FastBlaze

Ultra-Fast MESFET and HEMT Device Simulator

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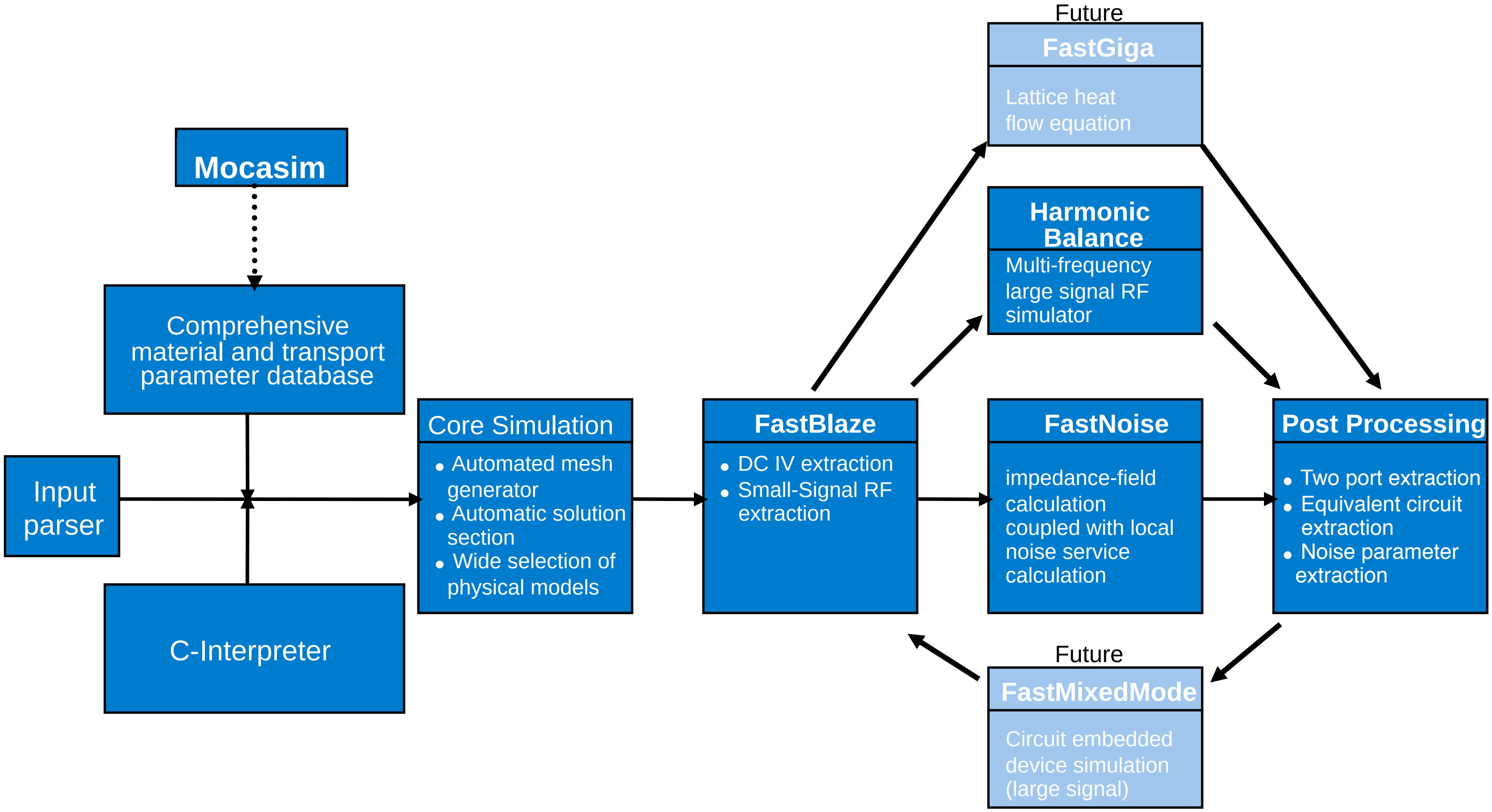
Introduction to MERCURY TCAD Framework

- The MERCURY framework is an application-specific TCAD tool set designed for FET simulation
- Three Main Foundations of MERCURY
  - Fast Simulations (typically less than 1 minute)
  - Accurate Physical Models
  - Accessible to all engineers

MERCURY Modules



Mocasim

Comprehensive material and transport parameter database

Input parser

C-Interpreter

Core Simulation
- Automated mesh generator
- Automatic solution section
- Wide selection of physical models

FastBlaze
- DC IV extraction
- Small-Signal RF extraction

Future

FastGiga

Lattice heat flow equation

Harmonic Balance

Multi-frequency large signal RF simulator

FastNoise

impedance-field calculation coupled with local noise service calculation

Post Processing
- Two port extraction
- Equivalent circuit extraction
- Noise parameter extraction

Future

FastMixedMode

Circuit embedded device simulation (large signal)

FastBlaze Applications

- Technologies:
  - MESFETs
  - HEMTs
  - pHEMTs
- Materials:
  - AlGaAs/GaAs
  - InGaAsP/InP
  - InGaAs/GaAs
  - user defined materials

FastBlaze Applications (cont.)

- Analyses possible:
    - I_D-V_{DS} for various V_{GS}
    - I_D-V_{GS} for various V_{DS}
    - Transconductance
    - Punchthrough
    - Gate capacitance
    - Time domain waveforms
    - RF two-port parameter extraction (eg. s-parameters)
    - RF parameters as function of frequency and bias

How Fast is FastBlaze?

Fast Blaze Simulation Timings		
Device	**Analysis**	**CPU Time (sec)**
MESFET	Charge Control Analysis	32
MESFET	DC I_D-V_{DS} Family	3.3
MESFET	DC I_D-V_{GS} Sweep	2.1
MESFET	RF Single Frequency	3.5
pHEMT	Charge Control Analysis	54
pHEMT	RF Swept Frequency	138

- All timings on a Sun ULTRA10 workstation
- All simulations were on a 0.5 um gate length recessed MESFET or pHEMT. The DC Id-Vd simulations were taken over the range -2.0V<Vgs<0,
- 0.5V increments, 0<Vds<5V, 0.1 V increments.
- The DC Id-Vgs sweep was taken over the range –2.0V<Vgs<0, 0.1V increments, with Vds fixed at 0.1V.
- The RF simulations were taken at Vgs=0V, Vds=2.0V, sweeping the frequency from 1 to 20GHz in 1GHz increments.

MERCURY Method

- Two phases to MERCURY solution:
  - Charge control simulation vertically under the gate, recess and cap regions
  - Transport simulation across the channel solving Poisson, current continuity, and energy balance equations

REFERENCES

R. Drury & C.M. Snowden, "A quasi-two-dimensional HEMT model for microwave CAD applications", IEEE Transactions on Electron Devices, Vol. ED-42, No. 6, pp.1026-1032, 1995

C.M. Snowden & R.R. Pantoja, "GaAs MESFET Physical Models for Process-Orientated Design", IEEE Transactions on Electron Devices, Vol. ED-40, No. 7, pp.1401-1409, 1992

B. Carnez, A. Cappy, et al. "Noise Modeling in Submicrometer-Gate FET's", IEEE Transactions on Electron Devices, Vol. ED-28, No.7, pp.784-789, 1981

MERCURY Method

- Solution method is fast because:
  - Charge control data stored and accessed directly as a lookup table
  - Current driven allowing integration method for carrier transport
  - Scales linearly with number of mesh points (N)
    - conventional schemes scale as N
  - Highly efficient Newton solver
  - Automated IV bias control to minimize the number of solution points required

MERCURY Method

- The consequences of the MERCURY approach are:
  - No need to tradeoff accuracy for speed. Rapid simulation allows use of the most sophisticated models
  - Meshing and bias stepping can be automated
  - Initial guesses and convergence control are taken care of inherently
  - Two-dimensional effects can be modeled such as punchthrough

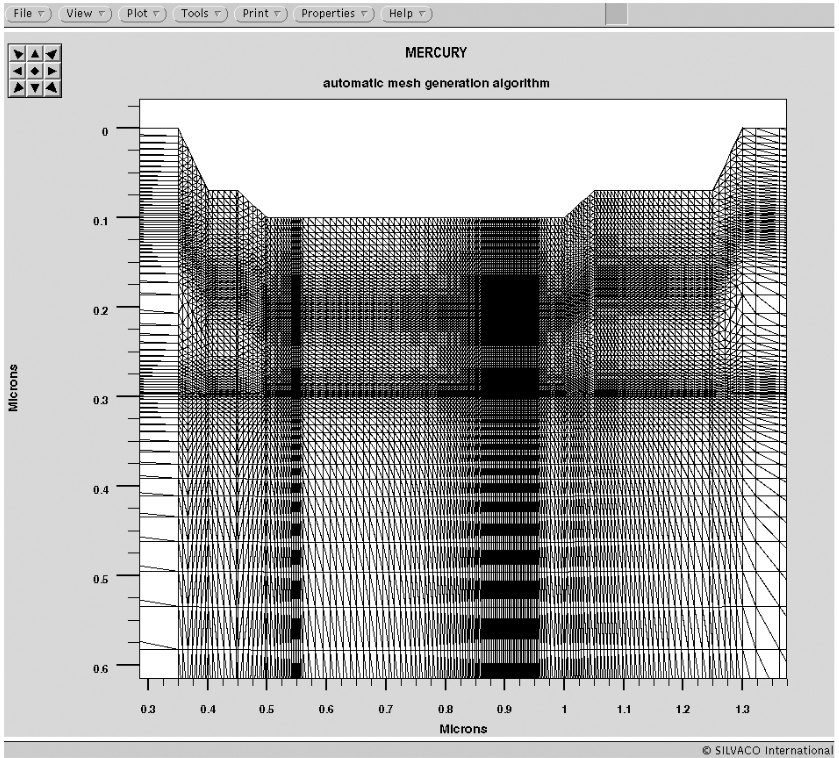
MERCURY Method: Experimentation

- Parameters which can be varied without recalculating the charge control
  - gate length
  - recess or contact lithography
  - transport models and parameters
  - extrinsic and intrinsic parasitics
  - gate workfunction
- Parameters which can be varied but do require a new charge control simulation
  - epitaxial layer materials or thicknesses
  - doping and trap densities
  - recess depth
  - trap occupation models

FastBlaze Key Features

- Two different classes of key features:
  - Advanced Physical Models
    - transport tuned using Monte Carlo Simulation
  - User Oriented Features
    - grid generation
    - bias stepping
    - direct simulation at any bias point
    - GUI for structure definition

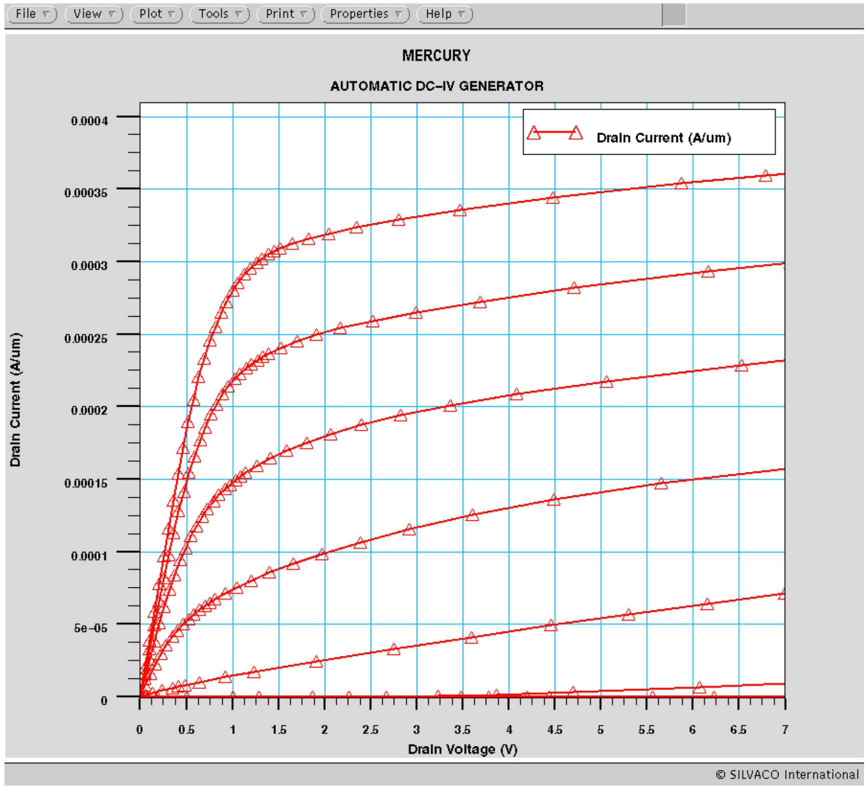
Automated Grid Generation



Mesh layout around the gate, automatically generated within MERCURY. Typical mesh size at drain edge of gate 2.8 x 0.6nm.

- Adaptive mesh refinement
- uses field solution obtained from very fine mesh (10A)
- adaptive step size control based on Taylor expansion

Automated Current Driven Bias Stepping

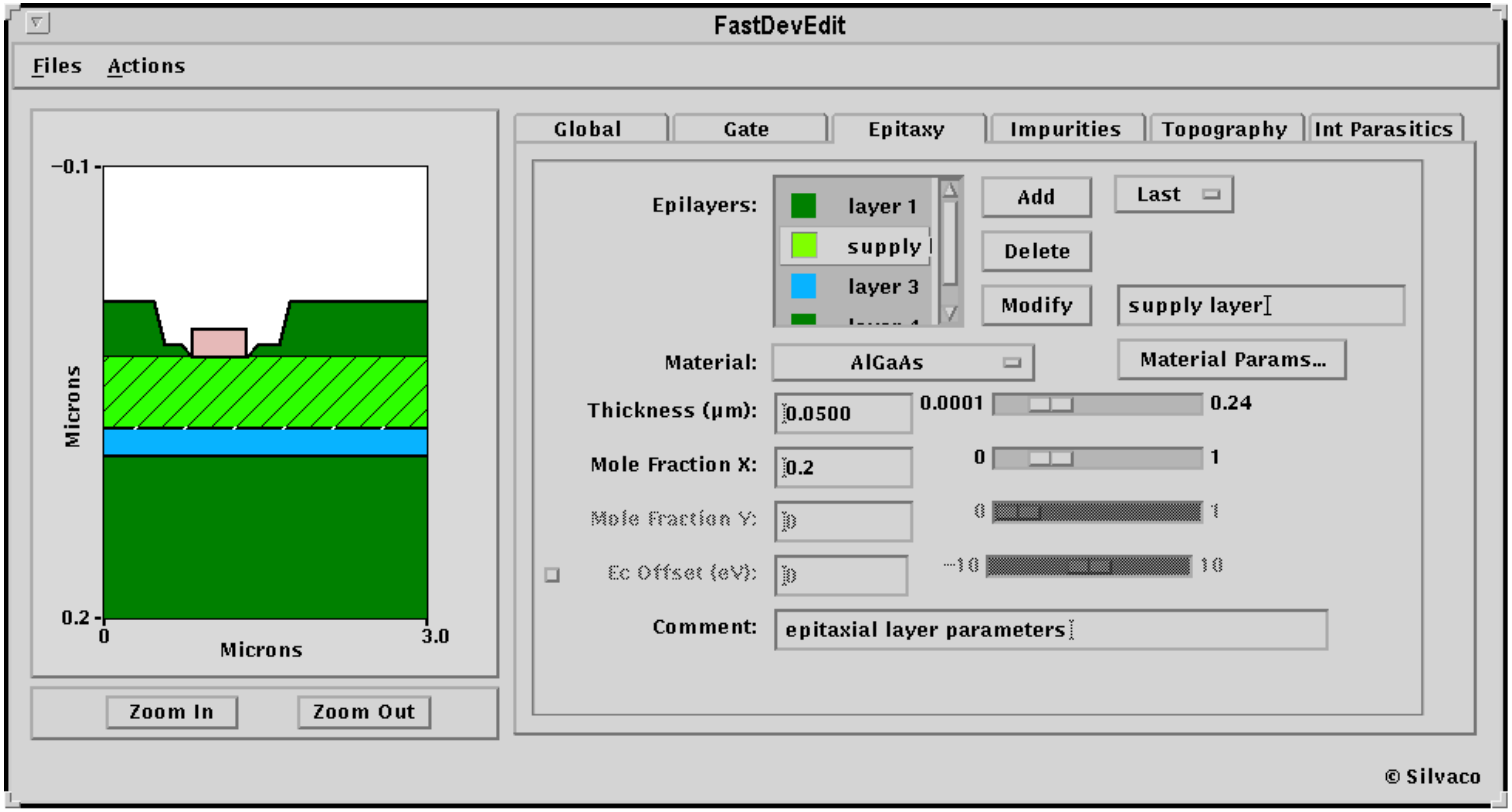


An automated DC-IV generator only samples bias points where needed. This provides a highly efficient method to characterize DC performance.

Integration with VWF Framework

- Code developed in-house to commercial standards
- Seamless integration with DeckBuild and TonyPlot
- General purpose optimization with optimizer
- RSM and advanced DOE using the VWF Automation Tools

Ultra-Fast MESFET and HEMT Device Simulator



Epilayers: 🟩 layer 1, 🟩 supply l, 🟦 layer 3

supply layer

Material: AlGaAs

Thickness (µm): 0.0500

Mole Fraction X: 0.2

Mole Fraction Y: 0

☐ Ec Offset (eV): 0

Comment: epitaxial layer parameters

A customized, FastBlaze specific, GUI enables rapid device definition. This includes the geometrical, model and solution description providing a straightforward setup of the simulation.

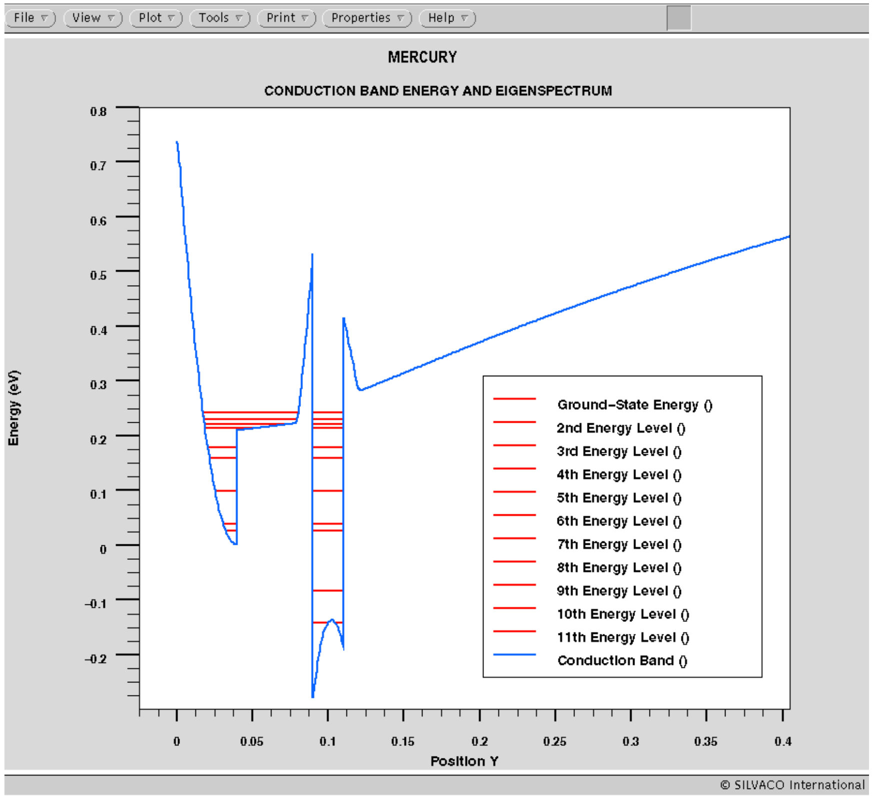
Advanced Physical Models

- Boltzmann, Fermi and Quantum Statistics
- Energy Balance always used
- Advanced transport models
  - Monte Carlo derived velocity and energy and momentum relaxation times
- Gate conduction Models (thermionic emission)
- Extrinsic parasitic simulation
- Interface and bulk traps
- Integrated with C-interpreter for user defined models

Quantum Mechanical Simulation

- Self-consistently solves the Schrodinger and Poisson equations in the charge control
  - Solves arbitrary number of bound states
  - Uses highly efficient eigen solver routine to maintain high speed
  - Shows wavefront broadening into adjacent layers

Conduction Band Energy and Eigenspectrum



The conduction band edge for a delta-doped GaAs/AlGaAs/InGaAs/GaAs pHEMT is illustrated together with the first eleven bound-state energy levels calculated using the quantum models.

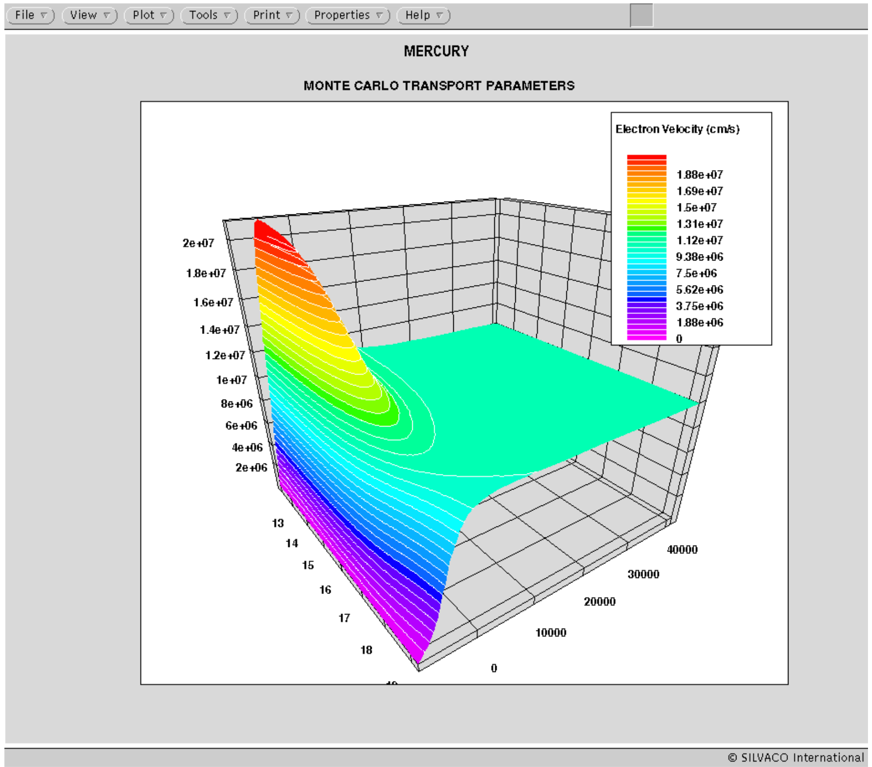
Mocasim: Monte Carlo Simulator

- A three valley ensemble Monte Carlo simulator
- Calculates bulk electron transport parameters for arbitrary three valley semiconductors
  - velocity
  - energy relaxation time
  - momentum relaxation time
- Derives four-dimensional material parameter set
  - applied field
  - doping density
  - mole fraction(s)
  - lattice temperature
- Used to derive transport parameters for device simulators such as FastBlaze

Mocasim: Features

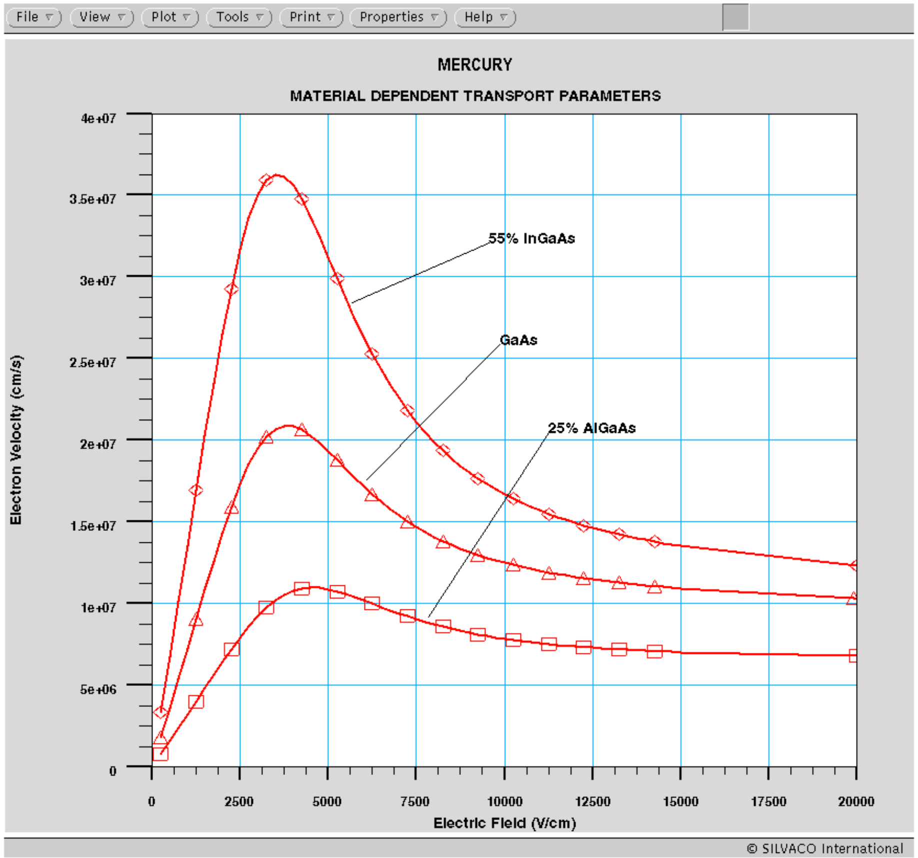
- Includes nine scattering mechanisms:
    - Polar optical phonon absorption and emission
    - Acoustic phonon scattering
    - Equivalent valley phonon absorption and emission
    - Non-equivalent valley phonon absorption and emission
    - Impurity scattering
    - Self-scattering

Monte Carlo Transport Parameters



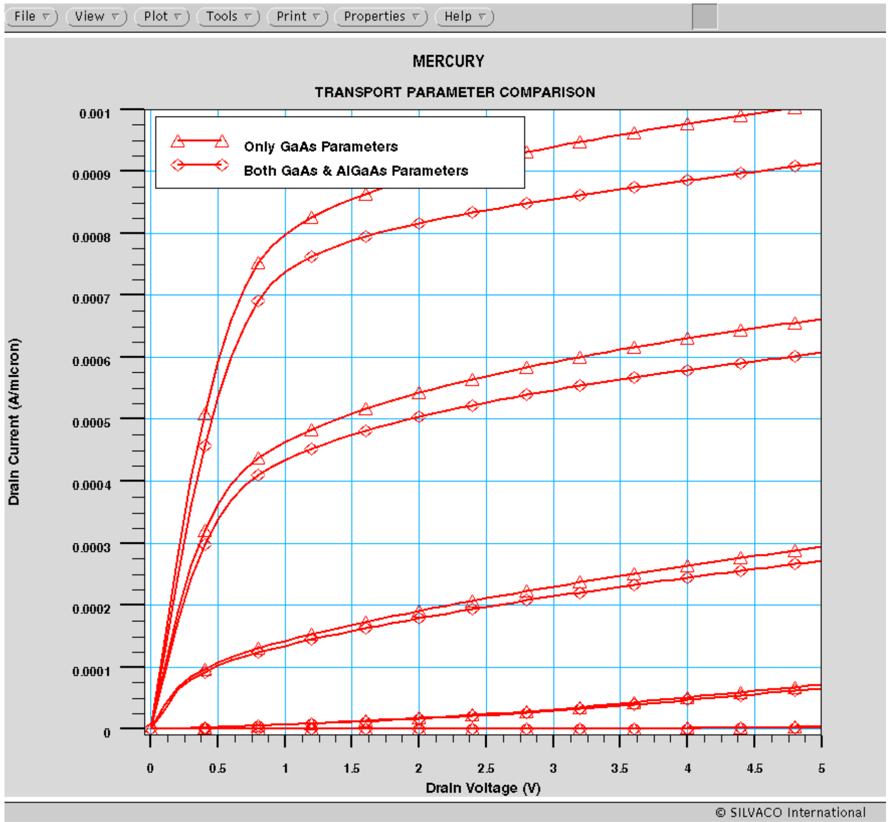
The electron velocity for GaAs at 300K is shown as a function of net impurity density and electric field. The Monte Carlo derived velocity is complemented by both energy and momentum relaxation times for a wide range of material systems.

Material Dependent Transport Parameters



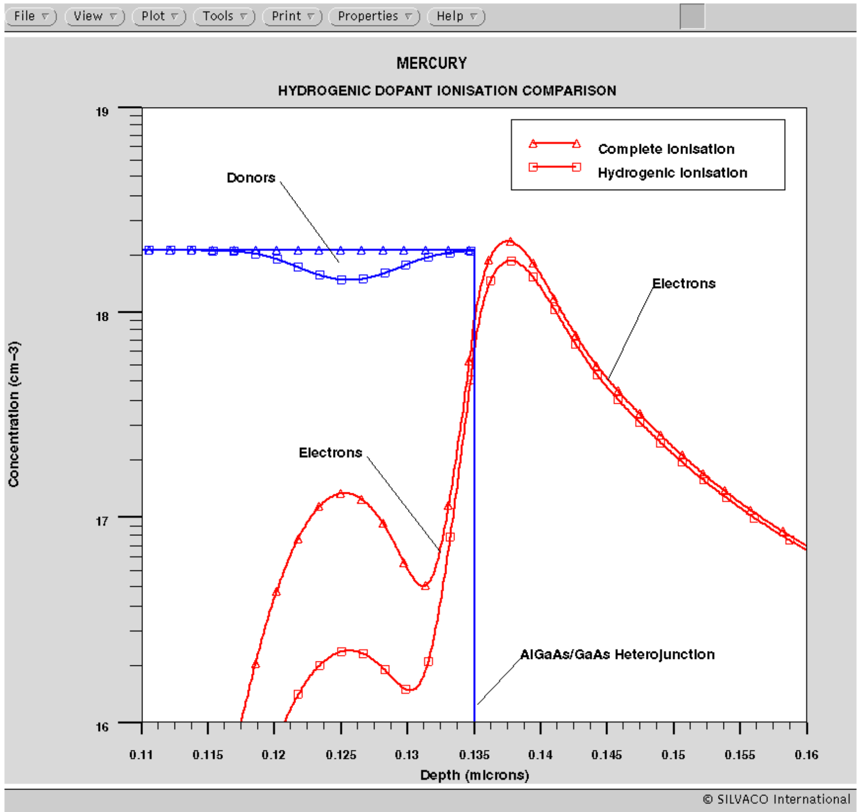
Velocity-field characteristics for various III-V materials.

Transport Parameter Comparison



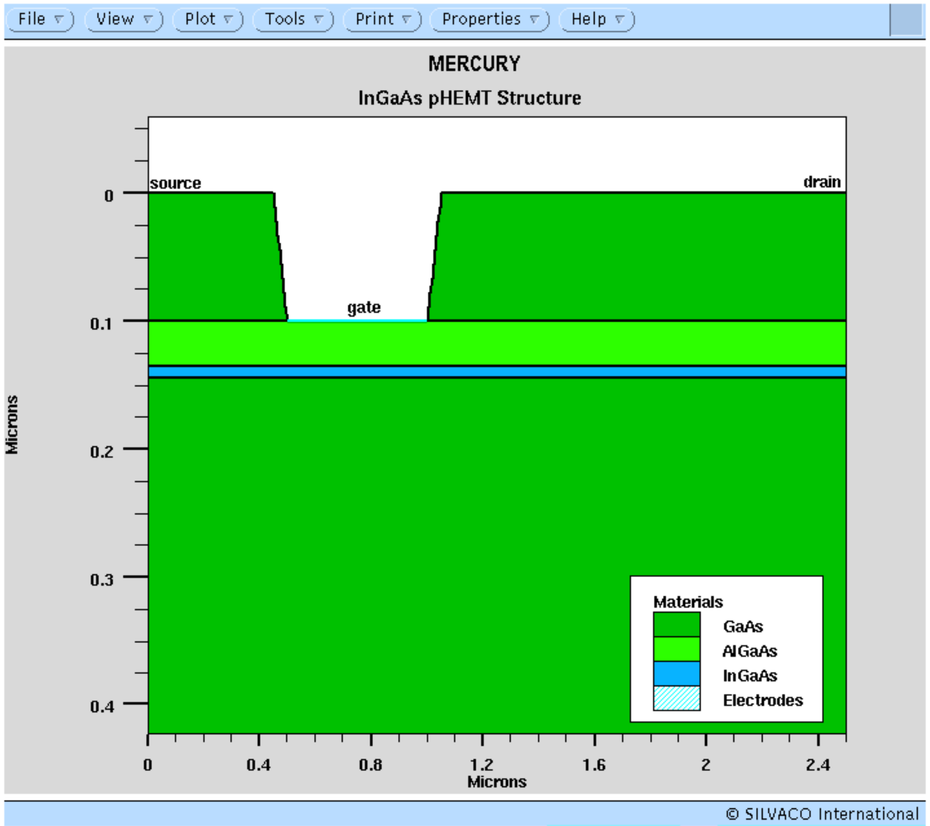
Comparison of HEMT Id-Vd using correct multi-layer transport models.
The AlGaAs transport parameters are derived from Mocasim.

Hydrogenic Dopant Ionization Comparison



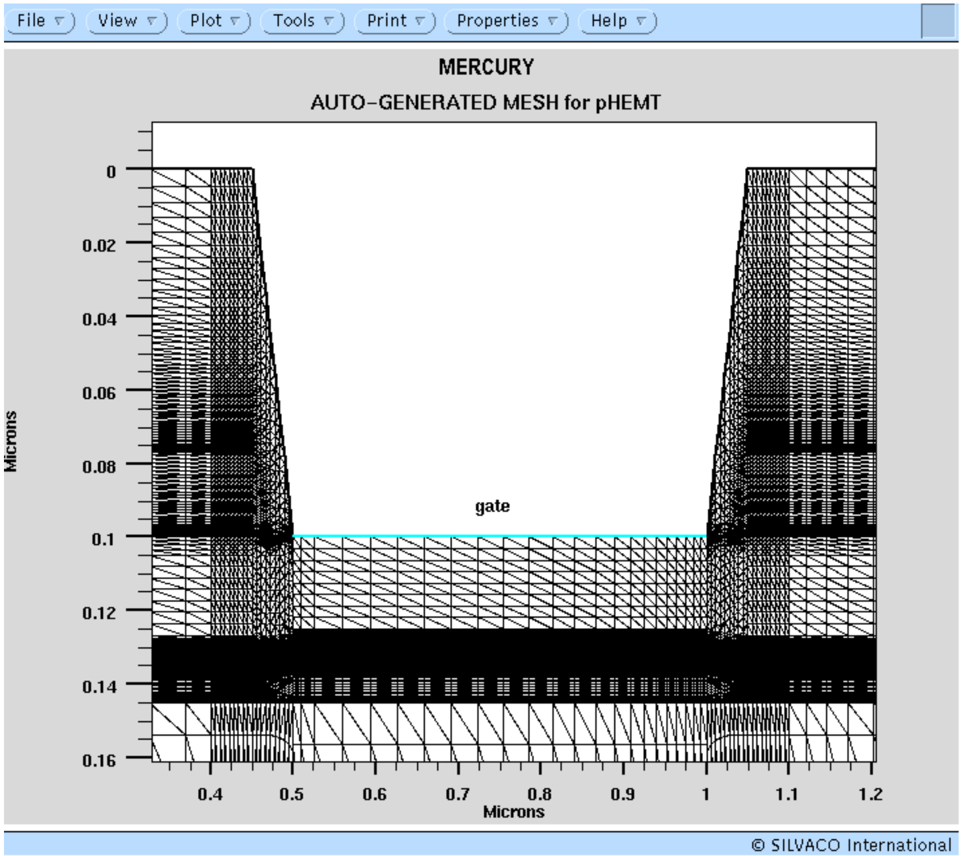
Effect of incomplete ionization on dopant and carrier densities. Both traps and dopant impurities have several occupation statistic models.

InGaAs pHEMT Structure



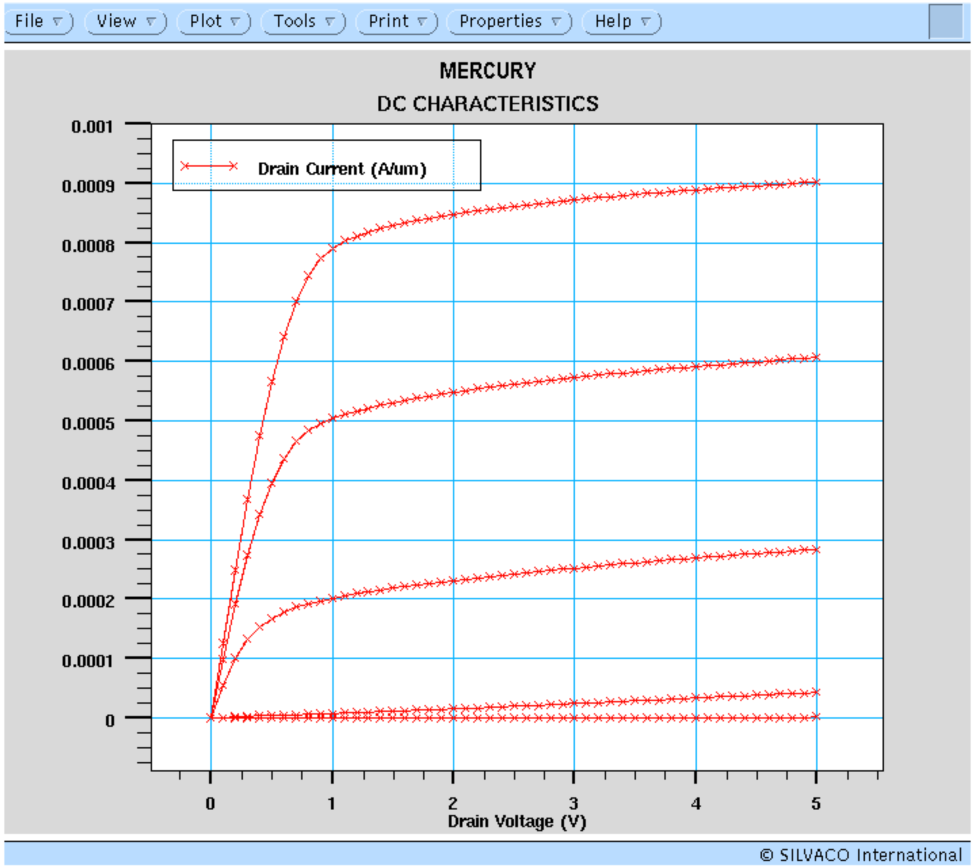
2D representation of pHEMT structure created in the MERCURY GUI.
Definition of epitaxy, doping and recess topography is menu-driven.

Auto-Generated Mesh for pHEMT



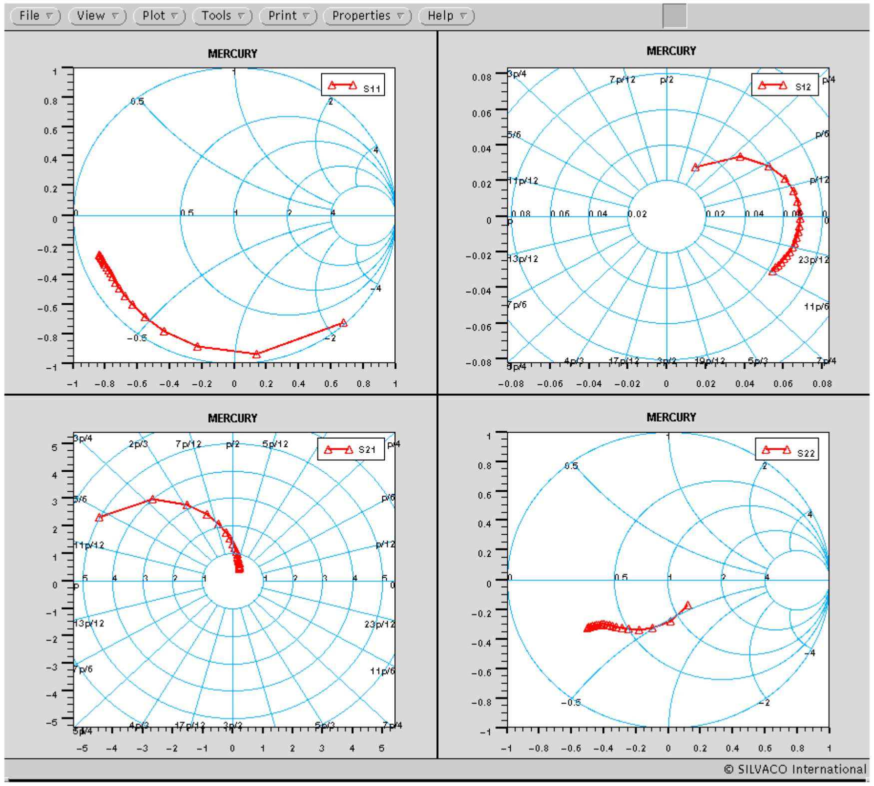
Mesh is automatically generated and focused in the pHEMT channel.

DC Characteristics



DC characteristics of the pHEMT displayed with uniform bias steps for clarity.

Small Signal S-Parameters for a pHEMT



The time-dependent simulation used for RF evaluation is able to transform directly to a variety of two-port descriptions. Here the small signal s-parameters for a pHEMT including external contact parasitics are displayed up to 25GHz.

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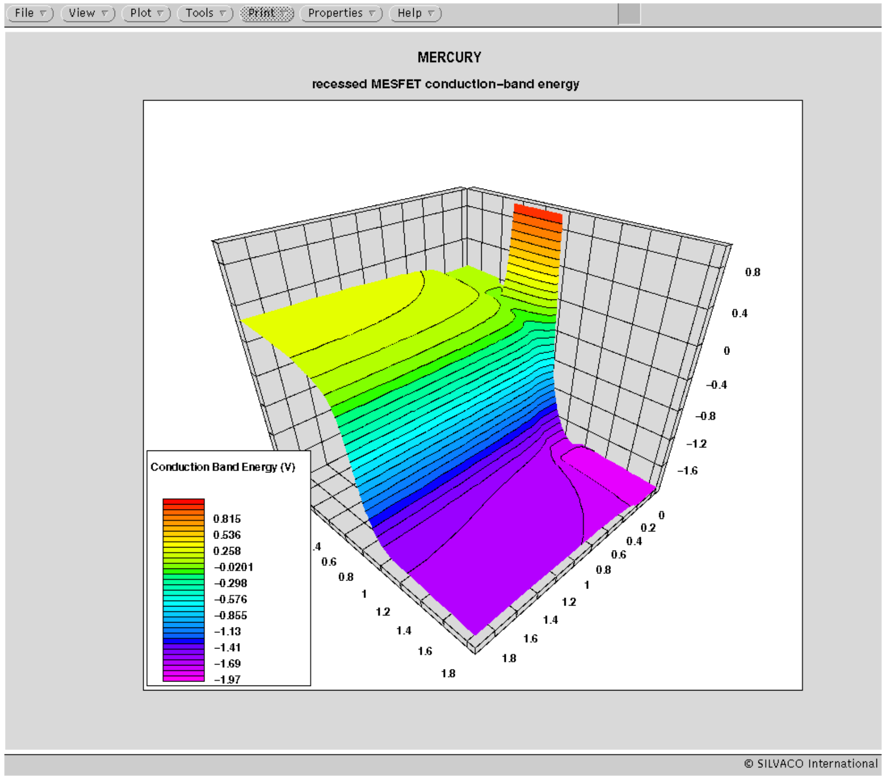
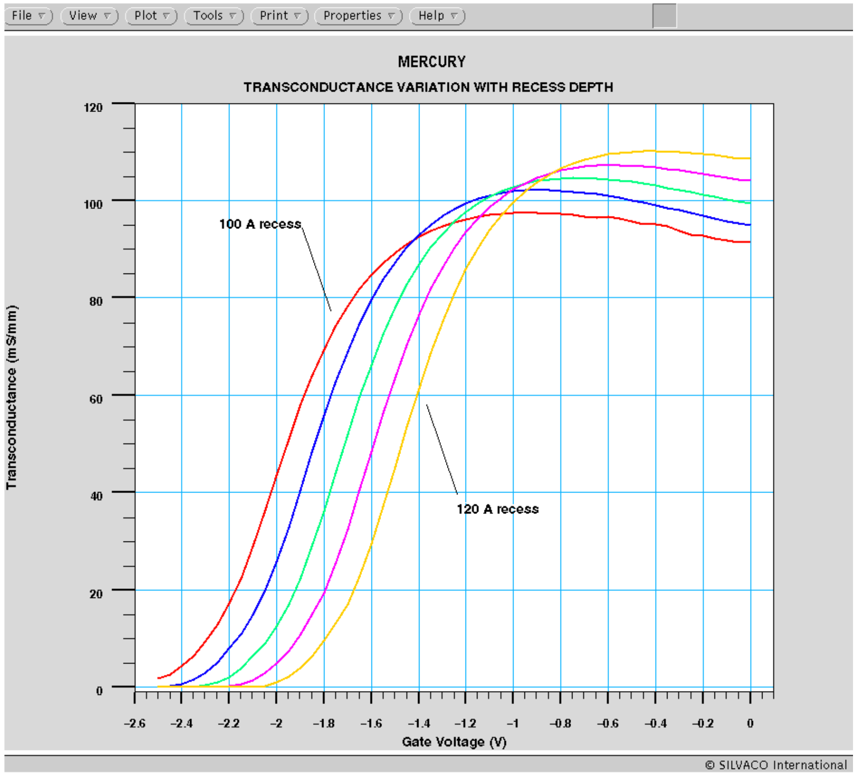
Recessed MESFET Conduction-Band Energy



Full 2D distributions are provided to allow direct visualization of the calculated physical parameters. This figure shows the conduction band edge for a recessed MESFET structure biased at VDS= 2V.

Transconductance Variation with Recess Depth



FastBlaze allows rapid prototyping of device structures in terms of topographical, epitaxial and doping variations. This figure illustrates the effect of increasing recess depth on transconductance.

Conclusion

- FastBlaze provides:
  - Ultra high speed simulation MESFETs and HEMTs
  - Uses accurate physical models
  - Monte Carlo derived parameters for modeling carrier transport
  - Powerful user interface integrated with VWF tools

MERCURY Speed Comparison

MERCURY – ATLAS Comparison

	ATLAS	MERCURY
Mesh Points	1200	7550 (auto generated)
CPU Time (s)	1400	49

- MERCURY and ATLAS were both used to simulate a planar 0.5 gate length GaAs MESFET on a SUN ULTRA 10 workstation. The total simulation time for an Id-Vd family of curves at Vg=0, -0.5V and -1.0V .