Introduction to Microelectronic Devices and Circuits

Instructor: Prof. Kip Coonley, Assistant *Professor of the Practice in MEMS & ECE*
Email: kip.coonley@duke.edu
Office Hours: Monday & Wednesday, 1:30pm2:30pm, Hudson Hall 233
Lecture Time & Location: Monday & Wednesday, 11:45am–1:00pm, Wilkinson 132
Lab Location & Sections: Labs occur in Hudson Hall 109 (attend *your scheduled* lab section time)

Lab Section	Time		
ECE 230L9-241L	Tu 1:25PM - 4:15PM	Hannah Lim	hannah.lim@duke.edu
ECE 230L9-341L	W 1:25PM - 4:15PM	Kevin Zheng	kevin.zheng@duke.edu
ECE 230L9-451L	Th 3:05PM - 5:55PM	Sofia Tsvihun	sofia.tsvihun@duke.edu
ECE 230L9-521L	F 10:05AM - 12:55PM	Lilly Chiavetta	lhc24@duke.edu
ECE 230L9-541L	F 1:25PM - 4:15PM	Michael Bryant	mcb115@duke.edu

Course Websites and Tools: *Canvas* http://canvas.duke.edu (for grades and files)
Ed Discussion (for Q&A and discussions)
Gradescope (for HW submission and grading)

GTAs: Victoria Ravel victoria.ravel@duke.edu Tuesdays, 3:30pm–5:30pm, FCIEMAS 3rd fl. fishbowl
Rahul Banerjee rahul.banerjee@duke.edu Mondays, 3:00pm–4:30pm, FCIEMAS 3rd fl. fishbowl

UGTAs: Alice Hu alice.hu@duke.edu see *Ed Discussion* post
Rodney Willoughby rodney.willoughby@duke.edu see *Ed Discussion* post

Lab Instructor: Anna McNally, anna.mcnally@duke.edu, Hudson 02C

Course Description:

Introduction to semiconductor materials and their corresponding electronic devices and circuits. In lab, students will perform photolithography and characterize devices and circuits. Lecture will cover the underlying physics of semiconductor materials, the operation of semiconductor devices, including diodes and transistors (MOSFETs), and the application of MOSFETs to digital circuits. Students will understand basic operation of semiconductor devices in a way that is foundational for the expansive semiconductor industry.

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 & describe the operation of MOSFETs, including through the use of band diagrams.
- Understand & demonstrate successful use of fundamental semiconductor fabrication processes.
- Characterize and analyze the operation of semiconductor devices.
- Understand and analyze how MOSFETs yield basic digital 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 including the challenges faced by current technologies.

Textbook:

Required textbook:

- D. A. Neamen, *Semiconductor Physics and Devices: Basic Principles—4th Edition*, McGraw-Hill, 2011.

*The textbook for this course is available for 3-hour checkouts at the Duke Libraries. Search the Libraries' Top Textbooks program here: https://library.duke.edu/course-support/course-reserves/textbooks

Here are a couple of other useful textbooks for reference:

- J. F. Shackelford, Introduction to Materials Science for Engineers, 9th ed., 2022
- P. Scherz and S. Monk, Practical Electronics for Inventors, 4th ed., 2016
- R. F. Pierret, *Advanced Semiconductor Fundamentals*, Prentice Hall, 2003.
- R. F. Pierret, *Semiconductor Device Fundamentals*, Addison Wesley Longman, 1996.
- S. Wolf and R. N. Tabuer, Silicon Processing for the VLSI Era, Vol. 1 Process Technology, 1986

Communication:

All questions on homework and lectures should be posted to the *Ed Discussion* (accessible via the *Canvas* course page) 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 *Ed Discussion* to be answered there for the entire class to access. Please check *Ed Discussion* prior to asking a new question!

Grading Criteria:

Homework	15 %
Quizzes	10 %
Labs	20 %
Exam 1	15 %
Exam 2	15 %
Final Exam	25 %

Homework (15%):

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 (***failure to follow these may result in up to 15% reduction in HW score!***)

Each assignment should follow these guidelines:

1) Use standard 8.5" x 11" paper (blank, college-ruled, or graph paper all work).
2) Write 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 your solution to a problem continues on the next page, then indicate it clearly.
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 or missing work!*
6) Submit assignment as a scanned PDF or image file to Gradescope before the due date + time.
7) Before final submission on Gradescope, be sure all problems/pages are in the correct order and orientation.

Homework Submission:
All assignments must be submitted to the Gradescope (lecture) site for this course. For instructions on how to upload an assignment to Gradescope, see here: https://gradescope-static-assets.s3.amazonaws.com/help/submitting_hw_guide.pdf Be sure your scanned homework file is of sufficiently high quality / resolution – illegible answers or work will be subject to deducted points.

Attendance and Late Homework Policy:
Attendance to the lectures is crucial to succeeding in this course. Based on the amount of content that will be covered, it will be crucial for students to be punctual and in attendance for every lecture! **Homework assignments** will be due each week and must be submitted through Gradescope by the indicated time (typically **Wednesdays at 10:00pm**) – *late homework will not be accepted* except with written approval from the professor (and even then, only once/student per semester for extenuating circumstances).

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, including resources from previous semesters, 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.

Artificial Intelligence Policy:
Artificial Intelligence (AI) can be a powerful tool to support learning, but it should be used to enhance understanding rather than undermine the learning objectives of this course.
In this course, the use of generative AI (e.g. ChatGPT) will be treated similarly to collaboration with another student. Generative AI may be used for homework assignments where collaboration is allowed. Generative AI is prohibited for graded assignments where collaboration is not allowed or is restricted to specific groups (e.g., your lab partner). If an assignment requires that sources or collaborators must be cited, then any use of generative AI must also be appropriately documented. Students should reflect on whether their actions would be permissible or considered cheating if carried out using another resource or with assistance from another student. For assignments where generative AI is allowed, some examples of permitted and prohibited uses are provided below. This list is not exhaustive, and students should ask an instructor or TA whenever use is unclear.

- Permitted Use Examples:
  - Interactive assistance in learning course concepts.
  - Summarize or clarify concepts alongside or in place of traditional internet searches.
  - Language support for non-native speakers.
  - Identifying and debugging coding errors.
  - Generating practice problems for test preparation.
- Prohibited Use Examples:
  - Copying work/solutions generated by AI for graded assignments.
  - Paraphrasing or simply rewriting work/solutions generated by AI for graded assignments.
  - Writing lab reports for you.

- Fabricating data, graphs, or citations.
- Generating code for submission.

To summarize, **copying work or answers from generative AI is considered cheating** and will be reported to the Office of Student Conduct.

Quizzes (10%):

Quizzes will be given at the beginning or end of most lectures and will cover any topic covered in the course to that point. These unscheduled quizzes are closed book, closed notes and *will be graded for correctness*. The purpose of these quizzes is to check the knowledge/mastery of students and to encourage attendance at lecture.

There will be absolutely no make-up quizzes, including if you are tardy or traveling!

***Missed Quizzes/Homework and Dropping of Lowest Scores:**

As there will be *absolutely no make-up quizzes or homework extensions*, the two lowest quiz scores 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 Lab TA in conjunction with the laboratory manager (Anna McNally, anna.mcnally@duke.edu, Hudson 02C) 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 Lab TA, any Head TAs, the laboratory administrator, and the course 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.

Pre-Laboratory assignments will be due each week prior to lab and must be submitted through Gradescope by the indicated time (typically **Mondays at 10:00pm**)

Laboratory assignments will be due each week and due one week following that lab. They must be submitted through Gradescope by the indicated time (typically **Fridays at 10:00pm**)

Midterm Exams (15% each) and Final Exam (25%):

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.

Lecture Notes:

As noted above, attendance in person is required for all students in this course. Should something occur that prevents a student from attending, any exception to in-person attendance must be made directly by the instructor with prior approval. All lectures notes will be distributed following class. *This does not mean students are allowed to miss class.* Note distribution is simply being used to allow students access later. Also, quizzes will not be included in the distributed class notes.

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 Duke Community Standard. University policy will be enforced in the case of any dishonest conduct.

Mental Health and Wellness Statement:

If your mental health concerns and/or stressful events negatively affect your daily emotional state, academic performance, or ability to participate in your daily activities, many resources are available to you, including ones listed below. Duke encourages all students to access these resources, particularly as we navigate the transition and emotions associated with this time. Duke Student Government has worked with DukeReach and student advocates to create the Fall 2021 "Two-Click Support" Form, and Duke Reach has expanded its drop in hours as well.

• **DukeReach**. Provides comprehensive outreach services to identify and support students in managing all aspects of wellbeing. If you have concerns about a student's behavior or health visit the website for resources and assistance. http://studentaffairs.duke.edu/dukereach

• **Counseling and Psychological Services (CAPS)**. CAPS services include individual, group, and couples counseling services, health coaching, psychiatric services, and workshops and discussions. (919) 660-1000

• **Blue Devils Care**. A convenient and cost-effective way for Duke students to receive 24/7 mental health support through TalkNow. https://bluedevilscare.duke.edu

Managing daily stress and self-care are also important to well-being. Duke offers several resources for students to both seek assistance on coursework and improve overall wellness, some of which are listed below. Please visit https://studentaffairs.duke.edu/duwell/holistic-wellness to learn more.

• **The Academic Resource Center**: (919) 684-5917, theARC@duke.edu, or arc.duke.edu,

• **DuWell**: (919) 681-8421, duwell@studentaffairs.duke.edu, or https://studentaffairs.duke.edu/duwell),

• **WellTrack**: https://app.welltrack.com/

Anticipated Course Schedule:

Date	Lab		Lecture	Reading	Homework
M, 8/25	0.1 SMIF Intro	Semiconductor Materials	1: Course overview: Big Picture		
W, 8/27			2: Crystal Structure of Solids	pp. 1-20	
M, 9/1	1. Orien-tation		**LABOR DAY**		
W, 9/3			3: Quantum Theory of Solids (brief intro to quant. mech.)	pp. 25-43	HW #1 due
M, 9/8	0.2 SMIF Tour		4: Quantum Theory of Solids (band structure)	pp. 58-72	
W, 9/10			5: Quantum Theory of Solids (conduction & DOS)	pp. 72-98	HW #2 due
M, 9/15	0.3 SMIF Photolith.		6: Quantum Theory of Solids (thermal equilibrium)	pp. 106-117	
W, 9/17			7: Quantum Theory of Solids (dopants & carrier stats.)	pp. 118-148	HW #3 due
M, 9/22	2. VanDer Pauw		8: Carrier Transport (drift & diffusion)	pp. 156-179	
W, 9/24		Semiconductor Devices	9: Current Flow and Energy Band Diagrams	pp. 72-82	HW #4 due
M, 9/29	**NO LAB** (Exam 1)		10: pn Junctions in Equilibrium	pp. 241-250	
W, 10/1			**EXAM 1 – *Semiconductor Materials***		
M, 10/6	3. PSpice		11: pn Junction Diodes 1 (reverse bias & forward bias)	pp. 251-286	
W, 10/8			12: pn Junction Diodes 2 (current, small-sig. model)	pp. 286-317	HW #5 due
M, 10/13	**NO LAB**		**FALL BREAK**		
W, 10/15			13: pn Junction Diodes 3 (diode transient) & Metal-Semi Junctions	pp. 331-358	HW #6 due
M, 10/20	4. pn jct. Diode		14: MOS Capacitors 1 (band structure)	pp. 371-385	
W, 10/22			15: MOS Capacitors 2 (operational modes)	pp. 385-394	HW #7 due
M, 10/27	5. MOS-FET		16: MOS Capacitors 3 (C-V characteristics)	pp. 394-403	
W, 10/29			17: MOSFETs 1 (structure & operation)	pp. 403-422	HW #8 due
M, 11/3	6. MOS-FET Spice		18: MOSFETs 2 (I-Vs and parameter extraction)	Notes	
W, 11/5			19: MOSFETs 3 (equivalent circuit)	pp. 422-431	HW #9 due
M, 11/10	**NO LAB** (Exam 2)	Circuits & Modern Transistors	20: MOSFETs 4 (deviations from ideal)	pp. 443-455	
W, 11/12			**EXAM 2 – *Devices***		
M, 11/17	7. Basic Digital		21: Digital Circuits 1 (CMOS inverters)	Notes	
W, 11/19			22: Digital Circuits 2 (CMOS logic gates)	Notes	HW #10 due
M, 11/24	**NO LAB**		23: Digital Circuits 3 (DRAM & SRAM)	Notes	
W, 11/26			**THANKSGIVING BREAK**		
M, 12/1	8. Non-idealities		24: Modern Transistors (short channel effects, size scaling, current technology)	pp. 455-463	
W, 12/3			Course Review for Final ("Create Final Exam Project")		HW #11 due
Su, 12/14			**FINAL EXAM, 9am – 12pm ; *Comprehensive***		