SYLLABUS
MICRO-ELECTRO-MECHANICAL SYSTEMS (MEMS) DESIGN
ECE 6030
SPRING 2019

Course Overview

- **Lectures:** Tue, Thu, 9:35-10:55 pm, Caldwell Laboratory, Room 102.
- **Office hours:** Please make an appointment by email.
- **Class web page:** http://carmen.osu.edu. Check class page frequently for announcements, assignments, and resources.
- **Instructor:** Prof. Nima Ghalichechian
- **Office**
  - Room #360 Dreese Laboratories (for office hours)
  - Room #245 ElectroScience Laboratory located at 1330 Kinnear Rd (West Campus)
- **E-mail address:** ghalichechian.1@osu.edu
- **RF Microsystems Research Group URL:** https://microsystems.osu.edu
- **TA or grader:** Class has no TA or grader.

Exam Date

Dates for midterm and final exams are:

- **Midterm:** TBD
- **Final:** Date and time for final exams are set by OSU.

Prerequisites

- Graduate standing in engineering or physics or permission of the instructor.

Grading

Homework Assignments	25 %
Midterm and quizzes	30 %
Project report and presentations	45%

Course Goals

Goal A: Students will develop a holistic view of the field of microsystems
Goal B: Student will be able to appreciate the role of MEMS sensors and actuators in your daily life. Being able to explain "Why we should care about these devices?"
Goal C: Student will understand the role of the MEMS design and trade-offs in real world.
Goal D: Student will understand the MEMS fabrication process
Goal E: Student will be able to use multi-physics simulation software to design a MEMS device
Goal F: Student will be able to read, digest, and discuss MEMS articles

Learning Outcomes Associated with Each Goal

A1. Students will be able to distinguish several classes of MEMS devices from one another.
A2. Student will be able to analyze the operation principle for each group.
A3. Be able to articulate how a given paper (literature) fit into the big picture.
B1. Be able to provide examples of practical uses for each device.
B2. Propose to use MEMS devices for a new (out-of-the-box) application.
C1. Deliver and present a design challenge assigned to each group.
C2. Be able to explain (in simple works) the design trade-offs for each class of devices.
C3. Be comfortable in applying and evaluating the impact of the electrical, mechanical, and chemical properties of each material to the design.
C4. Demonstrate the ability to design a simple MEMS device such as cantilevers, fixed-fixed beams, resonator, and comb-drive actuator.
C5. Successfully complete the design of the assigned projects. Deliver (report) and present a design challenge assigned to each group.
C6. Being able to efficiently summarize the approach and results in each project in a form of technical report.
D1. Being able to design a fabrication process for a given device involving surface and bulk micro-machining.
D2. Able to reconfigure the process, when the premises around using a certain material is changed.
D3. Able to explain how each fabrication process is different than other.
D4. Student will be able to propose (design from scratch) a new fabrication process for a given device.
E1. Be able to build, setup, and solve selected multi-physics simulation problems with COMSOL software.
E2. Become familiar and comfortable with COMSOL as a simulation tool.
E3. Be able to couple 2 or more physics together and run a simulation.
E4. Be able to perform basic thermal, structural and electrical simulations using COMSOL software.
F1. Being able to read and digest a MEMS article (journal or conference paper).
F2. Demonstrate that the key or major points of the paper can be summarized in a few simple sentences.

Reference Textbooks

You are <u>not</u> required to purchase any textbook for this class. The course structure relies heavily on reading selected papers. However, the following three reference books will be used throughout the semester to supplement the papers. <u>All three books are available</u> for 2-hour loan at the OSU 18th Ave library after week 1.

1. Foundation of MEMS, 2nd Edition, 2012, by Chang Liu ISBN-10: 0132497360
2. Microsystem Design, by Stephen D. Senturia, **TK7875 .S46 2000**
3. Fundamentals of microfabrication and nanotechnology, 2011, Third Edition (3 volume set), by Marc Madou, **TK7875 .M33 2012 v.1** (v.2 and v.3, see below for the volume list)

a. Volume 1: Solid-State Physics, Fluidics, and Analytical Techniques in Micro- and Nanotechnology
b. Volume 2: Manufacturing Techniques for Microfabrication and Nanotechnology
c. Volume 3: From MEMS to Bio-MEMS and Bio-NEMS: Manufacturing Techniques and Applications

Additional resource for simple explanation of semiconductor processes is "*Introduction to Microelectronic Fabrication*, 2nd edition, Richard C. Jaeger, 2002.

COMSOL Multiphysics Simulation

COMSOL Multiphysics software will be used for simulations. At the start of the semester, an introductory lecture will be devoted to how to use COMSOL.

- Please note that OSU license agreement with COMSOL for this course is strictly for the class use only. Research projects outside the scope of this class requires a different license.
- COMSOL 5.3 with update 3 has been installed on the ECE student lab systems in DL517 (Windows), DL557 (Linux), DL817 (Windows), and CL260 (Windows).
- Our package includes COMSOL program as well as the MEMS module.
- Use CARMEN for module information and guidelines.
- On the Windows systems the students can launch COMSOL by using the "COMSOL Multiphysics 5.3 (Class kit License)" desktop shortcut. I recommend using Windows systems for this class.
- On the Linux systems the students can launch COMSOL by going to Applications >> System Tools >> Terminal, and typing comsol.
- Request access to the COMSOL page at https://www.comsol.com/access/
- Use COMSOL support page for examples and instructions https://www.comsol.com/support
- COMSOL MEMS features: Buckling ,Elastic waves, Elastohydrodynamics, Electrostatics, Electrostatic actuation, Fluid-structure interaction (FSI), Joule heating, Large deformations, Gravity force, Modal analysis, Mechanical contact, Perfectly matched layers (PMLs), Piezoelectricity, Piezoresistivity, Prestressed structures, Solid mechanics, Rotating Frames with centrifugal, Coriolis, and Euler forces, Thermal stress, Thermoelasticity, Thin-film damping, Sensors, SPICE circuits, Vibrations, Viscoelasticity, Spin softening effect
- COMSOL MEMS application areas: Accelerometers, Actuators, Bulk Acoustic Wave (BAW) devices, Cantilever beams, Capacitors, Gyroscopes, Magnetostrictive devices, Resonators, Piezoelectric devices, Piezoresistive devices, RF MEMS, Sensors, Surface Acoustic Wave (SAW) devices, Thermal actuators

Search Database

Use Scopus database for searching for papers and assignments. Access this database from right menu on OSU library page at https://library.osu.edu/. Click on "Research Database Link" and find Scopus. This is a comprehensive database that covers engineering and technology topics. Use of Google Scholar is NOT recommended for this course.

Reference Journals

There are 3 main journals with MEMS focus. These are listed here. Selected articles will be used for this course.

1. Journal of Microelectromechanical Systems (IEEE)
   http://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=84

2. Journal of Micromechanics and Microengineering (IoP Science) http://iopscience.iop.org/journal/0960-1317
3. Sensors and Actuators A: Physical (Elsevier) https://www.journals.elsevier.com/sensors-and-actuators-a-physical

Also

- Collection of MEMS review papers - Oldies but goodies: *Proceedings of the IEEE, Vol. 86, Nov. 8, August 1998.*

Key Conferences

Selected articles from the list below will be used for course assignments.

- IEEE MEMS (annual)
- Transducers (odd years); Full name: Solid-State Sensors, Actuators and Microsystems Transducers
- Hilton Head (even years)- US participants only; Full name: A Solid-State Sensors, Actuators and Microsystems Workshop

Other Resources

Silicon Run DVD: MEMS, making micro machines: an overview of microelectromechanical systems, **TK7875 .M4267 2009 DVD** (See CARMEN for digital access)

Tentative Schedule

Week	Content
1	Overview and motivation History and commercial examples
2	Case study- Accelerometer Intro to multi-physics modeling software
3	Miniaturization and law of scaling Fabrication
4	Cantilevers Structural mechanics
5	Fabrication Multi-physics modeling software
6	Electrostatic actuators Fabrication
7	Comb-drive actuators
8	Structural mechanics Lumped modeling
9	Fabrication
10	Case study- Inertial and pressure sensors
11	Case study- Optical and RF
12	Case study- Power and Bio
13	Final project presentation
14	Final project presentation
Exam week	Final project report

- **Class Attendance:** Class attendance is required. During the class, it is recommended that you take notes. While supplementary lecture notes will be posted on CARMEN, the notes are not to be considered

as a direct replacement for the class notes and participation. Discussions during lectures are important part of the learning for this course. If you miss a lecture, contact other students for their class notes. Review these notes as well as the supplementary lecture notes on CANVAS. Complete the reading assignments and attend the office hours.

- **Reading and Homework Assignments:** Each week, particular sections of the textbook and/or selected papers will be assigned to be reviewed outside of the class. Several homework assignments will be given throughout the semester including video links. Some homework problems are from the reference books listed earlier. Therefore, you may need to go to the library to complete the assignments. Homework assignments are counted towards your final grade.
- **Quizzes:** Quizzes are designed to prepare you for your mid-term exam. Date for each quiz will be announced a week in advance. Any missing quiz will result in zero.
- **Projects:** Project assignments are integral part of this course and make up about half of the final grade. Please see class goals and outcomes on the previous pages for more information. Throughout the semester, small and large class projects will be assigned to each student. These projects include
  - **Classroom presentation:** Each student will give (at least once during the semester) a 10-15-minute seminar on a pre-assigned topic. Students will study the topic and prepare 10-15 power point slides for the presentation. Topics will be assigned a week in advance.
  - **Short design/simulation projects:** Typically, due 1 week after assignment.
  - **MEMS design project:** This is a group project that requires implementing everything you have learned in this class. It involves, process flow design, material selection, engineering trade-offs, literature review, layout, FE simulation, etc. The design project has 3 deliverables
    - Mid-term oral presentation discussing the project scope and approach. Since this will be an incomplete work, most results will be missing.
    - Final oral presentation: Each student will present his/her contributions to the project. Once group presentation is needed for each project.
    - Final report: Each group will submit 1 final report. This report should be free of language/grammar errors and should be prepared professionally. Figures and tables should be clear and legible with captions and descriptions. Spend time preparing the right figures. References marked with associated numbers. Table of content is included. Contributions of each member should be described. A template will be provided by the instructor that can be used as a starting point for your report.
    - Use Buckeye Box or OneDrive to collaborate on reports and presentations.
- **Working together:** Students are encouraged to work together on homework assignments, projects, simulations, etc. However, you must complete the quizzes and midterm without any external help or communication.
- **Midterm:** There is only one midterm exam. This will be closed book/notes. No internet-enabled devices are permitted. This course has no final exam.
- **Makeup policy (please read carefully):** The dates of the midterm and the final exam (held for class presentation) are announced in this document. Please note these dates and make the necessary arrangements to attend. Quiz dates will be announced a week in advance. No makeup exam/quiz will be given unless there is a medical emergency. You will need to provide proper documentation for these emergencies, and inform the instructor either before or within 48 hours of the exam to get the necessary approval. The report/ doctor's note should clearly indicate that you are in a condition that prevents you from attending school and taking an exam. Please note that pre-scheduled doctor's appointments (for

instance, your annual checkup), job interviews, job related issues, family reunions do not count as emergencies or valid excuses. If I agree to reschedule your midterm/quiz it will be held during final exam week. Any missed quiz or exam will result in a zero grade.

- **Regarding Policy:** Re-grading of a homework, quiz, midterm or project should be requested **within 5 working days** of them being returned to you. You will need a copy of all your graded tests for verification. Please keep all your graded papers until the final grade is assigned.
- **Contacting me:** Please feel to contact me anytime via email. You are highly encouraged to take advantage of the office hours. Outside of the office hours, my availability is limited, but you may schedule a meeting with me via email.

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Other Policies

Ohio State's academic integrity policy

Academic integrity is essential to maintaining an environment that fosters excellence in teaching, research, and other educational and scholarly activities. Thus, The Ohio State University and the Committee on Academic Misconduct (COAM) expect that all students have read and understand the University's *Code of Student Conduct*, and that all students will complete all academic and scholarly assignments with fairness and honesty. Students must recognize that failure to follow the rules and guidelines established in the University's *Code of Student Conduct* and this syllabus may constitute "Academic Misconduct."

Copyright disclaimer

The materials used in connection with this course may be subject to copyright protection and are only for the use of students officially enrolled in the course for the educational purposes associated with the course. Copyright law must be considered before copying, retaining, or disseminating materials outside of the course.

Statement on Title IX

Title IX makes it clear that violence and harassment based on sex and gender are Civil Rights offenses subject to the same kinds of accountability and the same kinds of support applied to offenses against other protected categories (e.g., race). If you or someone you know has been sexually harassed or assaulted, you may find the appropriate resources at http://titleix.osu.edu or by contacting the Ohio State Title IX Coordinator, Kellie Brennan, at titleix@osu.edu

Accessibility accommodations for students with disabilities

If you would like to request academic accommodations based on the impact of a disability qualified under the Americans with Disabilities Act and Section 504 of the Rehabilitation Act of 1973, contact me a week advance or as soon as possible to discuss your specific needs. Discussions are confidential. In addition to contacting me, please contact the Student Life Disability Services at 614-292-3307 or ods@osu.edu to register for services and/or to coordinate any accommodations you might need in your courses at The Ohio State University. Please go to http://ods.osu.edu for more information.