# EE 542 Semiconductor Device Physics
# Fall 2009

*Professor:*
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Office Hours: M 10:30 AM – 11:30 noon ; W 4:30 p.m. - 6:00 p.m.
Course Web Site: http://angel.psu.edu

**1. Meeting Times** Monday, August 25 – Friday, December 12, 2007

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| Section 1 (Datta) | Lecture | M W F | 12:20 PM – 1:10 PM | 365 Willard |

## 2. Introduction

In this course, we learn the relevant concepts in quantum mechanics and statistical mechanics pertaining to understanding the key physical mechanisms that govern the electrical, optical and even mechanical behavior of semiconductor materials and devices. This course explicitly deals with the graduate level fundamental physics of operation of electronic devices, and expounds on the practical aspects of device design given the inherently non-ideal nature of semiconductor devices in real life. In addition to learning the device physics fundamentals, the course will feature broad-based discussions regarding the ongoing state-of-the-art research concerning semiconductor devices.

Nanoelectronics today is a very broad discipline that extends the traditional solid-state active and passive devices such as transistors, diodes, resistors, capacitors, photodetectors, laser diodes commonly found in electronic and optoelectronic integrated circuits to a variety of emerging technologies such as large area flexible electronics, energy conversion devices, chemical and biological sensors, microelectromechanical devices. A continuous trend of fundamental breakthroughs at the materials and device architecture level keeps this field exciting and opens up new application space hitherto unexplored. The opportunity exists for you to get introduced at a broad level to each of these areas. This course will serve as a cornerstone of your graduate education in the Materials and Device area whether you join the 275 billion dollar global semiconductor industry or you decide to enter the doctoral program in the area of advanced materials and devices.

## 3. Prerequisite:

You must have completed EE 442 or a course equivalent with a grade of “B” or better for admission into this course.

## 4. Textbook

*Required*: Fundamentals of Modern VLSI Devices Yuan Taur and Tak H. Ning, Cambridge University Press, 1998. Physics of Semiconductor Devices S. M. Sze and Kwok K. N, Third Edition, Wiley Solid-State Electronic Devices Sixth Edition B. Streetman and S. K. Banerjee

## 5. Educational Objectives:

The lecture sessions provides learning opportunities that should enable you to do the following upon completion of this course:

**A.** Develop a basic understanding on the following key concepts in quantum and statistical mechanics relevant to physical properties of electronic materials and their device applications:

*i. Quantum Mechanics:*

Crystal structure of solids; space lattices; wave particle duality; Schrodinger's wave equation; particle trapped in a box; particle tunneling through a barrier; allowed and forbidden energy bands; propagating electron wave in a periodic lattice; effective mass; density of states; quantization effects in nanoscale devices

ii. *Statistical Mechanics:*
The Fermi-Dirac and Maxwell-Boltzmann probability distribution function; the Fermi energy;

iii. *Equilibrium vs non-equilbrium properties:*
Carrier distribution at equilibrium; doped semiconductors; compensated semiconductor; carrier transport phenomena; hall effect; excess carriers in semiconductors; continuity equation; Poisson's equation

iv. *p-n junction:*
Energy Band Diagram; Forward and Reverse Bias; Full depletion analysis; Transient Response of P-n junction; Linearly graded junction; Abrupt p-i-n junction; Hetero p-n junction; Forward bias Diode current (minority and majority carrier current); High injection effects; Generation and recombination current ; Heterojunctiondiode current; Reverse bias Diode breakdown

v. *Bipolar junction transistors:* Principle of Operation; Minority Carrier Profiles in a Bipolar Junction Transistor; Current Components and Current Gain; Bias modes and operation of bipolar transistor; Ebers-Moll Model; Turn on and off transients; Transit times; Non-ideal effects; Base width modulation; High injection effects; Base spreading resistance and emitter current crowding; Breakdown mechanisms in BJTs; BJT small signal equivalent circuit model; Heterojunction Bipolar Transistors

vi. *MOS Capacitors:* Surface Charge in Metal Oxide Semiconductor Capacitors; Capacitance-Voltage Characteristics of a MIS Structure; Low frequency capacitance; High frequency capacitance ; Deep depletion capacitance;

vii. *Metal Oxide Semiconductor Field Effect Transistors (MOSFETs):* Gradual Channel Approximation and Constant Mobility Model; Charge Control Model; Threshold Voltage; Onset of Pinchoff and Current Saturation; Sub-Threshold Characteristics; Substrate Bias Effects; Temperature effects; Effective Mobility concept in MOSFETs; Velocity Saturation Effects in MOSFETs

viii. *Short Channel MOSFETs:* Charge Sharing Model; Drain induced Barrier lowering (DIBL); Sub-threshold Current; 2D capacitor Model; Geometric Screening Length or Electrostatic Scaling Length Scaling; Constant field scaling; Constant voltage scaling; Inversion Layer Thickness or Quantum Capacitance; ITRS Discussions; Channel Dopant Engineering; Series Resistance in scaled MOSFETs; Effective Channel Length; Gate Resistance; Complementary Logic Circuits

**B.** Become proficient with the fundamental device physics concepts

**C.** Learn to analyze device characteristics in detail and brainstorm ways towards improving them or adapting them to new applications

## 6. Grading Policy:

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| Lecture Related: | Homework/Other | 25% | |
| | Mid Term | 30% | |
| | Final Exam | 40% | |
| | *Subtotal:* | | 95% |
| Instructor's Discretion: | Attendance/class participation | 5% | |
| | *Subtotal:* | | 5% |
| | *Totals:* | | 100% |

## 7. Attendance:

Attendance at all lecture classes is expected. If you have a conflict with a scheduled exam or with the submission of any in-class assignments, you must make arrangements with your instructor well in advance so that alternate times can be scheduled.

## 8. Homework:

Homework will be collected in class on most Fridays. For a specific list of homework assignments and due dates, see the course calendar on ANGEL. You may consult with other students and with your instructor while you are working on assigned problems but your goal in consulting should be limited to exploring options and approaches rather than avoiding work. The ability to solve problems develops through disciplined effort and the exams will require you to be able to solve problems. To obtain full credit for a homework assignment you must submit it to your instructor in class on the due date as described in the homework policy posted on ANGEL.

## 9. Academic Integrity

Most students are honest and work hard for their grades. There should not be an alternate route to a passing grade and a diploma. We expect that all graded work will be done without assistance from anyone else, unless the instructor has explicitly indicated otherwise. Incidents of academic dishonesty will be dealt with according to University policy. The current policy may be found at http://www.psu.edu/dept/oue/aappm/G-9.html