Master Course Syllabus for EE 280 (ABET sheet)

Title: Exploring Devices

Credits: 4

<u>UW Course Catalog Description</u>

Overview of modern electronic and photonic devices underlying modern electronic products including smartphones, traffic lights, lasers, solar cells, personal computers, and chargers. Introduction to modeling and principles of physics relevant to the analysis of electrical and optical/photonic devices. Prerequisite: PHYS122. Offered: Autumn/Winter/Spring

Coordinator: D. Wilson, Professor, Electrical and Computer Engineering

(Team) Faculty who have or are willing to teach this core course):
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Goals: To provide students with a broad and engaging overview of devices that are relevant to the design and operation of modern electronic and optical products by exploring underlying principles of semiconductors and light. Applications include basic digital logic gates and analog circuits, voltage regulators, battery chargers, shrinking CMOS (MOSFET) transistor technology, LEDs, photovoltaic (solar) cells, and related devices. This course prepares the student to take more advanced semiconductor and photonics courses and also apply knowledge gained in this course to advanced courses in VLSI, digital and analog circuit design, computer architecture, power systems, and similar areas in electrical engineering.

Learning Objectives: At the end of this course, students will be able to:
For Electronic Devices:
1. *Differentiate* a semiconductor from an insulator or a metal using energy band diagrams.
2. *Calculate* semiconductor conductivity based on doping levels and operating temperature.
3. *Quantitatively extract* relevant device parameters from a characteristic curve for a diode, MOSFET (transistor), photovoltaic cell, or similar electronic device.
4. *Qualitatively describe* the dynamic equilibrium of drift and diffusion in a diode.
5. *Mathematically calculate* the current through a diode.
6. *Qualitatively describe* the characteristic behavior of a MOSFET.
7. *Identify and estimate* capacitance relevant to diode (pn junction) and MOSFET operation.
8. *Compute* channel current in the three major regions of operation in a MOSFET (transistor).
9. *Build and characterize* a basic inverter and digital logic gates using MOS transistors,
10. *Qualitatively describe and mathematically characterize* the basic behavior of PN junction-based photodetectors and photovoltaic cells.

For Optical Devices:

11. *Qualitatively describe* how light is generated in an LED and semiconductor laser.
12. *Identify* fundamental parameters from the wave equation that describe propagation of light
13. *Quantitatively define* key performance metrics of photonic devices (e.g. photodiode responsivity, laser efficiency).
14. *Extract* performance metrics from photonic device data.
15. *Explain* how semiconductors play a major role in generation, propagation and detection of light.
16. *Identify* and *describe* emerging applications enabled by semiconductor optics.

For the Hands-on Course Laboratories:

17. *Use* a digital multimeter, breadboard, and an Arduino microcontroller (or similar device) to build circuits and collect data from various electronic and photonic devices (e.g., diodes, MOSFETs, LEDs, solar/photovoltaic cells).
18. *Apply* knowledge gained from lecture to extracting parameters, characteristic curves, and other relevant data from devices and interface circuits.

Textbook:
There is no required textbook for this class; however, readings from a variety of sources are provided by the instructor to supplement the lecture and lab instruction material for the course.

Prerequisites by Topic:

1. Basic familiarity with Maxwell's equations.
2. Basic circuit analysis (KCL, KVL)
3. Exposure to and understanding of valence band and conduction band in materials.
4. Recommended -- Computational: Matlab, Python, Linux will be useful but not essential.

Lecture Topics:

1. Broad overview of solid-state and photonic devices – 0.5 week
2. Select exposure and introduction to underlying physics of devices including bonding and atomic structure – 0.5 week
3. Intrinsic and extrinsic semiconductors (emergence of bandgap and effect of doping), Metals, Insulators– 1 week
4. PN junctions, drift and diffusion, diode I-V characteristics, diode circuits – 1 week
5. Carrier regeneration and recombination using photovoltaic cells and LEDs as examples (avoiding in-depth analysis) – 1 week
6. Operation of MOS capacitor and MOS Field-Effect Transistors– 1 week
7. Contemporary transistor circuits (digital and analog) introduction – 1 week
8. Overview of photonics concepts and applications– 1 week
9. Photonic devices: Lasers, LEDs (basic operating principles) – 1 week
10. Introduction to Silicon Photonics (basic principles) – 1 week
11. Contemporary topics (including introduction to quantum computing, AR/ VR display) – 1 week

Laboratory Topics:

- *Lab 1 (1 week):* catalog resistors, characterize resistivity of conductors, introduce current limiting and breadboarding skills to construct circuits with devices and electronic components.
- *Lab 2 (1 week)*: characterize voltage sources and use pulse width modulation to create a programmable voltage source; build familiarity with using a microcontroller (e.g., Arduino) to provide power to and collect data from electronic and photonic circuits.
- *Lab 3 (two weeks):* build, test, and characterize diode circuits including voltage regulators and battery testers.
- *Lab 4 (two weeks)*: build, test, and characterize photodetector circuits and photodetectors
- *Lab 5 (two weeks):* build, test, and characterize photovoltaic (PV) circuits and photovoltaic cells
- *Lab 6 (one week)*: construct and characterize basic inverters and other transistor circuits

Lab/project (optional, as time permits)
LED circuits applied to a holiday light display or similar project -- last 2-3 weeks of the course

Note: Labs are unlikely to always directly follow the content presented in class but content for each lab is covered prior to students beginning the lab, even if the lab lags 1-2 weeks behind the lecture material.

Course Structure: The main lecture meets for two 80-minute sessions per week; three 50-minute sessions per week; or equivalent; lecture times are dependent on time scheduling constraints and instructor preferences. In addition, students attend one 110-minute quiz/lab section each week which is led by a teaching assistant (TA). Typically, the quiz/lab section gives students time to work on laboratories (note; EE280 labs do not require laboratory facilities) under the guidance of the TA; however, instructors have discretion to organize the quiz/lab sections in any way they deem appropriate to their pedagogy and style.

The organization and delivery style of EE280 lectures is at the discretion of the instructor. Lecture sessions typically consist of lecture interspersed with (a) examples which illustrate the application of important concepts; (b) demonstrations which illustrate these principles at work in real devices; or (c) student-centered activities including small group problem solving activities and think/pair/share exercises designed to reinforce understanding of basic concepts and resolve misconceptions.

Note: The quiz section is not intended to allow students to fully complete each lab. At-home (out-of-class) work will be needed following the student's quiz section.

Assignments in the course consist of homeworks, lab assignments (based on scaffolded laboratory reports), exams/quizzes, and (optional) a project. The project allows the student to apply device principles and use modern electronic and optical devices to simulate or construct a practical system.

Computer Resources: Completion of homework assignments and the project requires knowledge of Python, Matlab, or similar software, data presentation and word processing software (e.g. MS Excel, Word, Powerpoint), and basic breadboarding/circuit prototyping techniques.

Laboratory Resources: none required. The course has hands-on/physical, at-home/take-home laboratories and will require a lab kit. This course will require a technology fee to supply those kits.

Laboratory Safety: this course requires the use of hands-on, take-home laboratory kits. The following lab safety issues are of particular concern to this course and should be conveyed to students by all instructors on a regular basis:

- Capacitors: non-polarized and electrolytic capacitors should be avoided in lab kits. If they become necessary, however, students should be supervised during the placement and use of these capacitors to avoid placement in improper orientation (and potential harm to the eyes and body).
- Resistors: some low-valued resistors in this course (particularly those rated at a higher wattage and evident by a larger component body) may become hot due to high current flow and subsequent power dissipation. Students should be cautioned to leave these resistors connected for as little time as possible and also to allow the resistors to cool down before handling them (because they may be hot to the touch).
- Power: all power supplies should be disconnected prior to rewiring or adjusting components or connections on a breadboard or on Arduino (or similar microcontroller).

Grading: Formative assignments (homeworks, in-class exercises) will make up at least 20% of the grade; laboratory assignments (in the form of scaffolded laboratory reports will make up at least 25% of the grade; summative assignments (e.g. exams and quizzes) will make up at least 40% of the grade. Specifics are at the discretion of the instructor.

It is highly recommended that part of the lab assignment grading include a direct, face-to-face laboratory demonstration that verifies that each student is learning the hands-on laboratory skills for which the course is designed and also minimize academic dishonesty. If students work in teams to complete the laboratories, a means for ensuring that each student contributes something meaningful to each laboratory report is strongly recommended. Homeworks may be completed in teams or solo (at the discretion of the instructor) while summative assignments (exams, quizzes) etc. should be completed solo.

ABET Student Outcome Coverage: This course addresses the following outcomes:
H = high relevance, M = medium relevance, L = low relevance to course.

(1) *An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.* **(**H**)**
The vast majority of the lectures and homework assignments deal with quantitatively applying fundamental principles of electronic and optical devices to device operation using math and physics expertise acquired from previous courses.

(3) *An ability to communicate effectively with a range of audiences* (M)

Several homework assignments will involve creating tutorials or demonstrations of fundamental principles and device operation. These tutorials will be designed with a specific audience in mind so that students become more fluent in communicating complex EE topics with a range of audiences.

(6) *An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions* (H)

In multiple homework assignments, students will collect data from optical or electronic devices or build small circuits/systems using those devices and collect data from those systems. Students will be required to compare experimental data to simulated or theoretical data to understand the impact of real-world operation and device variation on performance.

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Additional information and resources regarding teaching ECE courses (e.g., links to course repositories for materials from previous course offerings; guidelines for using AI tools in courses; syllabus language for course accommodations, etc.) can be found on the UW ECE Intranet:
https://peden.ece.uw.edu/academic-ops/