Introduction to Microelectronic Devices and Circuits

Instructor: Dr. Aaron Franklin, *Associate Professor in ECE & Chemistry*
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Office Hours: Tuesday & Thursday (10am – 11am) and Wednesday (1pm – 2pm), F-CIEMAS 3473
Class Time & Location: Tuesday & Thursday (1:25pm – 2:40pm), Hudson Hall 208
Lab Times & Location: Tuesday, 3:05–6:05pm, Wednesday, 3:05–6:05pm, Thursday, 3:05–6:05pm, Friday, 10:05am-1:05pm Hudson Hall, 02H (students must attend their *scheduled* lab section time)
Course Website: http://piazza.com/duke/fall2017/ece230L/home (for Q&A, discussions, files, etc.)
GTAs: Steven Noyce (steven.noyce@duke.edu) (Lecture, office hour: Fri. 10–11am, CIEMAS 3rd floor)
Jimmy Thostenson (james.thostenson@duke.edu) (Lecture, office hour: Tues. 9–10am, CIEMAS 3rd floor)
UGTAs: Sujay Garlanka (sujay.garlanka@duke.edu) (Lecture, office hour: Mon. 5–6pm, CIEMAS 3rd floor)
Gerry Chen (gdc9@duke.edu) (Lab 01L Tu 3:05–6:05PM)
Yao Yuan (yy123@duke.edu) (Lab 02L W 3:05–6:05PM)
Martin Li (ml328@duke.edu) (Lab 03L Th 3:05–6:05PM)
Michael Kuryshev (michael.kuryshev@duke.edu) (Lab 04L F 10:05AM–1:05PM)
Lab Instructor: Kip Coonley, Undergraduate Laboratory Manager (kip.coonley@duke.edu), Hudson 02C

Course Description:

Hands-on, laboratory driven introduction to microelectronic devices, sensors, and integrated circuits. Student teams of 3-4 students/team compete in a design, assembly, testing, characterization and simulation of an electronic system. Projects include microelectronic devices, sensors, and basic analog and digital circuits. Classroom portion designed to answer questions generated in laboratory about understanding operation of devices and sensors, and the performance of electronic circuits. Student evaluation based on project specification, prototyping, integration, testing, simulation and documentation.

Objectives:

Through this course the students will:

- Understand how the crystal structure of solids leads to the formation of solid-state quantum theory, including the energy band structure of semiconductors.
- Understand carrier transport in semiconductors and how such transport is controlled in junction-based devices.
- Analyze the behavior of p-n junction devices, including their operation and performance.
- Analyze the operation of MOS capacitors and MOSFETs, including extraction of key parameters and how they affect integrated performance.
- Understand and describe the operation of MOSFETs covering from a band diagram all the way to a circuit symbol picture.
- Understand and analyze how MOSFETs yield basic digital and analog circuits, including their operation and performance. Be able to design a digital logic gate using MOSFETs.
- Develop a conversational understanding of the field of micro/nanoelectronic devices and circuits, from silicon to the future digital/analog device options.

Textbook:

Required textbook:
E-Book – Introduction to Microelectronic Devices and Circuits. ISBN – 9781121962194.

  - Students can purchase the e-book directly from McGraw-Hill using a credit card by logging into https://create.mheducation.com/shop/ and searching by ISBN (note that the instructor name listed may not be accurate, but if the School is "Duke University" and the title is correct, then it is the right book).

- Note that this is a combination of the following two textbooks:
  - D. Neamen, *Semiconductor Physics and Device Physics—4th Edition*, McGraw-Hill, 2012. (Chapters 1-9)
  - D. Neamen, *Microelectronics: Circuit Analysis and Design—4th Edition*, McGraw-Hill, 2010. (Chapters 10-22)

Here are a couple of other useful textbooks for reference:

- R. F. Pierret, *Semiconductor Device Fundamentals*, Addison Wesley Longman, 1996.
- A. S. Sedra and K. C. Smith, *Microelectronic Circuits*, Oxford University Press, 1998.

Communication:

All questions on homework and lectures should be posted to Piazza for open discussion. It is ok for the post to be kept as "anonymous." If students email the professor or TAs with questions on the homework or lecture, they will likely be asked to post the question to Piazza to be answered there for the entire class to access.

Grading Criteria:

Homework	20 %
Quizzes	10 %
Labs	20 %
Exam 1	15 %
Exam 2	15 %
Final Exam	20 %

Homework (20%):

A homework assignment will be given each week. The assignments are intended to help the student solidify the important concepts of each principle/topic that is covered and will often require further textbook reading beyond what is included in our limited lecture time. Some of the problems will come from the course textbook while others will be created specifically for this course.

Homework Formatting Guidelines

Each assignment should follow these guidelines:

1) Use standard 8.5" x 11" paper (blank, college-ruled, or graph paper all work).
2) Staple the upper left corner with your name legibly in the top right corner of the first page, along with the date and assignment number.
3) Keep the problems in the order they are given in the assignment (in other words, don't put problem #3 on the first page with problem #1 on the second page—place them in order!).
4) If you use both sides of the paper, indicate when a problem continues on the reverse side.
5) Draw a box around (or clearly highlight) your final answer to each problem, with all needed work for arriving at the answer shown clearly and legibly. *Points will be taken away for sloppy work!*

Attendance and Late Homework Policy:

Attendance to the lectures is crucial to succeeding in this course. Homework will be due each week and must be turned in at the beginning of class – *late homework will not be accepted* except with written approval from the professor (and even then, only once/student per semester for extenuating circumstances). Note that between the weekly homework and quizzes, it will be crucial for students to be punctual and in attendance for every lecture!

Collaboration Policy:

Students are allowed to work together on homework, keeping in mind that the Duke Community Standard (http://www.integrity.duke.edu/new.html) applies to all assignments. Each student must personally work each problem, legibly write up his or her solutions, and submit his/her own solutions. This applies to all assignments, including computer simulations (e.g., MATLAB) and laboratory projects. Generally, it is suggested that you work through all problems on your own before discussing them with another student. Remember that you are just as responsible for the academic dishonesty if you allow someone to copy your original work as you would be if you did the copying yourself. The use of solution manuals or other sources of solutions is not allowed. Any student who copies (or allows copying of) any assignment or report will receive a failing grade for the assignment. If you have any questions regarding what is allowed and what is considered cheating, please ask.

Quizzes (10%):

There will be quick quizzes given at the beginning of lecture almost every week of the course. Quizzes will typically cover the material that students should have read in preparation for the lecture that will be given that day (based on the reading list in the course outline on the last page of the syllabus), or some recently taught material per the instructor's discretion. All quizzes will be administered via the program *Socrative*, which is accessible via any mobile device or computer as will be discussed in lecture. *There will be absolutely no make-up quizzes, including if you are tardy!*

Missed Quizzes/Homework and Dropping of Lowest Scores:

As there will be *absolutely no make-up quizzes or homework extensions*, the single lowest quiz score and the single lowest homework score will be dropped. The scores that are dropped are based on percentages as the assignments/quizzes may be worth a different point total. This allows for you to miss a class or homework for personal reasons.

Laboratory (20%):

The laboratory component of ECE 230L consists of a Shared Materials Instrumentation Facility (SMiF) portion where students will design and fabricate their own Silicon wafer, 8 microelectronics laboratory experiments, and a final lab project. Each lab is designed to provide a hands-on experience with electrical and computer engineering concepts presented in lecture. Attendance at each laboratory during your assigned group time is required. If you must miss a lab due to an illness or injury that prevents you from attending your assigned laboratory section, you must submit a Short-Term Illness form *prior* to the absence to your *course Instructor* (https://tts-fm-admin01.trinity.duke.edu/stinf/). Your instructor in conjunction with the laboratory manger (Kip Coonley, Hudson 114, (919) 660-5186 kip.coonley@duke.edu) will make arrangements with you to attend another lab section or otherwise make-up the work. If you must miss a lab for any other reason, you must notify your Instructor immediately so that arrangements can be made for you to complete the work. No student is allowed to attend another lab section without prior approval.

Midterm Exams (15% each) and Final Exam (20%):

The midterm exams and final exam problems will be very much like the homework problems, so that any student who has completed (and understood) all of the homework should be very familiar with what to expect on the exams. The final exam will be comprehensive, covering all material from the course. All exams will be closed book and closed notes. Further details to help you prepare for the exams will be given in lecture.

Grading Scale:

A+: 98-100	B+: 87-89	C+: 77-79	D+: 67-69	F: < 60
A: 93-97	B: 83-87	C: 73-76	D: 63-66	
A-: 90-92	B-: 80-82	C-: 70-72	D-: 60-62	

Academic Integrity:

Academic integrity is expected as part of the community to which you belong and each student will be held accountable for upholding the standard. University policy will be enforced in the case of any dishonest conduct.

Anticipated Course Outline:

Date	Lab		Lecture	Reading	HW/Quiz
T, 8/29	SMIF Intro	Semiconductor Materials	Course overview The Big Picture: Why Care About This Course?		
Th, 8/31			Crystal Structure of Solids	pg. 9-32	
T, 9/5	SMIF Tour		Quantum Theory of Solids (band structure)	pg. 34-48	Quiz #1
Th, 9/7			Quantum Theory of Solids (electrical transport)	pg. 48-81	HW #1 due
T, 9/12	Photolith I		Thermal Equilibrium	pg. 82-131	Quiz #2
Th, 9/14			Carrier Transport (drift)	pg. 132-147	HW #2 due
T, 9/19	Photolith II		Carrier Transport (diffusion)	pg. 148-155	Quiz #3
Th, 9/21		Devices	pn Junction Diodes (junction under zero-bias and reverse-bias)	pg. 169-190	HW #3 due
T, 9/26	pn Junction Diodes		pn Junction Diodes (junction under forward bias, ideal diode, deviations from ideal, light emitting diode)	pg. 204-232, 290-296	Quiz #4
Th, 9/28			**EXAM 1 – *Semiconductor Materials***		
T, 10/3	P-Spice Circuit Simulatn		pn Junction Diodes (small-signal equivalent circuit, diode transients)	pg. 232-245, 425-430	HW #4 due
Th, 10/5			pn Junction Diodes (large-signal analysis, half-wave rectifier)	pg. 416-425, 449-453	Quiz #5
T, 10/10	**NO LAB**		**FALL BREAK**		
Th, 10/12			MOSFETs (MOS capacitors)	pg. 313-336	HW #5 due
T, 10/17	Project Intro		MOSFETs (capacitance-voltage characteristics)	pg. 336-345	Quiz #6
Th, 10/19			MOSFETs (basic MOSFET operation)	pg. 345-364	HW #6 due
T, 10/24	MOSFET		MOSFETs (small-signal equivalent circuit, CMOS technology, circuit symbols)	pg. 364-373, 519-523	Quiz #7
Th, 10/26		Circuits	Digital (NMOS inverters)	pg. 547-550, 836-850	HW #7 due
T, 10/31	MOSFET Model		Digital (CMOS inverters and logic gates)	pg. 861-885	Quiz #8
Th, 11/2			**EXAM 2 – *Devices***		
T, 11/7	Basic Digital Circuits		Analog (DC Biasing of MOSFET circuits)	pg. 528-543	HW #8 due
Th, 11/9			Analog (common-source MOSFET amplifier)	pg. 550-551, 587-608	
T, 11/14	Multistage Amplifiers		Analog (common-drain, common-gate MOSFET amplifiers)	pg. 609-620	Quiz #9
Th, 11/16			Analog (single-stage MOSFET IC, multistage amplifiers)	pg. 620-626, 629-640	HW #9 due
T, 11/21	**NO LAB**		Analog (operational amplifier)	pg. 672-692	Quiz #10
Th, 11/23			**THANKSGIVING BREAK**		
T, 11/28	Op-Amp		Analog (operational amplifier applications)	pg. 692-708	HW #10 due
Th, 11/30			The Big Picture: Why does this matter? Future directions		Quiz #11
T, 12/5	Project Demos		"Create Final Exam" project		HW #11 due
Th, 12/7			Course Review for Final Exam		
Sa, 12/16			**FINAL EXAM, 2pm – 5pm – *Comprehensive***		