

# EEE 533: SEMICONDUCTOR DEVICE AND PROCESS SIMULATION

*Spring 2001*

**COURSE OBJECTIVE:** This course will introduce the students to the basic concepts of semiconductor device and process simulation, finite-difference discretization schemes for the solution of Poisson's and electron and hole current continuity equations. Several numerical techniques for solving large systems of linear equations will be covered. Students will also get a working knowledge of SILVACO, the commercial software for process and device simulation. Various parameter extraction schemes will be presented as well. At the end, a number of topics relevant for state-of-the-art MOSFETs will be covered, including quantum-mechanical space-quantization, short-channel (small geometry) and random dopant effects. Modeling of alternative device structures, such as SiGe and SOI devices, will also be discussed.

**PREREQUISITES:** EEE 436 or 531, or instructor's consent.

**INSTRUCTOR:** Dr. Dragica Vasileska (ERC565; phone: 965-6651, e-mail: [vasilesk@imap2.asu.edu](mailto:vasilesk@imap2.asu.edu)).

**OFFICE HOURS:** MW: 3pm - 5pm.

**CLASS MEETING:** MWF 8:40-9:30 in BAC328.

**COURSE MATERIAL:** Handwritten lecture notes (Noble library copy center), technical papers.

**REFERENCES:** Silvaco Manuals (computer: [enuxsa.eas.asu.edu](http://enuxsa.eas.asu.edu) and [enuxha.eas.asu.edu](http://enuxha.eas.asu.edu); location: /ug/silvaco/doc/html directory); S. Selberherr, *Analysis and Simulation of Semiconductor Devices*, 1984; C. M. Snowden, *Introduction to Semiconductor Device Modeling*, 1987. All three references can be found at the reserve section of the Noble Science Library.

**TOPICS COVERED:** **Device Modeling:**

1. **Carrier Modeling:** effective mass concept, intrinsic and extrinsic semiconductors, doping, incomplete ionization of the dopants, density of states function, equilibrium carrier distribution, carrier concentration calculations, introduction to the Fermi level concept, carrier concentration temperature dependence.
2. **Carrier Action:** drift, mobility, diffusion, Einstein relations, generation and recombination mechanisms, electron and hole continuity equations and their range of validity, Poisson equation, Fowler-Nordheim tunneling, hydrodynamic equations.
3. **Physical Parameters:** Carrier mobility modeling, carrier generation-recombination modeling, thermal conductivity modeling, thermal generation modeling.
4. **Drift-Diffusion Simulations:** choice and scaling of variables, boundary conditions, and general procedures of device modeling.
5. **Discretization of the Basic Semiconductor Equations:** finite difference scheme, discretization of the Poisson equation, Sharfetter-Gummel discretization scheme for the continuity equation, numerical solution of the Poisson and continuity equations (*direct methods*: LU decomposition; *iterative methods*: Gauss-Seidel, successive-over-relaxation), numerical solution schemes of the coupled system of nonlinear algebraic equations (Gummel's and Newton's scheme).

**Process Modeling:** Ion implantation, Diffusion, Oxidation.

**Parameter Extraction of small signal equivalent circuit element values:**

1. **Review of Y, Z and S parameters**
2. **FET Small Signal Equivalent Circuit Model Topology:** extrinsic and intrinsic elements.
3. **Parasitic Extraction Methods Based on Electrical Measurements:** Optimization and direct and semi-direct parameter extraction of extrinsic parasitics, such as  $R_g$ ,  $R_d$ ,  $R_s$ ,  $L_g$ ,  $L_d$ ,  $L_s$  (Fukui method, Cold chip and 3 bias level method, Cold chip-differential method).

### Getting started using Silvaco:

1. **VWF (Virtual Wafer Fab Framework) Interactive Tool:** TonyPlot (interactive graphics and scientific visualization), DeckBuild (tool invocation), DevEdit (Structure editor for specifying and modifying structures, such as meshing module, doping definition using analytical models).
2. **ATLAS-Device Simulation Software:** Overview of ATLAS, features and capabilities of ATLAS, Using ATLAS with other SILVACO software, ATLAS input and outputs, syntax, defining a structure, defining material parameters and models, choosing numerical methods, obtaining DC and small signal AC solutions, interpreting the results, solution files, S-PISCES (silicon MOS Devices, BJT's, floating gate structures, MOS reliability modeling, SOI simulation).
3. **ATHENA-2D Process Simulation Software:** Overview of ATHENA, features and capabilities of ATHENA, ATHENA input/output, using ATHENA/SSUPREM4 (simulating ion implantation, diffusion and oxidation, epitaxy process).

### Advanced Topics:

1. **Quantum-Mechanical Space Quantization Effect:** 1D Schrödinger equation and its solutions, introduction to SCHRED, modeling MOS structures using SCHRED and examining the shifts in the threshold voltage and the total gate capacitance.
2. **Small-Geometry Effects in Deep-Submicrometer MOSFETs**
3. **Random Dopant Fluctuations in Deep-Submicrometer MOSFETs**
4. **Modeling of SOI and SiGe Devices**

<b>GRADING:</b>	Homework assignments:	30%
	Term-project and report:	35%
	Final project and report:	35%

- MISCELLANEOUS:**
- (1) Due to the software and projects requirements, the number of students will be limited.
  - (2) Only one simulation job per student is allowed at any given time. This is to ensure fair distribution and availability of computer resources to all students. Violating this rule will mean automatic withdrawal from the course and *F* grade.
  - (3) Students need to work independently on the projects. Teamwork is highly encouraged for the homework assignments. Any programming language can be used for the term-project.