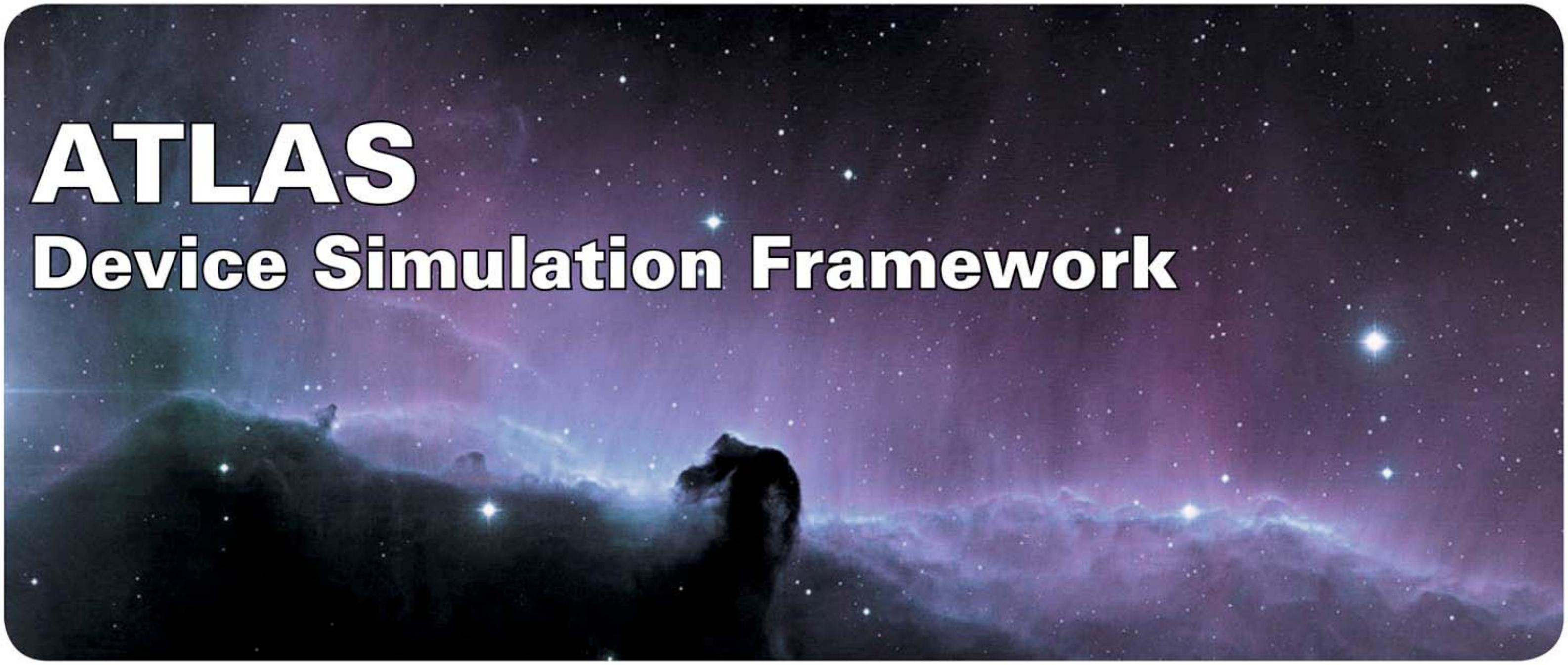
Calibrating Device Simulators



MULTI CORE TOKEN WORLD LICENSE

SILVACO

Sources of Error in Device Simulation

- Inaccurate doping profiles
- Insufficient physics
- Unknown or inaccurate material parameters
- Inaccurate model parameters
- Reliance on empirically fitted models
- Mesh induced errors
- External effects

Solving Doping Profile Errors

- This is the largest source of error for ‘small geometry devices’
    - Apply correction to doping if using SRP results
    - Use a process simulator
    - Account for CD biasing in mask edge locations
    - For further information see “Calibrating Process Simulators”

Solving Material Parameter Errors

- Silicon parameters generally well-tuned already
- For non-silicon materials, all parameters are subject to tuning
- Some parameters are substrate dependent and MUST be tuned
  - e.g. minority carrier lifetime
- Some parameters are process dependent
  - e.g. Qss

Solving Model Parameter Errors

- Remember that most models are empirically fitted to a particular set of data
- Should be used only after other errors are handled
- Most common parameters used are VSAT for saturation region tuning and Impact Ionization parameters for breakdown

Solving Mesh Errors

- Avoid obtuse triangles in the current path or high field areas
- Avoid discontinuities in mesh density
- Ensure adequate mesh density in high field areas

External Effects

- You are trying to compare measured data so you must understand your measurement system. The simulation is of a ‘perfect intrinsic device structure.”
    - External resistances
        - Long tracks in street structures, substrate contacts
    - Temperature. Simulator uses 300K. Do you?
    - Test systems use transients. Can be important for some device effects
    - Variations in measured data. Best to tune to a curve of data rather that a single point
    - Ensure extraction technique is the same
        - e.g at least 4 ways to get MOS Vt

How to Tune Device Simulators

- Problem
  - too many parameters to change
- Run many simulations
  - slow and tedious
- Use Optimizer™
  - easier, but may not converge in difficult cases
- User VWF™
  - currently only available if using parameterized input decks

How to Tune Device Simulators (cont.)

- Tactic
  - Eliminate or account for external effects
  - Measure what you can first to eliminate variables in the tuning
  - Thoroughly check all process related information
  - Use ‘unknown’ material parameters first
  - Use ‘major’ model parameters such as VSAT

Example 1: MOS Threshold

- Only 5 things affect a MOSFET threshold and you can tackle them individually to tune the simulator
  1. Doping profile (use tuned process simulator)
  2. Gate workfunction (is poly degenerately doped or not?)
  3. Surface states (controlled by QF parameter)
  4. Gate oxide thickness (input value from measurement)
  5. Short channel effects (drain doping profile)

Example 1: MOS Threshold (cont.)

- Tactic
  - Eliminate 5 by tuning to large channel length device first
  - Check 2 and measure 4 accurately to eliminate these
  - Tune 1 until result is close measurement
  - 3 has only small effect so can be used to apply final changes
  - Once large device is tuned, check 5. Probably need tuning in process simulator

Example 2: Bipolar Gain

- Many things affect this result. The most important are:
  - 1. Doping profile (use tuned process simulator)
  - 2. Correct physical models (use Models Bipolar)
  - 3. Recombinations (TAUN0, TAUP0 and Auger parameters AUGN, AUGP)
  - 4. Extrinsic resistances
  - Tactic
    - Set correct models 2
    - Measure 4 and add in if necessary
    - Check 1 by tuning to collector current in Gummel plot
    - Alter base current and hence gain by tuning using 3

Example 3: Diode Breakdown

- Could be MOSFET drain/substrate or Bipolar base/emitter. For good breakdowns set Method CLIMIT=1e4’
  - 1. Doping profile (use tuned process simulator)
  - 2. Correct physical models (may need tunneling at high doping)
  - 3. Impact ionization model coefficients (IMPACT SELB)
  - 4. Meshing
  - Tactic
    - Set correct models 2
    - Ensure you follow the rules for good mesh
    - Check 1 by SRP or tuning to forward behavior
    - Run impact and use impact parameters (AN1/AN2 for e- AP1/AP2 for h+)

Example 4: HBT Gain

- 1. Doping profile
- 2. Uniform or Graded Mole Fractions
- 3. Energy band structure
- 4. Physical models
- 5. Recombination parameters
- Tactic
  - use DevEdit to specify 2
  - modify energy bands using ALIGN or electron affinities
  - choose 4 for different materials
  - check 1 by tuning to collector current
  - alter base current by tuning 5

Lattice Heating Simulations

- Wachutka’s model of lattice heating accounts for
  - Joule heating
  - Heating/cooling from generation and recombination
  - Peltier and Thomson heating
- Lattice heating is required for many reasons
  - high power devices
  - ESD protection devices
  - SOI device operation
  - III-V material systems
  - bipolar carrier injection processes
  - accurate impact ionization
  - external heat sources

Tuning Lattice Heating Simulations

- There are four additional calibration requirements when simulating lattice heat flow
  - 1. Temperature dependent physical models
  - 2. Temperature dependent thermal conductivities
  - 3. Temperature dependent heat capacities
  - 4. Thermal boundary conditions
  - Tactic
    - choose correct models 1
    - control material heating by 2
    - transient heat flow control with 3
    - apply external heat sources/sinks 4

Energy Balance Simulations

- Energy balance simulations are required for todays technologies:
  - deep sub-micron CMOS transistors
  - advanced high mobility materials
  - accurate substrate current modeling
  - velocity overshoot effects
  - gate leakage currents
  - transconductance modeling
  - nonlocal transport phenomena

Reference: Simulation Standard article, Volume 6, Number 4, April 1995.

Tuning Energy Balance Equations

- The relaxation times of the energy balance equations are the critical parameter but are difficult to measure.
  - 1. Energy relaxation times
  - 2. Energy dependent mobilites
  - 3. temperature dependence of relaxation times
  - 4. Energy dependent impact ionization
  - Tactic

apply previous drift-diffusion calibration strategies
modify 1 to control velocity overshoot
2 is then coupled to 1
3 is uncharacterized but implemented for research purposes
specify energy relaxation length for 4

Examples of Calibration Parameters

Threshold Voltage	
Gate workfunction (WORKF)	CONTACT
Surface states (QF)	INTERFACE
Subthreshold Slopes	
Surface states (QF)	INTERFACE
Interface defect traps	INTTRAP
Discrete Bulk defect traps	TRAP
Distributed bandgap defect traps	DEFECTS
Theta	
Physical models (MOS)	MODELS
Mobility equations coefficients (DELTAN.CVT)	MOBILITY
Bipolar Gain	
Physical models (BIPOLAR)	MODELS
Mobility equations coefficients (MUN, MUP)	MOBILITY
Recombination coefficients (TAUN0)	MATERIAL
Extrinsic resistances (RESISTANCE)	CONTACT
Surface recombination (SURF.REC)	CONTACT

Examples of Calibration Parameters (cont.)

- I - V Curves

Physical models (MOBILITY, BGN)	MODELS
Mobility equations coefficients (VSAT)	MOBILITY

- Leakage Currents

Physical models (TUNNELING)	MODELS
Recombination coefficients (TAUN0)	MATERIAL
Trap density (see subthreshold slope)	

- Breakdown

Current level (Vt, Theta, Gain, etc)	
Impact ionization coefficients (SELB, AN1, BN1)	IMPACT

- EPROM Write/ Erase

Floating contacts (FLOATING)	CONTACT
Physical models (PROGRAM, ERASE)	MODELS
Tunneling equation coefficients (IG. ELINR)	MODELS
Coupling capacitances	CONTACT

Examples of Calibration Parameters (cont.)

- Lattice Heating

Physical models (LAT.TEMP)	MODELS
Thermal conductivities (TC.A, TC.B, TC.C)	MATERIAL
Heat capacities coefficients (HC.A, HC.B, HC.C)	MATERIAL
Thermal boundary conditions	THERMCONTACT

- Energy Balance

Physical model (HCTE)	MODELS
Relaxation times (TAUREL.EL)	MATERIAL
Impact ionization coefficients (LREL.EL)	IMPACT

Conclusion

- Calibration may be necessary when comparing measured data to simulated data
- Using a process simulator can increase the accuracy of doping profiles
- A good quality mesh is required in high field and hign current areas
- Always use appropriate physical models