Recent Progress on Sensitivity Analysis of Schottky Field Effect transistor Based Biosensors

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Abstract

In this review, we explored the modern development of schottky field effect transistor (SK FET) structures and the improvement of sensitivity of nanowire sensors using dielectric modulation. Here, the recent developments compared with the conventional schottky FET sensor, and modified conventional configuration have improved sensitivity and faster responses controlled by dielectric modulation and changing the barrier height. The change in sensitivity- with the current optimization has been considered for dissimilar gate, and drain voltage. The dielectric modulation can advance the finding limits, sensitivity, and reaction time of the novel structures in dissimilar applications, such as U-V finding, gas and chemical/biosensing. In addition, the efficiency and doped channel have been deliberately studied under dissimilar biomolecule model specifications. This article reviews a recent study on emerging future generation SK FET biosensors with their sensitivity performance and the effect of their metal and channel contact is presented.

Keywords Biosensor · Dielectric · Sensitivity · Tunnelling · Hetero-structure · Gate dielectric

1 Introduction

The Field-effect transistors (FET) are extremely capable of sensing applications for their great sensitivity, real-time suitability, ease to use, and change of integration on chips. A typical FET is made up of multiple probes, source and drain, that are linked by a semiconductor that acts as a conducting channel material. The FET biosensor retorts are based on the acquired analyte molecules gating, which causes the channel conductance to fluctuate (i.e., semiconductor). The gating result controls FET's performance characteristics, such as source/drain current. Hence shift in FET electric characteristics leads to a considerable signal shift [1, 2]. The majority of materials, such as gas-as oxide and polymers, were used as the channel in FET-based sensors. Unfortunately, their poor electrical characteristics and the restricted interface between target molecules and large materials limit their use, particularly when precise working conditions are required, such as high temperatures for gas sensors [3–5]. However, the nanomaterials, like carbon nanotubes (CNTs), and silicon base nanowires (SiNWs) have exposed excessive achievement as a channel in FET biosensors. The high sensitivity of nanomaterials is attributed to the large surface area and high $I_{on}/I_{off}$ proportion in CNTs and SiNWs [6–8]. Although SiNWs-FETs are used in a variety of sensing applications, it is difficult to scale or promote them because SiNWs have a lower carrier moment and a large device-to-device difference [9]. Although the fact that CNTs have superior chemical properties, good thermal and chemical constancy [10], excellent conduction [11, 12], and the capacity to easily immobilise bio-probes, their use in FET sensors is limited. Hence, it is illustrated by the difficulty of obtaining pure semiconductors or carbon nanotubes rather than producing a combination of both, which eliminates electrical properties and increases device-to-device differences [13]. The semiconductor materials provide a more conformal and durable probe connection. Moreover, easy to make because of their larger horizontal dimensions, which

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allow for better regulation of the FET channel construction. Furthermore, materials are prepared in the desired figure, scope, and breadth, and precisely transported to the biosensor substrate's desired location [14]. In Schottky-based FETs are the most widely utilised, with a large surface area and a high powered strength. Furthermore, Schottky-based FETs have extremely high potential carrier concentration [15], allowing them to have exceptional electrical characteristics for rapid electron transfer [16]. The Schottky-based FET [17–20] is a superior material for FET applications. Schottky FETs have been widely used for label-free bioanalyte detection [21, 22]. The range of electrostatic potential is widely utilised to estimate Schottky FET biosensors in response to the gating result induced by biomolecule controls [23, 24]. As a result, controlling the polarisation of the genetic analyte particle is crucial for the construction of the biosensor SK FET (n or p-type), which is determined during manufacturing by biochemical doping. Schottky Barrier FET (SB FET) based biosensors have lately attracted a lot of attention due to their industrial properties of implant-free low thermal budget management, atomically sharp interface topologies, and low residual S/D resistances [25, 26]. The SB FET biosensors may be more sensitive than doped equivalents. Furthermore, the alternative semiconductor-based SK FET relationships have been established and are rapidly growing [27–29]. As a result, researchers have employed Schottky-based FETs in a variety of applications and as biosensors. We also examine the current advances in bio-sensor sensitivity in terms of their architectures, arrangements, characteristics, and FET biosensors in this paper. Further, we also studied the issues that FET biosensors experience, the impact of metal/channel contact, and their prospects.

2 Categories of Biosensors Based on Receptors and Transducers

In common, sensors are categorised into two groups established with actuator and sensors shown in Fig. 1. The genetic awareness system transforms the material from the chemical province, most typically analyte absorption, into a physical yield signal with a specific sensitivity. The system's primary goal is to provide the sensor with a high point of discernment so that the analyte can be restricted [30]. The transducer makes up a large portion of the sensor. The sensor is responsible for transmitting the signal from the system's output dominion to the electrical province. The transducer portion of a sensor is also called a detector, sensor or electrode, but the term transducer is chosen to escape misperception [15]. The Electro-chemical transduction established biosensors is the supreme extensively overworked so far since of their modest standard of dimension and minor cost. In electro-chemical transducers contain voltammetry, amperometric, potentiometric, conductimetric, impedimetric, and semiconductor FET [31–34]. In response to a necessary development at the gate-dielectric junction, the second processes variations in conductance, deviations in carriers, potential deposit or charge layer, electrical resistance, and the carriers or the potential near a semiconductor area [4]. Several bio-medical claims have employed FET-based sensors to detect various bimolecular particles. Hence, these items are important indicators for the clinical diagnosis of disorders such as covid-19, heart diseases, renal injuries, diabetes, tumours, provocative, and transferrable diseases. Furthermore, bacteria detection for sickness analyses such as AIDS and hepatitis-B, and relevant bio-analytes...
like metabolite, are among the conceivable applications [35–38]. With these advances, SK FET established biosensors have been recognised as a decent applicant for the next generation [39].

To sense biomolecules with particularity using SK-FET platforms, the channel level has to be performed with bio-recognition molecules, particularly for the mark by companionable methods [40–43]. The Biological exchanges of enzyme–substrate, antibody-antigen, matching nucleic acid strands, etc., are developed in the SK FET biosensors to sense the region of a biomolecule with attractive precision [44]. After the region of molecules relates to the bio-receptor molecules, the natural interfaces might cause variations in the adjacent substance location and structures [45]. As a result of the effect of the electric field for the given gate voltage, the variations create an instant influence on the accumulated charge carriers near the silicon surface of the gate, transducing the biological interface into electrical characteristics as a measurable drain current ($I_D$) [46, 47]. Hence is the most common configuration for SK FET biosensors. In the past two eras, investigators have been exercising determinations, fitting techniques and biomolecules and nanomaterials are being added to biosensors in an attempt to make them ultrasensitive. Adding charged biomolecules to nano-objects, as well as inorganic/organic nano mixes to semiconductor FETs, opens up a lot of possibilities for label-free detection and real-time biosensing [48, 49]. Furthermore, a large number of bio-probes may be coupled to the sensor channel for very accurate and selective exposure of biological analytes. As a result, the semiconductor material is a significant difficulty in the implementation of SK FET-based biosensors [50].

### 3 Semiconductors based Channel for sensing biomolecules

Reducing the dimensions of silicon technology is fetching gradually inspiring, and concentrated investigation on a combination of materials has developed critical. Further, evaluation of silicon film SK FETs have high tunneling of carriers at small bias, greater transconductance, greater drain-source current, greater average electron speed, minor heat degeneracy and greater interchanging speed, and can hold advanced dielectric [51, 52]. The ultra-thin substrate which reduces the short channel effects (SCE) though instantaneously reaching great electron passage are featured a demanding schottky barrier as the potential device for upcoming high enactment scaled technology [30, 53, 54]. In addition, SK FETs are enormously hypersensitive to surface alteration, later they contain only of tunneling of elections [55]. In comparison to traditional nanomaterials devices, the nanodevice’s scaling dimensions and superior channel are thought to indicate higher sensitivity to various biomolecular responses that occur in its channel region [56, 57].

The SK FETs can have different band-gap levels which mainly define the performance. The metal/semiconductor-based schottky FETs, the sensitivity fluctuates expressively with tunneling and channel region with the immersion of numerous elements and molecules, and later able to identify several natural biodiversities like DNA, proteins, antibodies, living cells, and single molecules [58–60]. Figure 2 shows the typical SK FET structure [61].

### 4 Fabrication of SK biosensor

In the fabrication of biosensors, thin-film-silicon and metal combinations are used, which may be processed using specific manufacturing processes. The SK biosensor manufacturing technologies can provide a cost-effective and customizable sensing device for biomedical applications. For example, H1N1 virus and uranyl sensors may be made using e-beam lithography and chemical vapour installation, respectively [62]. The new research on schottky-based nanowire (SK NW) manufacturing as a transducing nanomaterial that allows for label-free, sensitive, and quick detection is also gaining traction. SKNWs are also utilised to detect a wide range of proteins, tiny particles, illnesses, and nucleic acids at ultra-low concentrations. Nozzle-jet type lithography is one of the most advanced processes created for the SK NW device. To produce source-metal, drain-metal, and gate metal leads, Nozzle-jet lithography does not require covers or chemical etchants. Hence, this type of printing technique is extensively utilized, on the occasion, to make radio frequency identification tags using roll-to-roll (R2R)
printing or to fabricate flexible presentations due to its cost-effective and fast process [63–65]. The SK FET biosensor, which was designed to quantify the amount of uranium that may be released as a result of exposure to a variety of industrial environments, was successful in sensing straight urine models by SK NW. The source/drain electrodes are also fabricated on top of SiO₂, with the Silicon surface functioning as a back gate. High-k dielectric materials have been used to substitute heavy silicon dioxide that is typically produced on top of the silicon wafer by Moore’s Law in device scaling. Hafnium silicate (HfO₂Si), zirconium silicate (ZrSiO₄), hafnium dioxide (HfO₂), and zirconium dioxide (ZrO₂) [66], yttrium oxide (Y₂O₃), and lanthanum oxide (La₂O₃) [67] are some of the materials employed. The use of high-k dielectric gate insulators results in electrostatic capacitance exceeding the quantum capacitance of SK FETs, which is difficult to achieve without a substantial leakage current (i.e., SiO₂). Furthermore, high-k materials have a reduced thickness and can attain the same capacitance as bulky low-k elements. Combining high-k dielectric materials with SK FETs also has improved subthreshold swings, high transconductance, and mobility in the submicron scale areas for device reduction [68–73].

5 Contemporary Studies on SK-Biosensor

The exciting incorporation of sensing in SK FET-based biosensors is no immunity. Schottky FETs have been the focus of intense investigation in recent years and have realised extensive applications in electrochemical biosensors. The SK devices are biodegradable and serve as dual-purpose: the carrier for biomolecules on their way being functionalized, and converter the identification of numerous bio-targets into electrical conductivity. In 2021, Rahul Singh et. al present a Dielectric Engineered Schottky Barrier MOSFET (DE-SBMOS) for biosensors, suggested device sensitivity was evaluated using I_on/I_off, threshold voltage (V_TH), and drain current characteristics. Furthermore, the influence of dielectric material on altering cavity length is investigated and compared to underlapped biosensors (UBS), aligned biosensors (ABS), and overlapped biosensors (OBS) (OBS). In comparison to ABS and UBS, the OBS gadget confirms that it has a higher sensitivity [74].

The physical/chemical reaction of devices at various pH values has been examined by Felix M et al. [75], and an evaluation with hypothetical restrictions has been explored. The Schottky barrier-powered silicon nanowire lab-on-a-chip stage was designed using nanofabrication and engineering. It is suitable for effective bio-detection and smooths for more composite biochemical studies. The suggested device has a collection of analogous ranges of silicon nanowires, which may be selected to increase current and reduce device-to-device dissimilarity, making it a good device to be merged into existing bio-nanoelectronic revealing devices.

Prashanth [76] et al. simulated the charge-plasma (CP)-based schottky barrier device has been explored by dielectric organised in cavity region of biomolecule sensor. The Hafnium material is used as a charge plasma near-source region that boosts the flow of carriers, which dramatically declines the tunneling thickness. Reducing tunneling improves its—current sensitivity for biomolecule. Furthermore, the ultra-sensing of the SB FET-based biosensor threshold voltage (V_th), irregularity in the on-current (I_on), and I_on/I_off ratio has been observed.

Sumeet Kalra [77] et al., have explored the ultrasensitive bio/chemical finding of FET biosensor by metal–semiconductor junctions. The simulations demonstrate a high detection sensitivity (105), a 104-fold configurable sensitivity aperture, and a large overall spectral response spanning >4 orders of magnitude with a single device (a 100-fold increase over a traditional FET biosensor). The modelled reaction abundantly validates the dispute of the extended dynamic range of the device.

Kyeong-Sik Shin [78] et al. observe the need for channel dimensions on the sensitivity of schottky junction in silicon nanowire field-effect transistor sensors. The experimental devices are used as photosensors as well as chemical sensors for pH sensing. The proposed device examined for two dissimilar channel dimensions are useful to identify the pH value of a solution compliant related to photo sense. For the given schottky contact, it is reduced the shorter channel effects when the sensor is employed in the ohmic region.

S.K. Yoo [79] et al. fabricated using hydrogen ions modulated in schottky barrier silicon nanowire field-effect by back-gate bias. The reaction shows that the differential drain-current rises with backside gate bias, whereas the I_on/I_off ratio meets unity. The response of pH level exposes that the process in the subthreshold region provides a 30% improvement in the sensitivity for the detection. An extremely sensitive finding using hydrogen ions was observed in the sub-threshold region.

Using flat aligned single-wall CNT, Chen [80] et al. (2016) developed a liquid-gated FET-based biosensor for label-free detection of Interleukin-6 (an anti-inflammatory myokine and pro-inflammatory cytokine). On a quartz substrate, aligned CNTs with diameters ranging from 2 mm to 100 nm dense and 200 m spread out were created using chemical vapour deposition and Au based source/drain electrodes. The detecting mechanism is established by a change in current created by a change in transducer conductance due to the demand for the analyte with the restricted IL-6R. Such a sort of sensor was said to have a sensitivity limit of 1.37 pg/mL.

The majority of previous biosensor reports, with a few exceptions, used metal source/drain electrodes in connection
with a silicon channel, reducing the device's ability to display a Schottky barrier (SB) effect, which is the major hurdle to free charge transport [81, 82]. Because of differences in work functions [83], portability [84, 85], and structural design of the two materials in interaction, and geometrically due to some dimensional actions such as contract length [86–91], contact geometry [92–94], the interaction of metallic electrodes with semiconducting channels results in a bulky resistance that rises in two directions, causing a mismatch of fermi levels. Based on extrapolation from past studies and examination of its influence on specific electronic process variables, the following unit explains and impacts contact matter between semiconductor and metal electrodes shown in Table 1.

**Regions of operation in schottky biosensor device** The gate bias, $V_{gs}$, and the drain bias, $V_{ds}$, organise the drain-current process in a SK TFET. The device is said to be working in one of three main parts based on these two constraints: below-threshold, ohmic, or saturation locations are described in Fig. 3.

The threshold voltage region, also known as the smallest gate bias ($V_{th}$), is where device current flows on the device and is crucial to the process. It also describes the gate bias needed to generate an inversion channel, in which the tunnelling carrier concentration at the channel's surface spreads the carrier density.

In a traditional SKTFET, when the gate bias is less than the threshold, the $I_{ds}$ (current) are raised to the subthreshold region and the schottky FET is activated in the SS region, which is commonly utilised for SK FET-biosensors. Here the analyte reaction can be improved, with the growing $I_{ds}$ exponentially dependent on changes in the gate bias by

$$I_{ds} = \frac{q(V_{gs} - V_{th})}{mK_bT}$$

where q is the electronic charge and m is the practical body-effect constant known as the body-effect constant.

The device is said to be functioning in the "ohmic" area when more than the $V_{th}$ ($V_T$) is supplied and the drain bias is small, as in $V_{gs} > mV_{ds} + V_{th}$, where m is the practical body-effect constant and $m = 1$. After the SK FET is in saturation mode, there is a large amount of current flowing in the device. The characterisation of SK FET-biosensors function on the standard of necessary analyte to the biosensor apparent effects in an alteration in electrostatic potential ($\Delta\psi_s$) through gating.

The variation in the device $V_{th}$, is calculated as an improved signal in the practice of a change in the $I_d$ by the transistor. The change in $\Delta V_{th}$ and the variation in $I_d$ can be calculated by calculating the variance in $I_d$ with regard to potential. In this sensing, any of these features could be used to respond. The Metrics are important for characterising SK FET biosensors can be determined using these measurements. The SS and transconductance ($g_m$) for the sequential range of operation are two often used measures to evaluate the sensor. The normalised change in current and the shift in threshold voltage are two prominent measures for evaluating biosensor sensitivity to samples. The following are the definitions for the four metrics displayed in Fig. 4. The SS is consistent in the subthreshold region, making device response straightforward to analyse. The SS value is a measurement of transistor reliability that depends on how effectively it responds to variations in gate potential. The gate voltage ($V_{gs}$) that must be changed to vary the subthreshold current is defined (1) [95].

![Fig. 3 MOSFE, sub-threshold, linear and saturation regions [95].](image)

| S/D Contact | Channel Material | $I_{on}$ Current | $I_{on}/I_{off}$ Ratio | Ref |
|-------------|------------------|----------------|----------------------|-----|
| NiSi        | Silicon          | $1 \times 10^{-6}$ | $1 \times 10^{5}$ | Rahul Singh [74] |
| NiSi        | polydimethyl-siloxane | $1 \times 10^{-6}$ | $1 \times 10^{4}$ | Felix M [75] |
| NiSi        | Silicon          | $1 \times 10^{-6}$ | $1 \times 10^{10}$ | Prashanth [76] |
| Au          | CNT              | $0.2 \times 10^{-6}$ | $1 \times 10^{3}$ | Iddo Heller [81] |
| NiSi2       | Silicon          | $1 \times 10^{-5}$ | $0.2 \times 10^{9}$ | Sumeet Kalra [77] |
| Au/Ti/Si    | Silicon          | $0.1 \times 10^{-5}$ | $1 \times 10^{3}$ | Kyeong-Sik Shin [78] |
Here the current is gradient dominated, when the drain bias is greater than $k_B T / q$, SS is independent of $V_{ds}$. A back-gate voltage, $V_g$, may be used to change the subthreshold slope, where (where $k_B$ is the Boltzmann constant and $T$ is the temperature) and SS is stated as:

$$SS = \frac{\partial V_{gs}}{\partial \log I_{ds}}|_{V_{ds}}$$  \hspace{1cm} (2)

Here the current is gradient dominated, when the drain bias is greater than $k_B T / q$, SS is independent of $V_{ds}$. A back-gate voltage, $V_g$, may be used to change the subthreshold slope, where (where $k_B$ is the Boltzmann constant and $T$ is the temperature) and SS is stated as:

$$SS \approx \frac{2.3 m k_B T}{q}$$  \hspace{1cm} (3)

The body-effect coefficient is denoted by $m$. As a result, at room temperature, the SS has a predicted lowest value of about 60 mV dec. Because the SS of 60 mV dec relates to the maximum limit for the response curve of traditional FET-sensors for a good change in gate bias, a lower value of the SS correlates to a bigger change in current for a given variation in gate bias. In both biosensors and pH sensors, the subthreshold slope reflects a transistor's capacity to convert a change in gate bias to a variation in current; as a result, the maximum variation in current can only be produced with a subthreshold slope of zero.

The $g_m$ kept static across the linear range, it's especially useful for describing the device characteristics. The slope of the current–voltage curve is measured by the transconductance, which is similar to the subthreshold slope.

$$g_m = \frac{\delta I_{ds}}{\delta V_{gs}}|_{V_{ds}}$$  \hspace{1cm} (4)

The sensor's fast reaction data are connected to analyte binding, which results in a longitudinal change in the $I_d-V_g$ curve, indicating a change in $V_{th}$ and $I$. When utilising current-response ($I$) as a performance metric, it is usual practice to divide the change in current by the original current to normalise the current ($I_{\text{norm}}$). A direct reading is also possible with the $V_{th}$. The $V_{th}$ equals the change in surface potential when an electrostatic gating process is considered, showing that this parameter can be employed for quantitative biosensing [96]. The assumption of electrostatic gating, on the other hand, is incorrect in some instances.

Analyte-induced variations to the metal–semiconductor work function, for example, provide a signal not originating from an electrostatic gating mechanism because the metal contacts to the semiconductor are not well-passivated and hence insufficiently insulated from direct interaction with the analyte. The important occurrence is when the analyte changes the voltage of the reference electrode. Heller et al. discuss how to utilise the $I_d-V_g$ to determine the mechanism of FET response in the literature (e.g. electrostatic gating, work function change etc.).

### 6 Sensitivity analysis of SKFET

The sensitivity analysis is primarily accomplished through the examination of factors such as threshold voltage sensitivity ($S_{V_{th}}$), current sensitivity ($S_{I_{on}}$), and sub-threshold swing sensitivity ($S_{SS}$), all of which may be stated in Table 2 [95].

$$S_{V_{th}} = \frac{V_{th(air)} - V_{th(bio)}}{V_{th(air)}}$$  \hspace{1cm} (5)

$$S_{I_{on}} = \frac{I_{on(bio)} - I_{on(air)}}{I_{on(air)}}$$  \hspace{1cm} (6)

### Table 2 Recently proposed Schottky FET biosensors sensitivity analysis

| Sensitivity | Sumeet Kalra [77] | Sangeeta Singh [98] | Prashanth [76] | Sumeet Kalra [97] | S.K. Yoo [79] | Won-June Park [99] | Ashish Raman [100] | Youfan Hu [101] |
|-------------|------------------|--------------------|---------------|------------------|---------------|-------------------|-------------------|-----------------|
| $S_{V_{th}}$ | 0.02             | -0.4               | 0.3           | 0.33             | 0.5           | 0.6               | 0.2               | 0.45            |
| $S_{SS}$    | 0.65             | 0.67               | 0.63          | 0.64             | 0.69          | 0.69              | 0.66              | 0.69            |
| $S_{I_{on}}$| 2500             | 2700               | 2450          | 2450             | 2650          | 2700              | 2500              | 2670            |
| $S_{I_{on}}/I_{off}$| $10^7$ | $10^6$ | $10^7$ | $10^7$ | $10^5$ | $10^4$ | $10^3$ | $10^3$ |

Superscript entries specify the sensitivity ON-OFF current ratio

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Table 2 outlines the detection limit and sensitivity of schottky biosensors found in the literature. The schottky FET-based biosensors have capabilities that are equivalent to those of other biosensor types. Unlike other biosensors, Schottky FET-based biosensors could be incorporated into the present semiconductor manufacturing process, enabling for a steady production strategy. Schottky FET-based biosensors has the ability to provide real-time monitoring at any time and from any location due to its smaller size. However, reducing the leakage will be a major issue as it lowers the detection limit which necessitate the development of new sensing films and unique bonding structure technique.

7 Challenges of SKFET-based biosensors

With the infrequent development of SK FET-based biosensors, high sensitivity biomolecule detecting technology can be recognized effectively. Moreover, the SK FET assistances scientific analysis but also occurs within specific confines in applications. Because of the rapid development of nanotechnology technologies, biosensors with smaller dimensions and lower concentrations are suitable for SK FET- biosensors in combination with other techniques. Furthermore, the sensibility of SKFET biosensors is a significant element that must be increased further. A fixed obstacle depends on the unpredictable schottky-barriers of the "Debye length issue. The $I_{on}$ deception in dielectric films causes drifting peculiar in specific types of SK FET-based biosensors, which drastically reduces the precision of detection. Further, virtuous resistance to $I_{on}$ aggressiveness will be a key growing technique for material collecting to address SK FET. A reproducibility of capacity will be a certain trial to calculate that it is consistent enough or not, when combined with encounters in exterior change, such as the constancy of necessary rate maintenance and regularity of responses. The FET-based biosensors, tend to assess charged biomolecules due to their process mechanism. The electroneutral biomolecules are reasonably suitable for other methods of discovery, such as fluorescence and electrochemical impedance spectroscopy. Huge and similar biomedical indication handling will be a developing route in next-generation biomolecular diagnosis. The specific requirements, such as biodegradable and wearable, come to mind to highlight these concerns, prospective biosensor applicants would be obliged to add signal dispensation methods, which are required to construct the system on a single chip [102–104]. As a result, in addition to the previously mentioned issues, similar impedance among subsystems will have a conclusive effect, limiting whether

the preferred signals can be captured with a high signal-to-noise ratio. Additionally, abilities to manage biodegradable and malleable substances must be improved. It could be a good concept to combine heterogeneous materials to generate novel ideas, which might provide several benefits such as high sensitivity, adaptability, and immediate convenience.

8 Conclusion

Finally, the computerised analysis obtained here indicates that the device must be maintained in the subthreshold region to increase SK FET-sensor sensitivity. The proposed device optimization must simultaneously target the device’s subthreshold slope and the electrolyte-oxide surface chemistry. The variation in the shift of threshold voltage with a tenfold increase in the concentration of the analyte was higher in biosensing responses than in pH sensing reactions. The greater unpredictability might be attributed to a variety of things. According to pH e.g. HfO$_2$ models, the density of analyte–receptor (e.g. hydroxyl groups) just at the surface is the most essential element in determining the above shift, and hence this might be an important factor defining biomolecular response variability. Furthermore, the impacts of ionic strength and absorption in biosensing are substantially more prominent than in pH sensing due to the biomolecule distance from the surface and the ability to change the pH of the buffer. The loss of a biomolecule owing to non-specific binding might result in a tenfold increase in analyte concentration causing even more variation in biosensing threshold voltage change. Because the bio sensitive zones have a small surface area in contrast to the overall larger surface area, this is especially troublesome for nanoscale devices. The biomolecule, as previously indicated, can be a basic source of variety. In the future, this finding will be crucial in the creation of highly sensitive schottky FET-based biosensors.

Author contributions All the authors are involved in the review on the schottky barrier FET device.

Data Availability There is no other data and material associated with this manuscript.

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declarations

Conflict of Interest The author declares that there is no conflict of interest.

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