


EE C247B - ME C218 Introduction to MEMS Design Spring 2016

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University of California at Berkeley
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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 & physics; (UC Berkeley) 140/240A, 143, 243, 245, 247B/ME218
- **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 2015
- **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 C247B/ME C218:**
 - ↪ 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: Thursday, March 17
 - ↪ Final Exam: Thursday, May 12, 8-11 a.m. (Group 13)
 - ↪ 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:

- How to deposit or grow those different layers.
- How to pattern or otherwise form the shapes of the layers shown.
- 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 Clot. Analysis & Design Using Op Amps

Ex.

$R_{eff} \parallel \frac{1}{sC_f} = \frac{R_f}{1 + sR_fC_f}$

Find the transfer function $\frac{V_o}{V_i}(s)$.

Ideal Op Amp Rules: (Apply when there's neg. FB)


- $V_i = V_-$
- $R_i = \infty$ (infinite input resistance)

$i_i = \frac{V_i}{R_i}$

$V_o = -i_i \left(R_f \parallel \frac{1}{sC_f} \right) = -\frac{V_i}{R_i} \left(R_f \parallel \frac{1}{sC_f} \right) \Rightarrow \frac{V_o}{V_i}(s) = -\frac{R_f}{R_i} \frac{1}{1 + sR_fC_f} = \frac{-R_f}{R_i} \frac{1}{1 + \frac{s}{\omega_b}} = \frac{V_o}{V_i}(s)$

$\omega_b = \frac{1}{R_fC_f}$


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Lecture Outline

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

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MEMS: Micro Electro Mechanical System

- 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

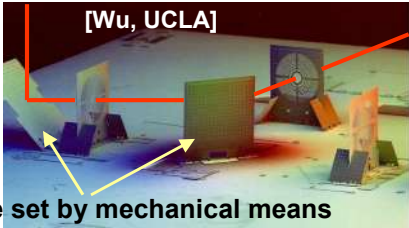
Output:

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, ...




Angle set by mechanical means to control the path of light

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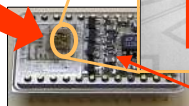
Other Common Attributes of MEMS

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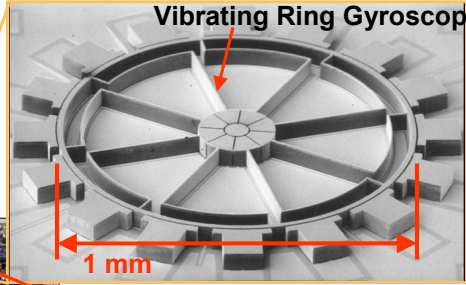
- Feature sizes measured in microns or less



80 mm
Gimbaled, Spinning
Macro-Gyroscope



Signal Conditioning Circuits



1 mm
Micromechanical
Vibrating Ring Gyroscope

MEMS Technology
(for 80X size Reduction)

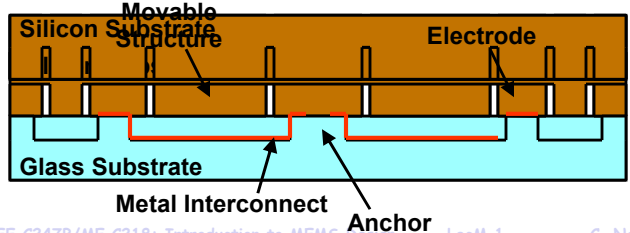
- Merges computation with sensing and actuation to change the way we **perceive** and **control** the physical world
- Planar lithographic technology often used for fabrication
 - ↳ can use fab equipment identical to those needed for IC's
 - ↳ however, some fabrication steps transcend those of conventional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

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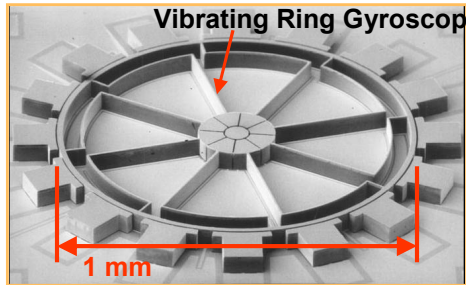
Bulk Micromachining and Bonding

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




Movable Structure
Silicon Substrate
Electrode
Glass Substrate
Metal Interconnect
Anchor



1 mm
Micromechanical
Vibrating Ring Gyroscope

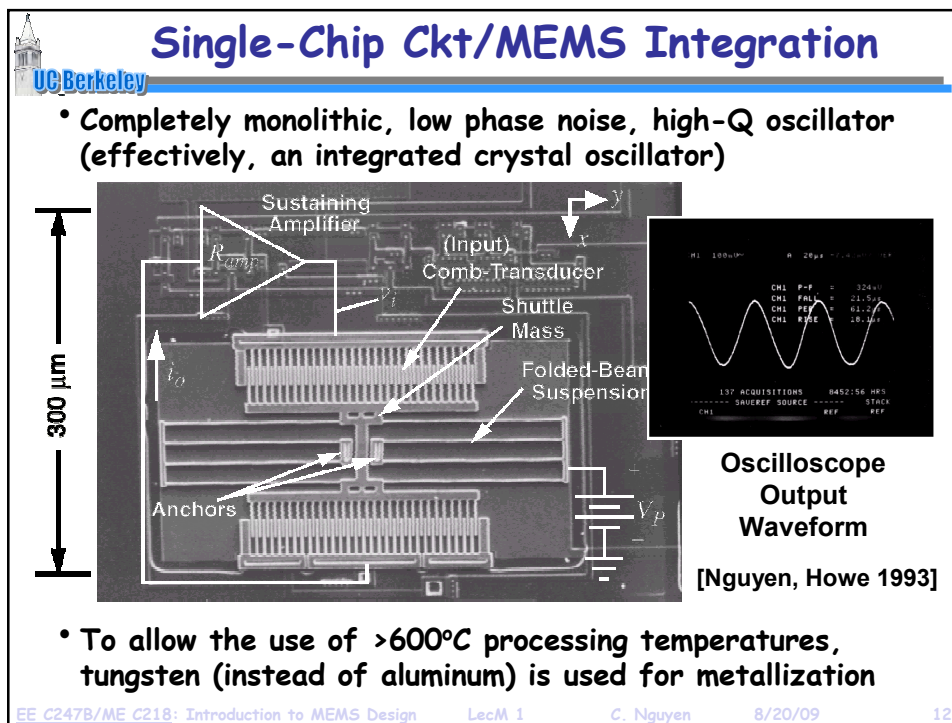
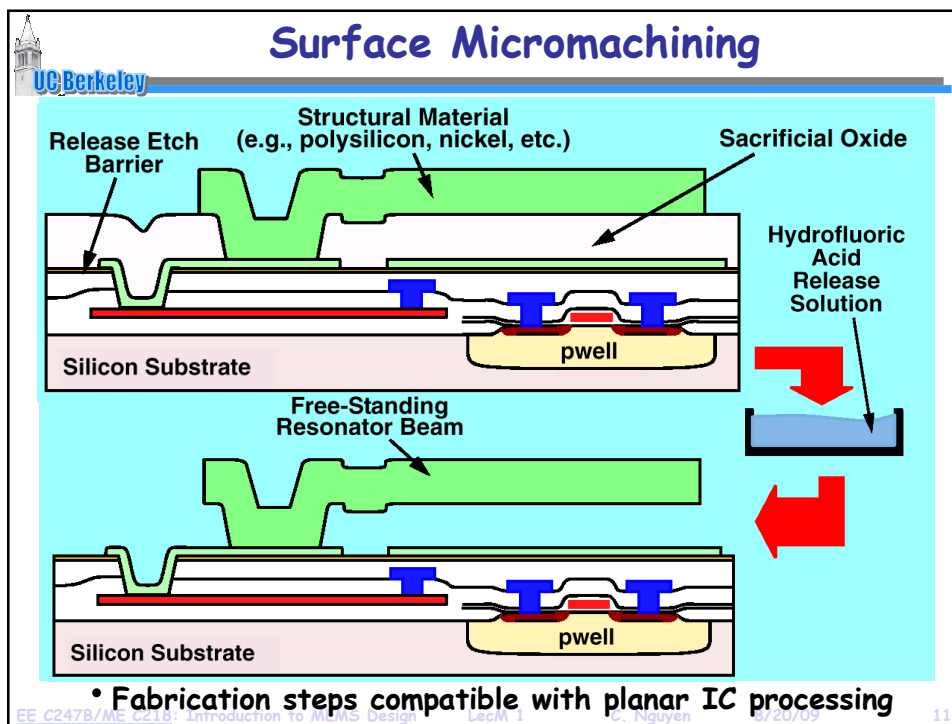
[Najafi, Michigan]



Microrotor
(for a microengine)

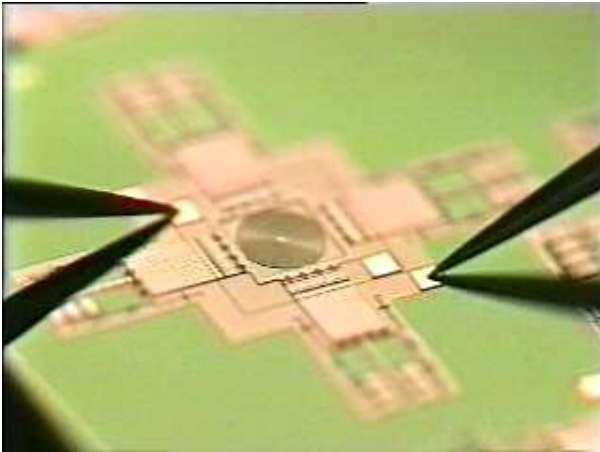
[Pisano, UC Berkeley]

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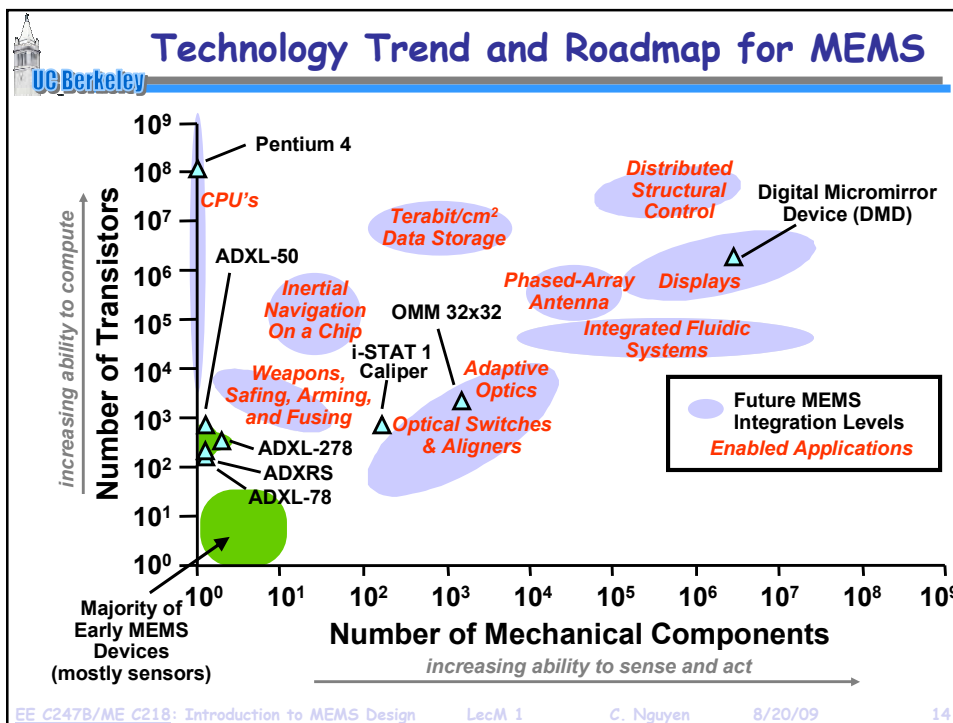
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3D Direct-Assembled Tunable L



[Ming Wu, UCLA]

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Example: Micromechanical Accelerometer

The MEMS Advantage:

- >30X size reduction
- accelerometer mechanism
- allows integration

Basic Operation Principle

$x \propto F_i = ma$

Micrograph: Analog Devices ADXL 78. Scale bar: 400 μm.

Callout: Tiny mass means small output → need integrated transistor circuits to compensate

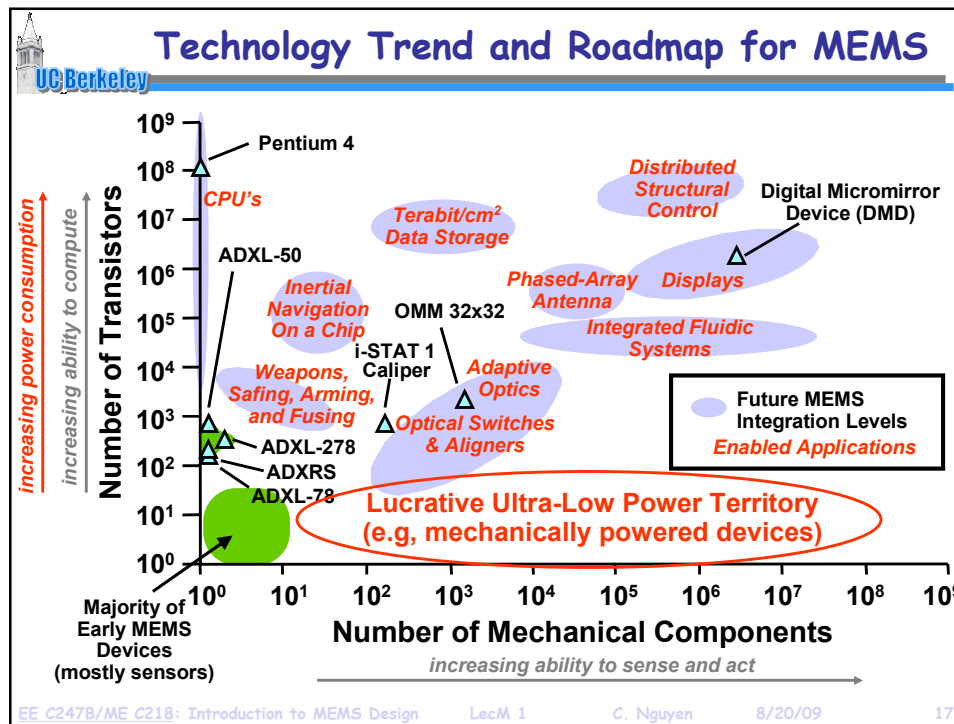
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Technology for MEMS

Device	Number of Mechanical Components	Advantages
Analog Devices ADXRS Integrated Gyroscope	~10 ³	Adv.: small size
Caliper Microfluidic Chip	~10 ³	Adv.: small size, small sample, fast analysis speed
i-STAT 1 Caliper	~10 ³	Weapons, Safing, Arming, and Fusing
OMM 8x8 Optical Cross-Connect Switch	~10 ⁴	Adv.: faster switching, low loss, larger networks
Optical Switches & Aligners	~10 ⁴	Adv.: faster switching, low loss, larger networks
TI Digital Micromirror Device	~10 ⁵	Adv.: low loss, fast switching, high fill factor

Other labels: Digital Micromirror Device (DMD), Adaptive Optics, Integrated Fluidic Systems, Future MEMS.

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Benefits of Size Reduction: MEMS

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- Benefits of size reduction clear for IC's in elect. domain
 ↖ size reduction ⇒ speed, low power, complexity, economy
- MEMS: enables a similar concept, but ...
MEMS extends the benefits of size reduction beyond the electrical domain

↓

Performance enhancements for application domains beyond those satisfied by electronics in the same general categories

- Speed ⇒ Frequency ↑ , Thermal Time Const. ↓
- Power Consumption ⇒ Actuation Energy ↓ , Heating Power ↓
- Complexity ⇒ Integration Density ↑ , Functionality ↑
- Economy ⇒ Batch Fab. Pot. ↑ (esp. for packaging)
- Robustness ⇒ g-Force Resilience ↑

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