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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SSUPREM3

- Structures can be doped with up to ten impurities
  - Boron
  - Phosphorus
  - Arsenic
  - Antimony

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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
  - Silicidaion

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Atlas

- 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.

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Atlas

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.

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Mercury

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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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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Athena

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