

MSE 404QM: Quantum materials for sensing of magnetic fields

Fall 2027 Syllabus

Homepage: <https://canvas.illinois.edu/courses/72612>

1.5 undergraduate credit hours, 1.5 graduate credit hours, ½ semester.

08/24/26-10/16/26

QM1: 2:00-4:50 PM Monday Wednesday

QM2: 2:00-4:50 PM Tuesday Thursday

QM3: 9:30 AM -12:20 PM Tuesday Thursday

The laboratory that houses the quantum diamond spectrometer is room MSEB 116. We will also use this room for discussion and prelab quizzes on Mondays (section 1) and Tuesdays (section 2, section 3) for the first 30 minutes of the scheduled class period (9:30-10:00AM, or 2:00-2:30 PM, approximately).

The course is organized into 7 laboratory exercises that will be conducted over two class periods, Monday and Wednesday for section 1; and Tuesday and Thursday for section 2 and section 3.

Laboratory reports are due midnight **4 days** after completion of the lab (i.e. Sunday for section 1 and Monday for section 2,3). This will be on Canvas.

Late laboratory reports will incur a penalty of 10% of the total possible points for each day past the deadline.

Instructor and TAs

Instructor: Prof. Christopher Anderson
Office hours: by arrangement during or outside of class times
Email: cpand@illinois.edu

TA: Siddhi Surawar
Office hours: by arrangement during or outside of class times
Email: surawar2@illinois.edu

Course Description

Use of a color center (the negatively charged nitrogen vacancy, NV⁻, complex) in diamond for the sensing of magnetic fields using atom-like energy levels and optical transitions of the defect. Topics include the Gaussian beam optics, photoluminescence, synchronous detection, noise in measurements, optically-driven and microwave-driven transitions between energy levels of the NV⁻ center, optically detected magnetic resonance, and the effects of magnetic fields on those transitions.

Course Objectives

Upon completion of the course, students will be able to:

- Calculate the propagation of a Gaussian laser beam.
- Use a lock-in amplifier to measure small signals.
- Explain the structure and energy levels and transitions of the NV- color center in diamond.
- Use photoluminescence intensity to measure strong magnetic fields.
- Use optically detected magnetic resonance to measure small magnetic fields.
- Evaluate the sensitivity of a measurement that is limited by noise.

Prerequisites

Credit in MSE 307 and 308 (Materials Laboratory I & II). Courses in quantum mechanics are helpful.

Course Expectations and Teaching Philosophy

This is a laboratory that combines many topics in the materials science of defects in crystals, applied optics, microwave engineering, signal processing, the quantum mechanics of atom-like states in solids, and the measurement magnetic fields (magnetometry). I will make a short (<30 min) lecture available for each week of the class, but the course will be conducted mostly in the spirit of a tutorial combined with independent study. Each section will have at most 3 students and each section will have approximately 4 hours of hands-on laboratory time each week to carry out the laboratory assignments.

MSE 404QM is a 1.5 credit hour, ½ semester course, and therefore requires a time commitment of approximately 9 hours per week. I expect you to spend approximately 4 hours per week doing experiments. You should spend approximately 5 hours per week doing the reading, analyzing data, doing homework assignments, and writing laboratory reports.

You may or may not need the entire lab period to complete the laboratory work.

Web Applications

URL	Purpose
Canvas	Course schedule, homework assignments, gradebook, and posting of text-based resources, e.g., syllabus, homework solutions, and readings in addition to the required texts, submission of homework assignments and lab reports.
OneNote	Laboratory write-ups will be distributed through OneNote. You should have received an email with the link.

Required Readings

Introduction to Error Analysis, by John R. Taylor, 2nd edition, University Science Books, 1996. We will refer to this text as “Taylor”. (There is a new 3rd edition but let’s save some money and use the older 2nd edition. There are inexpensive/free used copies of the 2nd edition available online).

Readings on the various aspects of the quantum diamond spectrometer and NV center magnetometry will be made available through canvas.

Course Requirements

1. Complete assigned readings.
2. Use Canvas to access the course materials and complete assignments within the guidelines established in the course calendar. Submit assignments via Canvas.
3. Adhere to assignment deadlines. The deadlines are firm unless a student is given special permission by the instructor. Late submissions are not subject to partial credit unless otherwise noted.
4. Attend laboratory sessions on time.
5. Contact the instructor if special circumstances cause interruption of course activities.

Course Communication

Please contact the instructor or the TA via email if you have questions at any time. In person meetings and Zoom/Teams or telephone consultations can be arranged outside of regularly scheduled class times. The instructor and TA will respond within one business day.

Announcements. The instructor and TA will use Canvas to make announcements. The default settings of Canvas are that new announcements are also sent immediately by email. You can change that default setting within Canvas if you prefer.

Assessment

Homework (10% of course grade): Problems will be assigned each week from Taylor. Homework is due and submitted electronically in Canvas by midnight on the due date (posted on Canvas). Late submissions will not be accepted. If you have a documented, extenuating circumstance, please communicate with Prof. Anderson for accommodation. The lowest relative homework score will be dropped.

Pre-laboratory quizzes: (10% of course grade): We will administer in-class quizzes at the beginning of each week's laboratory exercise. The pre-laboratory quizzes will start the second week of class. The lowest relative quiz score will be dropped. We will make paper copies of the readings available for you to consult during the quizzes. You will turn in a written paper copy with your answers and name/netid. No use of electronic devices is allowed.

Attendance (30% of course grade): Attendance at every lab session is required. You should arrive on time, i.e., do not be late. If you are unable to attend the lab session due to illness, emergency, or professional activity, you must schedule a make-up time with the TA. In most cases, these make-up sections will be held on Fridays.

Weekly laboratory reports (50% of course grade): Each student will individually turn in a laboratory report. Late assignments will incur a penalty of 10% of the total possible points for each day past the deadline.

The overall course grade will be converted to a letter grade on a curved scale. The curved scale will not be harsher than a straight scale (97-100 = A+; 93-97 = A; 90-93 = A-; 87-90 = B+; etc.), it can only help you.

Course Schedule

Assignments will be posted on canvas. We will use OneNote to distribute the lab write-ups and lecture notes.

Week. Topic
1. <u>August 24</u> . First week of class. No labs . Review reading materials and Syllabus.
2. <u>August 31</u> . Geometric optics and gaussian beam propagation. Observation of photoluminescence (PL) using CCD camera and photodetector.
3. <u>September 7</u> . Synchronous detection of PL using a lockin amplifier. Measurements of noise. <i>September 7 is Labor day. Lab sections Monday (Section 1) and Tuesday (Section 2,3) are cancelled. Lab sections Wednesday and Thursday Proceed as normal and the quizzes will be that day.</i>
4. <u>September 14</u> . Physics of the NV center in diamond: all optical measurement of longitudinal relaxation times.
5. <u>September 21</u> . Measurement of magnetic fields using PL intensity. Noise and measurement sensitivity.
6. <u>September 28</u> . Optically-detected magnetic resonance (ODMR): continuous wave.
7. <u>October 5</u> . ODMR spectra and the spin Hamiltonian.
8. <u>October 12</u> . Pulsed ODMR and magnetometry. Noise and sensitivity in measuring small dc magnetic fields

Homework and laboratory report policies

(Acknowledgement of this wording to Prof. Elizabeth Holm at Carnegie Mellon University.)

For the homework sets and laboratory reports in this class, you are welcome to work alone or in groups, at your own discretion, so long as the final result is your own.

- You understand and can explain in your own words each step in the solution.
- You independently verified all results and analysis.
- You are personally responsible for the correctness of the answers.
- You gained the knowledge and skills intended from the assignment.

AI use policy

Generative AI, such as ChatGPT, Microsoft Copilot, and Gemini, can answer questions and generate text, images, and other media. The appropriate use of generative AI varies from course to course. In MSE 404, there are times when generative AI may be useful in the course. If you choose to use generative AI as permitted below, you must document and attribute all AI contributions to your coursework and take full responsibility for the contributions including the accuracy of the information and reliability of

sources. When using generative AI, keep a journal documenting prompts, AI responses, and your usage. I may ask you to provide this documentation.

You may use generative AI in MSE 404 for the following:

- Proofing text
- Writing code
- Guiding understanding

You MAY NOT use generative AI in MSE 404 for the following:

- Generating plots of your data
- Outputting lab reports
- Solving homework problems
- Quizzes

If you have a question about the use of Generative AI, please reach out. Failure to abide by these guidelines is a violation of academic integrity. We will investigate suspected uses of generative AI that do not follow these guidelines and apply sanctions as outlined in the University of Illinois Student Code.

Much of the learning in this course occurs through direct, personal experience of laboratory report and analysis process.

Lab Safety

The only significant hazard in this laboratory is the 532 nm cw diode laser in the quantum diamond spectrometer. We will operate the diode laser at a power of 4 mW or below and therefore the laser falls into Class 3A operation and does not require the use of laser safety glasses. Nevertheless, we will keep a partition between the laser-setup and the seating areas. Do not place your eye near the level of the laser beam and do not place your hand or any other object within the optical beam path.

Academic Integrity Policy

The University of Illinois at Urbana-Champaign Student Code should also be considered as a part of this syllabus. According to the Student Code, “It is the responsibility of each student to refrain from infractions of academic integrity, from conduct that may lead to suspicion of such infractions, and from conduct that aids others in such infractions.”

Academic dishonesty may result in a failing grade. Every student is expected to review and abide by the Academic Integrity Policy: <http://studentcode.illinois.edu/>. Ignorance is not an excuse for academic dishonesty. It is your responsibility to read this policy to avoid any misunderstanding. Do not hesitate to ask me if you are ever in doubt about what constitutes plagiarism, cheating, or any other breach of academic integrity.

See also this quick reference guide to academic integrity:

<https://provost.illinois.edu/policies/policies/academic-integrity/students-quick-reference-guide-to-academic-integrity/>

Academic 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 (V/TDD), or e-mail a message to disability@illinois.edu. <http://www.disability.illinois.edu>

Family Educational Rights and Privacy Act

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.

Sexual Misconduct Policy and Reporting

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 and Disability Office. In turn, an individual with the Title IX and Disability Office will provide information about rights and options, including accommodations, support services, the campus disciplinary process, and law enforcement options. 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 at

<https://wecare.illinois.edu/resources/students/#confidential>

Other information about resources and reporting is available at <https://wecare.illinois.edu>

Community of Care

As members of the Illinois community, we each have a responsibility to express care and concern for one another. If you come across a classmate whose behavior concerns you, whether in regards to their well-being or yours, we encourage you to refer this behavior to the Student Assistance Center (217-333-0050 or <http://odos.illinois.edu/community-ofcare/referral/>). Based on your report, the staff in the Student Assistance Center reaches out to students to make sure they have the support they need to be healthy and safe. Further, we understand the impact that struggles with mental health can have on your experience at Illinois. Significant stress, strained relationships, anxiety, excessive worry, alcohol/drug problems, a loss of motivation, or problems with eating and/or sleeping can all interfere with optimal academic performance. We encourage all students to reach out to talk with someone, and we want to make sure you are aware that you can access mental health support at the Counseling Center (<https://counselingcenter.illinois.edu/>) or McKinley Health Center (<https://mckinley.illinois.edu/>). For mental health emergencies, you can call 911 or walk into the Counseling Center, no appointment needed.