

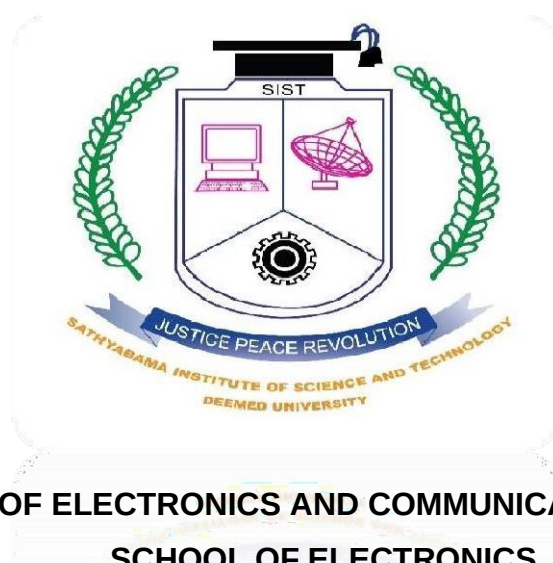
STUDY AND SIMULATION OF TUNNEL FIELD EFFECT TRANSISTOR MODEL BASED BIOSENSOR

Submitted in partial fulfilment of the
requirements for the award of
Bachelor of Engineering Degree in Electronics and Communication Engineering

By

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BONAFIDE CERTIFICATE

This is to certify that this Final Year Project Report is the bonafide work of DAGGUBATI AKHILA (REG NO: 39130101) who has done the project work as an individual who carried out the project entitled "STUDY AND SIMULATION OF TUNNEL FIELD EFFECT TRANSISTOR MODEL BASED BIOSENSOR" under my supervision from Jan 2023 to April 2023.



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ABSTRACT

This project presents brief review on Tunnel Field Effect Transistor based Biosensor from initial phase to currently used Tunnel field Effect Transistors for biosensing application. TFET based Biosensors have gained attention due to phenomenal properties such as high sensitivity, low cost, and ability to detect label-free biomolecules. Conventional Field Effect Transistors have lots of advantages as biosensors in comparison to other biosensors but there exist various limitations on subthreshold swing where ($SS > 60$ mv/decade), various short channel effects reduced the device sensitivity leading to restriction in using it as biosensors. For improving various research is going on so that scientists can find a way out to make a device overcoming all the disadvantages faced by previously developed biosensors made by different transistor devices. This project aims to clearly distinguish between different TFET Biosensors based on their working and sensitivity parameters to provide better insights to the researchers to further carry on the research for making more reliable and advance Biosensors. To reduce all these problems TFET structure was designed to provide lower sub threshold swing. Several other structures like double gate tunnel FET is used to increase the ON-state current. Hence, the amount of supply voltage decreases and the power consumption is also reduced. To enhance the tunnelling in the device new modification in structure is introduced in which four regions are there P-N-P-N double gate structure. It has been observed that the amount of current increases in the presence of neutral as well as charged biomolecule because the tunnelling width decreases and flow of carriers increases easily so, the effect was applied on double gate structure to get the desirable amount of current.

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CHAPTER 1

INTRODUCTION

1.1 INTEGRATED CIRCUIT:

The revolution in integrated circuit (IC) technology has led to a new era in the field of electronics with tremendous computational capabilities and computing power. The research and development carried out by the electronics community over the past four decades has resulted in the continued miniaturization of the conventional MOSFET dimensions leading to larger circuit density and higher functionality at reduced cost. Gordon Moore (Intel co-founder) predicted that “over the history of computing hardware, semiconductor chips would become two times more powerful every two years at lower cost, and they would ultimately be so small, that they could be embedded in homes, cars and smartphones” [1]. The predictions of Moore proved to be accurate for several decades, and guided/motivated the semiconductor industry to use them as benchmarks to set the goals for research and development. The evolution in IC technology and digital electronics is strongly linked to Moore’s law: quality adjusted microprocessor prices, memory capacity sensors and even the number and size of pixels in digital cameras. The miniaturization of the conventional MOSFET according to Moore’s law, cannot be continued forever. In 2015, Gordon Moore perceived that the pace of progress would eventually reach saturation, which started appearing at 22 nm node in 2012, and is continuing at 14 nm [1, 2]. Later Intel made an announcement that “our cadence today is closer to two and a half years than two”. This is scheduled to hold through the 10 nm width in late 2017 [2, 3]. They also made an announcement that as we progress from 14 nano meter technology node to 10 nanometre and plan for 7 nano meter and 5 nanometres and even beyond, our plans are proof that Moore’s law is still applicable [4–6]. In order to continue with Moore’s law, today’s hardware needs to utilize many architecture cores, and the programming should be done in a threaded manner to take the full advantage. In this emerging world, where science has made so much progress scientists try hard to find solutions to every problem. The recent problem such as COVID pandemic has disrupted people lives and such problem was also seen a couple of years ago when smallpox was introduced therefore these issues are never ending.

1.2 OBJECTIVE:

Conventional Field Effect Transistors have lots of advantages as biosensors in comparison to other biosensors but there exist various limitations on subthreshold swing where ($SS > 60$ mV/decade), various short channel effects reduced the device sensitivity leading to restriction in using it as biosensors. For improving various research is going on so that scientists can find a way out to make a device overcoming all the disadvantages faced by previously developed biosensor made by different transistor devices.

This project aims to clearly distinguish between different TFET Biosensors based on their working and sensitivity parameters to provide better insights to the researchers to further carry on the research for making more reliable and advance Biosensors.

1.3 BIOSENSORS:

Biosensors are the advancement of technology for such issues giving precise way to deal with the discovery of biomolecules [1]. Usually, a biosensor consists of two components: a recognition element (molecular) known as a receptor and target analytes like DNA, antibodies, cells, and a transducer to convert the information into a measurable quantity. Biological analytes are hard to detect based on their intrinsic properties, they need labels such as enzymes, radioactive molecules attach with the analyte for detection and it was a drawback as label-based detection are expensive and also time-consuming.

On the other hand, label-free detection does not require labels to facilitate measurements because they use intrinsic physical properties such as charge, size, dielectric permittivity, etc to detect the presence of biomolecules in a cheaper sample and time-saving. These ideal qualities of label free biosensors spread their applications in numerous zones like the clinical field for beginning phase location of biomolecules, conveyance of medications, food handling, natural observing, security, and observation. A Biosensor is a device that produces an electrical signal from the biophysical response.

The principal chemical-based biosensor was founded by Clark et al. in 1962 [1] and from that point forward this arising field has picked up loads of consideration among overall analysts for creating precise and more solid biosensors. The biosensor comprises of two different stages —

1) Biomolecule location and 2) Trans conduction. The first stage comprising of biomolecule location is one of the important tasks as locating a biomolecule in a device where it could be recognized by the biosensors helps in detecting the biomolecules in a more precise manner. The second stage transduction defines the process that is used to define biosensors by converting the recognized biomolecules into an electrical form or readable form for precise detection. All these biosensors are utilized to improve human existence. There are various biosensors based on the transduction process.

The working principle of electrochemical biosensor [2] is to experience the adjustment in the electrical properties of the sensor by response focused on biomolecules. The noticed changes are utilized as estimating boundaries for the sensor and depending on boundary noticed they are additionally characterized into amperometric, potentiometric, and conductometric. The exceptionally ground breaking substitute of ordinary insightful sort biosensor is optical biosensors as it needs extremely restricted groundwork for the location of the focused biomolecule. Optical fields with analyte are utilized in an optical biosensor to identify tumor cells, poisons, and so on. Calorimetric and Acoustic biosensors discover great applications for the discovery of DNA.

All these biosensors are utilized to improve human existence. Thermal and mass based biosensors are unpredictable and have low reaction time. Optical and electrochemical biosensors have taken more consideration for dependable and precise reactions because of their low location limit and extremely high particularity.

The working principle is same as tunnel FET and follows the band to band tunneling for the conduction of current. Voltage is applied to the gate terminal which controls the electric field and it provides the better control over channel current. The presence of double gate improves the control over tunnel junction with the gate voltage and this causes the current to increase by double amount coming from the thin device body. Hence, the sub threshold swing is decreased.

1.4 TUNNEL FIELD EFFECT TRANSISTOR:

There is a lot of progress going on TFET based biosensors but researchers face lots of problem in finding all the information related to Tunnel Field Effect Transistor based biosensors at one time. This manuscript has been bifurcated into three sections. Section I elaborates the brief literature review, Section II describes the structure and performance comparison of various biosensors, and finally in Section III conclusion is drawn. MOSFETs are developed gradually from the MOS integrated circuit technology. MOSFET is a four terminal device which can be applied in analog and digital circuits.

An Insulated layer of dielectric material which is mainly SiO_2 is deposited over silicon substrate its structure is same as planar capacitance. There are four terminals gate, source, drain, and body in which body is connected to source hence making it four terminal device. MOSFET structure: The current flow is supported by the electrons. Source and Drain regions are formed by using n^+ regions. In enhancement mode, channel starts forming between source and drain. When sufficient positive voltage is applied between gate and source the holes are repelled which leads forming a channel with negative charges. As gate voltage further increased, electron density at the inversion layer increases and current flow from drain to source increases.

The doping level plays an significant role to enhance the device characteristics like an increase in ON current and decrease in OFF current. The doping in source region should be high for the optimized on current and desirable characteristics because of the tunneling between the source and intrinsic region. The OFF-state current depends on the doping level in the drain region. The ambipolar behavior of the transistor is shown when the doping levels are equal in both source and drain region. The undesirable characteristics can be reduced by decreasing the doping level in drain side. This also decreases the OFF current level. The gate threshold voltage differentiates or checks the changes in the tunnel junction width through the energy barrier.

1.5 TFET STRUCTURE AND ITS OPERATION:

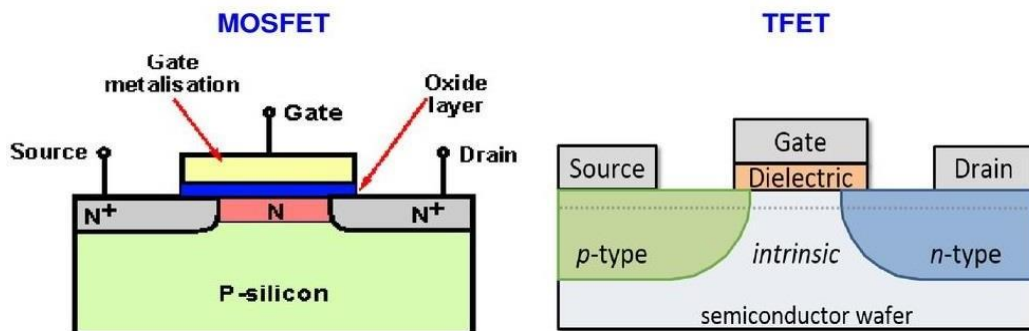


Figure 1.1 structure difference in MOSFET and TFET

Tunnel FET is a gated p-i-n diode. Due to its heavily doped p+ and n+ region, depletion region forms at the junction of intrinsic region and the n+ doped drain region. When a reverse bias has applied the width of the depletion region starts increasing, producing the swept charge carriers. These charge carriers tunnel through intrinsic region to source valence band by the band to band tunneling phenomenon.

TFET can be of two types n- type in which source is p+ doped and drain is n+ doped and a positive voltage is applied to the gate terminal. And other is p-type in which source n+ doped and drain is p+ doped and negative voltage is applied to gate.

1.6 BAND TO BAND TUNNELING:

It is a phenomenon of conduction of current used in Tunnel Field Effect Transistor. The phenomenon of tunneling is same in a Tunnel diode. The Fermi level present in the conduction band of n-type drain and valence band of the p-type source region. The electrons are present in n- type drain and holes are present in p- type source. At zero bias condition due to heavily doped p+ and n+ region, the conduction band of n side and the valence band of p side becomes align to each other. When applied reverse bias increases the height of potential barrier decreases and electric field increases. This causes the electrons from the conduction band of n- type drain flow to the valence band of p- type source side, due to which the current increases and max current flows.

Tunneling is of two types direct and indirect. In direct tunneling, the electrons pass from the valence band to conduction band without any absorption or emission of photons. The examples of this tunneling are GaAs etc. In indirect tunneling, there is a change of momentum due to absorption or emission phenomenon when the electrons are transferred from valence band to conduction band. The examples of the indirect band to band tunneling are germanium, silicon etc.

1.7 ADVANTAGES AND DISADVANTAGES

ADVANTAGES

TFET has feature that makes it efficient transistor in the upcoming future. The current carrying transport mechanism in the devices is different from MOSFET. As MOSFET uses drift and diffusion method for transfer of carriers and TFET uses the band to band tunneling process. MOSFET performance effects by the temperature is high as compared to tunnel FETs which are less dependent on temperature. Therefore, TFETs sub threshold potential is less than or equal to 60 mV/decade. In TFETs the tunneling width is controlled by the gate voltage and leakage current is less.

The value of sub threshold swing is reduced which reduces the amount of supply voltage required to operate and hence static and dynamic power dissipation is less. This decreased value of sub threshold swing helps them to behave as an ideal switch with the change in gate voltage in a small amount.

DISADVANTAGE

In silicon Tunnel FET the ON current is less since band to band tunneling is not much effective which is needed to be overcome.

The scaling on high scale of the device leads to very high OFF current and can vary the transistor performance.

The current flows for both the polarity of gate voltage gives ambipolar nature of TFET. It shows p-type behavior with excess holes and n-type with excess electrons. TFETs show the dominant phenomenon of ambipolar nature, in which symmetric structures

and the level of doping of drain and source is done same with single material of gate dielectric.

1.8 LABEL FREE TYPE OF BIOSENSOR:

A biosensor is an analytical device converting a biological information into a quantifiable and processable signal. Since the research by Clark and Lyons in 1962 on the first biosensor, the demand on such analytical tools in diagnostic applications was increasing. With the growing number of deaths due to late diagnosis and the high number of diseases being diagnosed in the world, biosensors are a critical tool in the early disease diagnosis.

In clinical laboratories, as described above, ELISA is the most common biomarkers detection method. It can detect more than hundred types of diseases. In biomarkers detection, most of the techniques currently employed use various labels or reagents like enzymatic, fluorescent or radiochemical labels. The labelling processes may hinder monitoring of the probe/target interaction rapidly. In other words, the labeling may affect the target-receptor interactions, which are caused by steric hindrance, induced by the label. In spite of the low detection limits and high sensitivity, these methods are still expensive, complex and time-consuming.

Additionally, such methods often require laboratory personnel with high skills. Thus, the development of sensitive, simple and high-throughput biosensors that are able to detect biomarkers without involving labeling is of great interest. Label-free bio sensing would eliminate the process steps for the modification and preparation of the target molecules, which significantly save the costs and time needed for sample preparation. Label-free biosensors are potentially very useful as clinical diagnostic tool, thanks to real-time and multi-analyte tests, quick detection and inexpensiveness.

So far, electrochemical transducers are being extensively used in biosensor. Among the variety of electrochemical transducers proposed for detecting biomolecules without labeling, the field effect transistor (FET) is an attractive approach. The FET biosensor can analyze kinds of biomarkers such as DNA and proteins without labeling and in a rapid, simple and inexpensive way.

1.9 FIELD EFFECT TRANSISTOR (FET) BASED BIOSENSOR:

Many types of biosensors exist in the fields of biomarker detection. FETs have been also used for the label-free detection of bio recognition events, such as antibody-antigen reactions, glycan-protein interactions, DNA hybridization reactions and cell identification. The FET biosensors are sensitive to the intrinsic electric charge of biomolecules. By modification of the FET gate surface with a bio molecular layer as a receptor, the changes in the gate voltage-drain current caused by the adsorption of analyte biomolecules can be detected.

Since target molecules are charged in an aqueous solution, the charge on the gate surface changes with bio recognition, and its density variation is transduced by field effect into an electrical signal. The bio recognition events on the FET gate surface can be found by detecting a shift of the threshold voltage. The immobilization of various bio recognition materials on the FET gate surface for biomarker analysis has been developed through surface modification technology.

Among many different types of FET devices, (MOSFET, MESFET, JFET and CHEMFET among others), commonly bio sensing applications are focused on ISFET (ion-selective field-effect transistor) devices. ISFET was firstly described by Bergveld in 1970, which was used as a transducer in electrochemical sensors for electrophysiological measurement of ion composition around nerve tissues. Several types of ISFET-based biosensors exist. Some forms of ISFET-based biosensors, such as enzyme ISFET, immuno ISFET, DNA-based ISFET and cell-based ISFET are explained in detail in this section.

1. Enzyme based ISFET : The concept of Enzyme ISFET revolves around the principle of pH-sensitive ISFET, stating that the enzymes are immobilized on the gate surface of the ISFET device. So far, enzyme ISFET is applied on the detection of numerous analytes such as penicillin, urea, glucose, pesticides etc. it was proven that the enzyme ISFET might be suitable for quick and sensitive detection of small amount of analytes, with the advantage of saving analysis time. Thus, this ISFET enzyme biosensor has been found to have potential of detection of complex samples.

MOSFET vs TFET:

There are three modes of operation of MOSFET: 1) cut off region: The Transistor is operated to be in off state and Drain current is zero. Applied gate voltage is less than the threshold voltage, which is not sufficient to form the channel. 2) linear or triode region: The applied gate voltage is increased such that it is greater than the threshold voltage, the current starts flowing between drain and source, drain to source voltage is less than difference of gate source voltage and threshold voltage. 3) Saturation region: For saturation region gate to source voltage is greater than the threshold voltage, as well as drain to source voltage is greater than difference of gate to source voltage and threshold voltage, in this region the MOSFET behaves as an ideal current source. Tunnel field effect transistor (TFET), because of its low subthreshold swing and excellent reduction in leakage current is attracting attention of the electronics community. They are being investigated for various low power applications.

TFET is a gated control PIN diode, in which tunneling takes place from valence band of source to the conduction band of the channel and this is controlled by the gate voltage. The gate voltage is used to modulate the tunneling barrier width at the source/body junction. The tunneling phenomenon was first observed in Tunnel diode by Esaki [45] in 1960. TFET can be operated at much lower voltage than the conventional MOSFET and, hence it consumes less power than the conventional MOSFET, but operating mechanisms in TFET and MOSFET are quite different. The structural difference between the conventional MOSFET and TFET is the asymmetric source and drain junctions as shown in. TFET can be viewed as a gated tunnel diode in series with the conventional MOSFET

connected via an internal node. The carrier injection mechanism from source to channel is different in both the devices as shown. Unlike the conventional MOSFET, where the injection of carrier takes place over the potential barrier (i.e. Thermionic emission), the carriers in TFETs are injected into the channel through the potential barrier via a process called band-to-band tunneling (BTBT). The transfer characteristics of TFET are also quite different from conventional MOSFET. TFET has some offset with respect to the drain voltage in the transfer characteristics.

The operation of conventional MOSFET relies on the modulation of channel potential by the applied gate voltage for the injection of carriers from the source into the channel through a process called thermionic emission. The barrier at the source/channel junction is modulated by the applied gate voltage. In OFF state, the barrier seen by the carrier from the source region is large, hence resulting current is leakage current the current is not zero because the thermal (exponential) distribution of carriers still permits a finite number of carriers to be injected over the large potential barrier. In the ON state, as the gate voltage increases the barrier at the source/channel junction is modulated and this results in exponential injection of carriers from the source into the channel (exponential current modulation). The thermal (Boltzmann) distribution of carriers in the source region ultimately defines, how steeply a MOSFET can switch from on to off-state. The steepness, defined by the amount of voltage required to modulate the current by one-order of magnitude, is called the subthreshold swing (S) and is limited to 60 mV/dec at room temperature [10]. We have shown the qualitative comparison of the transfer characteristics for TFETs and other device architectures for MOSFETs

TFET shows better subthreshold swing as compared to the MOSFETs. However, the ON current associated with the TFETs is The operation of TFET relies on the gate modulation of channel potential and the alignment of band at the source/channel junction. The range of energy over, which bands are aligned at the source/channel junction, forms an energy window (band pass filter) over which tunneling takes place. The path connecting two points of the same energy level is referred as a tunnel path. It may be noted here that the minimum tunneling path dominates the BTBT current. The alignment of bands at the junction can be staggered band type-I or type-II or broken band gap alignment. The BTBT current in a TFET can be toggled ON and OFF by controlling the band bending through the applied gate voltage. TFET is an ambipolar device that can show p-type behavior with dominant hole conduction and n-type behavior with dominant electron conduction. By using an asymmetric doping profile at the source and drain junction or by using a hetero junction, the tunneling at the drain end can be suppressed and the ambipolar current can be reduced. The asymmetry in TFET also achieves a low off-state current. In OFF state, the valence band and the conduction band are not aligned, as a result no tunneling path is formed in the device. Hence BTBT is suppressed and the OFF state current is limited by the reverse leakage current. As the gate voltage increases in the negative direction, bands are pulled upward. The conduction band gets aligned with the

valence band and a conducting channel is formed from the source valence band to the channel conduction band. At low temperature, the energy distribution of carriers at the source is restricted and the higher energy part of the source Fermi level is effectively cut off. This filtering function makes it possible to achieve a subthreshold slope of below 60 mV per decade.

The key to better voltage scaling of a TFET than a MOSFET is that subthreshold slope remains below 60 mV per decade over several orders of magnitude of drain current. The main stumbling blocks with TFET are its low ON state current (I_{ON}) compared to ITRS requirements and complicated fabrication steps required for extracting good performance. The low ON current in TFETs results in increased delay associated with the circuits. The methods to increase the ON current in TFETs can be categorized as follows:

Structural modifications (hetero junction source etc.): The low ON current issue in TFETs can be tackled by structural modifications. By using a hetero junction, with a smaller band gap material at the source, the ON current can be boosted. Raised Ge source TFETs, gate source overlapped TFETs (Vertical tunneling TFETs), extended source TFETs, and L-shaped TFETs have been used to increase the ON current. In a conventional lateral TFET, tunneling takes place in the lateral direction from the source to the channel. This tunneling is referred to as point-to-point (P-P) lateral tunnel.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION:

The following shows a survey done for Smart Farming for with and without internet on real time which includes an instant feedback mechanism that drives the appliances. This system is reliable to integrate on multiple platforms with the help of Arduino Uno board which serves as standard firmware. Further, the study was extended to multiple operation platforms like Linux, Windows, and IOS are discussed as follows. In this detailed survey, we have learned a lot in stabilizing our concepts from the existing feedback mechanisms that were designed in the previous study.

2.2 LITERATURE REVIEW:

Low cost, low power, rapid, small, ultra-sensitive, robust biosensors are highly recommended for Point of Care Applications. Biosensor build on Complementary metal oxide semiconductor compatible silicon nanowire tunneling field effect transistor (SiNW- TFET) has been proposed by **Anran Gao (2016)** [3]. It has been observed that SiNW- TFET provided good amount of parasitic capacity by using inherent ambipolar nature through biomarker of human lung cancer CYFRA21-1 and pH sensing as unfunctionalized Silicon nanowire TFET devices can be characterized as hydrogen ion sensors. Changes in surface charges at the Silicon nanowire surface gates the Tunnel Field Effect device that modulates the nanowire current. The ambipolar nature and conductivity was shown for both positive and negative voltages at gate. This ambipolar response discriminates the electrical noise to carry with object analysis.

Analytical model of p-n-p-n TFET for working as biosensor for label-free detection of biomolecules has been developed by **Rakhi Narang (2012)**. It has been observed that the proposed model gives two important properties

1) dielectric constant 2) charge. Comparison with conventional FET based biosensors was also made in the terms of sensitivity of TFET based biosensors consisting of various parameters like shift in threshold, variation in ON-current (I_{on}) level and ON- OFF ratio of current (I_{on}/I_{off}). Also, it was concluded that TFET based sensors show wide deviation in current level and therefore change in ON current (I_{on}) can be considered as appropriate

parameter for sensing.

Detection of biomolecules using electrical characteristics is attractive because inexpensive, label-free, provide stability and ease of on-chip fabrication of sensors. TFET having nanostructures or particularly nanowires has gained importance because of enough surface to volume ratio and high electrostatic control. For biomolecule detection specific receptor is transistor.

In 2018, **Deepak Soni et al** carried out research for improving the speed of sensing and sensitivity of TFET based biosensor using the concept of formation of plasma. The research was carried out by adding an electrode on the source region of conventional biosensors using negative supply for extending cavity above the source region. The introduction of additional Source Electrode with negative supply voltage forms the cavity over source region overcomes the issues such as abrupt junction formation at source junction and channel junction. It was also observed that issues related to solubility limit of silicon material was also solved because of formation of plasma layer of holes near Silicon and HFO₂ interface. It has been concluded that excess biomolecules in the region of source and cavity increased the concentration of plasma layer of holes near Silicon-HFO₂ because of better coupling that in return improved the capability of sensing and the sensing speed of Biosensors.

A transition metal dichalcogenide material based TFET was proposed by **Prabhat Kumar and Brajesh Kumar (2019)** as transition metal dichalcogenides (TMDs) are said to be promising candidates for sensing applications. It has been observed that TMDs have atomically thin-layered structure, dangling bond free structure and novel physical properties. The presented device showed Subthreshold swing of 50mV/ decade and measured sensitivity of 2.11 for 5mV change in voltage across gate. Label free biosensors is preferable due to their simple operation. L- shaped TFET [13] based biosensors are used because of their low voltage Subthreshold Swing, power consumption and off state current.

In 2016, **Sayan kanungo** investigated the effect of (SiGe) source and n+ pocket doped channel using extensive device level simulation. It has been observed that silicongermanium source DMTFET showed high superiority in comparison to n+ pocket Dielectric Modulated TFET to obtain higher subthreshold current level while maintaining the sensitivity of device.

In 2019, experimental study has been done by **Cao W** that provided good insights into Subthreshold Swing (SS) characteristics of TFET by examining effects of four critical parameters like level of source and doping, band gap, length, and tunnel effective mass in the perspectives of Fermi-Dirac Distribution and Tunneling probability variation. It was observed that shortening of Fermi Dirac Distribution, OFF-current and uncovered intrinsic Subthreshold Swing compete among themselves to provide minimum achievable Subthreshold Swing. This work also concluded that for homo junction TFET design: small channel length, suitably high doping level of source and small tunnel effective mass is suitable and for hetero junction Tunnel Field Effect Transistor design in these parameters, small band gap present at tunnel junction is preferable.

There are various types of biosensors as been discussed above and in that row **M Waleed Shinwari (2011)** presented the effect of distribution of DNA probe on reliability of label-free biosensors. As we have observed that since the miniaturization for increasing the sensitivity parameter, there was lack of research in knowing the variation of received signals with respect to the position of probes over sensitive surface therefore a computational study has been done by them using finite element model on three dimensional biological field-effect transistor (BioFET) via Monte Carlo simulations on the DNA molecules position.

It was also observed that SNR can be low enough to disturb the device functionality. Further study done by him was the effects of region of pinch-off and concentration of electrolyte on Signal to Noise ratio. It was concluded that sharing between ions across probes of DNA specifically at low-electrolyte concentration significantly increases the amount of change of charge inversion in FET thereby increasing the sensitivity. Therefore, there is a great need of properly controlled environment for achieving reliability of biosensors and mostly in miniaturization of devices.

In 2010, Jae- Hyuk Ahn et al proposed the double gate nanowire field effect transistor for increasing the sensitivity of conventional FET devices. Gate region was separated as G1 (primary) and G2 (secondary) allowing independent voltage control for modulating potential of channel and sensitivity was enhanced.

Due to the disadvantages of MOSFETs under miniaturization research on electronic devices has been moved to TFETs. Although TFET devices are suitable but still have few things that need to be controlled like it has low on currents that results in low switching speed and shows ambipolar behaviour. It was observed by Anne S. Verhulst (2007) that reduction of gate length leads to several advantages like increase in switching speed and decrease in processing complexity.

Furthermore, short gate TFETs investigation has been carried to know the capability of tunnel field effect transistor by simulating low power digital applications using supply voltages less than 0.5 V. The study done showed that tunneling current has very less or negligible contribution on charging and discharging gate capacitance of TFETs. It was also observed that although short gate TFET has high resistance region but the charging and discharging speed still meets requirements for application in low voltages.

The performance analysis was done on SG-TFETs using different materials like Silicon, Germanium and heterostructure studying various parameters such as voltage overshoot, static power, delay energy consumption etc. It was concluded that heterostructure Short Gate TFETs can be said as promising candidate for extending supply voltages to lower the voltages below 0.5 because of short gate structures, small bandgap material for source and sufficient driving current in Tunnel Field Effect Transistors.

CHAPTER 3

SIMULATION APPROACH

3.1 INTRODUCTION:

Atlas is a software provides general potentials for physically based two- and three-dimensional (2D, 3D) simulation of semiconductor devices. Atlas is designed in such a way that it can be used with the VWF Interactive Tools. The VWF (Virtual Wafer Fabrication) interactive Tools consist of the following: Mask Views, Optimizer, Deck Build, Tony Plot, and dev edit. Their functions are explained below:

1. Deck Build puts forward the condition for running Atlas command language.
2. Optimization across various simulators can be provided by Optimizer.
3. Through Tony Plot the outputs which are actually the electrical characteristics of the device along with structure files generated for the designed device can be seen.
4. IC layout correction is done by Mask Views.

Along with Atlas, there exists another process simulator called Athena. It can produce structure by many processing steps. The same structures can be used by Atlas as inputs. Later Atlas predicts the electrical characteristics related to the designed device. Now the outputs of the Atlas can be given as the used as the inputs to the SPICE modeling software and Utmost device characterization.

Atlas can be called as a physically-based simulator for devices as it is capable of calculating all the characteristics of a particular device with specified structure and voltage biases at the electrodes. The device area is divided by these simulators with grids called meshes and with mesh points called nodes. By applying differential equations which are derived from Maxwell laws, current conduction and electrical parameters at each location through the structure is determined. This type of physically based simulation has many advantages like, they provide a deep insight of the attributes of device without experimentally creating the device, calculation of very complex parameters are done very easily and quickly, estimation of the trends with the varying properties of the device according to its different bias conditions can be estimated through these simulations.

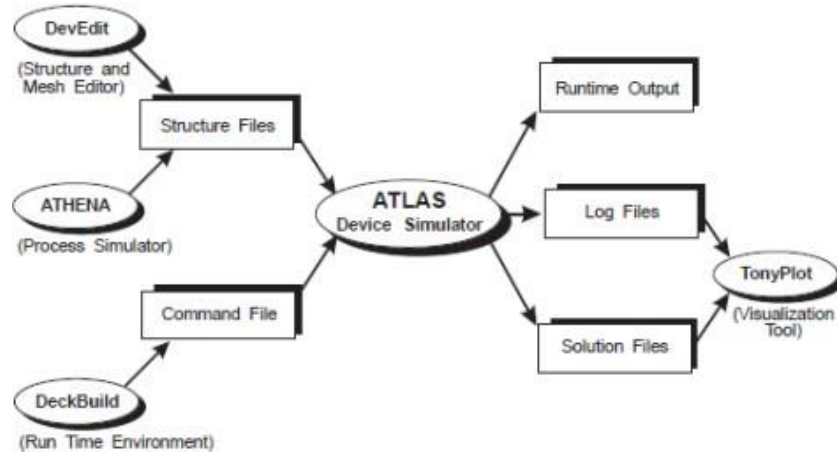


Figure 3.1 Inputs and Outputs of active device simulator

Information flowing through Atlas device simulator can be seen in the above diagram (Figure3.1). The text file, which contains Atlas command language and structure file, which has the structure on which simulations has to be performed are the two input files to Atlas device simulator. Atlas gives three types of output files: runtime output which gives the information being processed at every instant of execution of Atlas commands and simultaneously show the errors and warnings. log files which gives all the electrical characteristics which is specified in the Atlas command language and solution files which has the 2D or 3D data of the device parameters at each and every point in the device

In this work, the study of TFET with single and double gate, using different gate dielectrics and using dual material gate is done to improve the current and to achieve efficient characteristics. The simple model of the double gate is studied to get the desired amount of current with suitable sub threshold voltage. There is always the benefit of the extra gate like extra current can add to the original one. Hence, ON current is increased. The presence of two gate forms two tunneling junctions hence there is an increase in current and the OFF current is same in the range of pA. Sub threshold swing is decreased and I_{on}/I_{off} ratio is increased making it the suitable device for operation.

3.2 STEPS TO DEFINE SIMULATED STRUCTURE

There is sequence of step we have to follow to write code in silvaco atlas simulator:

- Step 1 Define Meshing :

Mesh specification starts with a mesh mult statement which multiplies the spacing between the meshes by a factor (taken along with mesh. mult command) so that finer or coarser meshes can be created according to the need.

Syntax:

Mesh space.mult=<value>Eg: Mesh space.mult=4.0

After this x.mesh and y.mesh statements are specified as follows: X.mesh LOC=<value1>SPAC =<value2>

Eg: X.mesh loc=0.00 spac=0.0001 Y.MESH LOC=<value3>SPAC=<value4>

Eg: Y.mesh loc=0.00 spac=0.0001

where value1 and value3 specifies the location of vertical and horizontal mesh line in microns respectively and value2 and value4 specifies the spacing between these mesh lines.

Step 2 Define Regions:

Different regions consist of different materials with a specific doping profile. For specifying the region the following command is used:

Region NUMBER=<value>X.MIN=<value1>X.MAX=<value2>Y.MIN<value3>Y.MAX
=<value4>MATERIAL=<material1>

Eg: Region number=1 x.min=-0.010 x.max=0.00 y.min=0.00 y.max=0.010 material=Silicon

The region number is specified by value and „value1 to value2 gives the range of the region on the x-axis while value3 to value4 on y-axis. material1 is the material forming the region (like Silicon, SiO₂ etc).

- Step 3 Define Electrodes :

ELECTRODE

NAME<electrode1>NUMBER=<value>X.MIN=<value1>X.MAX=<value2>Y.M

IN<value3>Y.MAX=<value4> Where the name of the electrode is given as „electrode1“. The location of the electrode is from x.min to x.max and y.min to y.max.

+

- **Step 4 Define Doping:**

DOPING<doping profile>CONC =<value><dopingtype>REGION=<number> Eg: doping uniform conc=1e14 n.type direction=y region=2

Doping profile can vary with its concentration and type of doping which are specified by value and doping type respectively. The doping profile can be either be uniform or Gaussian.

- **Step 5 Contact Name: Following Syntax Is Required:**

CONTACT NAME<contact name>WORKFUNCTION=<value>

Eg: contact name=source neutral

where name of the contact is given by contact name whereas its work function is specified by value

Instead of specifying the work function by value, it can also be specified by their name in the contact statement for the commonly used contacts like N.Polysilicon, P.Polysilicon, Aluminium, Tungsten, etc. The statements used for this type of contacts are: CONTACT NAME<f.gate> N.Polysilicon.

3.3 SPECIFICATION OF MODELS:

Usually, the statements for MODELS are used to indicate the physical models which are required for simulations. The selection of the MODELS is according to the physical phenomenon occurring inside the considered device. These MODELS be divided into the following 5 categories.

1. Carrier Statistics Models
2. Mobility Models
3. Recombination Models
4. Impact Ionization Models
5. Tunneling and Carrier Injection Models.

3.4 COMMON MODELS:

1. Concentration-Dependent Low-Field Mobility Model: To activate this model, CONMOB is used in the MODELS statement. This model provides the data for mobilities of electrons and holes at low field for silicon and gallium arsenide only at 300K.
2. Analytic Low Field Mobility Model: To activate this model, ANALYTIC is used in the MODELS statement. This model helps in specifying temperature and doping dependent lowfield mobilities. This model is also specified by default for silicon at 300K.
3. Lombardi CVT Model: CVT in the models statement are used for activating this model. This models priority is much more than all other mobility models. In this model, Matthiessen's rule is used for combining the components associated with mobility dependent on transverse field, temperature and doping. On activating this model by default, Parallel Electric Field Mobility Model will also get activated.
4. Shockley-Read-Hall Recombination Model: The SRH parameter is used in the MODELS statement for activating this model. There are a few user-definable parameters that used in the MATERIAL statement, like TAUN0 and TAUP0 the electron and hole lifetime parameters. This model gives the recombination of electron and hole through Shockley- Read-Hall recombination method happening within the device.[3]
5. Boltzmann Model: This model is the default carrier statistics model. It is activated by specifying BOLTZMANN in the MODELS statement. As the name indicates this model follows Boltzmann statistics.
6. Fermi-Dirac Model: This model follows Fermi-Dirac statistics. It is usually in those regions which are heavily doped but with reduced concentrations of carrier. To activate this model FERMI is used in the MODELS statement.

3.5 TUNNELING MODELS:

1. Standard Band To Band Tunneling Model: For high electric field, present in the considered device, tunneling of electrons can be caused by the localized electric field such that there is a bending of energy bands at the junction of tunneling. For such kind of application standard band to band tunneling model can be used. This model can be used BBT.STD needs to specified in the MODELS statement. The tunneling rate can be calculated by the following equation:

$$G_{BBT} = D \times BB.A \times e^{BB.GAMMA \times (-BB.B/E)}$$

Where D is the statistical factor, E is electric field. $BB.A$, $BB.B$, and $BB.GAMMA$ are userdefinable parameters with default values

$$BB.A = 9.6615e18 \text{ cm}^{-1} \text{ V}^{-2} \text{ S}^{-1} \quad BB.B = 3.0 \text{ e7 V/cm} \quad BB.GAMMA = 2.0$$

2. Non-local Band-to-Band Tunneling Model: This model is nonlocal in nature unlike all the rest of the models. The spatial variation of energy bands are taken into consideration by this model. It also considers the fact that generation recombination rate at each point does not depends only on the electric field local to the point. According to BBT.NONLOCAL the tunneling happens through 1D slices, at the tunnel junction where each slice and the tunnel junction are perpendicular to each other. These slices are parato themselves. The tunnel slices specification can be done in two different ways. They are:

- (i) Making rectangular area around the tunnel junction using the statements QTX.MESH and QTY.MESH.
- (ii) Making a region surrounding the tunnel junction using statements QTREGION

The first method is applicable for only planar junctions while second method can be used for both planar and non-planar junctions.

3.6 NUMERICAL METHODS:

The numerical methods are specified in the METHODS statement. To find solution there are three different types of techniques:

1. Gummel
2. Newton
3. Block

The first method finds solution for one unknown variable while the rest of the variables are constant. This process will continue until a stable solution is obtained. Unlike the Gummel method, Newton method solves and finds all the unknowns at the same time. Block method is in between Newton and Gummel methods as it solves a few unknowns at the same time. Gummel is generally used for the device studied in this project i.e. the tunnel FET.

3.7 METHODS TO OBTAIN SOLUTIONS:

To calculate current as well as other parameters such as carrier concentrations and electric fields, the device electrodes need to be supplied with voltages. At first, electrodes are provided with zero voltages, after that the bias voltage applied is varied in small steps. These need to be specified in the SOLVE statements.

1. DC Solution: A fixed DC bias can be applied on the electrode by using the DC solve statements. `SOLVE <v.electrode name>=<value>`.

According to this statement the required electrode, *electrode name* is supplied with DC voltage *value*.

For sweeping the bias of a particular electrode from *value1* to *value2* in a particular order of steps *step1*, the following command is used.

`SOLVE <v.electrode name>=<value1> VSTEP=<step1> VFINAL=<step2>
NAME=<electrode name>`.

Convergence can be obtained for the used equations by supplying a good original presumption for the variables that need to be evaluated at each bias point. Initial solution can be achieved by the given statement, `SOLVE INIT`.

DEVICE STRUCTURE AND TYPES OF BIOMOLECULES

As an alternative solution toward achieving steep subthreshold swing transistors, we propose a novel device concept of the tunnel source (PNPN) n-MOSFET. Its operation and optimization will be examined. Fig.3.1 shows the device structure of the novel asymmetric PNPn n-MOSFET. Instead of an n+ source as in a conventional MOSFET, a tunneling junction formed between a p+ region and a narrow fully depleted n+ layer under the gate acts as a source of electrons for the channel. The thin fully depleted n+ layer reduces the tunneling width and increases the lateral electric field, thereby minimizing subthreshold swing as well as potential drop at the tunneling junction.

[illegible]

24

4.2 WHAT IS NEED OF BIOMOLECULE SENSOR AND ITS TYPES:

Generally, term used for biomolecule are molecule and ions that are present in organisms, typically in biological process such as cell division, development of cell.

Biosensors produce a digital electronic signal which is proportional to the concentration of a specific analyte or group of analytes. While the signal may be continuous or discrete, devices can be configured to measure in specific format. Examples of Biosensors include immune sensors, enzyme biosensors, organism and cell-based biosensors.

These sensors are applied to variety of analytical scenario including medicine industry, biomedical research, drug discovery, the environment, food preservatives, process industries, security and defense.

4.2.1 TYPES OF BIOMOLECULES:

There are 4 main groups of biomolecules (organic) :

1. Carbohydrates (made of Monosaccharides): Used for energy e.g glucose Can be structural as in plant cells (cellulose Builds cell walls)
2. Lipids/fats : Very important as they are made up of the phospholipid Bi-layer or all animal cells .This membrane regulates what can come in and what is needed by the cell
3. Proteins (made of Amino Acids) : It can be functional and structural structural proteins allow us to build muscle filaments etc. Functional enzymes include which allow almost all chemical reactions to occur faster rate and at less energy.

4.3 DEVICE OPERATION:

The operation of the tunnel source (PNPN) n-MOSFET based on the principle of band-to-band tunneling. It is important to point out that tunneling is prohibited not only by large tunneling barrier width but also by the Fermi selection rule (the availability of density of states to tunnel to). We define a voltage V_A as the gate voltage required to align the p+ valence band to the channel conduction band.

When V_G is small ($< V_A$), the channel conduction band is above the p+ source and therefore, the current level is negligible since the electron from the p+ valence band can tunnel only to the trap state Fig.

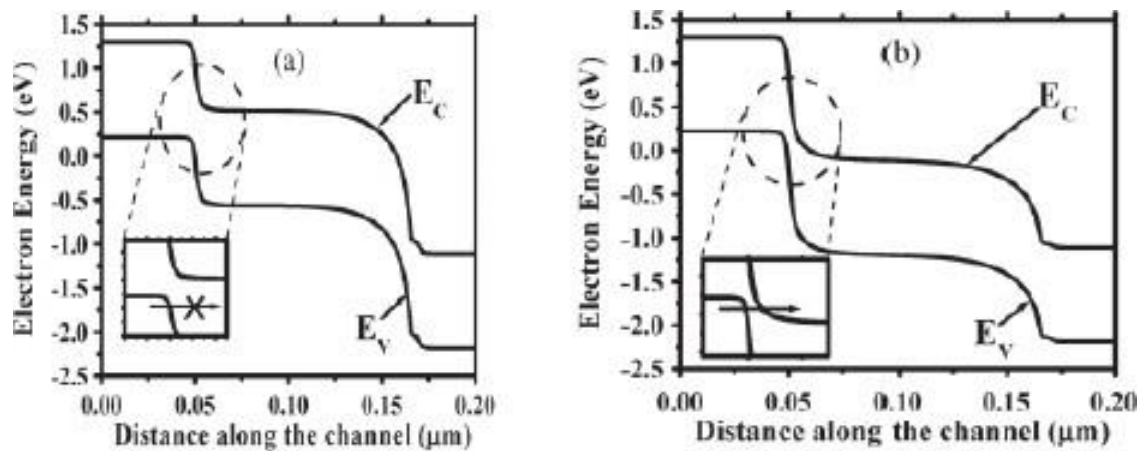


Figure 3.2: band diagram along channel when $V_G < V_A$. band diagram along channel when $V_G > V_A$

As V_G increases above V_A , tunneling width reduces and the channel conduction band goes below the p+ source valence band. Consequently, there are states in the channel region for the electrons from the p+ source valence band to tunnel to Fig3.2(b) thus giving rise to the device current. As V_G becomes high (V_A), the tunneling resistance at the source junction decreases due to reduction in tunneling

width and large density of available states for the electrons to tunnel into. Therefore, under large gate bias, device current is limited by the drift field in the channel as in a conventional MOSFET.

4.4 OPTIMISATION OF DEVICE PARAMETERS:

Extensive device simulations were performed using SILVACO's device simulator ATLAS coupled with analytical tunneling calculations. Since the mechanism for indirect tunneling in Si and Ge can be described by empirical expressions, the calculations in our case were based on the well known equations for the tunneling current I_t of the Esaki tunnel diode shown as follows

$I_{C \rightarrow V}$ is the tunneling current from the conduction band to the empty state of the valence band and $I_{V \rightarrow C}$ is the tunneling current from the valence band to an empty state of the conduction band. A is a constant, $FC(E)$ and $FV(E)$ are the Fermi–Dirac distribution functions, and $n_c(E)$ and $n_v(E)$ are the density of states in the conduction band and valence band, respectively. In our calculations, the tunneling probability was defined as

$$T_t = \exp(-C/E_{eff}) \quad ; \quad E_{eff} = E_g/W_{tun} \quad \text{where } C = \pi^2 \sqrt{m} E^{3/2} / \sqrt{2} qh$$

In which, m is the effective mass of the electron, E_g is the band gap of silicon, q is the electronic charge, and h is the Planck's constant. W_{tun} is the tunneling distance for each overlapping energy state. Parameters A and m were tuned to obtain a fit with the experimental data from silicon tunnel diodes.[4]

In which, m is the effective mass of the electron, E_g is the band gap of silicon, q is the electronic charge, and h is the Planck's constant. W_{tun} is the tunneling distance for each overlapping energy state.

The tunneling formalism can therefore be used satisfactorily to simulate similar tunneling structures like the proposed tunnel source (PNPN) n-MOSFET. Although the simulation issues involving the tunneling mass, the effective tunneling distance and indirect. The doping profiles used for the simulation are boxlike and abrupt.

4.5 COMPARING DIFFERENT TYPES OF TFETs:

1. Silicon Nanowire Tunnel Field Effect Transistor

The silicon nanowire TFET based biosensors was designed using novel CMOS compatible anisotropic wet etching approach and conventional lithography along with tetramethylammonium hydroxide.

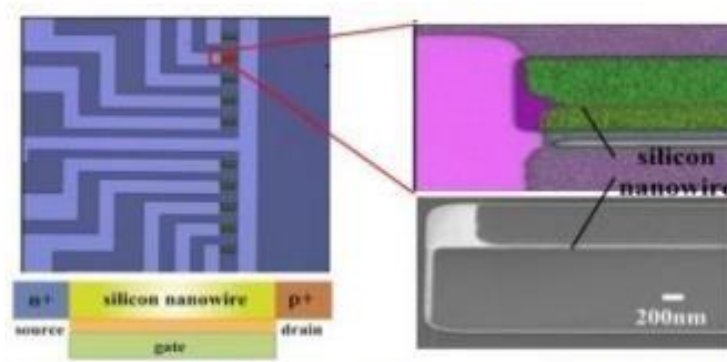


Figure 4.5 Silicon Nanowire based biosensor.

In Figure 4.5 , one can observe that SiNWs forms a cluster (10 wires each) that is used as one unit for sensing specific molecule. The structure clearly shows that the surface of Silicon nanowires are smooth and of high quality [3]. The ID-VG characteristics of SiNW-TFET and conventional TFET based biosensors in log scale was compared.

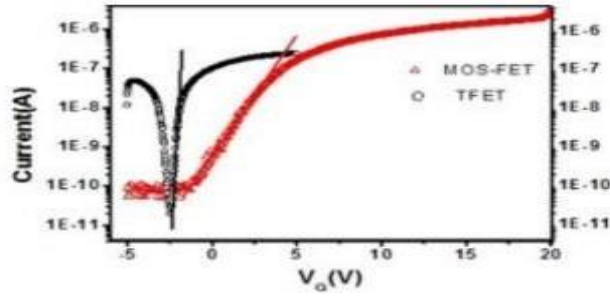


Figure 4.6 Id-Vg characteristics of Silicon nanowire and conventional TFET based biosensors.

It can be observed in Figure 4.6 that subthreshold swing of TFET was decreased in comparison to conventional FET device (MOSFET).

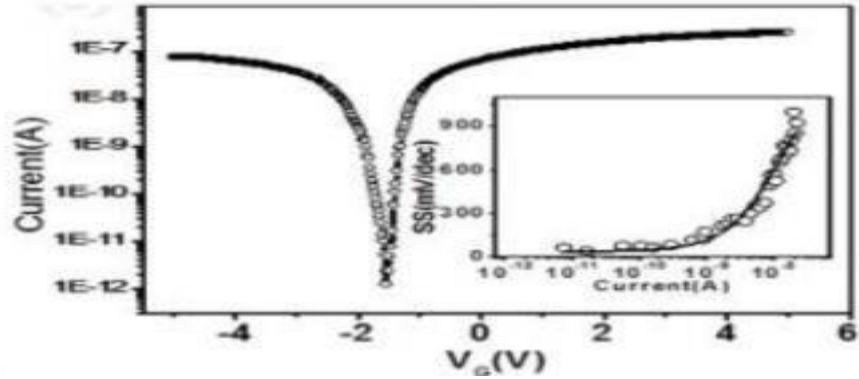


Figure 4.7 Id-Vg curve of Silicon nanowire TFET device for $V_d=1V$

In Figure 4.7, ID-VG curve of Silicon Nanowire TFET device for $V_D = 1$ V is shown that justify that this proposed structure has SS of 37 mV/dec for n-channel that simultaneously increased the sensitivity. The current and subthreshold swing

2. Dielectrically Modulated Tunnel FET based Biosensor.

We can observe ID-VG characteristics in Figure 4.8 that shows good response for different dielectric constant values and therefore the sensitivity of biosensor is improved. The thing that was not taken care was ambipolar conductivity which effect the sensitivity of the device and limits the performance of this device. They performed the sensitivity analysis by considering dielectric constant and charge separately but if we observe practically then the charge is present only when biomolecules are present therefore this is the concerning factor for in proposed device.

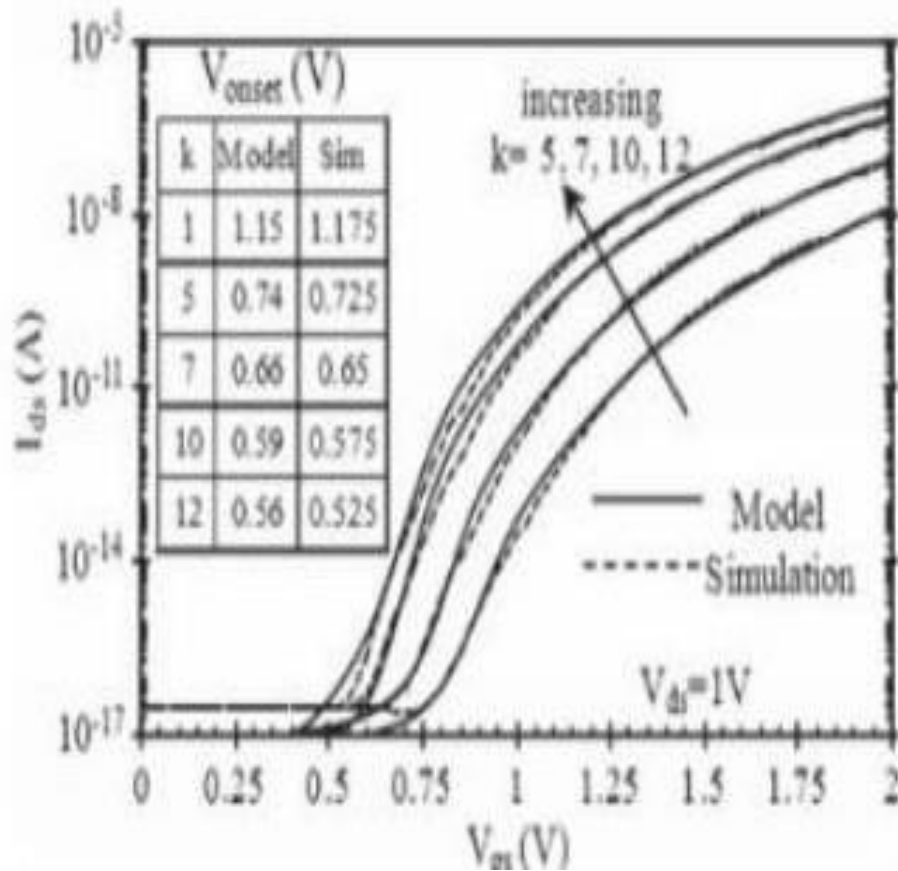


Figure 4.9 I_d - V_g characteristics of DM-TFET

3. Short Gate and Full Gate TFET Based Biosensor

Sayan Kanungo carried out performance analysis of both SG-TFET and FG-DMTFET. In the device, the two gates operate simultaneously and the dual gate structure enhances biomolecule impact on dielectric constant and leads to high sensitivity of the sensors. To enhance the value of tunneling current, Si-Ge was used as source with germanium concentration of 0.5 in both SG-TFET and FG-TFET.

The gate length of short gate TFET was kept 20 nm and Full gate was kept 42 nm as we can see in Figure 3(a) and (b). The SG-DMTFET limited the impact of ambipolar conductivity and showed improved sensitivity.

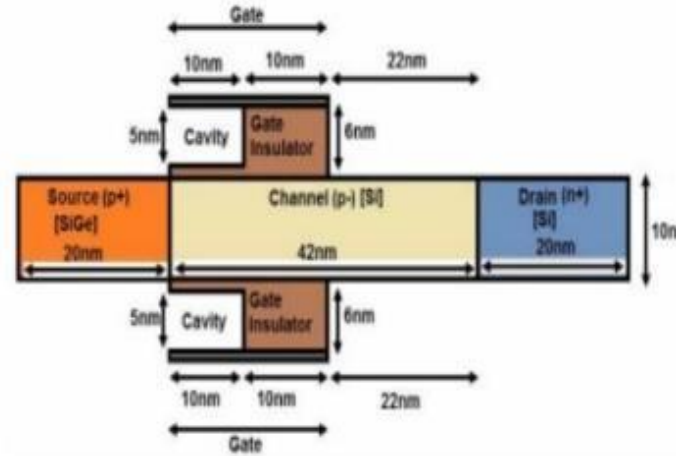


Figure 4.9(b) Structure of short gate TFET Biosensor

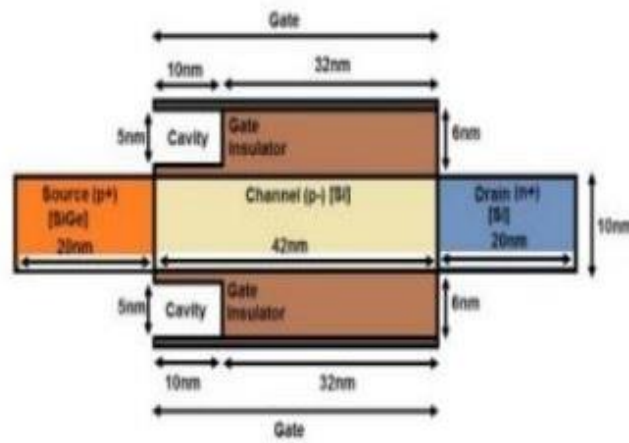


Figure 4.9(c) Structure of Double Gate TFET Biosensor

The full gated DMTFET consists of full gated intrinsic channel as which decreases the width of barrier and hence sensitivity is achieved. Further due to one- dimensional tunneling the on current of Dual metal gate is limited. The short gate TFET should be operated in specific biasing range and this precise biasing can enhance the sensitivity of SG-TFET (Short Gate Tunnel Field Effect Transistor) that

can produce sensitivity of drain current almost seven times that of FG-TFET (Full Gate Tunnel Field Effect Transistor). The I_D - V_G curve of both short gate and full gate TFET based Biosensor is shown in Figure 3 (c). Further, it is being said that structural enhancement in FG-TFET and material specifications can increase the sensitivity performance.

4. Junctionless based electrically doped TFET based Biosensor

The device structure is made of n+ heavily doped Si layer and isolated gates to form intrinsic region and p+ source region under the polarity gate (PG) and control gate (CG). The polarity bias of Si body is similar to that of conventional tunnel field effect transistor [14]. As the device is junction less, the device is free from doping control, thermal dissipation and fabrication complexity as shown in Figure 4 (a).

The performance of device is increased due to the absence of junction and improved the issue of random dopant fluctuation. The drain current sensitivity curve is shown in Figure 4 (c) and I_D - V_G curve at different dielectric constant is shown in Figure 4(b). Although it is free from short channel effects, fabrication issues etc but still the issue of ambipolar conductivity persist therefore structural modulation of the device is still needed.

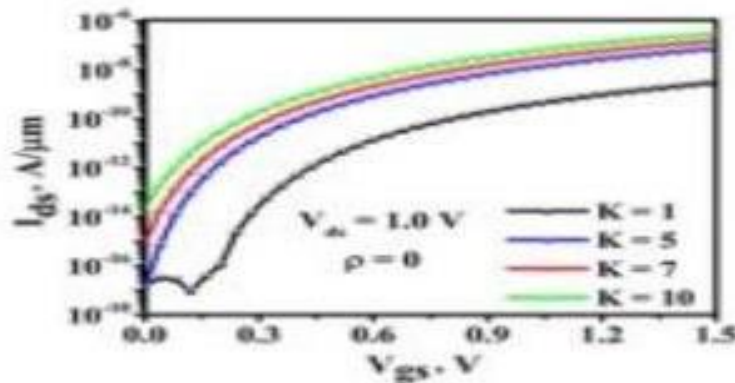


Figure 4.9(d) I_D - V_G Characteristics at different Dielectric Constant.

This research was carried out for improving the response time and sensitivity of Tunnel Field Effect based biosensor using the concept of formation of Plasma. The sensitivity was improved by adding an electrode on the source region of conventional biosensors using negative supply for extending cavity above the region of source [11]. The introduction of additional Silicon Electrode with negative supply voltage for forming the cavity over the source region overcomes the issues related to abrupt junction formation at junction of source and channel as shown .

It was also observed that issues related to solubility limit of silicon material due to layer of Plasma formation of holes near Si-HFO₂ interface was also solved. It has been concluded that excess biomolecules in the region of source and cavity increased the concentration of plasma layer of holes near Si- HFO₂ because of better coupling that in return improved the subthreshold swing, capability of sensing and the sensing speed of Biosensors as shown in Figure 5.

CHAPTER 5

SIMULATION RESULTS AND DISCUSSIONS

5.1 INTRODUCTION:

In this chapter, all the simulation results and its discussion are briefly described for the double gate tunnel field effect transistor as a biosensor. The input characteristic of the device has been simulated. Also the characteristic of the device for neutral and charged biomolecule were also simulated. The threshold voltage, subthreshold swing and sensitivity has been calculated in this chapter.

5.2 SIMULATED STRUCTURE: DM-LTFET

The difference between conventional TFET and proposed modified structure is that the region between source and drain is covered with intrinsic silicon. The intrinsic concentration of silicon is 1.08×10^{10} . The doping concentration of source and drain is in order of greater than 10^{19} . The conventional TFET is simulated as shown in

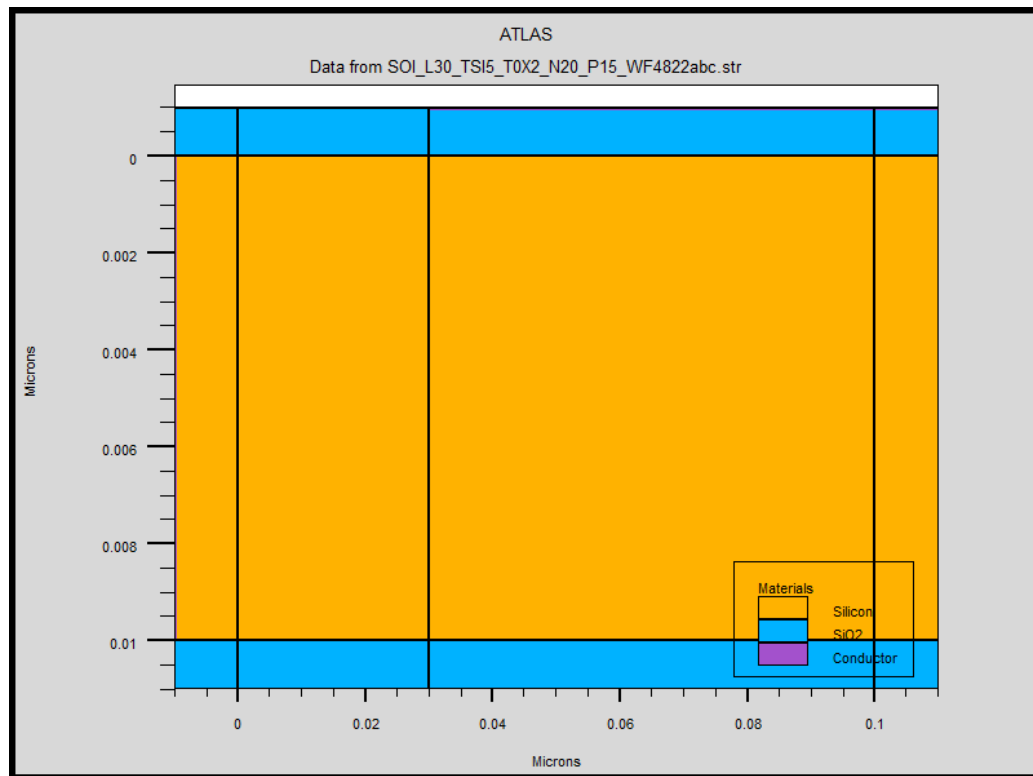


Fig 5.1 Simulated structure of pin TFET on silvaco Atlas

5.2.1 INPUT CHARACTERISTICS OF PIN TFET

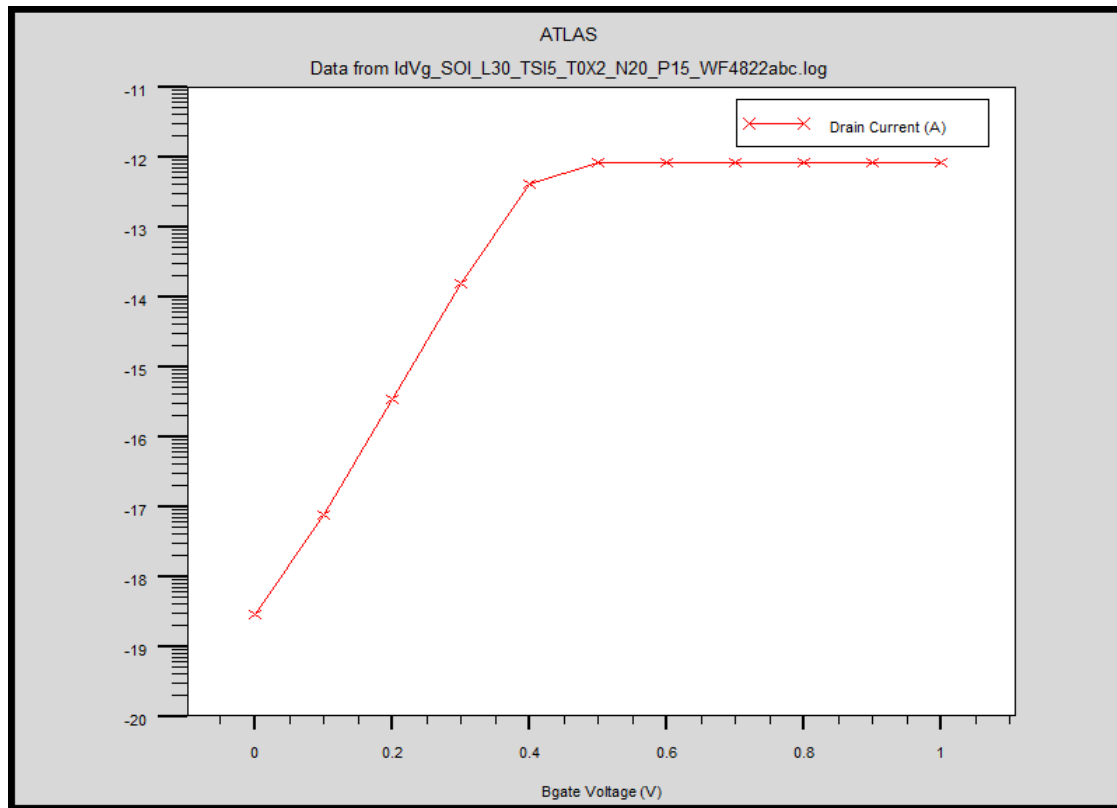


Figure 5.2 The Log ID versus Vgs characteristics of Pin TFET shows Ion current in the order of 10^{-18}

The figure shows the input characteristic for dissimilar drain voltage. It can be seen that off current in the order of 10^{-18} , which shows TFET is low power consumption device. There is a increase in the tunneling current, because in TFET tunneling current depends on the drain voltage also along with the gate voltage but. But beyond 0.6V of drain voltage there is not much improvement on the I_{ON} , due to the effect of the short channel effect (such as velocity saturation, DIBL and pinch-off mechanism).

5.3 DETECTION OF NEUTRAL BIOIMOLECULE:

In this study, we focused on using the DMFET to detect the biotin–streptavidin system because it has one of the highest free energies of association for a non-covalent bond between a protein (streptavidin) and a small ligand (biotin) in aqueous solution. This biomolecule system is also useful in the diagnosis of certain diseases. The effect of neutral biomolecules is simulated by introducing different dielectric material having dielectric constant i.e., $K > 1$ because of biomolecules have their own dielectric constant as reported in literature streptavidin = 2.1, protein = 2.50, biotin = 2.63.

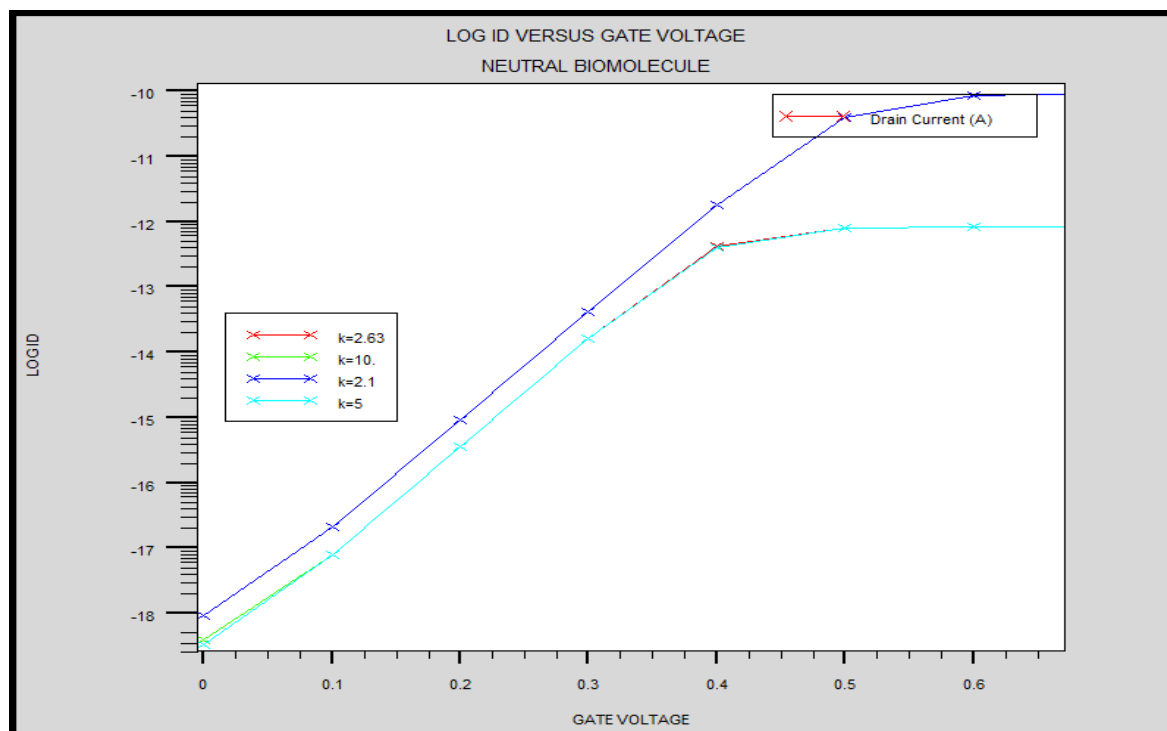


Figure 5.3 Log Id versus Gate voltage for different dielectric constant of biomolecule

The capacitance at the source side increases as the dielectric constant (of the biomolecule) in the nanogap cavity increases, resulting in additional band bending at the tunnel junction leading up to reduction in tunnel barrier width and, hence, increase in drain current. Also there is observation table which shows there variation threshold.

TABLE NO. 5.1

BIOMOLECUL ENAME	DIELECTRIC CONSTANT(K)	CHANGE IN THRESHOD VOLTAGE	SUBTHRESHOLD SWING(mv/decade)
Protein	2.50	0.778	60.3384
Biotin	2.63	0.108	60.3381
streptavidin	2.1	0.070	60.3393
APTES	3.57	0.179	60.3368
Air	1	0	60.3410

From the table 5.1 we can observe that change in threshold increases when we increase the dielectric constant of neutral biomolecule.

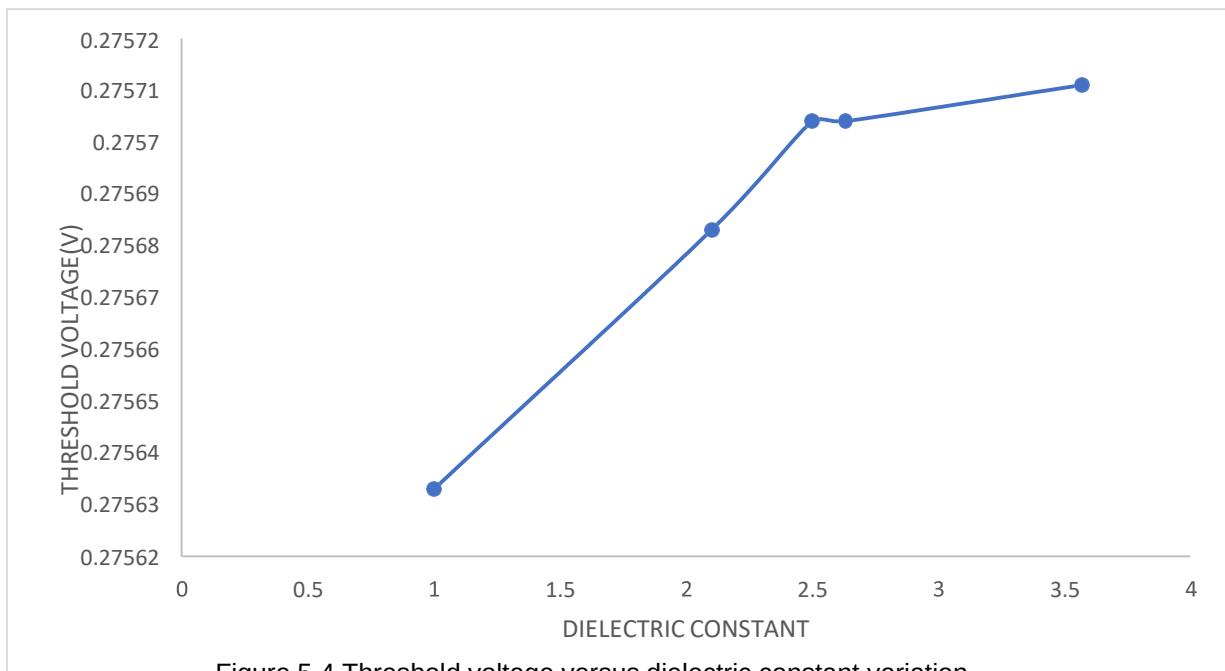


Figure 5.4 Threshold voltage versus dielectric constant variation

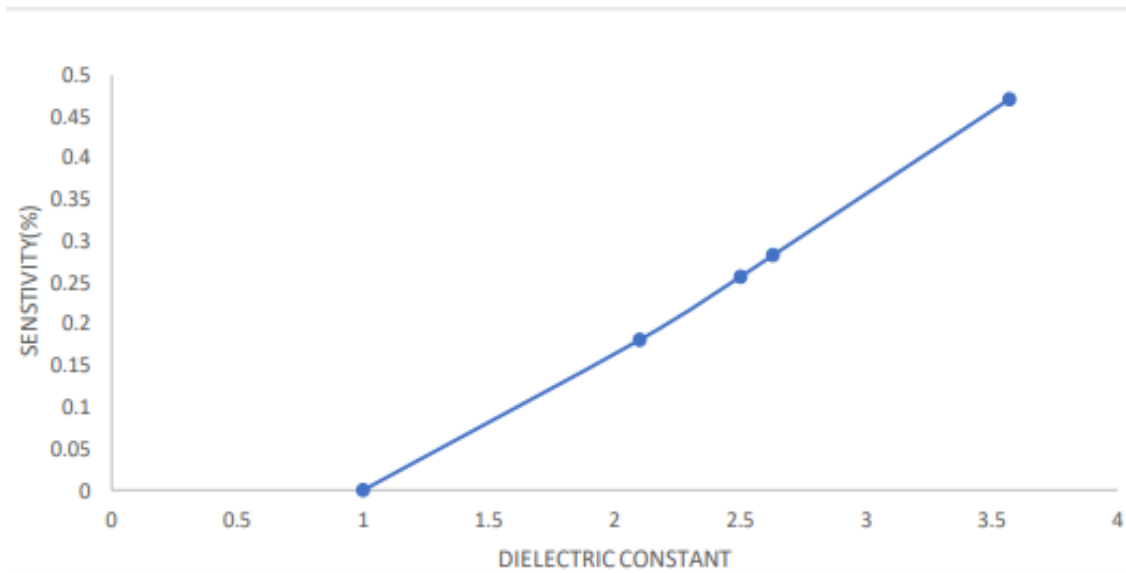
TABLE 5.2

CHARGE DENSITY OF BIOMOLECULE (m ²)	THRESHOLD VOLTAGE (V)	CHANGE IN ION CURRENT (%)	SUBTHRESHOLD SWING (mv/decade)
+5×10 ²⁰	0.381	84.8	56.1
-5×10 ²⁰	0.257	56.9	60.20
-5×10 ¹¹	0.2773	14.3	60.328
1×10 ¹²	0.2708	75.4	60.41
-1×10 ¹²	0.157	22.3	60.21

5.4 SENSITIVITY CALCULATION:

The mathematical formulation which has been considered to evaluate the sensitivity of n- type double gate TFET when the neutral and charged biomolecules are immobilized in the cavity is expressed as

- Sensitivity = $V_{th}(k=1) - V_{th}(k>1) / V_{th}(k=1)$ for neutral biomolecule
- Sensitivity = $V_{th}(\text{neutral biomolecule}) - V_{th}(\text{Charged biomolecule}) / V_{th}(\text{neutral biomolecule})$ for charged biomolecule
-
- Fig.4.10 gives sensitivity when neutral biomolecules are immobilized in the cavity region of n-type double gate TFET. As the dielectric constant of the biomolecules present in the cavity region increases, the sensitivity for n-type double gate TFET linearly increases.



As we can see sensitivity of device increases as dielectric constant of neutral biomolecule increases, hence it shows good result in terms of sensitivity.

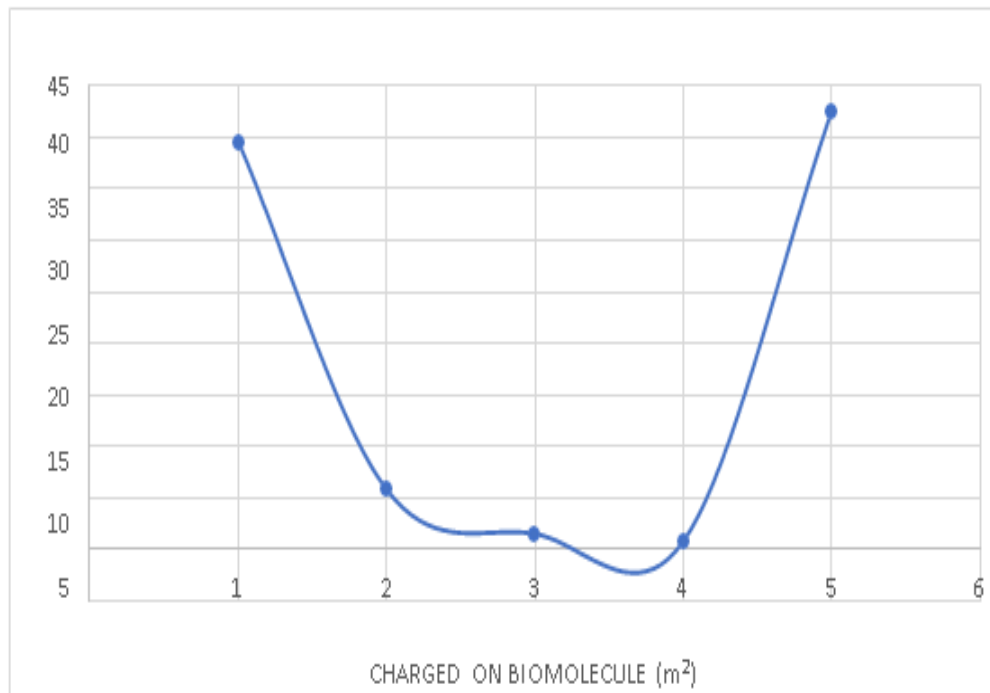


Figure Sensitivity in parabolic pattern with respect to charged on biomolecule

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 CONCLUSION:

The sensitivity of the DM-LTFET sensor was relatively high, which is very suitable for applications in the field of ultra-sensitive, low-consumption biosensors.

The sensitivity of the DM-LTFET sensor was mainly investigated by studying the transfer curve, current sensitivity, and threshold voltage sensitivity of the proposed structure with different dielectric constants, cavity thicknesses, and charged biomolecules. This factor can be purely eliminated with the help of future technologies.

It can be seen from the simulation results that the greater the relative permittivity of the biomolecules, the smaller the cavity, the greater the amount of positive charge, and the higher the sensitivity of the proposed sensor.

Therefore, DM-LTFET sensors have profound development potential and market prospects.

6.2 FUTURE SCOPE:

In near future if successful hardware implementation will be possible it will completely change the scenario of CMOS biosensor circuit design. Low energy consumption, low power dissipation, low scale size really needed for the future design and fabrication of ICs so future research work and development should be done to develop this kind of sensor. In coming it can provide big boost to health sector.

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