

Simulating GaN Based Devices



Optical and Electrical GaN Device Simulations



SILVACO



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Background

- 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 Hetero-Junctions
- Self Heating
- Quantum Solutions (Schrodinger – Poisson, NEGF, 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 (F_t , F_{max}).
- Capacitance – Inductance – Smith Charts
- Design of Experiments and Optimization
- Unified Structure Formats and Runtime Environment for all simulators



Physical Models for GaN FET Applications

- 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



Physical Models for Optoelectronic Applications

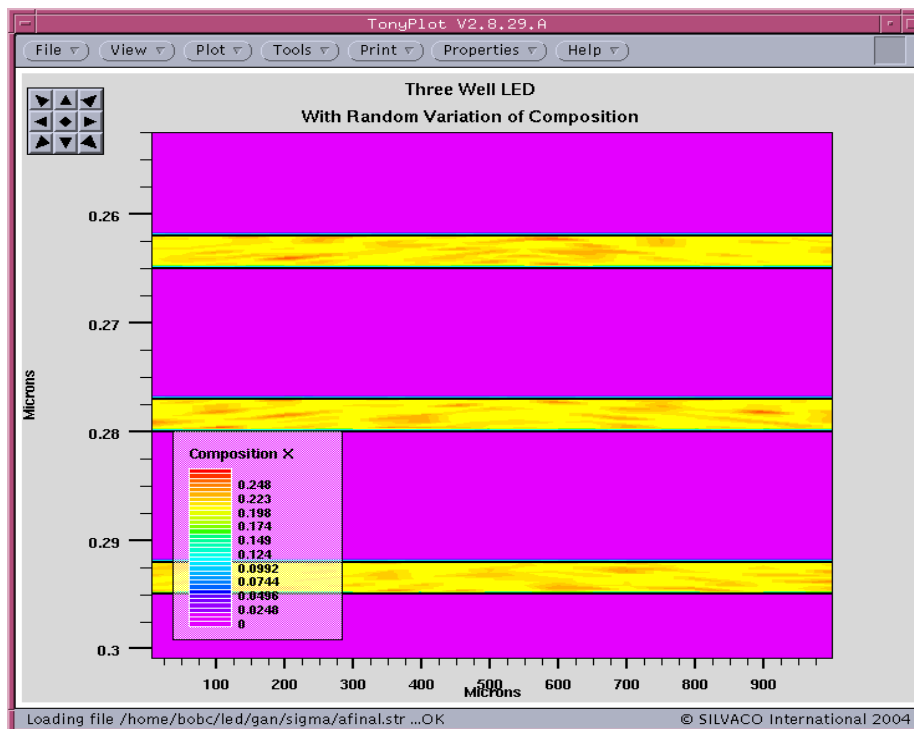
In addition to the GaN FET models on the previous slide, optoelectronic models for GaN devices include:-

- 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



Optoelectronic Examples – Composition Variation

- Random Compositional Variation in Quantum Wells
- User Inputs Mean and Std. Deviation of Composition Fraction or Doping

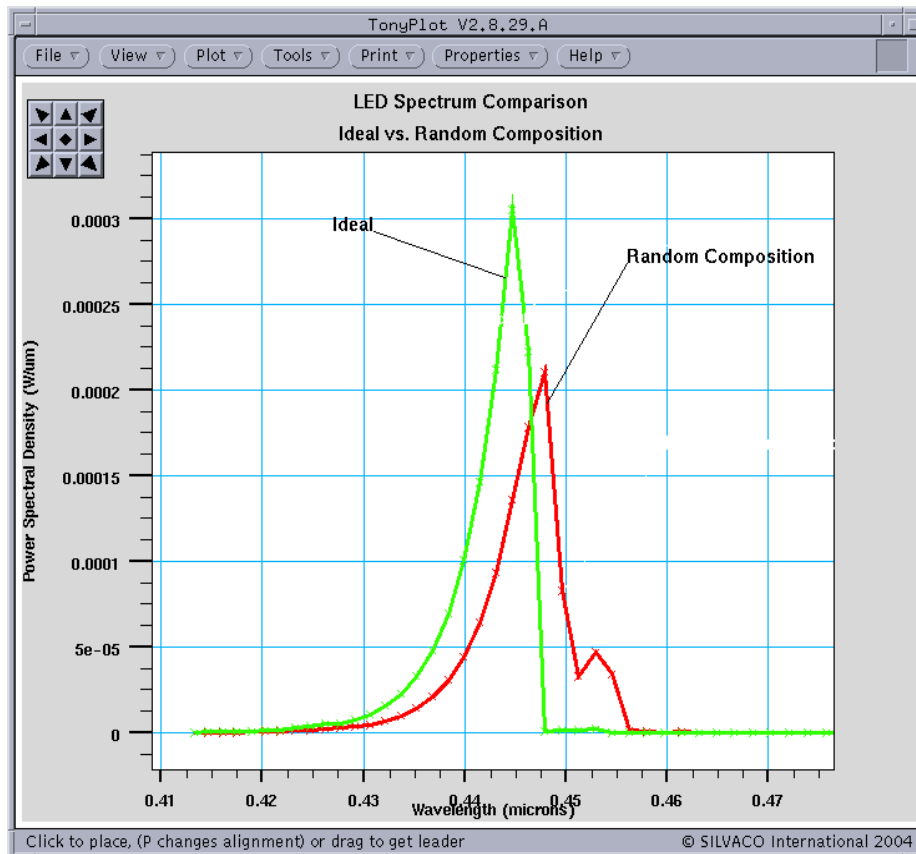


3 Quantum Well LED showing user defined Randomized X-Composition Variations in the Wells



Optoelectronic Examples – Composition Variation

- Effects of Random Composition on Emission Spectrum

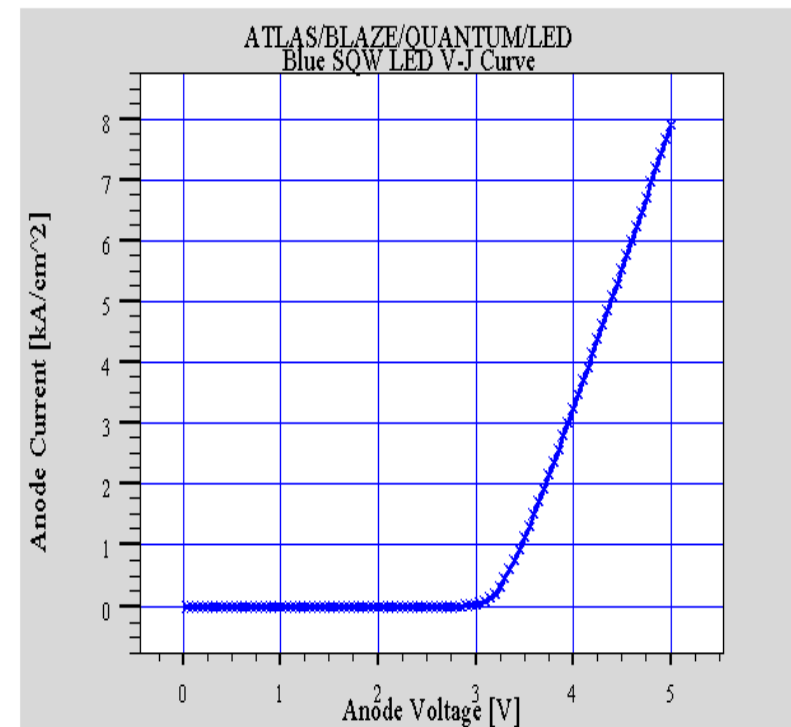
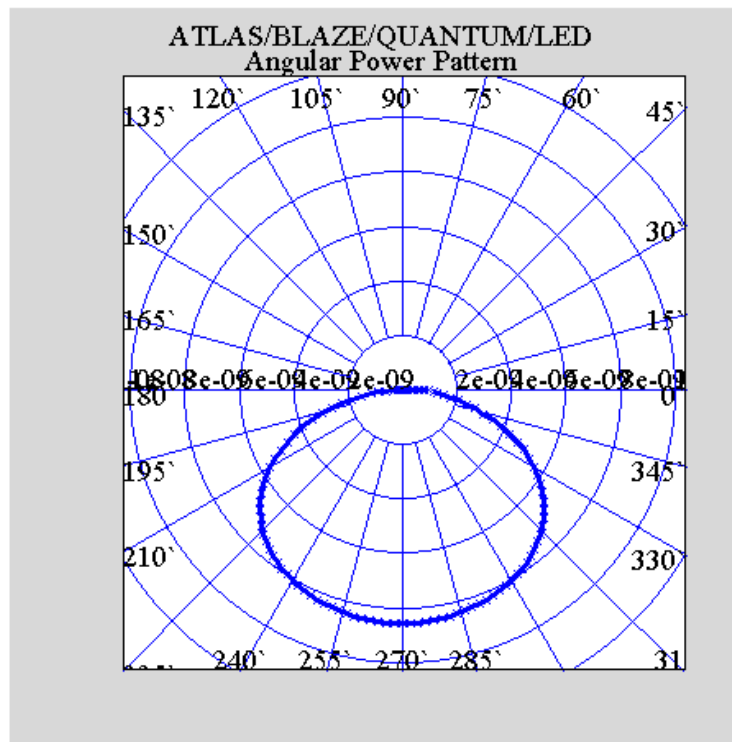


The double peak in the optical spectrum resulting from Band Splitting from Random Compositional Variation



Optoelectronic Examples – Blue LED

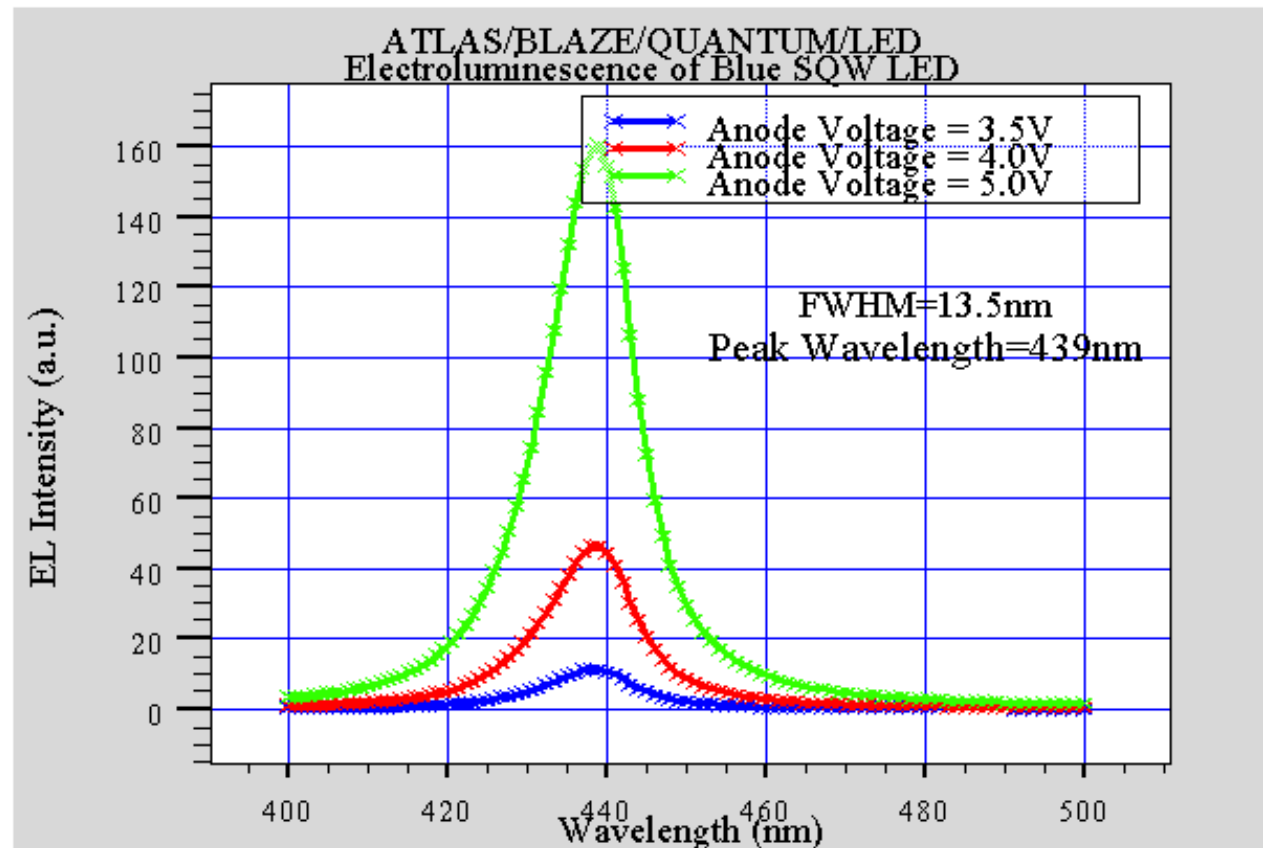
- Reverse Ray Trace and I-V Curve for a Blue LED





Optoelectronics – Blue LED

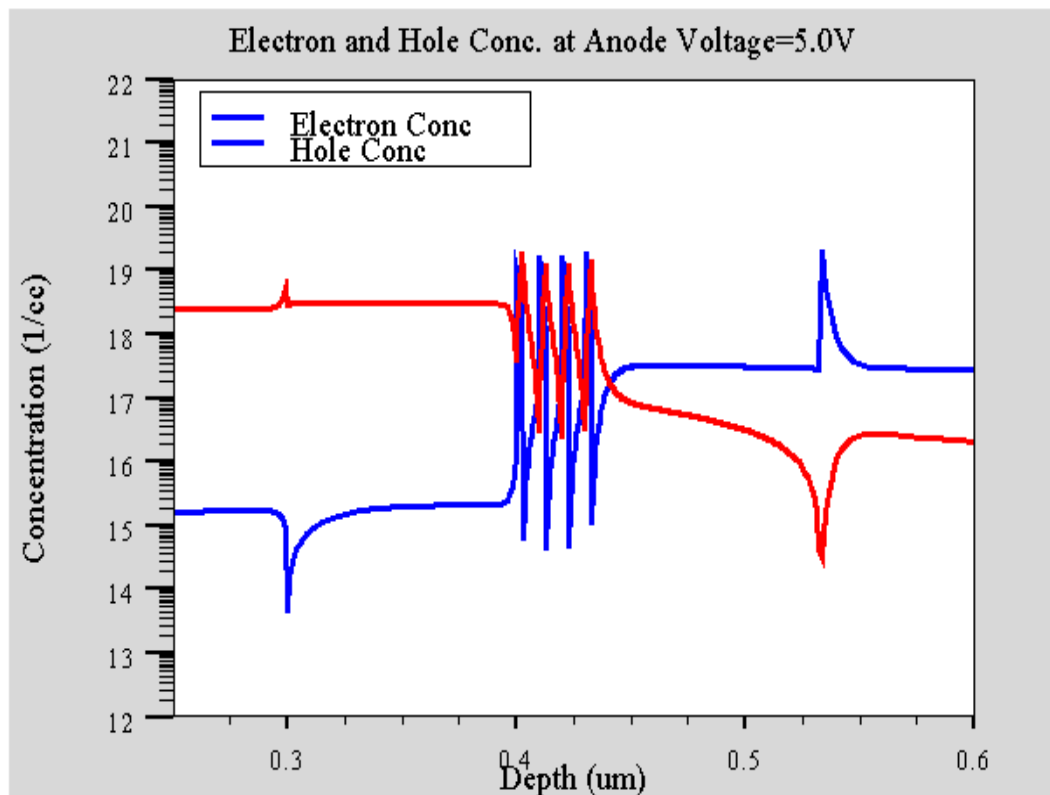
- Resulting Emission Spectra versus Bias for the Blue LED





Optoelectronics Examples – Multi Quantum Well

- Triple Multi-Quantum Well LED

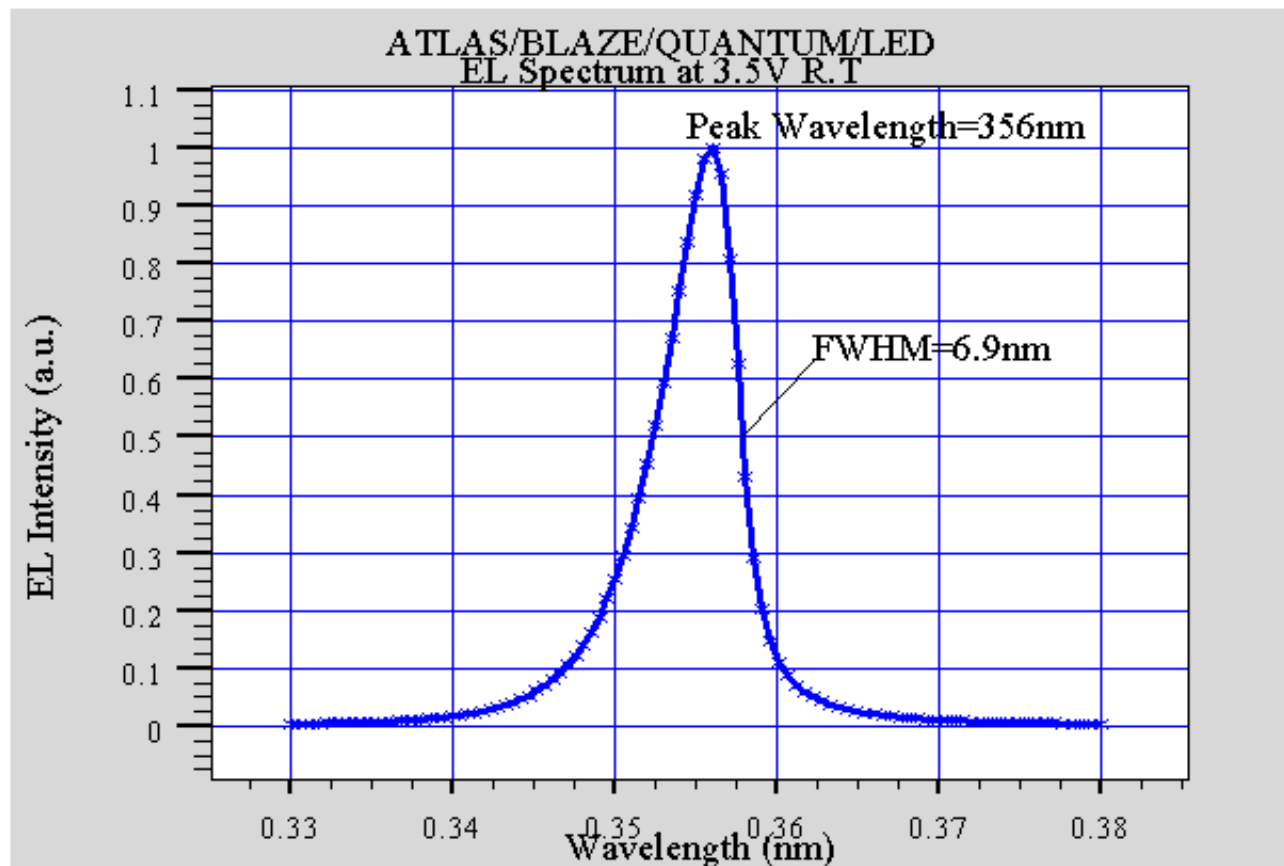


Showing electron and hole populations across the triple well LED



Optoelectronic Examples – Multi Quantum Well

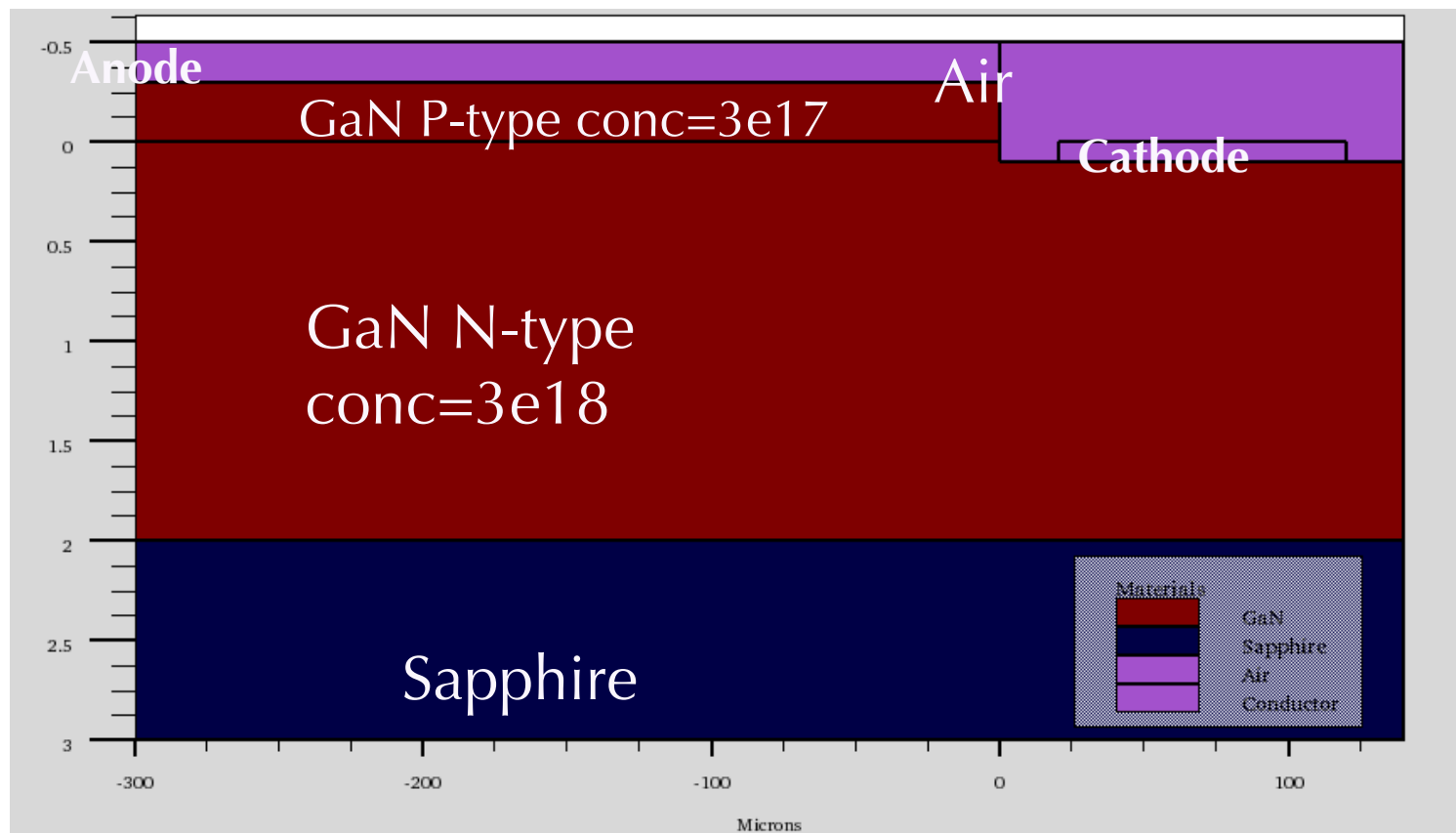
- Resulting Spectral Output from Triple Well LED





Optoelectronic Examples – GaN LED on Sapphire

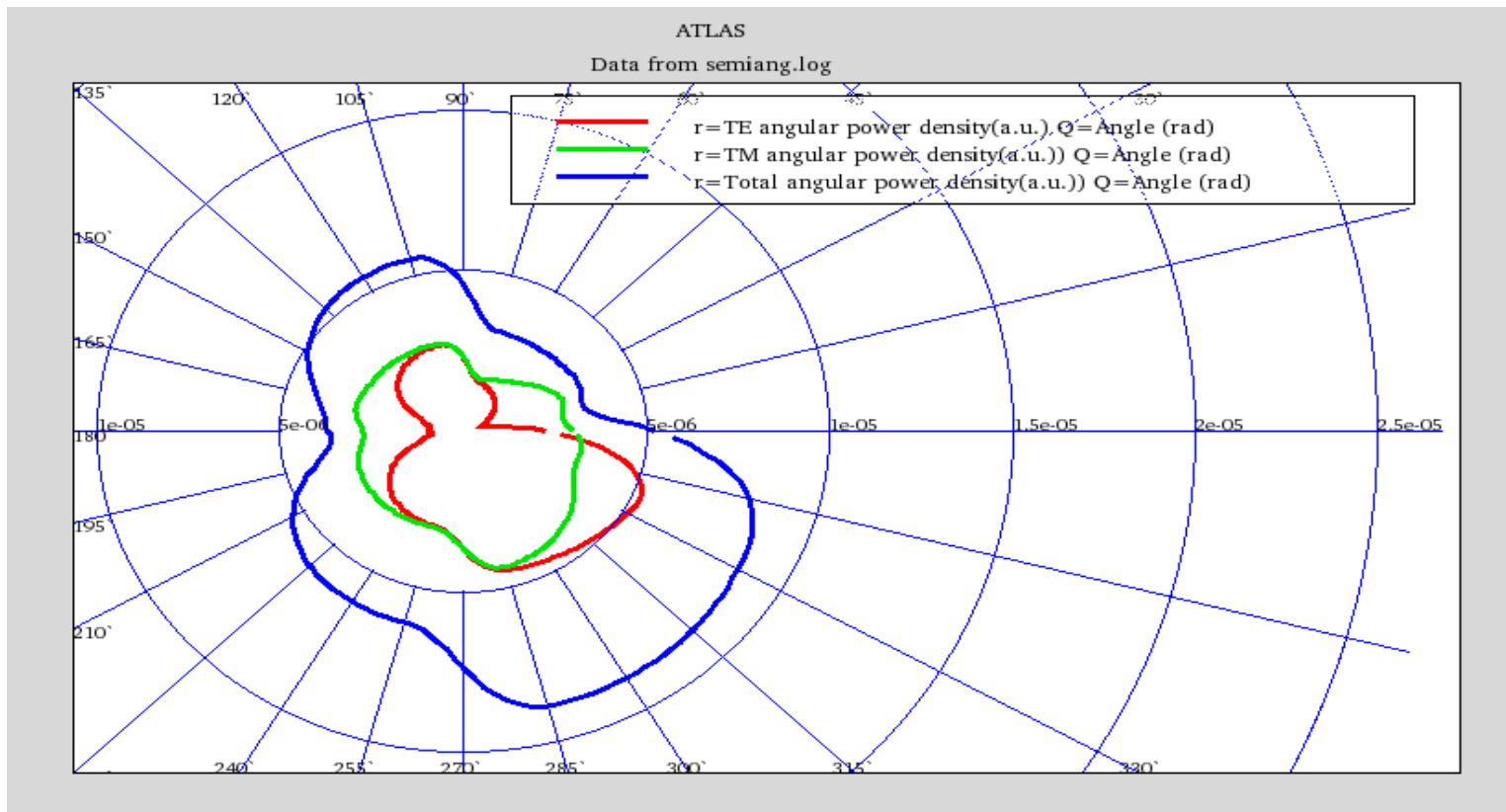
■ Device Cross Section





Optoelectronics Examples – GaN LED on Sapphire

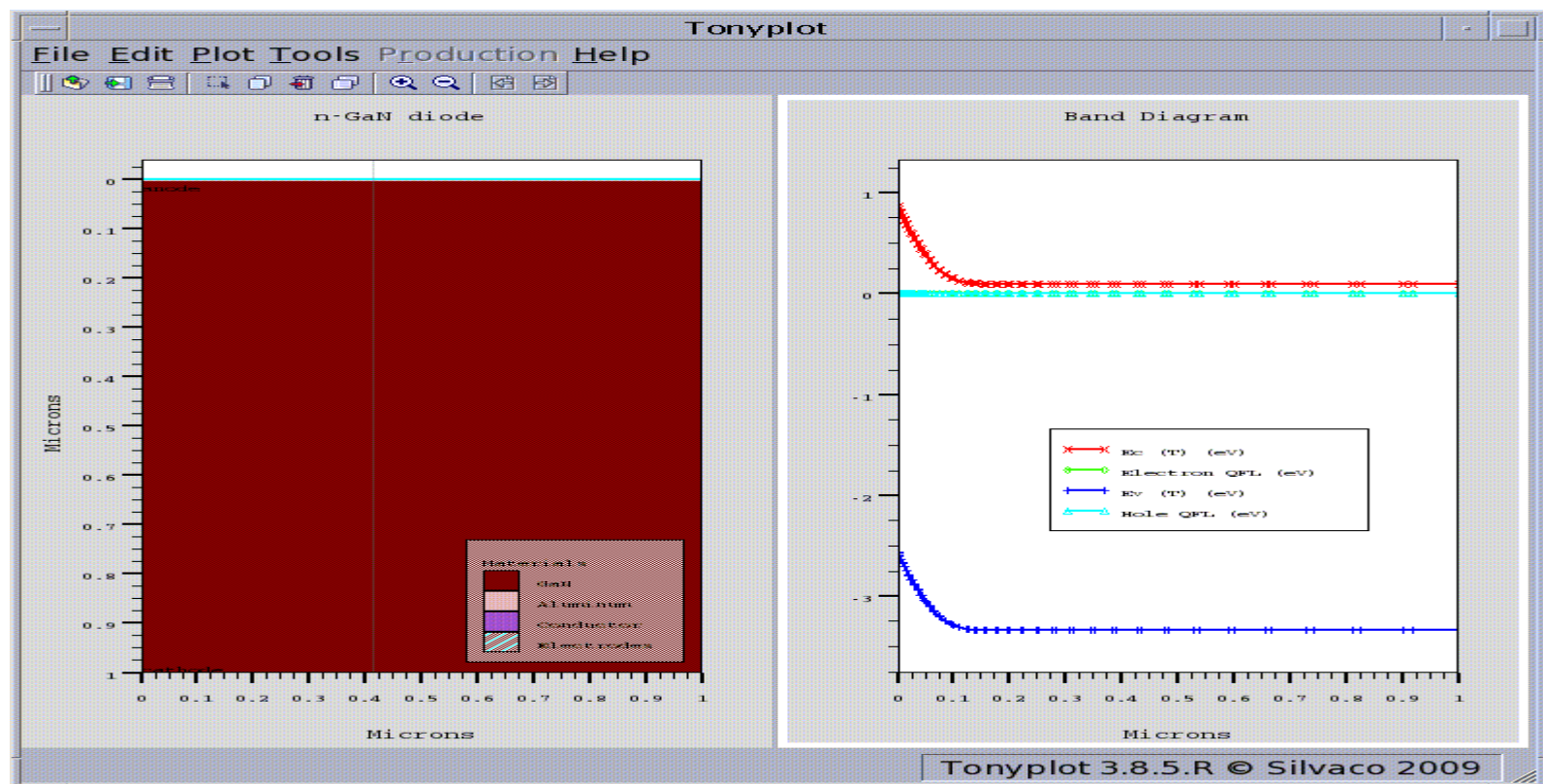
- Emitted Light Intensity versus Angle For GaN on Sapphire





Schottky Diode Application Example – Reverse IV Characteristics

- Device Cross Section and Band Diagram of a n-GaN Schottky Diode

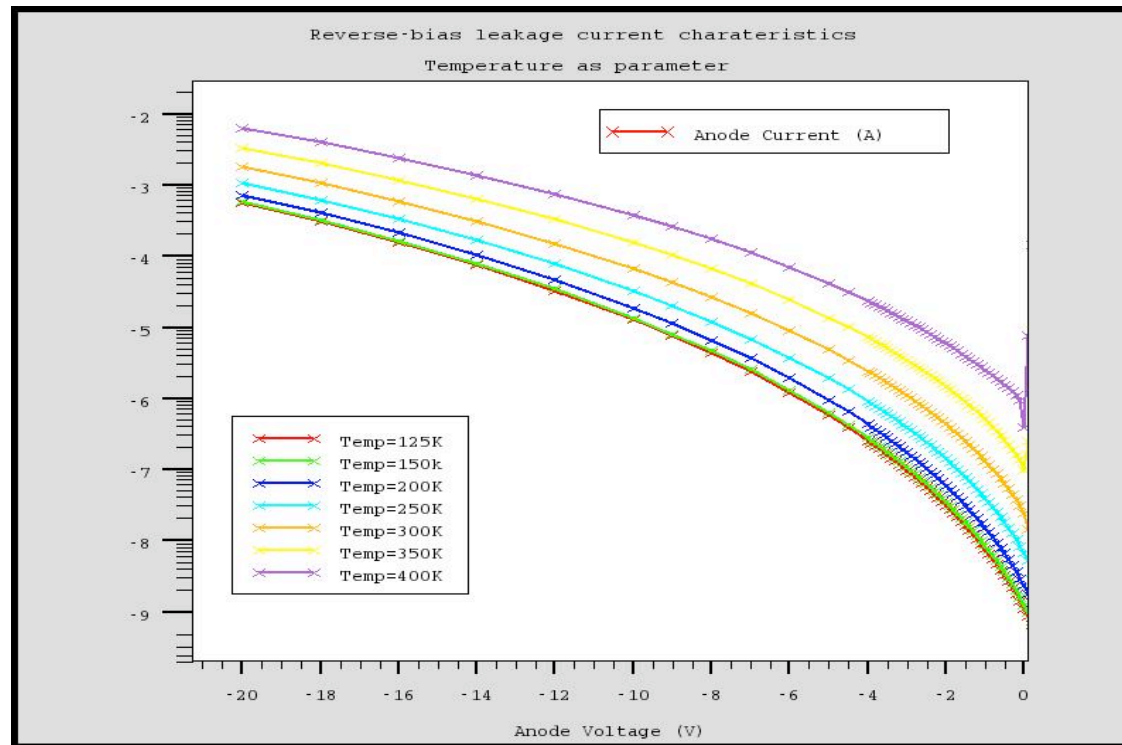


Ref P.Pipinis et al, J Appl Physics, 99, 093709 (2006)



Schottky Diode Application Examples – Reverse IV Characteristics

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

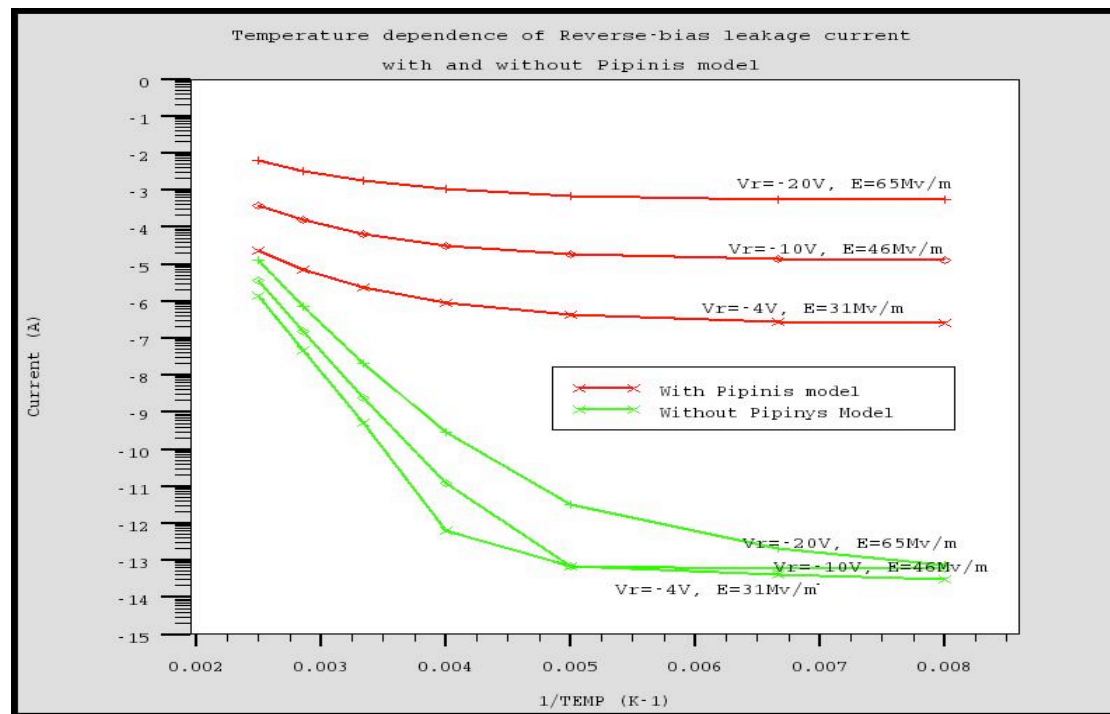


Ref P.Pipinis et al, J Appl Physics, 99, 093709 (2006)



Schottky Diode Application Examples – Reverse IV Characteristics

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

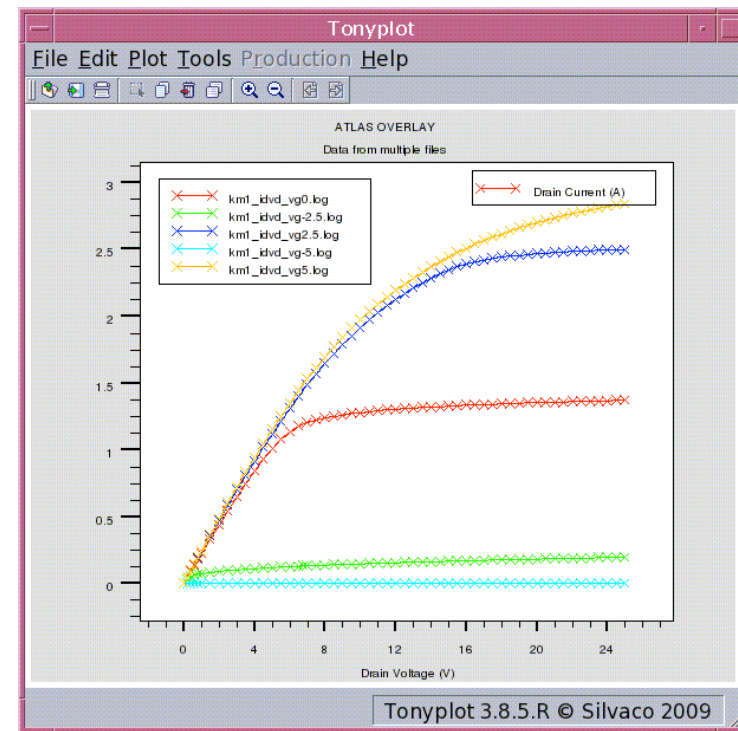
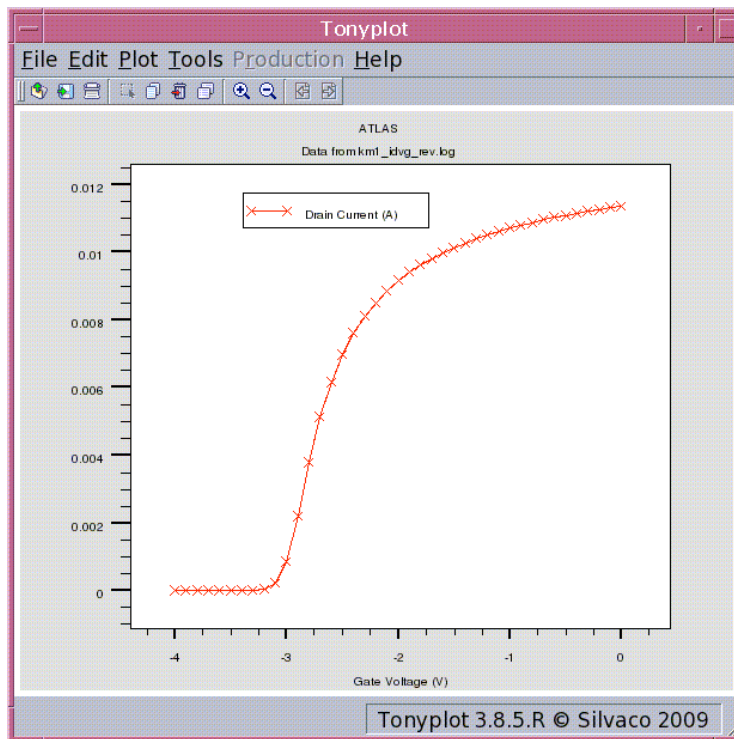


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FET Application Examples – IV Characteristics

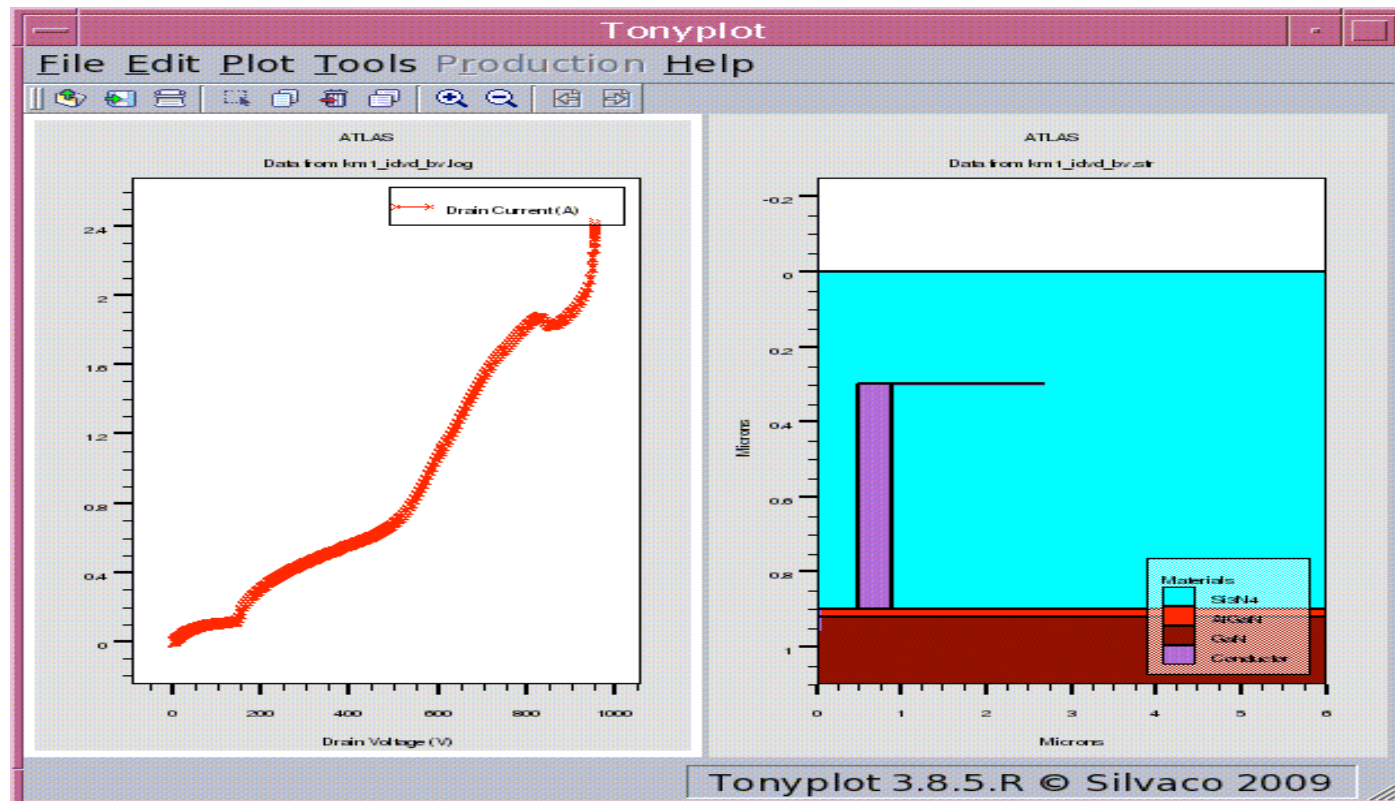
- Typical I-V characteristics





FET Application Examples – Optimizing Design

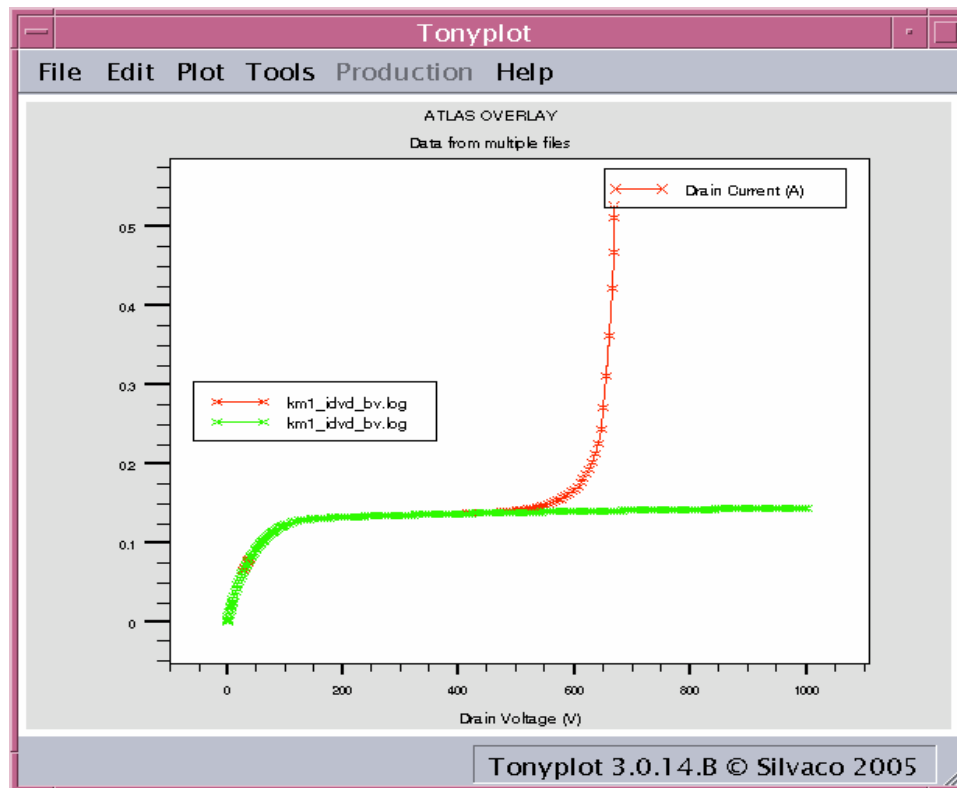
- Non Ideal Breakdown Characteristics using Standard Gate Field Plate Design. (Breaks down at 150 volts)





FET Application Examples – Optimizing Design

- After Optimizing Gate Field Plate Height and Over-Lap, a 600 volt breakdown was obtained.



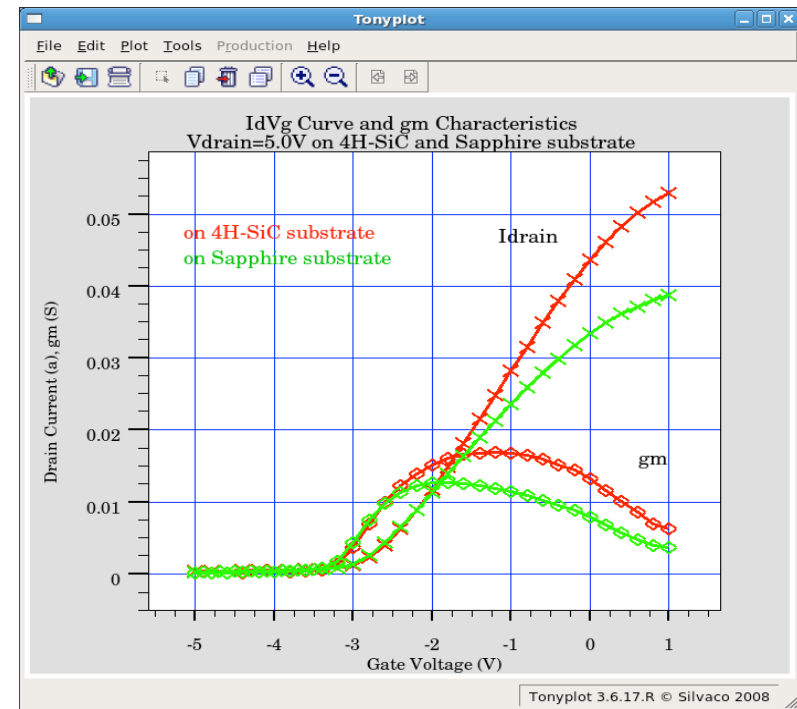
A DOE can be created using ANY parameter in the input file since anything can be made a variable



FET Application Examples – Self Heating Effects

- For GaN FETs on Sapphire or Silicon Carbide Substrates, Self Heating Effects are Significant. The slide below compares these effects on the resulting I-V and gm Curves

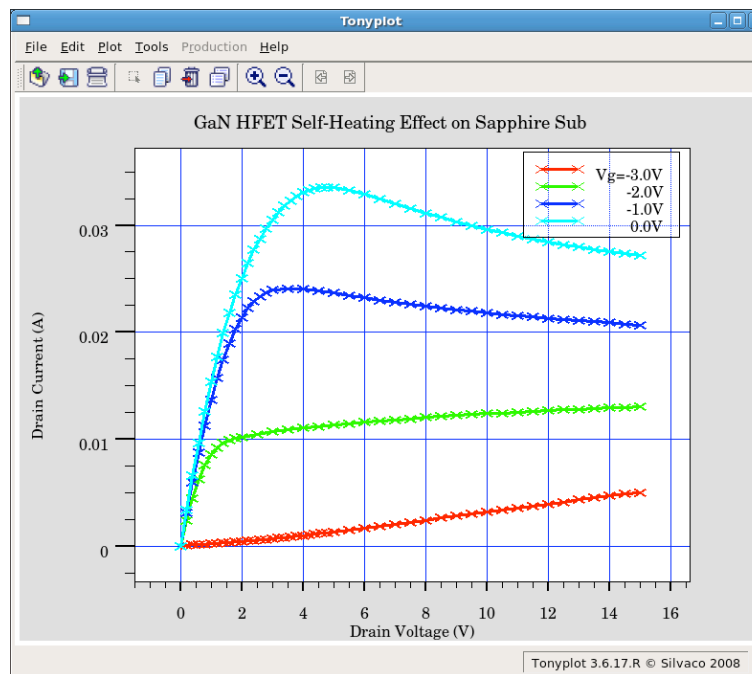
Source	Gate	Drain
Undoped AlGaN		
n+ AlGaN		
Undoped AlGaN		
2DEG		
Undoped GaN Buffer		
Undoped AlN		
4H-SiC or Sapphire Sub.		



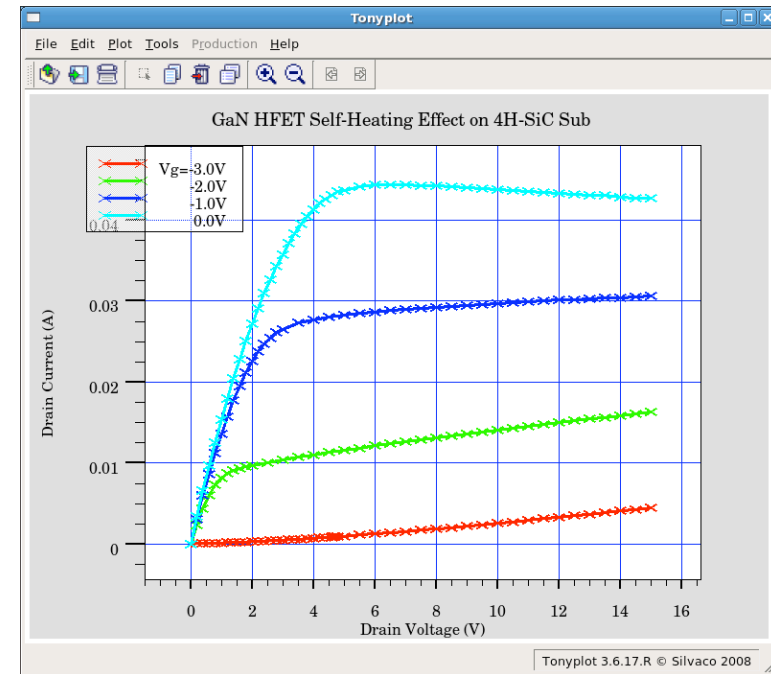


FET Application Examples – Self Heating

- Comparing IdVd Curves for a GaN FET on Sapphire and Silicon Carbide Substrates respectively



Sapphire Substrate



SiC Substrate



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 Proprietary 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