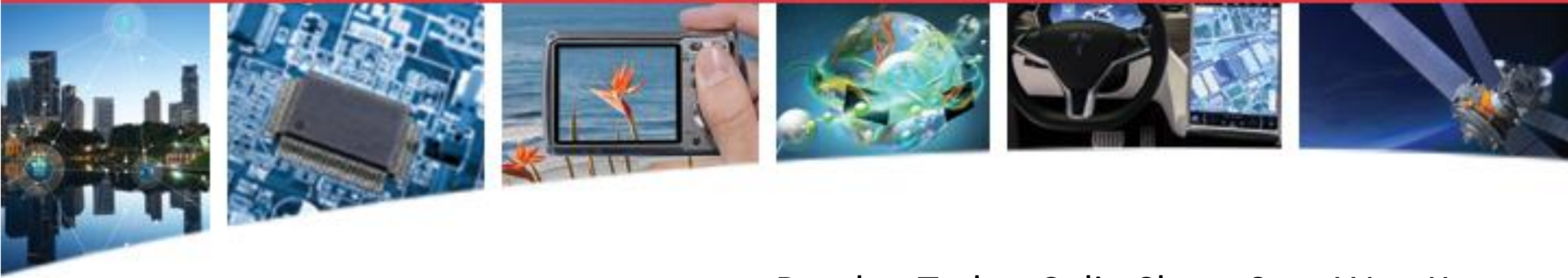
GaN HEMT Modeling



Bogdan Tudor, Colin Shaw, SungWon Kong

December 2018

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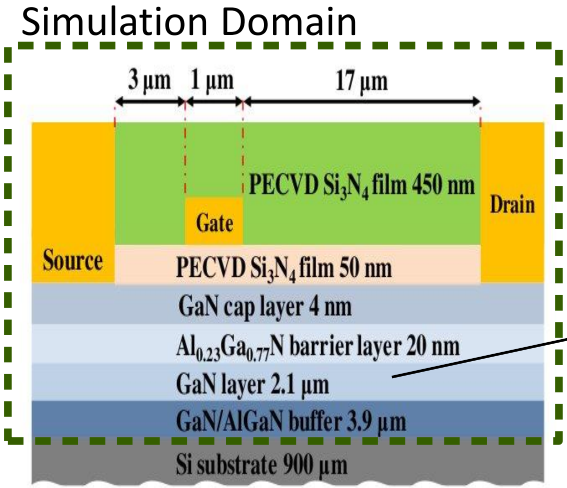
Agenda

- GaN HEMT TCAD Modeling
- Compact Modeling Standardization Effort
- GaN HEMT Model Extraction
- Conclusion

Example Structue of GaN MIS-HEMT



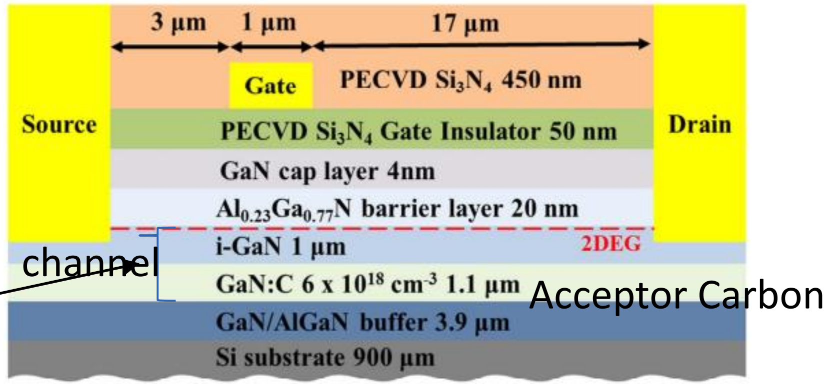


Figure 1. Schematic cross section of the fabricated MIS-HEMT device.

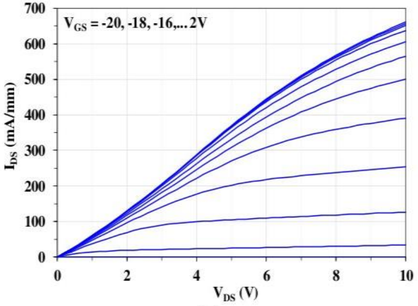
Ref:

1. Evaluation and Reliability Assessment of GaN-on-Si MIS-HEMT for power switching applications, Energies 2017, 10, 233, www.mdpi.com/journal/energies
2. Comprehensive dynamic on-resistance assessments in GaN-on-Si MIS-HEMTs for power switching applications, Semicon. Sci. Technol. 33(2018) 055012

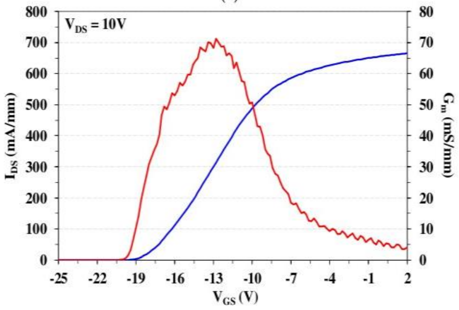
Simulation Results: Calibration of Polarization Charge




Measure

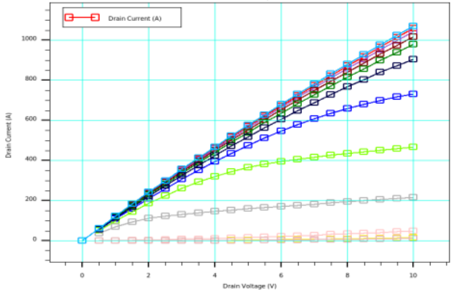


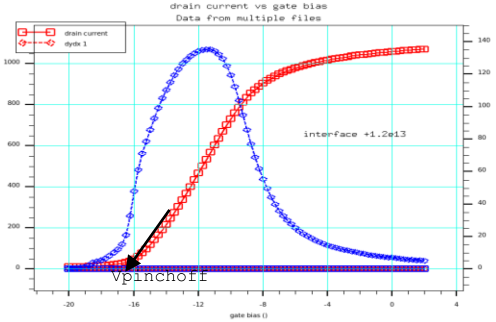
(a)



(b)

TCAD Simulation



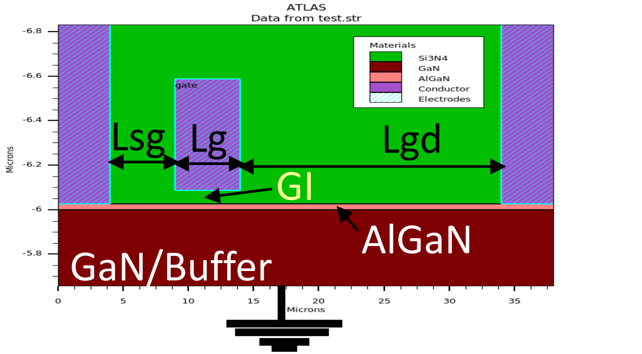


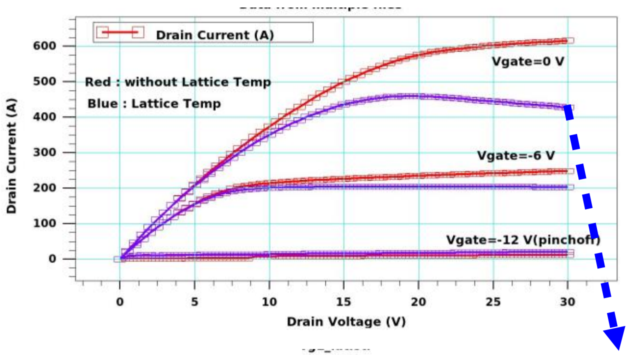
Ref: Evaluation and Reliability Assessment of GaN-on-Si MIS-HEMT for power switching applications, Energies 2017, 10, 233, www.mdpi.com/journal/energies

TCAD Device Simulation Models

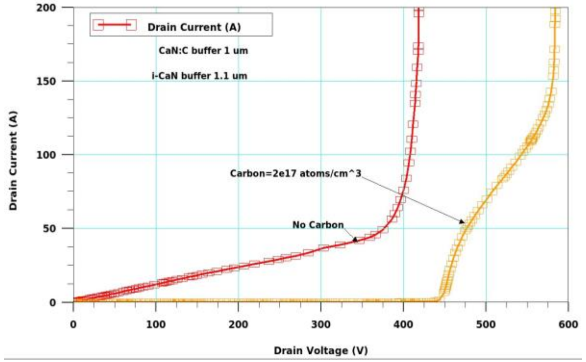
- Carrier Transport : Drift-Diffusion
- GaN wurtzite crystal low field and high field mobility model
- strain calculation by composition of AlN/GaN/InN
- Polarization(piezo + spontaneous) : User can directly define 2DEG charge at AlGaN/GaN interface as well as other interface
- Impact ionization for breakdown
- GaN acceptor/donor trap
- Leakage current model through dislocation or other traps
- Lattice temperature model

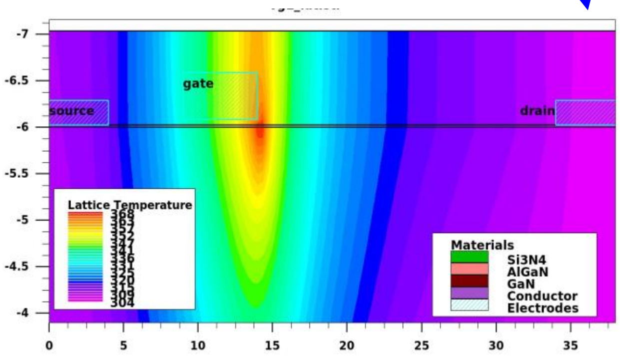
Simulation of Test GaN MIS-HEMT





Rth : thermal contact (cm2K/W)

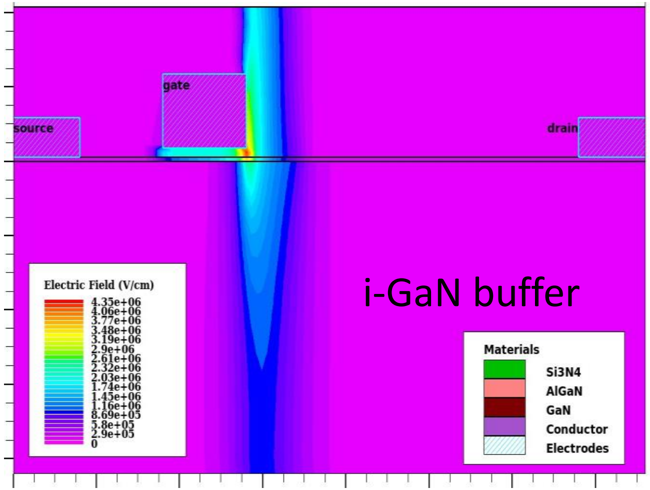




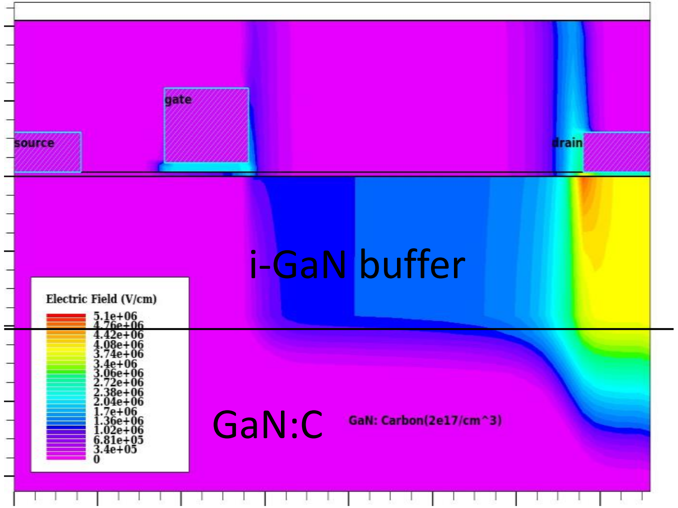
Simulation of Test GaN MIS-HEMT(con't)

Electric Field@Breakdown

No Carbon in i-GaN buffer

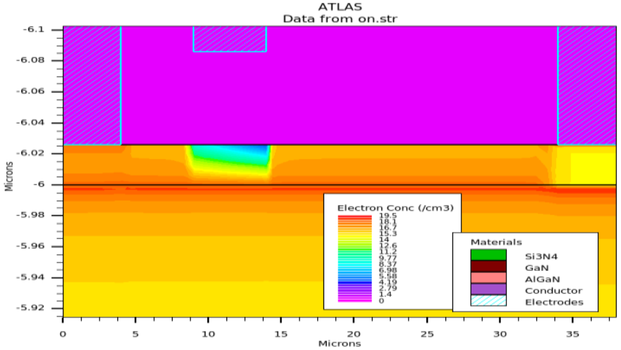


Carbon doped GaN

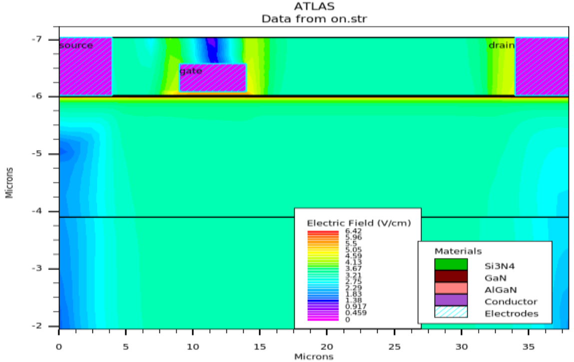


Electrical Quantities@ Vgs=0V and Vds=10V

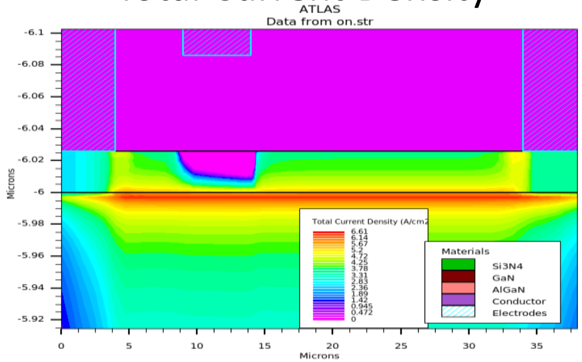
Electron Concentration



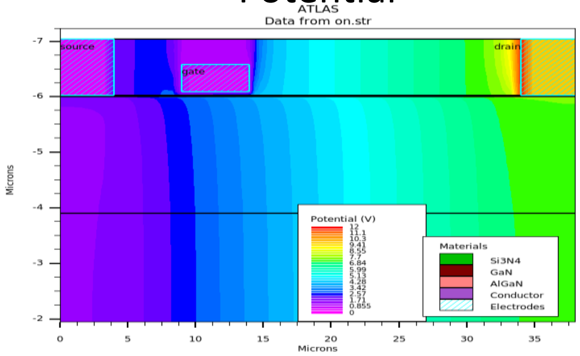
Electric Field



Total Current Density



Potential



Agenda

- GaN HEMT Process and Device: TCAD Overview
- Compact Modeling Standardization Effort
- GaN HEMT Model Extraction
- Conclusion

Standard Device Models - CMC

- Silvaco is fully involved with Implementing and upholding Standard device models as verified by the Compact Modelling Coalition (CMC).
- These are the core building blocks of any circuit simulation

- Silvaco chairs 3 standardization CMC working groups

OMI	–	Open Model Interface
ASM GaN HEMT	–	Power and RF GaN model
MVSG GaN HEMT	–	Power and RF GaN model

ASM GaN HEMT

- Model Release:

  Version 101.0.0 – 16- March - 2018

- Current status:

  Version 101.1.0 – Beta 1 - 07-Sep.-2018
  Version 101.1.0 – Beta 2 - 27-Nov.-2018

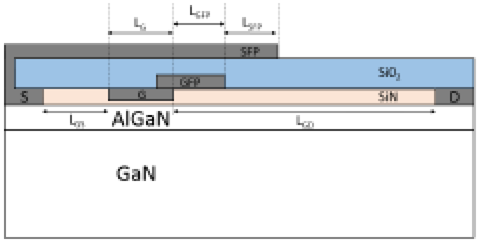
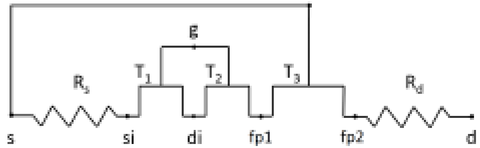


Figure 5: Cross-sectional view of the dual FP device showing the gate and source FPs and their appropriate connections to gate and source respectively.



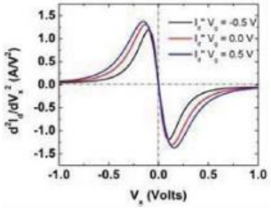


Figure 10: 2nd derivative of I_d vs V_x

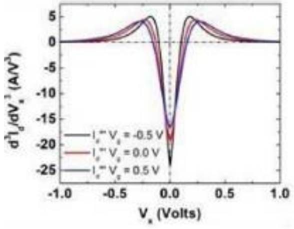


Figure 11: 3rd derivative of I_d vs V_x

MVSG GaN HEMT

- Model Release:

  Version 1.0.0 – 01- April - 2018
  Version 1.1.0 – 01- Sept. - 2018

- Current status:

  Version 1.2.0 – Beta 2 - 27-Nov.-2018

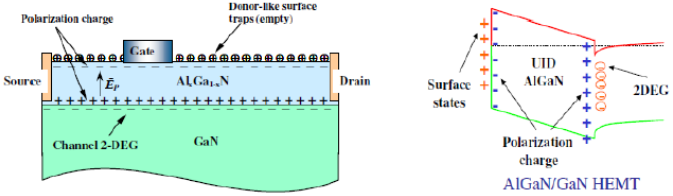


Fig.3: (a) Device structure schematic. (b) Band diagram of heterostructure showing different types of charges

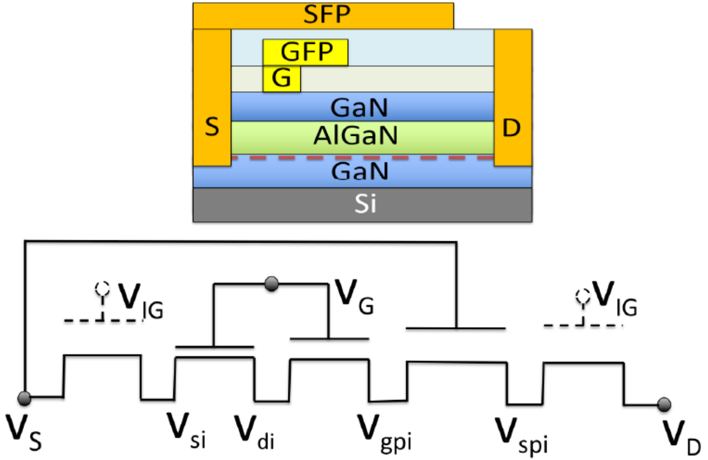


Figure 4. (a) Cross-sectional schematic of GaN HEMTs on Si. (b) The equivalent circuit for the model with intrinsic transistor, gate-field-plate, source-field-plate and implicit-gate access region transistors is shown.

Agenda

- GaN HEMT Process and Device: TCAD Overview
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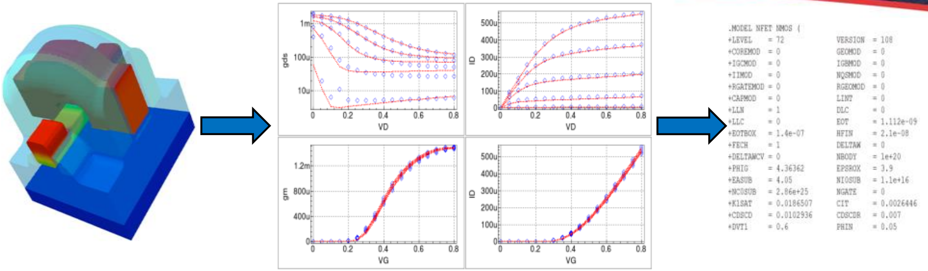
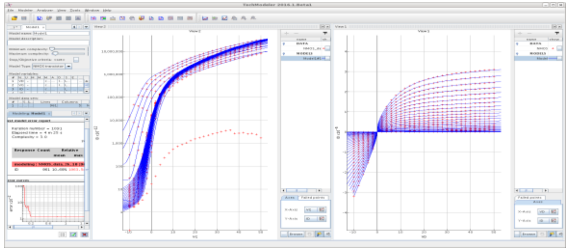
SPICE Modeling Solutions

- UTMOST IV
  - Extract and validate SPICE parametric models
  - Data from measurement equipment or TCAD simulations
  - Verilog-A and macromodel support



- TechModeler
  - Creates models using approximation functions
  - Modeling solution for novel devices: OTFT, OLED, Power devices



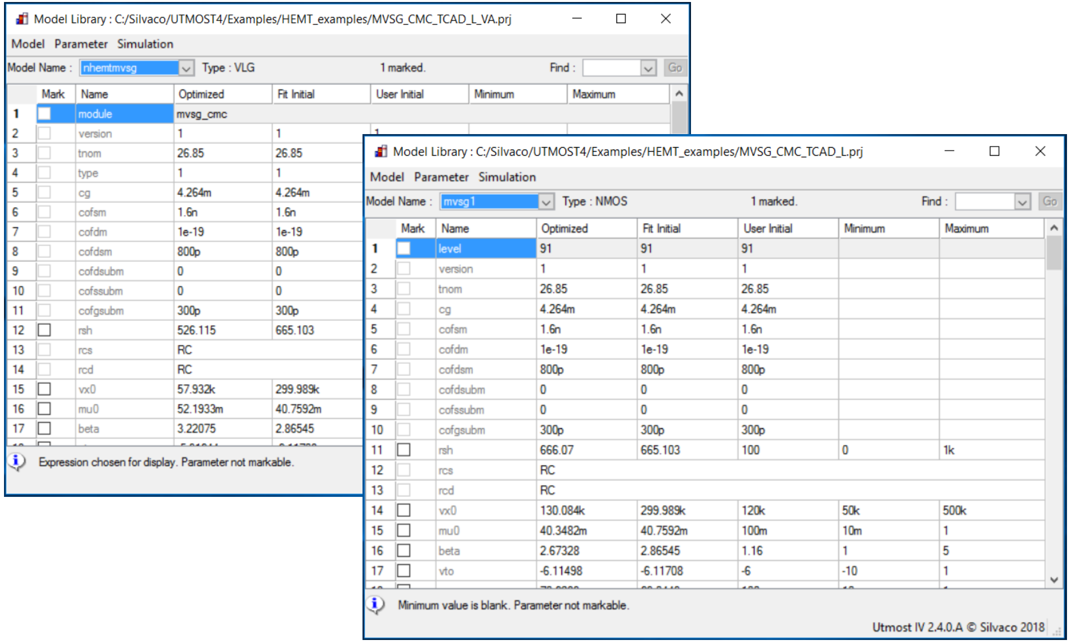
- Modeling Services

GaN HEMT Compact Models

- Two standard GaN HEMT models:
  - ASM-HEMT (SmartSpice Level 90)
  - MVSG-HV (SmartSpice Level 91)
- Model extraction flow initially based on Verilog-A, currently using built-in models

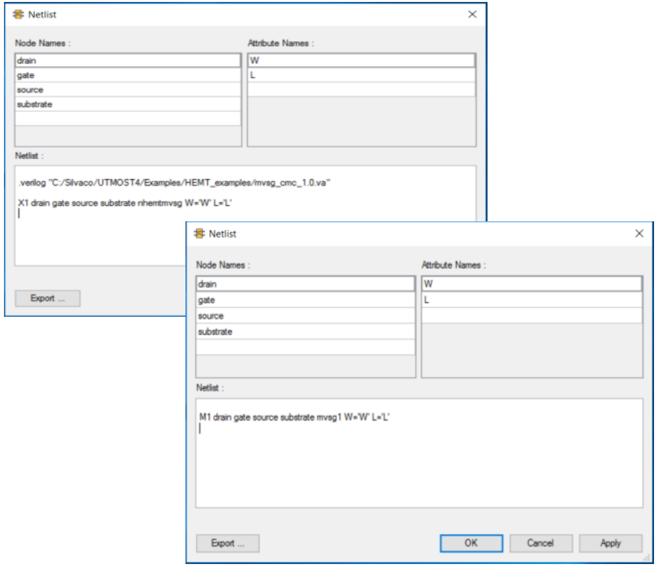
GaN HEMT: Verilog-A vs. Built-In Models

- MVSG model card and netlist: Verilog-A vs. built-in model



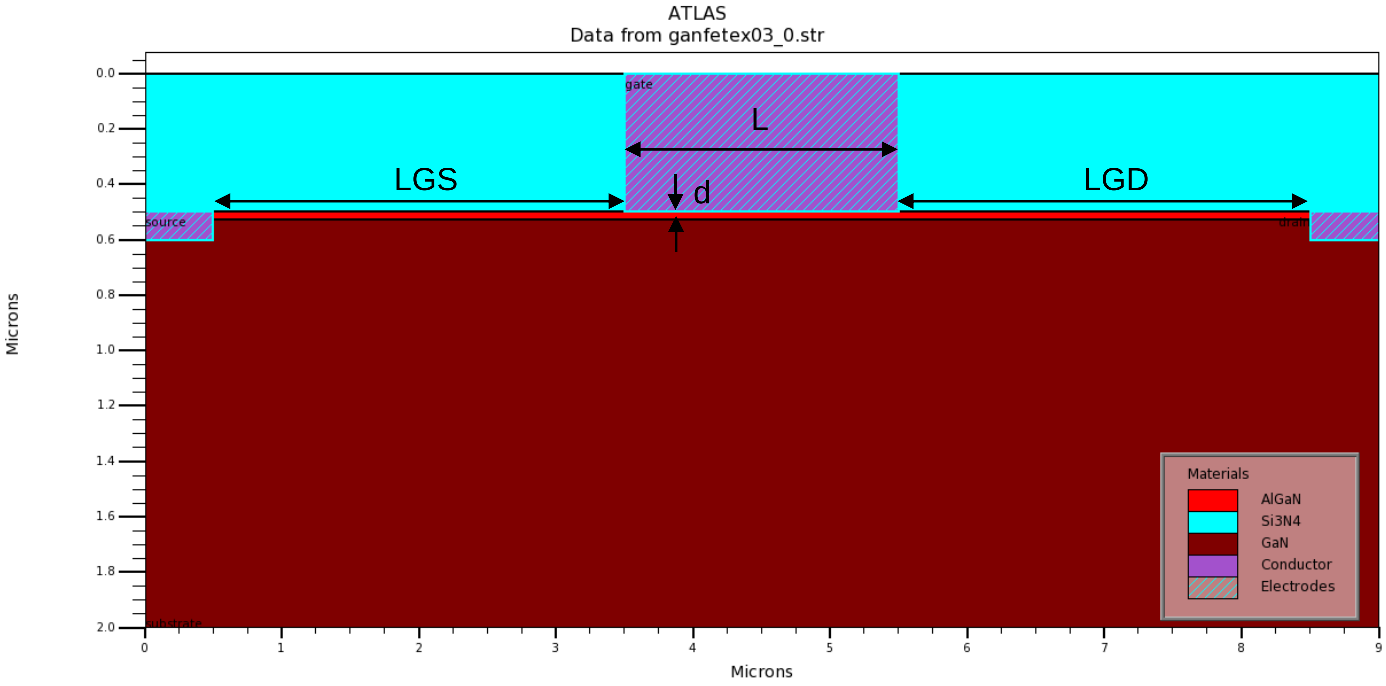
	Mark	Name	Optimized	Fit Initial	User Initial	Minimum	Maximum
1		module	mvsg_cmc				
2		version	1	1	1		
3		tnom	26.85	26.85			
4		type	1	1			
5		cg	4.264m	4.264m			
6		cofsm	1.6n	1.6n			
7		cofdm	1e-19	1e-19			
8		cofdsm	800p	800p			
9		cofdsubm	0	0			
10		cofssubm	0	0			
11		cofgsubm	300p	300p			
12		rsh	526.115	665.103			
13		rcs	RC				
14		rcd	RC				
15		vx0	57.932k	299.989k			
16		mu0	52.1933m	40.7592m			
17		beta	3.22075	2.86545			

	Mark	Name	Optimized	Fit Initial	User Initial	Minimum	Maximum
1		level	91	91	91		
2		version	1	1	1		
3		tnom	26.85	26.85	26.85		
4		cg	4.264m	4.264m	4.264m		
5		cofsm	1.6n	1.6n	1.6n		
6		cofdm	1e-19	1e-19	1e-19		
7		cofdsm	800p	800p	800p		
8		cofdsubm	0	0	0		
9		cofssubm	0	0	0		
10		cofgsubm	300p	300p	300p		
11		rsh	666.07	665.103	100	0	1k
12		rcs	RC				
13		rcd	RC				
14		vx0	130.084k	299.989k	120k	50k	500k
15		mu0	40.3482m	40.7592m	100m	10m	1
16		beta	2.67328	2.86545	1.16	1	5
17		vto	-6.11498	-6.11708	-6	-10	1



UTMOST IV Modeling Example 1: Symmetric GaN HEMT

- Using Atlas example “ganfetex03”.



Preliminary Model Parameters

- Device gate length: L = 2μm
- Source and drain side access region distances
  - (ASM) LDG = LSG = 3μm
  - (MVSG) LGS = LGD = 3μm
- Depth of AlGaN layer
  - (ASM) TBAR = d = 25nm
  - (MVSG) model: CG = ε_{AlGaN}/d = 0.004264 F
- Nominal room temperature: TNOM = 26.85 ^{o}C (default room temperature in Atlas)

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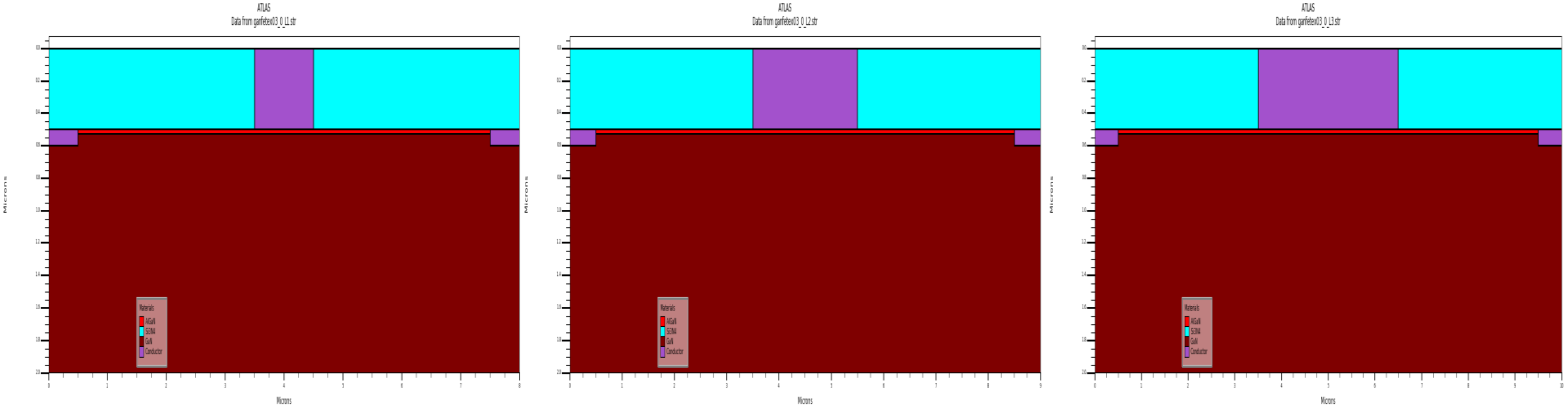
Geometry Scaling

- 3 device structures: L = 1μm, 2μm and 3μm, respectively.



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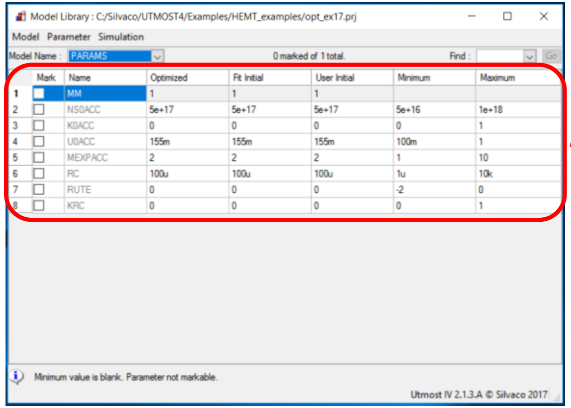
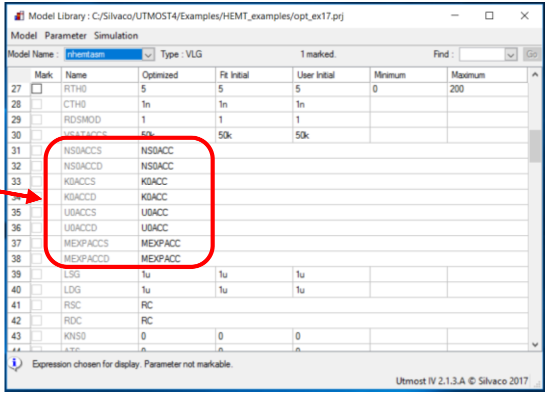
Model Parameters of Symmetric Devices: ASM

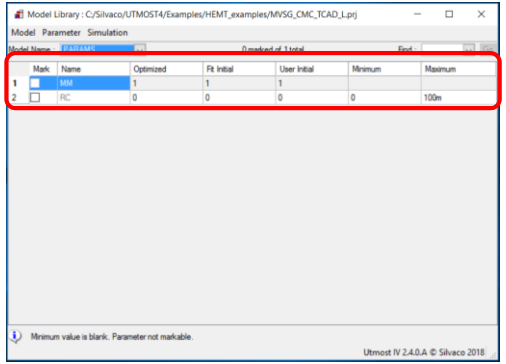
- Common set of model parameters for the source and drain regions.

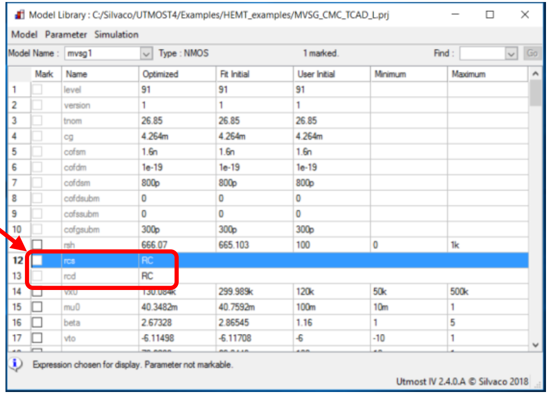




Model Parameters of Symmetric Devices: MVSG

- Common set of model parameters for the source and drain regions.





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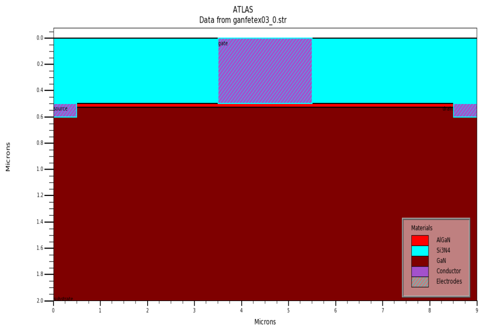
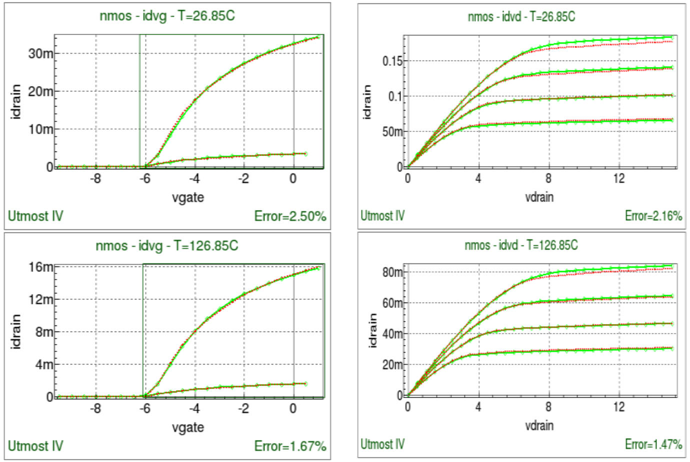
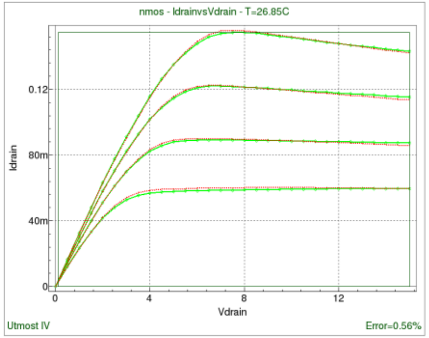
TCAD-based Parameter Extraction: Unique Advantages

- TCAD device simulation allows generating I-V characteristics with and without self-heating enabled
- This allows extracting temperature effect parameters in the absence of self-heating
- Then R_{th} is extracted based on self-heating data: the resulting model is physically-based and accurate







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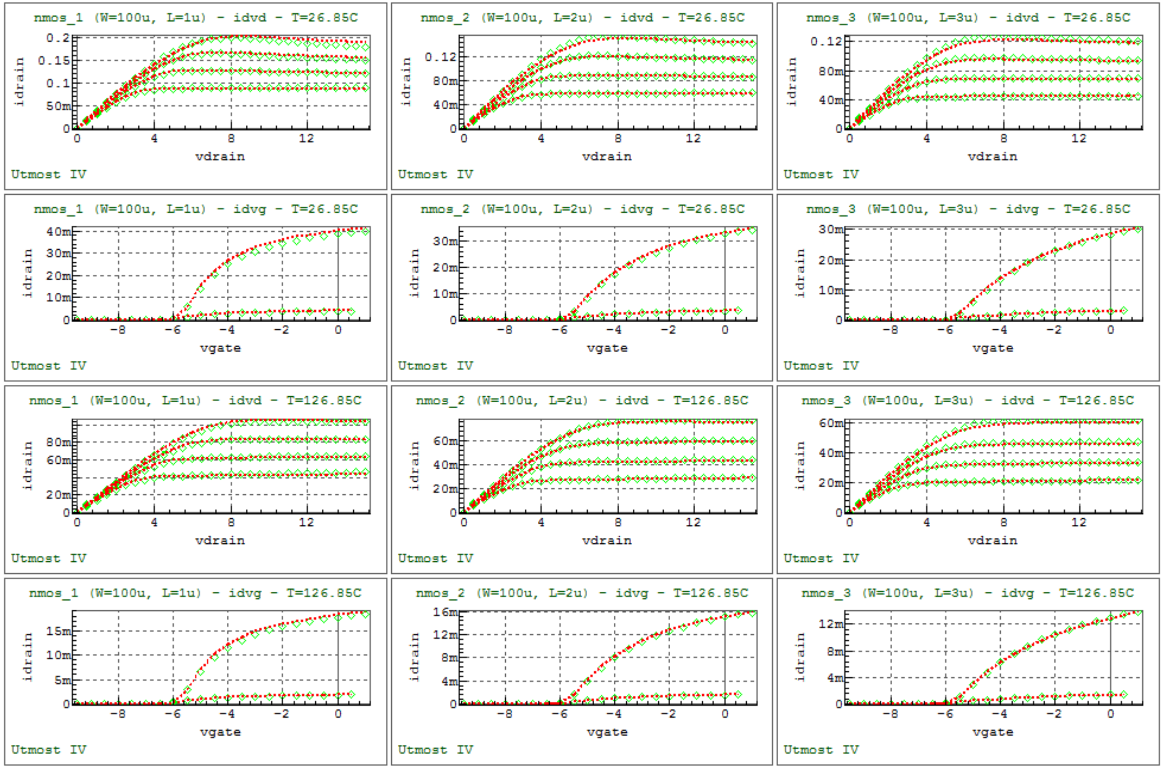
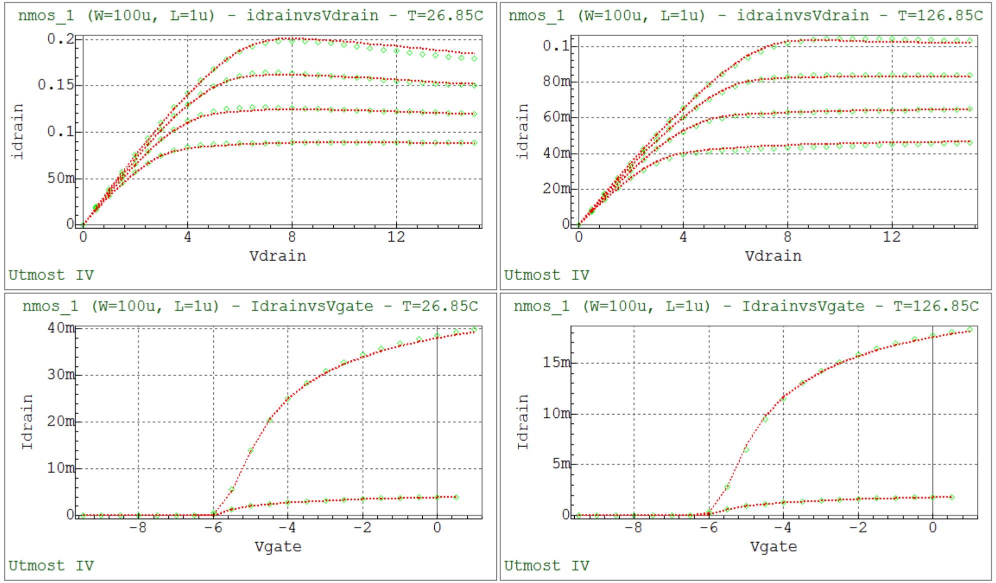
Symmetric HEMT: Extraction Results

- MVSG Model
  - Green lines: TCAD simulated data
  - Red lines: SPICE simulations

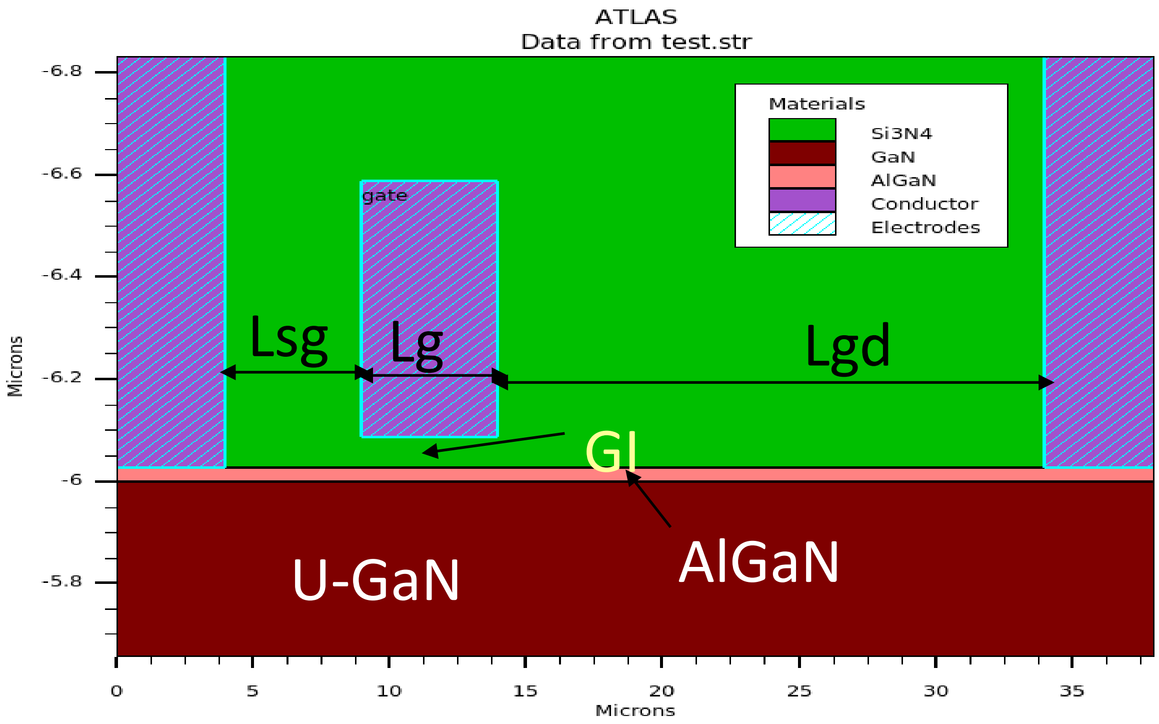


Symmetric HEMT: Extraction Results

- ASM Model (single device)
  - Green lines: TCAD simulated data
  - Red lines: SPICE simulations

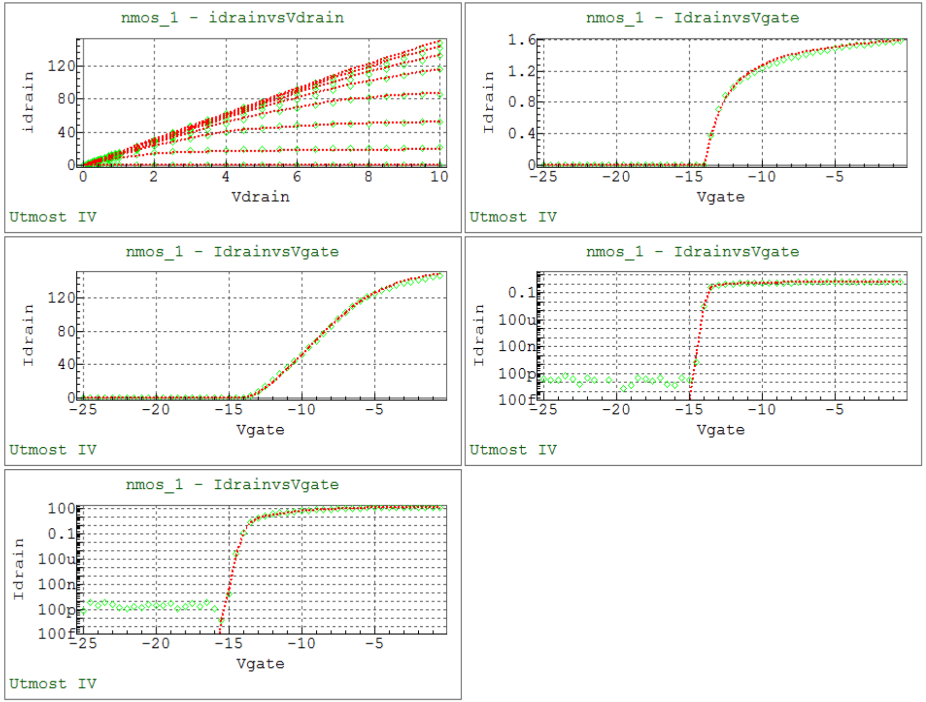


UTMOST IV Modeling Example 2: Asymmetric GaN HEMT



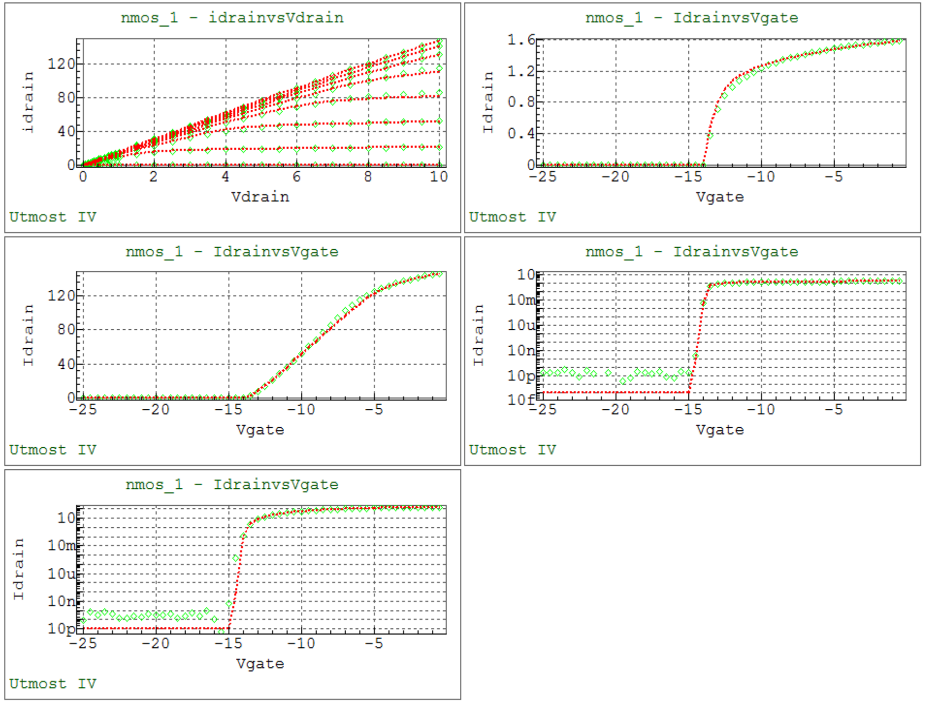
Asymmetric HEMT: Extraction Results

- MVSG Model
  - Green lines: TCAD simulated data
  - Red lines: SPICE simulations



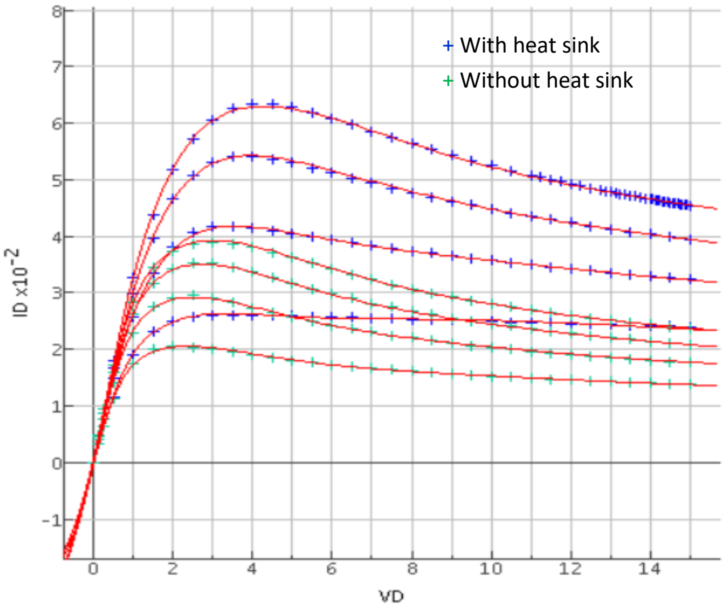
Asymmetric HEMT: Extraction Results

- ASM Model
  - Green lines: TCAD simulated data
  - Red lines: SPICE simulations



TechModeler SPICE Modeling: GaN HEMT With Heat Sink

- GaN HEMT device model created with TechModeler, including self-heating
- TechModeler can consider any design variables: this model takes into account the presence of a heat sink and its effect on heat dissipation



Conclusion

- Overview of GaN HEMT Process and Device Simulation
- Compact Modeling Standardization Effort: two standard models (ASM, MVSG)
- GaN HEMT Model Extraction for Symmetric and Asymmetric Devices
- The MVSG model has a good geometry scalability in fitting devices with different gate lengths
- TCAD simulations provides a unique approach to separate the extraction of temperature dependence and self-heating parameters
- This allows us to extract physically-based and accurate models

Thank you!