

Analysis of SOI-Tunnel FET With $\text{Al}_x\text{Ga}_{1-x}\text{As}$ As Channel Material

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Abstract— This paper investigated $\text{Al}_x\text{Ga}_{1-x}\text{As}$ as the channel material in Silicon – on – Insulator (SOI) Tunnel Field Effect Transistor (TFETs). Synopsys TCAD simulation has been used to analyses DC as well as AC analysis of the proposed device. The mole fraction $x = 0.2$ is used to study the $\text{Al}_x\text{Ga}_{1-x}\text{As}$ as channel material. The direct energy band gap for $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ is used because $x < 0.4$. It is observed that the proposed device shows high on/off ratio $\sim 10^{12}$ and the subthreshold swing of ~ 30 mV/dec. $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ is used as channel material, which shows a very small miller capacitance This study shows better performance in DC as well as in AC analysis with compare to other channel-material such as silicon, germanium, gallium-arsenide, silicon-germanium, and strained-Si

I. INTRODUCTION

MOSFET, basic building block of electronic society of integrated circuits (ICs), acts as horse-power and used as andom-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 [1]. The subthreshold swing could not reduce less than 60 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 nano devices [2]. 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 CNT FET, TFET, Nanowire FET, etc., in nanometer regime. Device performance of TFET do effect from short channel effects[3]. The subthreshold swing of the TFET could be smaller than 60 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, etc., [4]. 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[5].



Fig.1. Structure of TFET Device

Structure of TFET device consists of source, drain and gate respectively, as shown 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].

In this paper, a n-type TFET with $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ is considered as channel material. The proposed device shows high $I_{\text{on}}/I_{\text{off}}$ ratio $\sim 10^{12}$ and small subthreshold-swing of $\sim 30 \text{ mV / decade}$. The other materials used as the channel material for comparison are silicon (Si), silicon-germanium (SiGe), strained silicon (Strained Si) , gallium arsenide (GaAs), Aluminum Gallium Arsenide (AlGaAs), respectively. In TCAD, non-local band-to-band tunneling model has been used to generation rate of holes as well electrons [7]-[12].

II. $\text{Al}_x\text{Ga}_{1-x}\text{As}$ COMPOUND MATERIAL

Silicon is the ample semiconductor material which dominates the electronic society. ITRS predicted that the alternative semiconductor materials to 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. 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[13]. 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 [14]-[15]. For the proposed device, $\text{Al}_x\text{Ga}_{1-x}\text{As}$ 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 SOI – TFET. The channel material $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ 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.

III. PHYSICS OF PROPOSED DEVICE

Figure 2 shows a conventional SOI-TFET with polysilicon gate material. 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 $1 \times 10^{19} \text{ cm}^{-3}$, $1 \times 10^{19} \text{ cm}^{-3}$ and, $1 \times 10^{19} \text{ cm}^{-3}$, respectively.

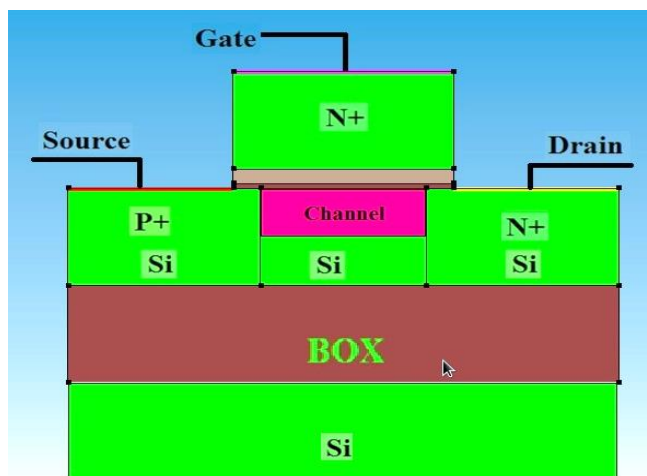


Fig.2. Structure of Proposed n-type TFET

The channel lengths of channel region, source region, and gate region are considered as 30nm, 35nm and 35nm respectively. $\text{HfO}_2/\text{SiO}_2$ 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.

IV. SIMULATION ANALYSIS AND RESULT

This section study the behavoiur of the proposed device in terms of transfer characteristics, Ion/Ioff ratio, subthreshold swing and miller capacitance.

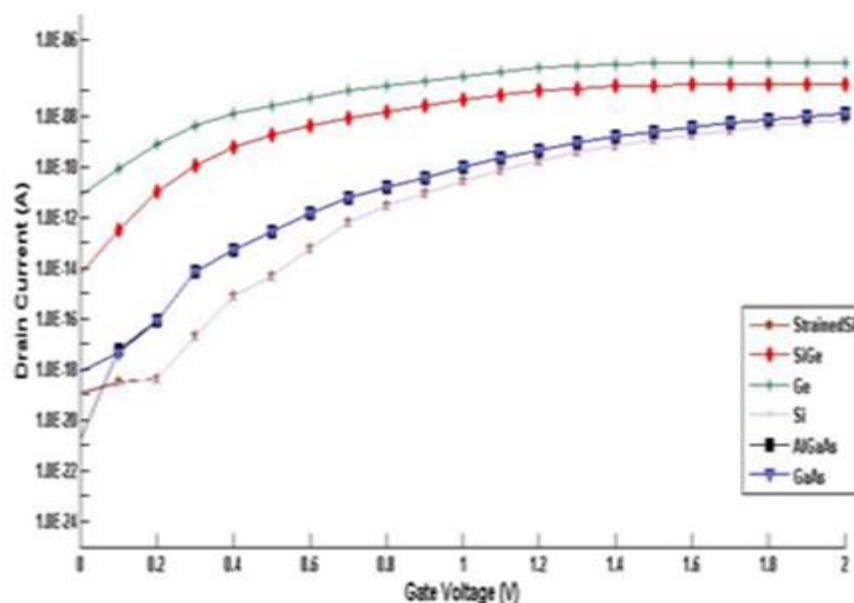


Fig.3. Transfer-Characteristics w.r.t channel materials

The results justified that the proposed device with $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ as channel materials shows better result in comparison to other channel material. Fig.3 shows the transfer characteristics (I_{ds} vs. V_{gs}) of the proposed device with $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ as channel material and compared to different channel materials $V_{DS} = 0.7 \text{ V}$ & $V_{GS} = 1 \text{ V}$. The germanium as channel material shows more ON current due to thin tunneling barrier and high OFF current due to high leakage current. The conventional Si channel and strained Si as channel materials shows more or less same transfer characteristics.

$\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ shows highest Ion / Ioff ratio in comparison with other channel materials, as shown in figure 4. The indirect band gap materials such Si, Ge and SiGe shows low Ion/Ioff ratio then direct band gap materials GaAs & $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$. Both GaAs and $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ are direct band gap material with wide energy band gap of 1.43 eV and 1.42 eV.

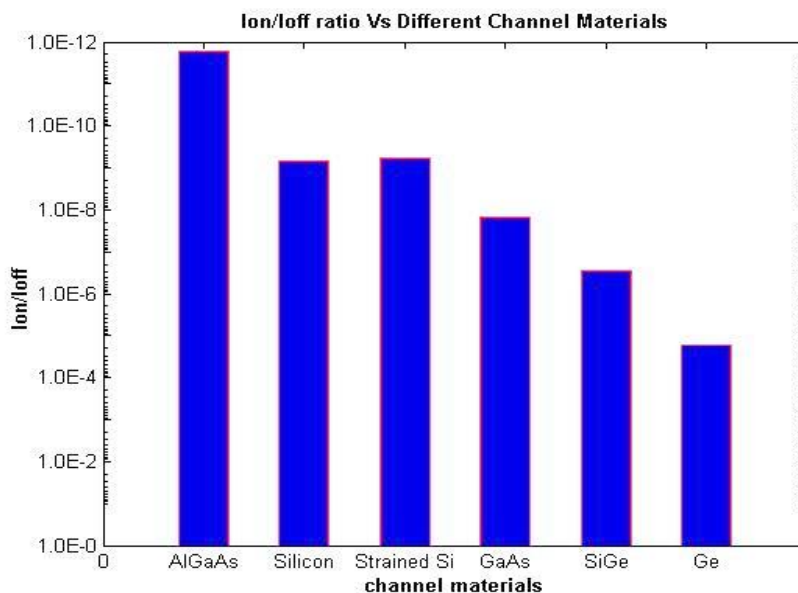


Fig. 4. ON/OFF current ratio with different channel materials

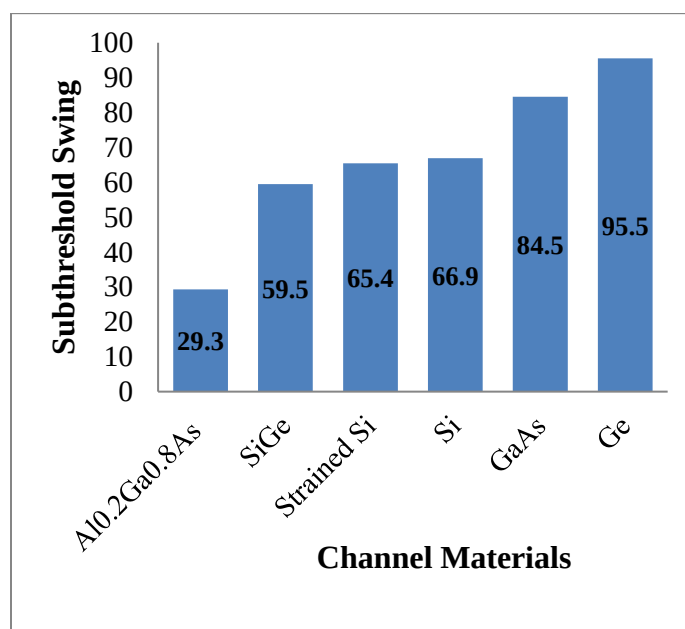


Fig.5. Subthreshold swing w.r.t. channel materials.

In case of $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ 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. It is clear from Fig.5, the subthreshold swing for $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ is lowest in compare to other than which justifies the good switching characteristic.

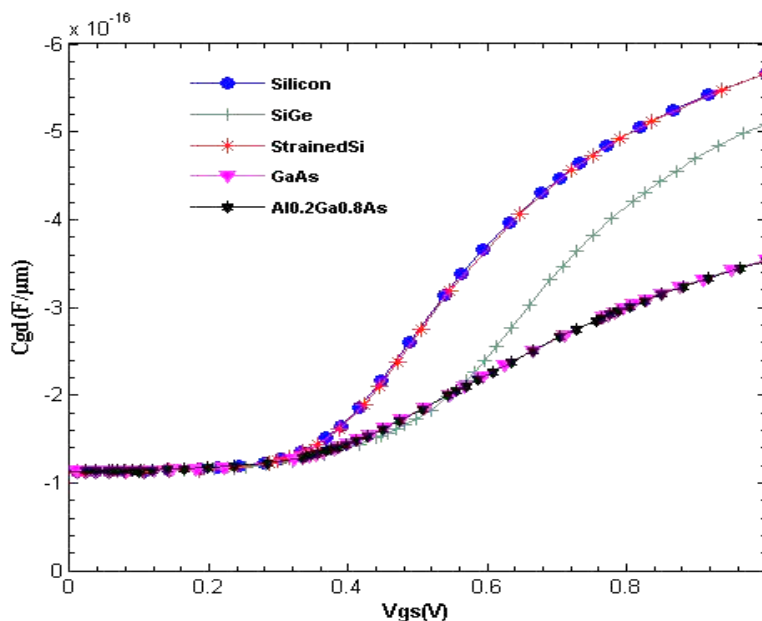


Fig 6. Miller Capacitance for different channel-material

One of the important requirements of TFETs is the minimum miller capacitance. The proposed device shows the miller capacitance C_{gd} is very small for $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ in compare to other channel materials.

V.CONCLUSION

In this work $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ is considered as channel material in SOI-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 $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ as channel material in TFET device. Miller capacitance Miller capacitance is alsois also small for the device. It is observed from the simulation results that the proposed TFET have high ON/OFF ratio of 10^{12} and the steepest subthereshold-voltage of 30 mV per devcade. The use of $\text{Al}_{0.2}\text{Ga}_{0.8}\text{As}$ as a chhel in TFET device shows a small miller

capacitance. Which is one of the essential requirement of TFET device This study shows better performance in DC as well as in AC analysis in compare to other channel-materials.

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