UNIVERSITY OF ILLINOIS

College of Engineering

Department of Materials Science and Engineering

**MSE 598: MATERIALS FOR QUANTUM SCIENCE**

*4- credits*

Fall 2025

**Instructor:** Prof. Chris Anderson, 270 MRL, cpand@illinois.edu

Lecture/Contact hours: Tu-Th 12:30-1:50 PM, 2200 Sidney Lu Mechanical Engineering. In person.

Duration: This is a full semester 16-week class.

Office Hours: By appointment. Please email to schedule any time. To discuss any aspect of the class.

**Teaching Assistant:** Yuvraj Misra (ymisra2@illinois.edu)

Office Hours: By appointment. Please email to schedule. The TA is primarily in charge of grading and managing assignments and can answer questions pertaining to that.

Website: https://canvas.illinois.edu/courses/61927

**Description:** Quantum technology can change the way we communicate, compute, and probe the natural world. Unfortunately, these applications are often hampered by issues related to materials science- defects, surfaces, heterostructures, film growth, fabrication, and beyond. On the other hand, quantum mechanical principles determine the properties of many common and exotic materials. In this class, students will learn the basics of qubits, coherence, quantum control and the different physical platforms utilized in quantum science. The connections between quantum and materials science will be explored through the examination of modern literature. Students will apply materials science techniques and principles to the outstanding problems in quantum information science in the form of projects and presentations.

As the correct level of background knowledge is being calibrated, the exact course outline and topics are subject to change. Bear with me as we forge this new course together.

Course Outline: (may revise as the course progresses): **12 Lectures**

*Lecture 1:* Introduction. Quantum systems and applications. Why materials science?

*Lecture 2:* Bits and Qubits. Observables/measurement. Eigenvalues. Vectors. Bra-ket notation.

Operators (Adjoint, Hermitian, Unitary), Pauli matrices, truth tables, p-bits. Superposition + entanglement.

*Lecture 3:* Schrodinger equation. Time evolution. Hamiltonians. Phases and energies. Schrodinger/Interaction picture. Change of frame. Energy-frequency relation. Phases and energies.

*Lecture 4:* Spin dynamics and spin precession. Rotating wave approximation. Driving transitions. Bloch sphere, Pulses, Rabi Oscillations/Formula/Chevron, gates. Dipole moments.

*Lecture 5:* 2-qubit states, inner product, the CNOT. Simple Bell inequality. Bell basis. Bell measurement. Quantum computing, large state spaces. No cloning. QKD/One-time pad. Quantum circuits, density matrix. Partial trace.

*Lecture 6:* Quantum sensing, linewidths (Fourier). Power broadening. Ramsey measurements. Decay of Rabi. (T2\*)

*Lecture 7:* Hahn-echo, dynamical decoupling. Noise. (T2) Radiative lifetime and lifetime limit. Inhomogeneity. Fermi’s Golden rule. (T1)

*Lecture 8:* Cooperativity and coupled systems. Zero-point energy/coupling. Light-matter. Hybridized level/polaritons. Squeezed states. Uncertainty principle. Quantum Errors. Noise.

*Lecture 9:* Defects as qubits, defects as noise. TLS.

*Lecture 10:* Superconducting/Semiconducting qubits/Majorana. Optical materials/Nonlinear optics

*Lecture 11:* Fabrication. Surface science.

Lecture 12: Emerging topics

Grading: ***1000 points total.***

 **100 points:** Attendance throughout the semester

 **250 points:** 5 Homework assignments (50 pts each)

 **200 points:** 8 Guest lecture reflections (25 pts each)

 **100 points:** Midterm group presentations

1. **points:** Final presentation

 **250 points:** Abstract (50 pts). Final report (200 pts)

* Students are expected to participate in guest lectures, midterm presentations, and final presentations.
* **Attendance is mandatory on those days and is tracked.** Attendance during guest lectures will be weighted heavily, our guests have taken time out of their busy schedules to be with us.
* Participation in lectures will be determined by the instructor by tracking engagement with digital and in-person activities (i.e. speed-reads) and is worth *100 pts* spread over the semester. **Please use your real name when entering responses, these will be used to track attendance, but not graded.**

**Grades will be assigned using the following scale. A curve will be implemented if needed. I expect most students will get some form of A or B. The number of assignments may be reduced/adjusted as we develop this course.**

A+: 98 and above

A: 94-97

A-: 90-93

B+: 87-89

B: 83-86

B-: 80-82

C+: 77-79

C: 73-76

C-: 70-72 D+: 67-69

D: 60-66

F: 59 and below

COURSE GOALS/LEARNING OBJECTIVES

Our goal is to gain a lens into the problems faced by quantum technology, and how techniques and concepts in materials science might help. Students will develop broad literacy in qubit platforms, coherence, hardware consideration, and beyond. On the flip side, how quantum technologies can impact traditional materials science will be explored. Presentation and scientific communication skills will be honed with presentations. Creative and scientific thinking, academic writing evaluated with a novel research proposal. Scientific literacy and rapid acquisition will be trained with speed reads. Students will engage deeply with guest lecture topics to explore the state-of-the-art. Homework assignments will establish core competencies in quantum physics, simulation, and concepts. The combination of these goals and skills prepares students for successful careers in industry and graduate work and provide a broad literacy in quantum technology.

PREREQUISITES

Prerequisites: I assume you have seen some form of quantum mechanics at some point in your academic training. Linear algebra experience needed. Graduate or Junior/Senior level Undergraduate Quantum class preferred. Open to MatSE, ECE, Physics students.

ABSENCE POLICY

If you know that you will be absent from class for religious or other reasons that can be known in advance, please let me know. If you must miss class due to sickness or family emergencies, please let me know. Remember that attendance/participation is a part of your grade.

LEARNING MANAGEMENT SYSTEM

This course requires students to use the Canvas course website often. All assignments (unless otherwise noted) will be submitted using Canvas. Lecture slides and other resources will be posted on Canvas. If you have issues accessing Canvas, please contact the instructor.

COURSE ASSIGNMENTS

1. **Homework assignments (throughout)**

There will be five homework assignments throughout the course, mostly in the beginning. The expectation is that you work through these problems yourself, using whatever computational resources are relevant. You should feel free to work with other students to solve problems as long as you make sure to understand and work through them yourself without copying. Please see the generative AI statement below for more details.

*This assessment practices fundamentals of quantum mechanics related to quantum technology.*

1. **Reflections (starting week 4/5)**

One week after each guest lecture, turn in a **one page** (Arial, 11 pt font, <1.5 spacing) reflection with the following flow/sections:

* Summary of the guest lecture presentation. What did you learn? One takeaway?
* A recap of questions that were asked, and questions you still have.
	+ I expect you to ask questions! Otherwise, no-one has anything to say here!
* Find a related paper to what was presented, and summarize it in **a single** paragraph- making the connection clear. Provide a reference at the bottom.

*This assessment practices academic writing, reading relevant literature, and encourages engagement with the speakers.*

1. **Midterm group presentations**

Teams of three will present for *10 minutes* on a paper related to the broad theme “Materials for Quantum Information Science”, with *5 minutes* for questions. Please send me the paper for review before finalizing at least one week before the presentation. You are responsible for checking that the A/V system works with your mode of presentation beforehand. Troubleshooting time will negatively affect your grade. You are responsible for breaking up the labor and presentation time as you see fit. If there is an issue with on of your teammates, let me know.

*This assessment focuses on teamwork, technical article synthesis, and presentation skills.*

1. **Final research proposal paper**

Each student will write a proposal paper on using materials science techniques or concepts to tackle a problem in quantum science/technology, or the use of quantum technology to benefit materials science. You may also focus on “quantum materials”, but the exact motivation and proposed science should relate to concepts from the course. You will submit an abstract to me beforehand which is worth 50 points. **Abstracts should be less than 500 words and contain appropriate citations (not included in word limit).** At this point I will provide “course correction” if you are off track. The paper/proposal should consist of 10 to 15 pages of text **plus figures** and references on a topic of your choice. The proposal should be significantly different from your thesis work. *Do not wait until the end of the semester to begin this!* Pretend you are writing an academic paper or grant proposal.

**Requirements:**

* 11 point font, <2.0 line spacing. 1” margins
* At least five figures (more is ok!). Cite where they are from. I highly encourage you to make your own diagrams and figures. All figures must have a figure number and figure caption. Figure not included in length.
* References are not included in length. Use Nature style. 20-30 or more is appropriate.
* The proposal should have three sections:
	+ Executive Summary
		- The executive summary should be 1 page or less and provide an overview of the proposed work.
	+ Background
		- The background should provide sufficient information for someone to understand what you are proposing, and the novelty of what you are proposing. This section will typically be 5-10 pages.
	+ Proposed Work.
		- The proposed work section should be **at least** 5 pages. It should both indicate what you intend to do in sufficient detail for evaluation, and include a discussion of results from the literature that support your plan of research. In the proposed work, I suggest you include a discussion of control experiments, and how these controls will enable you to do more important science.

*This assesment develops scientific writing skills.*

1. **Final presentation**

You will, by yourself, give a “lightning” elevator pitch of your final proposal/paper, taking approximately 5 minutes. Your goal is to clearly/succinctly explain the problem, and the tools you will use to solve them. It is your responsibility to be on time. Short is ok, but you need to clearly convey the problem, demonstrating understanding from the course, and the high-level overview of the approach. You should not have more than three slides. Do not spend too much time introducing yourself and the title. There will be time for some questions. *Your presentations will be sent to me 24 hours before the presentation so I can collate them into one master presentation*. **Please spend time making figures, diagrams, and practice communicating clearly. These are important skills for your careers.**

*This assessment focuses on concise scientific communication, distilling ideas, presentation skills.*

**There will be no final exam.**

**MSE 598 Course Schedule** (subject to revision)

**Week 1**

August 26: Lecture 1

August 28: Lecture 2

**Week 2**

September 2: Lecture 3

September 4: Lecture 4 (HW 1 Due)

**Week 3**

September 8: Lecture 5

September 11:Lecture 6 (HW 2 Due) (Midterm teams assigned)

**Week 4**

September 16: **Dr. Cyrus Zeledon Guest Lecture**

September 18: Lecture 7 **Yuvraj Misra** (HW 3 Due)

**Week 5**

September 23: **Superconducting qubits primer**: **Yuvraj Misra** (Zeledon reflection due)

September 25: **Dr. Giovanni Scuri Guest Lecture** (Midterm presentation abstract due)

**Week 6**

September 30: Lecture 8

October 2: Lecture 9 (Scuri reflection due)

**Week 7**

October 7: Midterm presentations, Day 1

October 9: Midterm presentations, Day 2

**Week 8**

October 14: **Prof. Andre Schleife Guest Lecture**

October 16: **Quantum transduction primer: Yuvraj Misra**

**Week 9**

October 21: Lecture 10 (Schleife reflection due)

October 23: Lecture 11 (HW 4 Due)

**Week 10**

October 28: **Prof. Angela Kou Guest Lecture**

October 30: Lecture12 (HW 5 Due)

**Week 11**

November 4: **Dr. Yi Li Guest Lecture** (Kou reflection due)

November 6: **Dr. Yizhi Zhu Guest Lecture** (Proposal abstracts due)

**Week 12**

November 11: **Prof. Simeon Bogdanov Guest Lecture** (Li reflection due)

November 13: **Prof. Mikael Backlund Guest Lecture** (Zhu reflection due)

**Week 13**

November 18: Lecture13 (Bogdanov reflection due)

November 20: Lecture 14 (Backlund reflection due)

**November 22-30: FALL BREAK**

**Week 14**

December 2: Final proposal presentations/lightning talks, Day 1

December 4: Final proposal presentations/lightning talks, Day 2

**Week 15**

December 9: Final proposal presentations/lightning talks, Day 3

December 11: **NO CLASS**

**Week 16**

December 16,18: **Finals week – NO CLASS. Final report due.**

Grading Policy

**All assignments due on Canvas by midnight of the due date**. Assignments uploaded after this until noon the following day will receive 25% pts off. Assignments will not be accepted after that. If you have professional engagements (e.g. interviews) or significant personal issues (e.g. illness), contact the TA and I via email for accommodations.

You are expected to have read the Student Code section related to Academic Integrity (<http://admin.illinois.edu/policy/code/article1_part4_1-401.html>). All infractions listed in the Student Code, including cheating and plagiarism, will result in penalties in accordance with the Student Code. If you have any question regarding what constitutes an infraction, contact me.

Plagiarism will be treated very seriously. If you do not understand what constitutes plagiarism, talk with me. For example, you cannot copy text from published papers without marking it as “copied from” or equivalent. Ignorance is not an excuse for any academic dishonesty. It is your responsibility to read this policy to avoid any misunderstanding.

Generative AI (adapted from CITL)

You may be inclined to use generative AI as you prepare your written material, code, and other documents. These can be valuable tools in many contexts, when used effectively. However, much of the learning in this course occurs through direct, personal experience of the writing/problem solving process. If you use these technologies in this class, use them ethically by disclosing how you used them (see, for example, the MLA citation guidelines for generative AI). Regardless of what you use to compose, you are responsible for what you turn in. For example, including inaccurate citations and sources from AI technology puts you at risk of academic integrity violations. Come to me with questions!

Disability-Related Accommodations

To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must 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, call 333-4603, e-mail disability@illinois.edu or go to https://www.disability.illinois.edu. If you are concerned you have a disability related condition that is impacting your academic progress, there are academic screening appointments available that can help diagnosis a previously undiagnosed disability. You may access these by visiting the DRES website and selecting “Request an Academic Screening” at the bottom of the page.

Diversity (Adapted from Prof. Perry & Leal)

I greatly value the diversity that students bring to the classroom, particularly in a discussion/presentation-heavy class such as MSE 598. I learn a lot from your questions, ideas, interests, and comments. Together as a class, our perspective on the science and applications is greatly broadened when everyone participates. More generally, it’s clear that diverse participation in engineering is needed to ensure that technology is designed to serve and be accessible to the whole population rather than a narrow subset. In science, diverse perspectives and lenses benefit the whole community through increasing creativity and innovation. Further, in the context of increasing globalization, students need to be well prepared for teamwork and communication in a diverse and international setting to address challenges. My goal is to create an inclusive classroom environment where all students can take risks to fully participate and thereby grow and learn. If you have suggestions for the instructor on improving the course environment and culture from a diversity perspective, please do reach out.

I encourage all students to learn more about DEI activities in MatSE and MatSE’s DEI committee here: https://matse.illinois.edu/dei. More generally, aspects of DEI in the UIUC community are well covered by the IDEA institute: https://idea.illinois.edu.

Inclusivity Statement from the College

The Grainger College of Engineering is committed to the creation of an anti-racist, inclusive community that welcomes diversity along a number of dimensions, including, but not limited to, race, ethnicity and national origins, gender and gender identity, sexuality, disability status, class, age, or religious beliefs. The effectiveness of this course is dependent upon each of us to create a safe and encouraging learning environment that allows for the open exchange of ideas while also ensuring equitable opportunities and respect for all of us. Everyone is expected to help establish and maintain an environment where students, staff, and faculty can contribute without fear of personal ridicule, or intolerant or offensive language. If you witness or experience racism, discrimination, micro-aggressions, or other offensive behavior, you are encouraged to bring this to the attention of the course director if you feel comfortable. You can also report these behaviors to the Bias Assessment and Response Team (BART) (https://bart.illinois.edu/). Based on your report, BART members will follow up and reach out to students to make sure they have the support they need to be healthy and safe. If the reported behavior also violates university policy, staff in the Office for Student Conflict Resolution may respond as well and will take appropriate action.

Sexual Misconduct Reporting Obligation

The University of Illinois is committed to combating sexual misconduct. Faculty and staff members are required to report any instances of sexual misconduct to the University’s Title IX Office. In turn, an individual with the Title IX Office will provide information about rights and options, including accommodations, support services, the campus disciplinary process, and law enforcement option. A list of the designated University employees who, as counselors, confidential advisors, and medical professionals, do not have this reporting responsibility and can maintain confidentiality, can be found here: wecare.illinois.edu/resources/students/#confidential. Other information about resources and reporting is available here: wecare.illinois.edu.

Religious Observances

Illinois law requires the University to reasonably accommodate its students' religious beliefs, observances, and practices in regards to admissions, class attendance, and the scheduling of examinations and work requirements. You should examine this syllabus at the beginning of the semester for potential conflicts between course deadlines and any of your religious observances. If a conflict exists, you should notify your instructor of the conflict and follow the procedure at https://odos.illinois.edu/community-of-care/resources/students/religious-observances/ to request appropriate accommodations. This should be done in the first two weeks of classes.

Family Educational Rights and Privacy Act (FERPA):

Any student who has suppressed their directory information pursuant to Family Educational Rights and Privacy Act (FERPA) should self-identify to the instructor to ensure protection of the privacy of their attendance in this course. See https://registrar.illinois.edu/academic-records/ferpa/ for more information on FERPA.