Tu1B-4

Modeling and Measurement of Dual-Threshold N-polar GaN HEMTS for High-Linearity RF Applications

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Outline

- Introduction
- Device level derivative superposition
- Modified MVSG model for N-Polar
- Dual-V_T model
- Results
- Conclusion

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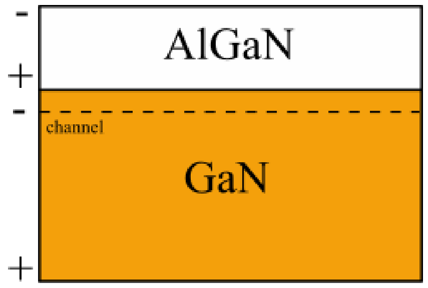
Compact Models for GaN

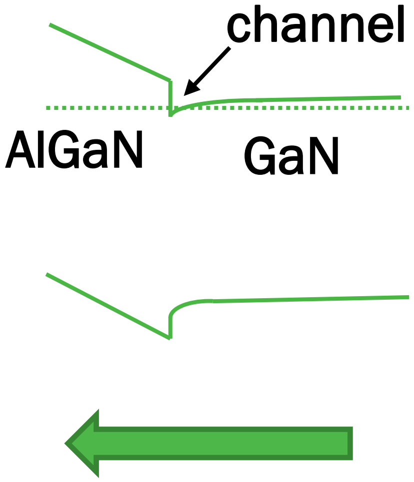
Empirical	Angelov-GaN EEHEMT	• No process info required • Does not capture device physics, Large Parameter set • Angelov(not scalable), EEHEMT(separate DC and AC models)
Artificial Neural Network	DynaFET	• Accurate but no physical intuition • Expensive and elaborate measurement setup
Physics based	MVSG (charge) ASM-HEMT (Surface potential)	• CMC standard • Requires basic process info • Unified and predictive Model. Captures device physics • Modelling over a large dynamic range and frequency

Ga-Polar vs N-Polar

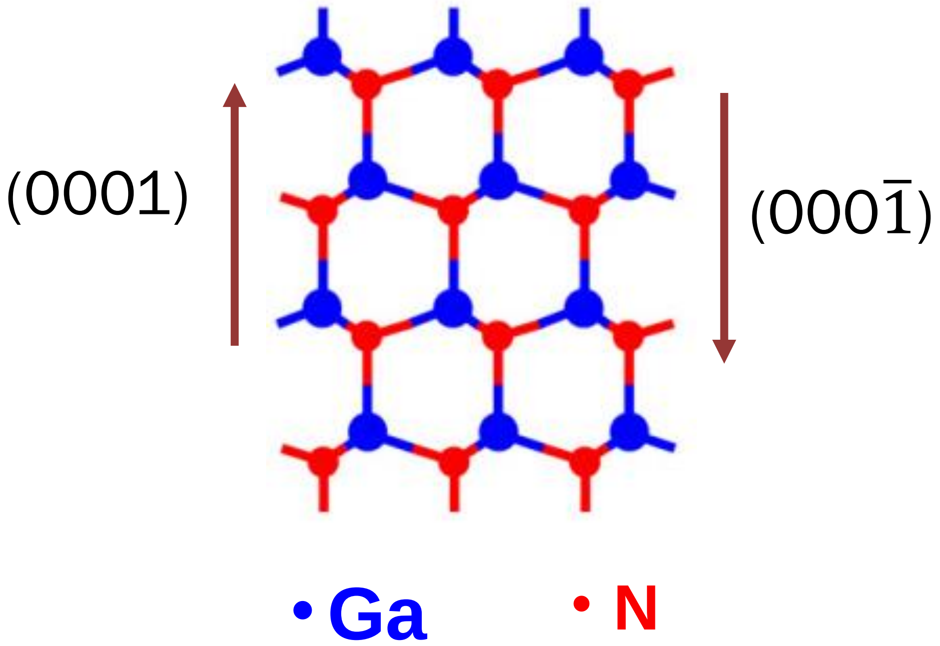
Ga-polar



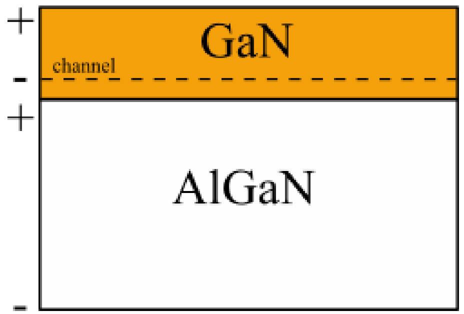
Top barrier induces 2DEG



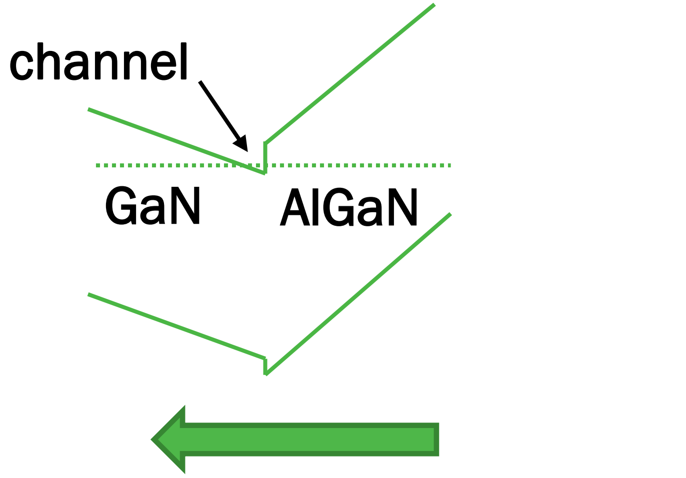
Growth direction



N-polar

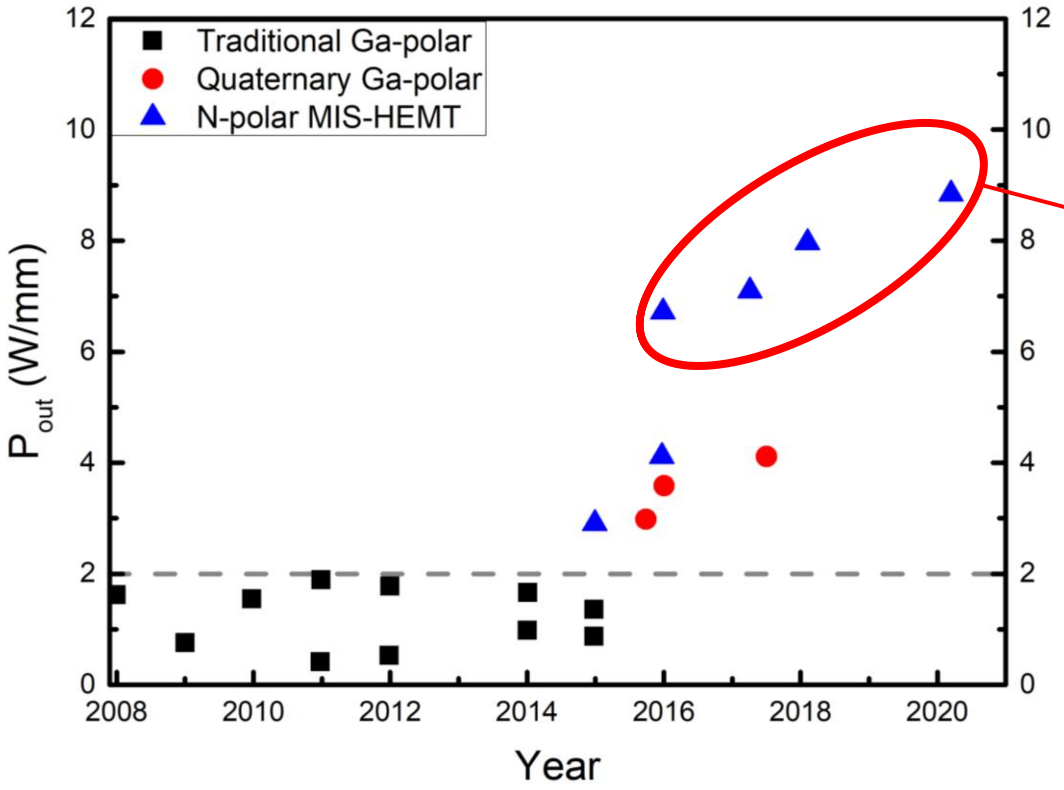


Back barrier induces 2DEG



Growth direction

N-polar GaN performance



N-polar GaN Deep Recess MIS-HEMTs achieved P_{out} ~ 8.8 W/mm @94 GHz

N-Polar provides break through output power density relative to traditional Ga-polar devices[1]

[1]B. Romanczyk, S. Wienecke et al., "Demonstration of constant 8 W/mm power density at 10, 30, and 94 GHz in state-of-the-art millimeter-wave N-polar GaN MISHEMTs," IEEE Transactions on Electron Devices, vol. 65, no. 1, pp. 45–50, jan 2018

GaN Receiver Applications

Need devices with high **OIP3/P_{DC}**

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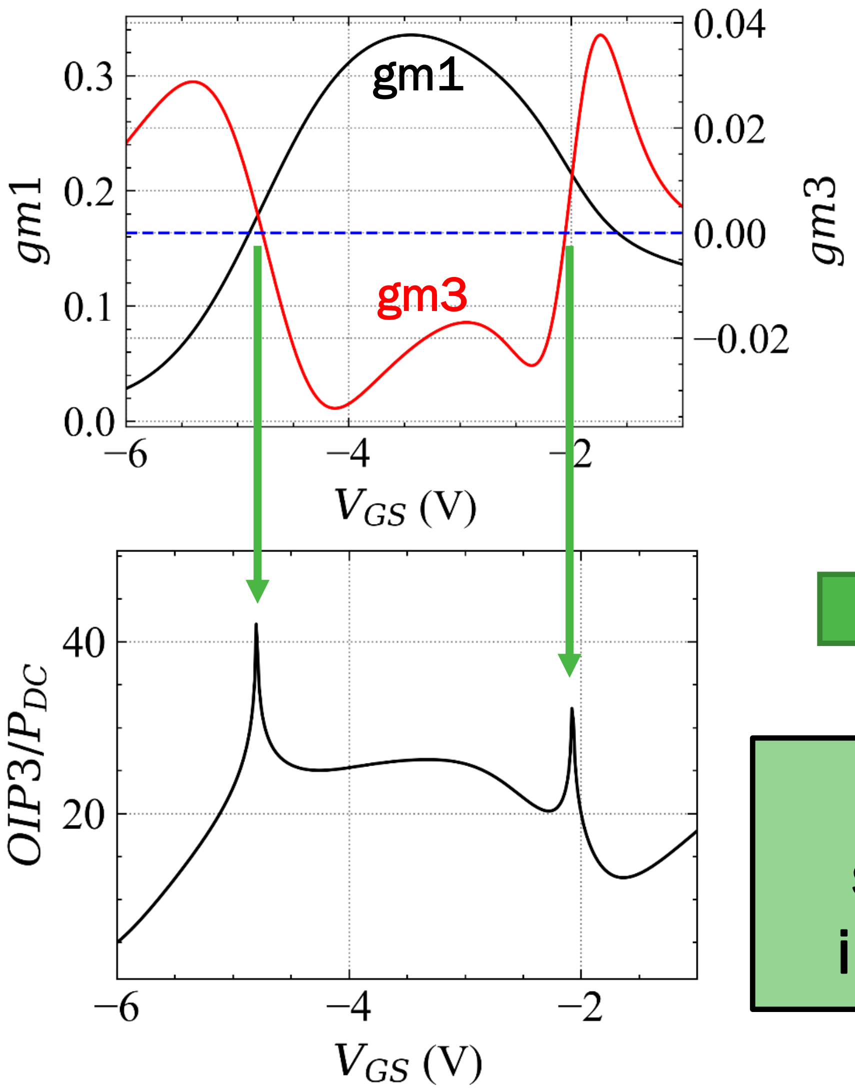
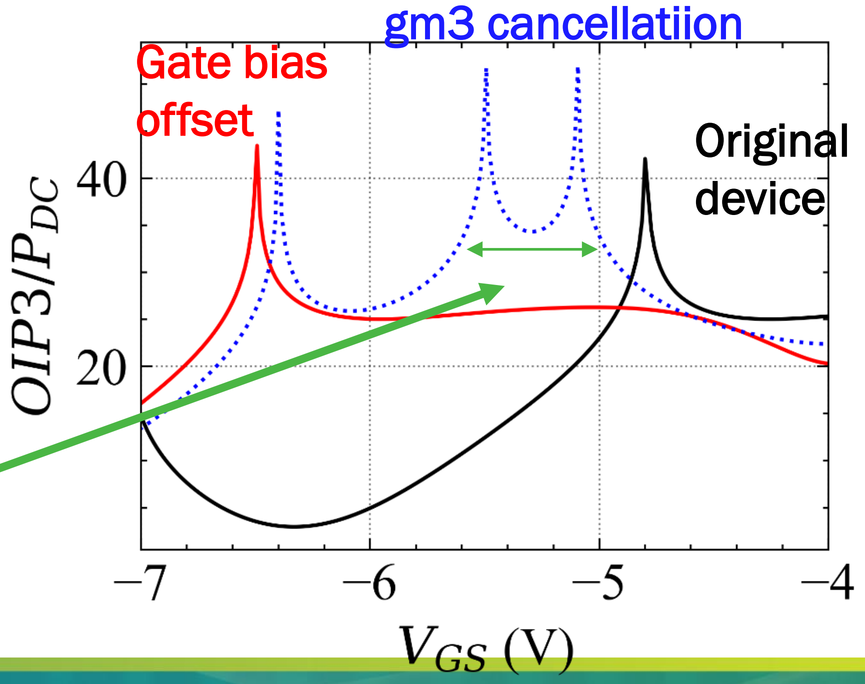
Linearity Sensitivity to Bias



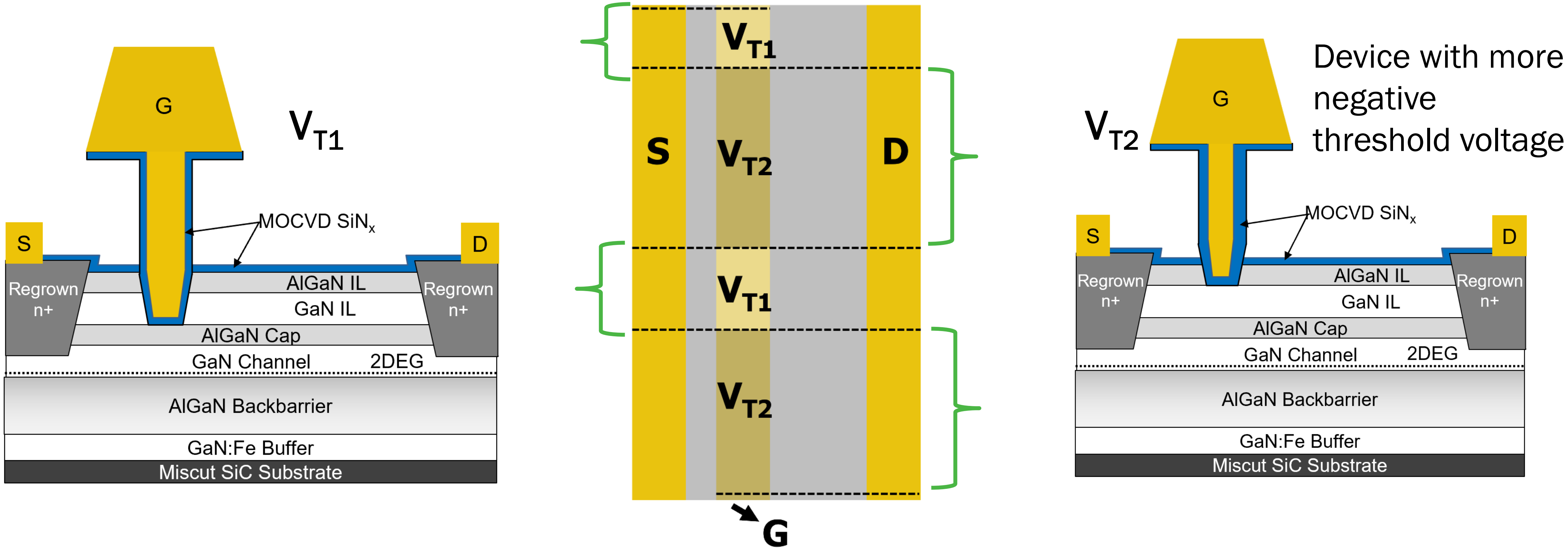
gm3 zero-crossings result in two peaks in the $OIP3/P_{DC}$ but it occurs in a narrow range of gate bias

Derivative superposition can improve bias range



Device Level Derivative Superpositon

Novel device structure where threshold voltages are shifted instead of the conventional gate bias offset in circuit level derivative cancellation



[2] P. Shrestha, M. Guidry et al., "A Novel Concept using Derivative Superposition at the Device-Level to Reduce Linearity Sensitivity to Bias in N-polar GaN MISHEMT," DRC, vol. 2020-June.

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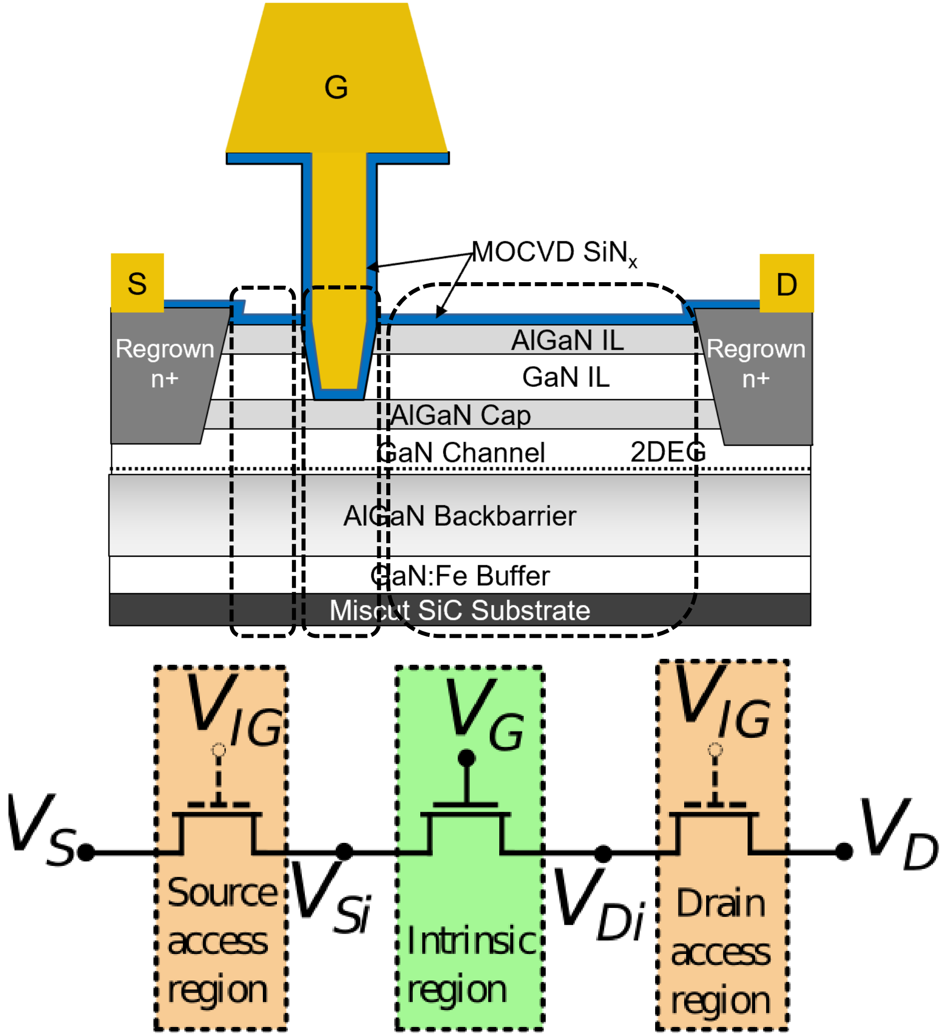
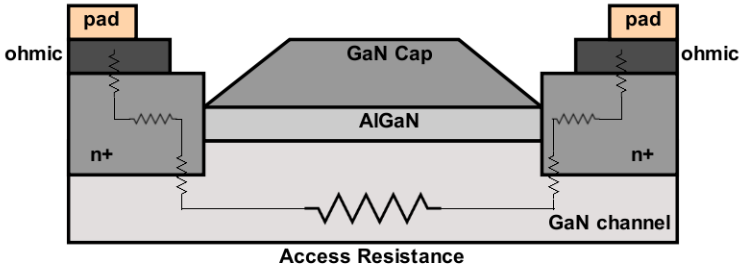
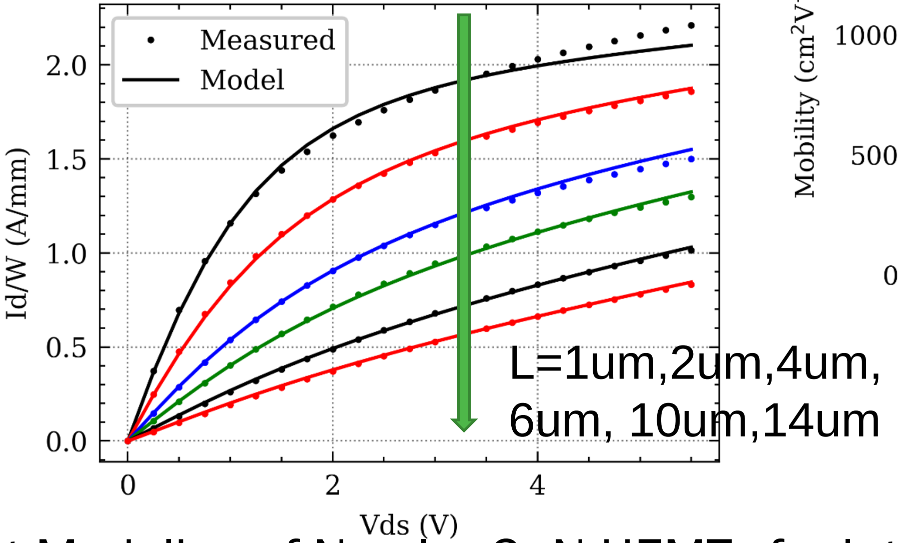
N-polar GaN MVSG model

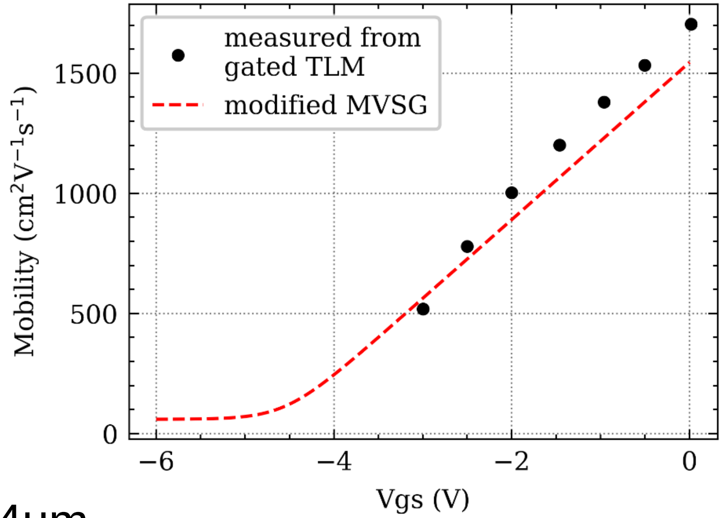




Access region model

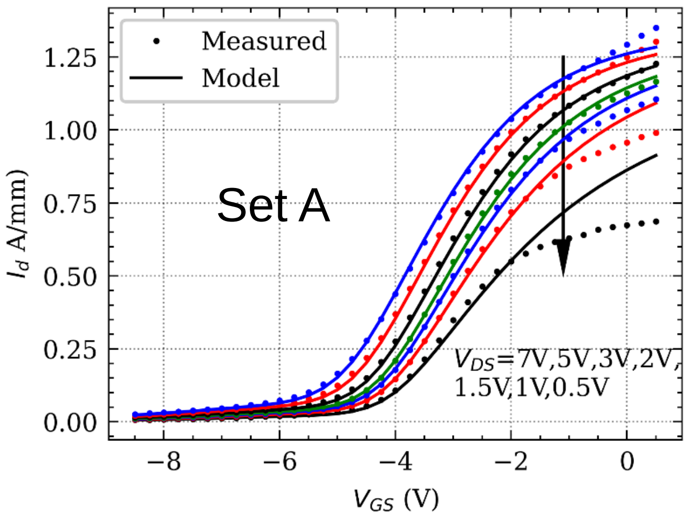


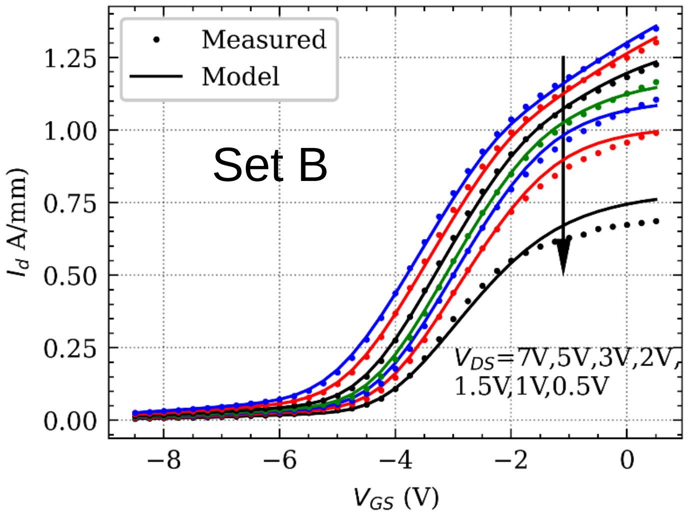
Mobility Enhancement

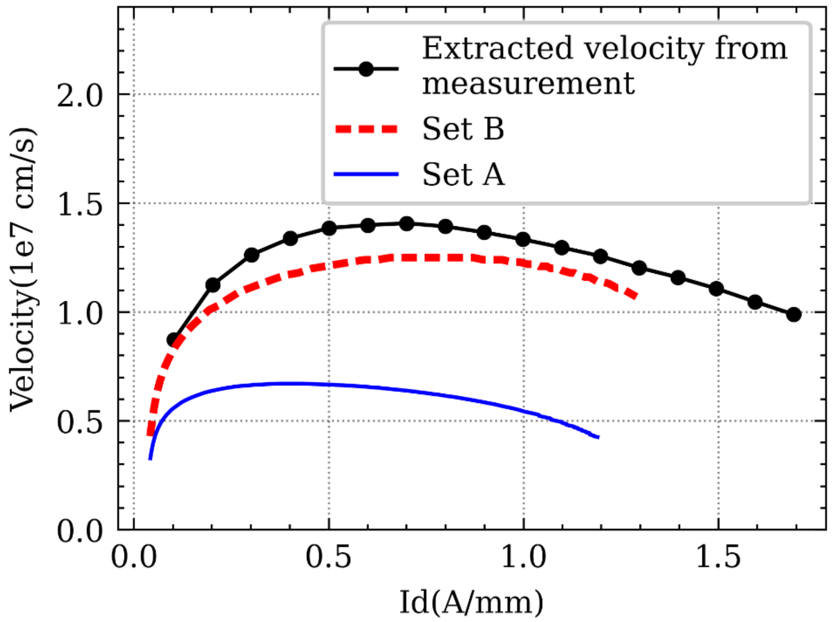


[3] R. R. Karnaty, P. Shrestha et al., “Compact Modeling of N-polar GaN HEMTs for Intermodulation Distortion in Millimeter-wave Bands,” IEEE Transactions on Microwave Theory and Techniques, 2023

Velocity Profile Extraction

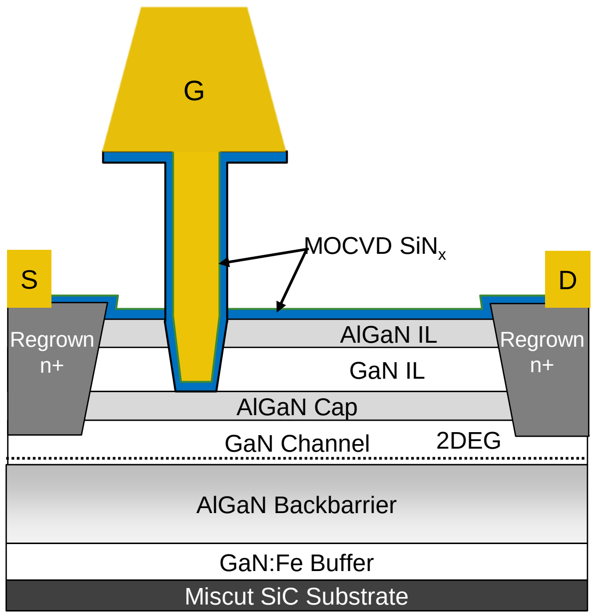




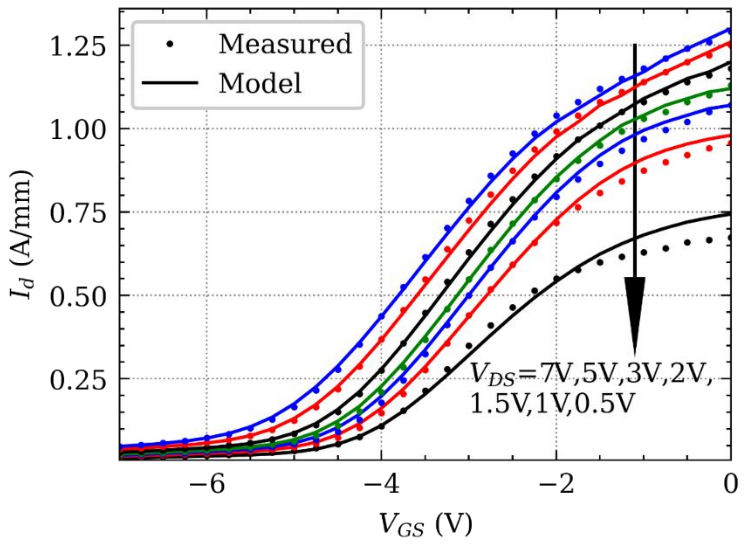


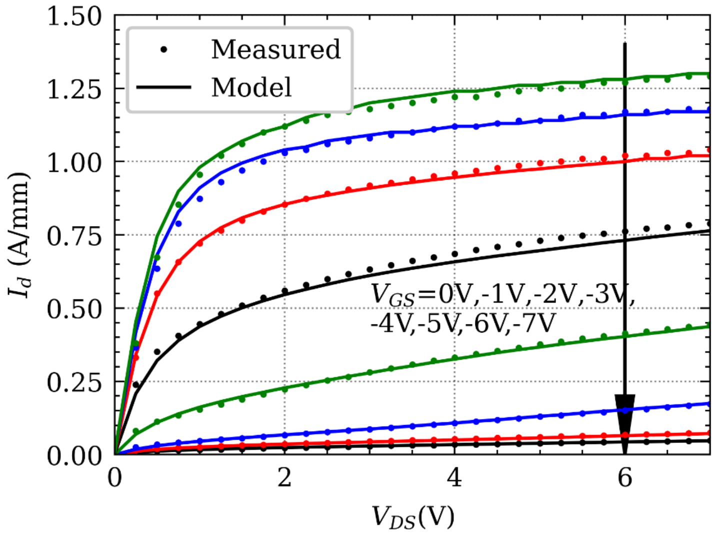
Extracted velocity profile is verified against measured data to choose between different parameter sets having similar IV model accuracy

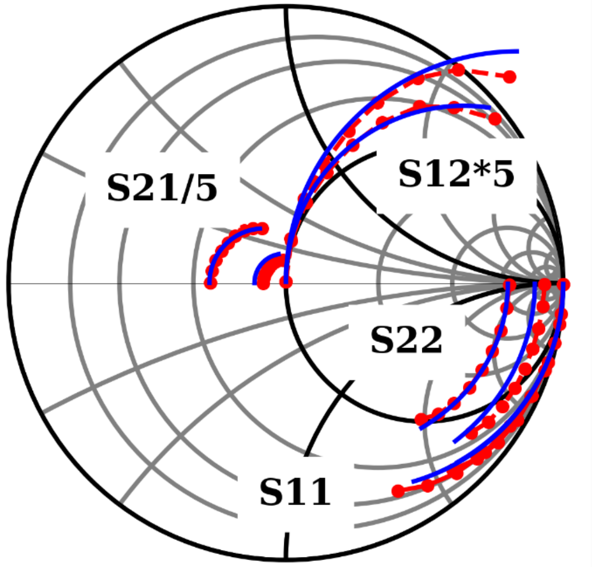
V_{T1} Device Modeling



L_G=60nm (channel length)
W=2x25 um
L_{GS} = 105nm (source access region)
L_{GD} = 335nm (drain access region)

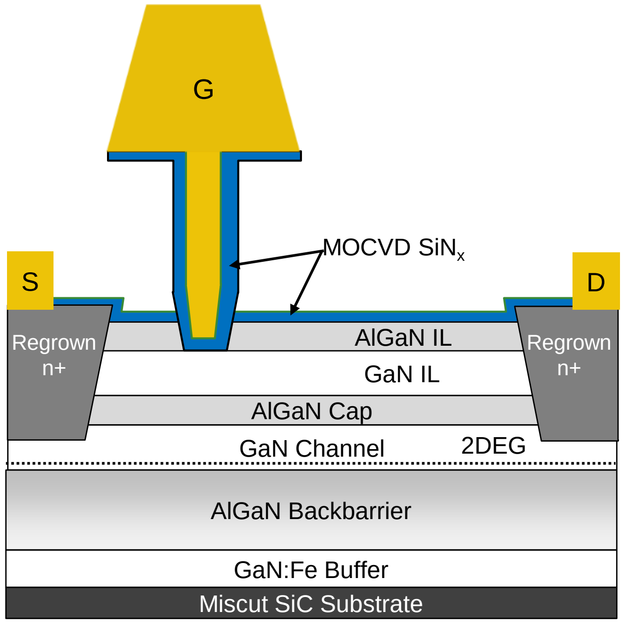






S-parameter(0-67 GHz)

V_{T2} Device Modeling



L_G=60nm (channel length)
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L_{GS} = 105nm (source access region)
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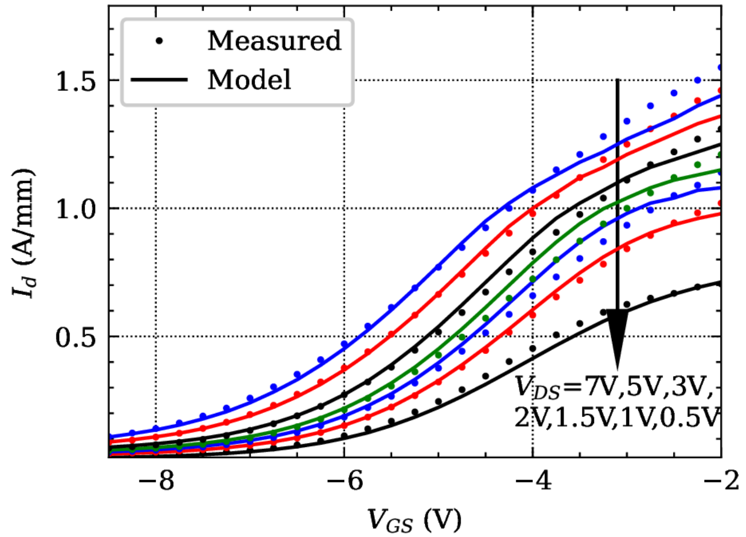

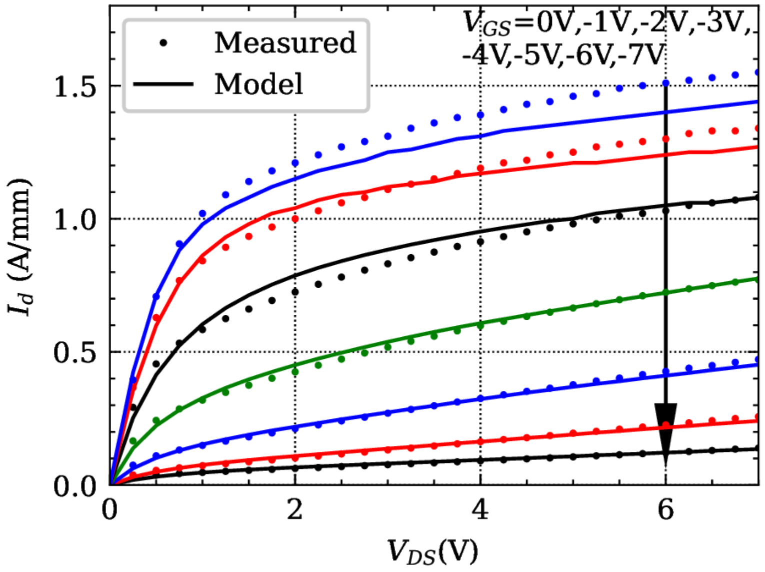

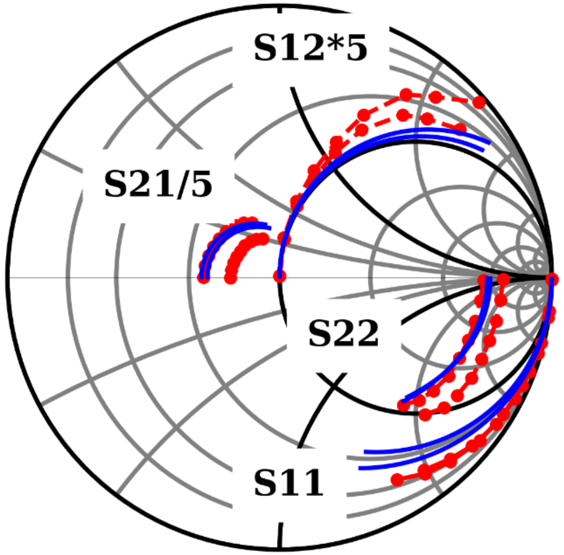

S-parameter(0-67 GHz)

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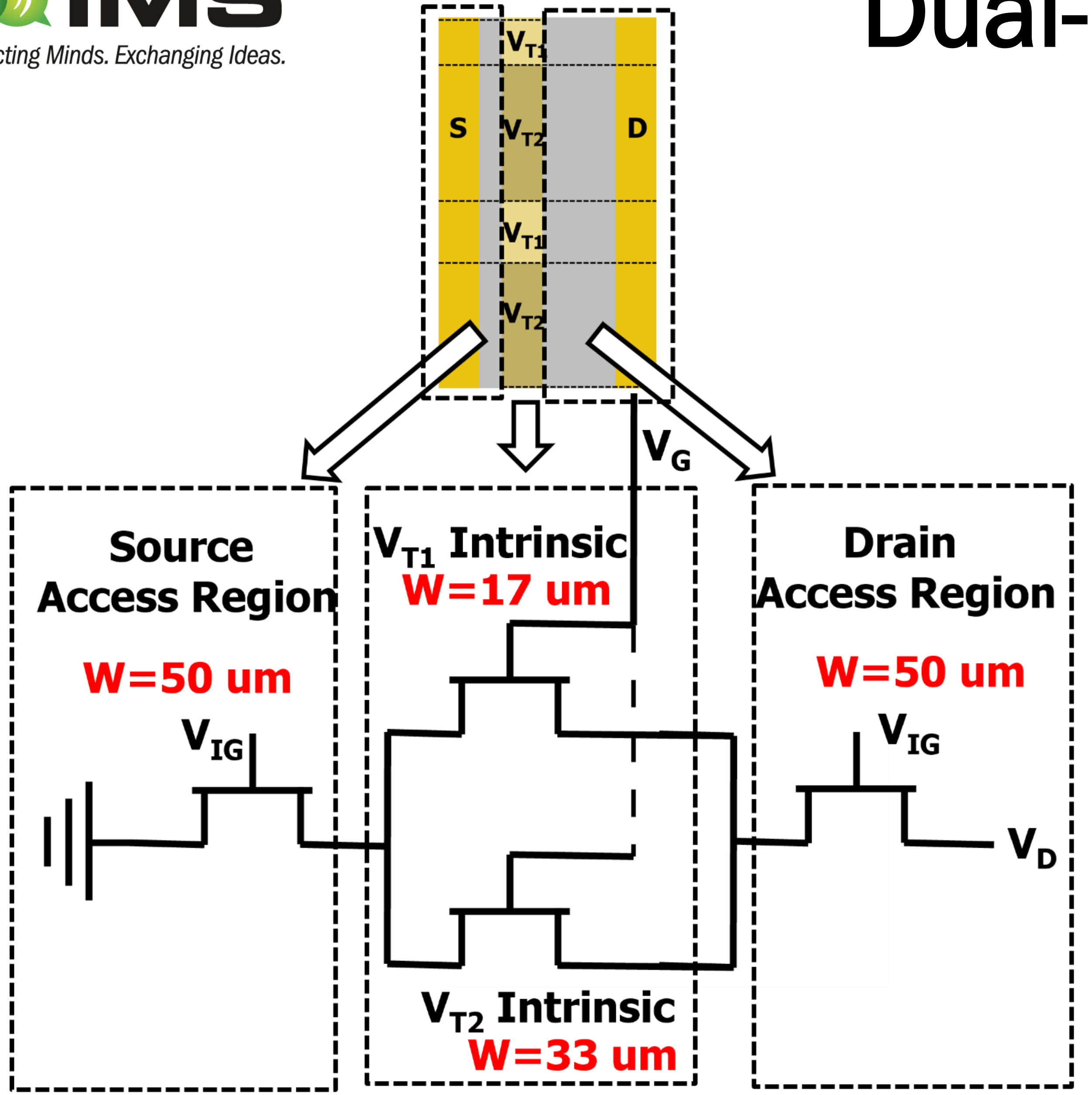
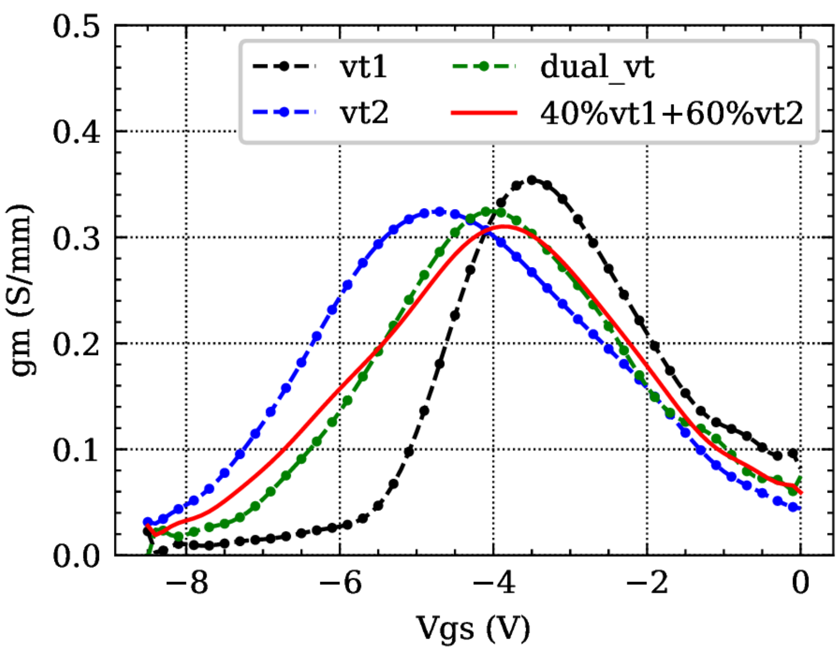
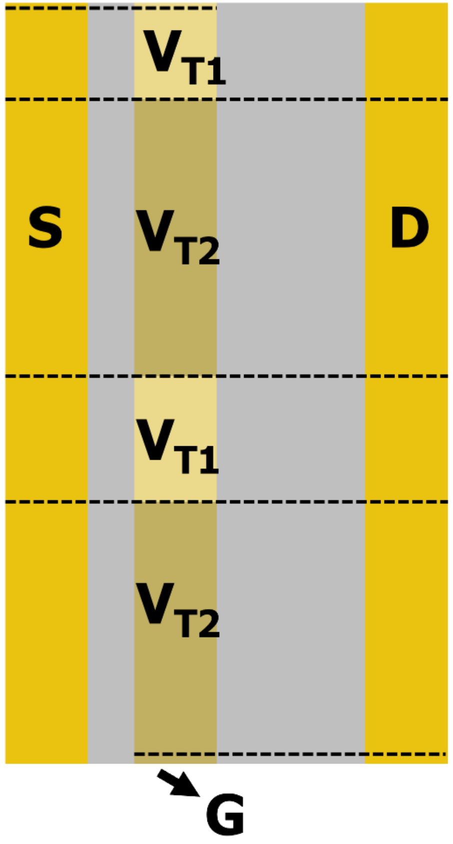
Dual-V_T Model

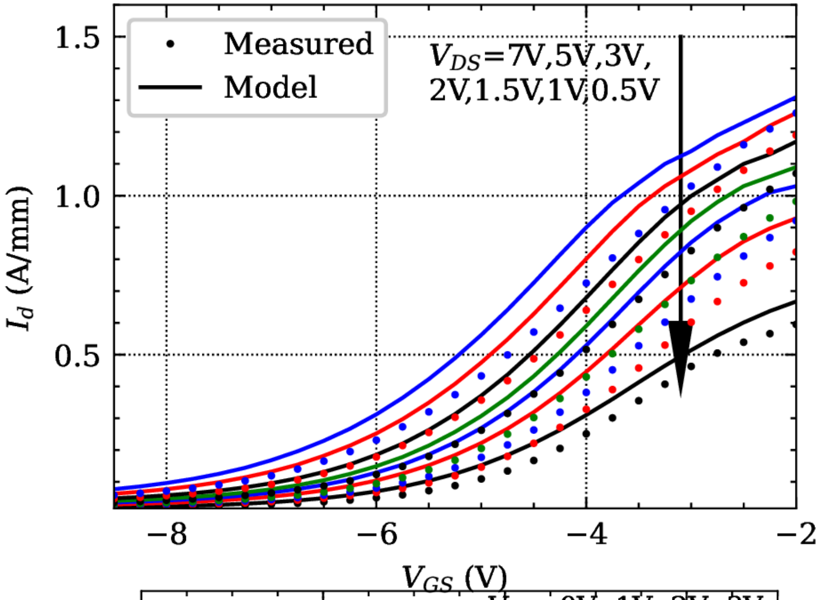


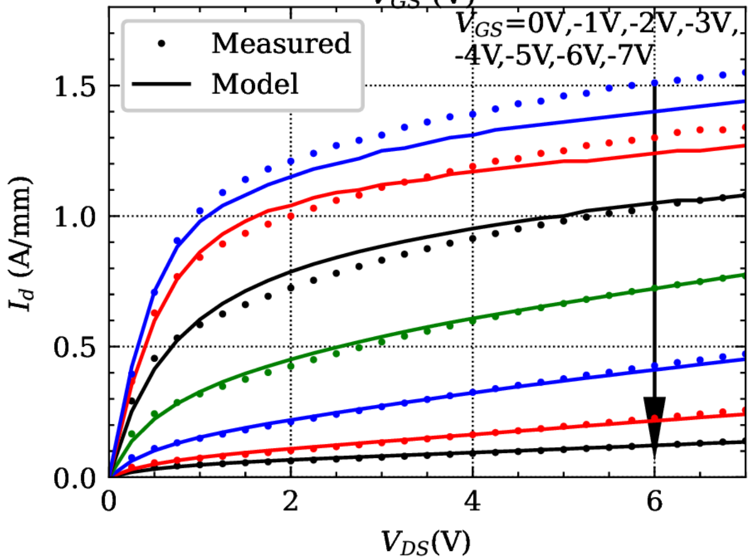


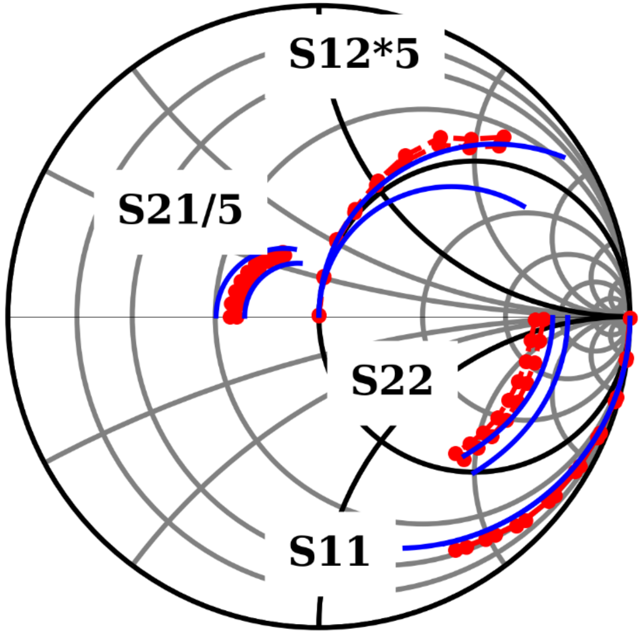
The dual-V_T model is created using the extracted models of the V_{T1} and V_{T2} devices. The intrinsic models are connected in parallel

Dual-V_T Model Results









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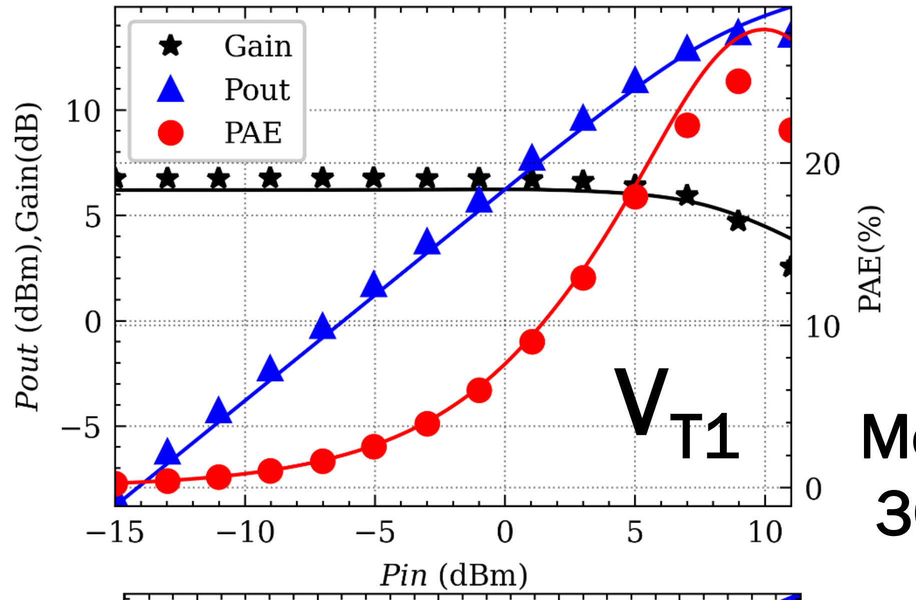
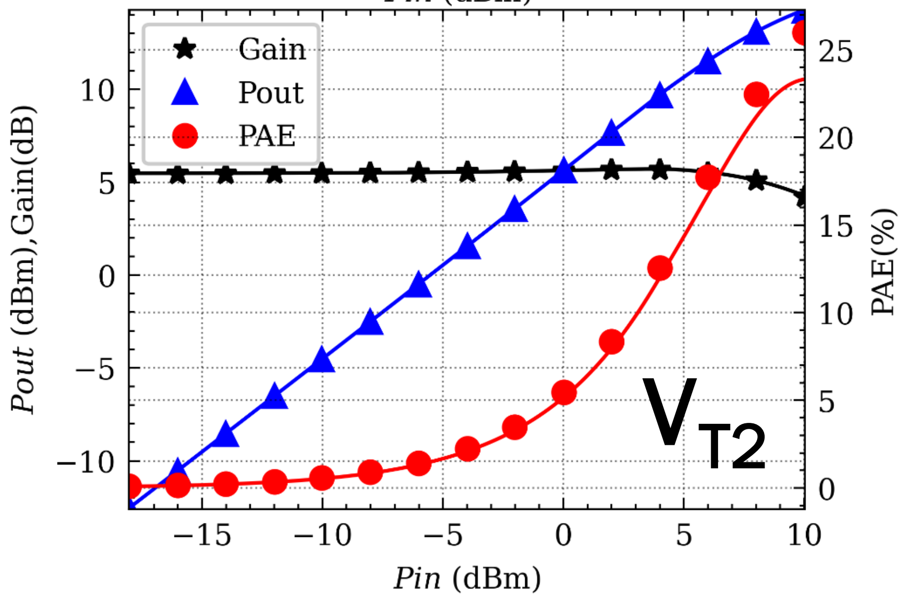
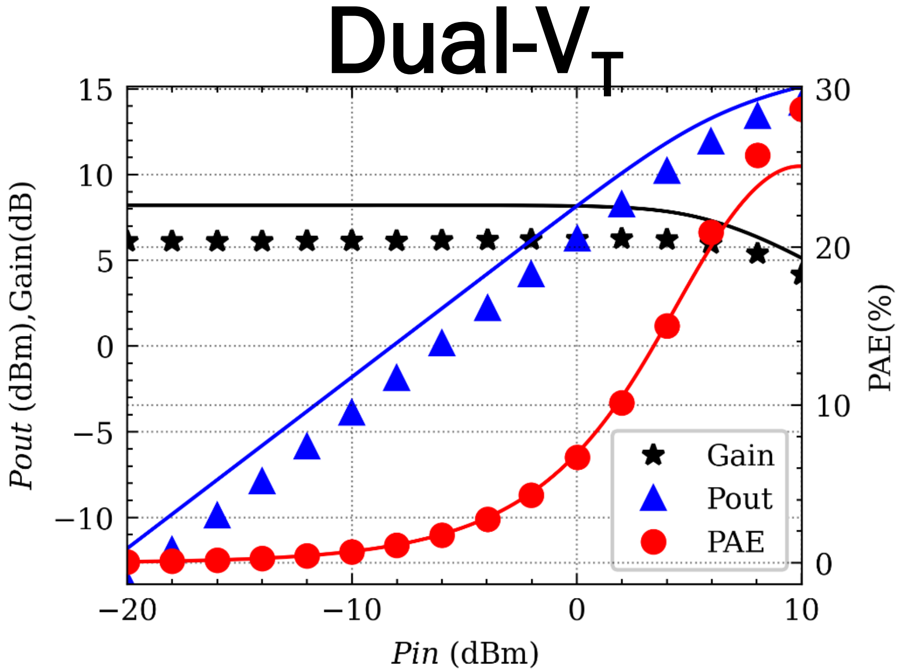
Large Signal Verification



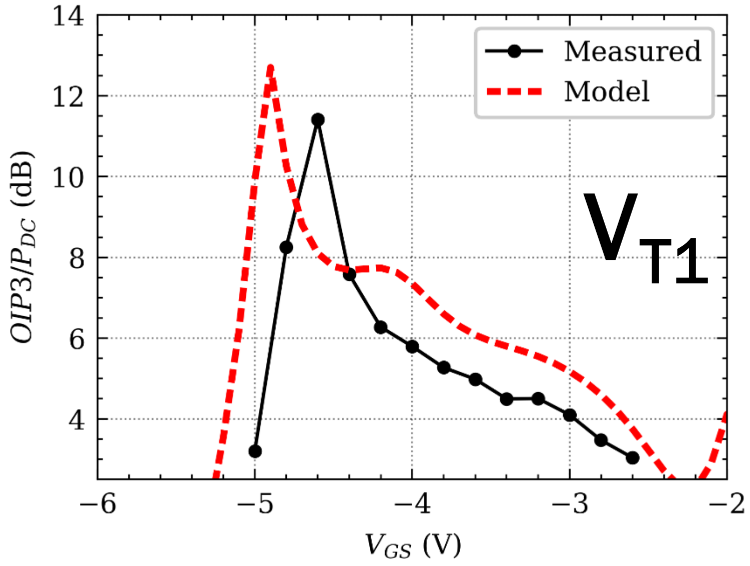


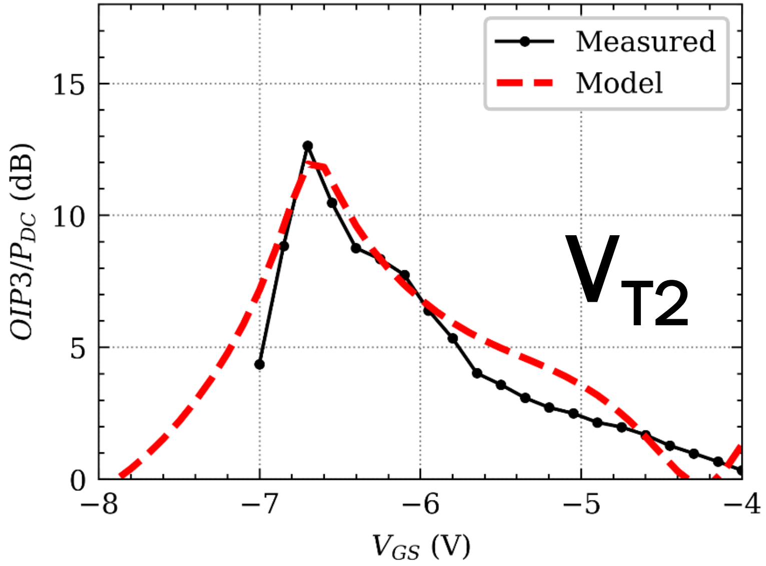
Measured at 30 GHz



Dual-V_T model predicts slightly higher gain and Pout compared to measurement

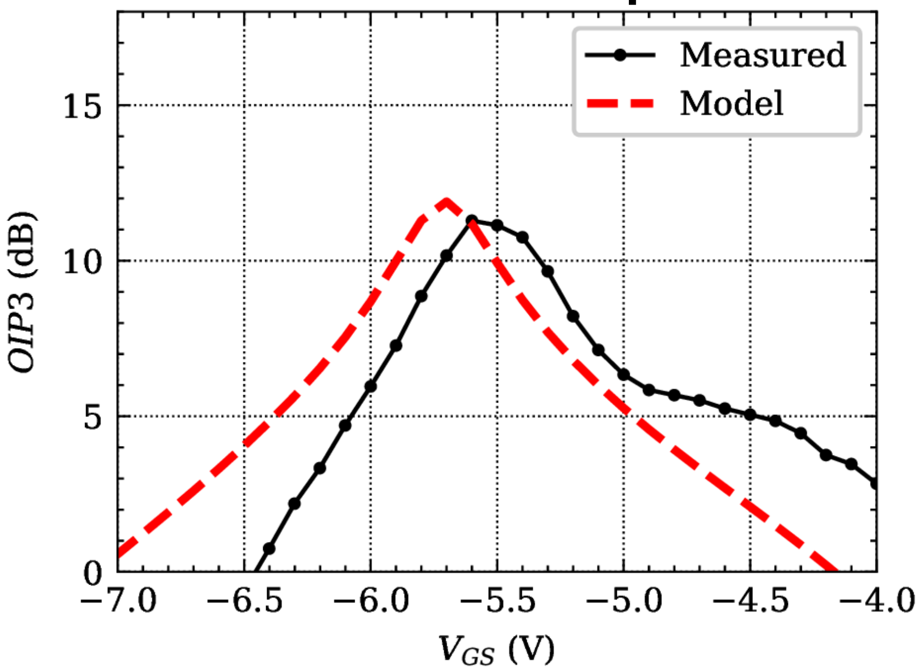
Intermodulation Distortion





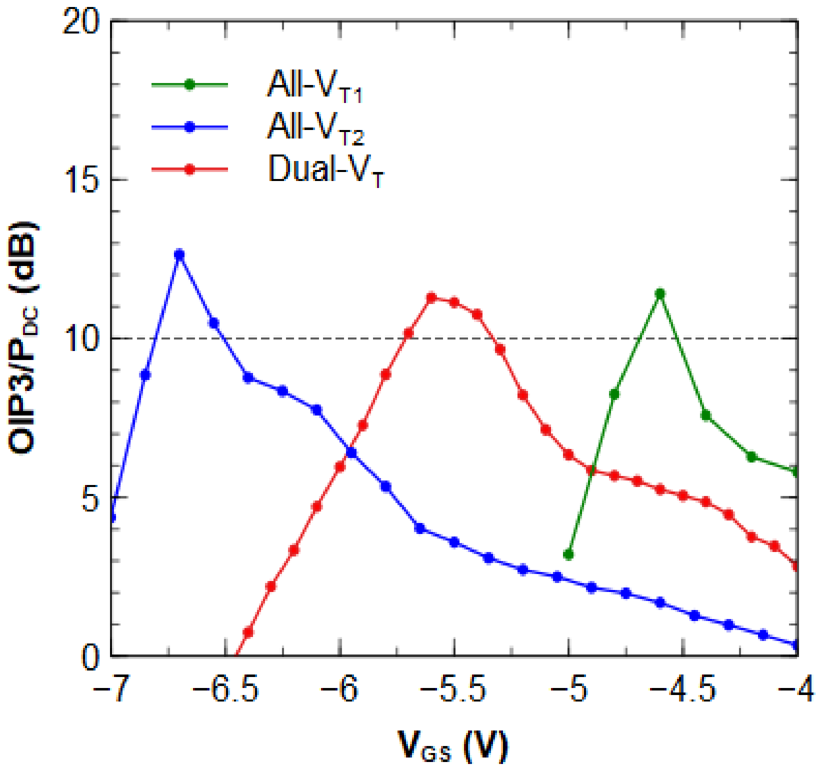
30 GHz measurement with tone spacing of 1 MHz

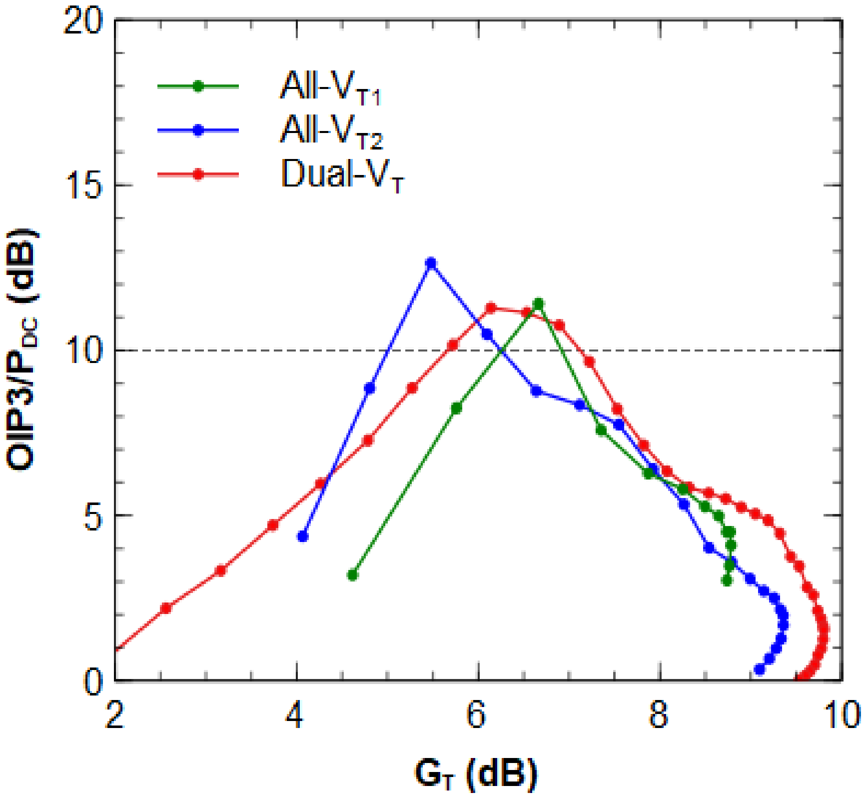
Dual-V_T



Discrepency in V_{T1} model is propagated to the Dual-V_T device

Improved sensitivity to bias





Dual-V_T device has higher range of gate bias with high OIP3/P_{DC} without degrading the gain.

Conclusion

References

[1]B. Romanczyk, S. Wienecke et al., “Demonstration of constant 8 W/mm power density at 10, 30, and 94 GHz in state-of-the-art millimeter-wave N-polar GaN MISHEMTs,” IEEE Transactions on Electron Devices, vol. 65, no. 1, pp. 45–50, jan 2018

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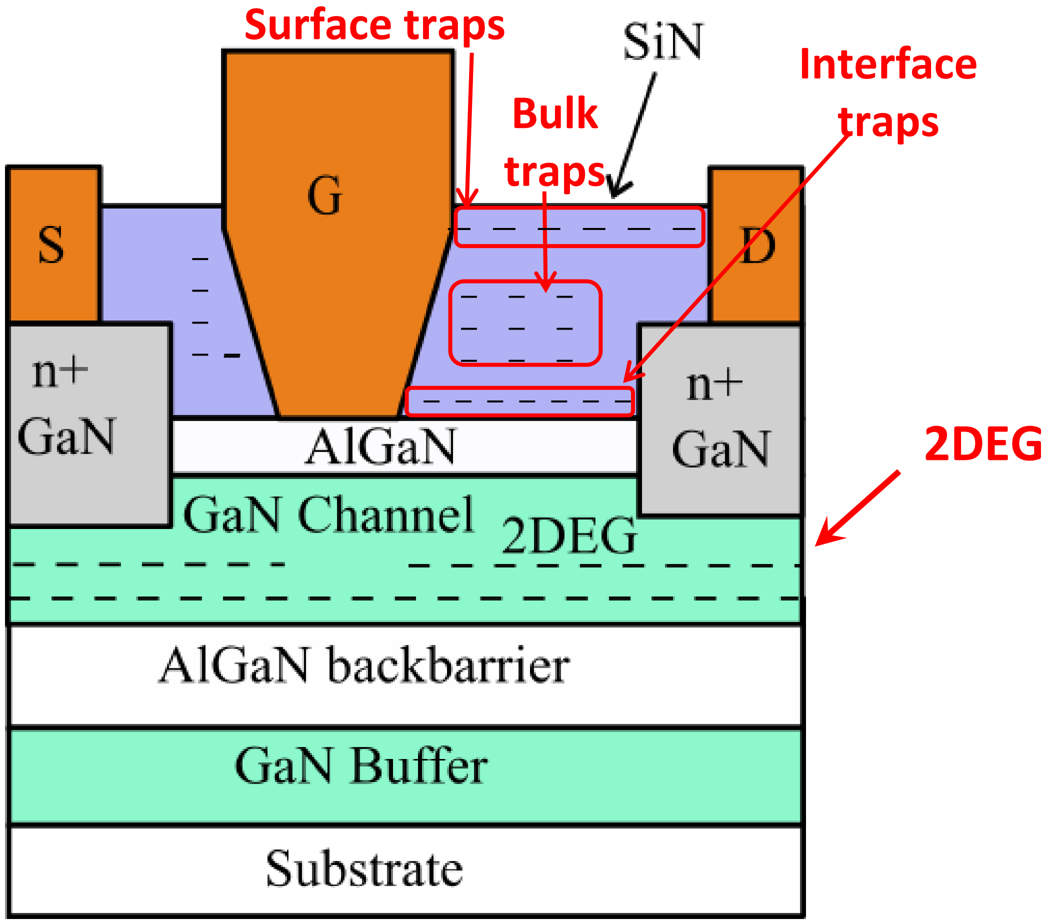
[3] R. R. Karnaty, P. Shrestha et al., “Compact Modeling of N-polar GaN HEMTs for Intermodulation Distortion in Millimeter-wave Bands,” IEEE Transactions on Microwave Theory and Techniques, 2023

Backup Slides

Deep Recess HEMT

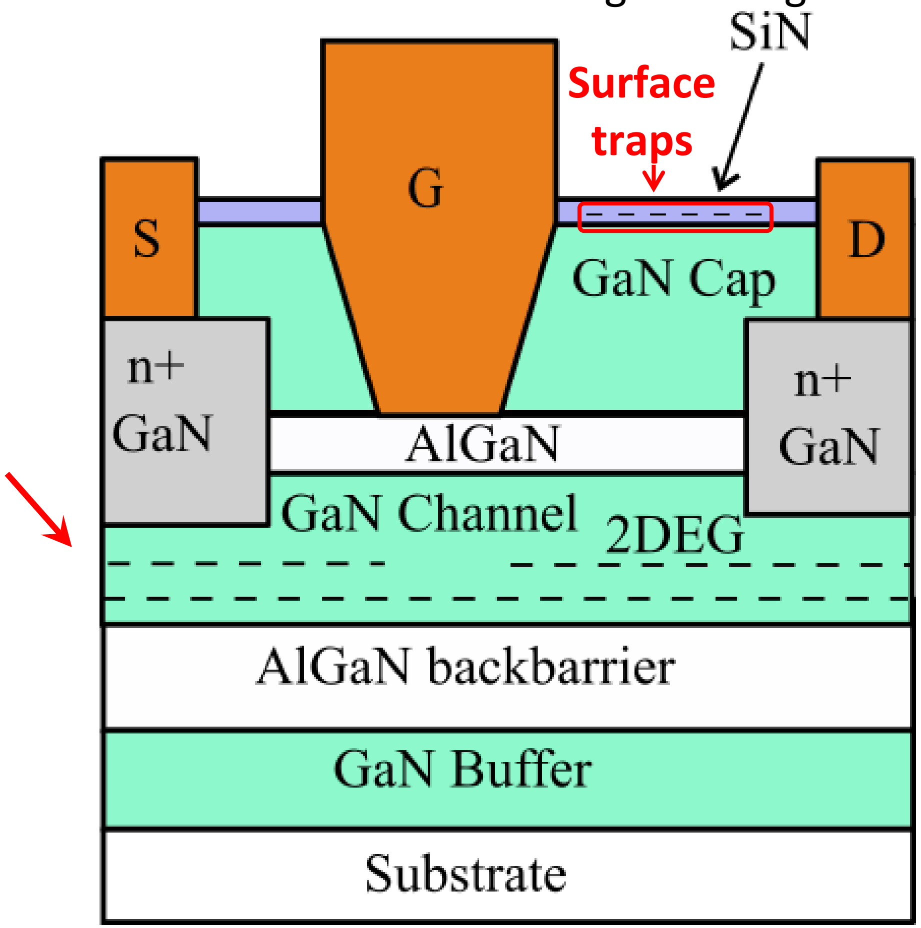
Traditional SiN Passivation

- More potential charge traps



GaN Cap with Deep Recess

- Interface/bulk traps removed
- Enhancement of access region charge and mobility



SEM of dual-V_T Device