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PERSPECTIVE ARTICLE

Perspectives on Dielectric Modulated Biosensing in Silicon Tunnel FETs

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Abstract
Consistent research on Tunnel Field Effect Transistors (TFETs) has led to the lookout for their viability in biosensing. The dependence of the tunneling probability on the gate dielectric constant of TFETs makes them ideal for the exploration of biomolecule sensing using modulation of the gate dielectric constant. Although numerous architectures of TFETs have been theoretically analyzed for dielectric-modulated label-free biomolecule sensing, there seems to be no distinct reported work on the fabrication of a TFET based dielectric modulated biosensor. Therefore, this article brings out the different prospects in taking forward TFETs as dielectric modulated biosensors, and discusses the challenges involved.

Keywords Silicon TFET · Biosensors · Dielectric modulation · Partial hybridization · Steric hindrance

1 Introduction

Despite being the most popular and established semiconductor device for electronic applications, Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) see several limitations when scaled down. Downscaling severely degrades the leakage current (off current), and fails to reduce the subthreshold swing (SS) below 60 mV/dec (thermal limit) at room temperature [1–3]. In an attempt to mitigate these limitations in MOSFETs, TFETs have emerged as one of the prominent alternatives for low power applications [4]. Compared to MOSFETs, TFETs are gated reverse biased *p-i-n* diodes (Esaki diodes) conventionally, which work on the principle of quantum band-to-band tunneling [5]. This interband tunneling offers a 'band-pass'-like window which cuts off the transmission of high energy tailed carriers from their source, resulting in opportunities to achieve lower subthreshold swings than MOSFETs [1].

TFETs are bipolar in nature, and depending on the voltage applied to their terminals, the same architecture can operate in *p* or *n* mode. Therefore, the doping concentrations of the source, and the drain regions play significant roles in their operation. In an n-type TFET, while the source doping concentration is important for its on-state current, the drain doping concentration decides its ambipolar current [6].

The exploration of TFETs, and their low power applications has been phenomenal in the past decade. However, they are not free from fundamental drawbacks. One of the disadvantages of TFETs is low on-state current (I_{ON}) as compared to MOSFETs due to the former's reverse biased *p-i-n* geometry [7]. Another disadvantage, the ambipolarity in TFETs, is an important physics-based phenomenon of concern for applications involving digital logic [8]. The design of a novel architecture of a TFET, therefore, depends on achieving higher on-state current and lower ambipolar currents through inexpensive manufacturing process.

The advantages of TFETs have propelled researchers to explore them for multiple applications, one of them being biosensing. Biosensing mechanism based on dielectric modulation is dependent on architectural design, and material composition of the device. The next three sub-sections, therefore, present a background to the theme of this article comprising of geometries and materials of TFETs along with the concept of dielectric modulation for biosensing.

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1.1 Evolution of Architectures

The concept of TFETs can be attributed to Stuetzer's report on a device in 1952, which was titled 'junction fieldistors' [9]. The article commented on the conductivity of a gated reverse-biased *p*-n junction, and experimentally showed the ambipolarity in the device. The experimental evidence of a sub-kT/q subthreshold swing was reported by Choi et al. for a 70 nm TFET, exhibiting an SS of 52.80 mV/dec [10]. The search for novel architectures of TFETs has led researchers to come up with innovative structures, utilizing the parameters on which they operate. The idea of double gate architecture in TFETs (DG-TFET) was first analyzed by Boucart and Ionescu to have an on-state current equal to 0.23 mA at a gate bias of 1.8 V [7]. Choi and Lee proposed a hetero-gate dielectric (HG) TFET where the gate dielectric comprised of a low-k dielectric towards its drain end, and a high-k dielectric towards its source end. The high-*k* dielectric (HfO_2) introduced a local minimum of the conduction band edge at the tunneling junction, thus facilitating more carriers to tunnel. On the other hand, the low-*k* dielectric (SiO_2) suppressed the ambipolarity owing to weaker gate-channel coupling near the channel-drain junction. HG TFETs showed ~80% smaller SS and two orders of magnitude higher I_{ON} than SiO_2-only TFET [11]. As a modification to the *p-i-n* body in conventional architectures, *p-n-p-n* TFETs having a heavily doped pocket between the source and channel displayed ~10 times higher I_{ON} comparatively with a steeper subthreshold slope [12]. Gate-All-Around (G-A-A) TFETs showed better gate controls over the channel with improved current driving capability due to the increased influence of the gate on the channel from all sides [13, 14].

1.2 TFETs Based on Novel Materials and Architectures

The ideas of 'More Moore' and 'beyond CMOS' designs have propelled the orientation of research in TFETs from conventional materials (Silicon or Germanium) and conventional *p-i-n* or *p-n-p-n* architectures to newer materials and designs [15]. Ionescu & Riel concluded that TFETs based on ultrathin films or nanowires can operate with low power reduced up to 100 times as compared to complementary metal-oxide-semiconductor (CMOS) transistors [1]. The two-dimensional heterojunction interlayer (THIN) TFETs were theorized, expected to have an SS of 14 mV/dec and a high on-current of ~300 μA/μm. The experimental demonstration was done using $WSe_2/SnSe_2$ stacked heterostructures. The structure consists of a top and a bottom layer consisting of 2D semiconductors separated by Van Der Waals gap [16].

Investigation by Mohata et al. demonstrated that a higher TFET drive current is obtained in III-V materials due to their lower bandgaps, and lower carrier mass. Further investigations showed that staggered and broken-gap hetero-junctions such as AlGaSb/InAs and InAs/GaSb, improved I_{ON} by reducing the tunneling length. Monolayer Transition Metal Dichalcogenide Channel-Based Tunnel Transistors were investigated by Ghosh and Mahapatra for five different MX_2 materials, and found that all five MX_2 support direct BTBT in their monolayer sheet forms, and offer an average I_{ON}, and SS of 150 μA/μm (at a drain voltage of 0.1 V), and 4 mV/dec, respectively [17]. While other switching mechanisms such as impact ionization, ferroelectric dielectrics, or mechanical gates can provide subthreshold swing below 60 mv/dec, TFETs have an advantage that they can operate below 1 V, and do not suffer from the delay caused by positive feedback intrinsic to the aforementioned switching mechanisms [18]. In a more exhaustive approach, Manocha et al. presented a detailed investigative multicriteria-based framework to architectures of TFETs based on low-dimensional materials (graphene, carbon nanotubes, and transition metal dichalcogenides) in order to arrive at the best material suitable for low power applications. Carbon nanotubes and WTe_2 were reported to be the most favorable materials for TFETs [19].

1.3 Dielectric Modulation in Biosensing TFETs

Biosensors based on TFETs have been proposed to work on (a) the gating effect [20] and (b) the dielectric modulation effect [21]. In the gating effect, the gate material is replaced by biomolecule receptors on top of the gate dielectric material, while in case of dielectric modulation, biomolecules are trapped in a nanocavity formed by etching out a part of the gate dielectric material (Fig. 1). The modulation of the gate dielectric constant is caused by the immobilization of the biomolecules which bind with the receptors in the gate embedded cavity, resulting in the change in various parameters like threshold voltage and drain current. The threshold voltage (V_T) and drain current are the most widely used parameters for expressing the sensitivity of a dielectric modulated biosensor. The most commonly used sensitivity expression for dielectric modulated TFET biosensors is the drain current sensitivity, defined as, $S_{ID} = \frac{I_{ON,k}}{I_{ON,air}}$, [22, 23] where $I_{ON,\,k}$ is the

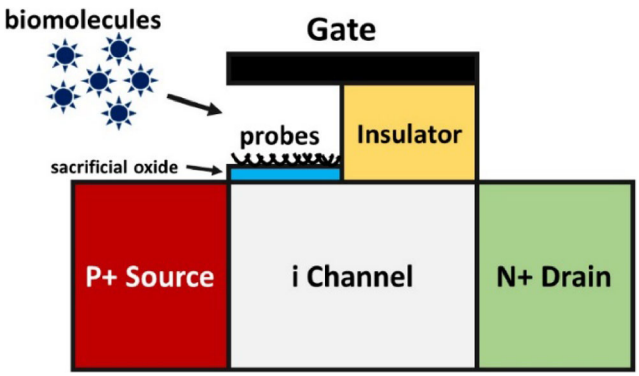

Fig. 1 A 2D representation of a DM TFET with embedded nanogap for biosensing, showing the probes over the sacrificial layer (*not to scale*)

on-state current of the biosensor when the cavity is filled with a biomolecule having dielectric constant, k, and $I_{ON,\ air}$ is the on-state current of the biosensor when the cavity is filled with air, both being measured at constant gate-to-source voltage and drain-to-source voltage. In a few reports [24–27], S_{ID} has also been defined as $\frac{I_{ON,k}-I_{ON,air}}{I_{ON,air}}$; however, owing to the dominance of $\frac{I_{ON,k}}{I_{ON,air}}$ over $\frac{I_{ON,air}}{I_{ON,air}} = 1$ for best cases, the definition of S_{ID} can be taken as the first expression. Similarly, the threshold voltage sensitivity is defined as $S_{VT} = V_{T,\ air} - V_{T,\ k}$ [27, 28] indicating the shift in threshold voltage caused by hybridization of biomolecules in the cavity with reference to an air-filled cavity.

Section 2 of this article presents the current status on DM TFETs as biosensors. Section 3 discusses the challenges involved, and possible scope in the area. Section 4 concludes the article.

2 Current Status

This section presents a summary of some of the most significant DM TFETs as biosensors proposed so far. Of the devices discussed in this section, almost all of them are based on Silicon. Ever since the emergence of this domain of research, researchers have attempted to analyze the biosensing effects in different architectures of TFETs. A list of 20 cases of DM TFETs as biosensors along with their sensitivities is tabulated in Table 1. It shall not be justified to compare the sensitivities for different TFETs in Table 1 because they have been analyzed under different conditions of voltages and geometry. Therefore, Fig. 2 is a status map which gives an idea of where each biosensor stands in terms of their sensitivities. However, Fig. 2 only plots the drain current sensitivities which is the most widely used metric.

One of the first DM FETs for biosensing application, which had a vertical gap fabricated by thin-film deposition and wet-etching technique, was reported by Choi et al. in 2007 [29]. The DM FET consisted of a chromium (Cr) layer between the gate and the gate oxide which was etched from the sides to create an air gap which could be filled with biomolecules. It was used for biotin-streptavidin detection. The change in threshold voltage was observed before Cr etch, after Cr etch and after immobilization. Simulations showed a V_T shift of +0.44 V after Cr etching and 0.18 V when the gap is filled with the low-k dielectric material. V_T shift observed after immobilization was −0.06 V due to the increase in gate capacitance at the gold side of the inner walls of the air gap.

Narang et al. proposed the concept of DM TFET for sensing neutral and charged bio-molecules [21]. It consisted of a *p-i-n* structure with a nanogap cavity at the source side. It saw an increased drain current by the reduction of the tunnel barrier as a result of the increased capacitance at the source side with the increase of the dielectric constant in the nanogap cavity With respect to $k = 1$, the change in the on-current was reported to be five, six, and seven orders of magnitude for $k = 5$, 7, and 10 in the case of *p-i-n* TFET, respectively, while the change for a MOSFET is 2.2, 2.6, and 3 times for $k = 5$, 7, and 10, respectively, with respect to $k = 1$.

Kanungo et al. reported that a short-gate TFET (SG-TFET) has better sensitivity as compared to a full-gate TFET (FG-TFET) [24]. A 42 nm long gate was defined for FG TFET and 20 nm gate length (from source to channel) for SG TFET. At biasing conditions, the gate-to-channel coupling is relatively weaker in the SG structure. As prior to biomolecule conjugation, the drain-induced gate-to-channel coupling reduction is the highest in the SG-DMTFET, the relative difference in the conduction band bending between the biosensors is also the highest. Greater modulation in minimum tunneling length is present in SG-DMTFET. With the increase in gate bias, the gate-to-channel coupling reduction in SG-DMTFET is significant, but decreases later as the gate takes control over the electrostatics [24].

Narang et al. did a comparative study between a Silicon DM-TFET and a DM-FET for the impact of partial hybridization (PH), the impact of biomolecules charge, and the impact of probe placement on sensitivity [23]. Increase in PH reduced the drain current by lowering the effective gate capacitance which lowers the channel potential in the cavity region. This lowers the electric field at the tunneling junction and affects the tunneling barrier. The TFET characteristics showed a delayed saturation effect. In TFETs, the sensitivity is largely governed by the profile of biomolecule hybridization, and not solely by the area covered by the biomolecules. Charge (negative) in biomolecules have a higher effect on sensitivity when the dielectric constant is lower. In the case of DM-TFET, there is more than a 40% reduction in the change in sensitivity values as compared to a 23% reduction for DM FET [23].

Abdi and Kumar presented a DM TFET with a gate-on-drain overlapped nanocavity, and carried out the analyses in terms of ambipolar current. As the biomolecules change the dielectric constant of the cavity, the effective capacitance increases, leading to increased depletion in the drain region, and thus widening of the tunneling barrier width at the channel-drain junction. The sensitivity of the device, as shown by 2D TCAD simulations, varies from 10^4 to 10^{10} when the dielectric constant changes from $k = 5$ to $k = 10$, respectively [30].

Ajay et al. developed a hetero-junction (HJ) Gate All Around *p-i-n* TFET architecture using GaSb-InAs for biosensing applications having good sensitivity towards charged and neutral biomolecules [28]. The non-uniform gate is in the form of a semi-circle, and the gate dielectric thickness is dependent on the radius of the circle. The change in the threshold voltage V_T was observed to be equal to 0.77 V when the nanocavity was filled with neutral APTES biomolecules from being empty. When negatively (positively) charged ($N_f = \pm 5 \times 10^{15}\ m^{-2}$)

Table 1 List of DM TFET biosensors with details and approximate sensitivity

SL	TFET biosensor	Measurement conditions	Sensitivity
1	DM-TFET [21]	V_{GS}=1 V, V_{DS}=1 V, k=10, charge=0	~1×10^{7}
2	FG-TFET [24]	V_{GS}=1 V, V_{DS}=0.4 V, k=4, charge=0	~2×10^{5}
3	SG-TFET [24]	V_{GS}=1 V, V_{DS}=0.4 V, k=4, charge=0	~1×10^{6}
4	DM-TFET [23]	(Uniform PH) V_{GS}=2 V, V_{DS}=1 V, k=10 charge=0	4.55×10^{6}
5	DM-TFET [23]	(Non-uniform step profile) V_{GS}=2 V, V_{DS}=1 V, k=10, charge=0	6.00×10^{5}
6	Gate-on-Drain TFET [30]	V_{GS}=−1 V, V_{DS}=1 V, k=10, charge=-5×10^{11} cm^{-2}	1×10^{10}
7	Circular Gate (CG) TFET [22]	V_{GS}=1.2 V, V_{DS}=1 V, k=12, charge=-10^{11} cm^{-2}	5.23×10^{7}
8	Heterojunction (HJ) TFET [22]	V_{GS}=1.2 V, V_{DS}=1 V, k=12, charge=-10^{11} cm^{-2}	2.387×10^{6}
9	Circular Gate (CG) TFET [22]	V_{GS}=1.2 V, V_{DS}=1 V, k=12, charge=10^{12} cm^{-2}	1.31×10^{8}
10	Heterojunction (HJ) TFET [22]	V_{GS}=1.2 V, V_{DS}=1 V, k=12, charge=10^{12} cm^{-2}	3.382×10^{6}
11	SiGe-source TFET [27]	Ge composition 10%, V_{DS}=0.5 V; k=2.1,charge=0	~495
12	Charge Plasma JLTFET [25]	V_{GS}=1.5 V, V_{DS}=0.5 V; k=10, charge=0	~3×10^{7}
13	Charge Plasma JLTFET [25]	V_{GS}=1.5 V, V_{DS}=0.5 V; k=5, charge=-5×10^{11} cm^{-2}	~1×10^{6}
14	EDTFET [26]	V_{GS}=0.9 V, V_{DS}=0.5 V, k=12, charge=0	~ 1×10^{9}
15	EDTFET [26]	V_{GS}=0.9 V, V_{DS}=0.5 V, k=4, charge=-1×10^{11} cm^{-2}	~1×10^{6}
16	FG-TFET [24]	V_{GS}=1 V, V_{DS}=0.4 V, k= 4, charge=0	~0.70 (surface potential sensitivity)
17	SG-TFET [24]	V_{GS}=1 V, V_{DS}=0.4 V; k= 4, charge=0	~0.95 (surface potential sensitivity)
18	HJ GAA TFET [28]	V_{GS}=1.5 V, V_{DS}=0.5 V, k=3.57, charge=0	+0.77 (threshold voltage sensitivity)
19	HJ GAA TFET [28]	V_{GS}=1.5 V, V_{DS}=0.5 V, k=3.57, charge=$+5\times10^{15}$ m^{-2}	+0.202 V (threshold voltage sensitivity)
20	HJ GAA TFET [28]	V_{GS}=1.5 V, V_{DS}=0.5 V, k=3.57, charge=-5×10^{15} m^{-2}	+0.157 V (threshold voltage sensitivity)

biomolecules are present in the cavity, the threshold voltage changes by 0.157 V (0.202) with comparison to neutral APTES biomolecules.

Kanungo et al. demonstrated that SiGe-source DMTFET gives higher subthreshold current level over $n+$ pocket DMTFET while retaining acceptable sensitivity [27]. A 10 nm long $n+$ pocket near the SiGe $p+$ source was introduced in a double gate TFET structure having nanogaps on both sides of the pocket. The Ge composition should be around 10% to maximize sensitivity and 30% for sensitivity-current optimization. Compared to $n+$ pocket DMTFET where sensitivity reduces by 50%, SiGe-source DMTFET was found to provide current improvement without significant sensitivity reduction.

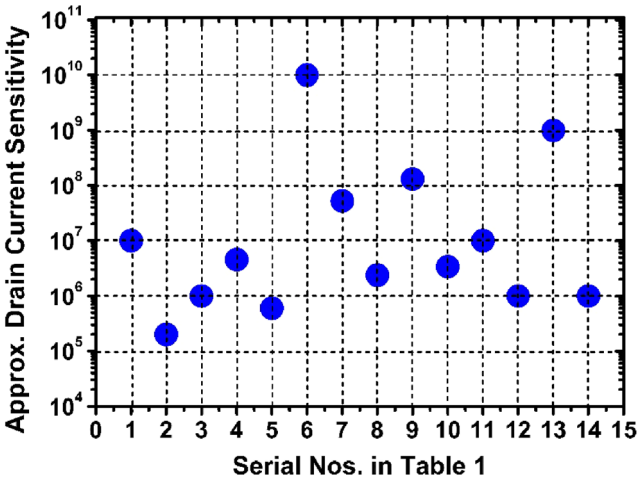

Fig. 2 Status map of DM TFETs as biosensors from Table 1

Goswami and Bhowmick did a comparative study of Circular Gate (CG) Tunnel Field Effect Transistor (TFET) and uniform gate Heterojunction (HJ) TFET as label-free biosensors based on dielectric modulation. They found that CG TFET exhibits higher sensitivity than HJ TFET due to its non-uniform gate architecture and a maximum sensitivity of 1.31×10^{8} (3.382×10^{6}) is achieved for fully filled nanogap in CG TFET (HJ TFET) for dielectric constant 12 [22].

Singh et al. developed a charge-plasma-based dielectric-modulated junctionless TFET for label-free biomolecule detection [25]. The formation of $p+$ source, and $n+$ drain regions in the DM JLTFET is done by the deposition of platinum (workfunction = 5.93 eV), and hafnium (work function = 3.9 eV) materials, respectively, over the silicon body. Similar to other TFET architectures, the on-state current and ratio of on-state and off-state currents for DM JLTFET for different biomolecules dielectric constants are extremely high in comparison with those for MOSFET [25].

Dielectric-modulated electrically doped tunnel field-effect transistor (DM EDTFET) as a biosensor for label-free detection was found to be immune against doping control issues, avoided thermal budget and fabrication complexity as compared to its counterpart as reported by Venkatesh et al. [26]. In

the said device, the n + drain and p + source regions are induced by considering polarity bias of PG-1 = +1.2 V and PG-2 = −1.2, respectively over the ultra-thin silicon body.

3 Future Needs and Prospects

The future direction and prospects of dielectric-modulated TFETs as biosensors can be best addressed by having an overview of the challenges involved in the area, which shall aid in realizing the viability of these devices from the perspectives of commercialization.

3.1 Challenges

The theoretical consideration of dielectric modulation in TFETs for biomolecule sensing is encouraging. However, there are a number of issues related to fabrication and measurement involving DM biosensors which need attention with respect to TFETs in particular.

Process induced defects (PIDs) pose a serious threat to the operation of a FET. These defects become significant in TFETs because the tunnel junction is the most sensitive zone for the transistor. In case of a DM TFET as a biosensor, the formation of a nanocavity in the gate dielectric is carried out by etching out a previously deposited gate dielectric material. This has immense possibility of creating damages to the gate oxide, examples being incomplete etching or damaged native oxide which is grown post etching. In more specific cases of using high-k/SiO_2 gate dielectric stacks, slow oxide traps have been found to originate during the etching process [31].

Moreover, there is a risk of damaging the Silicon substrate at the surface as well. Such process-induced phenomena leads to inferior electrical performance, especially in terms of parameters like on-state current, off-state current, and noise immunity. In TFETs where the tunnel junction and the surface of the substrate are extremely important for the conduction mechanism, damages due to etching close to the tunnel junction may render the device unsuitable for application as a biosensor. Therefore, etching a cavity in a TFET is challenging keeping in view that the sensitivity as a DM biosensor must not be degraded significantly. In light of this, Narang et al. [32] have reported that percentage change in on-state current due to damaged gate oxide in TFETs is higher than in MOSFETs by approximately 2.5 times for hybridization of biomolecules having a dielectric constant of 12.

Probe placement issues can significantly affect the sensitivities of a DM TFET biosensor. The distribution of biomolecules in the gate embedded nanocavity is far from being ideal as considered in most cases in theoretical analysis. The disparity in the placement of probes in the cavity may lead to discontinuous binding between the target and the probe molecules (Fig. 3). Such a condition may prove to be detrimental to the operation of TFET based dielectric modulated biosensors. The reason behind this is attributed to the non-uniform band-to-band generation profile in a TFET architecture. The band-to-band generation rate is the highest close to the tunnel junction. Therefore, the presence of probes in the gate nanocavity close to the tunnel junction is of utmost essential to influence a high sensitivity in the biosensing device. As presented by Narang et al. [32], the location of probes close to the tunnel junction is as important as the discontinuity between adjacent probes in TFETs. In the reported *p-n-p-n* DM-TFET, the onset voltage increased with a reduction in surface area covered by probe/target in the cavity. Similar analyses have also been reported by Goswami and Bhowmick for the cases of Circular Gate TFET and heterojunction TFET [22].

Partial hybridization (PH) of biomolecules in the cavity is another concern for TFETs (Fig. 3). The phenomenon of steric hindrance where the initially hybridized molecules in the cavity hinder the entry of others is a practical problem in nanocavity based sensors. Theoretically, such conditions are simulated by assuming specific profiles of biomolecules in the cavity. Narang et al [32] have addressed the problem of partial hybridization (PH) in the TFETs by assuming decreasing slant and step profiles, and Goswami and Bhowmick have similarly simulated the conditions for decreasing, increasing, concave and convex profiles in TFETs. The phenomenon of PH reduces the sensitivity of the DM TFET biosensors due to the reduced fill factor of the cavity, but more importantly, as pronounced in other phenomena, the sensitivity is high when the peak of the biomolecule profile is closer to the tunnel junction. Therefore, as deduced by Goswami and Bhowmick, the decreasing and concave profiles have been found to show higher sensitivities for the same fill factors as compared to the increasing and convex profiles.

3.2 Future Needs and Prospects

The challenges involving the use of dielectric modulation in TFETs for biosensing have led to several qualitative deductions that may prove to be strategical in implementing these devices as biosensors. Although these are not exhaustive in nature, yet they simultaneously address the drawbacks and prospects in this theme.

- One of the factors which define the suitability of using a device as a sensor is the repeatability of its results. From the perspective of challenges in the fabrication of nanocavity embedded architectures as outlined earlier, the occurrence of uneven damages may lead to inappropriate results of the same architecture. Hence, strategies must be taken up either in etching out a perfect cavity in the gate dielectric, which is tedious, and has the possibility of increased costs, or developing efficient bias circuitry

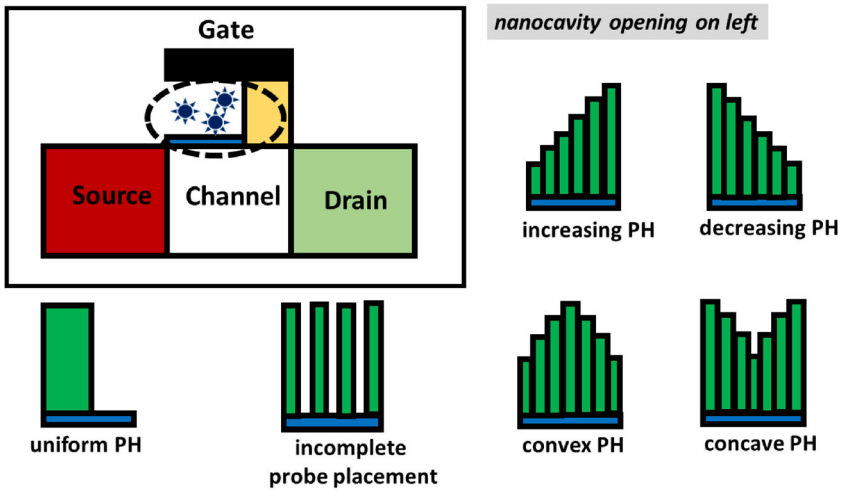

Fig. 3 Cases of uniform PH, non-uniform PH (step profiles: increasing, decreasing, convex and concave) and probe placement scenarios in DM TFETs as biosensors used during TCAD simulation in reported works [22, 23]

which can take into account the variations intelligently so as to produce results with acceptable tolerance levels.

- There is an undeniable interdependence between the subjects of fabrication of device architecture and modeling it. With the progress in the philosophy of modeling new architectures and device phenomena, it must be worth noting that although a theoretical background can present the concept of a device or a phenomenon, such backgrounds can only assist in designing the device, or feedforwarding concepts from similar devices. However, the actual principles of operation become evident from a fabricated architecture, the results of which further assist in strengthening the theoretical background of the device. In brief, both subjects of fabrication and modeling of architecture are recursive in nature in terms of design cum theoretical inputs. In case of DM TFET based biosensors, much has been worked on the theoretical analysis through simulations, but the percentage of work on the fabrication front is negligible. Therefore, many prospects lie in the realization of a working DM TFET biosensor, and relating the associated modeling to it. Once such works surface the research spectrum, the area shall see the light towards commercialization or at least useful inferences which may help to arrive at interesting conclusions. Therefore, to cause a major impactful shift in the scientific or technological scenario with DM TFET biosensors, fabrication of an architecture is the need of the hour.
- It is not mandatory that the nanocavity for hybridizing biomolecules must be located beneath the gate region. It will be more beneficial if the location of the nanocavity can be shifted from the gate region to other locations of the architecture, where the effect of dielectric modulation can be exploited. This shall hugely alleviate the problems of process-induced damages in the gate dielectric region, and maintain the fabrication cost at acceptable levels. However, the location of the cavity must be carefully selected, and the parameters appropriately optimized so that there is a significant resolution in the sensitivity values.
- TFETs exhibit low on-state currents. This creates a major setback in measurement systems when the biomolecule dielectric constant is of lower value, making the readouts more vulnerable to electronic noise. To tackle such problems, current amplifying circuits or trans-impedance amplifiers may be used, which essentially amplifies the current or converts to an equivalent voltage, and stabilizes the noise [33–35].
- An altogether different outlook on DM TFETs as biosensors may be perceived through the emerging scope of use of machine learning in sensing applications [36]. The interactions between the target and the probes, the probabilities of placement of probes, the damages to the semiconductor surface during etching of nanocavity, the biosensing circuit parameters and the acquisition of data from biosensor arrays may be well-modelled or better predicted by machine learning algorithms [37].

4 Conclusion

This article presented an overview of the challenges and prospects in realizing dielectric modulated biosensors based on TFETs. The article throws light on the different architectures of TFETs, and reveals the current status of the area by tabulating some of the various DM-TFET biosensors proposed so far. The emergence of TFETs has undoubtedly pushed them towards multiple applications but the challenges in realizing a fabricated DM-TFET biosensor have limited the reports of manufactured devices, which, in turn, have restricted new dimensions in theoretical approaches too. The area has immense prospects, and more insight can be drawn towards developing

robust theoretical models when reports of fabricated TFET sensors come into light.

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Declarations

Research Involving Human Participants and/or Animals This work does not involve research involving human participants and animals as this is an article under 'Perspective' category.

Informed Consent Not Applicable.

Consent to Participate Since this article is an article under 'Perspective' category, and does not involve human participants/ animals, therefore, this is not applicable.

Consent for Publication Since this article is an article under 'Perspective' category, and does not involve human participants/ animals, therefore, this is not applicable.

Conflicts of Interest/Competing Interests (Include Appropriate Disclosures) There is no conflict of interest.

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