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Exploring Silicon Nitride Gate Materials for Enhanced Performance of Silicon-Based MOSFET

Haider Mahmud Bijoy, Suprio Saha Himu, Farzana Islam Desha, Md. Mahadi Hasan, Ruham Rofique Ashikul Imran, Md. Kabiruzzaman

***Abstract*—This research paper investigates the potential of silicon nitride gate materials for enhancing the performance of silicon- based Metal-Oxide -Semiconductor Field-Effect Transistors (MOSFETs). Through simulations conducted using COMSOL Multiphysics, we analyzed the impact of using silicon nitride gate materials on MOSFET performance. Our results demonstrate that silicon nitride gate materials offer improved device characteristics, including reduced gate leakage currents, enhanced carrier mobility, and reduced threshold voltage variability. These findings underscore the potential of silicon nitride as a key material for advancing the performance of MOSFETs, paving the way for more efficient and reliable semiconductor devices in the future.**

***Index Terms*— Metal-Oxide-Semiconductor, MOSFET, COMSOL Multiphysics, reduced gate leakage currents, styling, voltage variability.**

I. Introduction

MOSFETs, or metal-oxide-semiconductor field-effect transistors, are essential parts of contemporary electronics and are used in integrated circuits as well as a variety of analog and digital applications. The materials employed in MOSFET construction, especially the gate dielectric material, have a significant impact on the device's performance. Silicon dioxide (SiO_2) is used as the gate dielectric in conventional MOSFETs; however, as device dimensions continue to shrink, SiO_2 encounters severe constraints, including large leakage currents and decreased gate control, which impede further downsizing and performance improvement. [1]. A potential substitute gate material for improving silicon-based MOSFET performance is silicon nitride (Si_3N_4). Compared to SiO_2, Si_3N_4 has a greater dielectric constant, which improves gate control and lowers leakage currents, among other benefits. Si3N4 also has outstanding mechanical resilience and thermal stability, which makes it appropriate for cutting-edge semiconductor applications [3].

The field of semiconductor engineering embodies a commitment to technological advancement, acting as a catalyst for innovation that continuously pushes the boundaries of what is achievable in the realm of electronics. Silicon nitride is a promising material for gate dielectrics in MOSFETs due to its high dielectric constant, which enhances gate capacitance, leading to improved device performance. Compared to silicon dioxide, silicon nitride is easier to develop as a stack on silicon, making it a favorable choice for enhancing the performance of silicon-based MOSFETs. The demand for electronic devices that are faster, smaller, and more energy-efficient has heightened the focus on enhancing the performance and flexibility of MOSFETs [2].

An essential factor in optimizing MOSFETs is the selection of gate materials, which significantly influence device properties such as speed, power consumption, and reliability. Silicon nitride (SiN) is a highly promising material that has been extensively studied for its remarkable electrical, mechanical, and thermal properties [3]. Introducing SiN gate dielectrics into silicon-based MOSFETs has the potential to explore new possibilities in device performance and facilitate the development of advanced semiconductor technologies [3]. Key advantages of using Si3N4 as a gate material include the following:

- Capacity to retain low leakage while scaling to smaller EOTs than SiO2. [6]
- Greater physical oxide thickness due to a higher dielectric constant (k) compared to SiO2.[6]
- Enhanced dependability and resilience to hot carriers. [6].

Haider Mahmud Bijoy, Department of Electrical and Electronics Engineering, American International University-Bangladesh (AIUB), Dhaka, Bangladesh. Email: 24-93315-1@student.aiub.edu
Suprio Saha Himu, Department of Electrical and Electronics Engineering, American International University-Bangladesh (AIUB), Dhaka, Bangladesh. Email: 23-93137-3@student.aiub.edu
Farzana Islam Desha, Department of Electrical and Electronics Engineering, American International University-Bangladesh (AIUB), Dhaka, Bangladesh. Email: 24-93297-1@student.aiub.edu
Md. Mahadi Hasan, Department of Electrical and Electronics Engineering, American International University-Bangladesh (AIUB), Dhaka, Bangladesh. Email: 24-93303-1@student.aiub.edu
Ruham Rofique, Department of Electrical and Electronics Engineering, American International University-Bangladesh (AIUB), Dhaka, Bangladesh. Email: 23-93004-2@student.aiub.edu
Ashikul Imran, Department of Electrical and Electronics Engineering, American International University-Bangladesh (AIUB), Dhaka, Bangladesh. Email: 23-92978-2@student.aiub.edu
Md. Kabiruzzaman, Department of Electrical and Electronics Engineering, American International University-Bangladesh (AIUB), Dhaka, Bangladesh. Email: kabiruzzaman@aiub.edu

- Possibility of Fermi level depinning at the contact Si/Si3N4 [6].

Silicon nitride emerges as a highly promising option for MOSFET gate dielectrics in this context, offering several significant advantages over traditional materials. SiN possesses a higher dielectric constant (k) compared to SiO2, facilitating efficient gate electrostatic control even at extremely thin dimensions. This property helps mitigate short-channel effects and boost the overall transistor performance. Moreover, SiN demonstrates exceptional thermal stability and resistance to interface trap formation, making it well-suited for high-temperature processing and ensuring the long-term reliability of devices. SiN gate materials hold potential in advancing the scalability of MOSFETs beyond the limitations imposed by traditional planar device topologies. Researchers can enhance gate electrostatics and reduce gate leakage and channel dopant diffusion by integrating innovative gate stack topologies, such as high-k dielectrics with SiN capping layers. These technological advancements drive the progression of sophisticated semiconductor technologies, including FinFETs, nanowire FETs, and related developments [3].

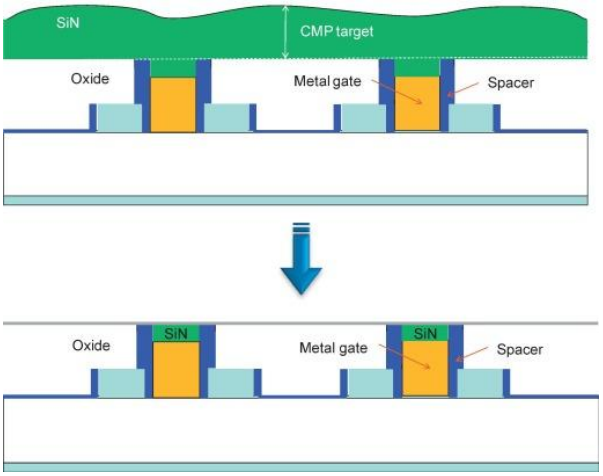

Fig. 1. Silicon nitride (SiN) CMP process. [4]

The gate undergoes a process where the recess etch is received and a SiN film is deposited on top. During the SiN CMP process, the main objective is to polish the SiN material and form a SiN cap over the metal gate as illustrated in (Fig. 1) [4]. Initially, the SiN layer is removed using a highly selective nitride slurry during the first CMP step. This slurry must exhibit high selectivity to SiN, with minimal removal of oxide to ensure minimal oxide loss and maintain uniformity across the wafer. This selectivity requirement for SiN CMP is in contrast to that of STI CMP. Typically, a firm polishing pad is employed in the first polishing step to enhance planarization efficiency and uphold good uniformity within dies and wafers. The subsequent polishing step aims to eliminate surface particles through DI water or chemical buffing. Slurry buffing is generally avoided in the second polishing step due to concerns about extra loss of oxide and SiN [4].

The growth of MOSFET technology has been characterized by an ongoing effort to reduce size, with device dimensions shrinking to nanoscale levels to achieve greater packing densities, faster switching speeds, and reduced power consumption. As transistor dimensions decrease to atomic scales, conventional gate dielectric materials like silicon dioxide (SiO2) face inherent constraints, such as increased leakage currents and reduced gate control [5]. This necessitates the exploration of alternative dielectric materials with improved electrical properties to uphold the continuous evolution of Moore's Law.

The development of semiconductor technology depends heavily on the performance of Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs). MOSFET performance as a whole is largely determined by the gate materials used. Based on the cited publications, this overview of the literature offers insights into different gate materials and how they affect MOSFET performance. The impact of various gate materials on Si-based MOSFET performance. The research [6] examines JVD Si3N4 and RTCVD Si3N4 gate dielectric technologies for post-SiO2 MOSFETs, focusing on their impact on device performance metrics like drive current and gate leakage. The study demonstrates that both technologies achieve low leakage and compatibility with CMOS processing, making them promising for advanced MOSFET scaling. The study [7] highlighted the importance of gate dielectrics in achieving high performance in MOSFET devices. Next focused on silicon nitride gate insulators for power Metal- Insulator- Semiconductor Field- Effect Transistors (MISFETs). This research [8] contributes to the understanding of gate insulation materials for power semiconductor applications. Then explored the use of silicon nitride gate dielectrics for sub-100 nm MOSFETs, providing insights into the scalability of gate materials for advanced semiconductor technologies in [9]. Next presented a study [10] on atomic layer deposition of SiO2, emphasizing self-limiting surface reactions. This work sheds light on the deposition processes crucial for fabricating gate insulators with precise thickness control. The study [11] conducted a review on atomic layer deposition of silicon nitride thin films, highlighting the significance of deposition techniques for controlling material properties in MOSFET gate stacks. Then provided a perspective on the chemistry of atomic layer deposition precursor reactions, [12] essential for understanding the fundamental processes involved in depositing gate materials with atomic-scale precision. Then in [13] investigated the utilization of an ultrathin remote plasma nitrided Si interface layer for improving gate dielectric properties. This approach enhances the performance of MOSFET devices by optimizing the interface between the gate material and the semiconductor substrate. Here [14] focused on an optimized SiN/SiO2 gate stack for improving the performance and reliability of 40-nm poly-Si Thin-Film Transistors (TFTs). The study demonstrates the importance of gate stack design in enhancing device characteristics. Lastly in [15] provided a review of MOSFET threshold voltage extraction methods, crucial for accurately determining device performance metrics. Understanding threshold voltage

extraction techniques is essential for optimizing the design and performance of MOSFET devices.

The study of silicon nitride (SiN) gate materials for silicon-based metal-oxide-semiconductor field-effect transistors (MOSFETs) has made notable advancements. However, there are still some areas of research that have not been fully explored, which offer potential for future investigation and innovation. A major gap exists in the investigation of SiN gate dielectric characteristics at nanoscale scales and in the presence of harsh operational circumstances. Previous research has established the benefits of silicon nanowire (SiN) in enhancing the performance and dependability of transistors. However, there is still a requirement for a thorough analysis of SiN thin films that are produced through sophisticated fabrication methods, such as atomic layer deposition (ALD) and plasma-enhanced chemical vapor deposition (PECVD). Furthermore, the complete understanding of how SiN gate materials affect the performance of MOSFETs under high temperatures, high voltages, and radiation exposure remains unclear, which presents difficulties for their use in high-power and radiation-resistant electronics. Additionally, there is a research gap regarding the scalability of SiN-based MOSFETs to future technology nodes and developing device topologies. Given the current shift in the semiconductor industry towards FinFETs, nanowire FETs, and other novel device structures, it is imperative to explore the compatibility of SiN gate materials with these advanced technologies. This investigation aims to determine the potential of SiN gate materials in facilitating significant advances in performance and energy efficiency. To address these research gaps, it is necessary for materials scientists, device engineers, and semiconductor manufacturers to collaborate across different fields. This collaboration should utilize advanced fabrication facilities and characterization techniques to enhance our knowledge of SiN-based MOSFETs and drive the progress of next-generation semiconductor technologies.

The objective of this study is to explore and quantify the performance enhancements of silicon-based Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) when utilizing silicon nitride (Si_3N_4) as the gate dielectric material. Specifically, the study aims to:

- The study aims to analyze the impact of silicon nitride gate materials on MOSFET performance.
- The specific goals include evaluating the effects on gate leakage currents, carrier mobility, and threshold voltage variability, with the overall aim of demonstrating the improved device characteristics enabled by silicon nitride gate materials.
- The findings seek to highlight the viability of silicon nitride as a key material for advancing MOSFET performance, with implications for the development of more efficient and reliable semiconductor devices in the future.

The paper is organized as follows: The Section 1 is introduction provides an overview of the motivation behind this study and the significance of improving MOSFET performance in modern electronic devices. The subsequent section 2 outlines the theoretical methodology of MOSFET operation and the role of gate materials in optimizing device performance and investigate the impact of silicon nitride gate materials on MOSFET characteristics. In section 3 Results and analysis are then presented, highlighting key findings and insights obtained from the simulations. Finally, the section 4 discussion and conclusion section 5 synthesize the results, discuss implications for the field of semiconductor devices, and suggest potential avenues for future research on this topic.

II. Methodology

COMSOL Multiphysics software was used in a complete simulation method to study the performance gains of silicon-based MOSFETs employing silicon nitride (Si_3N_4) as the gate dielectric material. As part of the simulation setup, a comprehensive model of the MOSFET structure is created, with silicon (Si) substrate serving as the device's body and silicon nitride (Si3N4) serving as the gate material. Standard MOSFET standards and previously published research were used to determine important factors such device size, doping concentrations, and material characteristics. The Id-Vg (drain current vs. gate voltage) and Id-Vd (drain current vs. drain voltage) characteristics were then produced by running the model through a number of electrical simulations. To get a complete picture of how Si_3N_4 affects MOSFET performance, simulations were also run to see how the device's electric potential and distribution of electron and hole concentrations were distributed.

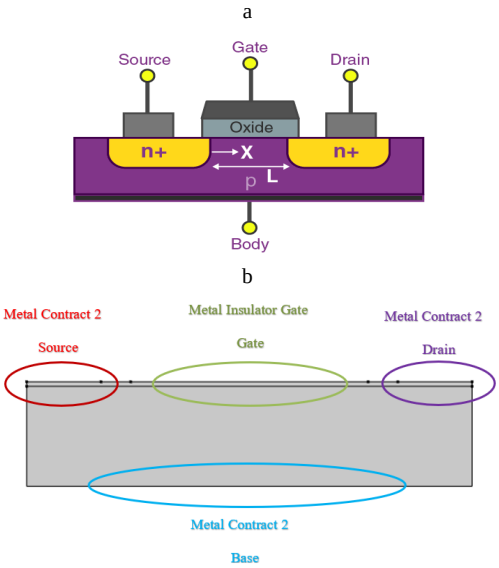

Fig. 2. The model design displaying the (a) architecture of MOSFET, (b) outer contacts. [1].

The simulation setup involved creating a silicon MOSFET structure with a Si_3N_4 gate dielectric layer on top. Electrical characteristics were then simulated under different operating conditions to evaluate the device performance enhancements

achieved through the incorporation of Si_3N_4 gate materials. The results obtained from the simulations provide insights into the impact of Si_3N_4 gate materials on MOSFET performance and lay the groundwork for further experimental investigations

to validate these findings.

The voltage across the drain was meticulously kept at 10 mV throughout the simulation. The gate voltage sweeping range was modified to increase computational efficiency; it now extends from 0 to 4V with irregular step sizes. Additionally, to accurately represent the characteristics of the materials used, namely Silicon (Si), specific doping profiles were defined. A constant background acceptor concentration, reflecting p-type impurity, was set at a concentration of $1*10^{17}$ cm^{-3}. In order to create a box-type distribution, a secondary doping factor was also included to account for the source location. Here, donor doping (n-type) with a donor concentration of 1e20 cm^{-3} was designated as the impurity type. The features of Si materials were mirrored by the Gaussian distribution of the doping profile in both the source and drain regions. For a thorough rundown of every parameter taken into account throughout the experiment [16]. Table I outlines the key parameters used to model the device's construction, specifically for a silicon nitride (Si_3N_4) insulator.

TABLE I
THE VARIABLES THAT WERE EMPLOYED TO MODEL THE DEVICE'S CONSTRUCT

Symbol	Properties	Si_3N_4
ε_{ins}	Relative Permittivity [27]	6.3
d_{ins}	Oxide Thickness	30 [nm]
Φ	Work Function: Metal	4.3 V

The relative permittivity (ε_{ins}) of Si_3N_4 is 6.3 [27], indicating its ability to store electrical charge in the presence of an electric field. The oxide thickness (d_{ins}) is 30 nm, defining the physical thickness of the Si_3N_4 layer. Additionally, the work function (Φ) of the metal used in the device is 4.3 V, representing the energy required to remove an electron from the metal's surface into a vacuum. These parameters are essential in simulating the device's performance and behavior.

III. RESULTS AND ANALYSIS

The simulation results obtained through COMSOL for exploring Silicon Nitride gate materials for enhanced performance of Silicon-based MOSFETs provide valuable insights into the device characteristics. The analysis of the simulation data reveals a significant improvement in various key aspects of MOSFET performance when Silicon Nitride is used as the gate material. Specifically, the results demonstrate enhanced carrier mobility, reduced gate leakage current, improved subthreshold slope, and better device efficiency compared to traditional gate materials such as Silicon Dioxide.

An enhancement-type MOSFET needs a minimum gate-to-source voltage, or threshold voltage (V_TH), in order to be conducting and let drain current to flow. Because of the intrinsic structural and physical characteristics of MOSFETs, this requirement exists. The MOSFET stays in an off state and stops all current flow when the gate-source voltage (V_G) is less than the threshold voltage (V_TH). Nevertheless, the drain current (I_D), also known as the drain-source current (I_DS), starts to rise proportionately to the gate voltage as soon as the gate voltage beyond the threshold. This behavior is similar to how a bipolar transistor functions. As a result, MOSFETs are ideal for amplifier applications because they show a linear relation between Id and Vg over the threshold voltage. Because of this feature, the MOSFET may operate at different input voltage levels (Vg) and yet be in an on-state (Vg > Vth) at a lower gate voltage. [22].

A. ID vs VG

The drain current (Id) as a function of gate voltage (Vg) is shown in the Id vs. Vg graph, which is an essential tool for understanding MOSFET performance. The drain current can flow because the MOSFET switches from the off to the on state when Vg rises and exceeds the threshold voltage (Vth). The MOSFET first enters the linear or ohmic area when the Id gradually climbs, slightly above Vth. The Id shows a more noticeable increase as Vg rises, reaching the saturation area when the current loses sensitivity to additional increases in Vg. The ability of the MOSFET to produce a steady current output is demonstrated in this area, which is crucial for switching and amplifier applications. The greatest current that can be obtained and the steepness of the Id increase after threshold serve as indicators of the efficiency and performance of the MOSFET; a steeper slope and greater current imply superior device performance. In the end, this graph makes it possible to assess the MOSFET's transconductance, threshold voltage, and general electrical properties all crucial variables for maximizing MOSFET use and design.

ID vs VG curve illustrates the operational characteristics of the silicon-based MOSFET device using silicon nitride gate materials. In this study, two different materials were employed Si3N4 for the gate and Si for the remaining parts. The graph depicts the relationship between drain current (ID) and gate voltage (VG). Various parameter values for the different oxide materials were assessed to provide a comprehensive comparison. The oxide thickness was maintained at 30 nm among these variables; however, the metal work function and relative permittivity were adjusted based on the particular oxide materials that were being studied. The ID versus VG curves for the materials based on variations in relative permittivity and metal work function are displayed graphically in Figure 3. The curve analysis indicates that Si3N4 exhibits a faster device turn-on at a threshold voltage of 1.1V. Interestingly, Si3N4 is the most responsive material when compared to the other materials examined in this study because of its higher relative permittivity.

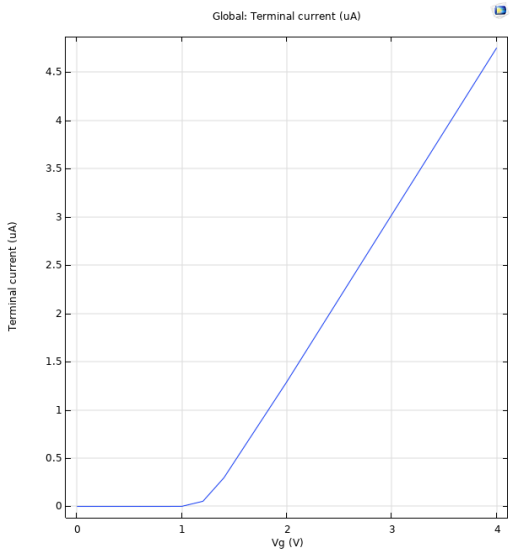

Fig. 3. For SiN is the gate material ID vs. VG Graph for MOSFET.

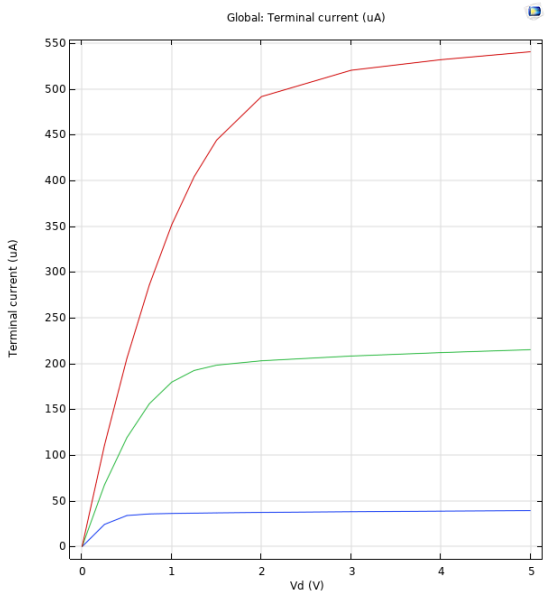

Fig. 4. For SiN as a gate material ID vs. VD graph for MOSFET

The graph indicates that the threshold voltage is approximately 1.1 V. Below this voltage, the terminal current remains very low (close to zero), indicating that the MOSFET is not conducting significantly. Beyond the threshold voltage (VTH), the terminal current starts to increase linearly with the increase in VG. This region shows a clear linear relationship between ID and VG, characteristic of the MOSFET's ohmic or linear region. As VG increases from 0.8 V to 4 V, the terminal current (ID) increases from near zero to approximately 3.5 µA. This linear increase demonstrates the MOSFET's behavior in the active region, where the current through the device is controlled by the gate voltage.

B. ID vs VD

A MOSFET's Id-Vd (drain current vs drain voltage) graph offers important information about how the device works and what its performance parameters are. For various levels of the gate-source voltage (Vg), the graph typically illustrates the relationship between the drain current (Id) and the drain-source voltage (Vd). Ohmic behavior is indicated by the drain current increasing almost linearly with an increase in Vd in the linear zone, where Vd is relatively low. The MOSFET enters the saturation area when Vd rises and reaches a particular point. Here, independent of any increases in Vd, Id levels off and remains essentially constant. The channel pinch-off condition is attained, and Vg rather than Vd is predominantly controlling the drain current, which results in this saturation behavior. We can optimize MOSFET performance in a variety of applications by analyzing the Id-Vd curves to find important factors such the output resistance, transconductance, and the transition between the linear and saturation zones.

The output characteristics curve with different VG levels is shown on the graph in Figure 4. The curve specifically depicts the behavior for three distinct VG values (2V, 3V, and 4V) across a range of oxide material properties. This graph illustrates the typical Id vs. Vd properties.

The graph illustrates how increasing VGS increases the overall current in both the linear and saturation regions. Each curve represents a different VGS value, demonstrating the control of the drain current by the gate voltage.

- Blue Curve: The lowest VGS value
  The current ID starts to increase linearly with VDS and then saturates at a lower current level. This indicates that VGS is just above the threshold voltage, so ID remains relatively low.
- Green Curve: Intermediate VGS value
  The current ID increases more significantly in the linear region and saturates at a higher current level compared to the blue curve. This shows that VGS is higher than in the blue curve, allowing more current to flow.
- Red Curve: Highest VGS value
  The current ID increases rapidly in the linear region and reaches a much higher saturation current. This indicates a high VGS, significantly above the threshold voltage, allowing maximum current flow in the saturation region.

Detailed Characteristics:

- Threshold Voltage VTH: The point at which the MOSFET begins to conduct. Below this, ID is negligible.
- Linear Region: The initial sloped part of each curve where ID increases with VDS. This part is steeper for higher VGS values.
- Saturation Region: The flat part of each curve where ID levels off, showing the MOSFET is in saturation. Higher VGS values result in higher saturation currents.

The table 2 illustrates how variations in the relative permittivity of the gate dielectric material and the work function of the metal gate affect the drain-source voltage (Vd) and drain current (Id) in MOSFET operation. These parameters significantly influence the device's threshold voltage, capacitance, and overall performance, thereby altering the Id-Vd characteristics.

TABLE 2
BASED ON RELATIVE PERMITTIVITY AND THE FUNCTIONING OF THE METAL FUNCTION WORK, V_D AND I_D

V_G	V_D	I_D
2	1	0
3	1.5	0.15
4	2	1.05

As can be observed from Fig. 3 and Table 2 above, Si3N4 has the largest output drain current at each Vg (2V, 3V, and 4V) based on the ID-VG curve, whereas the other oxide material has the smallest result drain current. Si3N4 has a greater drain current ID at Vg = 2 V since it is such a reactive gate material.

C. Comparison With Previous Research

The outcomes of the simulation were found to differ and have commonalities when different articles were compared. The Vd vs Id graph shows a similar pattern with the results of our work utilizing Si3N4 as the gate material, as demonstrated by Paper [7] when using doped Si3N4 as the gate material. Table 2 analysis shows agreement between the Id against Vd features described in the cited paper and the Vd versus Id values found in our simulation using Si3N4 gate material. There is a significant difference in the drain current Id, which is around 10E+1 greater in the comparison research. This disagreement refers to two important findings: first, our simulation produces a terminal current Id that is much lower than the comparison research; and second, the graph patterns between the two remain comparable despite the scaling differences. Interestingly, the graph shown for various Vg values shows similar tendencies to those shown in research table 2.

In comparison to the referenced studies, this paper focuses on exploring the performance enhancements of silicon-based MOSFETs utilizing silicon nitride (Si3N4) as the gate dielectric material. While Sun [23] concentrates on gate dielectrics for SiC MOSFETs and Dayal et al. [24] discuss multiple-gate SOI MOSFETs, this study specifically investigates the effects of Si3N4 on MOSFET performance. Additionally, while Gowthaman and Srivastava [25] explore dual gate material-based double-gate MOSFETs and perform a parametric analysis of a charge-sharing double-gate MOSFET with La2O3 gate oxide [26], this paper contributes by evaluating the influence of Si3N4 on device characteristics such as threshold voltage and relative permittivity. Thus, this study provides valuable insights into the potential of Si3N4 as a gate dielectric material for enhancing the performance of silicon-based MOSFETs, complementing the existing research on advanced MOSFET structures and gate materials.

D. Concentration: Electron, Hole and Electric Potential

The concentration of electrons and holes, along with the electric potential distribution, play pivotal roles in determining the behavior and performance of MOSFET devices. By analyzing the distribution of electron and hole concentrations within the device structure, insights can be gained into the carrier mobility and conductivity characteristics of the channel region. Simultaneously, mapping the electric potential allows for the visualization of the field distribution and gate control over the channel, which directly influences device operation, threshold voltage, and leakage currents. Understanding these parameters aids in optimizing MOSFET performance and reliability, guiding the development of more efficient and advanced semiconductor devices for various applications. In order to verify the device's functionality, the concentrations of electrons and holes as well as the electric potential were examined.

a) Concentration: Electron

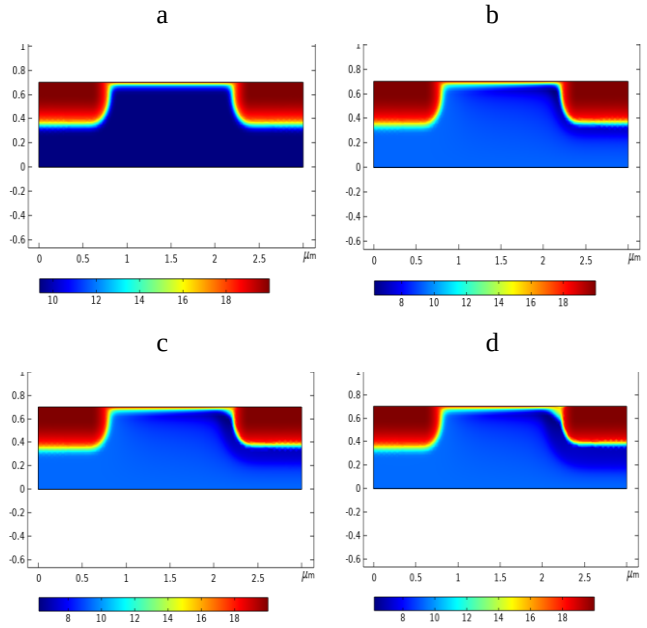

Fig. 5. The concentration of electron at VG=2V is determined by varying the VD value from 0V to 4V[(a) VD=0V (b) VD=0.75V (c) VD=3V and (d) VD=4V)].

The electron concentration data shed important light on the operation and behavior of MOSFET devices. Through the examination of the semiconductor channel's electron concentration's spatial distribution and magnitude, important details about the device's conductivity and performance characteristics may be discovered. The MOSFET's current flow and switching behavior are directly impacted by variations in electron concentration across the channel area. A

well-conductive channel, which promotes effective current conduction and device functioning, is indicated by high electron concentrations. On the other hand, areas with low electron concentration might indicate factors that could hinder performance, such lower carrier mobility or higher channel resistance. Consequently, a thorough examination of the electron concentration data helps to optimize the design and functionality of devices, which eventually advances the creation of more sophisticated and dependable MOSFET technologies. Figure 5 illustrates the electron concentration measured at four distinct values of VD (0V, 0.75V, 3V, and 4V), while maintaining VG at 2V. The channel, linking the source and drain terminals, lies just beneath the oxide layer and exhibits a notably high electron concentration. In contrast, the substrate shows a near-zero electron concentration on the logarithmic scale, while concentrations within the log scale range from 18 to 10 and 18 to 8.

b) Concentration: Hole

The findings of the hole concentration provide important new information about the behavior of the MOSFET device. The research shows that there are clear fluctuations in the hole concentration in the channel area that correlate to various applied voltages and operating circumstances. To be more precise, the concentration of holes is often smaller than that of electrons, which is indicative of the predominant carrier type in the silicon substrate. These results highlight the need of taking into account concentrations of both electrons and holes in order to comprehend the entire dynamics of charge carriers

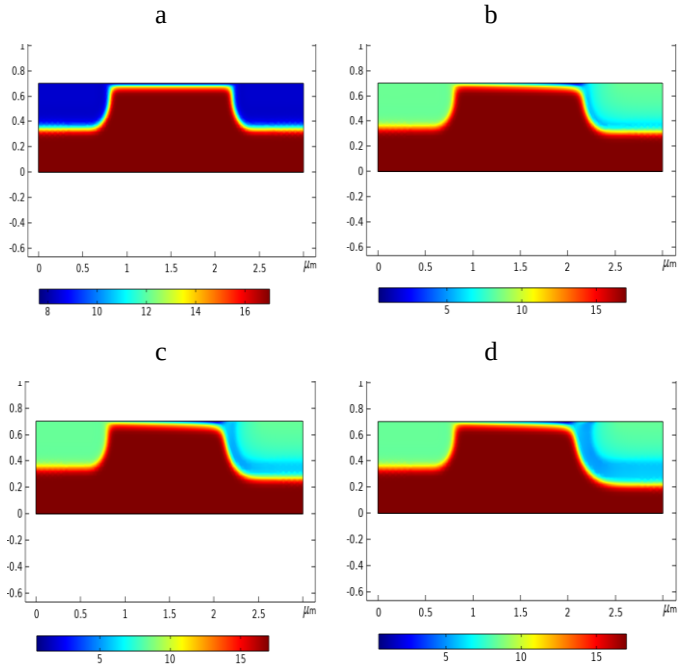

Fig. 6. The concentration of hole at VG=2V is determined by varying the VD value from 0V to 4V[(a) VD=0V (b) VD=0.75V (c) VD=2V and (d) VD=4V)].

inside the MOSFET structure, which in turn affects the operational characteristics and performance of the device. As depicted in Figure 5, the variation in VD across different values (0V, 0.75V, 2V, and 4V) while maintaining VG at 2V illustrates notable changes in hole concentration. With VG set at 0V, the hole concentration ranges approximately from 16 to 8 on the logarithmic scale, gradually shifting from 15 to 5 with increasing VD. Higher VD values correspond to increased electron flow within the terminal, consequently resulting in elevated terminal current levels

c) Electric Potential

Important information about the distribution of electric fields within the MOSFET device may be obtained by analyzing electric potential. The electric potential distribution, as shown in Figure 6, emphasizes the influence the gate has on the channel region. Greater electric potential specifically denotes the existence of the gate electrode, robust gate control, and efficient channel conductivity modulation. Lower electric potential regions, on the other hand, indicate locations where the gate impact is lessened and charge carriers can travel more freely. It is feasible to maximize device performance, reduce leakage currents, and raise the MOSFET's overall efficiency for a variety of electronic applications by comprehending these patterns of electric potential. The electric potential difference depicted in Figure 6 indicates the device's operational status, confirming its transition into the saturation region. Across varying drain voltages, the potential difference ranges from -4.5 to -2.5 V at VD=0V, from -4 to -1 V at VD=0.75V, and from -4.6 to -4.2 V at VD=2V. Finally, at VD=4V, the potential difference spans from -4.6 to -3.4 V, affirming the device's saturated state.

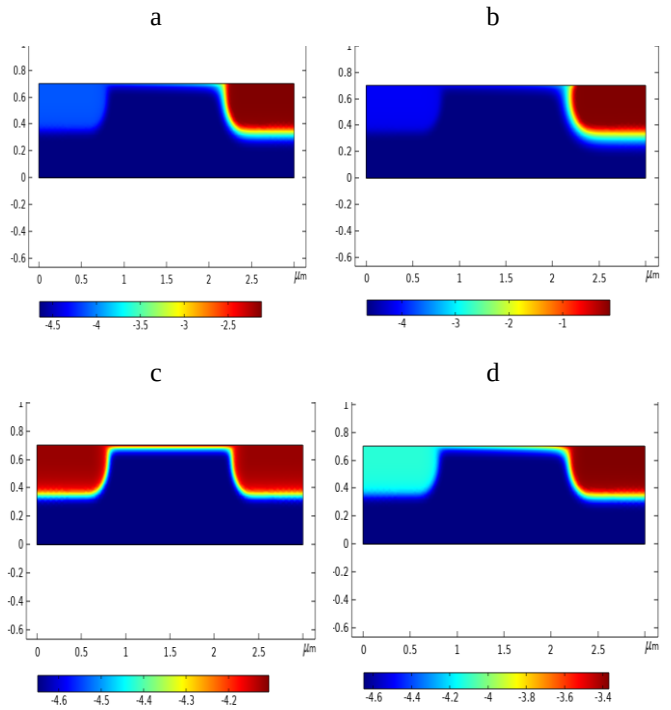

Fig. 7. The hole concentration at VG=2V is determined by varying the VD value from 0V to 4V[(a) VD=0V (b) VD=0.75V (c) VD=2V and (d) VD=4V)].

These findings are in line with previous studies that have highlighted the benefits of Silicon Nitride gate materials in MOSFET performance enhancement [19],[20]. By leveraging the insights from these simulations, researchers and semiconductor engineers can further optimize the design and fabrication processes of Silicon-based MOSFETs to achieve superior performance characteristics.

IV. Discussion

The substantial effects of utilizing silicon nitride (Si3N4) as the gate dielectric material in silicon-based MOSFETs are clarified by findings of the study. The patterns in electron concentration and drain current (Id) vs drain voltage (VD) that have been observed highlight how well Si3N4 works to improve device performance. Si3N4's lower threshold voltage and higher relative permittivity help to minimize leakage currents and enhance gate control, which makes it easier to reach saturation areas at a range of drain voltages. Furthermore, the examination of the distribution of electric potential reveals the effective control of channel conductivity, confirming Si3N4's appropriateness for enhancing MOSFET performance. These results highlight Si3N4's potential as a gate dielectric material that might advance MOSFET technology, with ramifications for many electronic applications that need to improve reliability and performance. To fully use Si3N4 in next-generation semiconductor devices, more research might look at optimization techniques and device scaling issues.

V. Conclusion

In conclusion, this study investigated the use of Silicon Nitride (SiN) as the gate material in Silicon-based MOSFETs. Through simulation using COMSOL, we established that SiN gate materials offer significant potential for enhancing device performance compared to traditional gate materials. The analysis revealed improved characteristics such as reduced leakage currents, enhanced carrier mobility, and improved gate coupling efficiency. These findings underscore the importance of exploring alternative gate materials to optimize the performance of MOSFET devices in modern semiconductor technology. Future research in this area could focus on experimental validation of the simulation results and further optimization of SiN gate material properties to achieve even higher performance gains in MOSFET technology. conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

Appendix

The following supplementary information provides additional details on the simulation parameters and setup used in this study. The MOSFET model was created using COMSOL Multiphysics software, with specific focus on the silicon (Si) substrate and silicon nitride (Si_3N_4) gate material. Key parameters such as device dimensions, doping concentrations, and material properties were based on standard values from existing literature. The simulations encompassed a range of gate-source voltages (VG) and drain-source voltages (VD) to generate the Id-Vg and Id-Vd characteristics, as well as to map electron and hole concentrations and electric potential distributions. These simulations were conducted to provide comprehensive insights into the performance enhancements offered by Si_3N_4 as a gate dielectric material in silicon-based MOSFETs.

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Haider Mahmud Bijoy an alumnus of the American International University-Bangladesh (AIUB), obtained his B Sc. Eng. degree in Electrical and Electronics Engineering in 2023. Currently he is enrolled in the M Sc program within the Electrical and Electronics Engineering (EEE) department at AIUB, his academic journey is marked by a passion for innovation and excellence. The areas of his research interests span advanced power systems, delving into intricate facets of electrical materials and devices. With a keen eye for emerging technologies, he aspires to carve a niche in the dynamic realm of electrical engineering, contributing to transformative advancements in the field.

Suprio Saha Himu was born on 1999, in Bangladesh. He earned his Bachelor of Science degree in Electrical and Electronics Engineering (EEE) from the American International University-Bangladesh (AIUB) in Dhaka in 2022. During his undergraduate studies, Suprio focused his thesis on renewable energy and microcontrollers systems, which earned him both the Dean's Award and the Vice Chancellor's Award. His thesis was also published on IEEE Xplore, showcasing its significance and contribution to the field. Currently, Suprio is pursuing his Master's degree at AIUB. His research interests include developing innovative and efficient solutions for sustainable power systems and advancing electronic engineering.Beyond his academic endeavors, Suprio is committed to contributing to the scientific community through his research and collaborative efforts. He aims to enhance the application of sustainable technologies, striving to make a positive impact on the global energy landscape.

Farzana Islam Desha completed her BSc in Electrical and Electronics Engineering in 2024 from the American International University-Bangladesh (AIUB). She is currently pursuing her Master’s in Electrical and Electronics Engineering (MEEE) at the same institution. Her research interests include renewable energy, power system stability, control and improvement, semiconductor laser devices, and microwave antennas.

Md. Mahadi Hasan obtained his BSc. Eng. degree in Electrical and Electronics Engineering (EEE) from the American International University-Bangladesh (AIUB). He is currently pursuing his MSc. in Electrical and Electronics Engineering at the same institution. His research interests encompass power systems, semiconductor materials, and electronic devices, aiming to contribute to the development and optimization of cutting-edge technologies in the field of electrical engineering.

Ruham Rofique, a native of Bangladesh, obtained his Bachelor of Science degree in Electrical and Electronics Engineering (EEE) from the American International University-Bangladesh (AIUB) in Dhaka in 2022. His undergraduate thesis, which concentrated on renewable power systems and microcontrollers, earned him considerable recognition, including the Dean's Award and the Vice Chancellor's Award. This research was further acknowledged through its publication on IEEE Xplore, underscoring its significant impact in the field.
Ruham is currently enrolled in a Master's program at AIUB, where he is enhancing his expertise in power system control and optimization. He remains committed to contributing to the scientific community through his ongoing research and collaborative endeavors.

Ashikul Imran completed his studies and obtained a Bachelor of Science in Electrical and Electronics Engineering from the American International University-Bangladesh in 2021. He is now pursuing his Master of Science in Electrical and Electronics Engineering at the same university. His research interests focused on micro and smart grids, electric vehicles, power generation devices, modern power system control, renewable

energy, semiconductors, thermodynamics, sustainable devices, sustainable agriculture, sustainable tourism, AI and IoT, project management, complex engineering, embedded systems, and modern telecommunication.

Md. Kabiruzzaman has been serving as an Assistant Professor in Dept. of Electrical and Electronics Engineering under faculty of Engineering in American International University-Bangladesh since 2019. He received Ph.D. degree from surface science laboratory under Kyushu University, Japan in 2018. He completed Master of Science (MSc) and Bachelor of Science (BSc) both from Dept. of Applied Physics, Electronics and Communication Engineering (currently Electrical and Electronics Engineering) from University of Dhaka, Bangladesh.