Junction less Accumulation Mode Surrounding Gate (JAM-SG) Hydrogen Gas Detector

A DISSERTATION REPORT

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

VLSI DESIGN & EMBEDDED SYSTEM

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M.Tech (VLSI Design and Embedded System) Shiv Shankar Yadav 2024

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CANDIDATE'S DECLARATION

I, SHIV SHANKAR YADAV(2K22/VLS/16) student of MTech (VLSI Design and EMBEDDED SYSTEM), hereby declare that the Minor Project report "**Junctionless Accumulation Mode Surrounding gate (JAM-SG)**" which is submitted by me to the department of Electronics and Communication Engineering, DELHI TECHNOLOGICAL UNIVERSITY, DELHI in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, fellowship or other similar title or recognition.

Place: Delhi MTech (VLSI Design and EMBEDDED SYSTEM) Date; 31/05/2024 Department of Electronics & Communication Engineering

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CERTIFICATE

We hereby certify that the Minor Project report titled "Junctionless Accumulation Mode Surrounding gate (JAM-SG)" which is submitted by SHIV SHANKAR YADAV(2K22/VLS/16) to the department of Electronics and Communication Engineering, Delhi Technological University, Delhi in the partial fulfillment of the requirement for the award of the degree of Master of Technology, is record work of the report work carried out by student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

In this report, analysis of Junctionless Accumulation Mode Surrounding gate (JAM-SG) as a hydrogen gas detector has been done. JAM-SG with metal gate for gas sensing applications is proposed for the first time in this paper. A simulated model is developed for n-channel JAM-SG to observe the different electrical parameters of the device for different values of pressure [1]. Different simulated results such as surface potential, electric field and electron velocity have been analyzed at two different values of pressure10^{-14}(Torr) and 10^{-13}(Torr). At pressure10^{-14}(Torr) work function of 5.0eV gets generated at metallic gate, maximum output drain current of 15.59μA at V_{DS}=1V, the maximum output conductance of 145(μ A/V) at V_{DS}=0V and maximum transconductance of 7.7(μA/V) at V_{GS}=0.8V is obtained, while at pressure of 10^{-13}(Torr),work function of 5.2eV gets generated at metallic gate, maximum output drain current of 5.31μA at V_{DS}=1V, the maximum output conductance of 61.2(μA/V) at V_{DS}=0V, and the maximum transconductance of 8.45(μA/V) at V_{GS}=1V is achieved.

ACKNOWLEDGEMENT

We would like to express our deep sense of gratitude to our highly respected and esteemed guide Asst. Prof. Dr. Sonam Rewari and Asst. Prof. Sachin Dhariwal for suggesting the topic of our minor Term project and for giving us complete freedom and flexibility to work on this topic. They have been very encouraging and motivating and the intensity of encouragement has always increased with time. Without her constant support and guidance, we would not have been able to complete this work. We extend our sincere thanks to all my family members who have patiently helped us directly or indirectly in accomplishing this work successfully.

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List Of Abbreviation

FET: Field effect transistor

JL: Junction less

JAM: Junction less Accumulation Mode

JAM SG: Junction less Accumulation Mode Surrounding

Gate TFET: Tunneling Field Effect Transistor

GAA: Gate All around

CPE: Charge Plasma Enhanced

MOSFET: Metal Oxide Semiconductor Field Effect Transistor

CHAPTER-1: INTRODUCTION

1.1 Introduction:

MOSFET is a voltage-controlled device that is used for applications such as switching and amplification purposes such as radiofrequency applications, passive elements also used to regulate DC motors, used in the design of chopper circuits. Scaling of MOSFET into nanometer scale in order to increase speed and number of compressed chips, imparts effects such as short channel effects, tunneling effects and threshold voltages effects. It also imparts constraints on drifting of electron in the channel, hot carrier's effects that downs the performances considerably. Short channel effects results in certain non- ideal effects such as channel length modulation, Drain Induced Barrier Lowering (DIBL)and velocity saturation [2] Multi-gate Surrounding Gate structures-based devices came into use to encounter the undesirable effects like short channel effects and uplifted the structural behavior towards linearity. It exhibits superior performances than bulk conventional MOSFET based devices with excessive scaling. Surrounding gate structure (SG)that covers the gate from all around, provides better flexibility and scalability as it has better grip over the gate section [1]. With miniaturization, in drain source junction management of doping and thermal budget becomes challenging. To avoid these many challenges Junction less transistor came into scenario because of its simplicity in fabrication and various other advantages related to characteristics parameters. Surrounding gate structure has superior coverage of surface than volume which imparts fine surface to volume ratio and its strong control over gate proves surrounding gate structures superior to be exploited for the device structure over existing conventional structures because of enhancement in sensitivity parameters. Junction less Mode Surrounding Gate (JAM-SG) is used as a hydrogen sensor, as it avoids the formation of drain-source junction so, no junction resistance region is created, which increases conductivity. Nowwe are proposing Junction less Accumulation Mode Surrounding Gate (JAM-SG) to compensate these limitations [3].

Due to high doping of source and drain, immunity to mobility degradation is built and ease fabrication. It also improves below par threshold voltage swings and threshold voltage instability. The proposed JAM -SG gas sensor exploits the phenomena of adsorption for the detection of the hydrogen gas. As the presence of hydrogen gas is felt by the metallic gate, variation in work function of the metallic gate which alters the threshold voltages, thus the characteristics parameters associated sensitivities would be considerable and observable, which can be used for the detection of hydrogen gases [1]. It is important to note that temperature should be maintained at room temperature because variations in temperature causes vapor pressure changes, which in turn affects the adsorption rate of hydrogen gas, thus imbalances the mathematical calculations [9].The proposed hydrogen gas sensor has been used in analysis of. different characteristics parameters like surface potential, electric field, electron velocity, drain current, output conductance, and transconductance to detect the presence of hydrogen gas. The device has been simulated on Silvaco Atlas TCAD (Technology Computer Aided Design) device simulator. discusses results obtained for different characteristics parameters surface potential, electron velocity, electric field, drain current, output conductance and transconductance at two different values of pressures10^{-14} (Torr) to 10^{-15} (Torr), used for observing the sensitivity of device, because with different values of pressures the above electrical properties have shown different characteristics, which is used for detection.

1.2 Motivation:

In the ever-evolving landscape of electronic devices, the quest for improved performance and efficiency remains perpetual. At the heart of this pursuit lies the field-effect transistor (FET), a fundamental building block of modern electronics. While traditional metal oxide semiconductor FETs (MOSFETs) have long been the backbone of electronic circuits, their inherent limitations have spurred the exploration of alternative technologies. MOSFETs, despite their widespread use, suffer from several drawbacks that hinder their performance in certain applications. These limitations include a restricted sub-threshold swing, a low Ion/Ioff ratio, and higher leakage currents. As electronic devices continue to demand higher performance and lower power consumption, the shortcomings of MOSFETs have become increasingly apparent, driving researchers to seek novel solutions. One promising alternative to MOSFETs is the JAM-SG FET JAM- SG FETs offer several advantages over their MOSFET counterparts, including reduced short channel effects, weaker temperature dependency, and enhanced scalability. These attributes make JAM-SG FETs particularly well-suited for application requiring low- power operation and improved energy efficiency. However, JAM-SG FET sare not without their own set of challenges. One significant hurdle is the ambipolar effect, wherein the device exhibits both electron and hole conduction characteristics, leading to degraded performance and reliability. To address this challenge, researchers have explored various techniques, such as gate-drain underlap and lower drain doping concentrations, aimed at suppressing ambipolarity and improving JAM-SG FET performance. Recent advancements in JAMSG FET design have also shown promise in mitigating the ambipolar effect. Dual material control gate charge plasma-based JAM-SG FET represent one such innovation, leveraging advanced gate structures to enhance device performance and reduce ambipolar behavior. Another significant development in transistor technology is the introduction of capacitance effect to reduce the barrier width for electron injection, there by improving device performance and efficiency. Moreover, addressing challenges associated with data loss in ferroelectric-based random access memory (RAM) is paramount for the practical implementation of these devices. By preserving data integrity through conductance sensing in the channel region, researchers aim to optimize the functionality of JAM-SG based FETs and enable reliable data storage and retrieval. Additionally, the utilization of silicon-doped hafnium significant breakthrough in overcoming challenges associated with scaling down the thickness of ferroelectric materials. By addressing issues such at the increase in coercive fields, silicon-doped hafnium oxide offers a promising solution for enhancing the performance and reliability of ferroelectric-based devices. Overall, this project embodies a comprehensive approach to advancing transistor technology, encompassing innovative device designs, materials engineering, and simulation techniques. By tackling key challenges such as ambipolarity and data loss, researchers aim to push the boundaries of electronic performance and pave the way for the next generation of high-performance, energy-efficient devices.

1.3 Objective

The proposed hydrogen gas sensor has been used in analysis of. different characteristics parameters like surface potential, electric field, electron velocity, drain current, output conductance, and transconductance to detect the presence of hydrogen gas. The device has been simulated on Silvaco Atlas TCAD (Technology Computer Aided Design) device simulator. Section 2 outlines the basic three dimensional and two-dimensional structural view of the JAM-SG hydrogen gas sensor. Section 3 discusses results obtained for different characteristics parameters surface potential, electron velocity, electric field, drain current, output conductance and transconductance at two different values of pressures10^{-14} (Torr) to 10^{-15} (Torr), used for observing the sensitivity of device, because with different values of pressures the above electrical properties have shown different characteristics, which is used for detection of hydrogen gases. Finally, Section 5 contains the conclusive portion of the paper [4].

CHAPTER-2: LITERATURE REVIEW

2.1 Literature Survey

MOSFET is used for applications such as switching and amplification purposes such as radiofrequency applications, passive elements also used to regulate DC motors, used in the design of chopper circuits. Scaling MOSFET into nanometer scale to increase speed and number of compressed chips, imparts effects such as short channel effects, tunneling effects and threshold voltages effects. It also imparts constraints on drifting of electron in the channel, hot carrier's effects that downs the performances considerably. Short channel effects results in certain non-ideal effects such as channel length modulation, Drain Induced Barrier Lowering (DIBL)and velocity saturation [2] Multi-gate Surrounding Gate structures-based devices came into use to encounter the undesirable effects like short channel effects and uplifted the structural behavior towards linearity. It exhibits superior performance than bulk conventional MOSFET based devices with excessive scaling. The surrounding gate structure (SG)that covers the gate from all around, provides better flexibility and scalability as it has better grip over the gate section [1]. With miniaturization, in drain source junction management of doping and thermal budget becomes challenging. To avoid these too many challenges Junction less transistor came into scenario because of its simplicity in fabrication and various other advantages related to characteristics parameters. Surrounding gate structure has superior coverage of surface than volume which imparts fine surface to volume ratio and its strong control over gate proves surrounding gate structures superior to be exploited for the device structure over existing conventional structures because of enhancement in sensitivity parameters. Junctionless Mode Surrounding Gate (JAM-SG) is used as a hydrogen sensor, as it avoids the formation of drain-source junction so, no junction resistance region is created, which increases conductivity. Now we are proposing Junctionless Accumulation Mode Surrounding Gate (JAM-SG) to compensate these limitations [3]. Due to high doping of source and drain, immunity to mobility degradation is built and ease fabrication. It also improves below par threshold voltage swings and threshold voltage instability. The proposed JAM -CG gas sensor exploits the phenomena of adsorption for the detection of hydrogen gas. As the presence of hydrogen gas is felt by the metallic gate, variation in work function of the metallic gate which alters the threshold voltages, thus the characteristics parameters associated sensitivities would be considerable and observable, which can be used for the detection of hydrogen gases [1]. It is important to note that temperature should be maintained at room temperature because variations in temperature causes vapor pressure changes, which in turn affects the adsorption rate of hydrogen gas, thus imbalances the mathematical calculations [9].

2.2 Conventional MOSFET structure as a sensor

The structure of Conventional gas sensor[14] using 2-D structure is as shown in fig.2.2.1, in which Silicon acts as substrate material while SiO2 acts as insulating layer having thickness (tIL) of 2 nm, gate material possessing thickness(t) of 10 nm, channel width(tCH)is 10 nm, channel length(L) of 50nm, drain length and source length, both are 45nm concentration of the n-typed doped drain source areas is $5x10^{18}/cm^3$, p -typed source is $1x10^{18}/cm^3$ whereas the p-type dopants in the channel is of concentration $1x10^{12}/cm^3$.Catalytic metal gate.

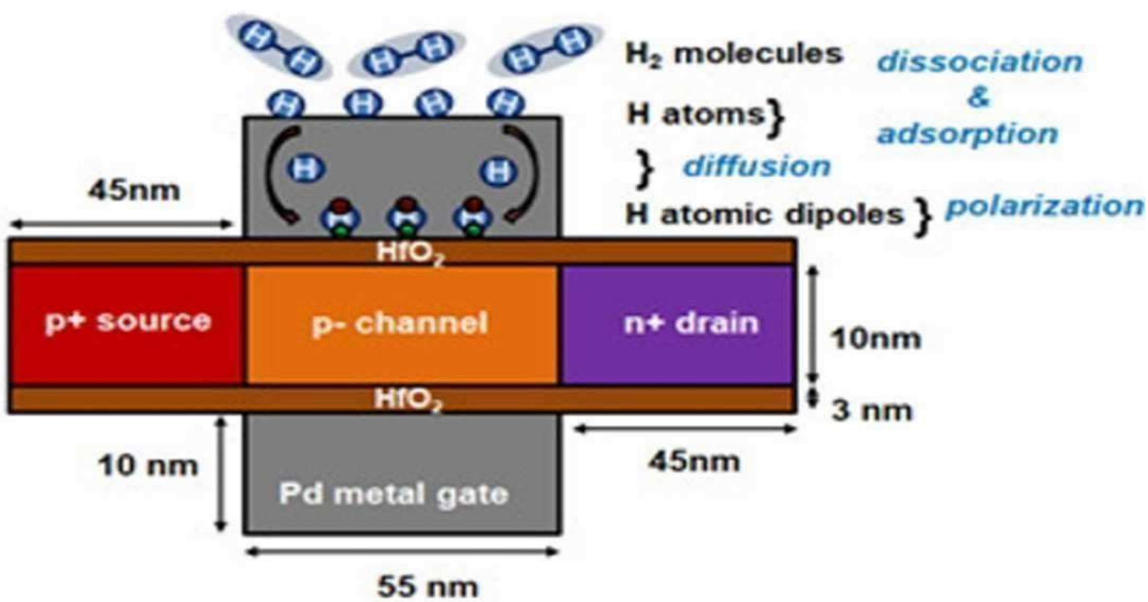
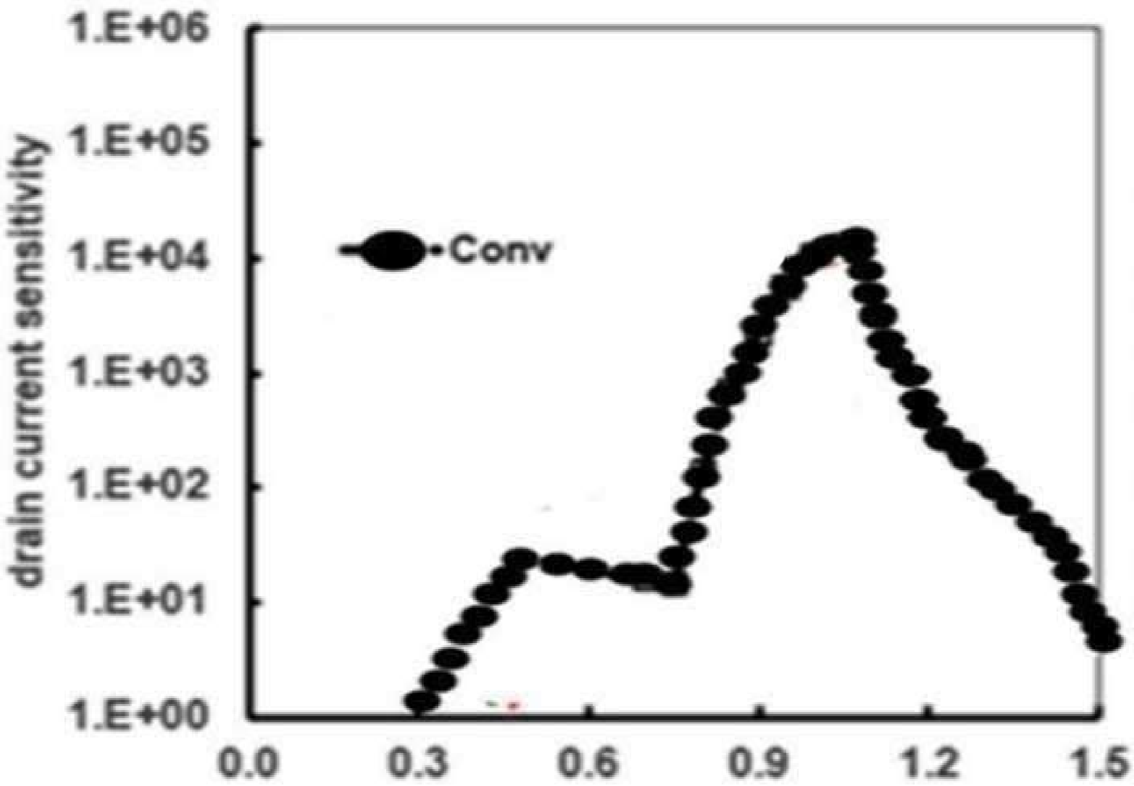


Fig. 2.2.1Schematic representation of Conventional -TFET

In the surrounding different concentration of hydrogen gases gives rise to differently valued pressure at metallic gate interface, as we know that pressure and work function are corelated as [1,9]



Variation in Gate bias Voltage (V)

Fig.2.2.2 Variation in drain current sensitivity with variation in pressure values.[14]

With adsorption of hydrogen gases, dipoles are formed at the interface of gate-oxide, the positively charged dipoles act as a puller for negative charges present in the substrate, causing an increase in negative charge carriers in channel region [5]. Hence, gives rise to enhancement in surface potential with increment in concentration of hydrogen gases. With enhancement in pressure, the minimum surface potential increases and threshold voltage diminishes It can be observed from Fig.2.2.2 that as pressures increase. Drain.

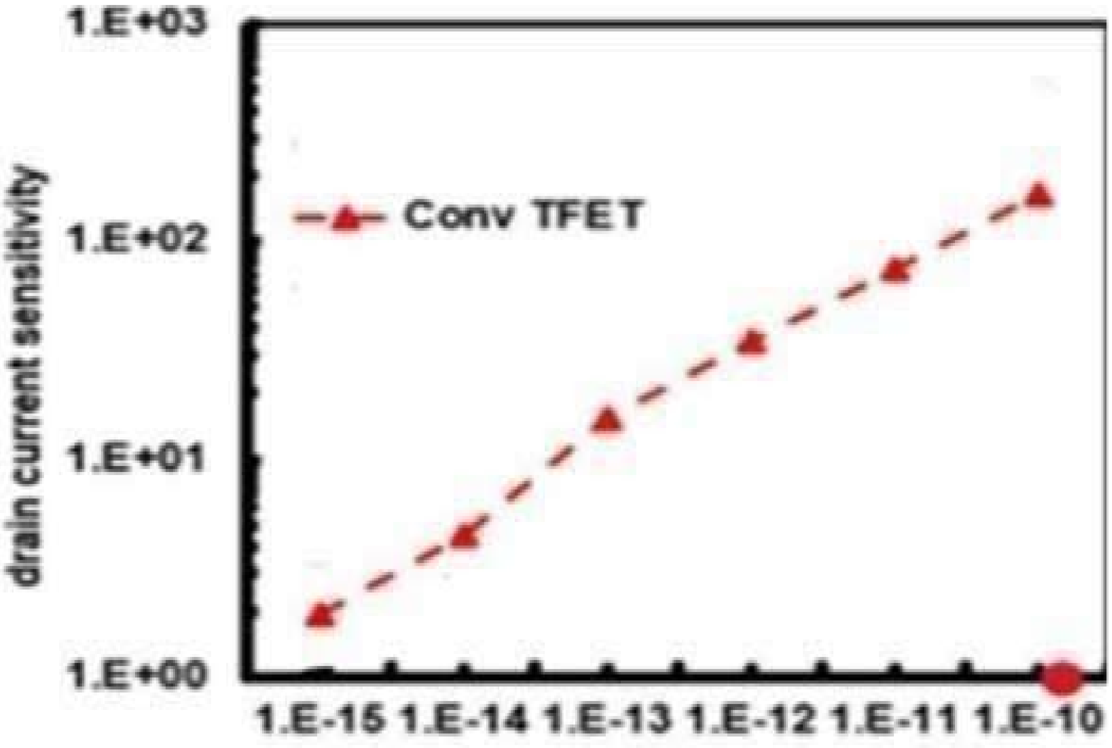


Fig. 2.2.3Variation in drain current sensitivity with variation in pressure values.[14]

With adsorption of hydrogen gases, dipoles are formed at the interface of gate-oxide, the positively charged dipoles act asa puller for negative charges present in the substrate, causing an increase in negative charge carriers in channel region [5]. Hence, gives rise to enhancement in surface potential with increment in concentration of hydrogen gases. With enhancement in pressure, the minimum surface potential increases and threshold voltage diminishes It can be observed from Fig.2.2.3 that as pressures increase drain. Short channel effects results in certain non-ideal effects such as channel length modulation, Drain Induced Barrier Lowering (DIBL)and velocity saturation [2] Multi- gate Surrounding Gate structures-based devices came into use to encounter the undesirable effects like short channel effects and uplifted the structural behavior towards linearity. It exhibits superior performance than bulk conventional MOSFET based devices with excessive scaling. The surrounding gate structure (SG)that covers the gate from all around, provides better flexibility and scalability as it has better grip over the gate section.

2.3 Charge Plasma Enhanced - TFET based H2gas Sensors.

The structure of Charge Plasma Enhanced TFET-based gas sensor [14]structures are shown in Fig.2-D structure is shown in fig.2.3.1, in which Silicon acts as substrate material while SiO_2 acts as insulating layer having thickness (t_{IL}) of 2nm, gate material possessing thickness(t) of 10 nm, channel width(t_{CH})is 10 nm, channel length(L) of 50nm, drain length and source length, both are 45nm,concentration of the n-typed doped drain source areas is 5x1018/cm3, p -typed source is 1x1018/cm3 whereas the p-type dopants in the channels of concentration 1x1012/cm3.Palladium (Pd) (work function of5.10 eV) is considered as a catalytic metal gate role is performed by pd (palladium) which exhibits work function of 5.10 eV.

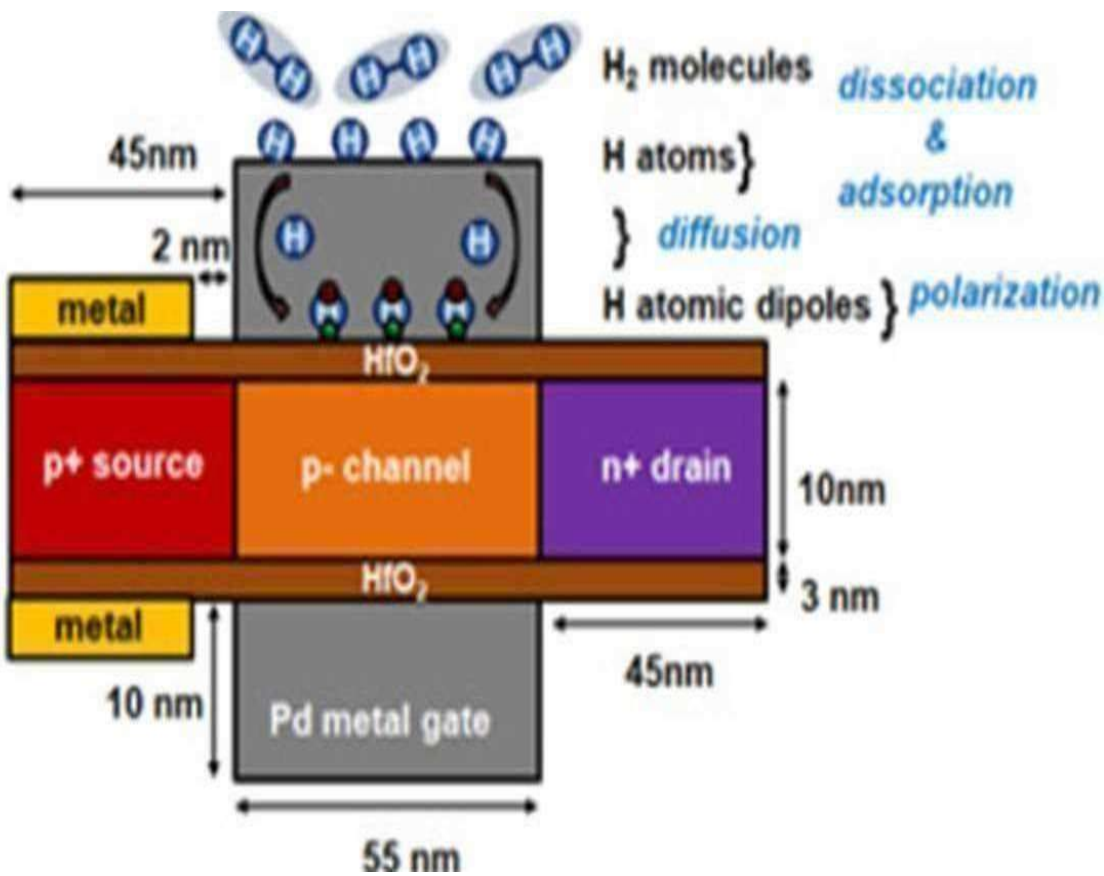
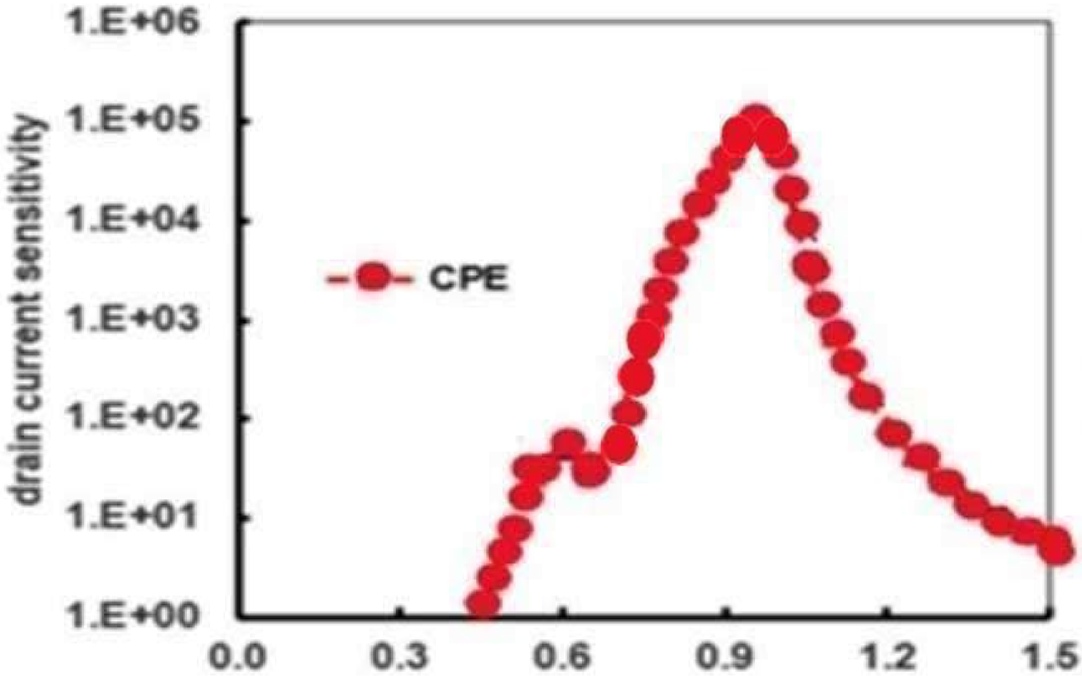


Fig.2.3.1 Schematic representation of Charge Plasma Enhanced -TFET based H_2 gas sensors.[14]

to enhanced work function, means raising the hole density as that of Conv-TFETs. Due to increased hole density for the same structure, increased dipole charges, so more pulling of negative charge carriers in the channel region. so increased in output current also, so from fig and fig more increased current sensitivity for the same variation in gate bias voltage is seen same is the case of drain current sensitivity variation with applied pressure values.[8] An enhancement in sensitivity is seen in case of CPE- TFET in compared to Conv- TFET, so CPE-TFET has been proven to possess higher sensitivity than Conv-TFET.[14]Tunneling Field Effect Transistors (TFETs) have ushered in a new era in semiconductor device physics, diverging from the conventional operation of Metal Oxide-Semiconductor Field Effect Transistors (MOSFETs) and introducing a novel approach to charge carrier transport. This departure from traditional transistor operation stems from the unique utilization of quantum tunneling phenomena, which allows for charge carrier transport across a thin insulating barrier. Unlike MOSFETs, where current modulation is achieved by manipulating the channel's conductivity through applied gate voltage, TFETs rely on quantum tunneling to facilitate charge transport. In TFETs, a sufficient gate voltage induces an energy barrier that enables electrons to tunnel from the source's valence band to the channel's conduction band. This process occurs in a region known as the tunneling region, characterized by distinct energy band configurations and transport mechanisms. The concept of band energy lies at the heart of TFET operation. Band energy refers to the minimum energy required for electrons to transition from the valence band to the conduction band. In TFETs, this transition occurs through quantum tunneling when a suitable gate voltage is applied. The energy band diagram, such as the one illustrated in Fig.2 for a Double Gate Nanowire TFET (DG-NCTFET), provides valuable insights into the energy levels of the valence band and conduction band, which are critical for understanding charge carrier transport mechanisms in TFETs. To activate the TFET and initiate current flow, electrons must tunnel across the energy barrier from the source's valence band to the channel's conduction band. This tunneling process is facilitated by the application of a gate voltage, which modulates the energy barrier and allows electrons to overcome the bandgap.

The energy band diagrams, with distinct traces for the conduction band and valence ban visually represent the energy states available for electron conduction and occupancy. One of the key advantages of TFETs is their potential for low-power operation. This stems from their ability to operate at lower supply voltages and exhibit reduced leakage current, attributes that are inherent to their reliance on tunneling mechanisms. This feature makes TFETs particularly promising for applications. requiring energy efficiency and high performance, such as portable devices and Internet of Things (IoT) systems. Ongoing research efforts in the field of TFETs are focused on optimizing device designs, exploring novel materials, and refining fabrication techniques to unlock their full potential. Researchers are investigating various TFET architectures, including DG-NCTFETs, to enhance device performance and efficiency. By leveraging advanced fabrication techniques, researchers aim to achieve precise control over device parameters such as channel length and doping profiles, which are critical for optimizing TFET operation. Moreover, the exploration of novel materials holds promise for improving TFET performance. Researchers are investigating materials with favorable band structures and tunneling properties to enhance device characteristics such as of state current and sub-threshold swing. Additionally, efforts are underway to integrate TFETs with complementary metal- oxide-semiconductor (CMOS) technology to realize hybrid devices with enhanced functionality and performance. Advancements in fabrication techniques are essential for realizing TFETs with reproducible and reliable characteristics. Techniques such as atomic layer deposition (ALD) and chemical vapor deposition (CVD) enable precise control over material deposition and interface engineering, crucial for optimizing TFET performance and reliability. Furthermore, advancements in nanofabrication technologies facilitate the fabrication of TFETs with reduced dimensions, enabling the realization of high-density integrated circuits with improved energy efficiency. In conclusion, TFETs represent a promising avenue for the development of low power, high-performance semiconductor devices. By harnessing quantum tunneling phenomena, TFETs offer unique advantages over conventional MOSFETs, making them well-suited for a wide range of applications in the field of electronics and beyond. Continued research efforts aimed at optimizing device designs, exploring novel materials, and advancing fabrication techniques are essential important aspects for all parts sections for unlocking.



Variation in gate voltage(V)

Fig.2.3.2Variation of drain current sensitivity with different gate voltage.[14]

2.4 MoS2, Based Dual Gate MOSFET structure with Metal gate as catalytic.

Fig.2.4.1 is 2D structure of the MoS2 based Dual MOSFET.[13] Itworked on the exploitation of concept of catalytic metal gate theory. It has 10nm channel length metal gate with work function as 5.20 1eV. has been distributed over the channel length region to invoke the chemical reaction among the hydrogen gas substituents and metallic gate (Pd), MoS2 body thickness is 7nm, and the length of source/drain is 10 nm. The low-k gate dielectric and the high-k gate dielectric has a thickness of 1nm and 2nm respectively. The n-typed source/drain region is doped with 1×1019 atoms/cm^3. N - channel region is doped with 1×10^{15} atoms/cm3.This has been simulated by using SILVACO ATLAS TCAD tool. It is depicted from below that effectively the off state.

current is reduced due to the metallic gate action with enhancement in gas concentration the device has negligible amount of OFF-state leakage current thus vanishing the short channel effects to a large extent. For sensing any physical quantity, a sensing parameter must be dependent on the former for getting notified. threshold.

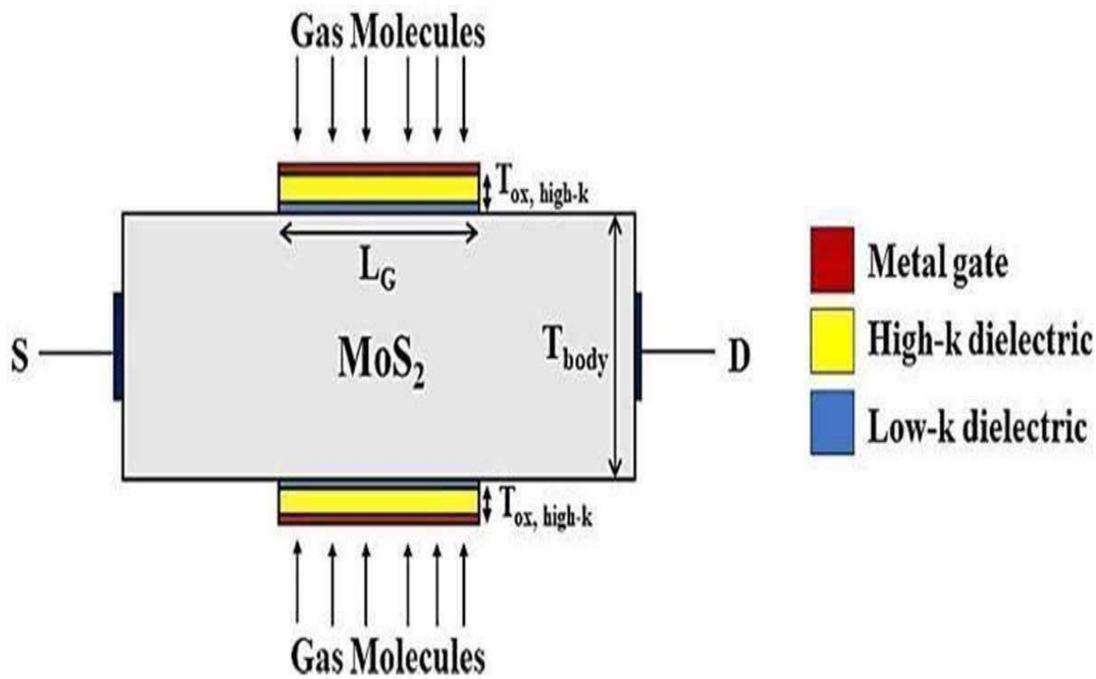
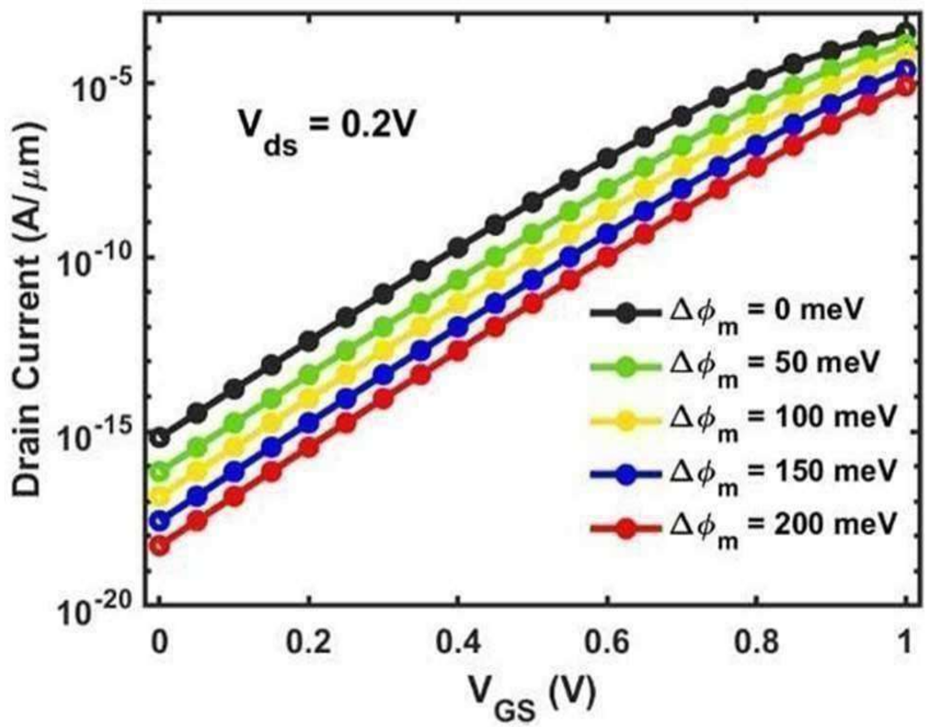


Fig.2.4.1 MoS2, Based Dual Gate MOSFET structure with Metal gate as catalytic.

chemical reaction and bring a difference of 50meV, in work function of gate metal henceforth changing the threshold voltage.[13] It is depicted from below that effectively the off-state current is reduced due to the metallic gate action with enhancement in gas concentration the device has negligible amount of OFF-state leakage current thus vanishing the short channel effects to a large extent. For sensing any physical quantity, a sensing parameter must be dependent on the former for getting notified, so here threshold voltage is acting as the sensing electrical parameter. It exhibits superior performance than bulk conventional MOSFET based devices with excessive scaling. The surrounding gate structure (SG)that covers the gate from all around, provides better flexibility and scalability as it has better grip over the gate section.



Variation in gate to source voltage

Fig.2.4.2 Characteristics against the variation of metal work function due togas absorption.[13]

that affects all output, input characteristics of a gas sensor, henceforth we detect the gas through characteristics.**[9]** effects that downs the performances considerably. Short channel effects results in certain non- ideal effects such as channel length modulation, Drain Induced Barrier Lowering (DIBL)and velocity saturation [2]. With adsorption of hydrogen gases, dipoles are formed at the interface of gate-oxide, the positively charged dipoles act asa puller for negative charges present in the substrate, causing an increase in negative charge carriers in channel region [5]. Hence, gives rise to enhancement in surface potential with increment in concentration of hydrogen gases. With enhancement in pressure, the minimum surface potential increases and threshold voltage diminishes It can be observed from Fig.2.4.2 that as pressures increase. drain. Short channel effects results in certain non-ideal effects such as channel length modulation, Drain Induced Barrier Lowering (DIBL)and velocity saturation [2] Multi-gate Surrounding Gate structures-based devices came into use to encounter the undesirable effects like short channel effects and uplifted the structural behavior towards linearity. It exhibits superior performance than bulk conventional MOSFET based devices with excessive scaling. The surrounding gate structure (SG)that covers the gate from all around, provides better flexibility and scalability as it has better grip over the gate section.

2.5 Pt/Pd-Silicon Dioxide Junctionless FinFET hydrogen sensor.

The device structure contains SiO2, n-Si channel. The doping concentration of the FinFET is 1x1019 cm-3 Channel length of 50nm SiO2 of 2nm thick catalytic palladium gate od width 10 nm The height (Hfin) is 40 nm thickness (Tfin) of fin is considered as 10nm VDS is maintained to be 0.1V for hydrogen gas sensor.[1]

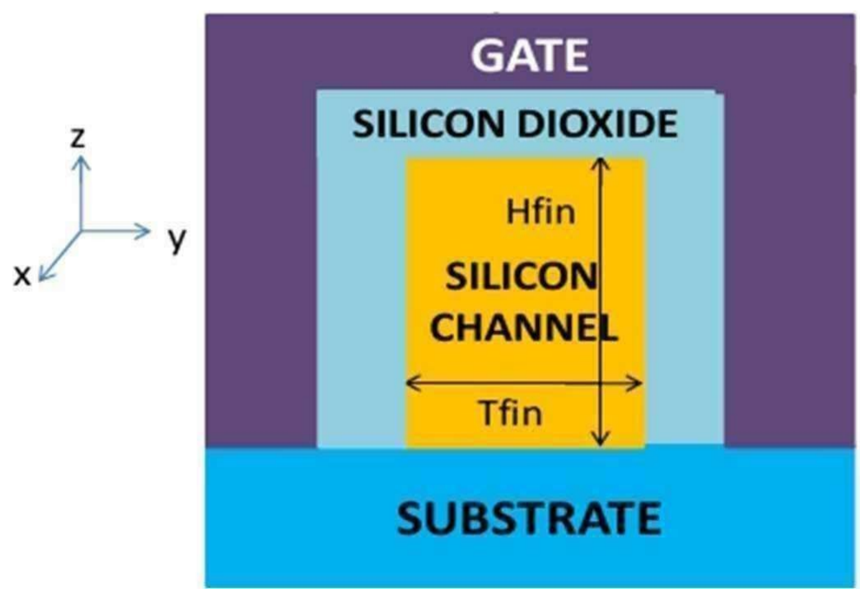


Fig 2.5.1 2-D structure of JL FINFET.

Variation of threshold voltage sensitivity with variation in pressure or concentration of hydrogen gas is observed, due to change in work function of gate metal, threshold voltage also changes which is an important detection metric parameter as other sensing parameter depends majorly on threshold With adsorption of hydrogen gases, dipoles are formed at the interface of gate-oxide.

with variation in Drain Voltage at different Pressures or different hydrogen concentration, different response of output conductance can be observed. In fig D.3Variation of threshold voltage sensitivity with variation in pressure or concentration of hydrogen gas is observed, due to change in work function of gate metal, threshold voltage also changes which is an important detection metric parameter as other sensing parameter depends majorly on threshold**.**

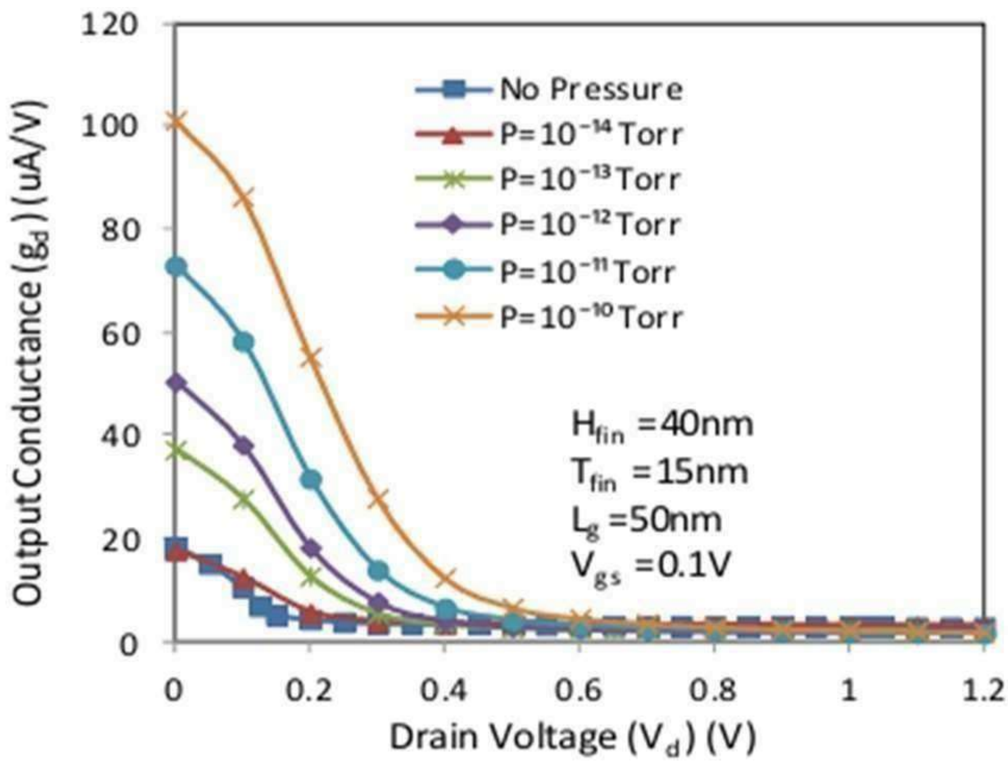
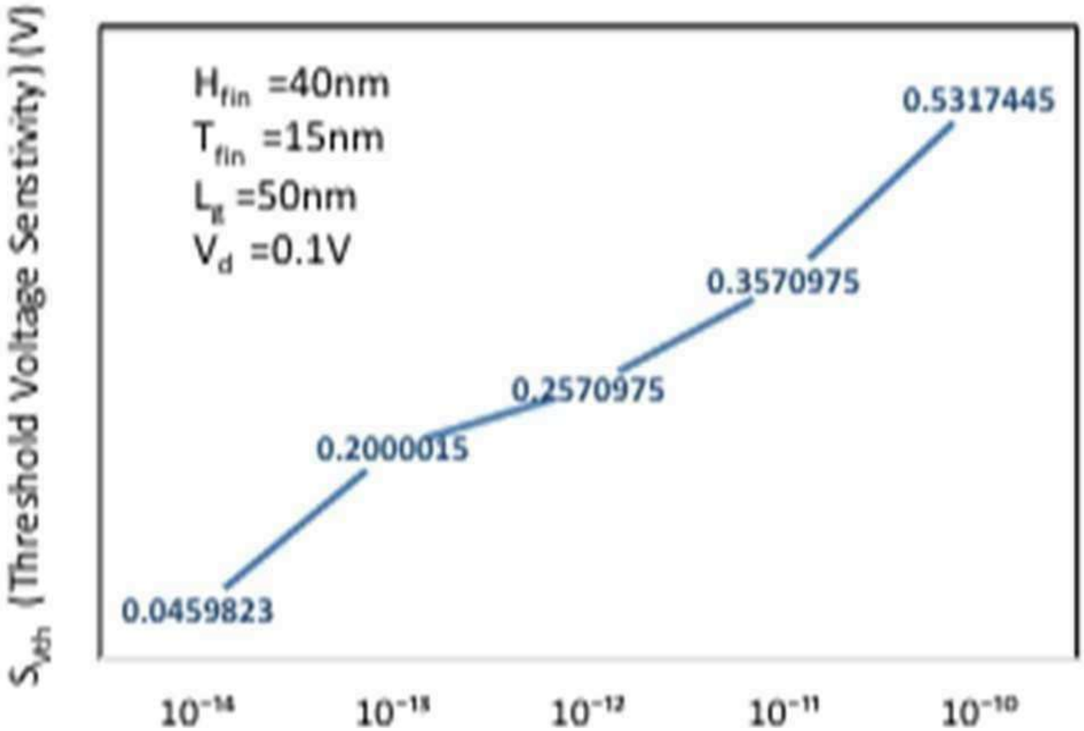


Fig.2.5.2 Variation of output conductance with drain bias voltages at different pressure or concentration of hydrogen.

Hydrogen gases, dipoles are formed at the interface of gate-oxide, the positively charged dipoles act as a puller for negative charges present in the substrate, causing an increase in negative charge carriers in channel region. Hence, gives rise to enhancement in surface potential with increment in concentration of hydrogen gases. With enhancement in pressure, the minimum surface potential increases and threshold voltage diminishes.



Variation of applied pressure (Torr)

Fig.2.5.3 Variation of threshold voltage sensitivity to different values of pressure (Torr) or concentration of hydrogen gas [1].

It exhibits superior performance than bulk conventional MOSFET based devices with excessive scaling. The surrounding gate structure (SG)that covers the gate from all around, provides better flexibility and scalability as it has better grip over the gate section. It worked on the exploitation of concept of catalytic metal gate theory. It has 10nm channel length metal gate with work function as 5.20 1eV. has been distributed over the channel length region to invoke the chemical reaction among the hydrogen gas substituents and metallic gate (Pd), MoS2 body thickness is 7nm, and the length of source/drain is 10 nm. the low-k gate dielectric and the high-k gate dielectric has a thickness of 1nm and 2nm respectively. The n-typed source/drain region is heavily doped with 1×10^{19} atoms/cm^3.

2.6 Gate-All-Around Nanowire Junctionless Transistor.

It exhibits superior performance than bulk conventional MOSFET based devices with excessive scaling. The surrounding gate structure (SG)that covers the gate from all around, provides better flexibility and scalability as it has better grip over the gate section. With miniaturization, in drain source junction management of doping and thermal budget becomes challenging. To avoid these too many challenges Junction less transistor came into scenario because of its simplicity in fabrication and various other advantages related to characteristics parameters. Surrounding gate structure has superior coverage surface than volume which imparts fine surface to volume ratio and its strong control over gate proves surrounding gate structures superior to be exploited for the device structure over existing conventional structures because of enhancement in sensitivity parameters.

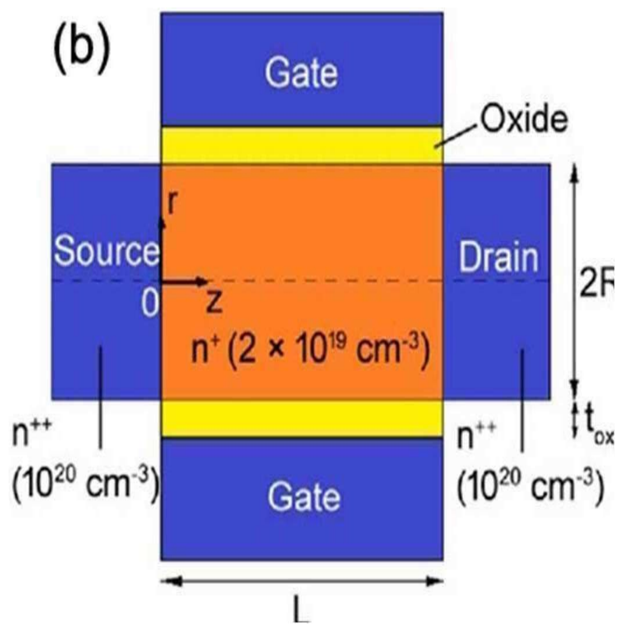
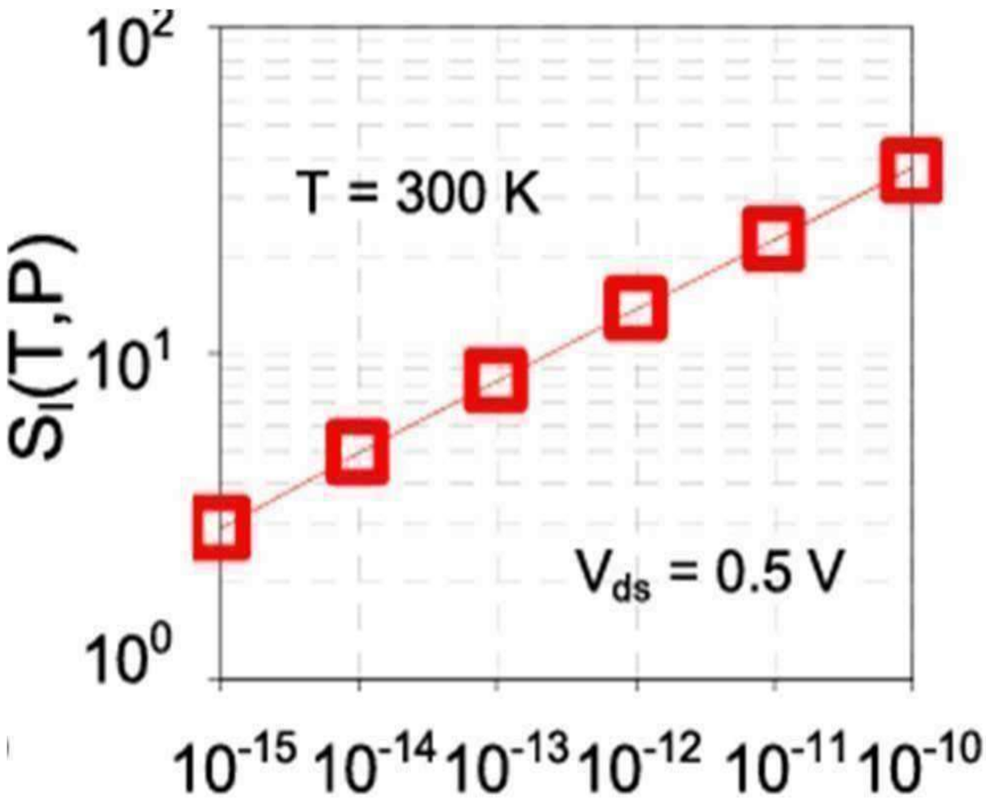


Fig.2.6.1 2-D Schematic of Gate-All-Around Nanowire JunctionlessTransistor**.[15]**

Junctionless Mode Surrounding Gate (JAM-SG) is used as a hydrogen sensor, as it avoids the formation of drain- source junction so, no junction resistance region is created, which increases conductivity. The proposed device's 2-D structure [15]is shown in fig.2.6.1, in whichSilicon acts as substrate material while SiO_2 acts as insulating.

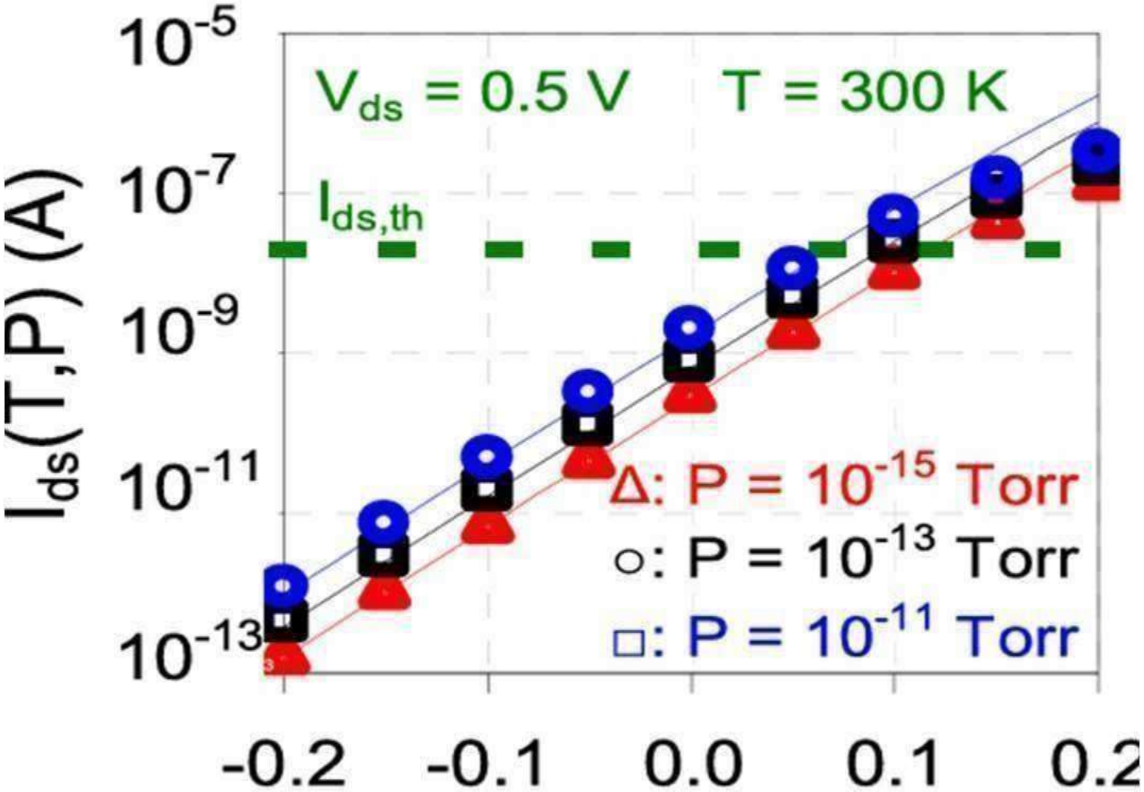
layer having thickness (t_{IL}) of 2 nm, gate oxide material possessing thickness(tG) of 2 nm, channel width(t_{CH})is 10nm, channel length(L)of 30nm, drain length and source length, both are10nm concentration of the n-typed doped drain-source areas is $1x10^{20}$/cm3, whereas the n-type dopants in the channel is of concentration $2x10^{19}/cm^3$Pd (Work function of 5.2 eV) acts as a catalytic gate metal. Variation of drain current sensitivity with variation in pressure values at fixed temperature of 300K, there is an increase in electron concentration with rising pressure. This concludes electrons invaded from the channel region because of decrement in the work function of metallic gate is lesser in number. this means enhanced number of electrons are available in the channel at increased pressures for the purpose of conductivity, therefore leading to increased drain with rising pressure.[15]



Variation of Pressure values at constant temperature(300K)

Fig.2.6.2 Variation of drain current sensitivity with variation in pressure values at (T=300K [15}

In Fig.2.6.2 Variation of drain current sensitivity with variation in pressure values at (T=300K). There occurs creation of different work function, hence different threshold voltages, hence different output current variation can be observed for different pressure, values or different hydrogen concentration in surroundings.[15] variation in Threshold voltage which in turn varies all other output parameters like drain current, output conductance, transconductance being a crucial parameter Gate bias voltage**.**



Gate Bias Voltage (V)

Fig.2.6.3 Variation of drain current with variation in gate bias voltage different values of pressures applied

2.7 PNIN-GAA-Tunnel FET with Palladium Catalytic Metal Gate as a Highly Sensitive Hydrogen Gas Sensor.

Fig.2.7.1 shows the 3-D schematic view of the device[12] , consists of a source doped with1×10^{20} cm^{-3} , an intrinsic (i) channel and a n+ drain doped with 5×10^{18} cm^{-3} with an n+ accumulation at the source channel interface., channel length is 50 nm its radius as 10 nm , and gate oxide thickness is 3 nm .The source pocket width being 4 nm and doping is 4×1019 cm-3 Pd .This device due to cylindrical structure has better controllability and grip over gate than preexisting structures such as double, triple gate structured MOSFET ,also it provides enhanced sensitivity output to Pd element.

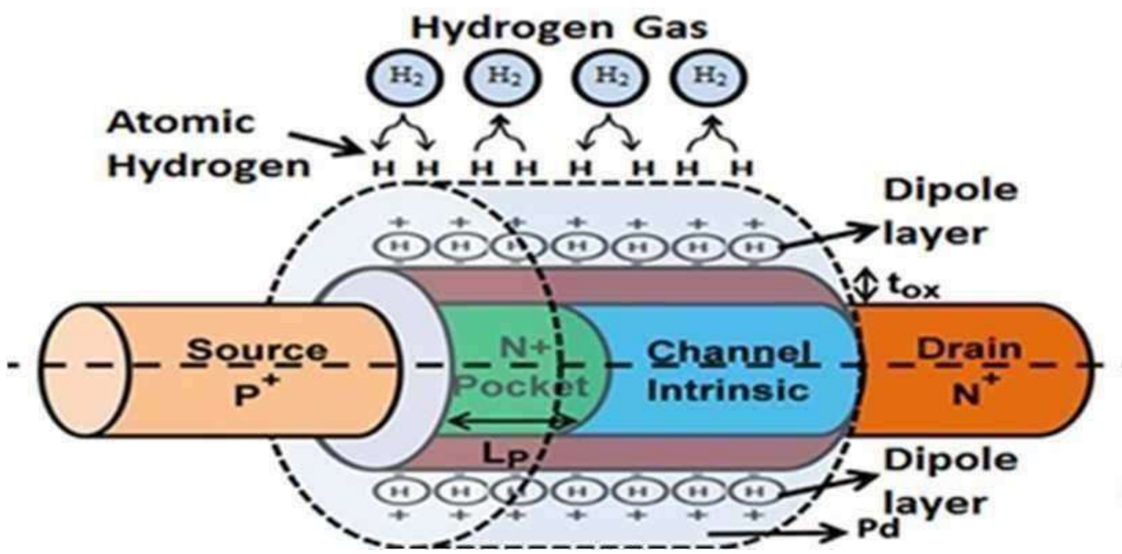
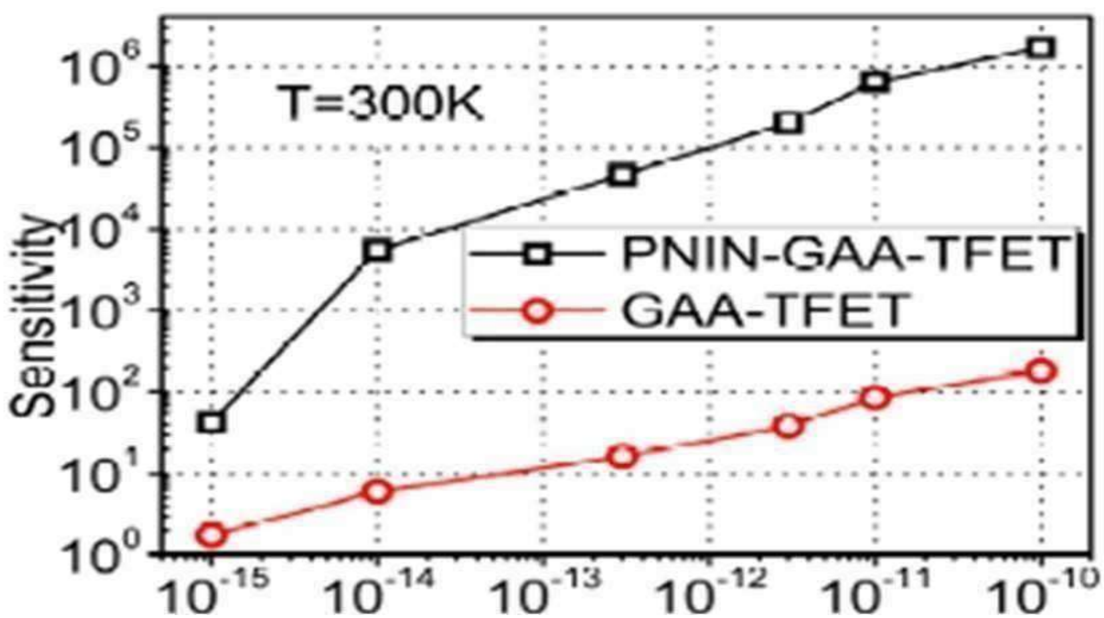


Fig.2.7.11the 3-D schematic view of the device [12].

In Fig.2.7.1, sensitivity of this versus gas pressure at fixed temperature. Increased sensitivity can be observed to a great extent because of accumulation of more n+ source, pocket, that decreases the negatively affecting tunneling barrier width, making contribution to more drain current hence by enhanced sensitivity is achieved. PNIN-GAA- Tunnel FET has more enhanced sensitivity than conventional GAA structure.[12] discusses results obtained for different characteristics parameters surface potential, electron velocity, electric field, drain current, output conductance and transconductance at two different values of pressures10^{-14} (Torr) to 10^{-15} (Torr), used for observing the sensitivity of device, because with different values of pressures the above electrical properties have shown different characteristics, which is used for detection of hydrogen gases. Finally, Section 5 contains the conclusive portion of the paper



Hydrogen gas pressure (Torr)

Fig.2.7.2Variation of sensitivity with variation in different values of pressures applied at (T=300K).

2.8 Junctionless Accumulation Mode Surrounding Gate (JAM-SG)

Junctionless Accumulation Mode Surrounding Gate (JAM-SG) is used as a hydrogen sensor, as it avoids the formation of drain-source junction so, no junction resistance region is created, which increases conductivity. Now we are proposing Junctionless Accumulation Mode Surrounding Gate (JAM-SG) to compensate these limitations [3]. Due to high doping of source and drain, immunity to mobility degradation is built and ease fabrication. It also improves below par threshold voltage swings and threshold voltage instability. The proposed JAM -SG gas sensor exploits the phenomena of adsorption for the detection of the hydrogen gas. As the presence of hydrogen gas is felt by the metallic gate, variation in work function of the metallic gate which alters the threshold voltages, thus the characteristics parameters associated sensitivities would be considerable and observable, which can be used for the detection of hydrogen gases [1]. It is important to note that temperature should be maintained at room temperature because variations in temperature causes vapor pressure changes, which in turn affects the adsorption rate of hydrogen gas, thus imbalances the mathematical calculations [9]

2.9 Work done in Project.

The proposed hydrogen gas sensor has been used in analysis of. different characteristics parameters like surface potential, electric field, electron velocity, drain current, output conductance, and transconductance to detect the presence of hydrogen gas. The device has been simulated on Silvaco Atlas TCAD (Technology Computer Aided Design) device simulator. Section 2 outlines the basic three dimensional and two-dimensional structural view of the JAM-SG hydrogen gas sensor. Section 3 discusses results obtained for different characteristics parameters surface potential, electron velocity, electric field, drain current, output conductance and transconductance at two different values of pressures10^{-14} (Torr) to 10^{-15} (Torr), used for observing the sensitivity of device, because with different values of pressures the above electrical properties have shown different characteristics, which is used for detection.

CHAPTER-3 SIMULATION RESULTS AND DISCUSSION

3.1 Device Structure.

The proposed device's 3-D structure is shown in fig3.1Silicon acts as substrate material while SiO2 acts as insulating layer having thickness (t_{IL}) of 2 nm, gate material possessing thickness(t_G) of 2 nm, channel width(t_{CH})is 10nm, channel length(L) of 30nm, concentration of the n-typed doped drain-source areas is $1x10^{19}/cm^3$, whereas the n-type dopants in the channel is of concentration $1x10^{16}/cm$. table is framed which contains values of different parameters of the device [2].

Fig.3.1.1 3-D view of Junctionless Accumulation Mode Surrounding Gate (JAM-SG).

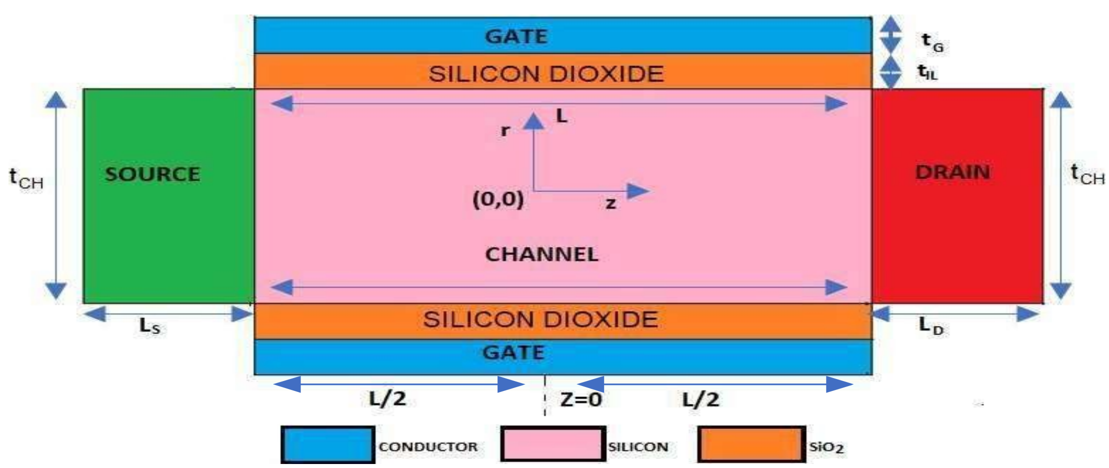


Fig.3.1.2 3-D view of Junctionless Accumulation Mode Surrounding Gate (JAM-SG).

Table 1 Different values of parameters.

Parameters	Symbol	JAM-SG
Channel length	L(nm)	30
Channel width	t_{CH}	10
Gate material thickness	t_G(nm)	2
Insulator thickness	t_{IL}(nm)	2
Source/Drain doping conc.	N(cm^{-3})	$1x10^{19}$
Channel doping conc.	N(cm^{-3})	$1x10^{16}$
Gate metal work function	ϕ_m (eV)	5.0eV,5.2eV,

The proposed hydrogen gas sensor has been used in analysis of. different characteristics parameters like surface potential, electric field, electron velocity, drain current, output conductance, and transconductance to detect the presence of hydrogen gas. To avoid these too many challenges Junction less transistor came into scenario because of its simplicity in fabrication and various other advantages related to characteristics parameters. Surrounding gate structure has superior coverage surface than volume which imparts fine surface to volume ratio and its strong control over gate proves surrounding gate structures superior to be exploited for the device structure over existing conventional structures because of enhancement in sensitivity parameters

3.2 Analysis of various Parameters.

In fig.3.2.1 and fig.3.2.2 are the contour plot, at different valued pressure of 10^{-14}(Torr) and of 10^{-15} (Torr)respectively. In the surrounding different concentration of hydrogen gases gives rise to differently valued pressure at metallic gate interface, as we know that pressure and work function are corelated as

$$\Delta\emptyset\mathbf{m}(\mathbf{P}) = -\left(\frac{\theta \mathbf{i} \mathbf{N} \mathbf{i} \mu}{\varepsilon}\right) \text{---- (i)}$$

θi represents the fraction or percentage of the surface area of the metallic gate dioxide interface that is covered by adsorbed hydrogen, Ni denotes the overall number or density of locations on the interface where hydrogen can bind or adsorb, μ defines the induced dipole moment due to hydrogen and ε is free space's permittivity [1]. In fig 3.2.1and fig 3.2.2, contours of surface potential are plotted at two different pressure values of 10^{-14} (Torr) 10^{-13} (Torr)respectively. With adsorption of hydrogen gases, dipoles are formed at the interface of gate oxide the positively charges dipoles act as a puller for negative charges present in the substrate, hence, gives rise to enhancement in surface potential with increment in concentration of hydrogen gases. It can be observed from figures that as pressures is change from 10^{-14} (Torr) to 10^{-13} (Torr), different results for surface potential were observed.

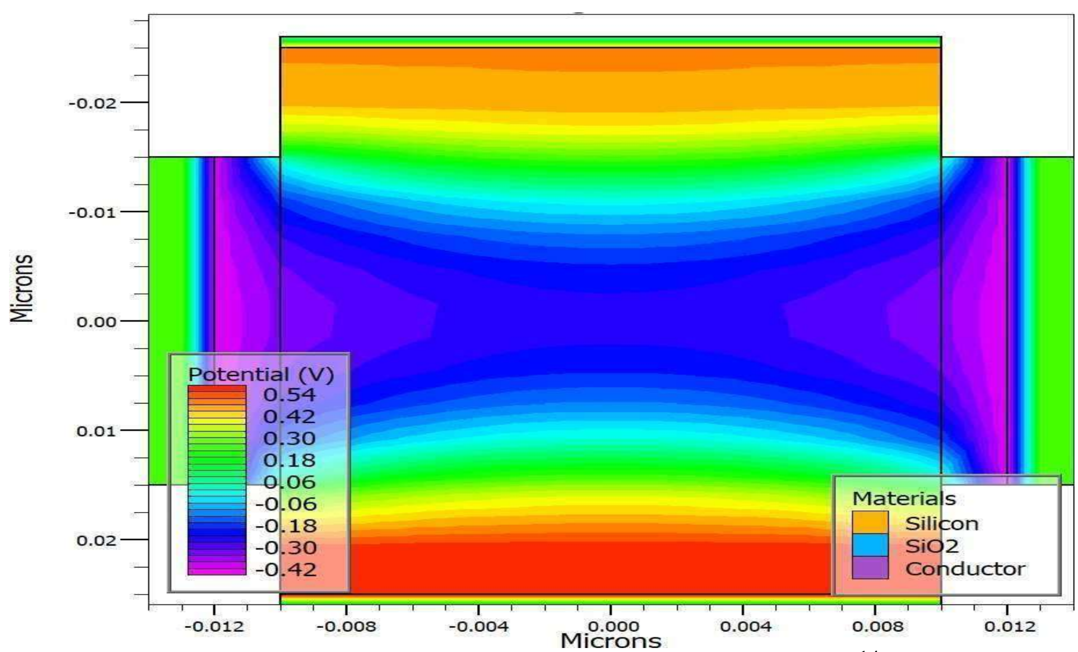


Fig.3.2.1 Potential for JAM -SG Sensor at pressure of 10^{-14} (Torr).

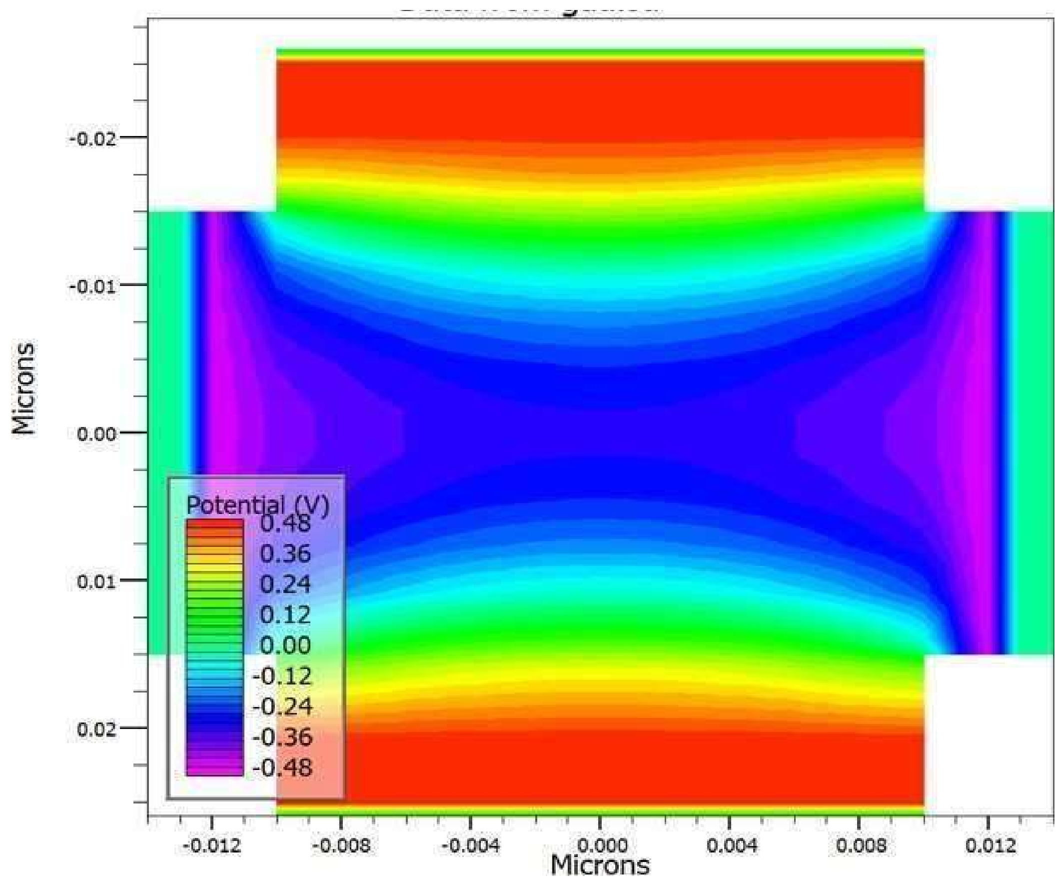


Fig.3.2.2 Potential for JAM-SG Gas Sensor at pressure of 10^{-13} (Torr).

Fig.3.2.1 .and fig.3.2.2 are the contour plots of Electric field for different values of pressure of 10^{-14}(Torr) and 10^{-13}(Torr) respectively [8].

$$E = -\frac{dV}{dx} \qquad \textbf{(ii)}$$

Where E is Electric filed generated due to potential V in device. As, we discussed, there was variation in potential with pressure, so the negative space derivative of electric potential also varies that is electric field. From contour plot it can be seen that that as pressures is changed from 10^{-14} (Torr) to 10^{-13} (Torr), different results for electric field are obtained [10].

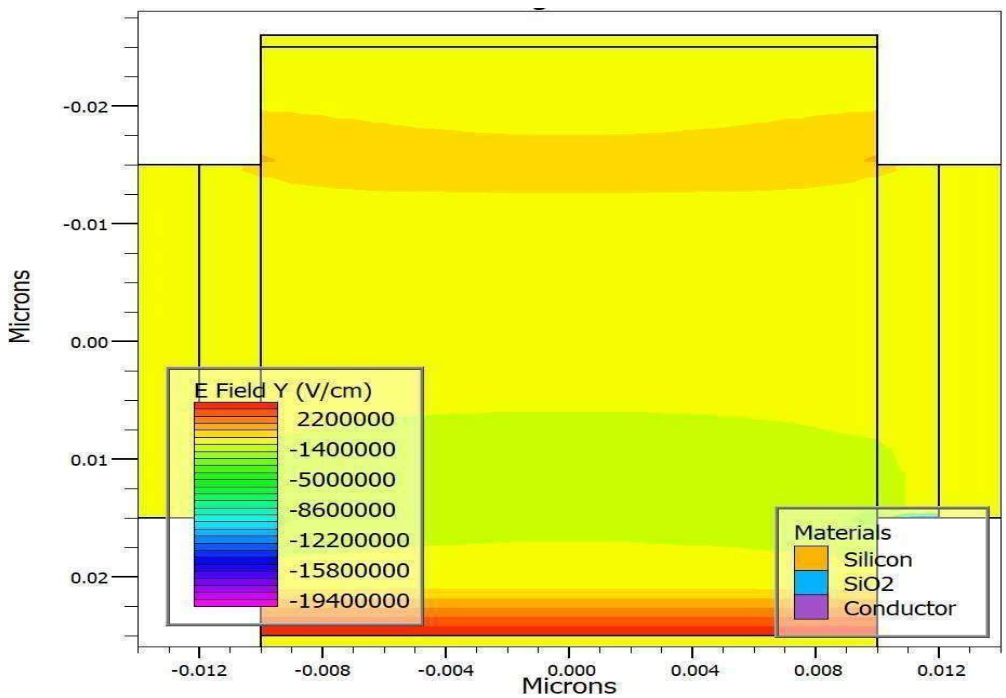


Fig.3.2.3 Variation of electric field in JAM-SG device at pressure of10^{-14}Torr

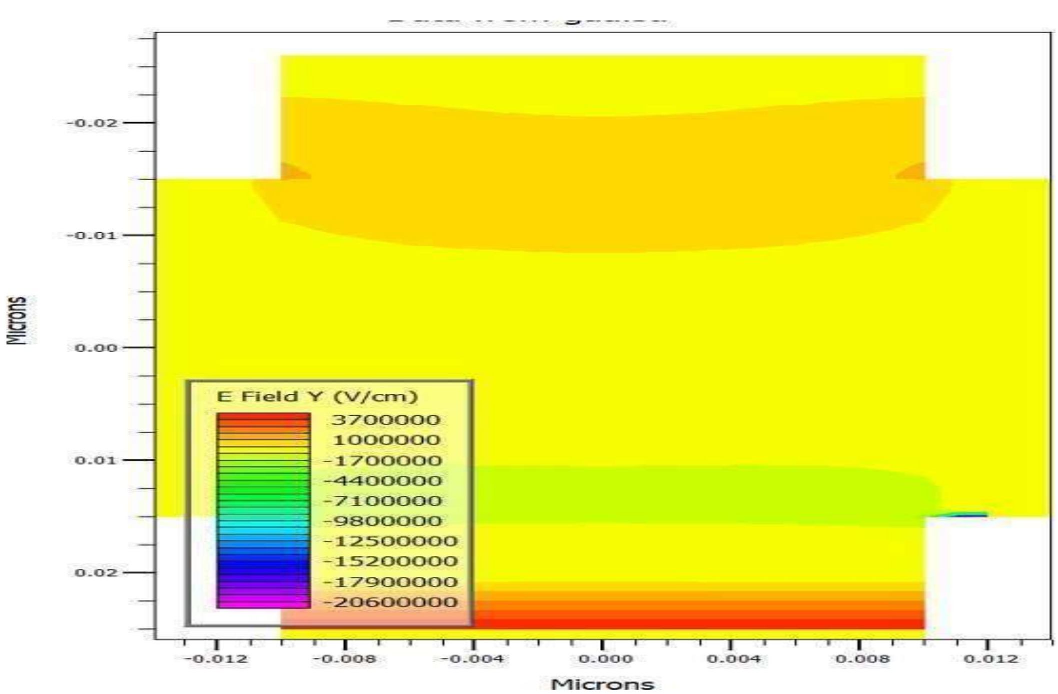


Fig.3.2.4 Variation of electric field in JAM-SG device at pressure of 10^{-13}Torr

Electron velocity is defined rate of motion of electron in the conductor. It is directly dependent on surface potential. In fig 3.2.5and fig.3.2.6 electron velocity contour results have been obtained at pressure of 10^{-14}(Torr) and 10^{-13}(Torr) respectively [6]. Electron velocity and potential are related to each other so as pressures is changed, different contours have been obtained. Junction less transistor came into scenario because of its simplicity in fabrication and various other advantages related to characteristics parameters. Surrounding gate structure has superior coverage surface than volume which imparts fine surface to volume ratio and its strong control over gate proves surrounding gate structures superior to be exploited for the device structure over existing conventional structures because of enhancement in sensitivity parameters.

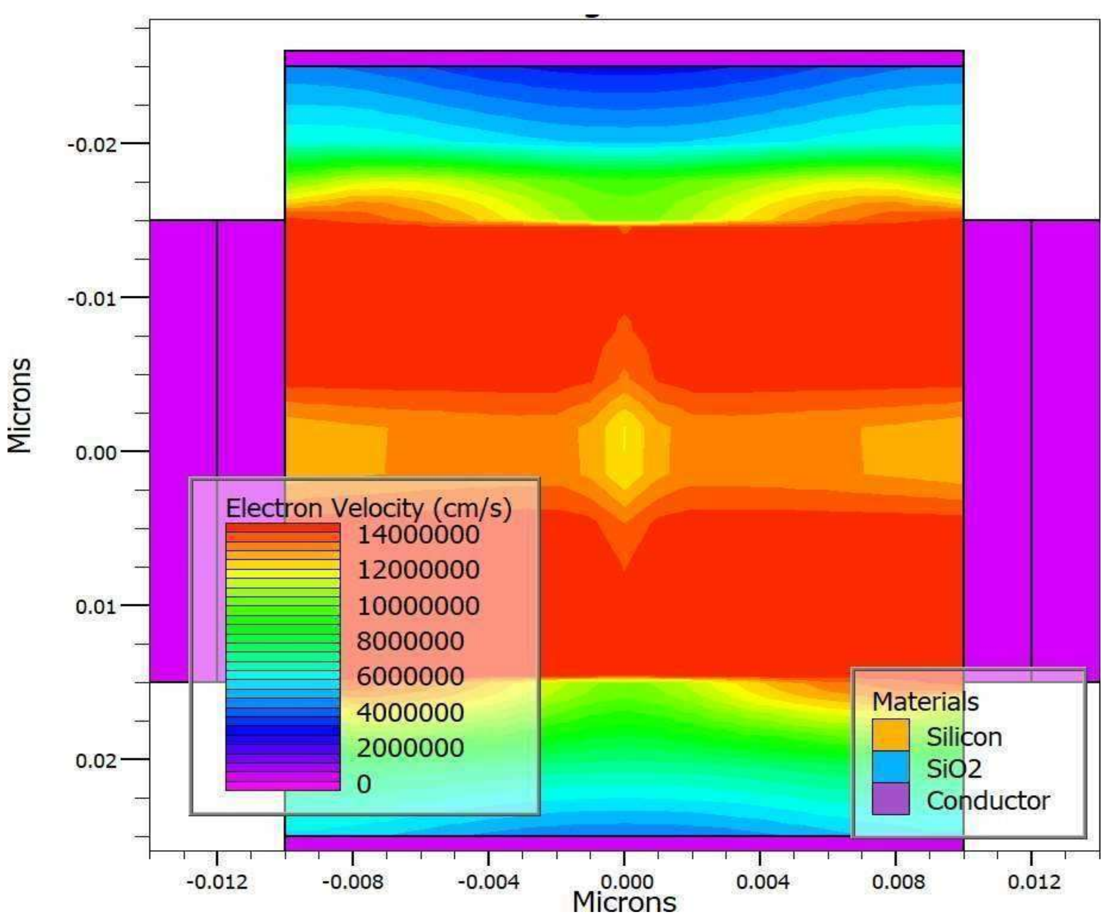


Fig.3.2.5 Electron Velocity JAM-SG device at pressure $=10^{-14}$ Torr

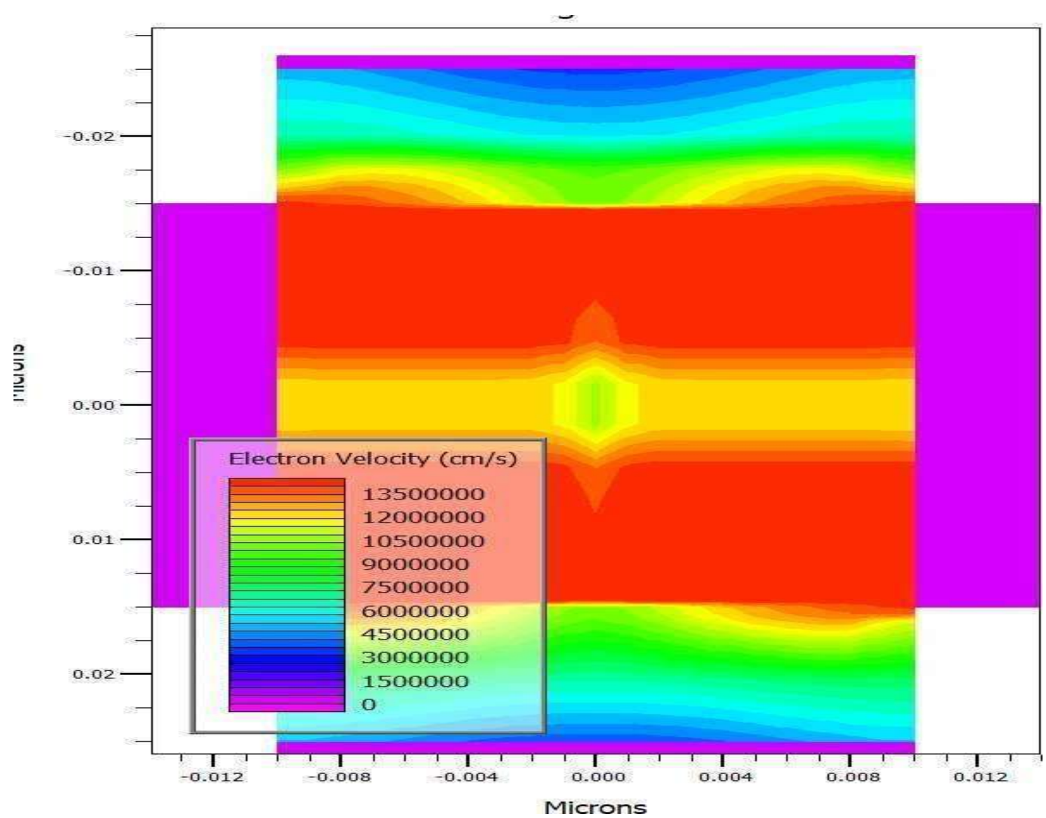


Fig.3.2..6 Electron velocity JAM-SG device at pressure =10^{-13}Torr

In fig.3.2.6, graph has been plotted for drain current versus drain to source voltage at different pressures of 10^{-14}(Torr) and 10^{-13}Torr, maximum drain current is 15.59µA at VDS =1V and 5.31µA at VDS=1Vrespectively. Different pressures impart different work function, which alters threshold voltages owing to the change in the dipole moment which varies the charge carrier concentration, generating different output current variation for different pressures, giving us an observable indication to sense the hydrogen gas [7]. Junction less transistor came into scenario because of its simplicity in fabrication and various other advantages related to characteristics parameters. Surrounding gate structure has superior coverage surface than volume which imparts fine surface to volume ratio and its strong control over gate proves surrounding gate structures superior to be exploited for the device structure over existing conventional structures because of enhancement in sensitivity parameters.

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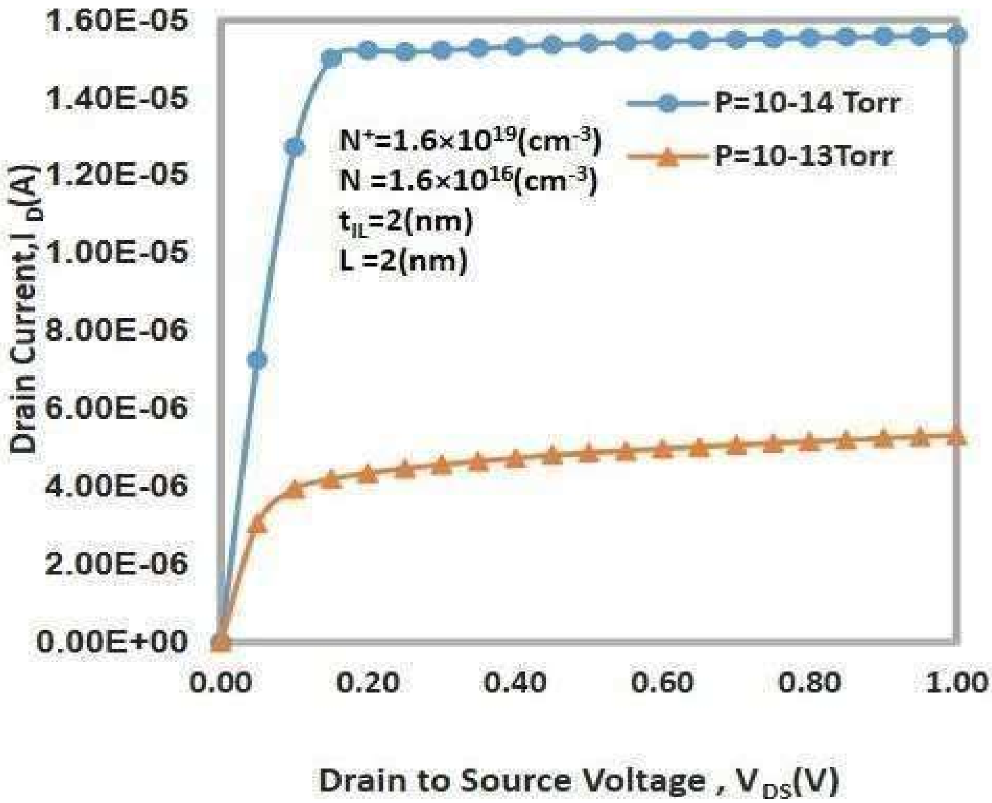

Fig.3.2.7 Variation in drain current versus drain to source voltage at different pressures

iI output conductance versus drain to source voltage graph, at different pressures of 10^{-14}(Torr) and 10^{-13}(Torr) have been plotted, with maximum output conductance of 61.2(μA/V) at V_{DS}=0V and 145(μA/V) at V_{DS} =0V respectively. In the surrounding different concentration of hydrogen gases gives rise differently valued pressure at metallic gate interface, which creates alters the work function, consequently variation in threshold voltages alters the charge carrier concentration in the channel rise giving rise to different output conductance at different pressures.

The proposed JAM -CG gas sensor exploits the phenomena of adsorption for the detection of hydrogen gas. As the presence of hydrogen gas is felt by the metallic gate, variation in work function of the metallic gate which alters the threshold voltages, thus the charact-eristics parameters associated sensitivities would be considerable and observable, which can be used for the detection of hydrogen gases [1]

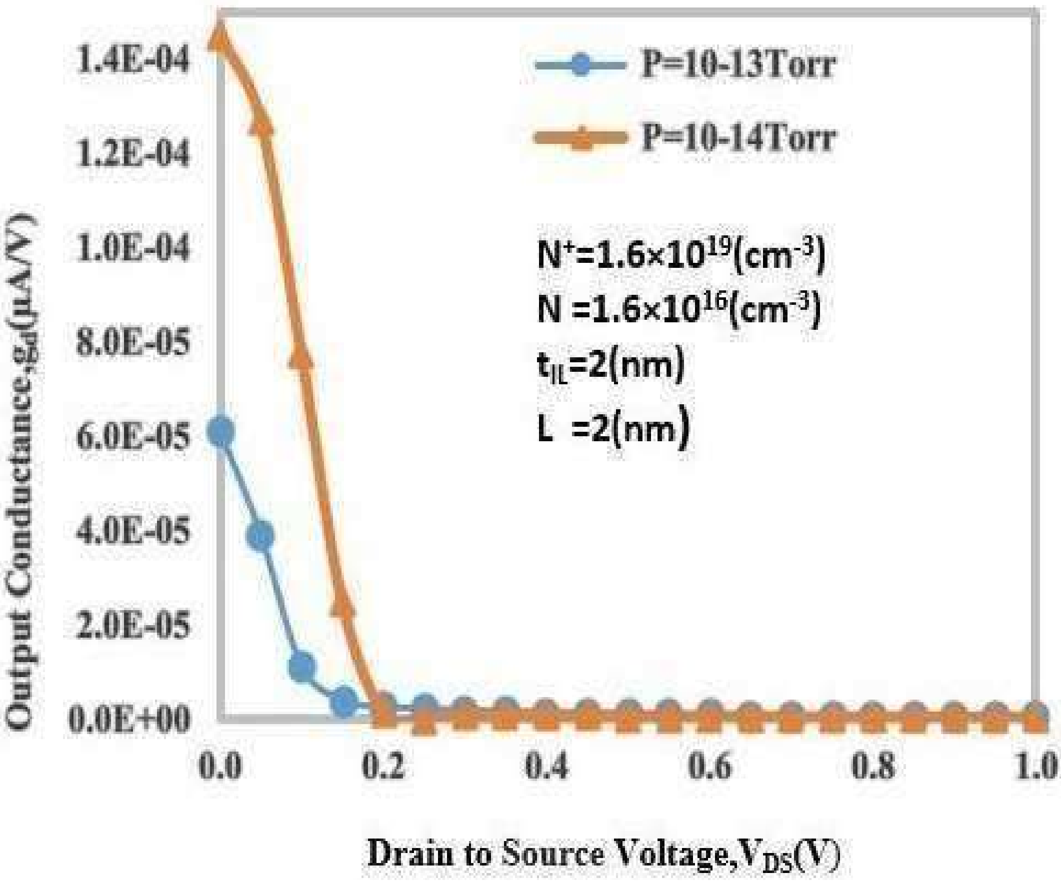

Fig.3.2.8 Variation in output conductance versus drain to source voltage at different pressure.

In fig.3.2.8, with the variation with gate to source voltage, drain current changes due to presence of hydrogen concentration, gives rises to pressure, hence increased number of charge carriers are added, due to this at different pressure values of 10 $^{-13}$(Torr) and 10^{-14} $^{(}$Torr)the maximum drain current obtained are 1.5µAat V_{GS}=1V and 0.84µA at V_{GS}=1V respectively]. It is important to note that temperature should be maintained at room temperature because variations in temperature causes vapor pressure changes, which in turn affects the adsorption rate of hydrogen gas, thus imbalances the mathematical expressions and ambo logical differences calculations.

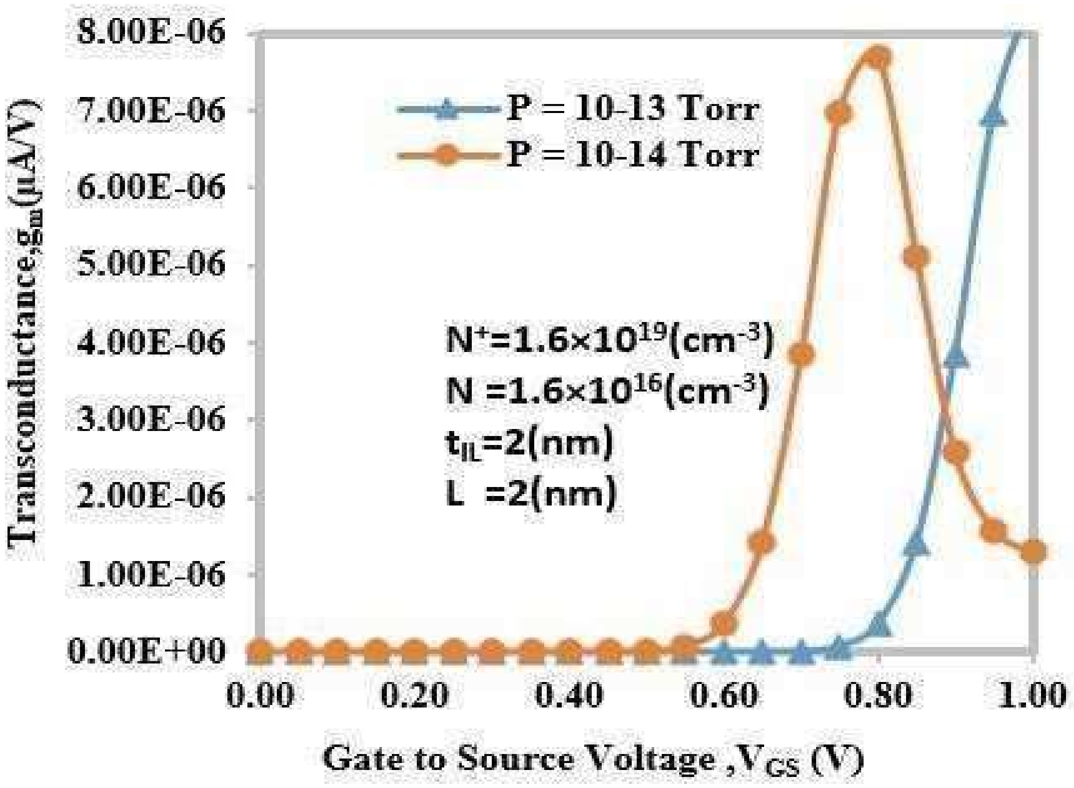

Fig.3.2.9 Variation in output current versus gate to source voltage at different pressure

In fig.3.2.9, variation in transconductance versus gate to source voltage at different pressure are plotted. Variation in hydrogen concentration gives rise to different charges carriers in the channel, which generates different drain current, therefore transconductance also varies with different concentration of hydrogen gases. At different valued pressure of 10^{-14}(Torr) and 10^{-13}Torr the transconductance of 1.295(µA/V) at VGS=1V and 8.45(µA/V) at VGS=1V are obtained respectively. The difference in transconductance is due to the fact that in the surrounding different concentration of phosphine gases gives rise differently valued pressure at metallic gate interface, which creates alters the work function, consequently variation in threshold voltages alters the charge carrier concentration in the channel rise giving rise to different transconductance at different pressures [1].

In fig.3.2.10, variation in transconductance versus gate to source voltage at different pressure are plotted. Variation in hydrogen concentration gives rise to different charges carriers in the channel, which generates different drain current, therefore transconductance also varies with different concentration of hydrogen gases. At different valued pressure of 10^{-14}(Torr) and 10^{-13}Torr the transconductance of 1.295(μA/V) at V_{GS}=1V and 8.45(μA/V) at V_{GS}=1V are obtained respectively. The difference in transconductance is due to the fact that in the surrounding different concentration of phosphine gases gives rise differently valued pressure at metallic gate interface, which creates alters the work function, consequently variation in threshold voltages alters the charge carrier concentration in the channel rise giving rise to different transconductance at different pressures [1].

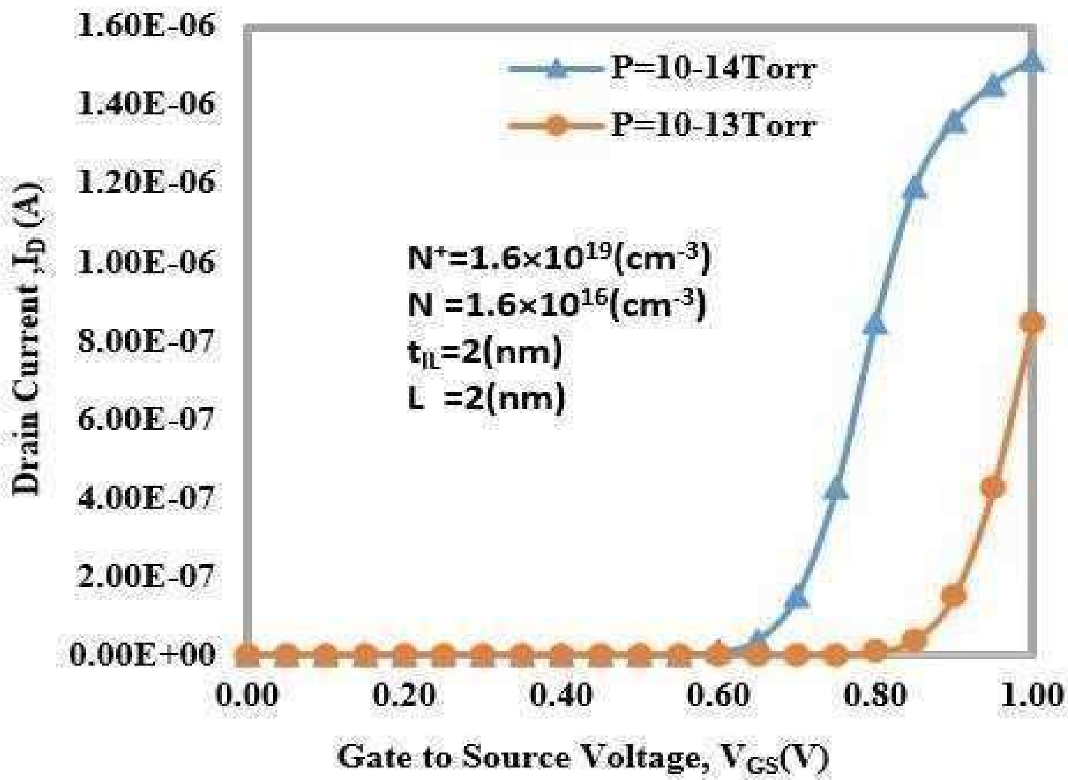

Fig.3.2.10Variation in transconductance versus gate to source voltage at different pressure

CHAPTER-4: CONCLUSION

4.1 Summary of Findings.

Analysis of Junction less Accumulation Mode Surrounding Gate (JAM-SG) has been carried out as an effective hydrogen gas sensor, through Atlas Silvaco TCAD simulation. The results are observed at different pressures which feature considerable changes in characteristics parameters of the device [6]. At pressure of 10^{-14}(Torr), work function of 5.0eV gets generated at metallic gate, the maximum output conductance of 145(µA/V) at V_{DS}=0V and maximum output current of 15.59µA at V_{DS}=1V is obtained, transconductance achieved maximum value of 7.7(µA/V) at V_{GS}=0.8V. At pressure of 10^{-13}(Torr), work function of 5.2eV gets generated at metallic gate, the maximum output conductance of 61.2(µA/V) at V_{DS}=0V and maximum output current of 5.31µA at V_{DS}=1V is obtained, the maximum transconductance achieved is 8.45(µA/V) at V_{GS}=1V.Apart from them at two different pressures 10^{-14}(Torr)and10^{-13}(Torr), different contours were obtained for surface potential, electric field and electron velocity. Thus, when different concentration hydrogen gas is present, changes in work function of metallic gate will cause a change in sensitivity parameters, potential, electric field, electron velocity, output conductance, drain current and transconductance exploitation of these will be used as an alarm for the detection of gas.

4.2 Future Scope of the work

Analysis of the effect of temperature variation on sensor, analysis of variation of threshold voltage at different pressures, computation and analysis of threshold voltage sensitivity, computation and analysis of drain current sensitivity, Schottky model can be framed out. More attempt to make it enhanced in sensitivity, plasma models can be embedded in this.

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LIST OF PUBLICATIONS

1.Shiv Shankar Yadav, Sachin Dhariwal, Sonam Rewari,” Junction less Accumulation Mode Surrounding Gate (JAM-SG) Hydrogen Gas Detector”, Micro2023,10th international conference on Microelectronics, circuits and systems.

2.Shiv Shankar Yadav, Sachin Dhariwal, Sonam Rewari,” MOSFET based different structures for Hydrogen gas sensor applications: a review”, First International Conference on Electronics, Communication, and Signal Processing ICECSP 2024. (IEEE -2024, NIT DELHI), accepted for publication.

Proof of publication of 1st[nd] paper Title "Junction less Accumulation Mode Surrounding Gate Hydrogen Gas sensor "

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You are requested to revise the paper as per the reviewer's suggestions (if applicable) before submitting the camera-ready paper.
Based upon the above decision, you are now requested to complete the registration procedure following the proper guidelines indicated on the conference website (https://icecsp.in/ Registration)
You are requested to visit the conference website for a schedule of presentations to be uploaded in due course.
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The conference will be held from August 08-10, 2024 at the NIT Delhi, India in hybrid mode. If you have any questions, please feel free to contact us through email.
Please note:
1. The acceptance is provisional. Authors will be required to submit the final paper in the prescribed IEEE format along with the copyright form as per the requirement, for which a separate email will be sent in due course of time.
2. The authors registered for the ICECSP 2024 with the paper publication may be asked to revise the paper or camera ready before/after the Conference based on any comments received from IEEE Explore for Final publication.
3. The similarity index should be less than 15%.
3. Please include extra page charges (after 6 pages) in the registration fees as per the submission category for the Full Length Paper Submission.

With kind regards,

ICECSP 2024

Conference email: icecsp2024@nitdelhi.ac.in

APPENDICES

silvaco code for the model:

```
go atlas

MESH THREE.D CYLINDRICAL

R.MESH LOC=0.0 SPAC=0.001

R.MESH LOC=0.010 SPAC=0.001

R.MESH LOC=0.012 SPAC=0.001

R.MESH LOC=0.014 SPAC=0.001

##########################################################################################

A.MESH LOC=0 SPAC=65

A.MESH LOC=360 SPAC=65

##########################################################################################

Z.MESH LOC=-0.026 SPAC=0.005

Z.MESH LOC=-0.025 SPAC=0.005

#Z.MESH LOC=-0.016 SPAC=0.005

Z.MESH LOC=-0.015 SPAC=0.0005

Z.MESH LOC=-0.014 SPAC=0.003

Z.MESH  LOC=0.014  SPAC=0.003

Z.MESH LOC=0.015 SPAC=0.0005

Z.MESH  LOC=0.016  SPAC=0.005

Z.MESH  LOC=0.025  SPAC=0.005

Z.MESH LOC=0.026 SPAC=0.005

##############################################################################################################
#

REGION NUM=1 MATERIAL=SILICON A.MIN=0 A.MAX=360 R.MIN=0.00 R.MAX=0.010 Z.MIN=-0.025 Z.MAX=0.025

REGION NUM=2 MATERIAL=oxide  A.MIN=0  A.MAX=360 R.MIN=0.010 R.MAX=0.012  Z.MIN=-0.015 Z.MAX=0.015

#REGION NUM=3 MATERIAL=oxide A.MIN=0 A.MAX=360 R.MIN=0.011 R.MAX=0.012 Z.MIN=-0.015 Z.MAX=0.015

ELECTRODE NAME=GATE A.MIN=0 A.MAX=360 R.MIN=0.012 R.MAX=0.014 Z.MIN=-0.015 Z.MAX=0.015

ELECTRODE NAME=DRAIN A.MIN=0 A.MAX=360 R.MIN=0.0 R.MAX=0.010 Z.MIN=0.025 Z.MAX=0.026
```

```
ELECTRODE NAME=SOURCE A.MIN=0 A.MAX=360  R.MIN=0.0 R.MAX=0.010 Z.MIN=-0.026 Z.MAX=-0.025

DOPING UNIFORM CONCENTRATION=1E19 N.TYPE R.MIN=0.00 R.MAX=0.010 A.MIN=0 A.MAX=360 Z.MIN=-0.025 Z.MAX=-
0.015

DOPING UNIFORM CONCENTRATION=1E16 N.TYPE R.MIN=0.00 R.MAX=0.010 A.MIN=0 A.MAX=360 Z.MIN=-0.015 Z.MAX=0.015

DOPING UNIFORM CONCENTRATION=1E19 N.TYPE R.MIN=0.00 R.MAX=0.010 A.MIN=0 A.MAX=360 Z.MIN=0.015 Z.MAX=0.025

MATERIAL REGION=2 PERMITTIVITY=3.9

#MATERIAL REGION=3 PERMITTIVITY=3.9

#Interface qf= 1E13 region=2

#Interface qf= 0E11 region=4

CONTACT NAME=GATE  P.POLY WORK=5.2

CONTACT NAME=DRAIN NEUTRAL

CONTACT NAME=SOURCE NEUTRAL

models auger consrh conmob fldmob b.electrons=2 b.holes=1 evsatmod=0 \

    hvsatmod=0 surfmob aln1=-0.16 aln2=-2.17 aln3=1.07 etan=0.5 \

    alp1=-0.296 alp2=-1.62 alp3=1.02 etap=0.33 mrefn1=481 mrefn2=591 \

    mrefn3=1270 mrefp1=92.8 mrefp2=124 mrefp3=534 boltzman bgn print \

    numcarr=2 temperature=300

########################  Methods##########################

#

method newton gummel itlimit=25 trap atrap=0.5 maxtrap=4 autonr \

    nrcriterion=0.1 tol.time=0.005 dt.min=1e-25 damped delta=0.5 \

    damploop=10 dfactor=10 iccg lu1cri=0.003 lu2cri=0.03 maxinner=25

output    e.field j.electron j.hole j.conduc j.total e.velocity h.velocity \

    ex.field ey.field flowlines e.mobility h.mobility qss e.temp h.temp \

    charge recomb val.band con.band qfn j.disp photogen impact tot.doping

Solve init

solvevgate=0.262

solve vdrain=0.1

save outf=gaa.str
```

```
tonyplot3d -nohw gaa.str

###################idvd#######################

Solve VGATE=1.0

LOG OUTFILE=jnt_30nmid5vd.log

Solve NAME= DRAIN VDRAIN=0 VFINAL=1.0 VSTEP=0.05

 extract name="gd" deriv(v."drain",i."drain") outfile="jnt_30nm5gd.dat"

#######################idvg###################

Solve VDRAIN=0.01

LOG OUTFILE=jnt_30nmidvg_nw.log

Solve NAME= GATE VGATE=0 VFINAL=0.5 VSTEP=0.1

#####################transconductance#################

extract name="gm" deriv(v."gate",i."drain")outfile="jnt_30nmgm.dat"

quit
```