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](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](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

<table>
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<tr>
<th>Homework Assignments</th>
<th>25 %</th>
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<tbody>
<tr>
<td>Midterm and quizzes</td>
<td>30 %</td>
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<tr>
<td>Project report and presentations</td>
<td>45%</td>
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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 not 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. All three books are available for 2-hour loan at the OSU 18th Ave library after week 1.

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


**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/](https://www.comsol.com/access/)
- Use COMSOL support page for examples and instructions [https://www.comsol.com/support](https://www.comsol.com/support)
- 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/](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.

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

Also


**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**

<table>
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<tr>
<th>Week</th>
<th>Content</th>
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| 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](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](http://ods.osu.edu) for more information.