Sensitivity Analysis of Physically Doped, Charge Plasma and Electrically Doped TFET Biosensors

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Received: 20 July 2021 / Accepted: 10 October 2021 / Published online: 21 October 2021
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Abstract

TFET based label-free biosensors are fast, sensitive and more power efficient as compared to CMOS biosensors, which are prone to short channel effects (SCEs). However, literature is flooded with various TFET biosensors that have become the reason of dilemma for researchers during pandemic situations like COVID-19. Therefore, in this work, a physically doped (PD), charge plasma (CP) and electrically doped (ED) dielectric modulated (DM) TFET based label-free biosensors are compared, which cover almost the entire range of doping and junctionless devices. Also, we found that the ED based TFET biosensors provide better current sensitivities of 5.10×10^7 , 4.77×10^8 and 7.11×10^8 for biomolecules with $K=12$, positive charge $= 1 \times 10^{13} \text{ C/cm}^2$ and negative charge $= -1 \times 10^{13} \text{ C/cm}^2$ respectively. Hence, ED-DM-TFET based biosensors can act as promising candidates to provide better detection and identification quality.

Keywords TFET · Biosensor · Physically doped (PD) · Charge plasma (CP) · Electrically doped (ED)

1 Introduction

The common human coronavirus (CoV), which infects millions of people every year are basically of two types: alpha (229E, NL63) and beta (OC43, HKU1, SARS-CoV, MERS-CoV). SARS (severe acute respiratory syndrome) CoV affected 8000 people in 2003 and MERS (Middle East respiratory syndrome) CoV infected more than 1700 people in 2012 [1, 2]. Now, the latest one, SARS-CoV-2, which is responsible for the rapid transmission of COVID (coronavirus disease) in 2019, turned into pandemic as it infected 230 million and killed 4.72 million people around the world as of September 2021. SARS-CoV-2 can spread directly from person to person through sneezing, coughing and talking within a six feet distance limit or through the indirect transmission from fomites on which infection lasts for hours. Therefore, the rate of SARS-CoV-2 spread and death

is much more as compared to the other CoVs as this virus damages respiratory system and fever, dry cough, shortness of breath are some of the symptoms which take 2-14 days to show its deadly effects [3]. Therefore, this is an alarming situation, where each individual has been instructed to wear a mask and maintain social distancing along with personal hygiene. Meanwhile, medical practitioners are searching for fast and accurate test kits, that could detect the infected persons and isolate them to stop transmission. However, the present reverse transcription polymerase chain reaction (RT-PCR) kits are slow and costly as they transform RNA to complementary DNA (C-DNA) and then measure the specific RNA amount by monitoring C-DNA amplification using PCR technique [4]. Unfortunately, the rapid test kits exhibit some limitations like sensitivity and wide deviation of test results (34 %-80 %), showing both false negative results and false positive results. Also, these rapid test kits can detect COVID only when someone is recently infected and could not provide any information about other diseases and their symptoms. Further, these kits rely on simultaneous capture and detection of the virus and so there is a possibility to miss the patients who have recovered from COVID-19. Therefore, the lack of accurate rapid test kits drove researchers to find suitable alternatives for the detection of SARS-CoV-2 and other such diseases in future.

Certainly, label-free dielectric modulated (DM) FET biosensors are one such alternative as they are capable to detect biomolecules with different dielectric constant values and are

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Fig. 1 SARS-CoV structure [3]

cost efficient as compared to the existing technologies [5–9]. Also, TiO_2 nanowires discussed in literature are good examples of glucose and vitamin detections using novel device techniques [10, 11]. SARS-CoV-2 structure is composed of multiple proteins such as spike (S), membrane (M), envelope (E) and hemagglutinin-esterase (HE) as shown in Fig. 1. The S-protein has dielectric values ranging from 1 to 4 that could be easily detected from label-free DM-FET biosensors. Also, RNA transformed to C-DNA would have dielectric values ranging from 1 to 64. There is enough evidence available in literature that many FET based biosensors are effective for detection and diagnosis of COVID-19 [12, 13]. Most of the works are centred on graphene [12] and carbon nanotube [14] based FETs. In addition, many 2-D materials [15] and novel FETs [13] mechanisms are also discussed for COVID detection. However, the CMOS based DM-FET biosensors are not

suitable for detection of wide variety of biomolecules as they have limitations like less sensitivity, low $I_{\text{ON}}/I_{\text{OFF}}$ ratio, sub-threshold swing (SS) greater than 60 mV/decade, short channel effects (SCEs) and random variations, which would reduce the test kit sensitivity and power efficiency. Alternatively, Tunnel FET (TFET) based DM biosensor provides better sensitivity due to tunneling phenomenon, SS lesser than 60 mV/decade generates higher $I_{\text{ON}}/I_{\text{OFF}}$ ratio at low supply voltage [16–18]. However, COVID-19 researchers are always in dilemma to select the appropriate DM-TFET biosensor as literature is flooded with such biosensors describing their applicability and hence, a decision based on proper guidance is required. Therefore, this manuscript is a small effort towards the comparative analysis of three basic structures which include physically doped (PD) [19], charge plasma (CP) and electrically doped (ED) DM-TFET biosensors [20–23]. Particularly,

Fig. 2 (a) PD-DM-TFET (b) CP-DM-TFET (c) ED-DM-TFET based biosensors structure

Table 1 Design parameter of PD-DM-TFET, CP-DM-TFET and ED-DM-TFET based biosensors

Parameter Name and Unit	Symbol	PD-DM-TFET	CP-DM-TFET	ED-DM-TFET
Drain doping (cm^{-3})	N_A	1×10^{20}	1×10^{15}	1×10^{15}
Source doping (cm^{-3})	N_D	1×10^{20}	1×10^{15}	1×10^{15}
Channel doping (cm^{-3})	N_{ch}	1×10^{17}	1×10^{15}	1×10^{15}
Overdrive source length (nm)	L_{OS}		50	50
Overdrive drain length (nm)	L_{OD}		50	50
Spacer length, gate to source (nm)	L_{GS}		5	5
Spacer length, gate to drain (nm)	L_{GD}		5	5
Source length (nm)	L_S	55	55	55
Drain length (nm)	L_D	55	55	55
Gate length (nm)	L_G	50	50	50
Overdrive source work function (eV)	ϕ_{OS}		5.93	4.5
Overdrive drain work function (eV)	ϕ_{OD}		3.9	4.5
Gate work function (eV)	ϕ_G	4.7	4.7	4.7
Silicon thickness (nm)	t_{Si}	10	10	10
Oxide thickness (nm)	t_{ox}	5	5	5
Cavity length (nm)	L_{cavity}	15	15	15
Cavity thickness (nm)	t_{cavity}	3	3	3
Drain and Source contact		NiSi	NiSi	NiSi

these three devices cover almost the entire research area of doping and doping-free (junctionless) TFETs and hence [24], this manuscript provides a strong interpretation for the selection of proper device technology for designing rapid and accurate biosensors in future.

2 Device Structure, Simulation Setup

The cross-sectional view of PD-DM-TFET, CP-DM-TFET and ED-DM-TFET biosensors are presented in Fig. 1. In PD-DM-TFET (Fig. 2(a)) N+ drain region and the P+ source

Fig. 3 Calibration of the simulated results with Experimental data [6]

region are created through doping where as CP-DM-TFET (Fig. 2(b)) and ED-DM-TFET (Fig. 2(c)) are junctionless devices as there are no physical boundaries between the regions through doping difference. But, in CP-DM-TFET and ED-DM-TFET external metal electrodes are placed above the source and drain regions and metal-semiconductor work function difference creates plasma of charge in CP-DM-TFET while opposite potentials applied on electrodes create source and drain in ED-DM-TFET [25]. TFET produces low ON current and high ambipolarity which affects biosensor sensing capability and power requirements. Therefore, hetero dielectric (HD) techniques are adopted by which half of the semiconductor from gate to source is covered with the high-K dielectric (HfO_2) which improves tunneling at the junction and hence [26, 27], provides better ON current where as a low-K dielectric (SiO_2) in the other half reduces the ambipolar conduction at drain/channel junction.

Further, to introduce body fluid in the biosensor, a test cavity is formed inside HfO_2 below gate electrode towards source region where due to dielectric value difference, the band bending at gate/source junction changes. This results in the variation of drain current which when measured confirms the presence/absence of a particular biomolecule. All device physical parameters used in the device simulation are the optimum values obtained from literature and are tabulated in Table 1.

The device fabrication process flow is as follows : Biosensors discussed in this manuscript include simple Silicon based TFET device that can be fabricated with the

Fig. 4 Energy Band Diagram of (a) n-PD-DM-TFET (b) n-CP-DM-TFET (c) n-ED-DM-TFET (d) p-ED-DM-TFET based biosensors

conventional MOSFET fabrication technologies. In PD biosensor, source and drain regions are created in Silicon substrate by selective window etching and doping by diffusion. Next, hetero dielectric layer can be deposited by liquid phase deposition method: first SiO_2 is completely deposited over Si substrate by dry oxidation process and then, half of the region is selectively etched by photolithography and then the Atomic Layer Deposition (ALD) deposits HfO_2 over the remaining portion. In CP and ED devices, additional metal layers are deposited over the oxide layers using metallization techniques. Finally, the test cavities can be formed by dry etching process and below the cavity, HfO_2 layer binds the biomolecules.

The device simulations are carried out in Silvaco 2D-ATLAS TCAD tool. Schottky contact effect is incorporated using Universal Schottky tunneling model (UST), Shockley Read Hall (SRH) and Auger models are used for recombination of carriers. At the tunneling-junction, the carrier generation rate is calculated using non-local band-to-band tunneling (BTBT) and bandgap narrowing (BGN) models. The Fermi Dirac statistics and Klaassen's Unified Low Field Mobility models (KLA) are used to describe the lateral field mobility effect on the device characteristics. The models have been

verified with the experimental result in [6] and we found that the simulated results are closely matched with the experimental data as depicted in Fig. 3.

3 Results and Discussions

This section deeply investigates the PD-DM-TFET, CP-DM-TFET and ED-DM-TFET biosensors and compare their sensing capability for a wide range of biomolecules present in human body, that can be captured through blood, swab or urine samples. These biomolecules having a dielectric value can be charged or neutral and hence, we considered the charge density ($-1 \times 10^{13} \text{ C/cm}^2$ - $1 \times 10^{13} \text{ C/cm}^2$) and K (1-12) values for the device sensitivity analysis.

3.1 Sensitivity Comparison for Dielectric Variation

In this section, we first focus on BTBT process variation at Source/Channel junction for various dielectric constants of biomolecules. Under ON state condition, the energy band diagram (EBD) of n-PD-DM-TFET, n-CP-DM-TFET, n and p ED-DM-TFET based biosensors are shown in Fig. 4(a-d)

Fig. 5 Surface Potential of (a) n-PD-DM-TFET (b) n-CP-DM-TFET (c) n-ED-DM-TFET (d) p-ED-DM-TFET based biosensors

with neutral charge and variable K values. In ON condition, the channel side conduction band (CB) and source side valence band (VB) aligns at source-channel interface. ON state EBD of all the three devices demonstrate that the band-bending increases and barrier width reduces with the increase of K values. It means that the electrons take less energy to tunnel through the barrier.

Figure 5(a-d) shows the variation in surface potential for three biosensors during ON and equilibrium conditions. It has been noticed that surface potential is lesser for $K = 1$ (vacant cavity) but in the presence of biomolecules ($K > 1$), potential increases because the effective gate-capacitance (C_{eff}) of biosensor rises with the dielectric constant value.

Figure 6(a-d) shows the drain current (I_d) characteristics of n-PD-DM-TFET, n-CP-DM-TFET, n and p ED-DM-TFET based biosensors with different values of K . During ON-state, minimum I_d is observed for air ($K = 1$). Also, drain current rises with the increment in dielectric constant ($K > 1$) in all the three devices. The peak current values are listed in Table 2.

For positively-charged biomolecules, the I_d - V_{gs} characteristics of n-PD-DM-TFET, n-CP-DM-TFET, n and p ED-DM-TFET based biosensors are shown in Fig. 7(a-d) with constant $K = 5$. In all three n-TFET based biosensors, the drain current

(I_d) rises with the increment in positive charge density value of biomolecules but in p-ED-DM-TFET the drain current (I_d) decreases with the increment in positive charge density. This could be better explained through EBD of ED-DM-TFET in Fig. 8. Figure 8(a) shows that in n-ED-DM-TFET, bands steepen more at tunneling junction as positive charge increases whereas this effect is reverse in EBD of p-ED-DM-TFET (Fig. 8(b)) due to the dominance of opposite charges in both devices. For negatively-charged biomolecules, the I_d - V_{gs} characteristics of n-PD-DM-TFET, n-CP-DM-TFET, n and p ED-DM-TFET based biosensors are shown in Fig. 9(a-d) with the same K value.

In all three n-TFET based biosensors, I_d decreases with the increment in negative charge density value of biomolecules but in p-ED-DM-TFET based biosensor, I_d rises with the increment in negative charge density. This effect is better understood though the EBD of ED-DM-TFET in Fig. 10 and the reason for the reverse trend in p-type and n-type TFET is similar to that explained 8(a) and (b). It can be clearly observed from Fig. 10(b), that in p-ED-DM-TFET, bands steepen more at tunneling junction, whereas the opposite effect is noticed in EBD of n-ED-DM-TFET (Fig. 10(a)) due to the dominance of opposite charges in both devices. The peak

Fig. 6 I_d - V_{gs} characteristics of (a) n-PD-DM-TFET (b) n-CP-DM-TFET (c) n-ED-DM-TFET (d) p-ED-DM-TFET based biosensors with different value of dielectric constant (K)

Table 2 Peak current value of PD-DM-TFET, CP-DM-TFET and ED-DM-TFET based biosensors for different dielectric constants (K)

Dielectric constant (K)	Peak current value (A/μm)			
	n-PD-DM-TFET	n-CP-DM-TFET	n-ED-DM-TFET	p-ED-DM-TFET
1	9.33×10^{-10}	1.99×10^{-10}	4.5×10^{-10}	1.03×10^{-9}
1.54	9.27×10^{-9}	2×10^{-9}	3.9×10^{-9}	4.7×10^{-9}
1.64	1.23×10^{-8}	2.6×10^{-9}	5.1×10^{-9}	5.65×10^{-9}
2.1	3.41×10^{-8}	6.52×10^{-9}	1.27×10^{-8}	1.07×10^{-8}
2.63	7.55×10^{-8}	1.29×10^{-8}	2.56×10^{-8}	1.77×10^{-8}
3.30	1.49×10^{-7}	2.32×10^{-8}	4.64×10^{-8}	2.76×10^{-8}
3.46	1.7×10^{-7}	2.58×10^{-8}	5.19×10^{-8}	3×10^{-8}
3.57	1.85×10^{-7}	2.77×10^{-8}	5.59×10^{-8}	3.17×10^{-8}
4.7	3.44×10^{-7}	4.72×10^{-8}	9.8×10^{-8}	5.04×10^{-8}
5	3.84×10^{-7}	5.26×10^{-8}	1.1×10^{-7}	5.57×10^{-8}
6.3	5.26×10^{-7}	7.79×10^{-8}	1.62×10^{-7}	7.94×10^{-8}
8	5.48×10^{-7}	1.44×10^{-7}	2.37×10^{-7}	1.12×10^{-7}
10	5.89×10^{-7}	1.62×10^{-7}	3.29×10^{-7}	1.49×10^{-7}
12	6×10^{-7}	2.1×10^{-7}	4.23×10^{-7}	1.8×10^{-7}

Fig. 7 I_d - V_{gs} characteristics of (a) n-PD-DM-TFET (b) n-CP-DM-TFET (c) n-ED-DM-TFET (d) p-ED-DM-TFET based biosensors with positive charge density

current value of all the three devices for positive and negative charged biomolecules are illustrated in Table 3.

The biomolecule detection quality of a biosensor is obtained through sensitivity analysis. Hence, higher the sensitivity, higher would be the detection probability. The biosensor sensitivity is calculated from Eq. (1).

$$S_{Id} = (I_d^{Bio} - I_d^{Air}) / I_d^{Air} \quad (1)$$

where I_d^{Bio} indicates drain current of the device in the presence of biomolecules and I_d^{Air} indicates drain current of the device for vacant cavity.

Greater the difference between the I_d^{Bio} and I_d^{Air} , higher would be the sensitivity. Therefore, increasing the difference between the drain current for $K=1$ and $K > 1$, increases I_d - V_{gs} sensitivity as shown in Fig. 11(a-d). Table 4 illustrates the I_d - V_{gs} sensitivity value of all three devices for several neutral

Fig. 8 Energy Band Diagram of (a) n-ED-DM-TFET (b) p-ED-DM-TFET based biosensors with positive charge density

Fig. 9 I_d - V_{gs} characteristics of (a) n-PD-DM-TFET (b) n-CP-DM-TFET (c) n-ED-DM-TFET (d) p-ED-DM-TFET based biosensors with negative charge density

biomolecules. In n-PD-DM-TFET and n-CP-DM-TFET based biosensors, the maximum I_d - V_{gs} sensitivity values are 1.07×10^6 and 3.15×10^7 for $K = 12$. In n-ED-DM-TFET, and p-ED-DM-TFET based biosensors, the maximum I_d - V_{gs} sensitivity values are 1.19×10^7 and 5.10×10^7 for $K = 12$.

For positively-charged biomolecules, the I_d - V_{gs} sensitivity of all three devices are shown in Fig. 12(a-d) with the constant $K = 5$ value. Depicted from the difference in drain current, the I_d - V_{gs} sensitivity rises with the increment in positive charge

density for n-TFETs but in p-ED-DM-TFET the I_d - V_{gs} sensitivity sensitivity decreases with the increment in positive charge density value of biomolecules. For negative-charged biomolecules, the I_d - V_{gs} sensitivity of all three devices are shown in the Fig. 13(a-d) for same K value. Here, also due to the drain current difference, I_d - V_{gs} sensitivity decreases with the increment in negative charge density in all three nTFET based biosensor but in p-ED-DM-TFET, I_d - V_{gs} sensitivity rises with the increment in negative charge density. The

Fig. 10 Energy Band Diagram of (a) n-ED-DM-TFET (b) p-ED-DM-TFET based biosensors with negative charge density

Table 3 Peak current value of PD-DM-TFET, CP-DM-TFET and ED-DM-TFET based biosensors for both positive and negative charged biomolecules

Charge Density for $K=5$ (C/cm^2)	Peak Current Value ($A/\mu m$)			
	n-PD-DM-TFET	n-CP-DM-TFET	n-ED-DM-TFET	p-ED-DM-TFET
5×10^{11}	4.06×10^{-7}	5.36×10^{-8}	1.13×10^{-7}	5.34×10^{-8}
1×10^{12}	4.29×10^{-7}	5.47×10^{-8}	1.17×10^{-7}	5.13×10^{-8}
3×10^{12}	5.31×10^{-7}	6.06×10^{-8}	1.37×10^{-7}	4.47×10^{-8}
5×10^{12}	6.46×10^{-7}	6.98×10^{-8}	1.67×10^{-7}	4.01×10^{-8}
1×10^{13}	9.76×10^{-7}	1.09×10^{-7}	3.16×10^{-7}	3.33×10^{-8}
-1×10^{13}	1.10×10^{-7}	3.83×10^{-8}	7.45×10^{-8}	1.57×10^{-7}
-5×10^{12}	2.13×10^{-7}	4.65×10^{-8}	8.78×10^{-8}	9.09×10^{-8}
-3×10^{12}	2.72×10^{-7}	4.88×10^{-8}	9.53×10^{-8}	7.36×10^{-8}
-1×10^{12}	3.43×10^{-7}	5.11×10^{-8}	1.04×10^{-7}	6.08×10^{-8}
-5×10^{11}	3.63×10^{-7}	5.18×10^{-8}	1.07×10^{-7}	5.08×10^{-8}

I_d - V_{gs} sensitivity value of three devices for positively and negatively charged biomolecules are shown in Table 5. Results observed in this paper show excellent agreement with

the data presented in [7,16–18], which signifies that the comparative analysis performed in this article is authentic for biomedical applications.

Fig. 11 Characteristics of I_d - V_{gs} sensitivity of (a) n-PD-DM-TFET (b) n-CP-DM-TFET (c) n-ED-DM-TFET (d) p-ED-DM-TFET based biosensors with different value of dielectric constants (K)

Table 4 I_d - V_{gs} sensitivity value of PD-DM-TFET, CP-DM-TFET and ED-DM-TFET based biosensors for different dielectric constants

Dielectric constant (K)	I_d - V_{gs} Sensitivity			
	n-PD-DM-TFET	n-CP-DM-TFET	n-ED-DM-TFET	p-ED-DM-TFET
1.54	17.48	61.39	62.21	97.04
1.64	27.88	110.98	111.74	183.49
2.1	165.60	1.01×10^3	0.64×10^3	1.8×10^3
2.63	782.30	6.45×10^3	5.89×10^3	12.53×10^3
3.30	3.41×10^3	3.51×10^4	2.98×10^4	6.69×10^4
3.46	4.58×10^3	4.97×10^4	4.13×10^4	9.44×10^4
3.57	5.54×10^3	6.23×10^4	5.13×10^4	11.84×10^4
4.7	2.61×10^4	3.89×10^5	2.95×10^5	7.21×10^5
5	3.63×10^4	5.67×10^5	4.22×10^5	10.40×10^5
6.3	1.12×10^5	2.06×10^6	1.44×10^6	3.60×10^6
8	3.02×10^5	6.53×10^6	4.30×10^6	10.89×10^6
10	6.47×10^5	1.64×10^7	1.03×10^7	2.67×10^7
12	1.07×10^6	3.15×10^7	1.19×10^7	5.10×10^7

Fig. 12 Characteristics of I_d - V_{gs} sensitivity of (a) n-PD-DM-TFET (b) n-CP-DM-TFET (c) n-ED-DM-TFET (d) p-ED-DM-TFET based biosensors with positive charge density

Fig. 13 Characteristics of I_d - V_{gs} sensitivity of (a) n-PD-DM-TFET (b) n-CP-DM-TFET (c) n-ED-DM-TFET (d) p-ED-DM-TFET based biosensors with negative charge density

Table 5 I_d - V_{gs} sensitivity value of PD-DM-TFET, CP-DM-TFET and ED-DM-TFET based biosensors for both positive and negative charged biomolecules

Charge density for K=5 (C/cm^2)	I_d - V_{gs} sensitivity			
	n-PD-DM-TFET	n-CP-DM-TFET	n-ED-DM-TFET	p-ED-DM-TFET
5×10^{11}	6.78×10^4	9.28×10^5	7.18×10^5	5.89×10^5
1×10^{12}	1.24×10^5	1.48×10^6	1.19×10^6	3.19×10^5
3×10^{12}	1.12×10^6	7.69×10^6	7.10×10^6	2.72×10^4
5×10^{12}	7.25×10^6	2.86×10^7	3.02×10^7	1.66×10^3
1×10^{13}	2.51×10^8	2.67×10^8	4.77×10^8	75.35
-1×10^{13}	155	489.72	267.13	7.11×10^8
-5×10^{12}	662.63	4.39×10^3	1.82×10^3	5.86×10^7
-3×10^{12}	1.39×10^3	2.35×10^4	1.43×10^4	1.59×10^7
-1×10^{12}	1.13×10^4	1.95×10^5	1.36×10^5	2.90×10^6
-5×10^{11}	2.20×10^4	3.37×10^5	2.42×10^5	1.76×10^6

Table 6 Comparison of the Sensitivity of our proposed work with the data available in literature

Biosensors	Sensitivity
JL-DM-ED-TFET [$L_{\text{cavity}}=10$ nm, $t_{\text{cavity}}=5$ nm, $k=10$] [28]	6.89×10^5
CP-DM-JL-TFET [$L_{\text{cavity}}=23$ nm, $t_{\text{cavity}}=5.5$ nm, $k=10$] [21]	1.08×10^8
CP-DM-GU-JLTFET [$L_{\text{cavity}}=23$ nm, $t_{\text{cavity}}=5.5$ nm, $k=10$] [29]	1.16×10^4
CG-TFET [$L_{\text{cavity}}=25$ nm, $t_{\text{cavity}}=11$ nm, $k=10$] [30]	2.32×10^7
DMDG TFET [$L_{\text{cavity}}=150$ nm, $t_{\text{cavity}}=9$ nm, $k=10$] [31]	4.82×10^7
This work [$L_{\text{cavity}}=15$ nm, $t_{\text{cavity}}=3$ nm, $k=10$]	1.03×10^7
HM-SE-TFET [$L_{\text{cavity}}=30$ nm, $t_{\text{cavity}}=5.5$ nm, $k=5$] [18]	4.1×10^4
DG-TFET [$L_{\text{cavity}}=23$ nm, $t_{\text{cavity}}=5.5$ nm, $k=5$] [32]	0.66×10^3
This work [$L_{\text{cavity}}=15$ nm, $t_{\text{cavity}}=3$ nm, $k=5$]	4.22×10^5

Fig. 14 Temperature dependent (a) Drain current variation of ED-DM-TFET, and (b) Sensitivity variation for three different TFET configurations

A detailed literature survey has been performed with the Si based biosensors and it is found that these works has closely matched sensitivity values as shown in Table 6.

4 Temperature Dependent Sensitivity

The temperate dependent sensitivity of the biosensor is also computed for the in-depth analysis of the biosensor. Figure 14(a) shows that as the temperature increases, OFF current increased recombination process in ED-DM-TFET. However, there is no appreciable variation in drain current for higher V_{gs} value. Therefore, the biosensor sensitivity depends on both V_{gs} and temperature. Hence, Fig. 14(b) shows the peak value of biosensor sensitivity in PD-DM-TFET, CP-DM-TFET and ED-DM-TFET and it is clear that the sensitivity reduces for higher temperature and the variation of sensitivity between the three types of biosensors also reduces with temperature.

5 Conclusions

A comparative analysis of PD-DM-TFET, CP-DM-TFET, n-ED-DM-TFET and p-ED-DM-TFET based biosensors are done

in this paper. Both charged and neutral biomolecules are identified and detected by these three devices. Some characteristics like energy band diagram, the surface potential, I_d-V_{gs} (transfer) characteristics and I_d-V_{gs} sensitivity are investigated to find better quality biosensor among these three. For neutral biomolecules with $K=12$ the I_d-V_{gs} sensitivity value of 5.10×10^7 is obtained for p-ED-DM-TFET biosensor which is the maximum among the three nTFET based biosensors. For positively-charged biomolecules with charge density of 1×10^{13} C/cm², the I_d-V_{gs} sensitivity value of 4.77×10^8 is obtained for n-ED-DM-TFET biosensor, which is maximum among the three TFET based biosensors. For negatively charged biomolecules with charge density of -5×10^{11} C/cm², the I_d-V_{gs} sensitivity value of 1.76×10^6 for p-ED-DM-TFET biosensor is the maximum. So, it could be concluded that ED-DM-TFET based biosensor exhibits better detection and identification capability among the three different configurations of TFET biosensors.

Author Contributions All the authors have contributed to the design, investigation, conceptualization and formal analysis. and design. Author Arpita Biswas prepared the first draft of the manuscript after performing the simulation study and validation. Author Chithraja Rajan edited the manuscript after data analysis and validation. D P Samajdar commented on the manuscript and supervised the entire work. All the authors read and approved the final version of the manuscript.

Data Availability Not applicable.

Code Availability Not Applicable.

Declarations

Consent to Participate All the authors contributed voluntarily to this work.

Consent for Publication In accordance with the copyright transfer or open access rules.

Conflict of Interest The authors declare that they have no conflict of interest.

Ethics Approval Not Applicable.

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