Sensitivity Analysis of Junction Free Electrostatically Doped Tunnel-FET Based Biosensor

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Received: 26 July 2021 / Accepted: 1 October 2021 / Published online: 6 January 2022
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Abstract
The electrostatic doping technique has a remarkable ability to reduce random dopant fluctuations (RDFs), fabrication complexity and high thermal budget requirement in the fabrication process of nano-scale devices. In this paper, for the first time it has been propose and simulated a junction-free electrostatically doped tunnel field-effect transistor (JF-ED-TFET) based biosensor for label-free biosensing applications. The dielectric modulation concept has been used to sense biomolecules using a nano-cavity incorporated within the gate oxide layer near to the source end. The sensing response of the JF-ED-TFET biosensor has been analyzed in terms of the electric field, energy band and transfer characteristic and sensitivity in terms of ON-current, $I_{ON}/I_{OFF}$ ratio and subthreshold swing. The sensitivity of the biosensor has been investigated based on practical challenges such as different filling factors and step-profiles generated from the steric hindrance. The effect of temperate and nano-cavity dimension variations on device performance has been also analyzed. In this work, various types of biomolecules such as Streptavidin ($k = 2.1$), Ferro-cytochrome c ($k = 4.7$), keratin ($k = 8$) and Gelatin ($k = 12$) has been considered for the performance investigation.

Keywords Junction Free · Polarity control · Electrostatic doping · Biosensor · Sensitivity

1 Introduction
The precise identity of biomolecules species and analysis of their properties are very important for disease assessment and treatment. In recent decades different types of biosensors are being used in various fields like medical, agriculture, food processing, environment condition monitoring [1–4] etc. The sensitivity, selectivity and fast detection timing are the basic design parameters of biosensors. For label-free detection of biomolecules, the FET-based bio-sensors played a very important role due to their cost-effective manufacturing, low power consumption and scalable properties [5–8]. In 1970, the first ISFET based biosensor was proposed by P. Bergveld [9]. ISFET biosensors can detect the charge biomolecules when they present between the gate dielectric and electrolyte but ISFET biosensors are not able to recognize the neutral biomolecules. To eliminate the ISFET biosensor’s limitation, dielectric modulated-FET (DM-FET) biosensors are proposed and DM-FET biosensors can detect the charged (e.g., DNA biomolecules) and non-charged (e.g. biotin, streptavidin) biomolecules effectively [10]. DM-FET biosensor is designed by incorporating the nano-cavity into gate dielectric material of conventional MOSFET. DM-FET based biosensor distress from low ON-current and low sensitivity issue [11]. The MOSFET-based biosensors attracted the attention of researchers by the ability of high ON-current comparatively to conventional FET-based biosensor [12]. But continually narrowing the dimensions beyond the limit, the MOSFET device generates unavoidable issues such as SCE (short channel effect), high OFF-state power consumption, poor control over the channel, quantum effect, low $I_{ON}/I_{OFF}$ ratio etc, hence the performance of MOSFET-based biosensors is degraded [12]. The TFET has numerous advantages over the MOSFET such as low power consumption, less leakage current, high-speed operation, low subthreshold swing, etc. [13–16]. By ITRS-2005, TFET becomes a futuristic device for low power applications [17]. The low ON-current and ambipolar conduction (OFF-state conduction) are the main drawbacks [18] of the TFET devices. For eliminating these

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limitations of TFET some techniques has been implemented such as hetero material, stack gate with high \( k \) material, vertical TFET, compound material, low bandgap source material, halo doping, packet doping [19–21]. The random dopant fluctuations (RDFs), complex fabrication process and high thermal budget requirement are critical issues of doped devices [22]. The new concepts of charged plasma and electrostatic doping are being employed to overcome these restrictions, and these techniques are lowering the fabrication cost and complexity of the nanoscale devices [23–25].

In this paper, a junction-free electrically doped tunnel field-effect transistor (JF-ED-TFET) based biosensor is proposed for label-free identification of biomolecules. To achieve high sensitivity, the nano-cavity is created near to source-channel interface junction of the device. For the performance investigation, the target biomolecules are considered neutral and charged with different dielectric constants \((k)\) and charge densities \((\rho)\) (positive and negative). The neutral biomolecules can be sense based on their own dielectric constant and charged biomolecules can be detected based on their charge densities as well as dielectric constants. For sensitivity analysis, we have considered the air \((k = 1)\) as reference biomolecules and compared with other biomolecules of different dielectric constants \((k > 1)\) and charge densities \((\rho)\). The sensitivity of the JF-ED-TFET biosensor is proportional to drain current \((I_{DS})\) and drain current \((I_{DS})\) is directly proportional to changes of the biomolecules dielectric constants \((k)\) as well as charge densities \((\rho)\).

### Table 1 Parameters of JF-ED-TFET biosensor used in simulation

| Design Parameters | Symbol | Value    |
|-------------------|--------|----------|
| Silicon layer thickness | \(T_{Si}\) | 10.00 nm |
| SiO\(_2\) thickness | \(T_{ox}\) | 0.50 nm   |
| HfO\(_2\) thickness | \(T_{HfO_2}\) | 5.50 nm   |
| Length of CG | \(L_{CG}\) | 50.00 nm  |
| Length of PG-1 | \(L_{PG-1}\) | 50.00 nm  |
| Length of CG-2 | \(L_{PG-2}\) | 50.00 nm  |
| Cavity length | \(L_{Cavity}\) | 25.00 nm  |
| Cavity thickness | \(T_{Cavity}\) | 5.50 nm   |
| Metal workfunction of all Gates | \(\phi_g\) | 4.5 eV |
| Source-Gate spacer | \(S_{gap}\) | 2.00 nm   |
| Drain-Gate spacer | \(D_{gap}\) | 8.00 nm   |
| Silicon layer concentration | \(n\)-type | 1e15 \(\text{cm}^{-3}\) |

### 2 2-D Structure and Design Parameters of Proposed Biosensor

The schematic view of the proposed JF-ED-TFET biosensor is shown in Fig. 1 and designing parameters are given in Table 1. The polarity concept (electrically doping) has been applied to convert the device from \(n-n-n\) (device region-drain, channel and source) to device \(n^+\)-i-\(p^+\) (TFET) [26].

Similar work function of polarity gates and control gate of 4.5 eV has been considered. For the drain/source contact Nickel Silicide (NiSi) with barrier potential of 0.45 eV [26] has been used. Spacer gap at drain-channel
junction ($D_{gap}$) has been considered 8 nm for reducing the ambipolar conduction and source-channel junction ($S_{gap}$) has been considered to the 2 nm to increase the drain current. Based on physical dimensions of biomolecules we have considered the nano-cavity height as 5.5 nm [27, 28]. During simulation, various kinds of biomolecules such as Streptavidin ($k = 2.1$), Ferro-cytochrome c ($k = 4.7$), Keratin ($k = 8$) and Gelatin ($k = 12$) with different dielectric constant as well as charge densities has been used to investigate the sensing performance of JF-ED-TFET biosensor.

3 Propose device Modulation and Calibration

The Silvaco ATLAS TCAD device simulator tool, version V5.0.10 R [29] is used for simulation of the JF-ED-TFET biosensor. The JF-ED-TFET biosensor works based on the band to band tunneling (BTBT) hence, to investigate the generation of carriers a non-local BTBT model has been activated at each mesh point of the tunneling zone [30]. Universal Schottky Tunneling (UST) model is considered for NiSi drain/source contact. The SRH (Shockley-Read-Hall) and Auger models are considered for concentration-dependent carrier recombination. For the account of carrier mobility, Fermi-Dirac statistic and field-dependent mobility models are used. The Wentzel-Kramers-Brillouin method has been employed for numerical tunneling. TAT model is also incorporated for process-dependent issues in simulation. For result accuracy at device interface layers and at the tunneling region a very dense meshing has been created.

For device calibration, the transfer characteristic of proposed device has been calibrated with conventional n-type TFET [31] and the simulated result, displayed in Fig. 2, is nearly identical to the result described in [31].

4 Results and Discussion

4.1 Impact of Biomolecules Properties on Device Characteristics

The variations of JF-ED-TFET biosensor characteristics due to immobilization of biomolecules in the nano-cavity region with different dielectric constants and charge densities have been studied in this section. For the performance investigation of the JF-ED-TFET biosensor, the biomolecule dielectric constants ($k$) of 1, 2.1, 4.7, 8, and 12, as well as the charge densities ($\rho$) of $\pm 1 \times 10^{11}$, $\pm 5 \times 10^{11}$, and $\pm 1 \times 10^{12}$ C/cm², have been considered.

4.1.1 Effect on Electric Field

The internal electric field variations of JF-ED-TFET biosensor with neutral biomolecules is shown in Fig. 3(a). It has been observed that when increasing the dielectric constant of biomolecules, the electric field at the tunneling junction increases. The high electric field at the tunneling junction, minimizes the tunneling width hence the drain current of the device gets increased. For dielectric constant ($k$) = 12, the peak electric field of $3.4 \times 10^6$ V/cm can be obtained at the source-channel junction.

For device calibration, the transfer characteristic of proposed device has been calibrated with conventional n-type TFET [31] and the simulated result, displayed in Fig. 2, is nearly identical to the result described in [31].
of positive (negative) charge density of biomolecules due to more negative (positive) charge carriers induced in the channel region. The electric field variation with positive and negative charge densities respectively are shown in Fig. 3(b)-(c).

### 4.1.2 Effect on Energy Band

The energy band profile of proposed biosensor with various dielectric constants \( k \) and charge densities \( \rho \) are shown in Fig. 4(a)-(c). It can be seen, when the dielectric constant of neutral biomolecules increase, the band-gap is decreases at tunneling junction hence tunneling probability of charge carriers increase as shown in Fig. 4(a). With dielectric constant \( k = 12 \), the band gap is very low as compared to dielectric constant \( k = 1 \), hence the tunneling probability of charge carriers is very high at \( k = 12 \). Figure 4(b) and (c) are shows the impact on band bending at the tunneling junction, in presence of different charge densities at the Si-SiO₂ interface. It can be seen with positive charge density, band-gap decreases and tunneling probability increases, while in case of negative charge density band-gap increases.

### 4.1.3 Impact on Drain Current

The \( I_D-V_{GS} \) characteristic of JF-PE-TFET biosensor with various dielectric constants \( k \) of neutral biomolecules \( \rho = 0 \) is shown in Fig. 5(a). It has been observed that by increasing the dielectric constant, the drain current of the device increases and the threshold voltage \( V_{Th} \) decreases. Figure 5(b) shows the \( I_D-V_{GS} \) plot with charged biomolecules at fixed dielectric constant \( k = 8 \), and it has been observed that by increasing the negative charge density the drain current decreases but with positive charge density, it increases. This phenomenon can be understood with the voltage balance equation of MOSFET [32] given as:

\[
V_{GS} = \psi_S + \phi_{MS} - \left( \frac{q N_{bio} C_{ox'}}{k t_{ox}} \right)
\]

where

\[C_{ox'} = k / t_{ox}\]

In Eq. 1 \( V_G, \psi_S, \phi_{MS}, N_{bio}, q, k \) and \( t_{ox} \) are representing gate voltage, surface potential, contact potential, contact potential, interface potential, and oxide thickness, respectively.

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**Fig. 3** Electric field variation along X-axis with varying (a) Dielectric constants \( k \) at \( \rho = 0 \) (b) Positive charge densities \( \rho \) at \( k = 8 \) (c) Negative charge densities \( \rho \) at \( k = 8 \)

**Fig. 4** Variation of Energy band along X-axis with varying (a) Dielectric constants \( k \) at \( \rho = 0 \) (b) Positive charge densities \( \rho \) at \( k = 8 \) (c) Negative charge densities \( \rho \) at \( k = 8 \)
Fig. 5  $I_{DS} - V_{GS}$ characteristic of proposed biosensor with various (a) Dielectric constants ($k$) at $\rho = 0$, (b) Charge densities ($\rho$) at $k = 8$. $I_{DS} - V_{DS}$ characteristic of proposed biosensor with various (c) Dielectric constant ($k$) at $\rho = 0$ and (d) Charge densities ($\rho$) at $k = 8$.

4.2 Sensitivity Analysis

Sensitivity is a very important parameter of any type of sensor and high sensitivity is desirable. The JF-ED-TFET biosensor sensitivity has been analyzed in terms of drain current ($S_{IDS}$), subthreshold swing ($S_{SS}$) and $I_{ON}/I_{OFF}$ ratio. The drain current sensitivity ($S_{IDS}$) is defined as [33]:

$$S_{IDS} = \left( \frac{I_{bio}^{DS} - I_{air}^{DS}}{I_{air}^{DS}} \right)$$

Here, $I_{bio}^{DS}$ and $I_{air}^{DS}$ are the drain currents when nano-cavity filled with biomolecules ($k > 1$) and air($k = 1$). Figure 6(a)-(b) are shows the JF-ED-TFET biosensor current sensitivity ($S_{IDS}$) along $V_{GS}$ with different dielectric constants ($k$) and charge densities ($\rho$). It is observed that with increasing the dielectric constants ($k$) of biomolecules, the sensitivity of device increases and similarly with positive charge densities due to increasing the $I_{ON}$ current of device. But with negative charge densities the ON-current decreases hence the sensitivity of the device decreases. Figure 6(c)-(d) are shows the drain current sensitivity ($S_{IDS}$) vs drain voltage ($V_{DS}$) plot with different dielectric constants ($k$) and charge...
**Fig. 6** $I_{DS}$ sensitivity of JF-ED-TFET biosensor along $V_{GS}$ with different (a) Dielectric constants ($k$) at $\rho = 0$, (b) Charge densities ($\rho$) at $k = 8$. $I_{DS}$ sensitivity of JF-ED-TFET biosensor along $V_{DS}$ with different (c) Dielectric constants ($k$) at $\rho = 0$, (d) Charge densities ($\rho$) at $k = 8$.

| Table 2 | Sensitivity of the JF-ED-TFET biosensor with various dielectric constants and charge densities |
|---------|--------------------------------------------------------------------------------------------------|
| Employed Biomolecules | Dielectric (k) Constant | Charge (\(\rho\)) Density | Sensitivity ($V_{DS} = 1.0\text{ V}$, and $V_{GS} = 1.2\text{ V}$) |
| Neutral | 2.1 | | 1.24\times10^{4} |
| Biomolecules | 4.7 | | 1.41\times10^{8} |
| | 8 | $\rho = 1\times10^{11}\text{ C/cm}^2$ | 1.20\times10^{10} |
| | 12 | $\rho = 1\times10^{12}\text{ C/cm}^2$ | 1.12\times10^{11} |
| Positive | 8 | $\rho = 1\times10^{11}\text{ C/cm}^2$ | 1.32\times10^{10} |
| Charged | 8 | $\rho = 5\times10^{11}\text{ C/cm}^2$ | 2.14\times10^{10} |
| Biomolecules | 8 | $\rho = 1\times10^{12}\text{ C/cm}^2$ | 3.64\times10^{10} |
| Negative | 8 | $\rho = -1\times10^{11}\text{ C/cm}^2$ | 1.01\times10^{10} |
| Charged | 8 | $\rho = -5\times10^{11}\text{ C/cm}^2$ | 5.61\times10^{9} |
| Biomolecules | 8 | $\rho = -1\times10^{12}\text{ C/cm}^2$ | 2.44\times10^{9} |
densities ($\rho$), observed the device offer high ON-current sensitivity ($S_{ODS}$) at lower drain voltage.

The reflection of charged and neutral biomolecules with different dielectric constants on the sensitivity of the JF-ED-TFET biosensor has been shown in Table 2. The sensitivity of biosensor increase with an increase in the dielectric constant as well as positive charge density due to increment of drain current but in case of negative charge densities the sensitivity of biosensor decrease due to decrement of drain current.

The sensitivity of the JF-ED-TFET biosensor can be analyzed in terms of $I_{ON}/I_{OFF}$ ratio and calculated as:

$$S_{I_{ON}/I_{OFF}} = \left( \frac{(I_{ON}/I_{OFF})^{bio} - (I_{ON}/I_{OFF})^{air}}{(I_{ON}/I_{OFF})^{air}} \right)$$

(3)

Figure 7(a)-(b) are depicts the increment in $I_{ON}/I_{OFF}$ sensitivity of JF-ED-TFE biosensor with increasing the dielectric constant and positive charge density of biomolecules because tunneling barrier width at tunneling interface start to decreasing hence drain current ($I_{DS}$) of device increase. But $I_{ON}/I_{OFF}$ sensitivity, shows adverse behavior with increment of negative charge density ($\rho$), is depicted in Fig. 7(c).

The TFET, become a futuristic device for low power applications because TFET offers low subthreshold swing (<60 mV/decade) and low OFF-current. The JF-ED-TFET biosensor offers a low subthreshold swing (SS) of 27.2 mV/decade hence it efficiently work at low voltage and detect the biomolecules within a limited time. The Subthreshold swing (SS) [34] and SS sensitivity of the JF-ED-TFET biosensor are evaluated [33] as:

$$SS = \left( \frac{\delta V_{GS}}{\delta \log I_{DS}} \right) (mV/\text{decade})$$

(4)

and

$$S_{SS} = \left( \frac{SS^{(air)} - SS^{(bio)}}{SS^{(air)}} \right)$$

(5)

The SS sensitivity variation of proposed biosensor with different dielectric constants ($k$) and charges density ($\rho$) is shown in Fig. 7(a)-(c) respectively. It can be observed that the SS sensitivity increase by increasing the dielectric constants ($k$) and positive charge density ($\rho$), where as SS
sensitivity decreases with increasing the negative charge densities.

The Transconductance-to-current ratio ($g_m/I_{DS}$) is a sensing metric [35] for better sensitivity and selectivity of neutral biomolecules. The $|g_m/I_{DS}|$ of JF-ED-TFET biosensor has been plotted against gate voltage with different dielectric constant shown in Fig. 8(a). From figure, it has been observed that with increment in the dielectric constant, the device offers a higher $|g_m/I_{DS}|$ value at lower drain current. The increment in $|g_m/I_{DS}|$ value and $|g_m/I_{DS}|$ sensitivity with increment in the dielectric constant of biomolecules is shown in Fig. 8(b). The $g_m/I_{DS}$ value is obtained as [35]:

$$|g_m/I_{DS}| = \frac{\ln(10)}{SS} (V^{-1})$$

(6)

4.2.1 Impact of Temperature Variation on Sensitivity

Figure 9(a)-(b) depicts the changes in device transfer characteristic and $I_{ON}$ sensitivity due to temperature variation. It can be seen that when temperature increases, the OFF-state current increases but ON-current slightly changes because the ON-current depends on BTBT tunneling rather than the temperature variation. The $I_{ON}$ sensitivity of JF-ED-TFET biosensor decreases because the drain current with empty cavity ($k = 1$) also increases by increasing the temperature, is shown in Fig. 9(b). The $I_{ON}/I_{OFF}$ sensitivity of JF-ED-TFET biosensor is shown in Fig. 9(c). The $I_{ON}/I_{OFF}$ sensitivity decreases with increasing temperature because, the OFF-state current increases by increasing the temperature. The values of subthreshold swing increases with increasing the temperature, is shown in Fig. 9(d).

The sensitivity values obtained from proposed JF-ED-TFET biosensor with different dielectric constants have been compared with various previously reported works are given in Table 3 and it has been observed that the JF-ED-TFET biosensor obtained high sensitivity of $1.12 \times 10^{11}$ with neutral biomolecules at dielectric constant $k = 12$ (varying $V_{DS}$ = 0.0 to 1.0 V and constant $V_{GS} = 1.2$ V).

![Fig. 9](image-url)  

(a) Transfer characteristic of the JF-ED-TFET biosensor, (b) $I_{ON}$ Sensitivity, (c) $I_{ON}/I_{OFF}$ sensitivity and (d) Subthreshold swing, at $k = 8$ for different temperature.
Table 3 Comparison of sensitivity values of JF-ED-TFET with previously reported works

| References | Dielectric constant (k) | Approximate Sensitivity |
|------------|-------------------------|-------------------------|
| [32]       |                         | 1.31 × 10^8             |
| [38]       |                         | 5.45 × 10^9             |
| [39]       | 12                      | 4.75 × 10^5             |
| [40]       |                         | 1.04 × 10^6             |
| [41]       |                         | 1.70 × 10^6             |
| [42]       |                         | 1.73 × 10^10            |
| Proposed   |                         | 1.12 × 10^11            |
| [43]       | 8                       | 2.60 × 10^5             |
| Proposed   |                         | 1.20 × 10^10            |
| [10]       | 2.1                     | 1.00 × 10^4             |
| Proposed   |                         | 1.24 × 10^4             |

4.3 Considering Non-Ideal Issues

When the biomolecules are conjugated into the cavity, it may be that the cavity is not fully filled with biomolecules. Hence, it is necessary to investigate the performance of biosensors with different fill factors (FF). The fill factor (FF) is defined as follows:

\[
FF\% = \frac{A_{\text{bio\ cavity}}}{A_{\text{total\ cavity}}} \times 100 \quad (7)
\]

Fig. 10 (a) Four different assumptions for nano-cavity filled by target biomolecules, (b) \(I_{\text{ON}}\) sensitivity, (c) SS sensitivity and (d) \(I_{\text{ON}}/I_{\text{OFF}}\) ratio, along different dielectric constant with different Fill Factor (FF)
Here $A_{cavity}^{bio}$ is area occupied by the target biomolecules and $A_{cavity}^{total}$ is total area of cavity [36]. In this work, we have discussed four possible FF as 25%, 50%, 75% and 100% as depicted in Fig. 10(a). The $I_{ON}$ sensitivity along dielectric constants at different FF, is shown in Fig. 10(b) and it has been observed that, when fill factor (FF) increase, the JF-ED-TFET biosensor $I_{ON}$ sensitivity increase. Figure 10(c)-(d) are shows the SS sensitivity and $I_{ON}/I_{OFF}$ ratio with varying dielectric constant and FF, here it has been observed that the sensitivity of the JF-ED-TFET biosensor improved by increasing the FF as well as the dielectric constant of biomolecules.

The JF-ED-TFET biosensor has been simulated in presence of steric hindrance to understanding the practical challenge of biosensor uses. Here we have considered four varying step profiles as decreasing, increasing, concave and convex with filling factor of $\approx 58\%$. This arrangement has been illustrated in Fig. 11(a). The $I_{ON}$ sensitivity along with different dielectric constant and step profile is depicted in Fig. 11(b) and it has been observed, the high sensitivity obtained with increasing and concave step profile because in these two-step profiles got highest proximity of target biomolecules at the source-channel interface, hence tunneling barrier decrease with these step profile [37]. Similarly the SS sensitivity and the $I_{ON}/I_{OFF}$ ratio are gets high with increasing and concave step profile as compared to decreasing and convex step profile. The SS sensitivity and $I_{ON}/I_{OFF}$ ratio with different step profiles are shown in Fig. 11(c)-(d).

### 4.4 Effect of Nano-Cavity Geometry Variations

The effect of nano-cavity dimension variations at the performance of biosensors has been investigated by simulation with two major constraints as cavity length ($L_{cavity}$) and cavity thickness ($T_{cavity}$). The $I_{DS-V_{GS}}$ characteristic of JF-ED-TFET biosensor with neutral biomolecule ($k = 8$) is shown in Fig. 12(a). It can be
seen that very less impact of $L_{cavity}$ variations over the drain current because the proposed device works based on the BTBT tunneling phenomenon. From Fig. 12(b), it has been observed that the $I_{ON}$ sensitivity increases with increasing the cavity length because drain current of the device decreases with an empty cavity ($k = 1$) by an increment in the cavity length. The effect of variation in cavity thickness ($T_{cavity}$) on the $I_{ON}$ sensitivity of the JF-ED-TFET biosensor is illustrated in Fig. 13(b) and it has been observe that, by increasing the cavity thickness ($T_{cavity}$), the sensitivity of the device decreases, as shown in Fig. 13(a), due to decreasing the effective gate capacitance of the device.

5 Conclusion

In this paper, the sensing performance of nano-cavity embedded dielectric modulated JF-ED-TFET biosensor has been investigated for label-free detection of biomolecules. The results show that the JF-ED-TFET biosensor can be used for the intuitive examination of charged or neutral biomolecules with different dielectric constants. The electrostatic doping concept offers less fabrication complexity, low cost and reliable device against RDFs. The effect of neutral and charged biomolecules on the electrical parameters of JF-ED-TFET biosensor as electric field, energy band, transfer characteristic, subthreshold swing...
(SS) and \( I_{ON}/I_{OFF} \) ratio have been studied. The simulated results as peak drain current \( (I_{DS}) \) of \( 8.55 \times 10^{-5} \) A/\( \mu \)m, Electric field of \( 3.70 \times 10^{6} \) V/cm, steeper subthreshold swing (SS) of 27.2 mV/decade \((< \text{theoretical limit as 60 mV/decade})\), \( I_{ON}/I_{OFF} \) ratio of \( 2.81 \times 10^{11} \) and \( g_{m}/I_{DS} \) value of 67 \((> \text{theoretical limit 38.4})\) are obtained from this proposed model. The JF-ED-TFET biosensor offers high drain current sensitivity of \( 1.12 \times 10^{13} \) and \( I_{ON}/I_{OFF} \) sensitivity of \( 5.74 \times 10^{7} \). SS sensitivity is 0.65 and \( g_{m}/I_{DS} \) sensitivity of 1.8 for neutral biomolecules with a dielectric constant \( k' \approx 12 \). In order to validate the realistic approach of the JF-ED-TFET biosensor, the irregular arrangement of biomolecules filled (step profile) in the cavity and different fill factors have been considered in the simulation. The device design parameters have been optimized for high sensitivity, hence the proposed device JF-PE-TFET becomes highly desirable device in the field of biosensing applications.

**Acknowledgements** The authors would like to thank the Department of Electronics and Communication Engineering, Jaypee Institute of Information Technology, Noida, Uttar Pradesh, India, for providing us the computational facilities.

**Author Contributions** 1. Kaushal Nigam - Concept and methodology. 2. Mukesh Kumar Bind - Resource, simulation.

**Data Availability** Availability of Data and Material (Data Transparency) All the data taken from another resource has been given the corresponding reference. The data, for which reference is not provided, is the original data.

**Code Availability (Software Application or Custom Code)** The code has been implemented on 2-D silvaco ATLAS device simulator.

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