Simulating GaN Based Devices

Optical and Electrical GaN Device Simulations
• Background
• General device simulator capabilities
• Physical models for GaN FET applications
• Physical models for GaN optoelectronic applications
• Optical application examples
  • Random compositional variation effects
  • Blue LED
  • Triple quantum well LED
  • GaN LED on sapphire
• Schottky diode application example
• FET application examples
  • I-V characteristics
  • Optimizing field plate design
  • Self heating effects
• Conclusions
• GaN device operation is dominated by Piezo-Electric charges generated by inter-layer stresses and spontaneous polarization

• Often FET devices have no intentional doping so all contacts are Schottky type

• Wurtzite Phase Material System

• DIODE, FET and LED are the most common applications
General Device Capabilities - Physics

- Drift-diffusion
- Energy balance
- Compositionally variant heterojunctions
- Self heating
- Quantum solutions (Schroedinger – Poisson, NEG, tunneling)
- Optical detection (Ray Trace, FDTD, TMM, BPM)
- Optical emitters (Helmholtz, photon rate, gain models)
- Reverse ray trace for LEDs
- 2D and 3D simulations
General Device Capabilities - Features

- Randomized composition or doping variation capability
- Interface and bulk traps (can also be used to simulate semi-insulating substrates)
- C-Interpreter for user-defined functions
- DC, small signal AC, large signal AC, transient
- S, H, Y and Z parameters
  - Gains (Ft, Fmax)
- Capacitance – inductance – smith charts
- Design of experiments and optimization
- Unified structure formats and runtime environment for all simulators
• Automated calculation of spontaneous and Piezo-Electric polarization
• Automated calculation of strain for the whole InAlGaN material system
• X and Y composition dependent models for bandgap, electron affinity, Permittivity, density of state masses, recombination, impact ionization, heat capacity, refractive Index, low and high field mobilities
• GaN specific impact ionization and field/temperature dependent mobility models
• Phonon-assisted tunneling model
In addition to the GaN FET models on the previous slide, optoelectronic models for GaN devices include:

- Three band parabolic strain dependent quantum k.p. models for gain and spontaneous recombination
- Adachi’s and Sellmeier’s refractive index models with frequency dispersion
- Temperature dependent refractive index
• Random compositional variation in quantum wells
• User inputs mean and std. deviation of composition fraction or doping

Three quantum well LED showing user defined randomized x-composition variations in the wells.
Optoelectronic Examples – Composition Variation

• Effects of random composition on emission spectrum

The double peak in the optical spectrum resulting from band splitting from random compositional variation.
Optoelectronic Examples – Blue LED

- Reverse ray trace and I-V curve for a blue LED
• Resulting emission spectra versus bias for the blue LED
Optoelectronics Examples – Multi Quantum Well

- Triple multi-quantum well LED

![Graph showing electron and hole populations across the triple well LED.](image)

Showing electron and hole populations across the triple well LED.
Optoelectronic Examples – Multi Quantum Well

• Resulting Spectral Output from Triple Well LED

![Graph showing EL Intensity vs Wavelength for a Triple Well LED with peak wavelength at 356 nm and FWHM of 6.9 nm.](image)
Optoelectronic Examples – GaN LED on Sapphire

- Device Cross Section

- Optical and Electrical GaN Device Simulations
- Emitted Light Intensity versus Angle For GaN on Sapphire -
• Device Cross Section and Band Diagram of a n-GaN Schottky Diode

• Reverse I-V Characteristic of a n-GaN Schottky Diode Showing Leakage Current due to Photon Assisted Tunneling versus Temperature

• Current-Temperature Characteristics of a GaN Schottky Diode, Simulated at Different Reverse Bias Voltage With and Without Phonon-Assisted Tunneling Mode

FET Application Examples – IV Characteristics

• Typical I-V characteristics
• Non Ideal Breakdown Characteristics using Standard Gate Field Plate Design (Breaks down at 150 volts)
After optimizing gate field plate height and over-lap, a 600 volt breakdown was obtained.

A DOE can be created using ANY parameter in the input file since anything can be made a variable.
FET Application Examples – Self Heating Effects

• For GaN FETs on sapphire or silicon carbide substrates, self heating effects are significant. The figures below compares these effects on the resulting I-V and gm curves.
• Comparing IdVd curves for a GaN FET on sapphire and silicon carbide substrates respectively
Conclusions

• Many automated models specific to the GaN material system with good default parameters
• Very intuitive and easy to use input file syntax
• Industry leading visualization tools for navigating results
• Open architecture for propriety in-house model development using Silvaco’s C-Interpreter model interface
• DOE and optimization on any parameter
• Virtual Wafer Fab (VWF) split lot runtime environment also available, running on 64 bit commercial database