SYLLABUS
ELEC 261: ELECTRONIC MATERIALS AND QUANTUM DEVICES
SUMMER 2017

Credit Hours: 3

Time and Place: Online Course — Summer Session III: June 26 - July 28, 2017

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Course Objective: This is an introductory solid state physics course that focuses on the atomic-scale physics behind the transport of electricity in materials and its fundamental role in modern electronic, optoelectronic, and themoelectric devices. While the primary focus of this course is on the classical and quantum mechanical views of electronic properties of solids, it will also include discussions on dielectric, optical, magnetic, mechanical, and thermal properties. It will not only cover past and current commercial processor and memory technology based on silicon, but will also highlight the physics behind ongoing research on possible alternatives and novel materials. Students will also learn basic scientific presentation and writing skills.

Required Textbook: James D. Livingston, *Electronic Properties of Engineering Materials* (Wiley, 1999)

Class Format: Flipped classroom. Students are required to watch video lessons and answer an online quiz BEFORE each classroom session. Classroom time (live sessions) will be devoted to questions & answers, discussions, and problem solving under the guidance and facilitation of the instructors and teaching assistants. There will also be separate online advising sessions by teaching assistants.

Engagement Time: (5 hours of engagement time per lecture day)

- 1.5 hour video lectures (1 hour of video split into 4-5 videos)
- 1.0 hour problem set solving and QA session (LIVE SESSION)
- 0.5 hours of independent problem solving
- 0.5 hours of video quiz and supplement videos
- 0.5 hours of readings

- 1 hour left per day
  - research paper/presentation (4 hours per week)
  - followup activities with the guest lectures for the week/open ended topic discussions (forums ~ 1 hour per week)

Grading: 45% – Exams (2 midterm and 1 final), 25% – Homework, 20% – Research Paper & Presentation, 5% – Module Quizzes, and 5% – In-Class Attendance

Exams: There will be two midterm exams and one final exam. They are take-home (off-line) exams. Exams MUST be an individual effort, and any violations of this will be considered violations of the Rice Honor Code.

Research Paper and Poster Presentation: You will write a 3-page paper regarding electronic materials and quantum devices. A minimum of 10 sources are required. A list of suggested topics will be provided, but there is some flexibility regarding this assignment concerning your topic. This paper can be about a materials property (electrical, optical, magnetic, thermal, mechanical) or a device (a field-effect transistor, a laser diode, a quantum cascade laser, etc.). The topic should be an area of great interest to you as you will be expected to be an expert on the subject after this assignment. In addition to summarizing the history and current status of the research topic, you should provide one paragraph at the end to propose a new experiment or calculation based on your own idea to make further progress in the field. Finally, you will prepare a poster to describe your literature search findings and your proposed research and present it during the virtual poster session to be held during the last live session. An advisor will be assigned to you for a weekly 1:1 meeting. The purpose of the 1:1 meeting is to answer questions, provide feedback and support your success with the poster presentation project and the course.

Homework: A problem set per week will be given, which students are required to download before the first class each week. There are two problems for each class; one is discussed and solved during the live session, and the other is for homework. Students are expected/encouraged to work in groups on the problem in class. Homework is due at 5:00 pm on Monday in the following week. Late homework will be accepted with a penalty of 10% per week after they are due.

Course Learning Outcomes: Students completing the course will be able to:

(1) discuss and apply fundamental concepts and theories of solid state physics focusing on the atomic-scale physics behind the transport of electricity in materials
(2) identify, formulate, and solve scientific and engineering problems related to the electronic, optoelectronic, and themoelectric properties of solids
(3) conduct a critical literature review and effectively present findings

(4) describe commercial processor and memory technology based on silicon and the physics behind ongoing research on possible alternatives and novel materials
(5) apply techniques, skills, and modern engineering tools necessary for practices in the field of solid state science and engineering

Detailed Course Learning Outcomes: Students completing the course will be able to:

(1) Calculate the electrical conductivity from the charge density and mobility
(2) Calculate the charge density from the Hall coefficient
(3) Calculate the plasma frequency from the charge density
(4) Calculate the effective mass from the cyclotron frequency
(5) Explain the differences among diamagnetism, paramagnetism, and ferromagnetism
(6) Explain why magnetic domains arise in ferromagnets
(7) Distinguish between soft and hard magnets from magnetization curves
(8) Describe the main characteristics of the phenomenon of superconductivity
(9) Explain the differences between type-I and type-II superconductors
(10) Explain the difference between elastic and plastic deformation
(11) Calculate the speed of sound from Young's modulus
(12) Sketch the relation between frequency and wave number for a sound wave in a mono-atomic chain
(13) Sketch the temperature dependence of electronic and lattice heat capacity
(14) Sketch the black-body radiation intensity as a function of frequency at a fixed temperature
(15) Calculate the wavelength of an electron or neutron moving at a fixed velocity
(16) Solve the Schrödinger equation for simple one-dimensional potentials
(17) Explain the meaning of the uncertainty principle
(18) Calculate the eigen-energy of a given quantum state in a hydrogen atom
(19) Explain the different types of atomic bonds
(20) Explain how bands and band gaps arise from a tight-binding picture
(21) Explain how bands and band gaps arise from a nearly-free electron picture
(22) Sketch the Fermi-Dirac distribution for a given temperature and Fermi energy
(23) Sketch the density of states versus energy for one-, two-, and three-dimensional systems
(24) Calculate the velocity and effective mass of a Bloch electron at a given wave number
(25) State the difference between metals and insulators
(26) State the difference between intrinsic and extrinsic semiconductors
(27) Estimate the intrinsic carrier density at room temperature from the effective masses and band gap

(28) State the difference between direct-gap and indirect-gap semiconductors

(29) Conduct a literature search on a given scientific or engineering topic

(30) Prepare and present a well-deigned poster on a research topic

Relationship of Course Outcomes to Program Outcomes: At the conclusion of ELEC 261, students should have gained (in SACS/ABET format):

- (a) an ability to apply knowledge of mathematics, science, and engineering
- (e) an ability to identify, formulate, and solve engineering problems
- (g) an ability to communicate effectively
- (j) knowledge of contemporary issues
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Program Outcomes Addressed	Tests & Assignments That Demonstrate This Outcome
(a)	HW1–HW5, Midterms, Final
(e)	HW1–HW5, Midterms, Final
(g)	Report, Poster Presentation
(j)	Report, Poster Presentation
(k)	HW1–HW5, Midterms, Final

Course Requirements for Audit Students: Audit students are required to watch all lesson videos, answer all on-line quizzes, attend all live classroom sessions, and participate in the final presentation sessions.

Rice Honor Code: In this course, all students will be held to the standards of the Rice Honor Code, a code that you pledged to honor when you matriculated at this institution. If you are unfamiliar with the details of this code and how it is administered, you should consult the Honor System Handbook at http://honor.rice.edu/honor-systemhandbook/. This handbook outlines the University's expectations for the integrity of your academic work, the procedures for resolving alleged violations of those expectations, and the rights and responsibilities of students and faculty members throughout the process.

Disability Support Services: If you have a documented disability or other condition that may affect academic performance, you should: 1) make sure that this documentation is on file with Disability Support Services (111 Allen Center, adarice@rice.edu, x5841) to determine the accommodations you need; and 2) talk with one of the instructors to discuss your accommodation needs.

Syllabus Change Policy: This syllabus is only a guide for the course and is subject to change with advanced notice.

Course Schedule: Below is a list of modules and lessons:

- Module 1: Introduction
  - Lesson 1: Overview
  - Lesson 2: Materials Science and Modern Technology
  - Lesson 3: Diverse Experimental Techniques
- Module 2: Electrical Conduction
  - Lesson 1: Early History of Metal Theory
  - Lesson 2: Ohm's Law
  - Lesson 3: DC Concudtivity
  - Lesson 4: The Hall Effect
  - Lesson 5: AC Conductivity
  - Lesson 6: The Plasma Edge
  - Lesson 7: Cyclotron Resonance
- Module 3: Dielectric and Optical Properties
  - Lesson 1: DC Polarization and Dielectric Constant
  - Lesson 2: AC Polarization and Dielectric Constant
  - Lesson 3: Optical Polarization and Refractive Index
  - Lesson 4: Dispersion, Attenuation, and Diffraction
- Module 4: Magnetism
  - Lesson 1: Diamagnetism, Paramagnetism, and Ferromagnetism
  - Lesson 2: Magnetic Domains
  - Lesson 3: Magnetic Anisotropy
  - Lesson 4: Hard and Soft Magnets
- Module 5: Superconductivity
  - Lesson 1: Superconductivity
  - Lesson 2: The Meissner Effect
  - Lesson 3: Type-II Superconductors
  - Lesson 4: High-T_c Superconductors
- Module 6: Mechanical and Thermal Properties
  - Lesson 1: Stress and Strain
  - Lesson 2: Elastic Waves
  - Lesson 3: Monoatomic Chain
  - Lesson 4: Group Velocity and Brillouin Zones

Lesson 5: Lattice Heat Capacity and Phonons

Module 7: Introduction to Quantum Mechanics

Lesson 1: Early History of Quantum Mechanics

Lesson 2: Planck's Law of Black-Body Radiation

Lesson 3: Radiation as Particles – Photons

Lesson 4: Particles as Waves – de Broglie's Relationship

Lesson 5: Schrödinger's Wave Equation

Lesson 6: Quantum Tunneling

Lesson 7: Bound States and Energy Levels

Module 8: Quantum States in Atoms

Lesson 1: The Hydrogen Atom I

Lesson 2: The Hydrogen Atom II

Lesson 3: Multielectron Atoms

Module 9: Interatomic Bonds

Lesson 1: The Born-Oppenheimer Approximation

Lesson 2: Linear Combination of Atomic Orbitals

Lesson 3: Hydrogen Molecule

Lesson 4: Covalent Bonds

Lesson 5: Polar Bonds

Module 10: From Bonds To Bands

Lesson 1: Polyatomic Molecules

Lesson 2: Delocalized Orbitals

Lesson 3: HOMO and LUMO

Lesson 4: Energy Bands

Module 11: Free Electron Fermi Gas

Lesson 1: Hamiltonian

Lesson 2: Density of States

Lesson 3: Electronic Heat Capacity

Lesson 4: Magnetic Susceptibility

Module 12: Electron Waves in a Crystal

Lesson 1: Nearly Free Electrons

Lesson 2: The Bloch Theorem

Lesson 3: The Kronig-Penny Model

Lesson 4: Dynamics of Bloch Electrons

Lesson 5: Effective Mass

Module 13: Semiconductors

Lesson 1: Why Semiconductors?

Lesson 2: Band Structure of Semiconductors

Lesson 3: Intrinsic and Extrinsic Semiconductors

Lesson 4: Alloys, Heterostructures, and Quantum Wells

Lesson 5: Quantum Wires and Quantum Dots

Module 14: Quantum Devices

Lesson 1: Solar Cells

Lesson 2: Quantum Cascade Lasers

Lesson 3: Carbon-Based Terahertz Device

Lesson 4: Semiconductor Spintronics

Guest Lectures: Below is a list of special lectures given by leading scientists:

- “Plasmonics,” by Guru Naik (Module 1)
- “Quantum Computation,” by Kaden Hazzard (Module 1)
- “Ultrahigh Conductivity Carbon Nanotube Fibers," by Matteo Pasquali (Module 2)
- “Optical Properties of 2D Materials," by Palash Bharadwaj (Module 3)
- “Methods for Generating High Magnetic Fields," by Junichiro Kono (Module 4)
- “Nanostructures and Thermopower,” by Doug Natelson (Module 6)
- “Electron Microscopy of Nanostructures," by Emilie Ringe (Module 7)
- “Ultracold Atomic Gases,” by Randall G. Hulet (Module 9)
- “Spectroscopy and Applications of Carbon Nanotubes,” by R. Bruce Weisman (Module 10)
- “Topological Matter,” Matthew S. Foster (Module 12)
- “Aligned Carbon Nanotubes,” by Junichiro Kono (Module 13)
- “Light Emitting Diodes,” by Gary L. Woods (Module 14)