ECE 3214: Semiconductor Device Fundamentals
VIRGINIA TECH
Course Syllabus (CRN *83463*)
Fall 2021 MW 4:00 PM-5:15 PM

I. ECE 3214 SEMICONDUCTOR DEVICE FUNDAMENTALS

<table>
<tr><td>Instructor:</td><td colspan="4">Prof. Mantu Hudait, Dept. of ECE, 626 Whittemore Hall
Phone: 540-231-6663 Email: mantu.hudait@vt.edu</td></tr>
<tr><td>TA</td><td colspan="4">Sowmya Muthurangan, Email: sowmyam@vt.edu</td></tr>
<tr><td rowspan="4">Class Room: Midterms, Final Exam date and time</td><td colspan="4">SURGE 104D</td></tr>
<tr><td>Exam Date:</td><td>December 10th, 2021</td><td>Midterm-I during class hour @ SURGE 104D</td><td>September 29th</td></tr>
<tr><td>Begin Time:</td><td>1:05 PM</td><td>Midterm-II @ SURGE 104D during class hour</td><td>November 3rd</td></tr>
<tr><td>End Time:</td><td>3:05 PM</td><td>Final @SURGE 104D</td><td>December 10th, 2021</td></tr>
<tr><td>Office Hours:</td><td colspan="4">Tuesday: 10:00 am-11:00 am in person and by appointment (e-mail please).
(Online 11am-12pm, Meeting ID: 81578248007, Passcode: 257575)
TA: Thursday 1:30pm-3:00pm, Online Meeting ID: 836 0308 3279
Passcode: 504626 ; Room: 256 Whittemore Hall</td></tr>
</table>

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 p/n junction diodes, bipolar junction transistors, MOS capacitor, and junction field effect transistors.

Learning Objectives (from ECE undergraduate courses):

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. PREREQUSITES & 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-)

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 provides 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.

[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): *Generation of light*: light emitting diodes and semiconductor lasers. *Detection of light:* Solid state detectors].

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 (**Tentative**)
1.	Crystalline Structures	2
2.	Basic Quantum Mechanics and Bandgaps	2
3.	Band Diagrams	1
4.	Carrier Concentration and Fermi Level	3
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 29h) in class room

Section 2

1.	p-n Diodes	4
2.	Schottky Diodes and Ohmic Contacts	1
3.	Heterostructures	2
4.	Bipolar Transistors	2

Midterm Exam 2 (November 3rd) in class room

Section 3

1.	MOSFETs, Quantum well FETs, FinFETs	4
2.	Tunnel FETs	1
3.	Solar cells and optical devices	2

Final Exam (December 10th) in class room **(Non-Cumulative)**

Read Book Chapters for this course:

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)

VI. GRADING POLICY

Homework (Online)	**10%**
Quizzes	**10%**
Midterm-I	**20%**
Midterm-II	**30%**
Final	**30%**
Total	**100%**

Home Work and Quizzes (Please Read): ***(10%+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. Only electronic submission of homework will be allowed due to COVID-19 situation. The submission window is 11:59pm on the 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 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): (80% = Midterm-I 20%+ Midterm-II 30%+Final 30%)

There will be only 2 mid-term exams and one final exam (September 29th for Midterm-I; November 3rd Midterm-II; December 10th Final. All exams will be in person format). 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**).

VII. 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 VT 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 person and in your class room.
- Practice sample test paper and solution (if available)
- Read syllabus and pages listed below
- Need help, email me!
- I will do relative grading and will curve the grade at the end after final exam for final grade with TA's input.

VIII. 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. For more details on the relevant honor codes, consult the websites listed below:

- Undergraduate Honor System, http://www.honorsystem.vt.edu/index.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."**

Every assignment and each exam paper, you must write: **"I have neither given nor received unauthorized assistance on this assignment and exam."**

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:

- 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. Hokies are expected to meet the academic integrity standards at Virginia Tech at all times.

- 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/

The Academic Integrity expectations for Hokies are the same in an online class as they are in an in-person class. **We strongly discourage to use these on-line websites such as Chegg, CourseHero, and GroupMe from using them**. Please remember that students office are able to effectively investigate students who are taking help from these websites and get a free-ride. All university policies and procedures apply in any Virginia Tech academic environment, and all students are expected to follow them.

- For additional information about the Honor Code, please visit: https://www.honorsystem.vt.edu/
- **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.
- **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.

- **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.
- **FABRICATION:** Fabrication includes making up data and results, and recording or reporting them, or submitting fabricated documents, or attempts thereof.
- **MULTIPLE SUBMISSION:** Multiple submission involves the submission for credit – without authorization from the instructor receiving the work – of substantial portions of any work (including oral reports) previously submitted for credit at any academic institution of attempts thereof.
- **COMPLICITY:** Complicity includes intentionally helping another to engage in an act of academic misconduct, or attempts thereof.
- **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).

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."

IX. Academic Integrity Success Module (please complete):

Please complete these two modules available in Canvas on Academic Integrity at Virginia Tech. This module takes no more than 30 minutes to complete, and will open August 20th, and is available throughout the year. Here is a link to the module: **https://canvas.vt.edu/enroll/CE7YK9.** The completion of this module will be verified by UG student's office.

Understanding the Code:

A limited time offering through Canvas for peer to peer education in a video format. This module is put together by the Undergraduate Honor Council delegates and addresses different Academic Integrity scenarios and answers frequently asked questions. Completion of UTC can also be verified through Canvas. UTC also takes students no longer than 30 minutes to complete. UTC will be open on Canvas from August 31st – September 3rd. Here is a link to Understanding the Code: **https://canvas.vt.edu/enroll/7HR4PF**

X. STUDENTS WITH SPECIAL ACCOMMODATION:

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

XI. 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 as well. 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!*** **Check my lecture notes and hand written notes after class.**

XII. HEALTH and COVID-19 Precautions

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

If you are exhibiting even very slight signs of illness, you **must** not attend class in person. Notify me by email and follow the instructions posted at https://vt.edu/ready/health.html#tips.

"Virginia Tech is committed to protecting the health and safety of all members of its community. **By participating in this class, all students agree to abide by the Virginia Tech Wellness principles"**

To uphold these principles, in this class you must do the following:

- Wear a mask at all times while in class.
- Wear a mask during all other activities conducted for the class in public indoor areas.
- Isolate yourself from campus if you test positive for COVID or begin to feel symptoms that might be related to COVID (see: https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html).
- Be respectful of the well-being of others by practicing appropriate personal hygiene and by providing appropriate physical distance when feasible.
- Masks may be reusable or homemade cloth masks, dust masks, or surgical masks and should fit close to the face to provide thorough filtration of breathed air. Face shields that are open around the sides do not satisfy this requirement and are currently not accepted as a viable alternative by the university (see: https://ready.vt.edu/faq.html).
- If a student feels that they cannot wear a mask for health concerns and must use an alternative form of face covering such as a face shield, they should contact Services for Students with Disabilities to request an accommodation. No exceptions for masks will be provided unless there is an official accommodation notice provided by SSD to the instructor.
- **These requirements will not be waived**. The instructor has the authority to terminate the class session early if the health and safety requirements are not maintained. Students who fail to follow the requirements will be reported to the Office of Student Conduct.
- If a student will miss significant class activities because of the need to self-isolate, then the Dean of Students Office should be contacted for an official absence verification. Prolonged absences may be difficult to make-up. Students should consult with their advisor about possible options if too much course work is missed to feasibly make-up.
- As pandemic conditions continue to evolve through the semester, these requirements may need to change. The guidance posted by the university at VT Ready should represent the most up-to-date requirements of the university and should be checked periodically for changes.

Face Shields are essentially prohibited. This is a reversal of earlier guidance and is now stated explicitly on the VT Ready FAQ page: "Instructors will be required to wear face masks. **Face shields are not a viable alternative.**" (see: https://ready.vt.edu/faq.html)

Faculty who feel that they need a face shield instead of a mask for health reasons are directed to contact the Office of ADA and Accessibility to receive and official accommodation.

If audibility is a concern, faculty are advised to use microphones and audio systems to amplify their voices. Classroom AV capabilities are listed at:

https://rooms.classroomav.vt.edu/search/results?usbCam=.

A tutorial on the use of classroom AV equipment is available through Page up:
https://virginiatech.pageuppeople.com/learning/6462.

Clear masks are also recommended. If faculty have students who are hearing impaired or indicate that they have some other health issue that requires a face shield, the faculty member should direct the student to Services for Students with Disabilities (SSD) to get an official accommodation. Faculty should follow the guidance communicated by SSD in handling such cases. Otherwise, students are expected to follow the mask mandate.

Some clear mask alternatives are listed below. If interested in any product, you should inquire with your department about options for procurement. This is not intended to be a complete list or an endorsement of any product:

- Clear Mask: https://www.theclearmask.com/
- Safe 'N' Clear: https://safenclear.com/
- Virginia Tech fabricated masks: https://vtx.vt.edu/articles/2021/06/unirel-clearmasks.html - *If interested in this option, have your department head or a designated individual in your department compile a desired quantity and contact Dr. Alex Leonessa (alenoness@vt.edu) in Mechanical Engineering to initiate fabrication.*

Additional information can be found on the Ready FAQ page: https://ready.vt.edu/faq.html.

See also: https://www.provost.vt.edu/provost-weekly-updates/weekly-august-2-6.html.

CDC information on COVID variants and measures to reduce COVID transmission:

- https://www.cdc.gov/coronavirus/2019-ncov/variants/variant.html
- https://www.cdc.gov/coronavirus/2019-ncov/vaccines/fully-vaccinated.html
- https://covid.cdc.gov/covid-data-tracker/#county-view

If you are exhibiting even the slightest sign of illness, you must not attend an in-person class. Notify me by email and follow the instructions posted at https://vt.edu/ready/health.html#tips.