

EENG 4010.012: Topics in EE: MEMS (undergraduate students) (cross-listed)
EENG 5940.012: Advanced Topics in EE: MEMS (graduate students) (cross-listed)

MTSE 5800.032: Special Topics: Micro-electro-mechanical-systems (MEMS): Materials, Devices and Applications (cross-listed); **MTSE 4900.032:** (cross-listed)

Spring 2021 semester

Course Units: 3 credits

Instructor: Prof. Anupama Kaul (anupama.kaul@unt.edu); C136G

Class and Lab Timings: Spring 2021 Semester, Face-to-Face; Tu: 1pm – 2:20 pm (theory/lecture); Th: Labs (TBD, multiple sections)

Location: Lecture DP B142; Labs: UNT cleanroom

Enrollment: (Total = 21 current max.)

Office Hours: Tu/Th, 12 pm – 1 pm

Specific Course Information

- a. *Brief description of the content of the course (catalog description)*
Principles of the materials, manufacturing strategies and device architectures used for sensors and actuators in micro-electro-mechanical systems (MEMS).
- b. *Prerequisites or co-requisites*
PHYS 1710. CHEM 1410/CHEM 1430 or CHEM 1415/CHEM 1435 or equivalent
- c. *Indicate whether a required, elective, or selected elective course in the program*
Elective

Please Note – all information in this document is subject to change. Changes will be communicated in class

Course Description

This course is designed to provide an introduction to conventional micro-electro-mechanical systems (MEMS), where the course starts with an overview of the semiconducting properties of silicon, the workhorse of the microelectronics industry. The impact of continued miniaturization on transistor performance is highlighted according to Moore's Law. Moving from Silicon as an electronic material, its mechanical properties are discussed which has been pivotal in the creation of the field of MEMS. A review of microfabrication technology conventionally used to form MEMS structures and devices using batch-fabrication is provided, which includes topics such as:

photolithography, etching, physical vapor deposition, chemical vapor deposition, surface micromachining, and bulk micromachining. Soft materials and thick film processes are also discussed that have been key enablers for microfluidics and BioMEMS. The practical applications of MEMS for sensors and actuators are highlighted, where electrostatic, thermal, piezoelectric and magnetic transduction schemes are used for actuation and sensing, including for RF wireless systems and bio-related applications for Lab-on-Chip (LOC). Students will gain a broad perspective in the area of miniaturized systems for sensors and actuators. The laboratory modules are intended to reinforce the concepts discussed in the lectures, with practical hands-on learning exercises. The lectures and accompanying lab modules will help cultivate interdisciplinary perspectives with hands-on exercises developed for the students.

Course Text

The assigned texts for this course are:

**Fundamentals of Microfabrication and Nanotechnology, Volume I*, third edition, by Marc Madou, CRC Press, 2012. ISBN: 9781420055115

**Manufacturing Techniques for Microfabrication and Nanotechnology, Volume II*, third edition, by Marc Madou, CRC Press, 2012; ISBN: 9781420055191

**From MEMS to Bio-MEMS and Bio-NEMS, volume III*, third edition, by Marc Madou, CRC Press, 2012; ISBN: 9781420055160

Volumes I, II and III above should be available for electronic purchase for the students registered in the course. The registered students should have received a link automatically for purchasing the electronic copy (unt.bncollege.com).

Other material for this course comes from:

- *The Materials Science of Thin Films* by Milton Ohring, 1992

Broad audience literature articles will also be circulated in class.

Teaching Strategies

- In class lectures via power point presentations, audio, and video assistance tools will be used as necessary.
- Students will be provided opportunities to work in small groups for discussion of class material and homework problems.
- Hands-on laboratory exercises will be provided as noted in the course schedule to help reinforce the concepts learned in class, which will be conducted in the UNT cleanroom and other labs at DP. Two lab modules that have been developed over the course of the semester focus on: (1) Si microfabrication technology for RF antenna prototyping and RF testing; (2) thick film processes for constructing microfluidic channels that are used in BioMEMS.

Specific goals for the course

Course Learning Objectives (CLOs):

1. Demonstrate ability to distinguish a p-type semiconductor from an n-type semiconductor with appropriate dopants to calculate electrical conductivity and how the electronic properties work side by side with the mechanical properties of Si for enabling MEMS devices.
2. Identifying the way in which line width resolution can be improved and understanding the differences between i-line resist, h-line resist and g-line resist.
3. Distinguishing between *in-use* stiction and *release* stiction for suspended micro machined structures.
4. Identifying the pull-in voltage and the material parameters it depends upon for electrostatic actuation of a suspended cantilever beam.
5. Perform lab experiments to realize specifically designed MEMS structures in a cleanroom environment using both positive resist and negative resist based processes.
6. Organizing, analyzing and writing technical lab reports as part of a team, and communicating results to a wide audience.
7. Exhibit awareness of societal implications associated with various materials, including specifically occupational safety and health and global availabilities of commodity material.

ABET Student (Learning) Outcomes (SOs):

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies

	Student/ABET Outcome (SO)	1	2	3	4	5	6	7
Specific Course Learning Outcome (CLO)								
Demonstrate ability to distinguish a p-type semiconductor from an n-type semiconductor with appropriate dopants to calculate electrical conductivity and how the electronic properties work side by side with the mechanical properties of Si for enabling MEMS devices.								
Identifying the way in which line width resolution can be improved and understanding the differences between i-line resist, h-line resist and g-line resist.								
Distinguishing between <i>in-use</i> stiction and <i>release</i> stiction for suspended micro machined structures.								
Identifying the pull-in voltage and the material parameters it depends upon for electrostatic actuation of a suspended cantilever beam.								
Perform lab experiments to realize specifically designed MEMS structures in a cleanroom environment using both positive resist and negative resist based processes.								
Organizing, analyzing and writing technical lab reports as part of a team, and communicating results to a wide audience								
Exhibit awareness of societal implications associated with various materials, including specifically occupational safety and health and global availabilities of commodity material.								

SCLOs address SO 1 and 6

Grading

Homework Sets (approx. 5 to 6 sets)	10 %
Quizzes (3)	15 %
Exam (1)	30 %
Lab Attendance and Lab Reports	25 %
Group Research Project Presentation	10 %
Group Research Summary Paper	10 %
Mini Quizzes (bonus) - for Attendance Lectures	5%

Team Project

The team project will be composed of a final paper (10%) and a presentation (10%) made toward the end of the semester, on a MEMS based topic. The written paper will follow the format of an IEEE style journal publication. More details on this will be provided in class.

Mini Quizzes and Attendance

Though a formal attendance roll will not be conducted during the lectures, at the *beginning* of most classes, pop-quizzes, or Mini Quizzes will be administered. These Mini Quizzes will be tagged toward your classroom attendance and you will have the ability to earn up to 5 bonus points toward your overall grade over the semester by attending the lectures. The Mini Quizzes will be administered sharply at 1 pm and will last for about 5 minutes. Therefore, if you are late to class, it will affect your score for attendance. Though the Mini Quizzes will not be graded, the material discussed on the Mini Quizzes will directly relate to the content on the Quizzes (3). The Mini Quizzes are intended for class discussion only and only those attending class will thus benefit.

COVID-19 Impact on Attendance

While attendance is expected as outlined above, it is important for all of us to be mindful of the health and safety of everyone in our community, especially given concerns about COVID-19. Please contact me if you are unable to attend class because you are ill, or unable to attend class due to a related issue regarding COVID-19. It is important that you communicate with me prior to being absent so I may make a decision about accommodating your request to be excused from class.

If you are experiencing any symptoms of COVID-19 (<https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html>) please seek medical attention from the Student Health and Wellness Center (940-565-2333 or askSHWC@unt.edu) or your health care provider PRIOR to coming to campus. UNT also requires you to contact the UNT COVID Hotline at 844-366-5892 or COVID@unt.edu for guidance on actions to take due to symptoms, pending or positive test results, or potential exposure. While attendance is an important part of succeeding in this class, your own health, and those of others in the community, is more important.

Statement on Face Covering

Face coverings are required in all UNT facilities. Students are expected to wear face coverings during this class. If you are unable to wear a face covering due to a disability, please contact the Office of Disability Access to request an accommodation. UNT face covering requirements are subject to change due to community health guidelines. Any changes will be communicated.

Notes related to Lectures and Grading

1. Canvas will be used as a communication tool where the syllabus, class schedule and Lecture Notes will be posted, along with distribution of materials during class.
2. Homework assignments are intended to serve as a way to exercise your understanding of the concepts along with the quizzes and the Mini Quizzes.
3. There will be 3 in-class quizzes that will be for a duration of approximately 15 to 20 min at the beginning of the designated lecture. The content of the quizzes will be based on the prior Mini Quizzes for material covered during lectures.

4. There will be 1 comprehensive exam toward the end of the semester. The exam will include a combination of multiple choice questions, short answer questions, and quantitative problems.
5. There will be approximately 10 labs in this course and two lab reports will count toward 20% of the course grade. Attendance for the labs is mandatory and lab attendance will be marked at 5%, making the lab contribution at 25% for the overall course grade. More details on the way the labs will be administered are provided in the lab section of this syllabus.
6. For all exams and quizzes, the only thing you may use during the exam is a calculator (plus a pencil, pen, and/or an eraser). Earphones, cell phones, laptops, etc. will not be allowed.

Makeup Exam Policy

If a student cannot take an exam on the scheduled date due to some unavoidable circumstances, such as an out of town business trip, sickness, etc., then he/she must notify the instructor *in writing* BEFORE the scheduled exam time to schedule a makeup exam immediately. A 10% penalty may be effective, if this is deemed necessary.

Calculators

Programmable calculators are not allowed. Sharing of calculators is not allowed. Bring them to quizzes and exams. You must have an inexpensive scientific calculator that can solve:

Trig functions (SIN, COS, TAN)

Exponentials (e^x)

Square Root

x^y

Natural Logs (LN)

Logs (LOG)

Inverse

Cell Phones

Please remember to turn off phones prior to class. Cell phones are not to be on the desks during quizzes or examinations.

Lab Session Class Timings: From Jan. 12 – Jan. 26, Tu and Th is lecture. Starting from 1/28, multiple labs session will be held on Thursdays from 1 pm – 2:20 pm, other time slots TBD. Class will be divided into these sections during first 2 weeks of class.

Location: UNT Cleanroom

All students in the course are required to have safety training class from the UNT Cleanroom Manager. If you miss this training, you will not be able to continue with this course, as this safety training cannot be rescheduled.

The Objectives of the Lab Sessions are:

- To practice and improve experimental skills and knowledge in engineering, microelectronics and MEMS.
- To apply the knowledge and gain hands-on experience in subjects covered in the lecture.

- To improve and cultivate interdisciplinary research skills and experience

Students will acquire hands-on opportunities to utilize manufacturing techniques for MEMS in a cleanroom environment for RF and microfluidic applications. The methods, tools, and measurement techniques used to create and characterize the device structures will be discussed. Different types of lithography methods will be presented, where the students will have a chance to work with thin-film photo-sensitive resists, as well as thick film processes using SU-8 resists, to create simple microfluidic devices that have future applications in *lab-on-a-chip (LOC)*.

Lab Grading:

<u>Lab Attendance (Lab 1 – 10)</u>	5 %
<u>Lab Report: There will be two lab reports due, Lab Report I (RF antenna fabrication and testing) and Lab Report II (microfluidic device fabrication and testing)</u>	
<u>Lab Report I should comprise of data obtained from Lab#3, 4, 5, 6, 7</u>	60 %
<u>Lab Report II should comprise of data obtained from Lab#8, 9, 10</u>	40%
<u>Points for the reports will only be counted if you attend the lab. Any missed lab will result in a grade of zero on that lab.</u>	
Your lab notebooks will also be graded and will comprise 5% of the grade for each of the 2 lab reports (i.e. 5% lab notebook documentation), and the rest will be for the content in your Lab Report I and II. The lab report due dates are noted in the schedule for the course	5%
<u>Lab Grade Counting toward overall grade for MEMS Course</u>	25%
Contribution of Lab Grades above from Lab Report I and Lab Report II to overall grade for course	(20%)
Attendance	(5%)

Lab Class Schedule

The students in this lab class will use MEMS based manufacturing processes and build devices for RF and microfluidic applications. They will work in groups of 3 or 4 students over the course of about 10 weeks, and will generate two final lab reports (noted in Evaluation Section) that will make up 25% of their overall grade for this MEMS class. The details of each lab are noted below

Lab 1 – Safety and Intro to Cleanroom
Lab 2 – Wafer Cleaning, Intro to equipment
Lab 3 – Lithography for antenna
Lab 4 – Metal evaporation and lift-off
Lab 5a – BOE etching to partially release antenna
Lab 5b – SEM imaging of antenna
Lab 6 – RF Simulations
Lab 7 – RF Measurements

Lab Report 1 due: Each team will provide a written lab report that will count toward their overall grade for the course.

Lab 8 – Thick film process for Microfluidics
Lab 9 – Micromolding for microfluidics
Lab 10 – Bonding and testing microfluidic structures

Lab Report II due: Each team will provide a written lab report that will count toward their overall grade for the course.

Lab Report 1: Labs 3 – 7 – due date is TBD.

Lab Report II: Labs 8 – 10 – due date is TBD. Please also turn in your lab notebooks which will be reviewed and graded as well.

ADA Policy

The University of North Texas complies with Section 504 of the 1973 Rehabilitation Act and with the Americans with Disabilities Act of 1990. UNT makes reasonable academic accommodation for students with disabilities. Students seeking accommodation must first register with the Office of Disability Accommodation (ODA) to verify their eligibility. If a disability is verified, the ODA will provide a student with an accommodation letter to be delivered to faculty to begin a private discussion regarding one's specific course needs. Students may request accommodations at any time, however, ODA notices of accommodation should be provided as early as possible in the semester to avoid any delay in implementation. Note that students must obtain a new letter of accommodation for every semester and must meet with each faculty member prior to implementation in each class. For additional information see the ODA website (<https://disability.unt.edu/>).

Additional Policies

Additional Policies

Authorized Absences and Extenuating Circumstances

Absences due to extenuating circumstances or participation in sponsored events must be verified by the Dean of Students. Consideration of such absences will be made for quizzes and examinations. For participation in sponsored activities, you must seek approval prior to the absence. For extenuating circumstances, you have 1 week to contact the instructor and/or the Dean of Students to initiate the process.

Absence for Religious Holidays

In accordance with state law, a student absent due to the observance of a religious holiday may take examinations or complete assignments scheduled for the day(s) missed, including those missed for travel, within a reasonable time after the absence. The student is responsible to notify the instructor of each class of the date of the anticipated absence as early in the semester as possible. Only holidays or holy days observed by a religion whose place of worship is exempt from property taxation under Section 11.20 of the Tax Code may be included. A student who is excused under this provision may not be penalized for the absence.

Academic Integrity Policy

Academic Integrity Standards and Consequences. According to UNT Policy 06.003, Student Academic Integrity, academic dishonesty occurs when students engage in behaviors including, but not limited to cheating, fabrication, facilitating academic dishonesty, forgery, plagiarism, and sabotage. A finding of academic dishonesty may result in a range of academic penalties or sanctions ranging from admonition to expulsion from the University. Therefore, students are expected to be honest and ethical in their academic work. Academic dishonesty is defined as an intentional act of deception in one of the following areas:

- * cheating – use or attempted use of unauthorized materials, information or study aids
- * fabrication – falsification or invention of any information
- * assisting – helping another commit an act of academic dishonesty
- * tampering – altering or interfering with evaluation instruments and documents
- * plagiarism – representing the words or ideas of another person as one's own.

For more information about academic integrity and the University's policies and procedures in this area, please see the UNT academic manual. Any student in violation of these policies will be given an overall **F grade (Fail)**. In addition, your case will be forwarded to university administrators, and you may be subject to additional punishments/sanctions according to university policies. When in doubt, please ask me.

Acceptable Student Behavior

You will be expected to conduct yourself in a professional manner. Student behavior that interferes with an instructor's ability to conduct a class or other students' opportunity to learn is unacceptable and disruptive and will not be tolerated in any instructional forum at UNT. Students engaging in unacceptable behavior will be directed to leave the classroom and the instructor may refer the student to the Dean of Students to consider whether the student's conduct violated the Code of Student Conduct. The University's expectations for student conduct apply to all instructional forums, including University and electronic classroom, labs, discussion groups, field trips, etc. Visit UNT's [Code of Student Conduct](https://deanofstudents.unt.edu/conduct) (<https://deanofstudents.unt.edu/conduct>) to learn more.

Prohibition of Discrimination, Harassment, and Retaliation (Policy 16.004)

The University of North Texas (UNT) prohibits discrimination and harassment because of race, color, national origin, religion, sex, sexual orientation, gender identity, gender expression, age, disability, genetic information, veteran status, or any other characteristic protected under applicable federal or state law in its application and admission processes; educational programs and activities; employment policies, procedures, and processes; and university facilities. The

University takes active measures to prevent such conduct and investigates and takes remedial action when appropriate.

Transmission and Recording of Student Images in Electronically-Delivered Courses

1. No permission is needed from a student for his or her image or voice to be transmitted live via videoconference or streaming media, but all students should be informed when courses are to be conducted using either method of delivery.
2. In the event an instructor records student presentations, he or she must obtain permission from the student using a signed release in order to use the recording for future classes in accordance with the Use of Student-Created Work guidelines above.
3. Instructors who video-record their class lectures with the intention of re-using some or all of recordings for future class offerings must notify students on the course syllabus if students' images may appear on video. Instructors are also advised to provide accommodation for students who do not wish to appear in class recordings.

Example: This course employs lecture capture technology to record class sessions. Students may occasionally appear on video. The lecture recordings will be available to you for study purposes and may also be reused in future course offerings.

No notification is needed if only audio and slide capture is used or if the video only records the instructor's image. However, the instructor is encouraged to let students know the recordings will be available to them for study purposes.

Class Recordings & Student Likenesses

Synchronous (live) sessions in this course may be recorded for students enrolled in this class section to refer to throughout the semester. There may also be prerecorded lectures. Class recordings are the intellectual property of the university or instructor and are reserved for use only by students in this class and only for educational purposes. Students may not post or otherwise share the recordings outside the class, or outside the Canvas Learning Management System, in any form. Failing to follow this restriction is a violation of the UNT Code of Student Conduct and could lead to disciplinary action.

Course Safety Procedures (for Laboratory Courses). Students enrolled in **Micro-electro-mechanical-systems (MEMS): Materials, Devices and Applications** are required to use proper safety procedures and guidelines as outlined in UNT Policy 06.038 Safety in Instructional Activities. While working in laboratory sessions, students are expected and required to identify and use proper safety guidelines in all activities requiring lifting, climbing, walking on slippery surfaces, using equipment and tools, handling chemical solutions and hot and cold products. Students should be aware that UNT is not liable for injuries incurred while students are participating in class activities. All students are encouraged to secure adequate insurance coverage in the event of accidental injury. Students who do not have insurance coverage should consider Standard Syllabus Statements Related Policy 06.049 Course Syllabi Requirements obtaining Student Health Insurance. Brochures for student insurance are available in the UNT Student Health and Wellness Center. Students who are injured during class activities may seek

medical attention at the Student Health and Wellness Center at rates that are reduced compared to other medical facilities. If students have an insurance plan other than Student Health Insurance at UNT, they should be sure that the plan covers treatment at this facility. If students choose not to go to the UNT Student Health and Wellness Center, they may be transported to an emergency room at a local hospital. Students are responsible for expenses incurred there.

Emergency Notification & Procedures. UNT uses a system called Eagle Alert to quickly notify students with critical information in the event of an emergency (i.e., severe weather, campus closing, and health and public safety emergencies like chemical spills, fires, or violence). In the event of a university closure, please refer to Canvas for contingency plans for covering course materials.

Student Evaluation Administration Dates. Student feedback is important and an essential part of participation in this course. The student evaluation of instruction is a requirement for all organized classes at UNT. The survey will be made available during weeks 13, 14 and 15 of the long semesters to provide students with an opportunity to evaluate how this course is taught. Students will receive an email from "UNT SPOT Course Evaluations via IASystem Notification" (no-reply@iasystem.org) with the survey link. Students should look for the email in their UNT email inbox. Simply click on the link and complete the survey. Once students complete the survey they will receive a confirmation email that the survey has been submitted. For additional information, please visit the SPOT website at www.spot.unt.edu or email spot@unt.edu.