LEDs and Solar Cells

ECE 443, Spring 2019

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Lectures: 2:00-2:50 pm MWF ECEB 3020
Computer Labs: 2:00-2:50 pm MWF EH 406B8 [alternates with lectures on select days]
Nano Labs: 2 hr/wk per section – ECEB 1003: (7 sections, 5 students per section)

Monday 12 - 1:50 pm; Tuesday 12 - 1:50 pm; Wednesday 9 - 10:50 am; Wednesday 11 - 12:50 pm; Thursday 12 - 1:50 pm; Friday 9 - 10:50 am; Friday 11 - 12:50 pm.

Office hours: By appointment

Catalog Description: This course explores the energy conversion devices from fundamentals to system-level issues. The course starts with a review of the electronic structure of atoms and semiconductors, quantum physics, and compound semiconductors. Then semiconductor heterostructures and low dimensional quantum structures, forming the basis of modern devices such as light emitting diodes and solar cells are introduced. Topics covered include energy transfer between photons and electron-hole pairs, light emission and capture, emission and absorption engineering via device simulation/design, radiative and non-radiative processes in devices, electrical and optical characteristics, carrier diffusion and mobility, and light extraction and trapping for high efficiency devices. Computer labs and clean-room labs reinforce modern device design and analysis such as light emitting diodes and solar cells.

Purpose: This is an advanced course in energy conversion physics, devices, and design technology. The course covers fundamentals as well as modern research topics, and will accommodate a broad range of backgrounds and interests from Electrical and Computer Engineering, Solid State Physics, and Material Science. If you are unsure of your individual preparation for this class, please check with the instructor. A solid knowledge of quantum mechanics, solid-state physics, semiconductors, and familiarity with a numerical computing software (e.g. Matlab, Python) is recommended.

Timeline: There are 42 hrs lectures {24 hrs classroom lectures & 18 hrs hands-on computer lab lectures}, and 22 hrs hands-on experimental labs spread over 14 weeks during the spring semester.

Lecture Electronics Policy: During the lectures, computer labs, and Nanolabs, cell phones or similar non-class use of electronics are NOT allowed. If, due to unforeseen circumstances, the student needs access to her/his cell phone, she/he shall inform the instructor in the beginning of the lecture and should sit in a way (typically furthest from the board) not to allow any students behind her/him get disturbed.

Attendance Policy: Attendance to all lectures are encouraged and attendance to all computer labs and ECE nano labs are required. Students are advised to contact both the TAs and the instructor via email (before the beginning of the lecture) if they are to miss a lecture due to unforeseen circumstances. Instructor and TAs reserve the right to take class attendance to use in future decision-making regarding course attendance policies. Class attendance includes in-class participation.

Historical Grading: Historical class grading distributions are provided below. This data does not imply future grading trends. The course is updated every year and the performance of students vary from year to year as well as the class average. The course is offered every year in the Spring semester only.

<table>
<thead>
<tr>
<th>Spring</th>
<th># of Grads</th>
<th># of Seniors</th>
<th># of Juniors</th>
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<tr>
<td>Spring 16</td>
<td>8</td>
<td>9</td>
<td>1</td>
<td>2 A+</td>
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<td>Spring 17</td>
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<td>2 A+</td>
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<td>Spring 18</td>
<td>4</td>
<td>11</td>
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Course Policy on Absence: In the event of illness, you must receive an Excused Absence Form from the Undergraduate College Office, Room 207 Engineering Hall, indicating what work you have missed and the reason for the absence. This form must be signed by a physician or medical official for a medical excuse, or by the Office of the Dean of Students (Emergency Dean) for a personal excuse due to personal illness, family emergencies, or other uncontrollable circumstances. The office may be reached at 333-0050. Note that Excused Absence Forms in the case of illness are now only given out by the office for the case of serious illness lasting more than 3 days. For missed classes or hour exams, present the completed form in person to the course director Prof. Bayram as possible after you return.

Classroom Lectures (24 hrs): The lectures involve power point presentations and black board notes on the subjects (as outlined in the lecture topics section later in the syllabus), example problem assignments and problem solutions, and class discussion. The lecture topics are to guide students as lectures are designed to be interactive and evolving with the recent breakthrough subjects in this area.

Classroom Lecture Topics: Approximate Hours:
I. Introduction to the Course and Instructor/Course Expectations 1
II. Materials, Physics, and Quantum Structures for LEDs and Solar Cells 3
III. Light Emitting Diodes 7
  a) Spectral Engineering
  b) Radiative and Non-radiative Recombination Centers
  c) Electrical Properties
  d) High Internal Efficiency Designs
  e) High Extraction Efficiency Designs & Optical Considerations
IV. Solar Cells 7
  a) Photovoltaic Effect
  b) Photocurrent and Quantum Efficiency
  c) Dark Current and Open Circuit Voltage
  d) Strategies for High Efficiency Solar Cells
  e) Light Management/Confinement/Recycling
  f) Concentration and Its Effects
V. Presentation & Writing Skills 1
VI. Project In-Class Presentations 4
VII. Review 1
Total: 24

Homeworks (Total Weight 12.5%): The homework will be assigned on Fridays in class and will be due next Friday pre-class. Due approximately every week, and some will contain open-ended “research” problems. That is, not all necessary information will be provided up front, you may have to look up constants, material properties, and make reasonable approximations. Some homeworks will involve computational work with Matlab or freeware software (BandEng, wxAMPS) available on campus, including numerical integrals, straightforward finite difference problems, and simple device simulation. You may work in groups on the homeworks, although separate write-ups must be submitted. In the Spring 19, there will be 12 homework sets.
(Computer) Lab Lectures (~18 hrs) (Total Weight 12.5%): Industrial finite element modelling Crosslight software is used during the hands-on computer labs for the design and simulation of quantum structures, light emitting diodes, and solar cells. For each lab set, there will be one in-class quiz to assess the student learning. The weight of each lab is different. The computer lab alternates for lectures as to be posted on a weekly basis (dependent upon the classroom lecture progress). The quiz is open book and open source. Each quiz will be for 40 minutes only and the students will be asked to provide their own software simulation code results in-class, at the end of the quiz time. The quiz starts sharp at 2:05 pm and will end sharp at 2:45 pm. The students will email their quiz solutions and source codes to the TA in charge. If post-marked later than 2:45 pm, 10% deduction per minute is implemented. No solutions will be accepted after 2:50 pm. Students are encouraged to complete their quiz questions as early as possible and submit early. Students cannot ask fellow students or the TAs/instructors for help during the quiz and students are expected to solve their own quiz problem with all open book and open sources (including handouts, books, and online/web resources).

The select topics of computer lab and their weight distribution are:

(1) (3 hrs) Quantum well simulation (Crosslight software).
   • (2.5%) End of lecture review quiz
(2) (6 hrs) AlGaAs-based light emitting diode simulation (Crosslight software).
   • (5.0%) End of lecture review quiz
(3) (6 hrs) Si-based solar cell simulation (Crosslight software).
   • (5.0%) End of lecture review quiz
(4) (3 hrs) Supervised Computer Lab (Crosslight software) [Contingent upon course progress].

Projects (Total Weight 12.5%): The class involves a final project. This will be an open-ended research project of your choice. The report is written following the National Science Foundation (NSF)-style. The details on the project can be found at the project documentation provided. You are encouraged to work in pairs/teams, and to think of topics as the course progresses. However, each student will have one independent project submission. Please refer to the project information document provided to you for the details on timeline, rubric, and guidelines.

(NanoFab) Cleanroom Work (~22 hrs) (Total Weight 12.5%): NanoFab cleanroom located in the ECE Building is used for the cleanroom activities related to the characterization of light emitting diodes and solar cells. There will be a formal report for each lab set. The formal report will be graded in its due assigned week. The weight of each lab is different due to the varying lab content.

The select topics of NANOFAb lab and their weight distribution are:

Week # 1 {defined as 1st full week starting with Monday Lecture Class}
(1) (Pass or Fail): Safety Training
Weeks # 2-3
(2) (Weight of 1.5%): SEM Training & SEM Inspection of LEDs and Solar Cells
Weeks # 4-5
(3) (Weight of 2.5%): Identification of leakage paths and loss mechanisms in LEDs
Week # 6-7
(4) (Weight of 3.0%): Effects of temperature on LED characteristics
Weeks # 8-9
(5) (Weight of 2.5%): Identification of leakage paths and loss mechanisms in a solar cell
Weeks # 10-11
(6) (Weight of 3.0%): Effects of temperature on Solar Cell characteristics * Series/Parallel Solar Cells
Midterm (Total Weight 20%): In the midterm, students are responsible for all subjects covered in the class including blackboard lectures, printed lecture notes, homework reading assignments, and all homework. It will be ONLY 2 HOURS long, from 7-9 pm. We will start at 7 pm in ECEB 2013 and finish the exam at 9 pm. This is a closed book and closed notes exam. You are allowed to bring ONE standard index card (3 by 5 inches) with hand-written notes - you can write on both sides. Instructor will be validating your index cards pre-exam. You are encouraged to write all the fundamental constants (h, pi, electron mass, and so on) into your index card. It is your responsibility to have all the constants and equations ready in your index card. Calculators and rules are allowed. Unless stated otherwise, do your work on the page of the problem and if necessary on the preceding blank page. Be sure to explicitly show the units in your work, as well as in your answers. Circle your answer. Be neat and write clearly! If we cannot read or follow your work, you get zero credit! For each problem, you must show complete work and indicate your reasoning. No credit will be given if you do not show the complete work and describe your procedure, even if the answer is correct.

Final (Total Weight 30%): In the final, students are responsible for all subjects covered in the class including blackboard lectures, printed lecture notes, homework reading assignments, and all homework. It will be ONLY 3 HOURS long, from 7-10 pm. We will start at 7 pm in ECEB TBD and finish the exam at 10 pm. This is a closed book and closed notes exam. You are allowed to bring TWO standard index card (3 by 5 inches) with hand-written notes - you can write on both sides. Instructor will be validating your index cards pre-exam. You are encouraged to write all the fundamental constants (h, pi, electron mass, and so on) into your index card. It is your responsibility to have all the constants and equations ready in your index card. Calculators and rules are allowed. Unless stated otherwise, do your work on the page of the problem and if necessary on the preceding blank page. Be sure to explicitly show the units in your work, as well as in your answers. Circle your answer. Be neat and write clearly! If we cannot read or follow your work, you get zero credit! For each problem, you must show complete work and indicate your reasoning. No credit will be given if you do not show the complete work and describe your procedure, even if the answer is correct.

Reading: No single textbook covers all topics. We will rely on recent news items, journal papers, lecture handouts, lecture notes/slides, and reading sections from several books including “Light Emitting Diodes” by E. Fred Schubert (Cambridge, 2003) (Lectures III-V) [http://www.amazon.com/Light-Emitting-Diodes-E-Fred-Schubert/dp/0521865387], and “The Physics of Solar Cells” by J. Nelson (Imperial College Press, 2003) (Lectures VI-VIII) [http://www.amazon.com/Physics-Solar-Properties-Semiconductor-Materials/dp/1860943497]. Multiple hard copies of these books are available in the reserve section of the Grainger Library.

Grade Appeal Deadline: Grade appeals or grade corrections must be requested within one after the grade assignment. No grades will be changed after the one-week mark irrespective of the grade correction nature.

Grading: Homeworks (12.5%). (Computer) Lab Lectures (12.5%). (NanoFab) Cleanroom Work (12.5%). Project (12.5%). Midterm (20%). Final Exam (30%).

Pre-reqs: ECE 340