Auger effect limited performance in tunnel field effect transistors

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Tunnel field-effect-transistors (TFETs) are promising candidates for next generation transistors for low power applications, as the TFETs promise low subthreshold swing (SS). Different from traditional MOSFET, the TFETs rely on energy-efficient switching of band-to-band tunneling (BTBT), therefore the SS in TFETs is not limited by the 60 mV/decade Boltzmann limit. This reduction in energy consumption makes TFETs suitable candidates to replace standard MOSFETs in low power applications. However, most experimentally demonstrated TFETs suffer from low on current[1], and the theoretical low SS is compromised by impurities and Auger generation. To understand the underlying physics and predict the device characteristics of TFETs, sophisticated numerical simulations can be used. On the other hand, physics based compact models are also required to provide fast predictions for existing and new device concepts. Furthermore, a physics based compact model is more efficient to model the effects like Auger generation which could be time-consuming for numerical calculations. In this work, we introduce a physics based compact model for homojunction TFETs with Auger generation effect considered. This compact model is based on the modified Simmons' equation at finite temperature[2]. With our compact model, the possible impact of Auger generation effect to off-current and SS is explored.

In the compact model, a standard double-gate homojunction TFET geometry is used as shown in Fig.1. We use a pseudo-2D surface potential model proposed by Bardon et.al [3]. The potential in the channel and junction depletion regions in the source and drain is given by

$$\psi_{si} = b_i e^{k_i(y-y_{i-1})} + c_i e^{-k_i(y-y_{i-1})} + \psi_d \qquad \text{-- (1)}$$

In Fig. 2, we show the band diagrams in the on and off states. Modified Simmons equation using a two-band model is used to calculate the tunneling current in the device. Equation (2) shows the modified Simmons equation.

$$I = \int dE_{\boldsymbol{k}||} T_{WKB}(E, \boldsymbol{k}||)[f_S(E) - f_D(E)] \qquad \text{-- (2)}$$

Auger generation occurs due to the collision of a high-energy carrier with an electron in the valence band. Since the ballistic current vanishes quickly in TFETs, the Auger generation can be a dominating mechanism in the off state and subthreshold region. In this work, we include the model of the Auger current proposed by Teherani et al.[1] Fig.3 compares the I_{DS}-V_{GS} characteristics of an ideal ballistic TFET to a TFET with Auger leakage current. It can be inferred from the plot that Auger generation leads to an increase in off-current. For a V_{DS} =0.3V, the ideal homojunction TFET has an SS of 3 mV/decade and the homojunction TFET with Auger current has a SS of 34 mV/decade. Our results show that the TFET can still have SS lower than 60mV/dec even if Auger leakage degrade the performance.

References:

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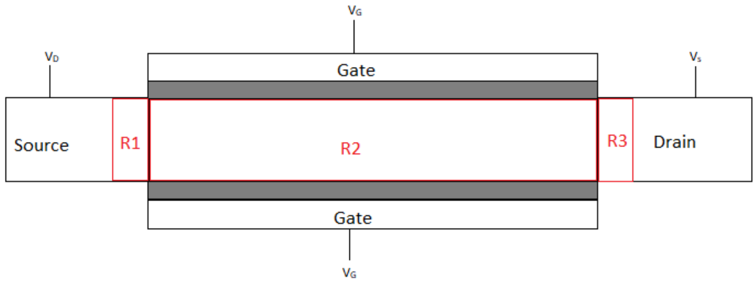

Figure 1. Double Gate TFET in which R1 R2 and R3 represents the source, channel and drain regions where Poisson's equation is solved to obtain the surface potential.

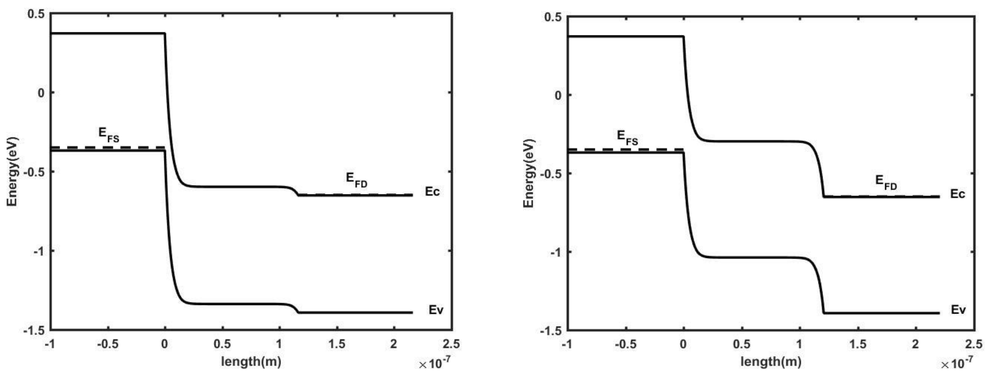

Figure 2. Band diagrams in on (left) and off (right) states. Energy window in the middle i-region which is controlled by the gate turns on and off the device.

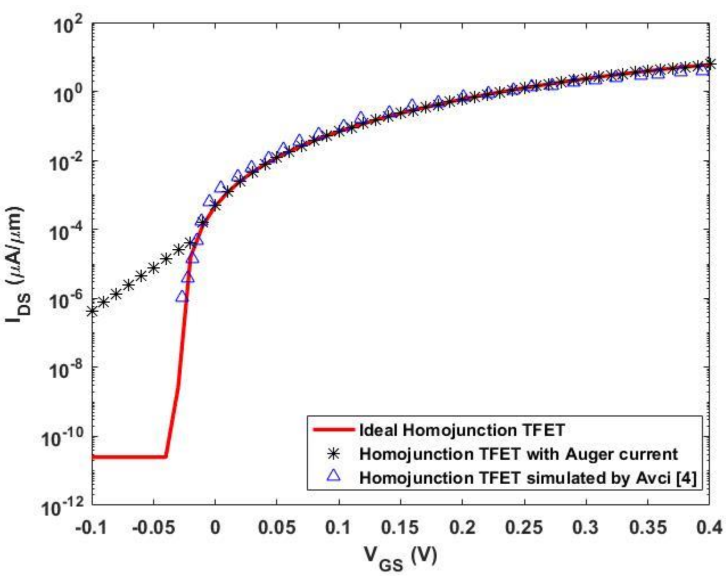

Figure3. Comparison of I_{DS}-V_{GS} characteristics of ideal homojunction TFET (compact model vs NEGF simulation in ref[4]) and Homojunction TFET with Auger current. The compact model match NEGF simulation well. And the Auger current is dominating the off-states in the TFET and worsen the SS.