


EE C247B - ME C218 Introduction to MEMS Design Spring 2015

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Lecture Module 1: Admin & Overview


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Instructor: Prof. Clark T.-C. Nguyen

- **Education:** Ph.D., University of California at Berkeley, 1994
- **1995:** joined the faculty of the Dept. of EECS at the University of Michigan
- **2006:** (came back) joined the faculty of the Dept. of EECS at UC Berkeley
- **Research:** exactly the topic of this course, with a heavy emphasis on vibrating RF MEMS
- **Teaching:** (at the UofM) mainly transistor circuit design courses; (UC Berkeley) 140/240A, 143, 243, 245
- **2001:** founded Discera, the first company to commercialize vibrating RF MEMS technology
- **Mid-2002 to 2005:** DARPA MEMS program manager
 - ↳ ran 10 different MEMS-based programs
 - ↳ **topics:** power generation, chip-scale atomic clock, gas analyzers, nuclear power sources, navigation-grade gyros, on-chip cooling, micro environmental control


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Course Overview

- **Goals of the course:**
 - ↳ Accessible to a broad audience (minimal prerequisites)
 - ↳ Design emphasis
 - ↳ Exposure to the techniques useful in analytical design of structures, transducers, and process flows
 - ↳ Perspective on MEMS research and commercialization circa 2014
- **Related courses at UC Berkeley:**
 - ↳ EE 143: Microfabrication Technology
 - ↳ EE 147/247A: Introduction to MEMS
 - ↳ ME 119: Introduction to MEMS (mainly fabrication)
 - ↳ BioEng 121: Introduction to Micro and Nano Biotechnology and BioMEMS
 - ↳ ME C219 - EE C246: MEMS Design
- **Assumed background for EE C245:**
 - ↳ graduate standing in engineering or physical/bio sciences
 - ↳ knowledge of microfabrication technology

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Course Overview

- The mechanics of the course are summarized in the course handouts, given out in lecture today
 - ↳ Course Information Sheet
 - ↳ Course description
 - ↳ Course mechanics
 - ↳ Textbooks
 - ↳ Grading policy
 - ↳ Syllabus
 - ↳ Lecture by lecture timeline w/ associated reading sections
 - ↳ Midterm Exam: tentatively on Thursday, March 19
 - ↳ Final Exam: Friday, May 15, 7-10 p.m. (Group 20)
 - ↳ Project due date TBD (but near semester's end)

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What Should You Know?

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Typical mid-2000's CMOS Process (good down to ~0.25µm)

You should either already know or be able to learn independently & very quickly:

- ① How to deposit or grow those different layers.
- ② How to pattern or otherwise form the shapes of the layers shown.
- ③ What determines the order by which the different layers are formed, e.g., temperature limits, topography limits, etc...

We will review these things, but we will do this very fast!

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What Should You Know?

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- Basic circuit analysis & design using op amps
- **Example:** Find the transfer function $v_o(s)/v_i(s)$ of the circuit below.

Ideal Op Amp: (Ruler)

- ① $R_i = \infty \rightarrow i_+ = i_- = 0$
- ② $A_o = \text{gain} = \infty \rightarrow \text{neg. f.B.} \rightarrow V_+ = V_-$
- ③ $R_o = 0$

$$v_o = -i_1 \left[R_f \parallel \frac{1}{sC_f} \right] = -\frac{v_i}{R_i} \left(\frac{R_f}{1 + sR_fC_f} \right)$$

$$\frac{v_o}{v_i}(s) = -\frac{R_f}{R_i} \frac{1}{1 + sR_fC_f} = -\frac{R_f}{R_i} \frac{1}{1 + \frac{s}{\omega_b}} \leftarrow \omega_b = \frac{1}{R_fC_f}$$

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Lecture Outline

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- Reading: Senturia, Chapter 1
- Lecture Topics:
 - ↳ Definitions for MEMS
 - ↳ MEMS roadmap
 - ↳ Benefits of Miniaturization

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MEMS: Micro Electro Mechanical System

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- A device constructed using micromachining (MEMS) tech.
- A micro-scale or smaller device/system that operates mainly via a mechanical or electromechanical means
- At least some of the signals flowing through a MEMS device are best described in terms of mechanical variables, e.g., displacement, velocity, acceleration, temperature, flow

Input:

voltage, current
acceleration, velocity
light, heat ...

MEMS

Output:

voltage, current
acceleration, velocity
light, heat, ...

Transducer to Convert **Control** to a **Mechanical Variable** (e.g., displacement, velocity, stress, heat, ...)

Control:

voltage, current
acceleration
velocity
light, heat, ...

[Wu, UCLA]

Angle set by mechanical means to control the path of light

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Other Common Attributes of MEMS

- Feature sizes measured in microns or less
- Merges computation with sensing and actuation to change the way we **perceive** and **control** the physical world
- Planar lithographic technology often used for fabrication
 - ↳ can use fab equipment identical to those needed for IC's
 - ↳ however, some fabrication steps transcend those of conventional IC processing

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[Najafi, Michigan] Micromechanical Vibrating Ring Gyroscope

80 mm

Gimballed, Spinning Macro-Gyroscope

MEMS Technology (for 80X size Reduction)

1 mm

Signal Conditioning Circuits

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Bulk Micromachining and Bonding

- Use the wafer itself as the structural material
- Adv: very large aspect ratios, thick structures
- Example: deep etching and wafer bonding

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Micromechanical Vibrating Ring Gyroscope

1 mm

[Najafi, Michigan]

[Pisano, UC Berkeley]

Microrotor (for a microengine)

Movable Structure

Silicon Substrate

Electrode

Glass Substrate

Metal Interconnect

Anchor

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Surface Micromachining

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Structural Material (e.g., polysilicon, nickel, etc.)

Release Etch Barrier

Sacrificial Oxide

Hydrofluoric Acid Release Solution

Silicon Substrate

pwell

Free-Standing Resonator Beam

Silicon Substrate

pwell

- Fabrication steps compatible with planar IC processing

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Single-Chip Ckt/MEMS Integration

- Completely monolithic, low phase noise, high-Q oscillator (effectively, an integrated crystal oscillator)
- To allow the use of >600°C processing temperatures, tungsten (instead of aluminum) is used for metallization

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Sustaining Vp-pipes

Anchors

Folded-Beam Suspension

Mass

Comb-Transducer

Struts

300 um

Oscilloscope Output Waveform

[Nguyen, Howe 1993]

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