# MSE 304: Electronic Properties of Materials, Spring 2021

**Lectures:** Monday, Wednesday and Friday 9:00 am – 9:50 am,
via Zoom Meeting ID 840 8808 3972.
The passcode for the Zoom Meeting is available on Compass.
Remember to sign in with UIUC Single Sign-On (SSO) to get access.
Lecture recordings and presentation slides will also be made available online via Compass and Mediaspace.

**Instructor:** Prof. Axel Hoffmann
**Office:** Materials Research Laboratory 1021 **Email:** axelh@illinois.edu

**Office Hours:** Monday, Wednesday and Friday 10:00 am – 11:00 am, or via prior appointment.
All office hour meetings will be via Zoom Meeting ID 891 9572 8329.
The passcode for the Zoom Meeting will be made available in class.
Remember to sign in with UIUC Single Sign-On (SSO) to get access.

**Teaching Assistants:**
Jinsong Cui (jinsong4@illinois.edu),
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**Office Hours:** See Compass for days and times of TA office hours.
All office hour meetings will be via Zoom Meeting ID 891 9572 8329.
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**Course Description:**
Students will be able to understand the theoretical description of various semiconductor devices and how that traces back to the materials they are made of. Students will obtain a grasp of the equations of quantum mechanics and their (analytical) solution for model systems. Moreover, students will obtain insight into modern computational techniques to describe electronic properties of solids as well as semiconductor devices. Students will be able to solve numerical problems.

**Scope:**
Fundamentals of quantum mechanics; atoms and small molecules; tunneling and Heisenberg's uncertainty principle; angular momentum; spectroscopy techniques; solids, in particular metals and semiconductors; Students should obtain a fundamental understanding of quantum mechanics and how it governs electronic properties of materials and devices.

**Prerequisites:**
PHYS212, PHYS214, MATH241, MATH285; as well as their prerequisites. *If you have not passed a prerequisite course, please see the instructor before continuing*.

**Textbook:**
*Principles of Electronic Materials and Devices*
By Safa O. Kasap
McGraw Hill, 4th edition (2018)

Alternative (optional) textbook:
*Electrical Properties of Materials*
By Laszlo Solymar, Donal Walsh, and Richard R. A. Syms
Oxford University Press, 10th edition (2019)
also available electronically from UIUC library

**Lecture policy:**
Prompt and regular attendance at lectures is required to obtain credit for quizzes administered via Zoom-polls. In addition, all lecture material will also be made available online via Compass. All the material presented in class is fair game for the homework and examinations. Furthermore, you are expected to check Compass, Campuswire, and your email regularly for course updates.

**Expectations:**
To succeed in this class, you will need to

- Read the chapter *before* coming to class, and formulate questions;
- Participate in the class;
- Make sure you understand the homework problems and solutions;
- Be able to *correctly* solve problems;
- Seek out help when you have trouble.

**Grading:**

| | | |
|---|---|---|
| In-class Zoom-poll quizzes: | 8% | |
| Homework (Online and Offline): | 26% | |
| Computational reports 1 and 2: | 12% | (6% each) |
| Prerequisite quiz: | 4% | |
| Quizzes 1–4: | 40% | (10% each) |

All assessment scores will be stored in the gradebook in Compass.

Numerical total score corresponds to the following final grades:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| A+ | (97–100) | B+ | (87–89) | C+ | (77–79) | D+ | (67–69) | | |
| A | (93–96) | B | (83–86) | C | (73–76) | D | (63–66) | F | (0–59) |
| A- | (90–92) | B- | (80–82) | C- | (70–72) | D- | (60–62) | | |

**In-class quizzes:**
Quizzes in each lecture will be administered via Zoom-polls. Thus, it is important that you join the Zoom meeting for class via the UIUC Single Sign-On (SSO) process, so that you receive proper

credit. The credit for the in class Zoom-poll quizzes is 60% participation and 40% correctness. Your lowest four in-class quiz scores will be dropped.

**Homework policy:**
All homework will be assigned through the MSE 304 course website on Compass. Links will either direct you to online homework through PRAIRIELEARN or to an assignment sheet with problems/computational homework (offline homework), see details below. All homework assignments (offline and online) are due on **Tuesdays at 11.59 pm**. Late submission will be penalized by 50% for each day late. Your lowest homework score will be dropped.

**Online Homework:**
Assignments on PRAIRIELEARN.

- You can rework completed items after the due date. This work will not be saved and will not affect your grades.
- You will receive a grade for ALL assigned online homework problems. Your homework (HW) score will also appear in the grade book.
- The online homework problems give explicit values and units to the relevant lengths, material properties, etc., and therefore you should give your final answer with an explicit numerical value. Nevertheless, when solving a homework problem, you should (to the utmost extent possible) assign symbols to all the relevant lengths, material properties, etc., and then solve the problem symbolically. As a last step, you should substitute the value and units of each of the symbols in the symbolic formula. You are encouraged to solve all problems symbolically.
- The symbolic form of working out the problems will be used in the lectures, in offline-homework assignments, and exams.
- You are encouraged to print out each homework problem and derive your symbolic solution on this print-out. Store these solutions for your future reference.
- You should come to office hours with the symbolic solution for your online assignment. We will be able to check your work better if you have that in hand.
- The "zeroth" online homework is optional, it contains questions regarding the syllabus. You can earn up to 0.5 of extra points to be added to your final grade.

**Offline Homework:**
Your solutions to work sheets must be submitted via GradeScope. The *only format* that will be accepted for submission is a single, properly-ordered PDF, in portrait format; your name must be printed legibly on the top of the first page. The TAs will grade the report. You may submit each report a maximum of two times; only the latest submission will be graded. After grading, any regrade requests will have to be submitted via GradeScope within *one week* of receiving the graded homework. Further information about using GradeScope is available at:
https://www.gradescope.com/help#help-center-section-student-workflow

*Computational reports*. Computational materials science and engineering is a field with increasing importance in research and industry; to give you experience in applying the tools of computational modeling to materials science and engineering, some of the offline work sheets that are assigned throughout the semester will require computational work. Additional information will accompany

these assignments, and you will be able to take advantage of additional support from a teaching assistant on these assignments.

Written reports are assigned to practice the communication of engineering concepts in writing. They will be graded based on presentation, neatness, correct use of symbols, quality of drawings and diagrams, and clarity of explanation (60 %). Reports should be neat and organized, hand-written or typed. Tables and graphical representations of results should be generated using some software program such as Excel, TecPlot, MatLab, etc., rather than being hand-drawn. Correct interpretation of the problem and correct final answers are important (40%). Point breakdown for the written report:

- 2: Correct interpretation of the problem
- 2: Correct final answer
- 1: Presentation quality
- 2: Clarity of explanation
- 1: Clear drawing and diagrams
- 1: Use of symbolic work
- 1: Use of units on numerical answers

**Pre-lecture Questions:**
Pre-lecture questions on the reading material will be assigned in PRAIRIELEARN before class and answers are due at **9 pm the day before each lecture**. Answering those is optional, but by participating you can earn up to 1.0 extra point to be added to your final grade.

**Online proctoring for exams:**
This course uses the College of Engineering Computer-Based Testing Facility (CBTF) for proctoring its quizzes and exams: https://cbtf.engr.illinois.edu. The policies of the CBTF are the policies of this course, and academic integrity infractions related to the CBTF are infractions in this course. If you have accommodations identified by the Division of Rehabilitation-Education Services (DRES) for exams, please communicate your Letter of Accommodation (LOA) to the CBTF before you make your first exam reservation. CBTF will advise you as to whether they provide your accommodations or whether you will need to make other arrangements with your instructor. Any problems during the testing while being proctored by CBTF must be reported to CBTF staff at the time the problem occurs. If you do not inform a proctor of a problem during the test, then you forfeit all rights to redress.

**Prerequisite quiz, Regular quizzes, and optional Comprehensive Final Exam:**
To aid in learning, this class uses quizzes to evaluate your learning and recall. There are five mandatory quizzes and one prerequisite quiz; they will take place via PRAIRIELEARN using proctoring by Computer-based Testing Facility (CBTF). You will be able to pick the exact date and time at which you will take your exam by signing up online. The weeks for each exam are provided in the schedule on the MSE 304 website. The optional comprehensive final exam will take place also via PRAIRIELEARN using CBTF ptroctoring. If you are unable to attend a quiz then you must inform your professor by email at the earliest possible opportunity. For non-emergency absences this notification must be at least one week in advance. Conflict-exam arrangements will be handled through the CBTF and will be scheduled for students with a legitimate scheduled

conflict according to the final exam policies. Exams are closed to all electronics (no calculators, no laptops, no phones, etc.).

Each quiz will cover a subset of topics from the class. The prerequisite exam covers a review of topics from the prerequisites for the class, while quizzes 1–4 each cover a broad topic (quantum mechanics, solid-state physics, and semiconductor devices). Lastly, the class will conclude with an optional comprehensive final exam. If you choose to take the final exam, your grade on the final exam will replace your lowest single quiz grade, provided that your final exam grade is not lower. This exam is an opportunity for you to demonstrate your understanding of the topics from class.

**Grade Reporting:**
All assessment scores are stored in the gradebook in Compass. Any errors in grade reporting appearing in the gradebook must be reported within 1 week of the grade being posted in the gradebook or by the last day of class, whichever is earlier. If you have a missing grade, contact the instructor.

**Course Materials, Discussions and Announcements:**
Course materials, including homework, lecture notes, and lecture recordings will be made available through our course Compass website at https://compass2g.illinois.edu/. Furthermore, the lecture recordings will also be accessible through a dedicated channel in Mediaspace. You can subscribe to receive automatic notifications of new videos posted by using the following link: https://mediaspace.illinois.edu/channel/MSE+304+Spring+2021+Electronic+Properties+of+Materials/197070193/subscribe.

Discussions and announcements related to course material will be facilitated by using Campuswire. This site will be used for all communication between the instructire, Tas, and students. You should register for this course on Campuswire using the access code 7169 at: https://campuswire.com/p/G8F877348 and you will need to provide a valid email address that you check regularly for subsequent communications. If you desire, then you can post anonymously or make a private post just to the instructor (rather than sending an email). TAs are scheduled to be checking Campuswire three times per day during the week. *Note that Campuswire should be used to communicate with your instructors, rather than email.*

**Obtaining help:**
The main two ways to obtain help are online at Campuswire or in person at the office hours. Please do not send email directly to TAs or professors for routine help or absences. In cases of emergencies related to exams (e.g., illness) you should email your professor at the earliest possible opportunity.

Do not ask TAs to work the homework problems before they are due; it is fine to ask specific questions on the details of your attempted solutions, or to work out problems that are similar to homework problems.

**Absences:**
Excused Absence Request Form: https://forms.illinois.edu/sec/7838715

1. Excuses from assessments will only be given in the following circumstances:
    a. Illness
    b. Personal crisis (*e.g.,* car accident, required court appearance, death f close relative)
    c. Required attendance at an official UIUC activity (*e.g.*, varsity athletics, band concert)
2. In all cases you must complete the online Excused Absence Request Form and upload a scan of the official written documentation explaining your absence.
3. In cases (a) or (b) an official excuse letter from the Dean on Duty must be submitted via the online form within 2 weeks of the due date of the missed assessment, but no later than reading day (May 6). In cases of extended or unusual illness, late submission of excuse documentation will be considered. See Student Assistance Center.
4. In case (c) an official letter from the designated university official must be submitted via the online form at least one week prior to the due date of the missed assessment.
5. If you will not be able to take an exam due to illness or any other reason, you must send email to your professor at the earliest possible opportunity. Excused exams will be replaced by a weighted average of the other exam scores at the end of semester.
6. Notwithstanding the above, at the professor's discretion you may be required to make up any excused work or attend substitute instruction or assessment.

**Accommodations:**
To obtain disability-related academic adjustments and/or aids, students should contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, e-mail disability@illinois.edu, or go to the DRES website: https://www.disability.illinois.edu. If you are concerned you have a disability related condition that is impacting your academic progress, academic screening appointments are available on campus that can help diagnose a disability.

For rare circumstances, such as extended illness and family emergencies that make it difficult for you to keep up with coursework, you should contact Professor Hoffmann via a Campuswire private message as soon as possible to discuss options. In these cases, I encourage you to reach out to the Dean of Students office, which can help you contact and manage accommodations with all of your courses.

**Academic Integrity:**
Honesty and integrity are fundamental to our community. Guidelines for academic integrity are detailed in Article 1, Part 4 of the Illinois Student Code. Any confirmed violations of that code will be taken seriously and may result in failure for the course.

**Changes to syllabus:**
May occur as deemed necessary by the professor; they will be announced.

**Calendar and Topics:**
Changes to the schedule will be announced; see the MSE 304 website on Compass for exact schedule, assignments, and to remain up to date.

**Course outline:** (topics may be adjusted as needed)

| *Date* | Reading | Topic | Assignment due |
|---|---|---|---|
| *M 1/25* | | Orientation and Introduction | |
| *W 1/27* | Solymar: 1, 2;<br>Kasap: 2.1; | Classical Conductivity;<br>Drude Model | |
| *F 1/29* | Solymar: 2, 3;<br>Kasap: 2.5, 3.1; | Hall effect | Prerequisite Quiz,<br>sign up at CBTF |
| *M 2/1* | Solymar: 3, 6.9, 7.3;<br>Kasap: 3.1; | Bragg's Law;<br>Photoelectric Effect | |
| *W 2/3* | Solymar: 3;<br>Kasap: 3.3, 3.4, 3.5 | Particle-wave duality;<br>de Broglie wavelength | |
| *F 2/5* | Solymar: 3;<br>Kasap: 3.5, 3.6, 3.7; | Basics of Quantum Mechanics;<br>Schrödinger Equation | |
| *M 2/8* | Solymar: 3;<br>Kasap: 3.3, 3.4, 3.6; | Operators; Free electrons | HW0 due 2/9 |
| *W 2/10* | Solymar: 2, 3;<br>Kasap: 3.3, 3.4, 3.6; | Infinite potential well | |
| *F 2/12* | Solymar: 3.6, 4;<br>Kasap: 3.5, 3.7, 3.8; | Infinite potential well,<br>Uncertainty principle,<br>Tunneling | Problem set # 4 due<br>(10/22)<br>Problem set #5 assigned |
| *M 2/15* | Solymar: 4;<br>Kasap: 3.8; | Tunneling | HW 1 due 2/16 |
| *W 2/17* | | (no class) | Quiz 1 (on 2/18)<br>sign up at CBTF |
| *F 2/19* | Solymar: 5;<br>Kasap: 4.1; | Hydrogen Atom I | |
| *M 2/22* | Solymar: 5;<br>Kasap: 4.1; | Hydrogen Atom II | HW 2 due 2/23 |
| *W 2/24* | Solymar: 5;<br>Kasap: 4.1; | Optical transitions,<br>Selection rules, Spin | |
| *F 2/26* | Solymar: 5;<br>Kasap: 4.1; | Beyond hydrogen | |
| *M 3/1* | XPS, Auger | X-ray emission | HW 3 due 3/2 |
| *W 3/3* | More Auger | X-ary absorption, Auger,<br>Synchrotrons | Quiz 2<br>sign up at CBTF |
| *F 3/5* | Solymar: 5;<br>Kasap: 1.3; | XPS, Auger | |
| *M 3/8* | Solymar: 5;<br>Kasap: 1.3; | Bonding in molecules:<br>LCAO method | |
| *W 3/10* | Solymar: 1;<br>Kasap: 1.3; | Bonding:<br>Potential energy surface | |
| *F 3/12* | Solymar: 6, 7;<br>Kasap: 4.2, 4.5; | Bonding | |

| *Date* | Reading | Topic | Assignment due |
|---|---|---|---|
| *M 3/15* | | Bulk modulus,<br>Madelung constant | HW 4 (online and offline)<br>due 3/16 |
| *W 3/17* | | Free electron gas,<br>Density of states | Quiz 3<br>sign up at CBTF |
| *F 3/19* | | Density of states,<br>Fermi distribution | |
| *M 3/22* | Solymar: 6, 7;<br>Kasap: 4.11; | Density of states,<br>Fermi distribution | HW 5 due 3/23 |
| *W 3/24* | | (no class) | |
| *F 3/26* | Solymar: 6, 7;<br>Kasap: 4.11; | Direct lattice and reciprocal lattice | |
| *M 3/29* | Solymar: 6, 7;<br>Kasap: 4.11; | Empty-Lattice Approximation:<br>Bands in Solids | HW 6 (online and offline)<br>due 3/30 |
| *W 3/31* | Solymar: 8;<br>Kasap: 5.11; | Nearly Free Electrons:<br>Bands in Solids | |
| *F 4/2* | Solymar: 8;<br>Kasap: 5.2, 5.3; | Nearly Free Electrons:<br>Semiconductors | |
| *M 4/5* | | Nearly Free Electrons:<br>Semiconductors | |
| *W 4/7* | | Electrons, holes in semiconductors | Quiz 4<br>sign up at CBTF |
| *F 4/9* | Solymar: 8, 9;<br>Kasap: 6.1, 6.2; | Mass action law, Fermi level | |
| *M 4/12* | Solymar: 8, 9;<br>Kasap: 5.4, 5.5; | Extrinsic semiconductors,<br>n and p doping | HW 7 (Comp. Report 1)<br>due 4/13 |
| *W 4/14* | Solymar: 9;<br>Kasap: 5.9, 6.2, 6.5; | Compensation doping,<br>effective mass fitting | |
| *F 4/16* | Solymar: 9;<br>Kasap: 6.6, 6.8; | Fermi level in doped materials,<br>Lattices | |
| *M 4/19* | Solymar: 9;<br>Kasap: 6.9; | Carrier densities, pn junction | HW 8 due 4/20 |
| *W 4/21* | Solymar: 13;<br>Kasap: 6.9; | pn junction:<br>built-in field and potential | |
| *F 4/23* | Solymar: 13;<br>Kasap: 6.10; | Diffusion current,<br>Forward and Reverse bias | |
| *M 4/26* | Solymar: 13;<br>Kasap: 6.10; | Bias, Diode, Carrier lifetimes | HW 9 due 4/27 |
| *W 4/28* | | Schottky junction, LEDs | Quiz 5<br>sign up at CBTF |
| *F 4/30* | | Carrier life times, LEDs | |
| *M 5/3* | | Heterojunction LED,<br>solar cells, transistors | HW 10, Comp. Report 2<br>due 5/4 |
| *W 5/5* | | Last Class | |
| *TBD* | | Final comprehensive exam | |