ECE 4214: Semiconductor Device Fundamentals
VIRGINIA TECH
Course Syllabus (CRN *12177)*
Spring 2011 MW 2:30-3:45 (Room: *RAND 116)*

I. ECE 4214 SEMICONDUCTOR DEVICE FUNDAMENTALS

Instructor: Prof. Mantu Hudait, Dept. of ECE, 626 Whittemore Hall
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Office Hours: Tuesday: 1:30-2:30 and by appointment (e-mail please).

Course Description:

The course will cover the device physics and device applications: Fundamental semiconductor device physics associated with semiconductor devices and in-depth understanding of p/n junction diodes, bipolar junction transistors, MOS capacitor, and junction field effect transistors.

Learning Objectives:

Having successfully completed 4214, students will be able to:
- Determine the band structure of semiconductors when supplied with basic materials properties and applying their knowledge of quantum mechanics.
- Calculate carrier distributions in thermal equilibrium and non-thermal equilibrium conditions for intrinsic and doped semiconductors.
- Apply basic semiconductor drift-diffusion equations to determine current flow in semiconductor devices.
- Differentiate between the fundamental difference of p/n junctions and field effect transistors
- Determine alignment of metal-semiconductor band diagrams and identify whether junction is Ohmic or Schottky.
- Design a bipolar transistor, metal-oxide-semiconductor and/or a field effect transistor that meet specific performance criteria through the selection of the appropriate semiconductor material(s), doping, and device dimensions.

II. PREREQUSITES & COREQUISITES

Pre: ECE 2204 or ECE3254 or PHYS 3455

The student will be introduced briefly the fundamentals of quantum mechanics. But some prior knowledge of this topic and solid-state physics will also help.

Related and Advanced Coursework:

- ECE 4234: Principles of semiconductor (VLSI) processing (I)
- ECE 5204: Power Semiconductor Devices (II)
- ECE 5200/5205/5206: Graduate-level semiconductor device courses (Solid-State Materials and Devices, High-Speed and Optoelectronic Devices)(I/II)

III.   TEXTS AND SPECIAL TEACHING AIDS

Required Text

D.A. Neamen, *Semiconductor Physics & Devices*, 3rd ed., McGraw-Hill, 2003 ; Hardcover, 768 pages©2003, ISBN-13 9780072321074.

Additional Reference Books:
* indicates more advanced material relative to the course textbook

- Umesh Mishra and Jasprit Singh, *Semiconductor Device Physics and Design*, Springer, 2008 (e-book available through www.lib.vt.edu)
- *M. Shur, *Physics of Semiconductor Devices*, Englewood Cliffs, NJ: Prentice Hall, 1990.
- J. Singh, *Semiconductor Devices: Basic Principles*, New York, NY: Wiley, 2001.
- B.G. Streetman and S. Bhattacharya, *Solid State Electronic Devices*, 4th ed., Englewood Cliffs, NJ: Prentice Hall, 1995.
- *S.M. Sze, *Physics of Semiconductor Devices*, 3rd ed., New York, NY: Wiley, 2007
- *S. Wang, *Fundamentals of Semiconductor Theory and Device Physics*, Englewood Cliffs, NJ: Prentice Hall, 1989.
- Robert Pierret, "Semiconductor Device Fundamentals", 1st or 2nd ed. [1996, Addison-Wesley or 2002, McGraw-Hill]

IV. 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:

Carrier distribution and field profile at a p-n junction; diode I-V characteristics and non-idealities, diode capacitance.

v. MOS capacitors and field effect transistors:

Understand and interpret C-V characteristics; understand the physical structure and detailed operation of Metal-Oxide Semiconductor Field-Effect Transistors (MOSFETs); understand the terminal I-V characteristics of MOSFETs and their associated non-idealities due to scaling; high electron mobility transistors.

vi. Optical devices:

Understand the physical operation of solar cell and its efficiency limits; heterojunctions to improve efficiency; potential impact on global energy crisis and light emitting diodes.

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

V.   SYLLABUS

Section 1

Topic	Number of Lectures
1. Crystalline Structures	1
2. Basic Quantum Mechanics and Bandgaps	2
3. Band Diagrams	1
4. Carrier Concentration and Fermi Level	3
5. Drift-diffusion and Carrier Mobility	2
6. Recombination and Generation of Carriers	3
7. Measurement of Resistivity and Mobility	Reading Materials
8. Exam 1	

Section 2

1. p-n Diodes	3
2. Schottky Diodes and Ohmic Contacts	1
3. Heterostructures	1
4. Bipolar Transistors	5
5. Exam 2	

Section 3

1. Field Effect Transistors	5
2. Final Exam	

VI.   GRADING POLICY

Homework/other	20%
Exam I	20%
Exam II	20%
Final Exam	40%
	100%

Home Work

Homework problems will be typically be assigned on a weekly basis and will be due at the end of class one week following its assignment. Homework may be turned in one day late with a 25% deduction. **No assignments will be accepted beyond one day late,** except in the case of unforeseen, officially documented absences.

Each problem solution should be **neatly worked out**. If a given assignment requires multiple pages of work, it must be stapled together prior to submission. Use neatly trimmed 8.5" x 11" paper and write on one side only. When possible, sketch illustrative diagrams and label current, voltage, and other relevant quantities on the

diagrams. Very rough sketches with no labels will receive no credit. Use industrially accepted notation for units, per discussion on Day 1 of class.

I will collect ALL assigned problems for grading. *However, all problems may not necessarily be graded*. I expect you to have worked ALL the problems and to be prepared to submit the problem solutions in the above format <u>at the end of class on the date due</u>.

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.

In-Class Activities:

There will be regular activities assigned during class, which will require your participation and may result in a submission at the end of the class period. I will grade you on your preparation for these activities, your level of participation, and the conclusions that you draw from these activities. These activities should help strengthen your understanding of the course materials and assist in preparing you for the exams.

Exams:

There will be 2 exams *tentatively* scheduled for the weeks of 3/15 and 4/19. **No make-up exams will be given** except for unforeseen, <u>officially documented</u> absences. If such a circumstance arises on a test date, it is your responsibility to contact me as soon as possible. If you expect to be absent on a test date for any legitimate reason (conferences, job interviews, project team competitions, etc.), it is your responsibility to give me sufficient prior notice so that we can make other arrangements. There will be a **FINAL exam** at the end of this course.

Academic Integrity:

The Virginia Tech Honor Code establishes the standard for **ACADEMIC INTEGRITY** in this course, and will be strictly enforced. *Discussion* of class material with your classmates or the instructor is encouraged; however, ALL submitted work, must represent your own efforts, and you must pledge to this effect on all work. For more details on the relevant honor codes, consult the websites listed below:

o   Undergraduate Honor System, http://www.honorsystem.vt.edu/index.html
o   Graduate Honor System, http://filebox.vt.edu/studentinfo/gradhonor/

Announcements:

I will use Scholar to post lecture notes, homework assignments, homework solutions, and other information pertaining to the course materials. You should check your email and the Scholar on a regular basis.

Attendance:

Attendance all lecture classes is expected and critical to your successfully completing the requirements of this course. While I may periodically check attendance against the class roll, I have no *explicit* penalties for your missing class. However, chronic absenteeism will be noted, and I will not be inclined to give such individuals the benefit of the doubt in judgment situations such as borderline final grades. In the event that you miss a lecture, it is <u>your</u> <u>responsibility</u> to obtain the missed notes from one of your classmates or from Scholar. 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.