COURSE INFORMATION

Instructor:
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Office Hours: F: 3:00pm-4:00pm; other times by appointment (Only acamedic matters)

Assistant Instructors:
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Graduate Student Instructor (GSI):
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Office Hours: T & Th: 11:00am-12:00pm, Location: 4440 EECS (CAEN Lab), tentative

Lectures: Tuesdays and Thursdays: 1:30-3:00pm, room 1303 EECS
Recitation: Fridays: 1:30-2:30pm, room 3150 Dow Building

Course Description:

Micro **E**lectro **M**echanical **S**ystems (**MEMS**) are miniature devices (with micron size tolerances) that are created using various techniques including many similar to those used to manufacture integrated circuits, and are capable of performing many tasks and functions that involve mechanical, electrical, optical, chemical, bio, fluidic, and other types of signals. We live in and interact with a non-electronic world, while computers and communication systems that dominate our daily lives today are electronic systems. Sensors and actuators allow us to interface our electronic systems to the non-electronic world. They provide analog information on the system being monitored through signal conditioning circuits to a microprocessor-based controller. The processor interprets the information, makes appropriate decisions (perhaps in conjunction with higher level control), and implements those decisions via the actuators. Sensors and actuators have been traditionally the weakest link in the development of most next-generation instrumentation and control systems. Where sensors exist at all, they are frequently unreliable, rarely attain an accuracy of 8 bits, and may cost more than the processor. They are usually very large in size and impose significant challenges in terms of packaging of the entire system. Only in the past few years has this situation begun to change with the emergence of solid-state sensors that are implemented using integrated circuit fabrication technologies. MEMS and Integrated Microsystems are increasingly finding applications in many areas including automotive, health care, industrial processing, environmental monitoring, biomedical systems, chemical analysis, energy sources, telecommunication, aerospace systems, consumer appliances, and many others.

This course introduces students to this rapidly emerging, multi-disciplinary, and exciting field. It will teach fundamentals of micromachining and microfabrication techniques, including planar thin-film process technologies, photolithographic techniques, deposition and etching techniques, and the other technologies that are central to MEMS fabrication. A designer of MEMS requires knowledge and expertise across several different disciplines. Therefore, this course will pay special attention to teaching of fundamentals necessary for the design and analysis of devices and systems in mechanical, electrical, fluidic, and thermal energy/signal domains, and will teach basic techniques for multi-domain analysis (e.g., electromechanical, electrothermal). Fundamentals of sensing and transduction mechanisms (i.e. conversion of non-electronic signals to electronic signals), including capacitive and piezoresistive techniques, and design and analysis of micromachined miniature sensors and actuators using these techniques will be covered. Many examples of existing devices and their applications will be reviewed.

Web Site:

This course is being offered as a multi-institutional course and is available through the web. Students will have access, on-demand, to all lecture materials, assignments, etc. over the internet via video streaming. For access to all course materials and taped lectures, you need an account on the course website. The course website is available through the UM Canvas service:

<div align="center">

https://umich.instructure.com/courses/246740

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I have to assign an account for all registered students. Those who are officially registered will automatically have an account.

Prerequisites:

This course is intended for undergraduate seniors and first year-graduate students, and is the first in a series of five MEMS courses offered as part of a comprehensive MEMS educational program developed by the Engineering Research Center for Wireless Integrated Microsystems (originally WIMS, and currently WIMS$_2$, http://wims2.org/) through the support from National Science Foundation. The rest of MEMS course series are EECS 425, 509, 510, 514, and 515. (Often special topics classes, EECS 598, include MEMS related topics.) This course is an introductory course designed for those students who are not familiar with MEMS, microfabrication technologies, integrated circuits, or non-electrical devices and systems. Therefore, the course pre-requisites are selected to allow students from MANY engineering or science disciplines, including mechanical, electrical, chemical, aerospace, biomedical, and materials engineering to take the course. The course is organized into lectures and recitations (discussions). The lectures present the materials that ALL students need to learn. Recitations are intended to teach students from different disciplines in areas where they may need additional training, including fundamentals and basics of heat transfer, mechanics (statics, and dynamics) basics of RLC circuit analysis, analysis of second-order systems in the frequency domain, etc.

The following academic background is required for this course:
1. College math and calculus, and differential equations
2. Basic college-level physics and chemistry

Textbook:

Recommended optional textbook:
Chang Liu, Foundations of MEMS, 2nd Edition, Pearson/Prentice Hall, 2010
This course does not have the required textbook but will have an optional, strongly recommended textbook. I will also utilize my own notes, handouts, etc. Handouts and other supplementary materials are provided through the web. However, I strongly encourage you to read the recommended textbook. The areas and applications of MEMS devises and technologies are so diverse and broad; so you may get easily lost if you rely on handouts only. The recommened textbook is available for purchase at the Common and also reserved in the Engineering Library.

There are also several other books which you can use for reference and they are also on reserve at the Duderstadt Center:

Reference textbooks:
1) Gregory T.A. Kovacs, *Micromachined Transducers Sourcebook*, McGraw Hill, 1998
2) Stephen D. Senturia, *Microsystem Design*, Kluwer Academic Publishers, 2000
3) S. M. Sze, ed., *Semiconductor Sensors*. New York: John Wiley, 1994.
4) R. S. Muller, et.al., *Microsensors*. New York: IEEE Press, 1991.
5) *M. Madou, Fundamental of Microfabrication*, CRC Press, Inc. Boca Raton, FL., 1997
6) M. Elwensoek, H. Jansen, "Silicon Micromachining," Kluwer Academic Publishers, 1998
7) J.W. Gardner, "Microsensors – Principles and Applications," John Wiley & Sons, 1994

Among these, "Microsystem Design" is available online through the libraray at:
http://mirlyn.lib.umich.edu/Record/006980018

Additional reading and Journals:
8) K.D. Wise, ed., Micromachined Sensors and Sensing Systems, *IEEE Proceedings, Special issue*, August 1998
9) *IEEE Transactions on Electron Devices*, Special Issues of December 1979, January 1992, and July 1985. These issues contained many of the seminal papers in the field.
10) Digest of Technical Papers, *International Conferences on Solid-State Sensors and Actuators (Transducers)*. This conference is held every other year. 1985 to 2007.
11) Digest of Technical Papers, *Solid-State Sensor and Actuator Workshop* (Hilton Head, SC Series), 1984 through 2008
12) Proceedings, *IEEE Micro Electro Mechanical Systems Workshop (MEMS Conference)*, 1987 to 2008
13) Digests of Technical Papers, *IEEE International Electron Devices Meetings (IEDM)*. This conference contains many of the seminal papers on solid-state image sensors and tracks the development of this and some of the other sensor technologies over the years.
14) Digests of Technical Papers, *IEEE International Solid-State Circuits Conference (ISSCC)*. This conference has also served as the focal point for leading edge work, particularly in image sensors.
15) *IEEE/ASME Journal of Micro Electro Mechanical Systems (IEEE JMEMS)*, published by the Institute for Electrical and Electronics Engineers. See IEEE website at www.ieee.org
16) *Sensors and Actuators* Journal [A (Physical), B (Chemical), and C (Materials)], published by Elsevier Publishing, http://www.elsevier.com/inca/publications
17) *Journal of Micromechanics and Microengineering* (JM&M), published by British Institute of Physics), http://www.iop.org/Journals/jm
18) Sensors and Materials Journal, MYU Publishing, Japan

Reading Assignments:
Reading assignments will be given prior to the lecture in which the corresponding material is covered (see the Course Outline). Students are responsible for all reading materials (for problem sets, quizzes, and the final examination). Also, supplementary notes will be available for key topics. *All of the class lecture notes will be available on the web before a given lecture, and you are expected to bring them to class.*

Problem Sets:
Problem sets will be assigned according to the attached outline (this is tentative). They are usually issued on Tuesdays and are due the following Tuesdays at 1:30pm, beginning of the class (no late homeworks will be accepted without checking with me beforehand). Solutions will be on the course web site. We will try to get the graded homework back to you by the following class so that you will receive feedback on your performance quickly. Make sure that you do all the homework sets as they are designed to cover the materials presented in the lecture, and try not to use solutions from previous semesters.

Computer Aided Design and Simulation Tools and Assignments:
Because of their multi-domain nature, and due to their intrinsically three-dimensional features, design and analysis of MEMS is often complicated and requires access to a host of modeling and simulation tools. In an attempt to facilitate understanding of basic concepts and aid in the analysis of simple MEMS devices, we have acquired access to one of the most comprehensive modeling and simulation tools currently available. We plan to use COMSOL, a multiphysics simulation tool, this year. I will also be happy to discuss other CAD options that you may have available to you if you do not have access to the above (this applies mostly to non-UM students).

There will be three CAD assginments, through each of which you will learn different features of the software and techniques needed to solve complex problems. For those who do not have access to this software package, you can try to utilize free and available softwares. ***If you do not have access to this software package, please let me know as soon as possible.***

Quizzes:
The approximate dates of the two quizzes in this course are indicated in your course outline. We will try to adhere to these dates so much as possible. The quizzes will be held during the class time or early evening (to be decided in class), and will be approximately 1.5 hours each.

Pop Quizzes:
In addition to two quizzes, we will have several pop quizzes during the class. Pop quiz will be given at the beginning of the class without any announcement. Typically, it will be just one problem which will take less than 10 minutes to solve. Although you do not get the right answer, there will be a credit which will reflect your attendance to the class.

Final Exam:
The final exam will take place during the Examination period as indicated in the outline, and will cover all of the material in the course. This includes everything covered in problem sets, lectures, the textbook, and the handouts.

Grading Policy:
Course grades will be assigned according to the following grading formula. *Please note that this formula is tentative*; students will be informed of any major changes.

Problem Sets and CAD Assignments….. 20%
Pop Quizzes………………………… 5%
Quiz 1:………………………............… 15%
Quiz 2:...… 25%
Final Exam:...… 35%

In most cases students will be made aware of the basic statistics (mean, median, and standard deviation) for each assignment, quiz and final.

Guest Lectures:
A couple of years ago, we had a series of guest lectures to cover the application spaces in biomedical sensors, RF MEMS, advanced inertia sensors, packaging, etc. These will give a good perspective of recent trends in MEMS research and applications along with the fundamentals in MEMS sensing and actuating schemes covered in the class. This year I may invite one or two guest lectures, if time permits and guest lecturers are available. If arranged, the lecture titles and speakers will be posted as they are arranged.

Course Syllabus
(Tentative)

1) **Introduction (1 lecture, Chapter 1)**
   a) Motivation, examples
   b) Course goals and coverage
      i) Need to fabricate small components: structures, transducers, circuits
      ii) Study different transduction techniques, specifically capacitive and piezoresistive

2) **Review of standard semiconductor planar processing technologies (~5 lectures, Chapter 2)**
   a) Silicon as an electronic and mechanical material: properties, crystal structure, wafers, etc.
   b) Basic technologies and processes
      i) Photolithography: photoresist, exposure, developing, and masking
      ii) Silicon oxidation: wet and dry
      iii) Doping: Ion implantation, diffusion (pre-deposition and drive-in)
      iv) Deposition: (CVD, PECVD, LPCVD, evaporation, sputtering)
      v) Etching: wet and dry
   c) Different thin-film materials used in integrated circuit (IC) manufacturing and their composition: oxides, nitride, polysilicon, metals, polymers, diamond/Sic, etc.
   d) Review of basic semiconductor physics and electronics devices

3) **Review of specific micromachining technologies (~7 lectures, Chapter 10, 11)**
   a) Silicon etching: isotropic, anisotropic, dry, other techniques
   b) Wafer bonding (anodic, fusion, eutectic, polymer)
   c) Etch stops (concentration dependent, electrochemical, dielectric)
   d) Review of the most common micromachining technologies:
      i) Silicon bulk micromachining: wet and dry
      ii) Surface (sacrificial) micromachining: polysilicon, metals, polymers, etc.
      iii) Molding: electroplating, hot embossing, etc.

4) **Signal/Energy domains and basic mechanical properties (~2 lectures, Chapter 3)**
   a) Lumped modeling with circuit elements
      i) Review of basic circuit elements and analysis to be done in discussion)
         (1) Electrostatics
         (2) Basic elements and relationships (RLC circuits) for circuit analysis
         (3) First and second order linear systems
      ii) Review of basic mechanics (force, pressure, moment, static relationships)
      iii) Capacitor, resistor, inductors as model elements

5) **Introduction to micro electro-mechanical transducers (sensors & actuators) (~5 lectures, Chapter 4)**
   a) Introduction, motivation, why we need to analyze electro-mechanical systems
   b) Elasticity (basic definitions of stress, strain, etc.)
   c) Mechanical structures
      i) Bending of beams
      ii) Bending of plates
   d) Energy conserving transducers
      i) The capacitor as sensor and actuator (basic capacitive transduction)
      ii) Application to sensors, parallel plate and overlap area change
   e) Electromechanical capacitive transducers
      i) Examples, like pressure and acceleration sensors
      ii) Capacitive actuators

6) **Piezoresistive transducers (sensors & actuators) (~3 lectures, Chapter 6)**
   a) The piezoresistance effect in semiconductors

      i)   Introduction to basic semiconductor properties
      ii) Piezoresistive effect
   b) Electromechanical piezoresistive transducers
      i)   Bridge configuration, and sensing structure
      ii) Examples, like pressure and acceleration sensors

7) Introduction to micro electro-mechanical-thermal transducers (sensors & actuators) (~6 lectures, Chapter 5)
      i)   Thermal material property issues and definitions
      ii) Fundamentals of heat transfer
      iii) Electro-thermal analogy
      iv) Thermal sensors such as temperature, infrared, flow, pressure, and acceleration
      v) Thermal actuators, Joule heating

8) Introduction to RF MEMS, BioMEMS and Microfluidics (~1 lecture, if time permits)

DETAILED COURSE OUTLINE (tentative)

Mo.	Date	Material Covered	HW's	Comments
Sep.	**4**	Administrative Information, Introduction, Motivation (Chap 1)		
	6	Review standard semiconductor processing technologies (Chap 2)		
	7-D	*Review basic semiconductor electrical properties (Lecture)*		*See Lecture Video: Intro. basic semiconductor physics*
	11	Review standard semiconductor processing technologies (Chap 2)		
	13	Review standard semiconductor processing technologies (Chap 2)		
	14-D	*LNF (Lurie Nanofabrication Facility) Tour*		
	18	Silicon micromachining technologies (Chap 10)	HW#1 Due	
	20	Silicon micromachining technologies (Chap 10)		
	21-D	*Introduction to COMSOL*		
	25	Standard micromachining & MEMS process technologies (Chap 11)	HW#2 Due	
	27	Standard micromachining & MEMS process technologies (Chap 11)		
	28-D	*Review of standard micromachining & MEMS process technologies*		
Oct.	**2**	Standard micromachining & MEMS process technologies (Chap 11)	HW#3 Due	
*	4	Materials and Material properties (Chap 3)		
*	5-D	*Fabrication process design guidelines & Stress and deformation*		
*	**9**	Mechanical structures, Elasticity (Chap 3)	HW#4 Due	
	11	Mechanical structures, Elasticity (Chap 3)		
	12-D	*Quiz #1 preparation*		
	16	**Fall Study Break, No Class**	HW#5 Due	
	18	**Quiz #1: Microfabrication and Micromachining Technologies**	*Exam held in class time*	
	19-D	*Stress and deformation – continued*		
	23	Energy conserving transducers: capacitive sensors (Chap 4)		
*	25	Energy conserving transducers: capacitive sensors (Chap 4)		
	26-D	*Various supportive structures*		
	30	Energy conserving transducers: capacitive sensors (Chap 4)	HW#6 Due	
Nov.	1	Capacitive Actuators (Chap 4)		
	2-D	*Various supportive structures (continued)*		
	6	Capacitive Actuators (Chap 4)	HW#7 Due	
	8	Capacitive Actuators (Chap 4)		
	9-D	*Capacitive sensors – how to model and simulate*		
*	**13**	Piezoresistive Transducers (Chap 6)	HW#8 Due	
	15	Piezoresistive Transducers (Chap 6)		
	16-D	*Quiz#2 Preparation*		
	20	Electro-thermal MEMS (Chap 5)	HW#9 Due	
	22	**Thanksgiving Break**		
	23-D	**Thanksgiving Break**		
	27	**Quiz #2: Capacitive & Piezoresistive Transducers**	*Exam held in class time*	
	29	Electro-thermal MEMS (Chap 5)		
	30-D	*Thermal MEMS*		
Dec.	**4**	Electro-thermal MEMS (Chap 5)	HW#10 Due	
	6	Electro-thermal MEMS		
	7-D	*Final exam preparation*		
	11	**Last Day of Class, Course Evaluations**		
Dec.	20	**Final Exam**: Wednesday Dec. 19, 1:30-3:30pm	*Location posted later*	

*(KEY: Letter D next to date refers to Discussion, * shows dates I will be out of town, Bold Dates are Tuesdays)*
(Note: CAD assignments will be due on Fridays by 11:59 PM EDT)