ELECTRICAL ENGINEERING & COMPUTER SCIENCE
COLORADO SCHOOL OF MINES

EENG 421 – Semiconductor Device Physics and Design

Fall 2016

Course Description: This course will explore the field of semiconductors and the technological breakthroughs which they have enabled. We will begin by investigating the physics of semiconductor materials, including a brief foray into quantum mechanics. Then, we will focus on understanding pn junctions in great detail, as from this device we can extrapolate to many others (bipolar transistors, LEDs, solar cells). We will explore these topics through a range of sources (textbooks, scientific literature, patents) and discuss the effects they have had on Western society. As time allows, we will conclude with topics of interest to the students (possibilities include quantum devices, MOSFETs, lasers, and integrated circuit fabrication techniques).

Prerequisites: EENG 385 and/or consent of instructor.

By the end of the course, you will be able to:

1. Explain what a semiconductor is and how to change its properties (through doping, application of a voltage potential, etc.)

2. Use a band diagram to explain how a pn junction diode works

3. Describe how innovations in semiconductor devices (the integrated circuit, high efficiency white LEDs, improved solar cells) has changed our world (modern computing, energy efficiently lighting, alternative energy).

4. Identify the idealities in device models and understand their limitations

5. Apply the concepts learned in class to the design of novel devices or improvement of an existing device

6. Characterize the difference between devices of the same "family" (BJTs vs. MOSFETS, lasers vs. LEDs vs. photovoltaics)

7. Explain concepts to a broad audience through varied forms (written, multimedia, etc.)

Instructor and meeting times:

Stephanie Claussen, Ph.D. (sclausse@mines.edu) Office location: Brown 251

Office hours: Monday 3-4:30pm, Wednesday 10-11am, and Friday 8:30-10am, and by appointment.

My views on teaching and learning:

This semester, I will strive to…

… help you make connections that increase your conceptual understanding. These connections could be to past learning, to the current material, to future applications and fields, and to the broader world around you. Assessment and the classroom environment will be aligned to help accomplish this goal.

… create an interactive learning environment which supports your learning, where you feel comfortable asking questions, exposing any gaps in your understanding and helping each other learn.

…motivate and inspire you. Semiconductor devices have enabled the society we live in today, which I will emphasize and constantly remind you of. Real-world examples in homework assignments and course projects will be used to highlight the potential career pathways engineering provides.

…remind you that engineering is a human endeavor that can make a positive impact on the world. At its core, engineering leads to products and technologies that affect people world-wide. In engineering, there aren't always right answers. Rather, we have answers we believe are the "most right" at this moment. Engineering always requires tradeoffs, and an engineer's background and values impact how these tradeoffs are made.

Textbook:

R.F. Pierret, *Semiconductor Device Fundamentals* (required)

D. Neamen, *An Introduction to Semiconductor Devices*, 1st edition (supplemental)

S.M. Sze, *Physics of Semiconductor Devices*, 3rd edition (supplemental)

B. Streetman and S. Banerjee, *Solid State Electronic Devices*, 6th edition (supplemental)

Course reading: Reading from Pierret will be assigned each lecture. Supplemental reading will also be provided (articles, scientific papers, websites). Some reading will be specified as "Required." "Required" reading must be completed before the start of class. Completing this reading on time will count towards your participation grade.

Assignments and assessment:

- *Participation*: Active participation in class and in office hours is very important for your learning. This will include working in small groups on short problems, asking questions, brainstorming solutions as a class, and working together and with your instructor outside of class. In addition, participation in class discussions via Piazza is encouraged. Student questions posted on Piazza will be responded to by the instructors before emailed questions.

- *Homework:* Weekly homework assignments will consist of problems ranging from the math-intensive to open-ended. You are encouraged to work together, but your work and answers must be your own. Some assignments will be longer and more substantial than others.

  Homework will be assigned on Wednesday and due the following Wednesday in class, unless otherwise noted. There is no penalty for late homework, though it will not be accepted beyond one week after the due date, except for Homework 5 which will not be accepted beyond the date/time of the midterm exam. Homework 10 must be turned in by the last day of class.

- *Midterm and final exams:* These exams will be used to assess your understanding up to the current point in the course. The questions will be similar to those asked on homework assignments and in class. The final will cover material *since* the midterm.

- *Final project:* The final project can be completed in groups or individually. They will consist of a multimedia product (a video, a website, a comic book….). You will be expected to meet with and propose your initial project idea to the instructor, and present it to the class at the end of the course.

The point distribution for these assignments is:

Attendance and participation	10%
Homework	25%
Midterm Exam	22.5%
Final Exam	22.5%
Final project	20%

The letter grades for the course are awarded according to the following criteria:

A	92 - 100%	Exceeds expectations in an outstanding manner.
A–/B+	89 – < 92%	Meets expectations.
B	81 - < 89%	Meets most expectations.
B–/C+	77 - < 81%	Meets most expectations, with minor reservations.
C	69 - < 77%	Meets some expectations
C–/D+	64 - < 69%	Meets some expectations with minor reservations.
D	58 - < 64%	Meets only a few expectations.
D–	55 - < 58%	Meets only a few expectations but with reservations.
F	0 - < 55%	Unacceptable performance.

Attendance policy: Attendance in classes is encouraged and is very important. It is not directly graded, but participation (in a variety of forms) will be. Occasionally attendance may be recorded as evidence of participation. Official absences for university sanctioned events or documentable illnesses are recorded, and students may request make-up times for missed quizzes and exams and extensions for homework and project due dates which will normally be allowed by the instructor. Similar requests for unofficial absences may be allowed at the discretion of the instructor.

Academic Dishonesty Policy

The consequences of academic dishonesty at the Colorado School of Mines are severe and can lead to expulsion. It is imperative that each student take responsibility for their education and adhere to the Academic Dishonesty Policy.

The policy on homework allows students to work on the homework together in groups. However, all students must turn in individual homework (unless otherwise stated) and they must understand what they turn in. Copying of solutions without understanding them is not allowed. If a student copies a solution and cannot explain it adequately it is considered academic dishonesty. For computer exercises, each student is expected to generate their own solution. One cannot copy another person's computer solution and modify it slightly to make it look like it is their own work. All external sources used must be referenced and cited in their entirety.

Each student should read and abide by the Academic Integrity Policy, provided on-line at: http://inside.mines.edu/UserFiles/File/policies/STU/AcademicIntegrityPolicy.pdf.

Each student should also read and abide by the Student Honor Code, provided online at: http://inside.mines.edu/UserFiles/File/policies/STU/Student%20Honor%20Code.pdf

EENG 421 Fall 2016 Course Schedule

Class	Date	Topics	Reading and homework
1	Mon., Aug. 22	Introduction. Course overview.	
2	Wed., Aug. 24	Introduction to semiconductors. Crystal structure and quantization.	Course syllabus. Pierret 1.2–1.2.3 (p. 6-11).
3	Fri., Aug. 26	Basic principles of quantum mechanics	
4	Mon., Aug. 29	Introducing Schrodinger's wave equation and its implications. Energy band theory.	Pierret 2.1-2.2.2 (p. 23-29).
5	Wed., Aug. 31	Energy band model vs. bonding model. Intro to carrier statistics.	Pierret 2.2.3-2.3.3 (p. 29-35)
6	Fri., Sept. 2	State and carrier distributions	Pierret 2.4 (p. 40-49).
	Mon., Sept. 5	Labor day – No class!	
7	Wed., Sept. 7	Equilibrium carrier concentrations	Pierret 2.5.1-2.5.3, 2.5.6 (p. 49-57, 61-64) (**required)**. **Homework 1 due.**
8	Fri., Sept. 9	Doping	Pierret 2.3.4-2.3.5 (p. 35–40)
9	Mon., Sept. 12	Determining extrinsic carrier concentrations.	Pierret 2.5.4, 2.5.5, 2.5.7, 2.6 (p. 57-61, 65-67).
10	Wed., Sept. 14	Carrier I - Drift	Pierret 3.1 (p. 75-89). **Homework 2 due.**
11	Fri., Sept. 16	Carrier transport II – Drift and mobility	
12	Mon., Sept. 19	Carrier transport III – Diffusion, drift + diffusion	Pierret 3.2 (p. 94-104).
13	Wed., Sept. 21	Carrier transport IV	**Homework 3 due.**
14	Fri., Sept. 23	Intro. to non-equilibrium. Carrier generation and recombination.	Pierret 3.3.1, 3.3.3 (p. 105-116).

15	Mon., Sept. 26	E-k diagrams – "Why are there no Si LEDs?"	Pierret 3.3.2 (p. 107-109).
16	Wed., Sept. 28	Generation/recombination II	Pierret 3.3.4, 3.5 (p. 116, skim p. 117-120, p. 131-136). **Homework 4 due.**
17	Fri., Sept. 30	Transient behavior	Pierret 3.4 (p. 120-131).
18	Mon., Oct. 3	Introduction to pn junctions	Pierret 5.1.1-5.1.3 (p. 195-202).
19	Wed., Oct. 5	Midterm review	**Homework 5 due.**
	Fri., Oct. 7	Class canceled (tentative)	
	Mon., Oct. 10	**Midterm exam**	
20	Wed., Oct. 12	pn junction electrostatics I	Pierret 5.1.4, 5.1.5, 5.2-5.2.2 (p. 203-215).
21	Fri., Oct. 14	Introduction to forward & reverse biased pn junctions	Pierret 5.2.3-5.2.4 (p. 215-221).
	Mon., Oct. 17	Fall break – No class!	
22	Wed., Oct. 19	pn junction diode – I-V characteristics	Pierret 6.1.2-6.1.3 (p. 241-249). **Homework 6 due.**
23	Fri., Oct. 21	pn junction diode – I-V characteristics II	Pierret 6.1.4 (p. 249-259).
24	Mon., Oct. 24	pn diode non-idealities	Pierret 6.2 (skim) (p. 260-281).
25	Wed., Oct. 26	Bipolar Junction Transistors (BJTs) I	Pierret 10.1-10.4 (p. 371-382). **Homework 7 due.**
26	Fri., Oct. 28	BJTs II	Pierret 10.5 (p. 382-384), Pierret 11.1 (*optional*, p. 389-407).
27	Mon., Oct. 31	BJTs III	

28	Wed., Nov. 2	Introduction to MOSFETs	Pierret 15.2.1-5.2.2, 16.2, 17.1 (p. 530-536, 565-571, 611-617). **Homework 8 due.**
29	Fri., Nov. 4	Comparison of transistors: MOSFETs vs. BJTs	
30	Mon., Nov. 7	Introduction to photonic devices	Pierret 3.3.2 (review- p. 110-112).
31	Wed., Nov. 9	Photovoltaics I	Pierret 9.3 (p. 356-361). **Homework 9 due.**
32	Fri., Nov. 11	Photovoltaics II	
33	Mon., Nov. 14	LEDs I	Pierret 9.4 (p. 361-368).
34	Wed., Nov. 16	Introduction to solid state lighting	
35	Fri., Nov. 18	LEDs II	
36	Mon., Nov. 21		
	Wed., Nov. 23	Thanksgiving – No class!	
	Fri., Nov. 25	Thanksgiving – No class!	
37	Mon., Nov. 28		**Homework 10 due.**
38	Wed., Nov. 30		
	Fri., Dec. 2	**Final project presentations**	
	Mon., Dec. 5	**Final project presentations**	
	Wed., Dec. 7	Last day of class. Final review.	