ECE 618: Fundamentals of Solid State Electronics II

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Welcome to ECE 618!

- **Course:** ECE 618 Fundamentals of Solid State Electronics II
- **Web page:** [http://blogs.umass.edu/eceng618-zlatana/](http://blogs.umass.edu/eceng618-zlatana/)
- **Instructor:** Zlatan Aksamija
- **E-mail:** zlatana@engin.umass.edu
- **Meeting Times:** MWF 10:10-11:00 in room 305 Engineering Labs
- **Office Hours:** MWF 12:30-1:30 walk-in at my office 201B Marcus Hall???
Course Description

- This is a course in semiconductor physics, focusing mostly on a description of electron transport and electron interactions beyond the drift-diffusion (continuum) level description covered in introductory semiconductor device course.

- You were taught things like electron (and hole) mobility and relaxation time; in this course we learn where they come from and how they are calculated.

- The course is aimed at ECE, Physics, and “Materials Science” graduate students who are interested in the fundamentals of semiconductor physics as it pertains to semiconductor devices and nanostructures, but without a strong focus on device design.
Course Coverage and Topics

- Physical (crystal) and electronic structure of semiconductors,
- Band theory including pseudopotentials, $k.p$, and tight-binding,
- Semiconductor statistics, scattering processes including electron-phonon interactions,
- Carrier transport based on the Boltzmann transport equation, optical properties
- Modern quantum electronic devices including transport in inversion layers, confined/nano-structures, heterostructures and interfaces.
Relationship to other courses

- **Prerequisite**: ECE 607 or equivalent knowledge of basic quantum mechanics. Essential background will be reviewed in the first few lectures of the course.

- **“Co-requisite”**: ECE 609—this course is scheduled right after 609 for a reason: the two courses are meant to work together.

- While ECE 609 covers devices with some semiconductor physics, we will complement it by going into the details of electron properties (bandstructure), electron statistics (distribution function), electron interactions (scattering with phonons, impurities, other electrons, etc.) and electrons dynamics (Boltzmann transport equation, confined structures, quantum devices).
Course assignments

- Your grade is composed of 3 parts: homework/quizzes, exam and final project
- ~6 homeworks assigned on a bi-weekly schedule
- Homework collected each time next homework is assigned
- Homework is intended for practice only and will be graded mostly on completion rather than a detailed grade
- Homework completion scores count 5% of the grade
- 6 bi-weekly homework assignments will be followed by an in-class discussion/problem class and a short in-class homework quiz
- 5 best homework quiz scores count 25% of the grade
- Exam will be a comprehensive take-home exam, 35% of the grade; date for exam to be decided
Final Project

- Develop a Matlab/Octave/C/Java/Python code to simulate a physical process or implement a calculation based on a topic covered in class, based on your own research, or based on reading a research or review paper.
- Project can be done individually OR in teams of 2, however:
  - Give conference-level talks individually and present a collaborative paper following guidelines and formatting for a research journal.
  - All presentations are 15 min plus 5 min for questions.
- Project can be selected to enhance your own research project.
- Final presentation is worth 10% and project report is 25% of the grade.
- Presentation grade will be based on class feedback.
- Final presentations will be held the last week of class.
- Final project report is due the last day of class with automatic extension until the last day of final exams.

- Most of the course material will come from this book and we will follow its layout and coverage for the majority of the course.
- This is also a classic reference text that every graduate student in the semiconductor area should own.
Supplemental Textbooks

“Fundamentals of Semiconductors: Physics and Material Properties” by Peter Y. Yu and Emanuel Cardona (Springer)
  • A little more on the physics side, but an excellent textbook with great coverage of electronic structure, electron scattering rates, and transport in chapters 2, 3 and 5, respectively

“Basic Semiconductor Physics” by Chihiro Hamaguchi (Springer)
  • Great coverage of transport in chapter 6 and quantum structures in chapter 8. Overall an accessible textbook with excellent explanations.

“Fundamentals of Carrier Transport” by Mark Lundstrom (Cambridge University Press)
  • Very accessible textbook requiring less quantum mechanics background than the previous 3 offerings. Focuses more on transport and spends a lot of time discussing the various electron scattering rates and transport equations, with some introduction to numerical simulation via Monte Carlo and Rode’s method.
Other Resources: Sister courses at other schools

- ECE535: Theory of Semiconductors and Semiconductor Devices at the University of Illinois Urbana-Champaign
  - http://courses.engr.illinois.edu/ece535/
  - Check out how much homework they have!
  - Very nice practice final exam

- MIT Open Courseware for EECS6.73 Physics for Solid State has some of the same coverage
  - Some lecture notes available
Online resources: NanoHUB.org

- The NanoHUB is an excellent resource providing an on-line community portal
- Key features:
  - Lectures (slides+video/sound) by leading researchers in the nano area
  - Tools: simulation widgets with nice GUIs on various topics, especially in electronic structure, electron and phonon transport
  - Great way to interact with topics in electronic structure, transport, and even thermal properties
- Go to http://nanohub.org and set up a free user account
- Hosted by Purdue University, network of contributors
- Could be used for projects (some tools even have source code available, many are in Matlab)
Let’s do a quiz to learn about your background

1. Q: What is the crystal structure of Si and Ge (group IV) called? A: diamond structure (technically it is two interpenetrating face-centered cubic lattices).

   How about GaAs and InP (III-Vs)? A: zinc-blende

2. Q: What is the equilibrium distribution function of electrons? A: Fermi-Dirac

   Q: Write down the equation. A: \( f_{FD}(E) = \frac{1}{1+\exp[(E-E_F)/(k_BT)]} \)

3. Q: What is the difference between a semiconductor and a metal?

   A: normally we say a semiconductor has a gap but more accurately we should say that the Fermi level is in or near the gap, or that there are few or no states near the Fermi level in a semiconductor.

   Q: What happens we they come in contact? A: Fermi levels align causing either a Shottky barrier or an ohmic contact depending on the work function of the metal.

4. Q: Which equation governs the electrostatic potential inside a semiconductor? Write down the equation. A: Poisson equation \( \nabla^2 V = \rho \)

Thank you for your attention!

- Questions?