

ECE 3214: Semiconductor Device Fundamentals
VIRGINIA TECH
Course Syllabus (CRN 83711)
Fall 2023 MW 4:00 PM-5:15 PM (NCB 110A)

I. ECE 3214 SEMICONDUCTOR DEVICE FUNDAMENTALS

Instructor: Prof. Mantu Hudait, Dept. of ECE, 626 Whittemore Hall
Phone: 540-231-6663 Email: mantu.hudait@vt.edu or mantu@vt.edu

Class Room: NCB 110A

Final Exam date and time Exam Date: **December 8th, 2023** **Midterm-I during class hour** **September 27th**
Begin Time: **1:05 PM** **Midterm-II during class hour** **November 1st**
End Time: **3:05 PM** **Final (classroom)** **December 8th, 2023**

Office Hours **Tuesday (Dr. Hudait): 10:00 am-12:00 pm** and by appointment (e-mail please).

TBD (Sengunthar Karthikeyan): karthikms91@vt.edu

Course Description:

The course will cover the device physics and device applications: Fundamental semiconductor device physics associated with semiconductor devices and in-depth understanding of PN junction diodes, bipolar junction transistors, MOS capacitor, 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 applying 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 difference of p/n junctions and field effect transistors
- Determine alignment of metal-semiconductor band diagrams and identify whether junction is Ohmic or Schottky.
- Design a bipolar transistor, metal-oxide-semiconductor and/or a field effect transistor that meet specific performance criteria through the selection of 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 the fundamentals of quantum mechanics. But some 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 on the following key concepts in quantum and statistical mechanics relevant to 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; the Fermi energy;

iii. Equilibrium vs non-equilibrium properties:

Carrier distribution at equilibrium; doped semiconductors; compensated semiconductor; 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 p-n 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 physical operation of solar cell and its efficiency limits; heterojunctions to improve efficiency; potential impact on global energy crisis and light emitting diodes.

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

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 bandgaps for matching solar spectrum.

[*Generation of light*: light emitting diodes and semiconductor lasers. *Detection of light*: Solid state detectors: Take ECE6214 graduate level course (taught by either me or Prof. Luke Lester for these topics after this course if you are pursuing 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 towards improving them or adapting them to new applications

V. SYLLABUS

Section 1

Topic	Number of Lectures (<u>Tentative</u>)
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 (September 27th)

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 1st)

Section 3

1. MOSFETs, Quantum well FETs, FinFETs, NSFETs	5
2. Tunnel FETs	1
3. Solar cells and optical devices	2

Final Exam (December 8th)

(Non-Cumulative)

VI. GRADING POLICY

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

Home Work (Please Read): (10%)

Homework problems will typically be assigned on a weekly basis and will be due at the end of class one week following its 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 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**. If a given assignment requires multiple pages of work, it must be stapled together prior to submission. Use neatly trimmed 8.5" x 11" paper and write on one side only. 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 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 ALL the 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 but 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. To obtain full credit for a homework assignment you must submit it to your instructor in class on the due date. Note that if you use open-source solution for your homework, you will have a difficulty to answer questions in either midterm or final exam. I usually ask questions during class and your participation is most important.

Attendance: (0%)

Attendance all lecture classes is expected and critical to your successfully completing the requirements of this course. In the event that you miss a lecture, it is your responsibility to ask one of your classmates or **read text book or read my posted lecture notes, video and hand written notes**. If you have a conflict with a scheduled exam, you must make arrangements with your instructor well in advance so that alternate times 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 (September 27th for Midterm-I; November 1st Midterm-II; December 8th 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 Exams score along with 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 own 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 academics 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 pledge that each member of the university community agrees to abide by 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 own original work, or attempts thereof.

C. FALSIFICATION

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

D. FABRICATION

- Fabrication includes making up data and results, and 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 pledge that each member of the university community agrees to abide by 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 in order 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 your all exams will be supervised by them or online with double time. You can't give one exam at SSD center and other exam online. I must need to follow the school policy. You need to sign your special aid paper as soon as possible. Due to large number of incoming students, you also must work with me so that TA knows how many students need double time for exam after you have received paper from SSD center.

IX. ANNOUNCEMENTS

I will use Canvas to post homework assignments, homework solutions, and other information pertaining to the course materials. You should check your email and the Canvas on a regular basis. In case, I use any teaching materials not from the text book, I will post **those lecture notes** in Canvas. Lecture notes I prepared for enhancement of your participation in class. **You need to read the text book prior to class or after the 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 text book. Need help, email me or TA
- Attend class if you are not sick. Read Virginia Tech daily news for COVID-19 and other health related news
- Do homework and take help of my office hour as well as TA office hour
- All exams will be in class hour EXCEPT students with special accommodation
- Practice sample test paper and solution (if available)
- Read syllabus and pages listed below
- Need help, email me!

Read Chapters for this course from your text book:

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 156-184 (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)