Credit Hours: 3

Time and Place: Online Course — Summer Session II: May 29 – June 29, 2018

Instructors: Junichiro Kono, Professor of Electrical & Computer Engineering, Physics & Astronomy, and Materials Science & NanoEngineering, 351 Brockman Hall, kono@rice.edu.

Teaching Assistant: David W. Tam, Graduate Student, Physics, dtam@rice.edu.

Course Objective: This course focuses on the classical and quantum physics behind the electrical and optical properties of materials and their fundamental role in modern electronic and optoelectronic devices. It will not only cover silicon, which is the main material used in the past and current commercial processor and memory technology, but will also highlight ongoing research on possible alternatives and novel materials. Students will also learn basic scientific presentation and writing skills.


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 instructor and teaching assistant. There will also be separate online advising sessions.

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:** 30% – Exams (2 midterm exams), 30% – Homework, 30% – Research Paper & Poster Presentation, 5% – Module Quizzes, and 5% – In-Class Attendance

**Exams:** There will be two midterm exams. 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 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 on Friday in the fourth week. 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 and optoelectronic 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) Sketch the black-body radiation intensity as a function of frequency at a fixed temperature
(6) Calculate the wavelength of an electron or neutron moving at a fixed velocity
(7) Solve the Schrödinger equation for simple one-dimensional potentials
(8) Explain the meaning of the uncertainty principle
(9) Calculate the eigen-energy of a given quantum state in a hydrogen atom
(10) Explain how bands and band gaps arise from a tight-binding picture
(11) Explain how bands and band gaps arise from a nearly-free electron picture
(12) Sketch the Fermi-Dirac distribution for a given temperature and Fermi energy
(13) Sketch the density of states versus energy for one-, two-, and three-dimensional systems
(14) Calculate the velocity and effective mass of a Bloch electron at a given wave number
(15) State the difference between metals and insulators
(16) State the difference between intrinsic and extrinsic semiconductors
(17) Estimate the intrinsic carrier density at room temperature from the effective masses and band gap
(18) State the difference between direct-gap and indirect-gap semiconductors
(19) Conduct a literature search on a given scientific or engineering topic
(20) Prepare and present a well-designed 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

<table>
<thead>
<tr>
<th>Program Outcomes Addressed</th>
<th>Tests &amp; Assignments That Demonstrate This Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>HW1–HW5, Midterms</td>
</tr>
<tr>
<td>(e)</td>
<td>HW1–HW5, Midterms</td>
</tr>
<tr>
<td>(g)</td>
<td>Report, Poster Presentation</td>
</tr>
<tr>
<td>(j)</td>
<td>Report, Poster Presentation</td>
</tr>
<tr>
<td>(k)</td>
<td>HW1–HW5, Midterms</td>
</tr>
</tbody>
</table>

### Course Requirements for Audit Students
Audit students are required to watch all lesson videos, answer all online 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
   Lesson 4: Mathematical Foundations I: Complex Numbers and Partial Derivatives
   Lesson 5: Mathematical Foundations II: Vector Calculus
   Lesson 6: Mathematical Foundations III: Differential Equations

Module 2: Electrical Conduction
   Lesson 1: Early History of Metal Theory
   Lesson 2: Ohm's Law
   Lesson 3: DC Conduction
   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: 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 5: Quantum States in Atoms
   Lesson 1: The Hydrogen Atom I
   Lesson 2: The Hydrogen Atom II
   Lesson 3: Multielectron Atoms
Module 6: Free Electron Fermi Gas
   Lesson 1: Hamiltonian
   Lesson 2: Density of States
   Lesson 3: Electronic Heat Capacity
   Lesson 4: Magnetic Susceptibility

Module 7: Electron Waves in a Crystal
   Lesson 1: Nearly Free Electrons
   Lesson 2: Crystal Structures
   Lesson 3: Reciprocal Lattice
   Lesson 4: The Bloch Theorem
   Lesson 5: The Kronig-Penny Model
   Lesson 6: Interatomic Bonds
   Lesson 7: The Tight-Binding Method
   Lesson 8: Dynamics of Bloch Electrons
   Lesson 9: Effective Mass

Module 8: 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 9: 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)
- “Electron Microscopy of Nanostructures,” by Emilie Ringe (Module 4)
- “Ultracold Atomic Gases,” by Randall G. Hulet (Module 5)
• “Spectroscopy and Applications of Carbon Nanotubes,” by R. Bruce Weisman (Module 6)
• “Topological Matter,” Matthew S. Foster (Module 7)
• “Aligned Carbon Nanotubes,” by Junichiro Kono (Module 8)
• “Light Emitting Diodes,” by Gary L. Woods (Module 9)