ECE 3214: Semiconductor Device Fundamentals
VIRGINIA TECH
Course Syllabus (CRN *83914*)
Fall 2025 MW 4:00 PM-5:15 AM (WHIT 257)

I. ECE 3214 SEMICONDUCTOR DEVICE FUNDAMENTALS

Instructor: Prof. Mantu Hudait, Dept. of ECE, 626 Whittemore Hall
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Class Room: **WHIT 257**

Final Exam date and time

Exam Date:	**December 16th, 2025**	**Midterm-I during class hour**	**October 1st, 2025**
Begin Time:	7:45 AM	**Midterm-II during class hours**	**November 5th, 2025**
End Time:	9:45 AM	**Final (classroom)**	**December 16th, 2025**

Office Hours **Wednesday (Dr. Hudait)**: **11:00 am-12:00 pm** and by appointment (e-mail please).

TA: TBD

Course Description:

The course will cover device physics and device applications: Fundamental semiconductor device physics associated with semiconductor devices and an in-depth understanding of PN junction diodes, bipolar junction transistors, MOS capacitors, and junction field effect transistors.

Learning Objectives:

Having successfully completed 3214, students will be able to:

- Determine the band structure of semiconductors when supplied with basic materials properties and apply their knowledge of quantum mechanics.
- Calculate carrier distributions in thermal equilibrium and non-thermal equilibrium conditions for intrinsic and doped semiconductors.
- Apply basic semiconductor drift-diffusion equations to determine current flow in semiconductor devices.
- Differentiate between the fundamental differences of PN junctions and field effect transistors
- Determine the alignment of metal-semiconductor band diagrams and identify whether the junction is Ohmic or Schottky.
- Design a bipolar transistor, metal-oxide-semiconductor, and/or a field effect transistor that meets specific performance criteria by selecting the appropriate semiconductor material(s), doping, and device dimensions.

II. PREREQUISITES & COREQUISITES

Prerequisites: ECE 2204 (MIN grade of C-) or (ECE 2214 (MIN grade of C), ECE 2804) (MIN grade of C) or MSE 3204 (MIN grade of C-). **Prerequisites Enforced: Yes**

The student will be introduced briefly to the fundamentals of quantum mechanics. However, prior knowledge of this topic and solid-state physics will also help.

III. TEXTS AND SPECIAL TEACHING AIDS

Required Text

D.A. Neamen, *Semiconductor Physics & Devices*, 4th ed., McGraw-Hill, 2012; Hardcover, 768 pages©2012, ISBN-13 978-0-07-352958-5.

Additional Reference Books:

- Umesh Mishra and Jasprit Singh, *Semiconductor Device Physics and Design*, Springer, 2008 (e-book available through www.lib.vt.edu)
- M. Shur, *Physics of Semiconductor Devices*, Englewood Cliffs, NJ: Prentice Hall, 1990.

IV. EDUCATIONAL OBJECTIVES

The lecture sessions provide learning opportunities that should enable you to do the following upon completion of this course:

A. Develop a basic understanding of the following key concepts in quantum and statistical mechanics relevant to the physical properties of electronic materials and their device applications:

i. Quantum Mechanics:

Crystal structure of solids; space lattices; wave-particle duality; Schrodinger's wave equation; particle trapped in a box; particle tunneling through a barrier; allowed and forbidden energy bands; propagating electron wave in a periodic lattice; effective mass; density of states; strain effect on band structure; quantization effects in nanoscale devices

ii. Statistical Mechanics:

The Fermi-Dirac and Maxwell-Boltzmann probability distribution function, and the Fermi energy.

iii. Equilibrium vs non-equilibrium properties:

Carrier distribution at equilibrium; doped semiconductors; compensated semiconductors; carrier transport phenomena; Hall effect; excess carriers in semiconductors; continuity equation; Poisson's equation.

iv. p-n junction:

Carrier distribution and field profile at a PN junction; diode I-V characteristics and non-idealities, diode capacitance, heterostructures, band alignment; quantum well properties.

v. MOS capacitors and field effect transistors:

Understand and interpret C-V characteristics; understand the physical structure and detailed operation of Metal-Oxide Semiconductor Field-Effect Transistors (MOSFETs); understand the terminal I-V characteristics of MOSFETs and their associated non-idealities due to scaling; high electron mobility transistors; tunnel transistors; FinFETs.

vi. Bipolar junction transistors:

Understand the operation principle of BJT and the fundamental differences between BJT and MOSFETs.

vii. Solar cells and optical devices (if time permits)

Understand the physical operation of solar cells and their efficiency limits; heterojunctions to improve efficiency; potential impact on the global energy crisis; and light-emitting diodes. Carrier recombination and lifetime; carrier transport of p-n junction under illumination; solar cell parameters and device design; III-V heterojunctions, single and multijunction solar cells; tailor-made band gaps for matching solar spectrum.
[*Generation of light*: light-emitting diodes and semiconductor lasers. *Detection of light:* Solid state detectors: Take the ECE6214 graduate-level course if you are pursuing an MS degree in Micro and Nano Systems.

B. Become proficient with the fundamental device physics concepts

C. Learn to analyze device characteristics in detail and brainstorm ways to improve them or adapt them to a new application

V. SYLLABUS

Section 1

	Topic	Number of Lectures (**Tentative**)
1.	Crystalline Structures	2
2.	Basic Quantum Mechanics and Bandgaps	2
3.	Band Diagrams	1
4.	Carrier Concentration and Fermi Level	2
5.	Drift-diffusion and Carrier Mobility	2
6.	Recombination and Generation of Carriers	1
7.	Measurement of Resistivity and Mobility	Reading Materials

Midterm Exam 1 (October 1st, 2025)

Section 2

1.	PN junction Diodes	4
2.	Schottky Diodes and Ohmic Contacts	1
3.	Heterostructures	2
4.	Bipolar Transistors	2

Midterm Exam 2 (November 5th, 2025)

Section 3

1.	MOSFETs, Quantum well FETs, FinFETs, NSFETs	6
2.	Tunnel FETs	1
3.	Solar cells and optical devices (if time permits)	1

Final Exam (December 16th) **(Non-Cumulative)**

VI. GRADING POLICY

Homework (submit online)	**10%**
Midterm-I	**30%**
Midterm-II	**30%**
Final	**30%**
Total	**100%**

Homework (Please Read): *(10%)*

Homework problems will typically be assigned weekly and due at the end of class one week following their assignment. **No assignments will be accepted after the solution is posted,** except in the case of unforeseen, officially documented absences. The solution will be posted on the day homework is due. Please submit your homework electronically and check the time and submission day.

Each problem solution should be **neatly worked out**. When possible, sketch illustrative diagrams and label current, voltage, and other relevant quantities on the diagrams. Very rough sketches with no labels will receive no credit. Use industrially accepted notation for units, per the discussion on Day 1 of class.

ALL assigned problems will be considered for grading. *However, all problems may not necessarily be graded*. I expect you to have worked on ALL problems and to be prepared to submit the problem solutions in the above format at the end of class on the date due (check submission time and day on CANVAS).

You may consult with other students and with your instructor while you are working on assigned problems. However, your goal in consulting should be limited to exploring options and approaches rather than avoiding work. The ability to solve problems develops through disciplined effort, and the exams will require you to be able to solve problems. Note that if you use an open-source solution for your homework, you will have difficulty answering questions in either the midterm or final exam. I usually ask questions during class, and your participation is most important.

Attendance: (0%)

Attendance in all lecture classes is expected and critical to your completing the requirements of this course. If you miss a lecture, **read the textbook and my posted lecture notes**. If you have a conflict with a scheduled exam, you must make arrangements with your instructor well in advance so that an alternate exam time can be scheduled.

Exams (Please read): (90% = Midterm-I 30%+ Midterm-II 30%+Final 30%)

There will be only 2 mid-term exams and one final exam (October 1st for Midterm-I; November 5th for Midterm-II; December 16th Final. All exams will be in your classroom). No make-up exams will be given except for unforeseen, officially documented absences. If such a circumstance arises on a test date, it is your responsibility to contact me as soon as possible. If you expect to be absent on a test date for any legitimate reason (conferences, job interviews, project team competitions, *etc.*), it is your responsibility to give me sufficient prior notice so that we can make other arrangements. There will be a **FINAL exam** at the end of this course **(non-cumulative)**.

- **I will do relative grading based on your HWs and exam scores, along with the TA's input.**

VII. OFFICE OF UNDERGRADUATE ACADEMIC INTEGRITY

The Virginia Tech Honor Code establishes the standard for **ACADEMIC INTEGRITY** in this course and will be strictly enforced. *Discussion* of class material with your classmates or the instructor is encouraged; however, ALL submitted work must represent your efforts, and you must pledge to this effect on all work. The Office of Undergraduate Academic Integrity is poised to help students become successful through their academic and leadership involvement. The Office seeks to foster an environment that promotes fairness, personal responsibility, and integrity. For more details on the relevant honor codes, consult the websites listed below:

- https://honorsystem.vt.edu/content/honorsystem_vt_edu/en/resources/syllabus.html

Honor Code Pledge for Assignments:

The Undergraduate Honor Code pledges that each member of the university community agrees to abide by the states:

"As a Hokie, I will conduct myself with honor and integrity at all times. I will not lie, cheat, or steal, nor will I accept the actions of those who do."

Students enrolled in this course are responsible for abiding by the Honor Code. A student who has doubts about how the Honor Code applies to any assignment is responsible for obtaining specific guidance from the course instructor before submitting the assignment for evaluation. Students are strongly discouraged from misusing sites such as Chegg and CourseHero, as well as misusing ChatGPT and other Generative Artificial Intelligence. Students are strongly encouraged to consult their faculty members regarding the use of such outside materials, as the misuse of these sources may constitute a violation of the Honor Code. Ignorance of the rules does not exclude any member of the University community from the requirements and expectations of the Honor Code. For additional information about the Honor Code, please visit:

- https://www.honorsystem.vt.edu/

- All assignments submitted shall be considered "graded work," and all aspects of your coursework are covered by the Honor Code. All projects and homework assignments are to be completed individually unless otherwise specified.
- Commission of any of the following acts shall constitute academic misconduct. This listing is not, however, exclusive of other acts that may reasonably be said to constitute academic misconduct. Clarification is provided for each definition with some examples of prohibited behaviors in the Undergraduate Honor Code Manual located at https://www.honorsystem.vt.edu/

A. CHEATING

- Cheating includes the intentional use of unauthorized materials, information, notes, study aids, or other devices or materials in any academic exercise or attempts thereof.

B. PLAGIARISM

- Plagiarism includes the copying of the language, structure, programming, computer code, ideas, and/or thoughts of another and passing off the same as one's original work or attempts thereof.

C. FALSIFICATION

- Falsification includes the statement of any untruth, either verbally or in writing, concerning any element of one's academic work, or attempts thereof.

D. FABRICATION

- Fabrication includes making up data and results, recording or reporting them, or submitting fabricated documents, or attempts thereof.

E. MULTIPLE SUBMISSION

- Multiple submission involves the submission for credit—without authorization of the instructor receiving the work—of substantial portions of any work (including oral reports) previously submitted for credit at any academic institution or attempts thereof.

F. COMPLICITY

- Complicity includes intentionally helping another to engage in an act of academic misconduct or attempts thereof.

G. VIOLATION OF UNIVERSITY, COLLEGE, DEPARTMENTAL, PROGRAM, COURSE, OR FACULTY RULES

- The violation of any University, College, Departmental, Program, Course, or Faculty Rules relating to academic matters that may lead to an unfair academic advantage by the student violating the rule(s).
- **Honor Code Pledge for Assignments:**
- The Undergraduate Honor Code pledges that each member of the university community agrees to abide by the states:
- **"I have neither given nor received unauthorized assistance on this assignment."**
- Students enrolled in this course are responsible for abiding by the Honor Code. A student who has doubts about how the Honor Code applies to any assignment is responsible for obtaining specific guidance from the course instructor before submitting the assignment for evaluation. Ignorance of the rules does not exclude any member of the University community from the requirements and expectations of the Honor Code. For additional information about the Honor Code, please visit www.honorsystem.vt.edu. Students should report alleged honor code violations to their course instructors. ***THE HONOR CODE WILL BE STRICTLY ENFORCED IN THIS COURSE. HONESTY IN YOUR ACADEMIC WORK WILL DEVELOP INTO PROFESSIONAL INTEGRITY***.

Academic Misconduct Sanctions:

"If you have questions or are unclear about what constitutes academic misconduct on an assignment, please speak with me. I take the Honor Code very seriously in this course. The normal sanction I will recommend for a violation of the Honor Code is an **F*** sanction as your final course grade. The F represents failure in the course. The "*" is intended to identify a student who has failed to uphold the values of academic integrity at Virginia Tech. A student who receives a sanction of **F*** as their final course grade shall have it documented on their transcript with the notation "FAILURE DUE TO ACADEMIC HONOR CODE VIOLATION." You would be required to complete an education program administered by the Honor System to have the "*" and notation "FAILURE DUE TO ACADEMIC HONOR CODE VIOLATION" removed from your transcript. The "F," however, would be permanently on your transcript."

VIII. SPECIAL AID STUDENTS:

You must work through our SSD center, and all your exams will be supervised by them or online, with double the time. You can't take one exam at the SSD center and other exams online. I need to follow the school policy. You need to sign your special aid paper as soon as possible. Due to the large number of incoming students, you also must work with me so that the TA knows how many students need double time for exams after you have received a paper from the SSD center.

IX. ANNOUNCEMENTS

I will use Canvas to post homework assignments, homework solutions, and other information about the course materials. You should check your email and Canvas regularly. In case I use any teaching materials not from the textbook, I will post **those lecture notes** on Canvas. Lecture notes I prepared for the enhancement of your class participation. ***You need to read the textbook before or after class, please!***

X. HEALTH and COVID-19 Precautions

By participating in this class, all students agree to abide by the Virginia Tech Wellness principles.

XI. COURSE EXPECTATIONS

- Read lecture notes before and after class or READ the textbook. Need help, email me or the TA
- Attend class if you are not sick. Read Virginia Tech's daily news for COVID-19 and other health-related news
- Do homework and take help from my office hours as well as the TA office hours
- All exams will be in class hour EXCEPT for students with special accommodations
- Read the syllabus and pages listed below
- Need help, email me!

Read the Chapters for this course from your textbook:

Chapter 1: pages 1-20 (exercise: 21-24)
Chapter 2: pages 25-52 (exercise: 52-57)
Chapter 3: pages 58-100 (exercise: 100-104)
Chapter 4: pages 106-149 (exercise: 149-154)
Chapter 5: pages 156-1840 (exercise: 184-191)
Chapter 6: pages 192-201 (exercise: 233-240)
Chapter 7: pages 241-262 (exercise: 269-274)
Chapter 8: pages 276-295 (exercise: 323-330)
Chapter 9: pages 331-364 (exercise: 365-370)
Chapter 10: pages 371-419 (exercise: 433-441)
Chapter 12: pages 491-521 (exercise: 560-565)
Chapter 14: pages 618-639, 648-662 (exercise: 663-668)

This course is elective, and please take this course ONLY if you are genuinely interested in learning semiconductor device physics.

Reading Assignment: Operation principle of a MOSFET (Please read before attending this course).