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Silvaco TCAD

Leader in Power Device Technology Development

Silvaco TCAD for GaN Technology

Process Simulation
Device Simulation
Examples

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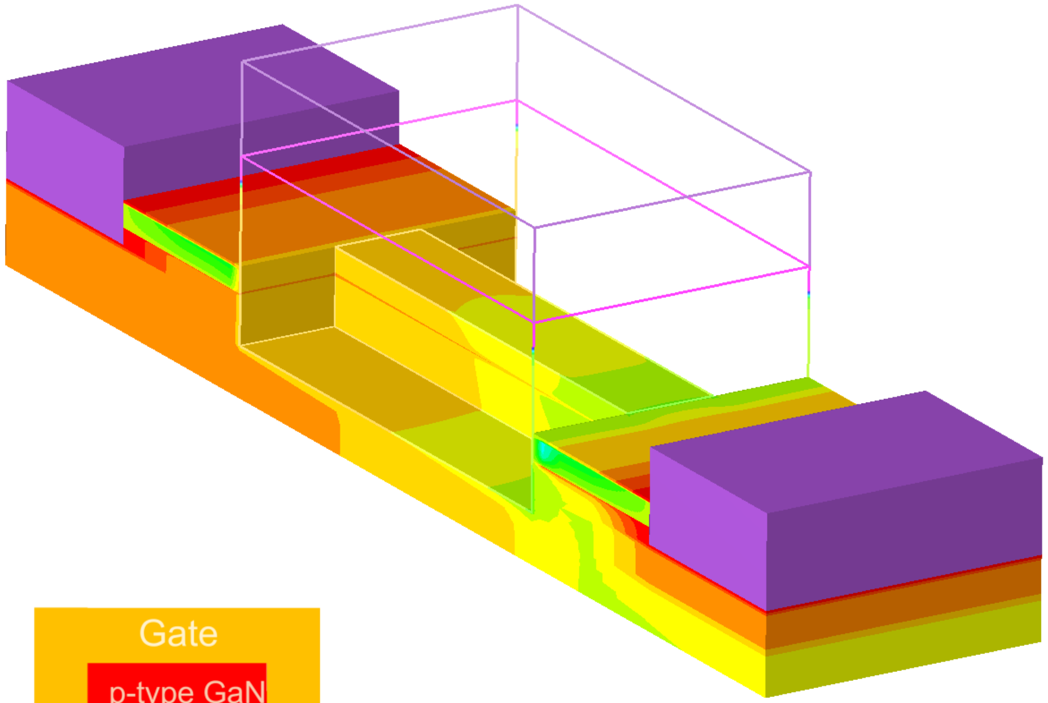
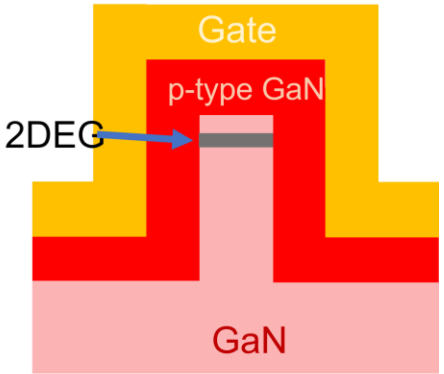
Victory Process GaN Simulation Overview

Virtualize your process flow to optimize and understand how the next generation power devices should be fabricated

- **Full 2D/3D TCAD Process Solution**
  - Build, debug, calibrate in fast 2D
  - Easy transition to realistic 3D for full 3D technology design
  - Seamless integration into Device Simulation
- **Process simulation for GaN**
  - Etch & Deposition
  - Stress
  - Implantation
  - Dopant Activation
  - Open Model Library and Material database
    - Allows for user customizability





GaN Tri-Gate Structure

Etch and Deposition for Next Generation Devices

Capturing material geometry faithfully ensures TCAD simulation matches the fab

- **GDSII driven TCAD,** connecting fab to TCAD
  - Import layout to use as masks for any process step

- **Simple geometric models** for fast simulating etch & deposition steps
  - Define etch/deposition thicknesses and a geometric model

- **Detailed physical models** for deeper understanding of your process steps
  - Define deposition/etch rates for each material
  - Sticking factors, flux parameters
  - Useful for understand visibility effects

Accurately Predict Stress Distribution in Process

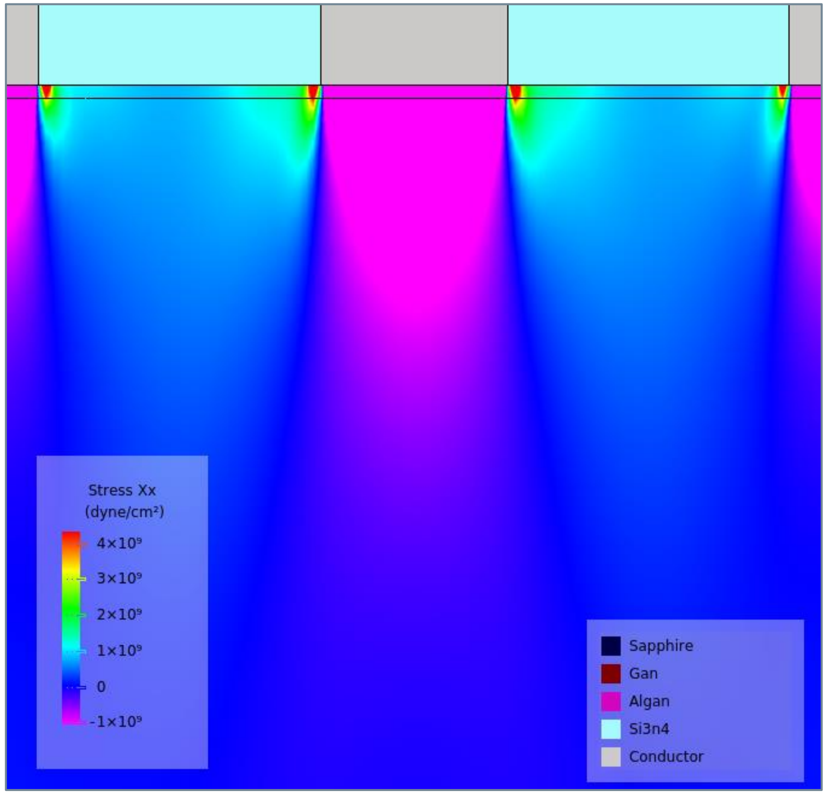
Victory Process provides capabilities covering stress simulation

Stress analysis of arbitrary 2D/3D device structure

- Stress simulation for various crystalline and isotropic materials
- Generic 3D anisotropic stress simulation
- Estimation of mobility enhancement factors by use of piezoresistivity model devices

Models for various sources of strain and stress

- Thermal mismatch between material layers
- Local lattice mismatch due to doping
- Initial deposit stress in specified regions
- External (hydro-static) stress from capping layers
- Stress/strain generated in previous processing step



Compressive Stress from Nitride Layer in GaN HEMT Device

Understand Implantation Details

Future GaN Devices will incorporate doping in new ways. Accurate implantation modeling will be required

- **Monte Carlo Implantation**
  - User-Definable Implant Properties
    - Substrate type/orientation, angle, dose and energy
  - Well calibrated stopping within crystal channels and random direction
    - Crystal Damage & Scattering due to damage accumulation

- **Empirical Methods to define doping in process**
  - Doping profiles by analytical distribution function
    - Quickly add Gaussian doping
  - Doping profiles defined by external data files
    - Use SIMS profiles to build your TCAD process

Victory Device for GaN Power Devices

Victory Device covers the breadth and depth of GaN device simulation needs

Simulate DC, AC and transient electrical simulation

- Understand how your device performs in any scenario

Self-Heating Simulation

- Gain insight into self-heating effects that influences electrical physics

Reliability and Radiation

- Simulate device degradation due to electrical stress, as well as radiation effects (TID, DD, SEB)

MixedMode circuit/device simulation

- Simulate TCAD devices within a SPICE circuit

User-customizable physical models & material parameters

- Calibrate any simulated device to your experimental data
- Novel wide bandgap materials can be simulated by adjusting the physical parameters

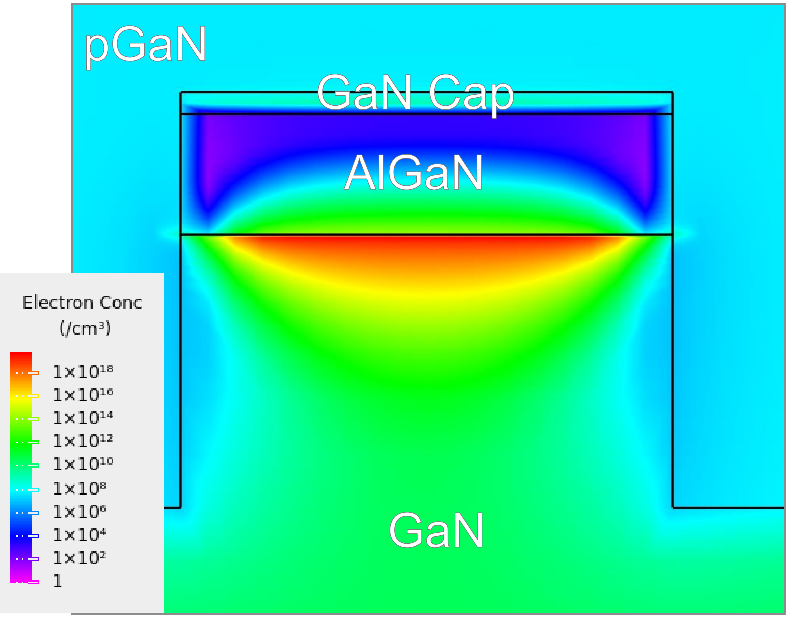
Advance numerical solvers and methods

- Multithreaded simulations and numerical extended precision available for the more difficult simulations

Calculate Essential Interface Charges

Heterojunction interfaces make GaN technology possible

- **Spontaneous and Piezo-Electric Polarization**
  - Victory Device can automatically calculate the Spontaneous and Piezo-Electric Polarization Interface Charges
    - Quickly generate and understand the 2DEG in your device
- **Composition Dependent Physical Models**
  - All models are composition dependent for AlGaN and other ternary and quaternary material sets
    - Band gap, Electron Affinity, Permittivity, Density of State Masses, Recombination, Heat capacity, Refractive Index
    - Analyze how composition may affect performance

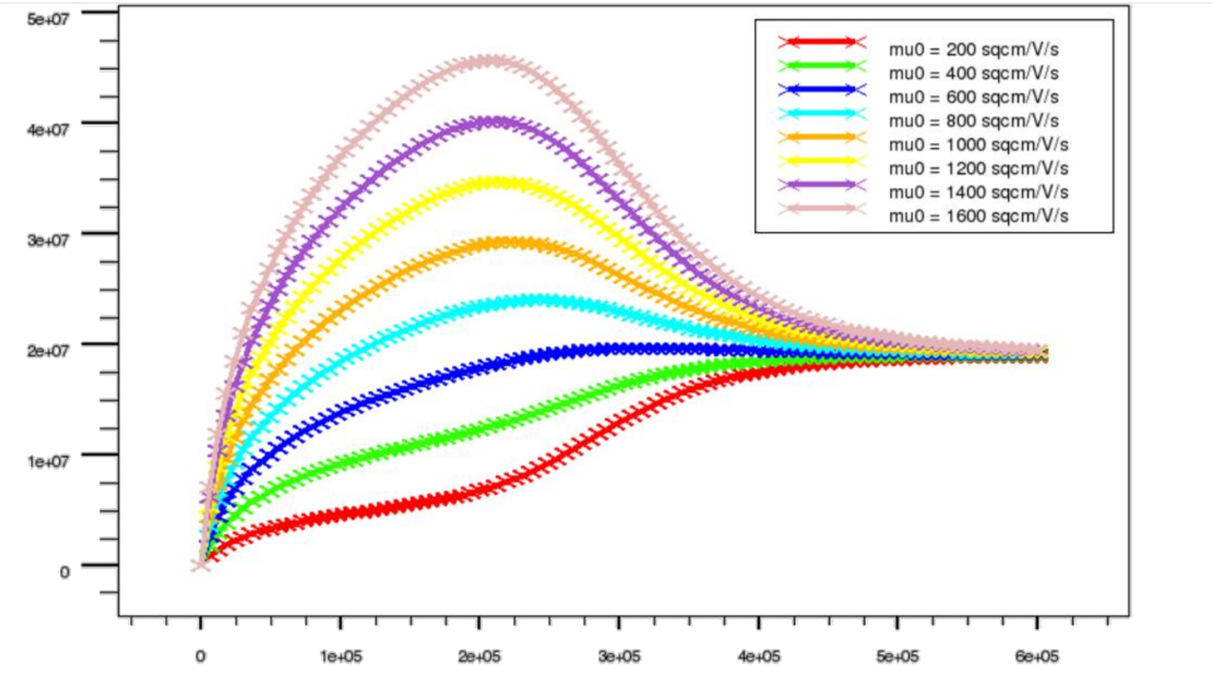


2DEG formed inside Tri-Gate GaN HEMT Device

Accurately Model Mobility in GaN

Using the correct mobility models are essential for simulating your device properly.

- **High Field and Low Field Models for Mobility**
  - GaN Specific Mobility Models for Low Field and High Field
  - **Low Field: Albrecht & Farahmand**
    - Albrecht Model consist of 3 components that can be calibrated to fit your device
    - Farahmand Model is a Caughey-Thomas like model Calibrated for Nitride material sets
  - **High Field: GaNSat**
    - Simulate high-field effects such as negative differential mobility with respect to the electric field



Vital Physical Models for GaN Power Devices

Victory Device can simulate all the important effects needed to fully simulate GaN power device

Incomplete Ionization of Impurities

- Can directly or indirect effect mobility and other physical properties in device

Bulk and Interface State Models

- Correctly model the defects in GaN that can degrades performance and can affect DC/transient response

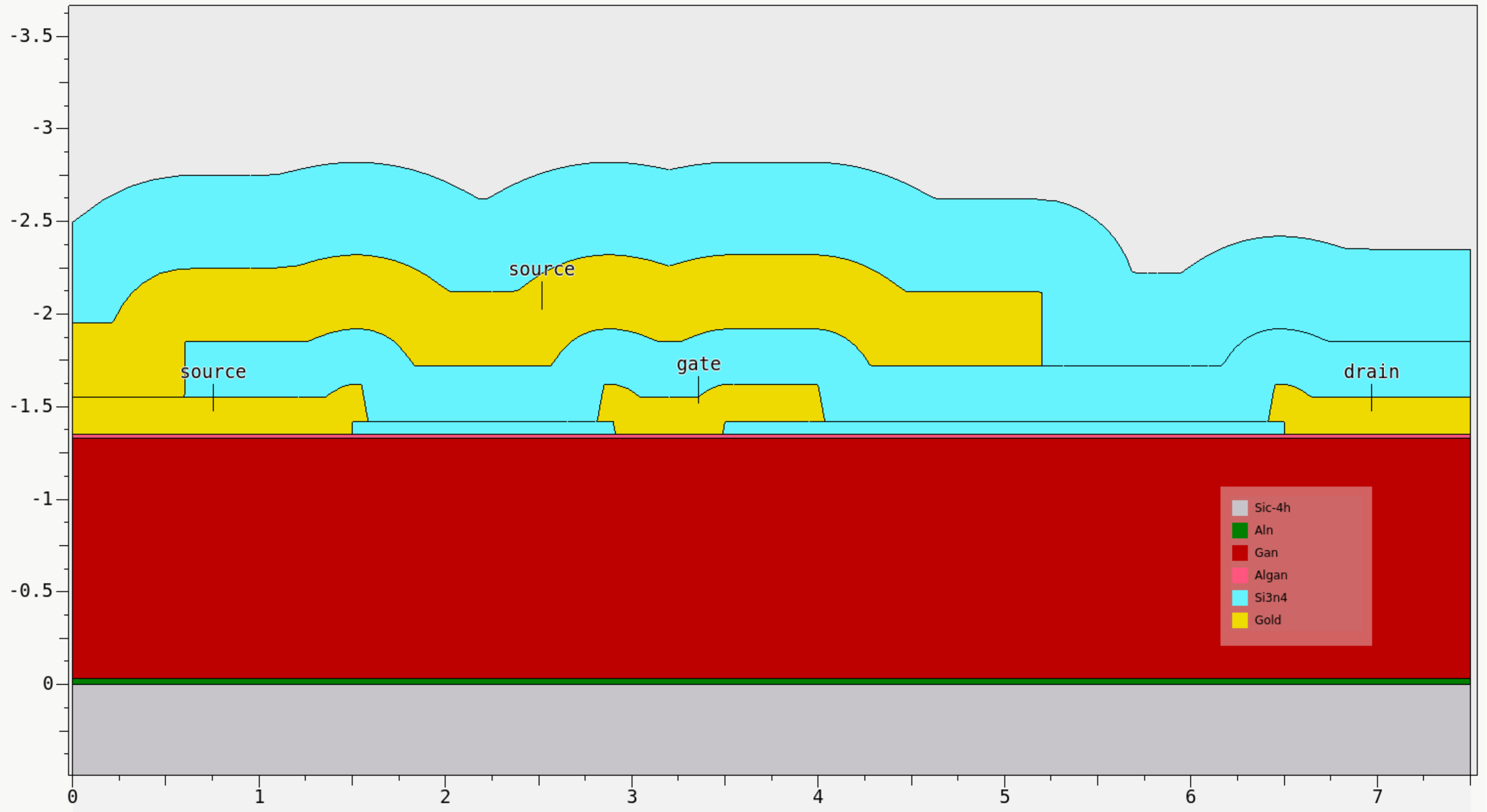
Leakage Current Models useful in GaN

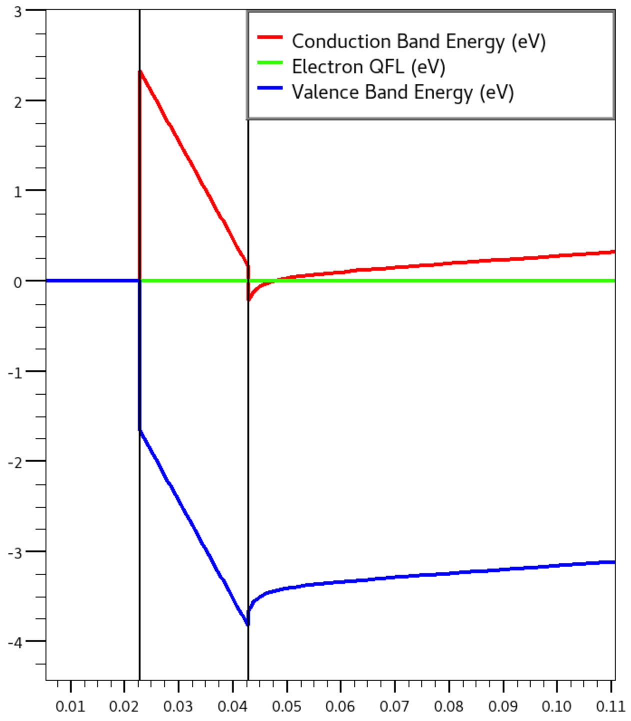
- Trap Assisted Schottky Tunnel
- Variable Range Hopping

Gallium Nitride Examples

GaN HEMT - Process + Device

Multi-layer GaN structures simulated accurately to optimize device structure and performance

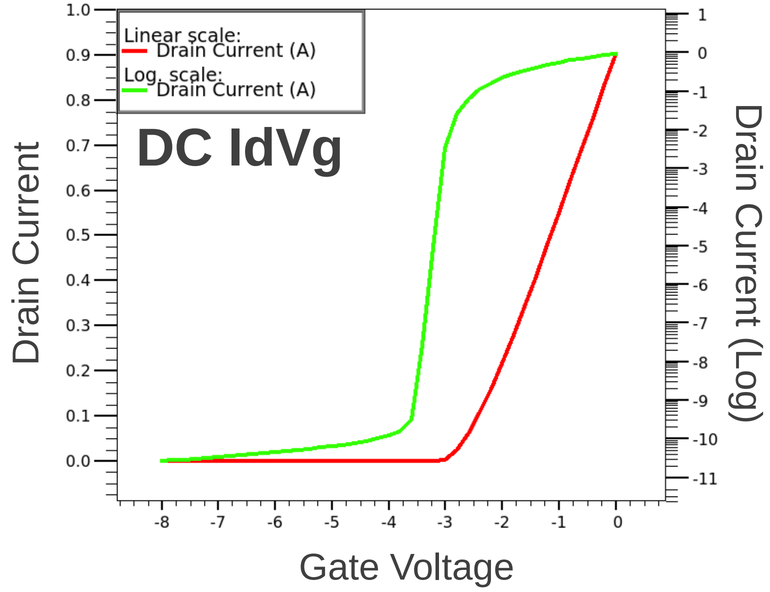




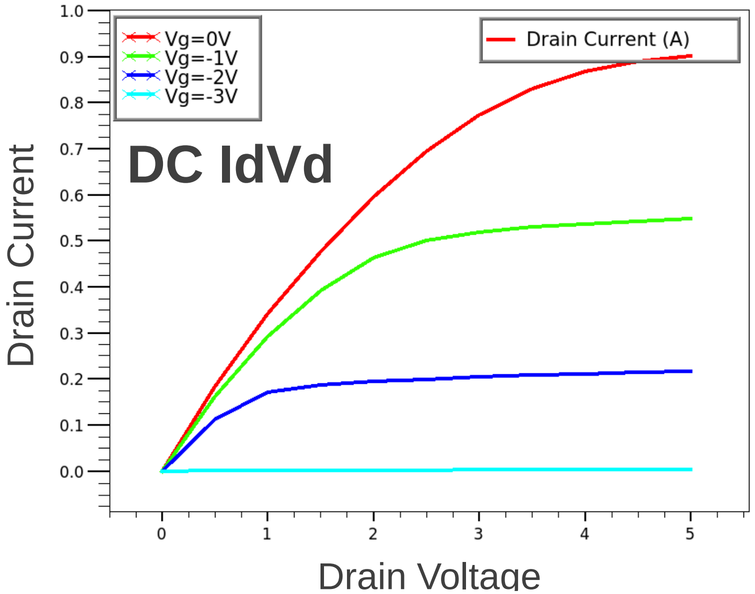
Vertical Cutline through Gate / AlGaN / GaN stack

GaN HEMT - IV Characteristics

Multi-layer GaN structures simulated accurately to optimize device structure and performance

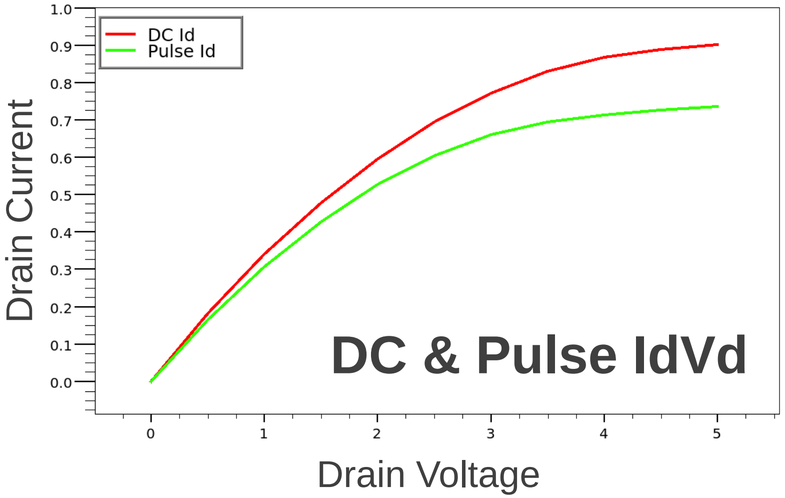


Simulation of HEMT showing DC Id-Vg & Id-Vd Family



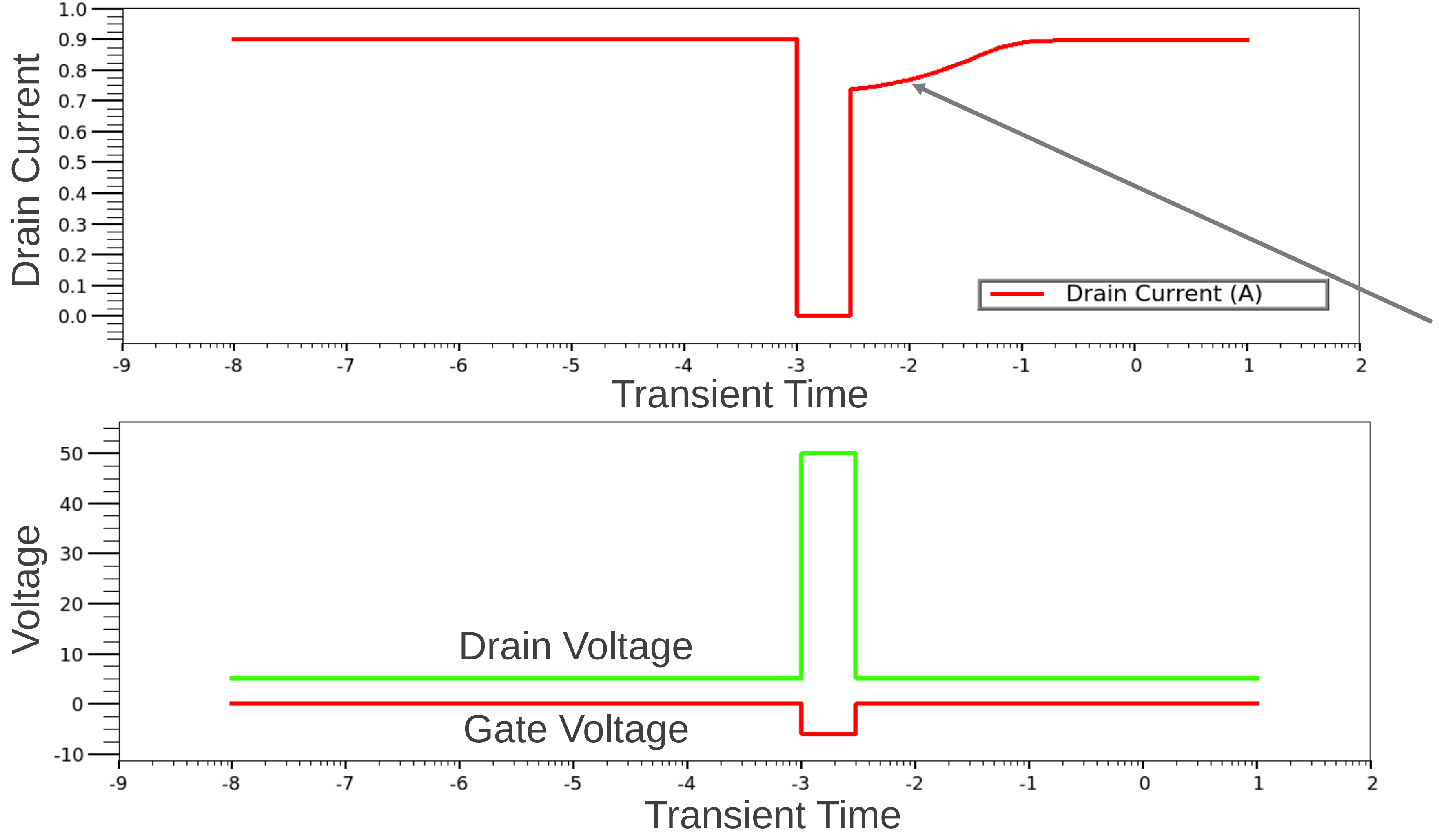
Simulation Comparing the DC IdVd and Transient Pulse IdVd at Vg=0V

- Pulse IdVd shows reduction of current flow by 18% at Vd=5V



GaN HEMT - Transient Pulse Simulation

Current Collapse

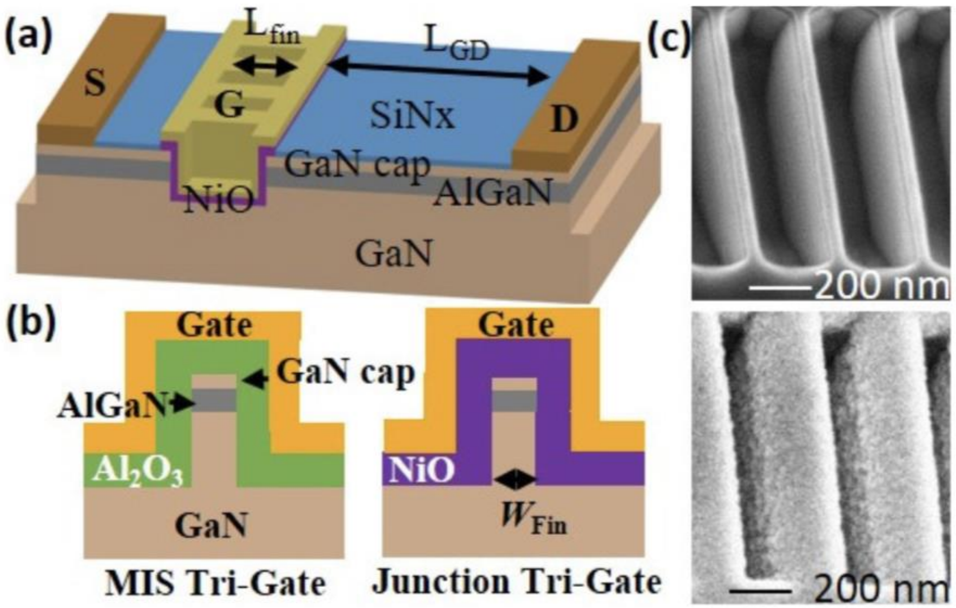


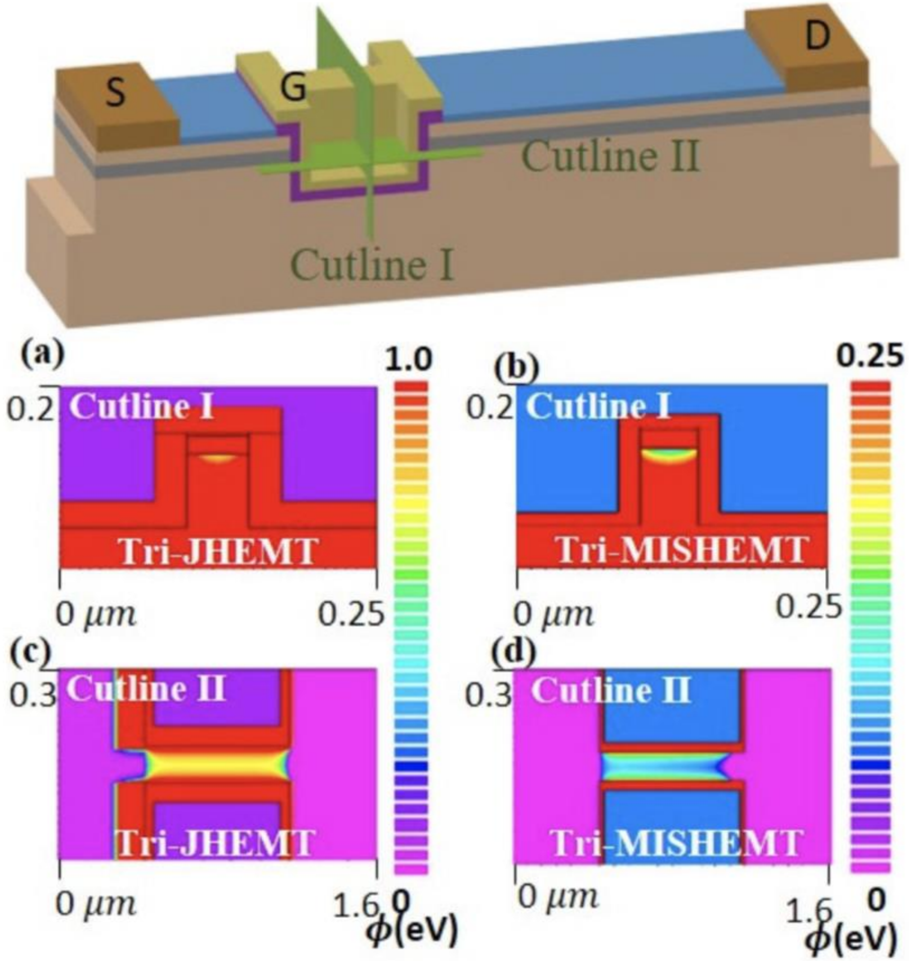
Current collapse caused by bulk traps within the buffer layer

Novel 3D GaN Devices

Silvaco is embedded in tier-1 university research

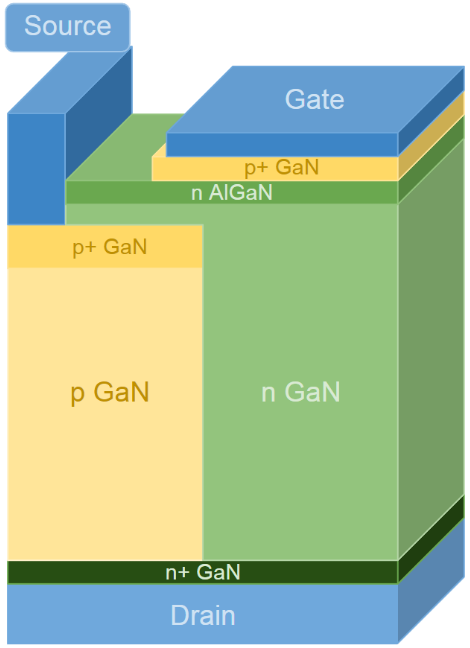
- Example from Virginia Tech University (Silvaco Collaborator)
  - Y. Ma et al., "**Kilovolt Tri-Gate GaN Junction HEMTs with High Thermal Stability**," 2021 33rd International Symposium on Power Semiconductor Devices and ICs (ISPSD), 2021



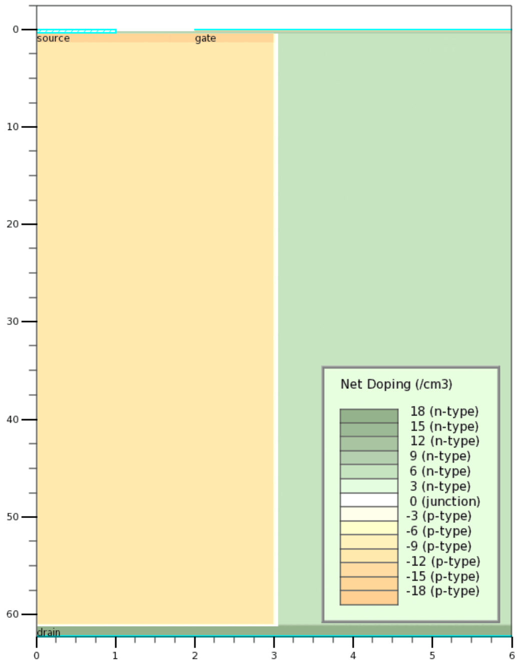


Vertical GaN Superjunction HEMT Simulation

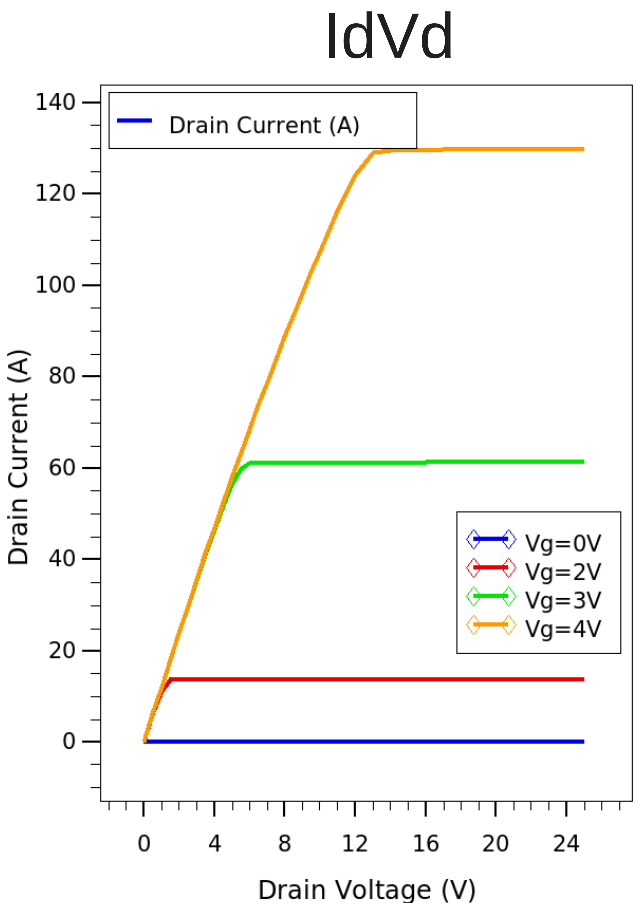
Based on Reference Paper - L. Zhongda, T.P. Chow, "**Design and simulation of 5-20-kV GaN enhancement-mode vertical superjunction HEMT**", IEEE Trans. Electron Dev, vol.60, no.10, 2013, pp.3230-3237.

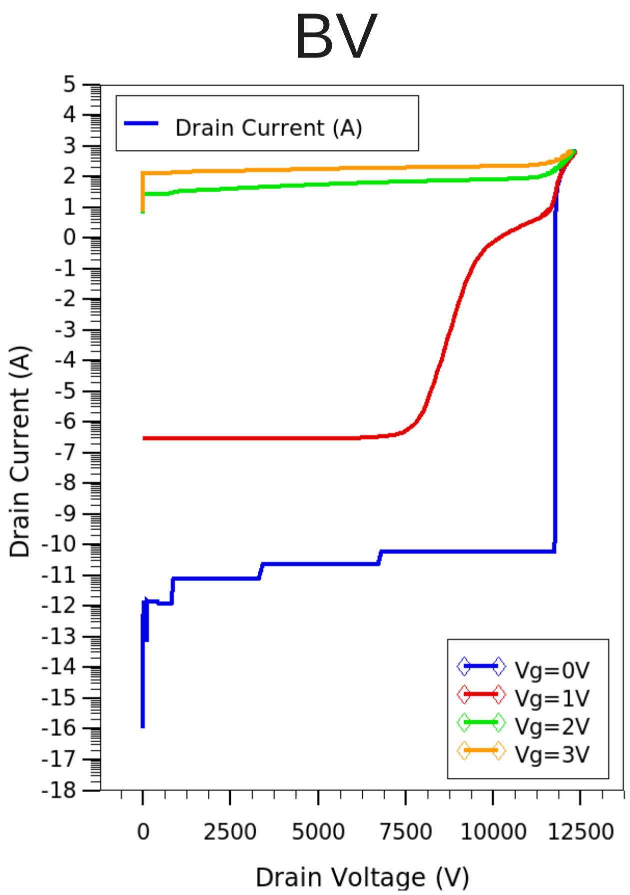


Basic Device Sketch



2D TCAD Design





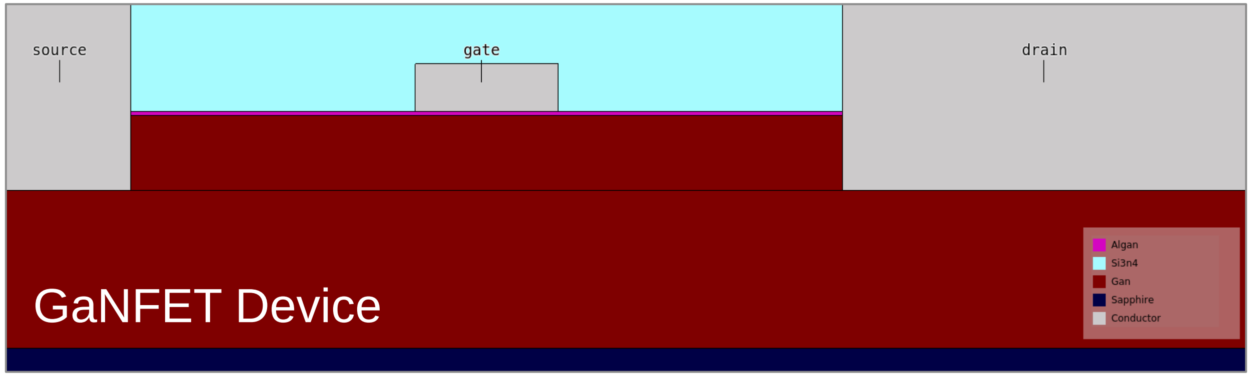
Simulation Results

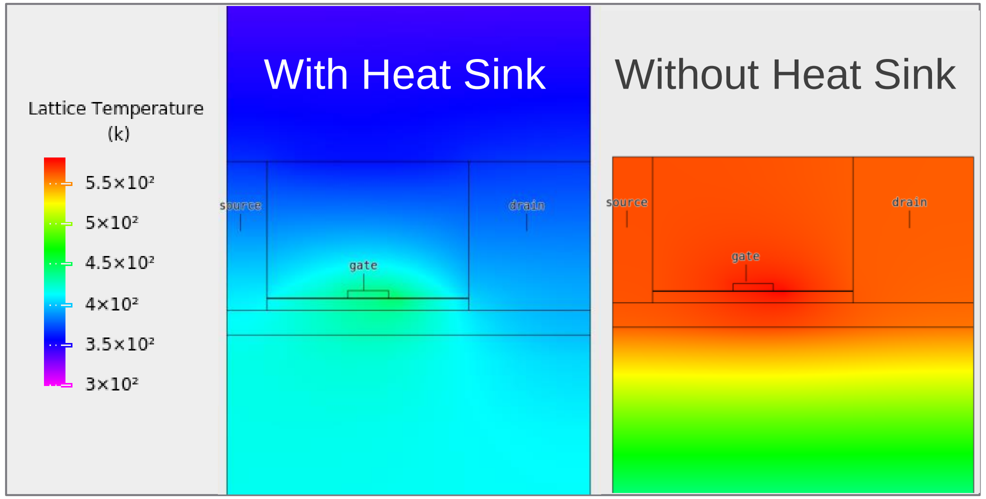
Lattice Heating Simulations

GIGA Module allows users to simulate self consistent electro-thermal physics

GaNFET device with/without top heat sink

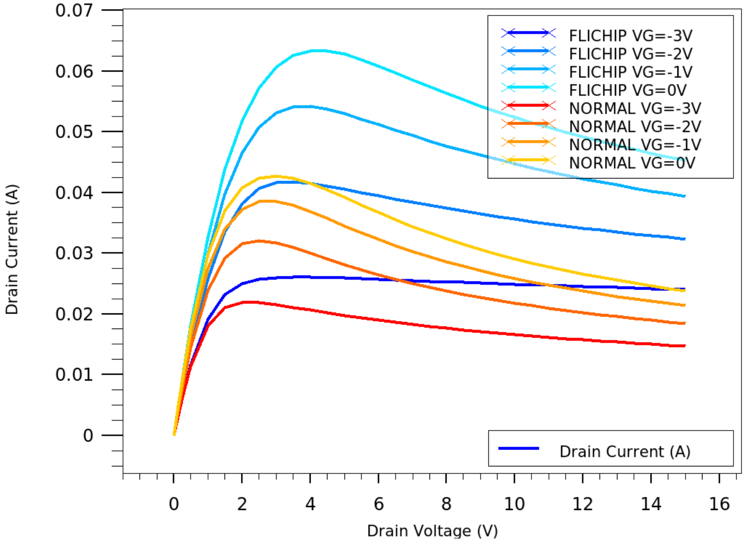
- Device without heat sink shows significant heating & degradation in device electrical performance



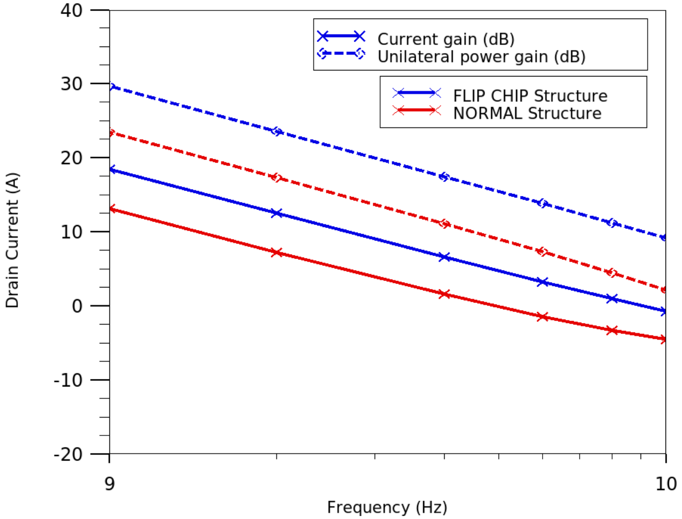


Temperature Profiles During Operation

IdVd



Freq Response



Effect of Self-heating on DC and RF characteristics with/without top heat sink

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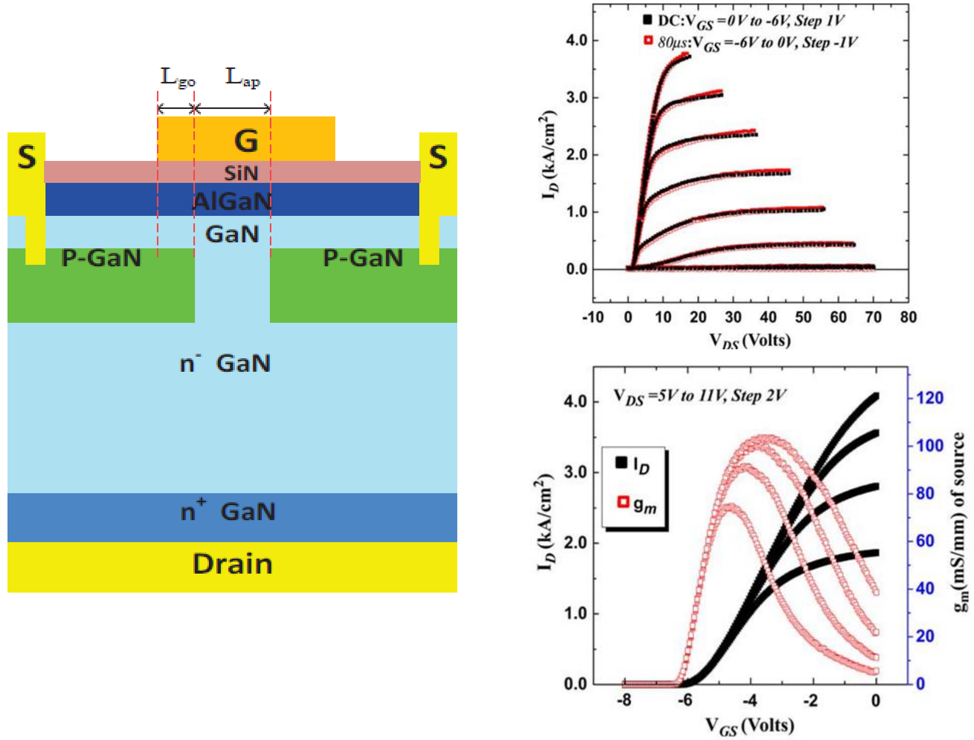
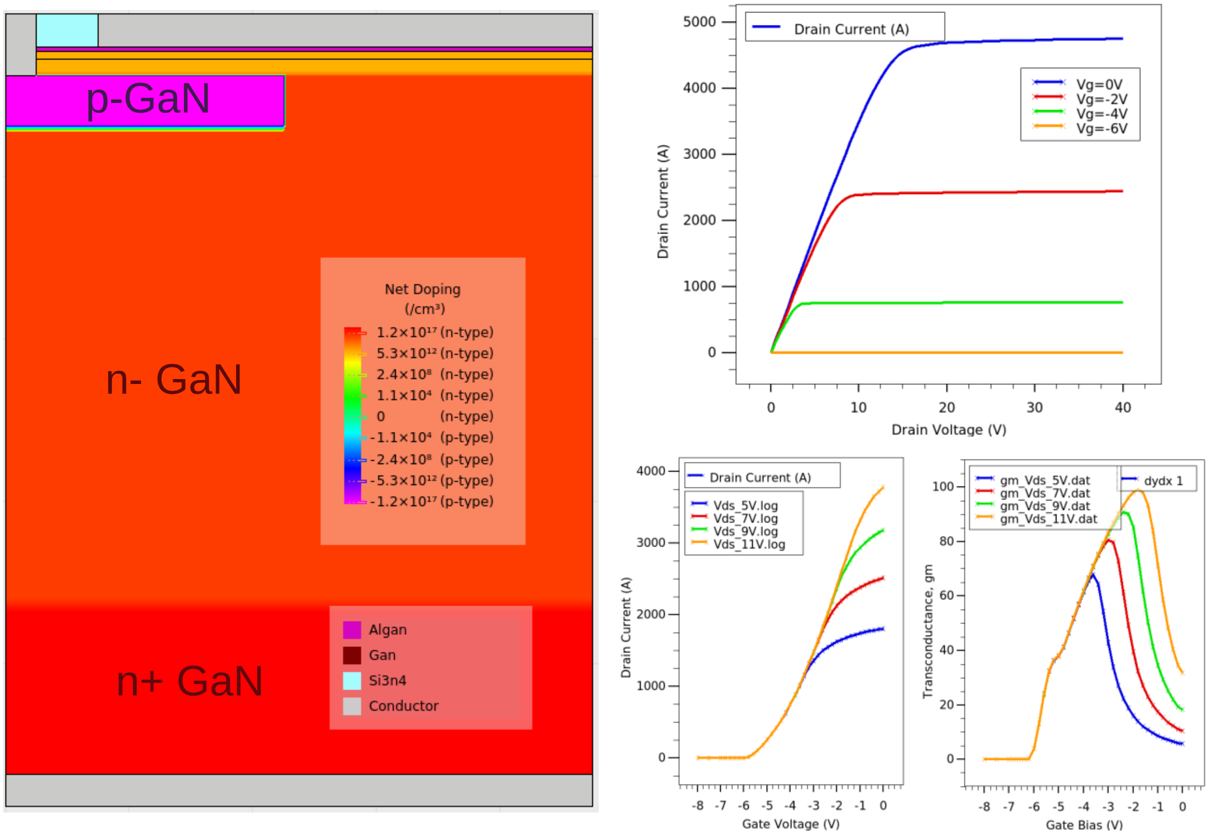
Vertical GaN Devices

Current Aperture Vertical Electron Transistor (CAVET)

S. Chowdhury, M. H. Wong, B. L. Swenson, and U. K. Mishra, "CAVET on bulk GaN substrates achieved with MBE-regrown AlGaN/GaN layers to suppress dispersion", IEEE Electron Device Letters, vol.33, Jan. 2012.



UC Davis Experimental Data



Silvaco Simulations

Silvaco is leading the way for next generation Power Device Technology simulation