MSE 404QM: Optically-detected magnetic resonance for magnetic field sensing

Spring 2024 Syllabus version January 2, 2024

Homepage https://canvas.illinois.edu/courses/42665

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

Because Monday January 15 is a holiday, to maintain symmetry between the three sections, sections 2 and 3 will not meet on Tuesday January 16. Thus, the first meeting of section 1 is Wednesday January 17 and the first meetings of sections 2 and 3 are Thursday January 11.

The laboratory that houses the quantum diamond spectrometer is 215N Ceramics Bldg. We will use the conference room next door (213 Ceramics Bldg) for lecture, discussion, and prelab quizzes on Wednesdays (section 1) and Thursdays (sections 2 and 3) for the first 30 minutes of the scheduled class period.

The course is organized into 7 laboratory exercises that will be conducted over the course of two days. For section 1, that cycle will be Wednesday and the following Monday. For sections 2 and 3, the cycle will be Thursday and the following Tuesday. For section 1, laboratory reports are due at 5 PM on Thursdays, i.e., 3 days after the completion of the lab. For sections 2 and 3, laboratory reports are due at 5 PM on Fridays, i.e., 3 days after the completion of the lab. During the week of

Instructor and TAs

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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 optically detected magnetic resonance to measure small dc 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). The course will not include formal lectures and will use a structure more in spirit of a tutorial combined with independent study. Each section will have 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 preparing for weekly presentations.

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.
Campuswire	Discussion form, communications with TAs and Instructor
Google Colaboratory	(Optional) Python notebooks for analyzing and plotting data

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. Use Campuswire class feed for communicating with the instructor, TAs, and peers.
2. Complete assigned readings.
3. Use Canvas to access the course materials and complete assignments within the guidelines established in the course calendar. Submit assignments via Canvas
4. 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.

5. Contact the instructor if special circumstances cause interruption of course activities.

Course Communication

Please contact the instructor or the TAs via the Campuswire discussion forum 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 TAs will respond within one business day.

Announcements. The instructor and TAs 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.

Campuswire. The Campuswire forum is an important part of the course. Please minimize the use of direct messaging and emphasize posting to the entire class. If you want clarification of an assignment or help in understanding the reading, then it is likely that many of your classmates will benefit from your question and will benefit from the responses of classmates, the TAs, or instructor. Feel free to carry on an extended discussion with your classmates independent of feedback from the instructor or TAs. The TAs will intervene if the discussion gets off track.

Netiquette. In any social interaction, certain rules of etiquette are expected and contribute to more enjoyable and productive communication. The following tips for interacting online are adapted from guidelines originally compiled by Chuq Von Rospach and Gene Spafford at UIS.

- Remember that the person receiving your message is someone like you, someone who deserves and appreciates courtesy and respect.
- Be brief; succinct, thoughtful messages have the greatest impact.
- Your messages reflect on YOU; take time to make sure that you are proud of their form and content.
- Use descriptive subject headings.
- Think about your audience and the relevance of your messages.
- Be careful with humor and sarcasm; without the voice inflections and body language of face-to-face communication, Internet messages can be easily misinterpreted.
- When making follow-up comments, summarize the parts of the message to which you are responding.
- Avoid repeating what has already been said; needless repetition is ineffective communication.
- Cite appropriate references whenever using someone else's ideas, thoughts, or words.

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 Tuesdays. 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 20% 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 1st week of the semester, i.e., January 17 for section 1 and January 18 for sections 2 and 3 but we will not grade the quizzes during the 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. 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 typically operate the diode laser at a power of 4 mW 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.

COVID Policy

If you test positive for COVID and are isolating for the 5 day period following the positive test, you are excused participation points, homework due dates, and quizzes during the 5 day isolation period. If you have not fully recovered after the 5 day isolation and unable to attend class, please contact Prof. Cahill.

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 and lab write-ups will be posted in canvas. In what follows, the date given is Wednesday, the first day of the lab exercise for section 1. The first day of the lab exercise for sections 2 and 3 is the next day (Thursday) of that week.

Week. Topic
1. January 17. Geometric optics and gaussian beam propagation. Observation of photoluminescence (PL) using CCD camera and photodetector.
2. January 24. Synchronous detection of PL using a lockin amplifier. Measurements of noise.
3. January 31. Physics of the NV center in diamond: all optical measurement of T1
4. February 7. Measurement of magnetic fields using PL intensity. Noise and measurement sensitivity.
5. February 14. Optically-detected magnetic resonance (ODMR): continuous wave.
6. February 21. ODMR spectra and the spin Hamiltonian.
7. February 28. Pulsed ODMR and magnetometry. Noise and sensitivity in measuring small dc magnetic fields
8. No new laboratory exercises. Section 1 finishes week 7 lab on Monday and turns in report for the week 7 lab on Thursday. Sections 2 and 3 finish week 7 lab on Tuesday and turn in report for the week 7 lab on Friday.