MSE 404QM: Quantum materials for sensing of magnetic fields

Spring 2026 Syllabus version January 12, 2026

Homepage https://canvas.illinois.edu/courses/67051

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

Because Monday January 19 is a holiday, and there was a delay in getting a TA assigned to this course, we will not meet the week of January 19. The first week of the course will be January 26. During the final week of the course (the week of March 9), each section will meet only once (Monday for section 1 and Tuesday for section 2). Throughout the semester, section 3 will start at 8:30 AM (not 8:00 AM as listed in the campus course schedule.)

The laboratory that houses the quantum diamond spectrometer is room 215N Ceramics Bldg. We will use the conference room next door (213 Ceramics Bldg) for discussion and prelab quizzes on Mondays (section 1) and Tuesdays (sections 2 and 3) for the first 30 minutes of the scheduled class period (2:00 PM for section 1 and 2; 8:30 AM for section 3).

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 sections 2 and 3. For section 1, laboratory reports are due at 10 PM on Sunday; and for sections 2 and 3, laboratory reports are due at 10 PM on Mondays, i.e., 4 days after the completion of the lab. For the final week of the class, lab reports are due at 10 PM on Thursday (March 12) for section 1, and 10 PM on Friday (March 13) for sections 2 and 3.

Instructor and TAs

Instructor: Prof. David Cahill
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TA: Siddhi Surawar
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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

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.

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 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.
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 meeting and Zoom 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 5 pm on the due date. The due dates will typically be on Wednesdays at 5 PM. Late submissions will not be accepted. If you have a documented, extenuating circumstance, please communicate with Prof. Cahill for accommodation. The lowest relative homework scores will be dropped in assigning the 10% of the course grade that comes from homework.

Pre-laboratory quizzes: (10% of course grade): We will administer and in-class quiz and the beginning of each week's laboratory exercise. The pre-laboratory quizzes will start the week of January 26 but we will not grade the quizzes during for this first week of class. The lowest relative quiz score will be dropped in assigning the 10% of the course grade that comes from quizzes. We will make paper copies of the readings available for you to consult during the quizzes.

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.

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.)

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.

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.

Course Schedule

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

Week. Topic
1. January 26. Geometric optics and gaussian beam propagation. Observation of photoluminescence (PL) using CCD camera and photodetector.
2. February 2. Synchronous detection of PL using a lockin amplifier. Measurements of noise.
3. February 9 Physics of the NV center in diamond: all optical measurement of longitudinal relaxation times.
4. February 16. Measurement of magnetic fields using PL intensity. Noise and measurement sensitivity.
5. February 23. Optically-detected magnetic resonance (ODMR): continuous wave.
6. March 2. ODMR spectra and the spin Hamiltonian.
7. March 9 (short week). Pulsed ODMR and magnetometry. Noise and sensitivity in measuring small dc magnetic fields