MSE 404QS: Coherent control of quantum states for magnetometry and thermometry

Spring 2025 Syllabus version February 22, 2025.

Homepage: https://canvas.illinois.edu/courses/55015

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

The first meeting of section 1 is Monday March 17 and the first meetings of sections 2 and 3 are Tuesday March 18. The class will not meet during the week of April 7 because Prof. Cahill will be attending the Spring Materials Research Society meeting that week.

The laboratory that houses the quantum diamond spectrometer is 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 6 laboratory exercises that will be conducted over the course of two days. For section 1, that cycle will be Monday and Wednesday. For sections 2 and 3, the cycle will be Tuesday and Thursday. For section 1, laboratory reports are due at 5 PM on the following Mondays after completing the lab. For sections 2 and 3, laboratory reports are due at 5 PM on the following Tuesday.

Instructor and TAs

Instructor: Prof. David Cahill
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TA: Siddhi Surawar
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Course Description

Coherent control of a color center (the negatively charged nitrogen vacancy, NV-, complex) in diamond for quantum sensing of temperature and magnetic fields using atom-like energy levels and optical transitions of the defect. Topics include the optically detected magnetic resonance, transverse and longitudinal relaxation times, Ramsey interface for measurements of static magnetic fields, measurement of ac magnetic fields using Hahn and CPMG pulse sequences.

Course Objectives

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

- Explain the structure and energy levels and transitions of the NV- color center in diamond
- Use optically detected magnetic resonance to measure the spectrum of excitations.
- Optimize laser and microwave pulse sequences for the measurement of temperature and magnetic field through the coherent control of an ensemble of NV- defects.

Prerequisites
Credit in MSE 307 and 308

Course Expectations and Teaching Philosophy
This is a laboratory that combines many topics in the quantum mechanics of atom-like states in solids, magnetic resonance, and the measurement of temperature (thermometry) and 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.

The course is organized into 6 laboratory exercises that will be conducted over the course of two days except for the sixth exercise which will be conducted on a single day. (The last day of instruction is May 7 but section 1 will not meet on May 7).

MSE 404QS 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 assigned reading, analyzing data, 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
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

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 (35% 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 (55% 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 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.

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. In what follows, the date given is Monday, 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 (Tuesday) of that week. The course will not meet the week of April 7. The last week will have only one lab session, Monday for section 1, and Tuesday for sections 2 and 3.

Week. Topic
1. March 24. Optically detected magnetic resonance
2. March 31. Transverse relaxation times and Rabi oscillations
3. April 7. No class meetings (instructor at MRS Spring Meeting)
4. April 14. Magnetometry of dc magnetic fields using Ramsey interference
5. April 21. Magnetometry of ac magnetic fields using the Hahn pulse sequence
6. April 28. Thermometry near zero-magnetic field using coherent control
7. May 5. CPMG pulse sequence (short week)