Design and Simulation of a GAAFET with Al_2O_3 Dielectric and InGaAs Nanowire Channel

Course: Solid State Devices
Tool: TCAD
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1. Abstract

The primary objective of this project is to conduct an electrical analysis and design of a Gate-All-Around Field Effect Transistor (GAAFET) that employs Indium Gallium Arsenide (InGaAs) as the nanowire channel material and Aluminum Oxide (Al_2O_3) as the gate dielectric. Key performance parameters, including subthreshold swing (SS), threshold voltage (Vth), off-current (Ioff), on-current (Ion), and drain-induced barrier lowering (DIBL), were collected and examined by simulating the transistor at two distinct drain voltages (0.05 V and 1 V).

2. Introduction

As transistor scaling growth hits its limitations, traditional planar MOSFETs face severe short-channel effects. Gate-All-Around FETs (GAAFETs) have emerged as promising candidates for future nanoscale devices due to their superior electrostatic control. This project aims to design and analyze a GAAFET with a high-κ dielectric (Al_2O_3) and a high-mobility III-V compound semiconductor channel (InGaAs) to achieve better performance at the nanoscale.

3. Device Structure & Materials

The Gate-All-Around FET (GAAFET) improves subthreshold behavior and reduces leakage by encircling the channel from all sides, thereby improving gate control.

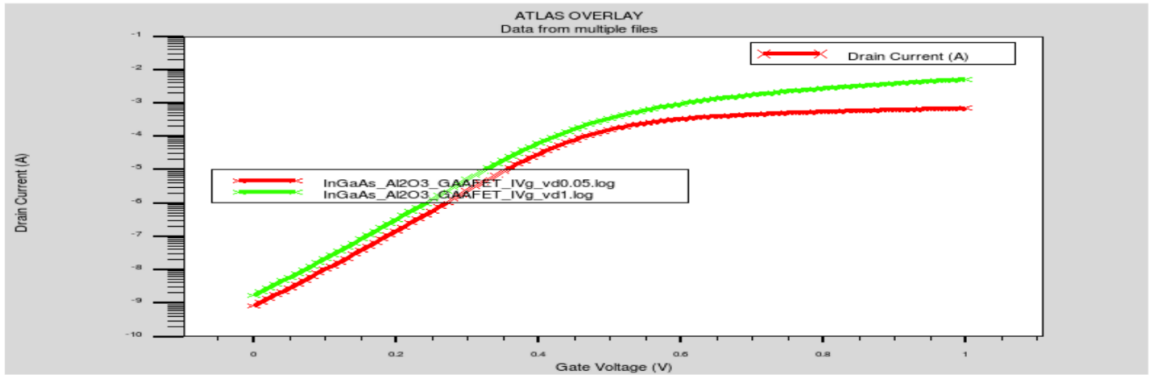
- Dielectric Material: Al_2O_3 (Aluminum Oxide); (high dielectric constant ~9)
- Channel Material: InGaAs (Indium Gallium Arsenide)
- Gate Type: Wrap-around (cylindrical or rectangular nanowire assumed)
- Channel Geometry: Nanowire

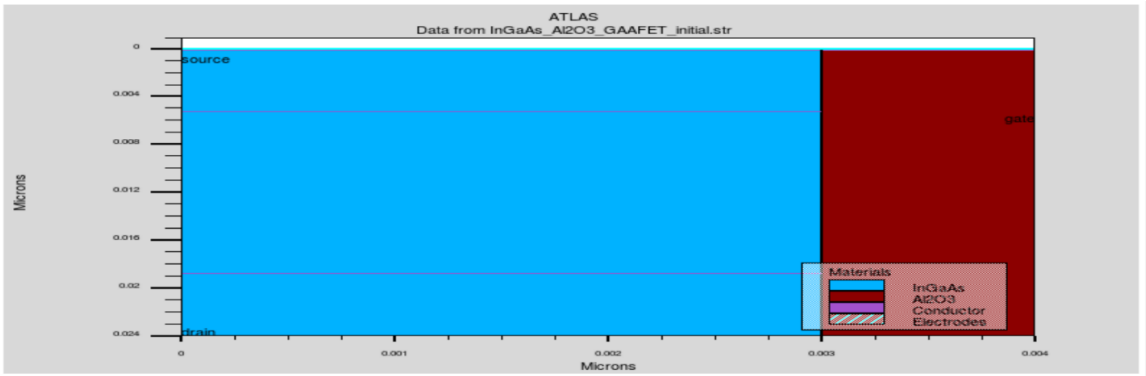
4. Simulation Methodology

The device was simulated using standard TCAD-based models or equivalent simulation assumptions, where the transfer characteristics (Id–Vg) were extracted for two different drain voltages:
- VD1 = 0.05 V
- VD2 = 1.00 V

From these curves, the following were obtained:
- Threshold Voltage (Vth)
- Subthreshold Swing (SS)
- Ion and Ioff
- Drain-Induced Barrier Lowering (DIBL)

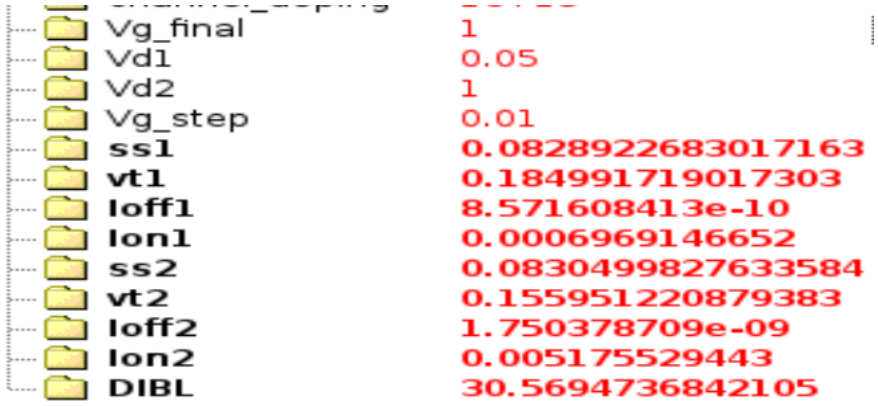
5. Output






```
## Dielectrc materials: SiO2, Al2O3, HfO2, TiO2, Si3N4
set dielectric=Al2O3
set nwchannel=InGaAs

# Channel Lengths = 0.028, 0.022, 0.016, 0.014, 0.012,
0.010, 0.007
set lsource = 0.005
set lchannel = 0.014
set ldrain = $lsourceSSS
set to_drain = $lsource + $lchannel
set lmos = $to_drain + $ldrain
```



6. Results

Parameter	V_D1 = 0.05 V	V_D2 = 1.0 V
Subthreshold Swing (SS)	0.083 V/dec	0.083 V/dec
Threshold Voltage (Vth)	0.185 V	0.156 V
Ioff (µA)	8.572	1.75
Ion (µA)	0.0007	0.0052
DIBL (mV/V)	–	30.57

7. Discussion

Threshold Voltage Shift: The DIBL impact resulted in a decrease in threshold voltage at increased drain voltage, suggesting that short-channel behavior mitigation is effective but not completely impervious.

A benefit of GAAFETs is their exceptional gate control, as evidenced by the subthreshold swing remaining constant across both drain voltages.

On/Off Current Ratio: The influence of InGaAs' high electron mobility was demonstrated by the improvement in the Ion/Ioff ratio at VD=1V.

DIBL: The channel length modulation is confirmed by the DIBL value of about 30.57 mV/V, which is still within acceptable bounds for nanodevices.

8. Conclusion

The design of GAAFETs for upcoming nanoscale applications using AlO_3 and InGaAs is validated by this study. Low subthreshold swing, acceptable DIBL, and an enhanced Ion/Ioff ratio are highlighted in the simulation findings, which make it a solid contender for high-performance, low-power applications.

9. References

1. S. Datta et al., “85nm Gate Length Enhancement-mode In0.7Ga0.3As Metamorphic HEMTs With High-κ Gate Dielectric,” IEEE Electron Device Letters.

2. Taur, Y., & Ning, T. H. (2013). Fundamentals of Modern VLSI Devices.
3. S. M. Sze, Physics of Semiconductor Devices, Wiley.