Course: ECE 609 Semiconductor Devices

Instructor: Zlatan Aksamija (zlatana@engin.umass.edu)

Meeting Times: Tuesday and Thursday 11:30 am - 12:45 pm in ELab RM 327

Office Hours: 201B Marcus Hall, Tuesday and Thursday (times TBD)

Course Description (based on SPIRE): In-depth examination of semiconductor devices. The physics of semiconductors, p-n junction diodes, bipolar transistors, Schottky barriers, JFETs, and MOSFETs. Beyond CMOS devices will be explored through additional readings and term paper.

Prerequisite: E&C-Eng 344, or introductory semiconductor theory or device course.

Course Vision: this course serves two purposes: 1) as a graduate-level course in semiconductor devices for students interested in further study of this topic (aka the specialists), and 2) as a core PhD course in the semiconductor area for a broad array of students in the doctoral program (the generalists). As such we have the two-fold goal of depth and breadth—depth for the sake of the first group (the specialists) and breadth for the sake of the second group (the generalists). For these reasons, we will cover semiconductor materials and the underlying physics in some depth (Chapter 1), and then we will launch into a fairly broad survey of semiconductor devices, starting with junctions (Chapters 3-4), bipolar transistors (Chapters 6-7), and metal-oxide-semiconductor transistors (MOSFETs in Chapters 8-10). Because of the breadth requirement, we will not be able to cover all devices (the list is very long!!!) so we will have a series of reading assignments to complement the lectures, culminating in a term paper on a beyond-CMOS devices of each student's choice.

Course Goals:

- To understand the physical structure and electrical properties of semiconductor materials.
- To master the fundamental concepts and equations of semiconductor device analysis, and apply them to the description of semiconductor junctions and structures.
- To understand how the terminal characteristics of junction diodes, bipolar transistors, and field-effect transistors derive from device structure and material properties.

"Required" Textbook: "Modern Semiconductor Devices for Integrated Circuits" by Chenming Calvin Hu https://www.amazon.com/Modern-Semiconductor-Devices-Integrated-Circuits/dp/0136085253

this is a very nice text covering most of the topics in ECE609. It is particularly good for devices in the second half of the course. Pdfs of chapters will be posted in Moodle and assigned as reading on Perusall (also linked on Moodle) when they are covered in the lectures.

Suggested (supplemental) Textbooks:

Best for 1st half of the course: "Semiconductor Physical Electronics" by Sheng S. Li. Available (free?) via SpringerLink: https://link.springer.com/book/10.1007%2F0-387-37766-2

"Device Electronics for Integrated Circuits" by Muller, Kamins, and Chan http://www.amazon.com/Device-Electronics-Integrated-Circuits-Richard/dp/0471593982/ref=sr_1_32?ie=UTF8&qid=1452102821&sr=8-32&keywords=semiconductor+devices

Additional Resoureces: free and comprehensive on-line textbook "Principles of Semiconductor Devices" by Bart Van Zeghbroeck, available at http://ecee.colorado.edu/~bart/book/

Good print book: **"**Advanced Semiconductor Fundamentals" by Robert F. Pierret

Webpage: the course uses Moodle (http://moodle.umass.edu) for notes, homework handouts and solutions, announcements, and discussions. Lecture slides and/or scanned handwritten notes of the lectures will be uploaded after each section of the course. Please use the discussion forum in Moodle to ask questions relating to course content and homework. Questions asked via email, unless they pertain to a student individually, will be posted on Moodle and answered there.

Video Recordings: Lecture videos containing PPT slide, blackboard video and lecture audio will be posted via a link in Moodle to ECHO360. There may be a several day delay between recording and the lecture video being ready to post; in addition, not all lectures are guaranteed to be made available due to unforeseen technical issues with ECHO360 software.

Assignments: consisting of 8 homework problem sets (1 per chapter), 4 quizzes, participation, term paper, midterm, and final exams

- 8 homework problem sets (1 for each chapter) assigned on a (roughly) 1.5 weekly schedule worth 15% of the total grade. Homework assignments are due on the stated due date. No late homework will be accepted under any circumstances.
- However, the lowest HW grade will be dropped in computing the final grade.
- Homework assignments will be a mix of textbook problems and numerical problems based on Matlab or the nanoHUB.org, including code and figures. For such assignments, you will submit all your codes and figures, as will be specified in each HW handout.
- HW assignments will be submitted electronically via Moodle. After the HW deadline, solutions to the HW will be released and you will have an opportunity to "self-grade" your HW (only mark correct those answers that match my solutions, nothing else). Then you turn in a paper copy of your HW along with corrections for an improved grade.

Homework corrections must be complete, detailed, include an explanation of the error(s) in your HW, and **written on a separate sheet** in order to qualify for credit.

- Conceptual lecture-based quizzes will be administered in the form of tutorials given in office hours. These tutorial-quizzes will be around 15 minutes and will count for 10% of the total grade. More information about scheduling them will be provided in lecture.
- 5% of the grade will be based on in-class participation and solving lecture problems
- Term paper will be a 4-page journal-style write-up about a device of your choice, due last day of lecture and worth 20% of the grade.
- Mid-term exam will be given March 5-7 and is worth 20% of the total grade.
- The final exam will be held in early May. There will be a final review earlier that week (time and location TBD). The final will be cumulative and worth 30% of the total grade.
- Make-up exams will be given only if you provide a valid written excuse and notify me *prior* to the missed exam. Other missed exams will be considered failures.

Course Inclusivity Statement: "The diversity of the participants in this course is a valuable source of ideas, problem solving strategies, and engineering creativity. If you feel that your contribution is not being valued for any reason, please speak with me privately. If you wish to communicate anonymously, you may do so in writing or speak with Dr. Paula Rees, Director of Engineering Diversity Programs (rees@umass.edu, 413.545.6324, Marston 128). We are all members of an academic community where it is our shared responsibility to cultivate a climate where all students are valued and where both they and their ideas are treated with respect."

Course Topics:

1. Semiconductor Electronics Fundamentals:
    a. Crystal structure
    b. Basic quantum mechanics: single-electron Schroedinger equation
    c. Energy gaps and electronic structure: the Kronig-Penney model
    d. Density of states and carrier statistics in equilibrium
    e. Carrier transport: scattering mechanisms and mobility
    f. Carrier motion: drift and diffusion
2. Metal-Semiconductor Contacts
3. pn Junctions:
    a. basic principles and electrostatics
    b. Generation-recombination processes
    c. Currents in pn Junctions—ideal diode law
    d. Non-idealities: junction breakdown mechanisms
4. Midterm Exam and spring break, start class project

5. Select junction devices:
    a. Heterostructures
    b. pn junction field effect transistors (JFETs) and MESFETs
6. Bipolar Transistors (BJTs): Basic Properties and Models
7. Properties of the Metal-Oxide-Silicon System
8. MOS Field-Effect Transistors I: Physical Effects and Models
9. MOS Field-Effect Transistors II: High-Field, Short-Channel, and Sub-Threshold Effects