Internet of Things (IoT) has the potential to increase the gamut of biosensor manifold by providing integrated health solutions to the customers. Furthermore, artificial intelligence (AI) could also empower the biosensor technology, leading to ever more productive and cooperative coexistence of human and machine [19, 20]. There are two types of biosensing: labeled and label-free [8]. Label-free bio-detection is preferred for its simple detection scheme. Label-free detection of biological samples is made possible by using a field-effect transistor (FET) [5,15-18,21] based biosensors. Biological samples do have certain charge density and also certain dielectric constant values. FET based biosensors [1,3,4,6] recognize analytes volumetrically by attaching of the targeted biomolecules to the gate cavity region of the device and thus changing the required output characteristics. The parameters which primarily get modified by the analytes (biomolecules to be detected by sensor) are on-state current, transconductance, threshold voltage, and capacitance. Such biosensors have several advantages like low power requirement, the possibility of integration on chips, and scaling. Dielectrically modulated field-effect transistor (DMFET) can detect both the charged and charge-neutral biological species and they are being researched extensively in the scientific community [3]. In DMFET the analytes get embedded into the gate dielectric-nanocavity and the effective capacitance is changed. Dielectrically modulated tunnel field-effect transistors (DMTFET) are studied extensively as a possible alternative to legacy MOSFET based biosensors. TFET works on the principle of the band to band tunneling. In the off-state of TFET [1-3,9], the barrier height between the drain and the channel is high and tunneling probability between the drain and channel is low. They are superior to MOSFET biosensors in terms of power dissipation, speed, and subthreshold swing (<60mV/dec) [5-14]. Band to band controlled tunneling (BTBT) led carrier transport phenomenon leads to much-improved performance. There are two types of DMFET – short gate dielectrically coupled field-effect transistor (SG-DMFET) and full gate dielectrically coupled field-effect transistor (FG-DMFET).

FG-DMTFET [3] is stated to be inherently inferior to its short gate counterpart depicted in Fig.1, because of the larger drain bias dependence of BTBT causing greater sensitivity factor at output available for SG-DMTFET. The sole intension of this article is to boost the on-state current for extended gate DMTFET with full-fledged structural parameter variations.

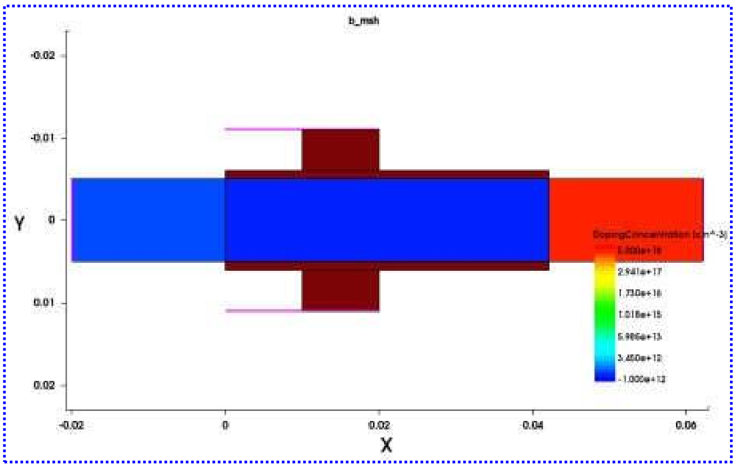


Fig.1. SG-DMTFET structure on SENTAURUS

## II. CALIBRATION OF DIELECTRICALLY MODULATED FULL GATE TFET

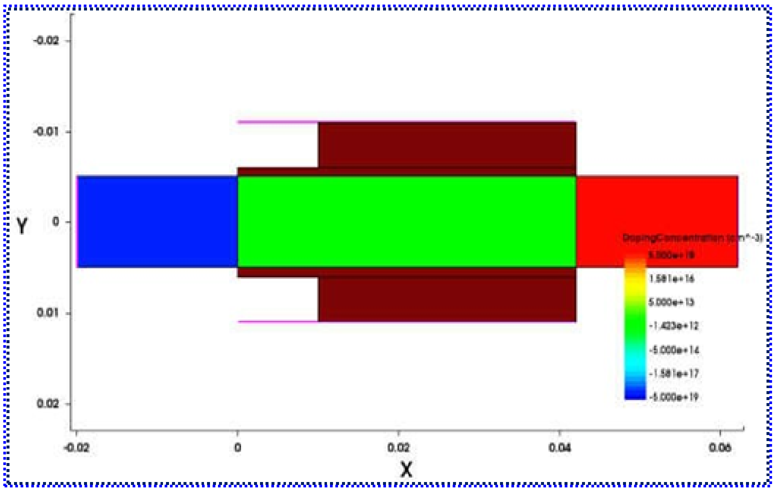


Fig.2. FG-DMTFET structure on SENTAURUS for Calibration

FG-DMTFET under simulation is described as in Fig.2 with the length of the cavity section to be 10nm, gate length 42nm, oxide thickness 6nm, Silicon-based body thickness being 10nm having low p-type doped ($1*10^{12}$/cc), and highly doped source and drain at an order of $10^{19}$/cc of reverse polarity carrier concentration. While driving each simulation iteration on SENTAURUS [17], some well-known internal physics models like Doping Dependence, E-Normal, and Dynamic nonlocal path BTBT model have been used as BTBT [13] to be the dominant carrier transfer phenomenon.

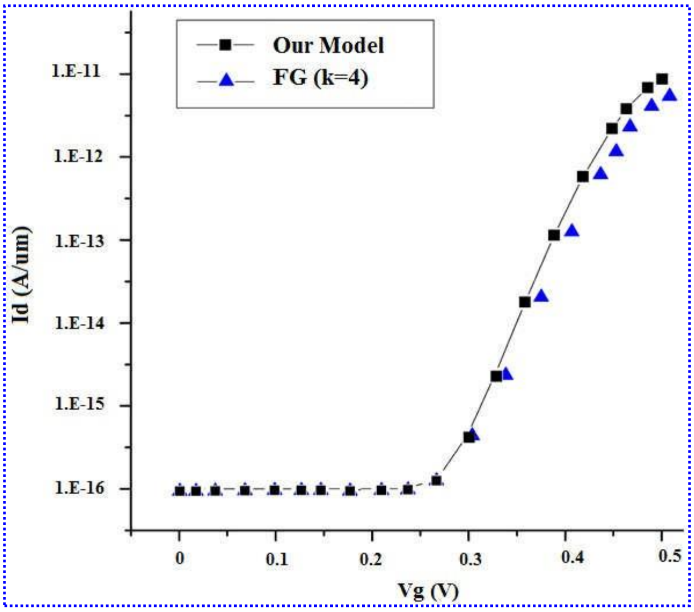


Fig.3: Calibration of Id-Vg characteristics

Fig.3 above depicts the calibration of our model with some standard data provided on [3] for biomolecule dielectric constant to be k=4.

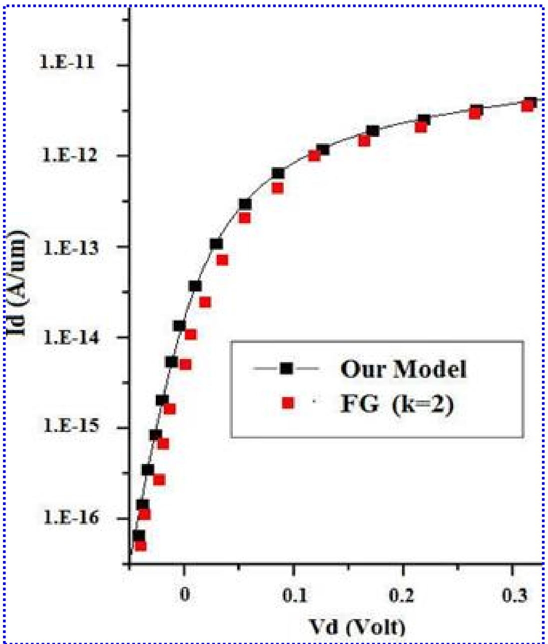


Fig.4: Calibration of Id-Vd characteristics

Calibration of Id-Vd (output characteristics) in Fig.4 shows good agreement with the data captured on [3] for k=2 and hereby validates the feasibility of our model.

III. PARAMETER VARIATION ON FULL GATE DMTFET FOR ON-CURRENT IMPROVEMENT

To investigate the Drain bias dependence on Source-Channel junction for reduced Gate length FG-DMTFET as explained in [2], we changed the existing Lg=42 to 30nm and 20nm respectively at Vg=1.0V. Fig.5 shows considerable improvement in drain current going down from 42nm to 20nm.

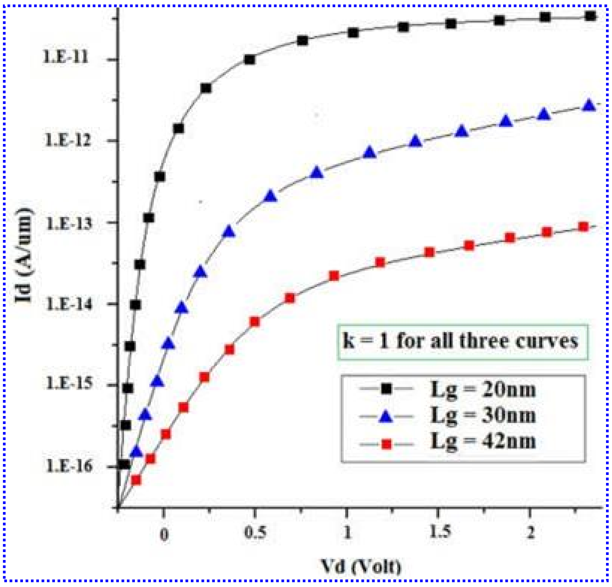


Fig.5. Variation of Gate Length from 42nm to 20nm

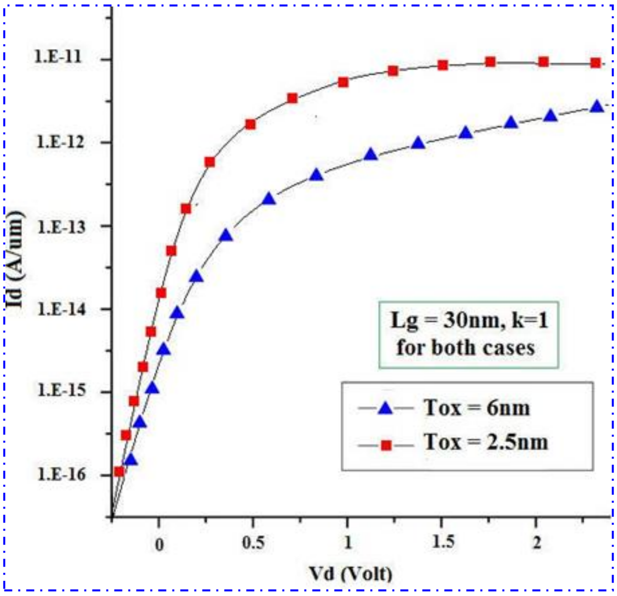


Fig.6: Effect of Gate Oxide thickness reduction

We have kept the value of k=1 for all simulations in this section. In Fig.6 it is easily seen that the capacitive coupling [6] is considerably increased resulting in an effect on source-channel tunnel junction at on-state and the corresponding drain current improves a lot. The comparison is made concerning the data for Lg=30nm at [3]. The Id-drop at higher drain bias seemingly stands for minimal gate tunneling through the 2.5nm oxide as provided here.

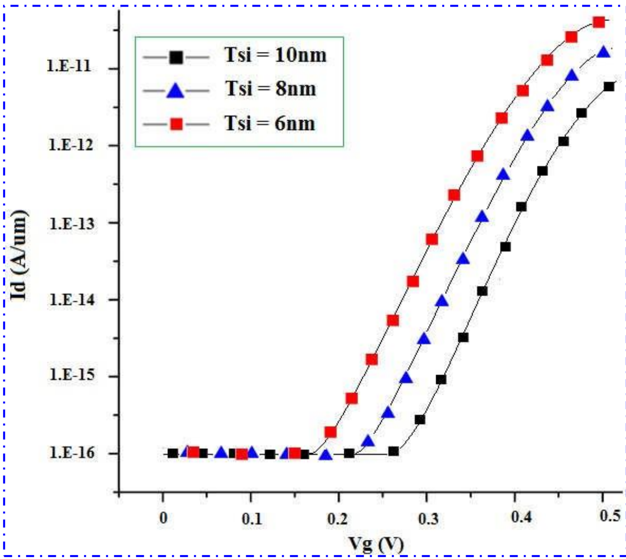


Fig.7. Dependence of Id on modification of thickness of Si-body

To get the best Gate coupling between both sides, we have reduced the silicon body thickness from 10nm to 6nm as displaced in Fig.7. Drain current gets higher with the application of the necessary Quantum Correction Model on SENTAURUS.

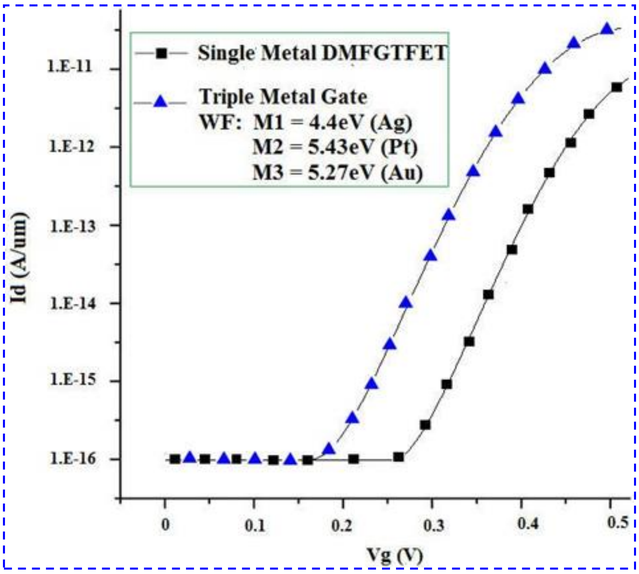


Fig.8. Effect of work-function modulation by Triple Metal Gate

According to the analytical model presented on [4], the tunneling length at source-channel can be engineered with the help of Triple Metal as Gate metal specifically M1=(Ag=4.4eV), M2=(Pt)=5.43eV & M3=(Au)=5.27eV having a reduction of Off-current with higher drain- channel barrier and enhancement of On-state-current as presented in Fig.8.

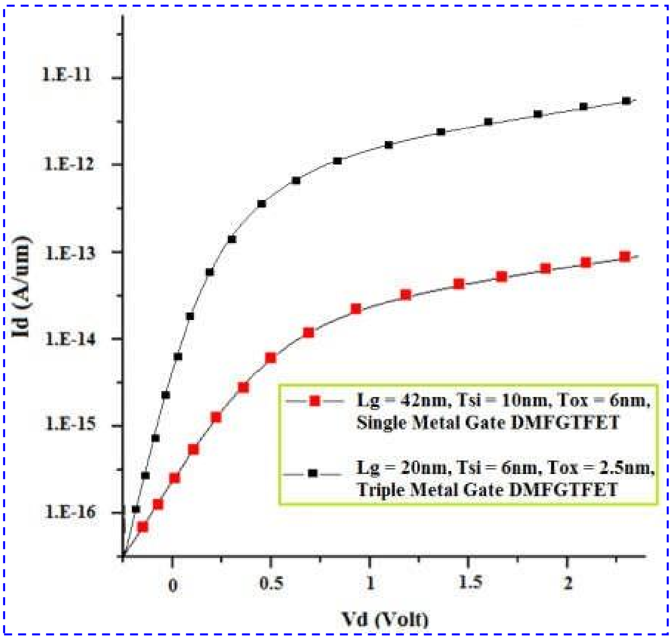


Fig.9. On-Current boosting by the implementation of every structural modification altogether

Fig.9 tells about the successful application of Gate-length (20nm), Oxide thickness (2.5nm), Si-body thickness (6nm) variation along with putting Triple Metal Gate for work-function modulation instead of the conventional single metal gate and thereby improving the On-state- current by around two orders of magnitude at Vg=1.0V.

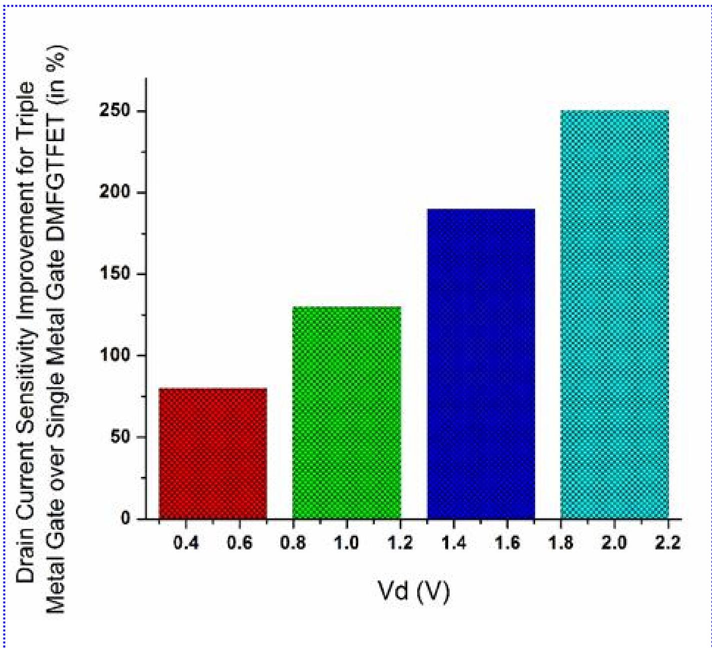


Fig.10. % Drain current sensitivity improvement compared for Triple Metal DMFGTFET with its Single Metal counterpart

Fig.10 depicts our claim on the betterment of device performance for the two types of structures following their %of drain current sensitivity improvement as sensitivity directly depends on the difference between the current observed after absorbing biomolecules and before that over nominal drain current for the same device and with same gate bias.

## IV. CONCLUSION

We have made full utilization of spatial electrostatics to boost the on-current for the device under operation. With some healthy modifications in terms of gate length, oxide thickness on both sides of gates, Si-body thickness, and metal work-function on gate electrode we have got an excellent two-order of magnitude enhancements of drain current, and subsequent enhancement in sensitivity was noted as well. This kind of device can find a good place for Food Analysis, Drug Development (Quality control), Crime detection (Forensic science), Medical diagnosis (clinical and laboratory use), and Industrial Process Control as Bio-detector. We can opt for a Linearly Graded Binary Metal Alloy gate in place of our triple metal gate for some performance modifications by varying the mole fraction of each element on that. As a whole, we can state that our proposed device has the potential to be the next generation bio-recognition-nano-tool with a better response.

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