Silvaco
TCAD
Part I - Overview

ECE 543
Spring 2005
Silvaco TCAD Simulation Modules

- **Athena**
  - 2D Process Simulator

- **Atlas**
  - 1D/2D/3D Device Simulator
  - “a modular and extensible framework for one, two and three dimensional semiconductor device simulation”

- **SSuprem3**
  - 1D Process Simulator

- **Mercury**
  - “Fast” 2D Device Simulator
  - “provides general capabilities for numerical, physically-based, two-dimensional simulation of FETs”

- **Mocasim**
  - “Advanced three-valley Monte Carlo simulator designed to generate the transport parameters used in the physical device simulators”
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General Comments

• Each module is designed to simulate a specific range of processes
• Learning the syntax of each module is similar to learning a programming language – but simple and intuitive (for the most part)
• **Very extensive manuals available for** Athena *(438 p.)*, Atlas *(two volumes; 316 p. & 332 p.)*, Mercury *(168 p.)*, Mocasim *(112 p.)*, and Ssuprem3 *(218 p.)*
Silvaco – TCAD SSUPREM3

• A FAST universal 1D process simulator with simple device simulation extensions (programming syntax)
• Predicts process doping profiles without the need for experimental backup***
• Calculates layer thickness for device simulators
• Can also be used to calculate some electrical quantities
• Most important results
  – Layer thickness of materials that make up the semiconductor structure
  – Distribution of impurities
• Mainly used to generate impurity profile for transfer into ATHENA or ATLAS

*** remember GIGO
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• Process step capabilities
  – Inert ambient drive-in
  – Oxidation of silicon, poly-silicon, silicon nitride
  – Ion implantation
  – Epitaxial growth of silicon
  – Low temperature deposition or etching of various materials
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• Can define up to ten different materials
• There are five default materials
  – Single crystal silicon
  – Polysilicon
  – Silicon dioxide
  – Silicon nitride
  – Aluminum
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- Structures can be doped with up to ten impurities
  - Boron
  - Phosphorus
  - Arsenic
  - Antimony
Silvaco – TCAD Athena

• Comprehensive software tool for modeling semiconductor fabrication processes
• Provides techniques to perform efficient simulation analysis that substitutes for costly real world experimentation
• Combines high temperature process modeling such as impurity diffusion and oxidation, topography simulation, and lithography simulation
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Athena Modules

• **ATHENA**
  – This tool performs *structure initialization and manipulation*, and provides *basic deposition and etch facilities*

• **SSUPREM4**
  – This tool is used in the design, analysis, and optimization of silicon semiconductor structures. It *simulates silicon processing steps* such as ion implantation, diffusion and oxidation.

• **ELITE**
  – This tool is a general purpose *2D topography simulator* that accurately describes a wide range of deposition, etch and reflow processes used in modern IC technologies.

• **OPTOLITH**
  – This tool performs *general optical lithography simulation* including 2D aerial imaging, non-planar photoresist exposure, and post exposure bake and development.

• **FLASH**
  – This tool is used in the design, analysis and optimization of *compound semiconductor structures*. It simulates implantation and diffusion in GaAs and other compound semiconductor materials, including SiGe.
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Athena “Shortlist”

• ATHENA Features and Capabilities
  – Bake
  – CMP (Chemical Mechanical Polishing)
  – Deposition
  – Development
  – Diffusion
  – Epitaxy
  – Etch
  – Exposure
  – Implantation
  – Oxidation
  – Silicidation
ATLAS is a physically-based two and three dimensional device simulator.

It predicts the electrical behavior of specified semiconductor structures and provides insight into the internal physical mechanisms associated with device operation.
ATLAS provides a comprehensive set of physical models, including:

- DC, AC small-signal, and full time-dependency.
- Drift-diffusion transport models.
- Energy balance and Hydrodynamic transport models.
- Lattice heating and heatsinks.
- Graded and abrupt heterojunctions.
- Optoelectronic interactions with general ray tracing.
- Amorphous and polycrystalline materials.
- General circuit environments.
- Stimulated emission and radiation
- Fermi-Dirac and Boltzmann statistics
- Advanced mobility models.
- Heavy doping effects.
- Full acceptor and donor trap dynamics
- Ohmic, Schottky, and insulating contacts.
- SRH, radiative, Auger, and surface recombination.
- Impact ionization (local and non-local).
- Floating gates.
- Band-to-band and Fowler-Nordheim tunneling.
- Hot carrier injection.
- Thermionic emission currents.
Mercury provides a comprehensive set of physical models, including:

- DC, AC small-signal, and full time-dependent analysis
- Quantum, Fermi-Dirac, and Boltzmann statistics
- Advanced energy balance transport models including Monte Carlo derived mobility, energy-relaxation, and potential energy relationships
- Abrupt heterojunctions
- Heavy doping effects
- Ohmic and Schottky contacts
- Breakdown effects including impact ionization
- Thermionic and tunneling gate currents
- General terminal circuit environments
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Mercury Modules

• **MERCURY**
  – framework supplies general capabilities that are accessed by all the device simulation products.

• **FASTBLAZE**
  – simulates devices fabricated using arbitrary semiconductors (II-VI, III-V, and IV-IV materials) and heterojunction devices.

• **FASTGIGA**
  – adds the ability to perform non-isothermal calculations that include the effects of lattice heating and heat sinks.

• **FASTMIXEDMODE**
  – offers circuit simulation capabilities that employ numerical physically-based devices as well as compact analytical models.

• **FASTNOISE**
  – adds a physically-based noise simulator.
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Part II - Examples

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Silvaco – TCAD SSUPREM3
1D process simulator

- Define mesh density in INIT step!!!
- Oxidation Example
  - Dry (slow, better quality – for FET gates)
  - Wet (fast, lower quality – for masking)
- Diffusion Example
  - Pre-deposition step (specify conc. of impurity)
  - Drive in step (extract final junction depth)
- Ion Implantation Example
  - Dose, energy, tilt
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1D/2D process simulator

- Define mesh density/grid first!!!
- Oxidation Example
- Diffusion Example
  - Pre-deposition step (specify conc. of impurity)
  - Drive in step (extract final junction depth)
- Ion Implantation Example
  - Dose, energy
- Oxidation with etch and diffusion
Silvaco – TCAD Homework

- **Chapter 3**
  - See table 3.3 for sample
  - Problem 3.21 (compare to results of 3.8)
  - Problem 3.23 (compare to results of 3.6)

- **Chapter 4**
  - See p.94 and 95 for sample
  - Problem 4.20
  - Problem 4.21

- **Chapter 5**
  - Redo Example 5.3 with Silvaco
Silvaco – TCAD Homework

• Hint: Use STATEMENTS section of manuals for help
  – P. 57 in ssuprem3_um.pdf
  – P. 251 in athena_users.pdf
    • Also look at chapter 2 in this particular manual for a short Athena tutorial
    • this is optional, but if you go through this tutorial, you’ll almost have your homework done!

• Specific info about manuals
  – Pcitools.pdf
    • Page 49 has details on EXTRACT command for ssuprem3 (Chapter 2 in this manual)
  – TonyPlot has built in help that you might want to investigate