Study of III-V Semiconductor Channel Material in Tunnel Field Effect Transistor

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Abstract—This paper presents a simulation study of channel material $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ in tunnel field effect transistor. An extensive simulation is used to analyse ac and dc analysis of the proposed device. It is observed that the proposed device shows high on/off ratio $\sim 10^{12}$ and the subthreshold swing of $\sim 30 \text{ mV/dec}$ when $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ is used as channel material in tunnel field effect transistor. This study shows better performance in dc and ac analysis with compare to other existing channel materials.

Keywords: TFET, MOSFET, subthreshold voltage, threshold voltage.

I. Introduction

The subthreshold swing could not reduce less than $60 \text{ mV/dec}$ and this cannot allow for further supply voltage scaling. The increase leakage current and ono-scaled supply voltage increases the power consumptions of the nanodevices. MOSFET, basic building block of electronic society of integrated circuits, acts as horse-power and used as random-access memory, and some other device applications. In nanoscale device, the dimension scaling of the MOS device is not possible because it will increase the leakage current. According to International-Roadmap-for-Semiconductors reports, the power-dissipation is the major barrier in switching devices for nanoelectronics systems. These limits of MOSFET motivates the researcher to develop alternative devices such as CNTFET, TFET, Nanowire FET, etc., in nanometer regime. Device performance of TFET do effect from short channel effects [1]-[3]. The subthreshold swing of the TFET could be smaller than $60 \text{ mV/dec}$, which is another advantage of TFET. This advantage enables window for further scaling of supply voltage of nano-devices. However, TFETs have some disadvantages such as low ON-current, high threshold voltage, ambipolarity, and high miller capacitances [4]-[5]. To address these disadvantages, an alternative materials and device structures has been investigated. III-V compound semiconductor based TFETs acts as alternative device for semiconductor applications applications, due to lightweight effective mass of III-V material and this leads large mobilities of electron and large ON current, which could express high performance of devices at low supply voltage.

![TFET Structure](image_url)

Figure 1. TFET Structure
Structure of TFET device consists of source, drain and gate respectively, as sown in Fig. 1. The source is a highly doped region, known as p region, whereas drain is a highly doped region, known as n region. The undoped channel region is known as intrinsic region. This configuration is also called gated p-i-n diode [6]-[8].

In this paper, a n-type TFET with Al$_{0.2}$Ga$_{0.8}$As is considered as channel material. The proposed device shows high Ion/Ioff ratio $\sim 10^{12}$ and small subthreshold-swing of $\sim 30$ mV/decade. The other materials used as the channel material for comparison are silicon, silicon-germanium, strained silicon, gallium arsenide, Aluminum Gallium Arsenide, respectively.

II. Channel Material of TFET Device

Silicon is the ample semiconductor material which dominates the electronic society. ITRS predicted that the alternative semiconductor materialsto silicon are III-V elements. III-V elements have been obtained by adding group III elements such as gallium, aluminum, and indium, with group V such as nitrogen, arsenic, antimony, phosphorous, etc., respectively. The combination of III and V elements provide twelve possible combinations of III-V compound semiconductor such as GaP, InP, GaN, GaAs, AlGaAs, etc., respectively [9]-[12]. The electrons of III-V materials move more quickly than silicon so these are better option for high-speed devices. III-V materials are rarer as well as expensive than silicon material so it is difficult to use III-V as next-generation chip material. To avoid this issue, a layer of III-V element can be stick on SOI device. One of the important materials of III-V semiconductor materials is AlGaAs, which acts major role in various transistors as well as in optoelectronics. For the proposed device, Al$_x$Ga$_{1-x}$As has been used as channel material with direct energy band gap because when $x < 0.4$ the band gap is considered as direct bandgap in TFET [13]-[15]. The channel material Al$_{0.2}$Ga$_{0.8}$As plays an outstanding work as channel material and its better shows output characteristics of the proposed device. It shows the improved Ion/Ioff ratio, subthreshold swing and miller capacitance, $C_{gd}$ of the device. The source is considered as p-type and drain region is of n-type material, whereas the channel region is the intrinsic type of material. In TCAD simulations, concentration used to dope source, drain and channel are $1 \times 10^{19}$ cm$^{-3}$, $1 \times 10^{19}$ cm$^{-3}$ and, $1 \times 10^{19}$ cm$^{-3}$, respectively. The channel lengths of channel region, source region, and gate region are considered as 30nm, 35nm and 35nm respectively. HfO$_2$/SiO$_2$ is used as gate dielectric whereas polysilicon is used as gate material. SiO$_2$ with low dielectric constant gives gate oxide breakdown and reliability issues. To overcome these issues, HfO$_2$ has been stacked with a thin layer of SiO$_2$ to bring the desired result in the proposed device.

III. Result Analysis

The simulation result of subthreshold swing is illustrated in this section. The results justified that the proposed device with Al$_{0.2}$Ga$_{0.8}$As as channel materials shows better result in comparison to other channel material. The proposed device with Al$_{0.2}$Ga$_{0.8}$As as channel material and compared to different channel materials $V_{DS} = 0.7$ V & $V_{GS} = 1$ V. The germanium as channel material shows more ON current due to thin tunneling barrier and high OFF current due to high leakage current. The indirect band gap materials such Si, Ge and SiGe shows low Ion/Ioff ratio then direct band gap materials GaAs & Al$_{0.2}$Ga$_{0.8}$As. Both GaAs and Al$_{0.2}$Ga$_{0.8}$As are direct band gap material with wide energy band gap of 1.43 eV and 1.42 eV. In case of Al$_{0.2}$Ga$_{0.8}$As, the leakage current is much smaller than the GaAs which shows that Ge is high electron mobility material so the on current is higher with high injection velocity and reduced delay.
IV. Conclusion

In this paper Al$_{0.2}$Ga$_{0.8}$As is considered as channel material in TFET, which demonstrated better performance in compare to other existing channel materials, SiGe, Ge, Si, Ge, Strained Si and GaAs. The indirect band gap material ON/OFF ration and steepest subthreshold-swing, while using Al$_{0.2}$Ga$_{0.8}$As as channel material in TFET device. It is observed from the simulation results that the proposed TFET have high ON/OFF ratio of $10^{12}$ and the steepest subthreshold-voltage of 30 mV per decade.

REFERENCES


