

**Course:** ECE 618 Fundamentals of Solid State Electronics II

**Instructor:** Zlatan Aksamija ([zlatana@engin.umass.edu](mailto: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

**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. The course is aimed at ECE, Physics, and Material Science graduate students who are interested in understanding the fundamentals of semiconductor physics as it pertains to semiconductor devices and nanostructures, but without a strong focus on device design. The course will cover 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, and modern quantum electronic devices including transport in inversion layers, confined/nano-structures, heterostructures and interfaces. Prerequisite: ECE 607 or equivalent knowledge of basic quantum mechanics. Essential background will be reviewed in the first few lectures of the course.

**Suggested Course Textbook:** “Advanced Theory of Semiconductor Devices” by Karl Hess (IEEE Press).

- 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.

### **Course Topics:**

1. Introduction and brief review of classical and quantum mechanics
2. Crystal and lattice structure and brief overview of group theory
3. Energy Bands in Crystals:
  - a. Free and nearly-free electron model
  - b. Fourier analysis, band extrema
  - c. Pseudopotential method
  - d. k.p perturbation method and effective mass
  - e. tight-binding or LCAO method for band structure
4. Imperfections and defects in semiconductor crystals
  - a. Shallow impurity levels—Dopants
  - b. Deep impurities
  - c. Dislocations, surfaces, interfaces
5. Equilibrium statistics and electrostatics
  - a. Density of states
  - b. Carrier Statistics
  - c. Self-consistent Poisson equation
  - d. Dielectric properties and screening
6. Carrier Scattering and Interactions
  - a. Introduction, Drude theory, simple models
  - b. Phonons revisited: lattice vibrations in the harmonic approximation
  - c. Matrix elements for scattering, Fermi Golden rule
  - d. Deformation potential (acoustic phonon) scattering
  - e. Optical, polar optical, and inter-valley phonon scattering
  - f. Piezoelectric potential scattering
  - g. Ionized Impurity scattering
  - h. Carrier-carrier and Plasmon scattering
7. Electron transport
  - a. Boltzmann transport equation (derivation)
  - b. Collision integral and solutions of the BTE
  - c. Equilibrium, steady-state, and detailed balance

- d. Relaxation time approximation and low-field mobility
  - e. High-field transport and hot carrier effects
  - f. Velocity overshoot and saturation
8. Transport in quantum structures
- a. Electronic bands and Density of states of confined/nanoscale structures
  - b. Inversion layers and transport in a 2-d electron gas
  - c. Heterostructures and transport parallel to and across interfaces
  - d. Confined structures and quantum transport

**Assignments:** bi-weekly homework, mid-term and final project.

Your grade is composed of 3 parts: homework and homework quizzes, midterm exam and final project

- 6 homeworks assigned on a bi-weekly schedule
- Homework collected each time next homework is assigned, but ultimately due at the exam practice class and last day of class
- 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
- Mid-term exam will be a comprehensive take-home exam, 35% of the grade

**Final Project:**

- Project will be computational in nature
- 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