South Dakota School of Mines & Technology
Electronic, Magnetic, & Optical Properties of Materials, Spring, 2024
EE 362-M01 (3-0) 3 credits

Instructor Information

Instructor's Name- Thomas Montoya

Instructor's Contact Information- (605) 394-1219, Thomas.Montoya@sdsmt.edu, EEP 314

Instructor Office Hours- 8:20-9 am & 3-4 pm MWF, or when available (open door policy).

As I do not always notice voicemails in a timely fashion, e-mails or in person are the preferred contact methods. Unless I am traveling or it arrives late at night, I typically respond to e-mails the same day.

Course Information

Course Start/End Dates- 1/8/2024 to 5/3/2024.

Course Meeting Times and Location- MWF from 1-12:50 pm in EEP 338

Course Delivery Method- The course will be delivered in-person for lectures, quizzes, and exams. The syllabus and a link to my web page http://montoya.sdsmt.edu will be posted on D2L. The course web page will be used for posting assignments, examples, solutions, etcetera. E-mail will be used to notify students of course-related information and events (**check daily**). Your first.last@Mines.sdsmt.edu address will be used for these e-mails.

Course Description

This course studies the behavior of materials of interest to electrical engineers and covers fundamental issues such as energy band theory, density of states, Fermi-Dirac statistics, equilibrium statistics in semiconductors, and Fermi energy. This foundation is then used to study topics such as conduction and semiconductor devices. Other topics include Peltier devices, optoelectronics, and piezoelectric devices.

Course Prerequisites- MATH 225, MATH 321, and (PHYS 213/213L or PHYS 209)

Student Learning Outcomes

Student Outcomes (SOs)

Student Outcomes are defined in ABET's accreditation standards for engineering programs:

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. An ability to communicate effectively with a range of audiences.
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Course Learning Outcomes (CLOs)

Upon completion of this course, students should demonstrate the ability to:

A. Describe the physical structure of semiconductor materials. (SO 1)
B. Understand the basic concepts describing the behavior of bulk semiconductors, including the energy-band model, the Fermi function, and the calculation of electron and hole densities in semiconductors. (SOs 1 & 2)
C. Understand the roles played by diffusion current, drift current, and generation-recombination in describing current flow in semiconductors. (SOs 1 & 2)
D. Describe the electric fields and electric potential inside a pn junction. (SOs 1 & 2)
E. Understand the mechanism of rectification in a pn junction. (SOs 1 & 2)
F. Understand the operation of LEDs and photodiodes. (SOs 1 & 2)
G. Understand the operation of, and terminology used in describing and specifying the properties of MOSFETs. (SOs 1, 2 & 6)
H. Understand the operation of, and terminology used in describing and specifying the properties of BJTs. ((SOs 1, 2 & 6)
I. Understand operation of, and applications for thermoelectric devices. (SOs 1 & 2)
J. Understand operation of, and applications for piezoelectric devices. (SOs 1 & 2)
K. Understand operation of, and applications for ferromagnetic materials. (SOs 1 & 2)
L. Understand dissimilar metal corrosion and means for preventing it. (SOs 1 & 2)

Course Goals

Students should gain a basic familiarity with the properties of a variety of materials useful for electrical and electronic applications in order to apply them and to predict their behavior.

Course Topics- See course description and tentative course schedule.

Course Materials

Required Textbook(s) and Materials

Semiconductor Physics and Devices: Basic Principles (4th Edition), Donald A. Neamen, McGraw Hill, 2012, ISBN 978-0-07-352958-5.

Technology Equipment Needed for the Course

The course requires use of a computer and scientific calculator (capable complex number operations). Software needed/used in the course will include a pdf reader (Acrobat), D2L, MATLAB and/or MathCad, and Microsoft Office.

Technology Skills Needed for the Course

Ability to navigate D2L and internet, upload/download files (e.g., text and pdf files), using MS Office programs, communicating via email, and, **depending on COVID,** connecting audio/video and using tools such as Zoom. MATLAB and/or MathCad can/will be used for some assignments.

Course Grading

Coursework

- Course instruction will be delivered in lectures.
- Instructor course notes are posted to course webpage, a 3-ring binder is suggested (2.5" or above).
- Bring notes, text, and calculator to every class. Most quizzes will be unannounced and require a calculator and may be open book/notes (no borrowing, no smartphones, no computers).
- To aid grading, homework shall meet the following specifications (example on course web page):
  (a) Use the front (i.e., single-sided) of 8.5" × 11" engineering graph paper or plain white paper (NO pages torn from spiral notebooks) for assignments.
  (b) At the top of **each** page put date, course number, your name, and page numbering (i.e., page *x* of *y* or *x*/*y* formats in upper right-hand corner). Ensure problems & pages are in order.
  (c) All work exceeding one page should be stapled - no paper clips, folded corners, or folders.
  (d) Write-out problem numbers & descriptions, copy/draw figures, and **show all** work so it can be understood without the text. No work (i.e., "magic" answer) → no credit.
  (e) Writing/figures/graphs must be legible and large enough to read → illegible = no credit.
  (f) Reference equations derived in the text (e.g., equation number and/or page number). Fundamental equations (e.g., Maxwell's equations, Ohm's Law ...) are excluded from this requirement.
  (g) Use notation, especially for vectors, and conventional engineering units & prefixes (i.e., MKS) as given in class and text. For example, $\bar{E} = \hat{a}_\theta\, 10$ kV/m and 100 MHz ***NOT*** $\bar{E} = \hat{\theta}\, 100$ V/cm and 10^5 kHz. Answers with incorrect notation and/or without applicable units are incomplete/incorrect.
  (h) Answers should be boxed/double underlined, in **decimal** format if a number (no fractions) with variables, values & units (if any) included. Also, use lead zeros for fractional answers. For example, "$\boxed{V_x = 0.4\text{ V}}$" ***not*** "$V_x = .4$" or "$V_x = 2/5$ V". Typically, 4-6 significant digits are used.
  (i) Work problems sequentially in a **single** vertical column with subparts clearly labeled, e.g., a), b) ... Leave space (~1/2") between consecutive parts of a problem, and draw a line across the page at the end of each problem if there is more than one.
  (j) **No** more than **two** problems on any single page.

Attendance Policy

Attendance is required. Notify instructor in advance (when possible) if you will be absent from class.

Late/Make-up Assignment Policy

- Homework (HW) is due at the beginning of class on the specified days (up to 20% penalty for being late w/out doctor's note, etcetera). If you know that you will be missing a class, it may be turned in early. HW will **not** be accepted or graded after solutions are posted on the course web page.
- Missed quizzes will **not** be made up. If you know that you will be missing a class for a school-related activity (athletic travel, conference, etcetera), you may stop by the day before and ask to take a quiz early (if available).
- Make-ups for exams only allowed for school-sponsored events, documented illness, …
- If 2/3 of quizzes and 2/3 of HW are completed at a **passing** level, the lowest HW grade and lowest two quiz grades will be dropped (no questions asked). If not, **all** quizzes and HW will count (no drops). The drops are meant to cover any absences, including those due to illness, interviews, trips…

Academic Integrity

South Dakota Mines is committed to academic honesty and scholarly integrity. The South Dakota Board of Regents Policy 2:33 provides a comprehensive definition of "Academic Dishonesty", which include cheating and plagiarism. All Instructors at South Dakota Mines are required to report allegations of academic misconduct to the Student Conduct Officer. The South Dakota Board of Regents Policy 3:4 provides detailed information regarding key definitions, policy information, prohibited conduct, and the Student Conduct process adhered to at South Dakota Mines. Any student suspected of violating academic integrity standards will be reported in accordance with the process outlined on the South Dakota Mines website.

- Students are encouraged to discuss homework with classmates in general terms. However, copying, plagiarism … is not acceptable and will be penalized (e.g., grade of zero).

Grading and Assessment

Student learning is assessed by a combination of laboratories/projects, exams, and quizzes as well as homework.

Description	Percent
Three (3) Hourly exams @ 15% each	45%
Quizzes	20%
Homework	15%
Final exam	20%
Total	**100%**

Special Note Regarding Final Exams: Per South Dakota Mines Policy (II-6-2), if you are scheduled to take three or more final/last exams on the same day during finals week, you may request that the middle exam(s) of the day be rescheduled. ***You are required to make this request of your Instructor(s) at least 30 days prior to the last day of regular classes.***

Grading Scale- 100 > A > 90, 89 > B > 80, 79 > C > 70, 69 > D > 60, F < 60.

Academic Freedom Statement

Academic Freedom is the cornerstone upon which higher education is built. Academic freedom, as defined by BOR policy 1:11, is fundamental to the advancement of truth, development of critical thinking, promotion of civil discourse, and contribution to the public good. Each course includes the freedom to discuss relevant matters and present various scholarly views in the classroom, as determined by the subject-matter expertise of the instructor. Students are encouraged to develop the capacity for critical thinking and to pursue the truth, debate ideas, express and evaluate their opinions, and draw conclusions. Students are free to take reasoned exception to the views offered in any course of study and to reserve judgment about matters of opinion, but they are responsible for learning the content of any course of study for which they are enrolled.[1]

[1] *Language adapted from the American Association of University Professors "Joint Statement on Rights and Freedoms of Students".*

Complaint Process

While we hope that every student has a meaningful and positive experience at South Dakota Mines, should a concern arise, students are encouraged to first attempt to resolve their concern directly with the person or office directly involved. Following that attempt, should the concern remain unresolved, students are encouraged to reach out to the Dean of Students office at DeanOfStudents@sdsmt.edu or 605.394.2416. Additionally, students may access the online form to submit their complaint, appeal, or grievance.

Grade Appeal Policy

In alignment with BOR Policy 2:9, students who wish to appeal their final course grade shall first discuss the matter with the course instructor. If the concerns are unresolved following that discussion, students may utilize the online form to submit "Appeal – Academic" for a "Grade Dispute".

Opportunity for All - Student Success Services and Support

Students are provided a one-stop source for information regarding all the services and supports to ensure success. Visit the Opportunity for All page to access service and department information including ADA accommodations, Career Services, Counseling, Office for Inclusion, Slide Rule (math support), Student Success, Title IX, Tutoring, and Veterans Services, to name a few.

South Dakota Board of Regents Required Syllabus Statements

The following statements may be found online in South Dakota Board of Regents Academic Affairs Council Guideline 5.3.A:

- Freedom in Learning
- Americans with Disabilities Act
- Academic Dishonesty and Misconduct
- Acceptable Use of Technology
- Emergency Alert Communications

Electronic Devices Policy

Please silence/turn off your cell phone before class starts. No text messaging or headphones in class. You may use a laptop/tablet in class for purposes of note taking (NOT allowed for exams or quizzes). No other use of any other electronic/computer media, other than calculators, is allowed during class time.

Topics/Course Schedule: Selected topics from Chapters 1-8, 10, and 12, supplemented by notes. See attached tentative schedule.

Class | Date	Tentative Topics/Activities	Reading/Text
1 | 1/8/24 2 | 1/10/24 3 | 1/12/24	**The Crystal Structure of Solids-** Semiconductor Materials, types of solids, space lattices, diamond structure, and atomic bonding. Time allowing- imperfection & impurities in solids, growth of semiconductors	• 1.0 - 1.2 • 1.2 - 1.4 • 1.5 - 1.8
1/15/24	**Holiday**	
4 | 1/17/24 5 | 1/19/24 6 | 1/22/24	**Introduction to Quantum Mechanics-** Principles of Quantum Mechanics, Schrodinger's Wave Equation, Applications of Schrodinger's Wave Equation, Extensions of the Wave Theory to Atoms	• 2.0 - 2.1 • 2.2 - 2.3 • 2.3 - 2.5
7 | 1/24/24 8 | 1/26/24 9 | 1/29/24	**Introduction to the Quantum Theory of Solids –** allowed & forbidden energy bands, electrical conduction in solids, extension to three dimensions, density of states function, statistical mechanics	• 3.0 - 3.2 • 3.3 - 3.4 • 3.4 - 3.6
10 | 1/31/24	**Exam #1**- Covers material from Chapters 1 and 2	
11 | 2/2/24 12 | 2/5/24 13 | 2/7/24 14 | 2/9/24 15 | 2/12/24	**The Semiconductor in Equilibrium-** charge carriers, dopant atoms and energy levels, extrinsic semiconductor, statistics of donors and acceptors, charge neutrality, position of Fermi energy level	• 4.0 - 4.1 • 4.2 - 4.3 • 4.3 - 4.4 • 4.5 - 4.6 • 4.6 - 4.7
16 | 2/14/24 17 | 2/16/24 **2/19/24** 18 | 2/21/24	**Carrier Transport Phenomena-** carrier drift, carrier diffusion, graded impurity distribution, Hall Effect (time-allowing)	• 5.0 - 5.1 • 5.1 – 5.3 **Holiday** • 5.3 – 5.5
19 | 2/23/24 20 | 2/26/24	**Nonequilibrium Excess Carriers in Semiconductors-** carrier generation & recombination, characteristics of excess carriers, ambipolar transport	• 6.0 - 6.1 • 6.2 - 6.3
21 | 2/28/24	**Exam #2**- Covers material from Chapters 3,4, and 5	
22 | 3/1/24 23 | 3/4/24	ambipolar transport continued, quasi-Fermi energy levels, time allowing- excess carrier lifetime, surface effects	• 6.3 - 6.4 • 6.5 - 6.7
24 | 3/6/24 25 | 3/8/24 **3/11 – 3/15** 26 | 3/18/24	**The pn Junction-** basic structure of the pn junction, zero applied bias, reverse applied bias, junction breakdown	• 7.0 - 7.1 • 7.2 - 7.3 **Spring Break** • 7.3 – 7.4
27 | 3/20/24 28 | 3/22/24 29 | 3/25/24	**The pn Diode –** pn junction current, generation-recombination currents and high-injection levels, small-signal-model of the pn junction, time allowing- charge storage and diode transients, tunnel diode	• 8.0 - 8.1 • 8.2 - 8.3 • 8.4 - 8.6
30 | 3/27/24 **3/29/24** 31 | 4/1/24	**Fundamentals of the Metal-Oxide – Semiconductor Field-Effect Transistor**- two-terminal MOS structure, capacitance-voltage characteristics	• 10.0 - 10.1 **Holiday** • 10.2 - 10.3
32 | 4/3/24	**Exam #3**- Covers material from Chapters 6, 7, and 8	
33 | 4/5/24 34 | 4/8/24	Basic MOSFET operation, frequency limitations, time-allowing- CMOS technology	• 10.3 - 10.4 • 10.4 - 10.6
35 | 4/10/24 36 | 4/12/24	**The Bipolar Transistor-** bipolar transistor action, minority carrier distribution, transistor currents & low-frequency common-base current gain	• 12.0 - 12.1 • 12.2 - 12.3
37 | 4/15/24 38 | 4/17/24 39 | 4/19/24 40 | 4/22/24 41 | 4/24/24	**Special Topics-** thermoelectric devices, piezoelectric devices, optoelectronics, ferromagnetic devices, dissimilar metal corrosion, and ??	• Notes • Notes • Notes • Notes • Notes
42 | 4/26/24	**Make-up & Review**	
	Final Exam- Friday, May 3, 2024 from 2 - 3:50 pm, EEP 208	