Design of tunneling field-effect transistor (TFET) with $Al_xGa_{1-x}AS/In_xGa_{1-x}AS$ hetero-junction

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Abstract: *In this paper a hetero-junction tunnel field effect transistor (HJ-TFET) with the channel length of 20 nm has been introduced and simulated in which the source/channel hetero-junction is $Al_xGa_{1-x}As$ /$In_xGa_{1-x}As$. With precise selection of the mole fraction this hetero-junction, excellent device operation has been achieved. With optimized mole fraction and doping value in the source and the channel regions, on-state current as high as 18 μA/μm* and *very low off-state current of 10^{-18} is attained. Moreover in the proposed TFET I_{on}/I_{off} ratio is 10^{13} which is very high. Also sub-threshold swing of 30 mv/decade is achieved which is well below 60 mv/decade.*

Keywords: band-to-band tunneling, high-k dielectric, hetero-junction, gated p-i-n diode, sub threshold swing, tunneling transistor

1. Introduction

Continuous down scaling of transistors in very large scale (VLSI) integrated circuit imposes new challenges in term of short channel effect (SCEs), increase power consumption and high leakage current[1-4]. Fundamental physical limitation of 60 mV/decade sub-threshold (SS) prevent more scaling of electron devices, due to high off-state current and low on-state to all state current ratio, new device designates are necessary to overcome these problem. Tunnel field-effect transistors (TFET) has demonstrated the potential to surpass to those limitations. High on current, low off current and low sub-threshold swing (below 60 mv/decade at room temperature) are important features that distinguish tunnel FET from MOSFETs. It predicates that the TFET, with improvement in the structure and the theory, can be replaced to conventional transistors [5],[6]. Various techniques are applied to the TFET but each of them has its own specific problems [7]. Effect of material on the device performance, has recently been considered and Since the band to band tunneling (BTBT) mechanism is used the TFET device and band gap is regarded as barrier potential, band gap engineering take into consideration.

In proposed TFET by using different materials in the source and channel, we will indicate that at junction side the minimum band gap has been made and the high ON current and low sub-threshold swing has been obtained. In this paper to enhance and optimize pervious design on TFET , a novel high performance double gate hetero-structure tunnel field effect transistor (DG-HJ-TFET) is introduced.

2. Device architect

The structure of a hetero-junction tunnel field effect transistor (HJ-TFET) which consist of p and n type semiconductor as depicted in Fig. 1, the source and drain region has high doping level. The source doping of 1×10^{20} cm^{-1} and drain doping of 1×10^{19} cm^{-1}. The channel region (intrinsic) is equal 1×10^{17} cm^{-1} and length of 20 nm. The sources region is filled from AlGaAs with 120-nm length. InGaAs is used for channel and drain region. 4-nm is designated for effective oxide thickness (EOT), HFO2 is used as high-k dielectric (k=29), double gate structure is employed to the device and the gate material is metallic with work function of 4.8 eV.

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Engineering at materials to source/channel region of proposed TFET can create minimum band gap at junction side make high on current and the low sub threshold swing (SS). With respect to high doping at source and drain region and band to band tunnelling mechanism, band gap narrowing, SRH recombination and nonlocal BTBT models is used at two diminution simulation ATLAS SILVACO software.

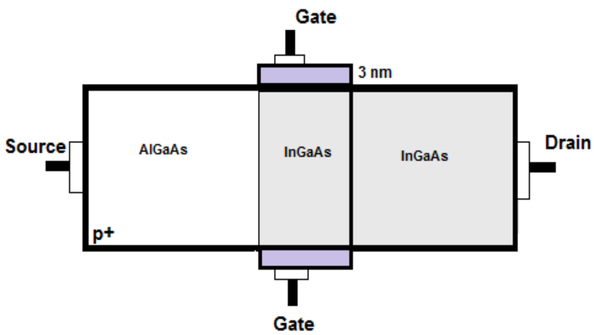

Fig.1: structure of proposed hetero-junction tunnel FET (HJ-TFET).

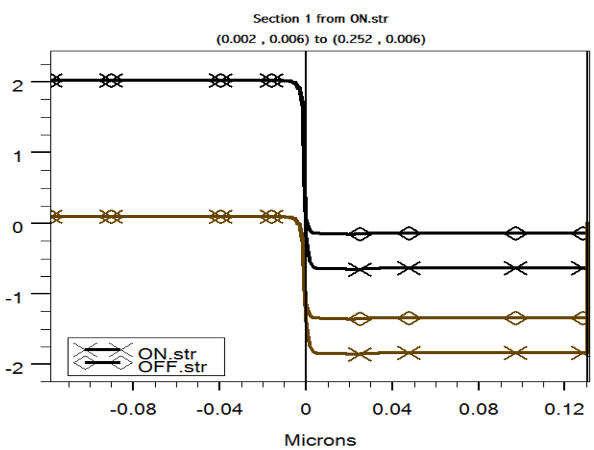

Fig. 2: conduction and valance band at ON and OFF state

3. Operation and Simulation result

In the tunnel field effect transistor (TFET) an electron can tunnel from source to channel trough band gap and this mechanism control with gate voltage , in n type TFET (this structure) for better monitoring of this phenomenon, $Al_xGa_{1-x}As/In_xGa_{1-x}As$ hetero-junction is employed. The tunnelling distinction in the junction side can be tuned by engineering in the band gap, to do this; mole fraction can be change at the source and the channel region. In the OFF state (V_{DS}=1 V and V_{GS}=0 V), tunnel barrier width is large and OFF current is mainly due to leakage. If a positive voltage apply to drain and gate contact (V_{DS}=V_{GS}=1 V), energy bands at source and channel are close together and the electron can be tunnel from the caused space. In this paper we denote that performance of the TFET is improved by engineering at the band gap in source/channel region and a novel $Al_{0.4}Ga_{0.6}As$ /$In_{0.85}Ga_{0.15}As$ hetero-junction TFET is introduced, whereas potential barrier is function of mole fraction, in proposed structure with x=0.4 and x=0.85 high performance TFET is optimized and output result is recorded in fig. 3. This curve (I_D Vs V_{GS}) evident that tunnelling pass at source/channel is decrease due to high ON current at the device. I_d is 18 µA/µm at V_{DD}= 2 V, this value is comparable to similar device[8]. In the OFF state lowest current pass through the device that is about 10^{-18} A/µm, Ion/Ioff ratio is a important parameter for compare same tunnel FET, for this structure is about 10^{13} . The low sub threshold swing at this kind of device demonstrate different from MOSFET and the required voltage to increase one order of current is 40 mv/decade, this value is defined the sub threshold swing (SS). Threshold voltage and sub threshold swing can calculate from logarithmic curve with constant current method, threshold voltage is about 30 mV. Graph of the Drain current Vs Drain voltage with different gate voltage is shown at fig. 4. From this curve output impedance is derive that is about 100 kΩ. Fig. 5 shows the energy band diagram of proposed structure with different power supply, this curve show if V_{DD} increase, the overlap of the conduction band and the valance band will execs.

4. Conclusion

In this paper a hetero-junction tunnel FET (HJ-FET) based on $Al_{0.4}Ga_{0.6}As$ /$In_{0.85}Ga_{0.15}As$ has been simulated and its related result are recorded in fig. 3 and fig. 4. Besides, these curves are indicated that performance of the proposed transistor can be optimized with the change of mole fraction. The exact choice of mole fraction in each region, the sufficient tunnelling distinction at the source/ Channel side can be provided. High on current (18 µA/µm) and low sub-threshold swing (40mv/decade) are considered as significant parameters which assure the performance of TFET; moreover, in this state, the proposed transistor can be replace to previous devices and output characters shows that this TFET is a good candidate for analogue and digital applications.

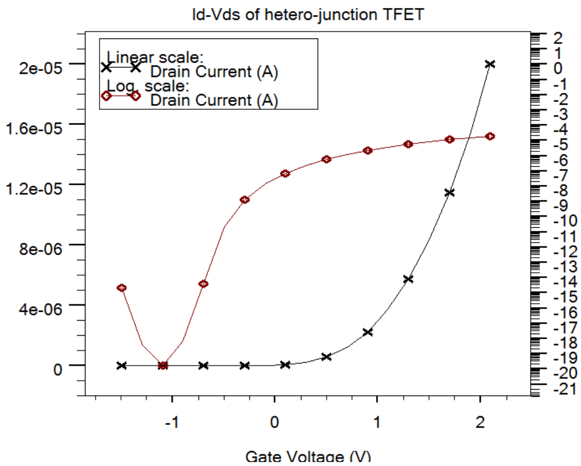

Fig.3. I_d-V_{gs} curve in linear and logarithmic of proposed TFET

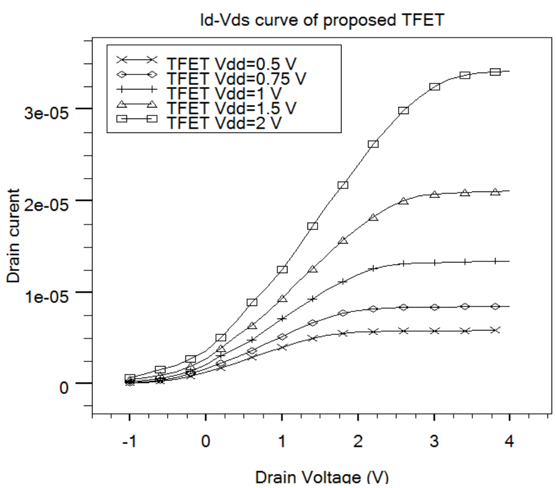

Fig.3. I_D-V_{DS} curve of proposed TFET with different Drain voltage

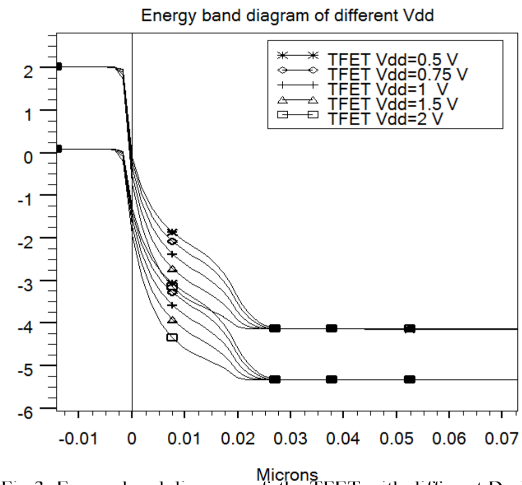

Fig.3. Energy band diagram of the TFET with different Drain voltage

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