ECE 230L

Professor Willie Padilla

Course Syllabus ECE 230L
Introduction to Microelectronic Devices and Circuits
Spring 2017

(Revised 1/11/2017)

Instructor: Prof. W.J. Padilla, Professor in ECE
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919-660-5220

Office Hours: Tuesday & Thursday (2:45pm – 3:45pm), Ciemas 3579
Class Time & Location: Tuesday & Thursday (1:25pm – 2:40pm), Hudson Hall 125
Lab Times & Location: Tuesday, 3:05–5:35pm, Wednesday, 3:05–5:35pm, Thursday, 3:05–5:35pm, Hudson Hall, 02G (students must attend their scheduled lab section time)
Course Website: (for Q&A, discussions, files, etc.)
TAs: Dhruv Luthra (dhruv.luthra@duke.edu); Shruti Preetam (shruti.preetam@duke.edu)
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. Teams of 3-4 students compete in 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:

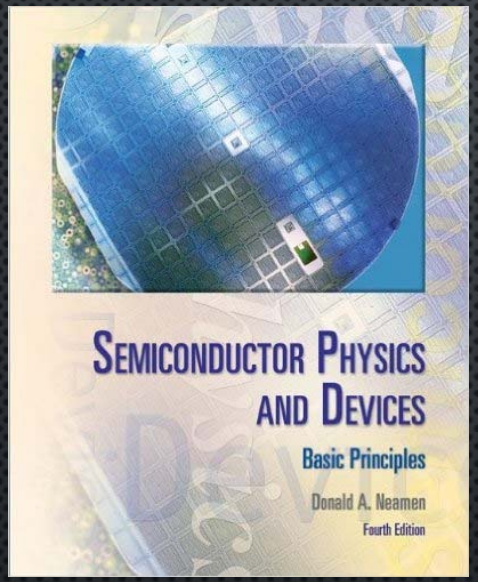
Required textbook:

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

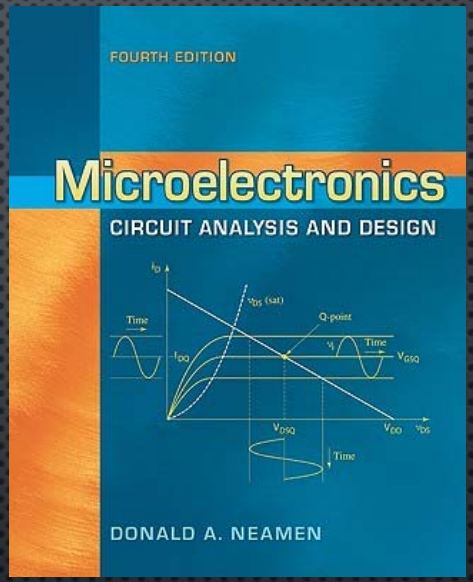
Students can purchase the e-book directly from McGraw-Hill using a credit card by logging into https://create.mheducation.com/shop/ and searching by ISBN (note that the instructor name listed may not be accurate, but if the School is "Duke University" and the title is correct, then it is the right book).

Textbook:

Note that this is a combination of the following two textbooks:



D. Neamen, *Semiconductor Physics and Devices—4th Edition*, McGraw-Hill, 2012. (Chapters 1-9)



D. Neamen, *Microelectronics: Circuit Analysis and Design—4th Edition*, McGraw-Hill, 2010. (Chapters 10-22)

Other useful reference textbooks:

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.

https://piazza.com/duke/spring2017/ece230l/home

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:

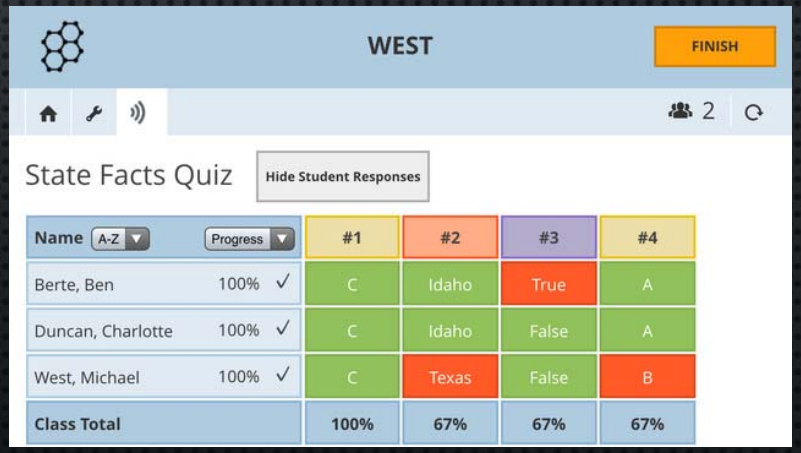
1) Use standard 8.5” x 11” paper (blank, college-ruled, or graph paper all work).
2) Staple the upper left corner with your name legibly in the top right corner of the first page, along with the date and assignment number.
3) Keep the problems in the order they are given in the assignment (in other words, 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.* The only exception is 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 02C, (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.

WEEK	MON	TUES	WED	THUR	FRI
0 JAN	9	10	11	12 Lec1 First day of classes	13
1	16 Holiday	17 Lec2	18	19 Lec3	20
2	23	24 Lec4	25	26 Lec5	27
3 FEB	30	31 Lec6	FEB 1	2 Lec7	3
4	6	7 Lec8	8	9 Lec9	10
5	13	14 **EXAM 1**	15	16 Lec10	17
6	20	21 Lec11	22	23 Lec12	24
7 MAR	27	28 Lec13	MAR 1	2 Lec14	3
8	6	7 Lec15	8	9 Lec16	10
9	13 Spring Recess	14 Spring Recess	15 Spring Recess	16 Spring Recess	17 Spring Recess
10	20	21 Lec17	22	23 **EXAM 2**	24
11	27	28 Lec18	29	30 Lec19	31
12 APR	3	4 Lec20	5	6 Lec21	7
13	10	11 Lec22	12	13 Lec23	14 Holiday
14	17	18 Lec24	19	20 Lec25	21
15	24	25 Lec26 LAST CLASS	26 Last Day of All Classes	27	29
16 MAY	1 Beginning of Final Exams	2 FINAL: 7pm – 10pm	3	4	Sat 6 Last Day of Finals

Lectures

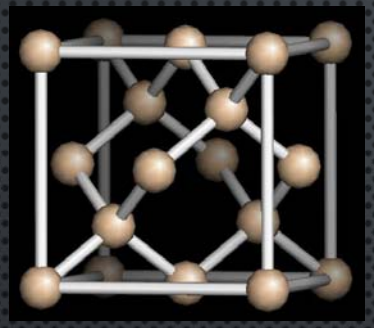
Lec 1 Course overview; The Big Picture: Why Care About This Course?
Lec 2 Crystal Structure of Solids
Lec 3 Quantum Theory of Solids (band structure)
Lec 4 Quantum Theory of Solids (electrical transport)
Lec 5 Thermal Equilibrium
Lec 6 Carrier Transport (drift)
Lec 7 Carrier Transport (diffusion)
Lec 8 pn Junction Diodes (junction under zero-bias and reverse-bias)
Lec 9 pn Junction Diodes (junction under forward bias, ideal diode, deviations from ideal, light emitting diode)
Lec 10 pn Junction Diodes (small-signal equivalent circuit, diode transients)
Lec 11 pn Junction Diodes (large-signal analysis, half-wave rectifier)
Lec 12 MOSFETs (MOS capacitors)
Lec 13 MOSFETs (capacitance-voltage characteristics)
Lec 14 MOSFETs (basic MOSFET operation)
Lec 15 MOSFETs (small-signal equivalent circuit, CMOS technology, circuit symbols)
Lec 16 Digital (NMOS inverters)
Lec 17 Digital (CMOS inverters and logic gates)
Lec 18 Analog (DC Biasing of MOSFET circuits)
Lec 19 Analog (common-source MOSFET amplifier)
Lec 20 Analog (common-drain, common-gate MOSFET amplifiers)
Lec 21 Analog (single-stage MOSFET IC, multistage amplifiers)
Lec 22 Analog (operational amplifier)
Lec 23 Analog (operational amplifier applications)
Lec 24 The Big Picture: Why does this matter? Future directions
Lec 25 "Create Final Exam" project
Lec 26 Course Review for Final Exam

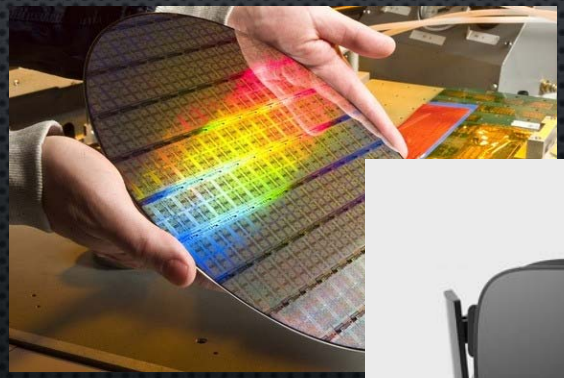
Laboratories

Week 1: SMiF intro
Week 2: SMiF tour
Week 3: SMiF processing/Lab 1 orientation (lab sections split in 1/2 each)
Week 4: SMiF processing/Lab 1 orientation (lab sections split in 1/2 each) (same as above)
Week 5: No lab (Exam 1)
Week 6: Lab 2 pn junction
Week 7: Lab 3 p-spice
Week 8: Project intro
Week 9: Spring Break
Week 10: Lab 4 MOSFET characterization
Week 11: Lab 5 MOSFET model
Week 12: Lab 6 digital circuits
Week 13: Lab 7 multistage amplifier
Week 14: Lab 8 op-amp
Week 15: Projects due by last day of classes (can be demonstrated anytime before this week as well)

Th, 1/12	SMIF Intro	Semiconductor Materials	Course overview; The Big Picture: Why Care About This Course?		
T, 1/17			Crystal Structure of Solids	pg. 9-32	
Th, 1/19			Quantum Theory of Solids (band structure)	pg. 34-48	Quiz #1
T, 1/24	SMIF Tour		Quantum Theory of Solids (electrical transport)	pg. 48-81	HW #1 due
Th, 1/26			Thermal Equilibrium	pg. 82-131	Quiz #2
T, 1/31	Photolith I		Carrier Transport (drift)	pg. 132-147	HW #2 due
Th, 2/2			Carrier Transport (diffusion)	pg. 148-155	Quiz #3
T, 2/7	Photolith II	Devices	pn Junction Diodes (junction under zero-bias and reverse-bias)	pg. 169-190	HW #3 due
Th, 2/9			pn Junction Diodes (junction under forward bias, ideal diode, deviations from ideal, light emitting diode)	pg. 204-232, 290-296	Quiz #4
T, 2/14	No Lab		**EXAM 1 – *Semiconductor Materials***		
Th, 2/16			pn Junction Diodes (small-signal equivalent circuit, diode transients)	pg. 232-245, 425-430	HW #4 due
T, 2/21	pn Junction Diodes		pn Junction Diodes (large-signal analysis, half-wave rectifier)	pg. 416-425, 449-453	Quiz #5
Th, 2/23			MOSFETs (MOS capacitors)	pg. 313-336	HW #5 due
T, 2/28	P-Spice Circuit Simulation		MOSFETs (capacitance-voltage characteristics)	pg. 336-345	Quiz #6
Th, 3/2			MOSFETs (basic MOSFET operation)	pg. 345-364	HW #6 due
T, 3/7	Project Intro		MOSFETs (small-signal equivalent circuit, CMOS technology, circuit symbols)	pg. 364-373, 519-523	Quiz #7
Th, 3/9			Digital (NMOS inverters)	pg. 547-550, 836-850	HW #7 due
T, 3/14	**NO LAB**	Circuits	**SPRING BREAK**		
T, 3/21	MOSFET		Digital (CMOS inverters and logic gates)	pg. 861-885	Quiz #8
Th, 3/23			**EXAM 2 – *Devices***		
T, 3/28	MOSFET Model		Analog (DC Biasing of MOSFET circuits)	pg. 528-543	HW #8 due
Th, 3/30			Analog (common-source MOSFET amplifier)	pg. 550-551, 587-608	
T, 4/4	Digital Circuits		Analog (common-drain, common-gate MOSFET amplifiers)	pg. 609-620	Quiz #9
Th, 4/6			Analog (single-stage MOSFET IC, multistage amplifiers)	pg. 620-626, 629-640	HW #9 due
T, 4/11	Multistage Amplifiers		Analog (operational amplifier)	pg. 672-692	Quiz #10
Th, 4/13			Analog (operational amplifier applications)	pg. 692-708	HW #10 due
T, 4/18	Op-Amp		The Big Picture: Why does this matter? Future directions		Quiz #11
Th, 4/20			"Create Final Exam" project		HW #11 due
T, 4/25	Project Demos		Course Review for Final Exam		
Th, 5/2			**FINAL EXAM, Tu May 2nd, 7pm-10pm–*Comprehensive***		

Introduction to Microelectronic Devices and Circuits

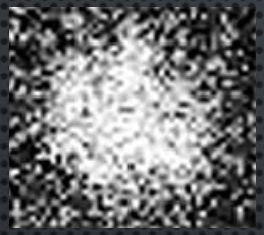




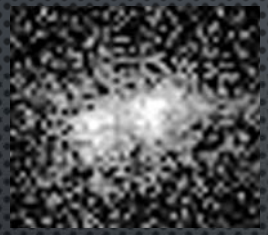
Astronomical Photography

An astronomical target with the 2MASS ID J03323578+2843554

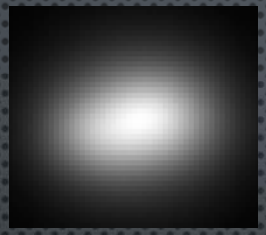
The distance of the system is about 45 parsecs (pc) = 8.6e+14 miles



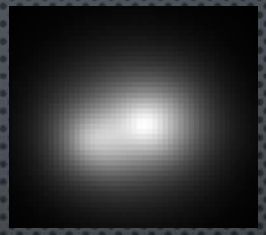
Single exposure with low image quality



Single exposure with very high image quality, selected for reference image



Average of 50,000 images = 21 minute exposure



Average of all 50,000 images but here with the center of gravity (centroid) of each image shifted to the same reference position.

The 25,000 best images averaged, after the brightest pixel in each image was moved to the same reference position.

The best 1% images averaged, after the brightest pixel in each image was moved to the same reference position.