



# EE C245 - ME C218 Introduction to MEMS Design Fall 2010

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Dept. of Electrical Engineering & Computer Sciences  
University of California at Berkeley  
Berkeley, CA 94720

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, 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

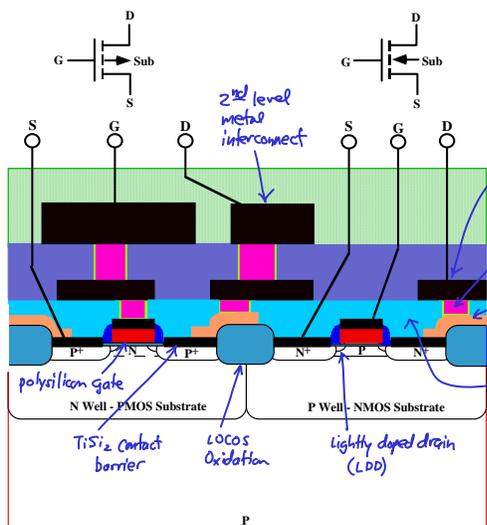
- **Goals of the course:**
  - ↗ Accessible to a broad audience (minimal prerequisites)
  - ↗ Design emphasis
    - Exposure to the techniques useful in analytical design of structures, transducers, and process flows
  - ↗ Perspective on MEMS research and commercialization circa 2010
- **Related courses at UC Berkeley:**
  - ↗ EE 143: Microfabrication Technology
  - ↗ EE 147: 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

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## What Should You Know?

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 Clf. Analysis & Design Using Op Amps

Ex.

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

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

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

- ①  $V_i = V_-$
- ②  $R_i = \infty$  (infinite input resistance)

Virtual Ground

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

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

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

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### Course Overview

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- 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 set for Thursday, Oct. 28
    - Final Exam: Friday, Dec. 17, 7-10 p.m.
    - Change this Final Exam time?
    - Project due date TBD (but near semester's end)

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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

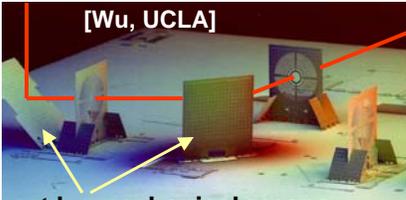
Input:  
voltage, current  
acceleration, velocity  
light, heat ...

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, ...



Angle set by mechanical means to control the path of light

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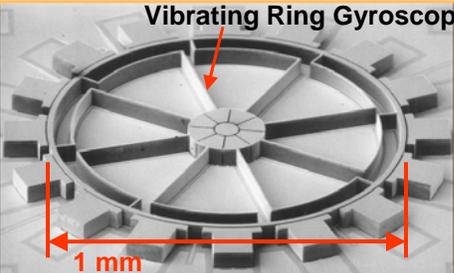
### Other Common Attributes of MEMS

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- Feature sizes measured in microns or less

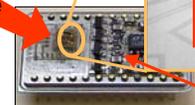


80 mm  
Gimbaled, Spinning  
Macro-Gyroscope



[Najafi, Michigan]  
Micromechanical  
Vibrating Ring Gyroscope

1 mm



**MEMS Technology**  
(for 80X size Reduction)

Signal Conditioning Circuits

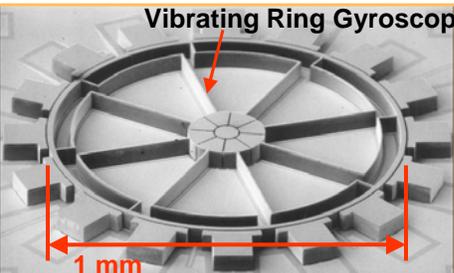
- Merges computation with sensing and actuation to change the way we **perceive** and **control** the physical world
- Planar lithographic technology often used for fabrication
  - can use fab equipment identical to those needed for IC's
  - however, some fabrication steps transcend those of conventional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



Micromechanical  
Vibrating Ring Gyroscope

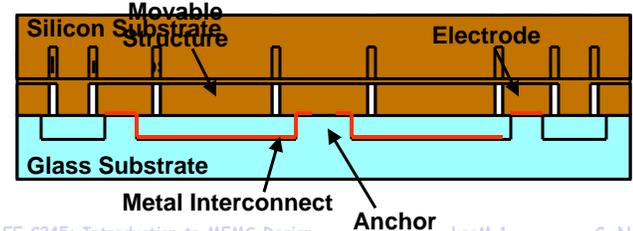
1 mm

[Najafi, Michigan]



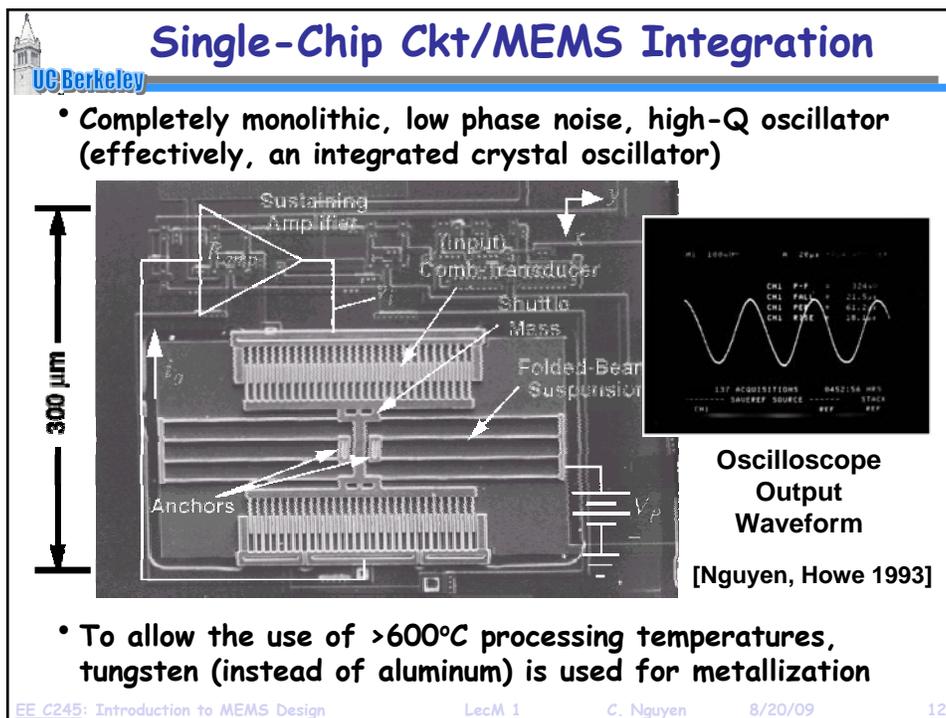
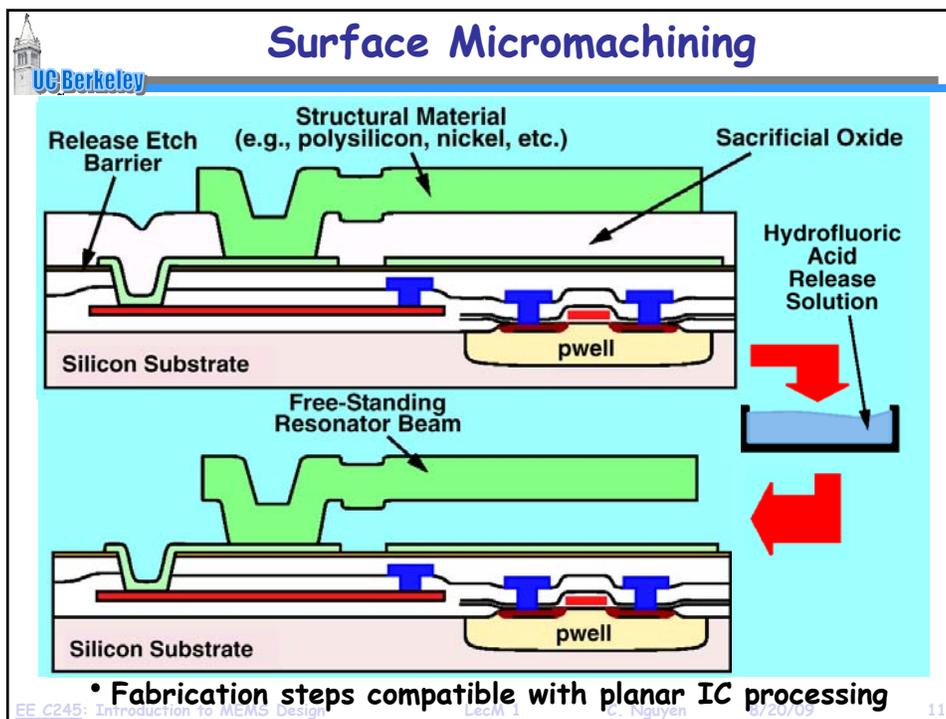
[Pisano, UC Berkeley]

Microrotor  
(for a microengine)



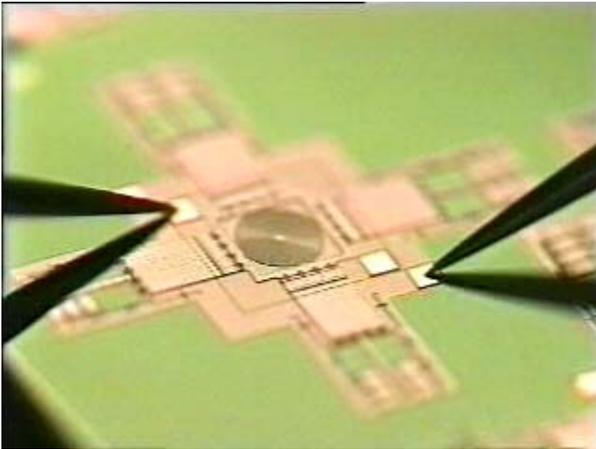
Silicon Substrate Movable Structure Electrode  
 Glass Substrate Metal Interconnect Anchor

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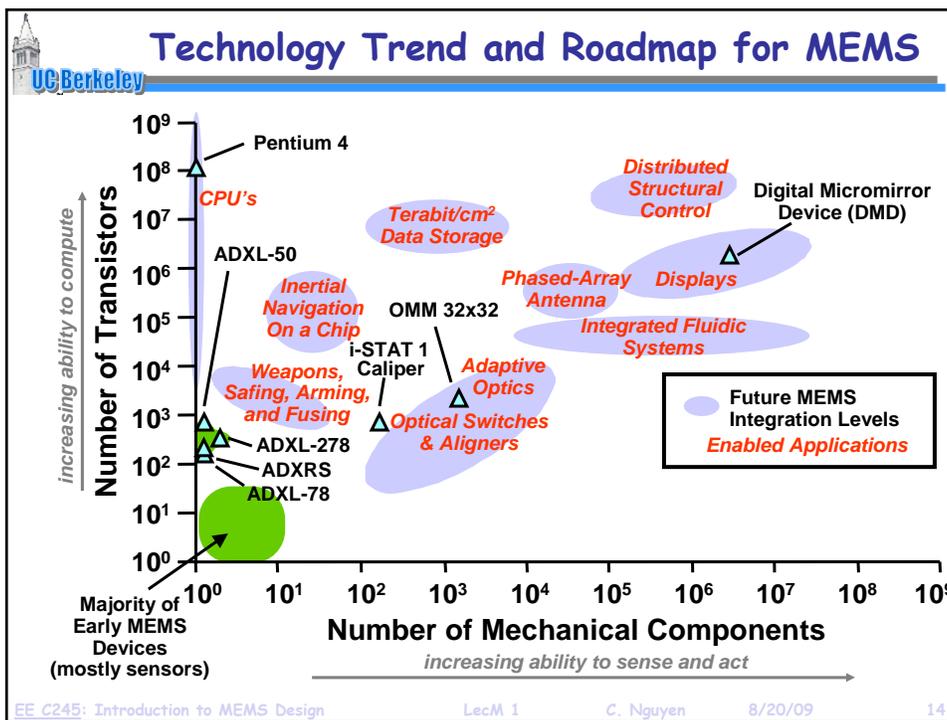
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## 3D Direct-Assembled Tunable L



[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.

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

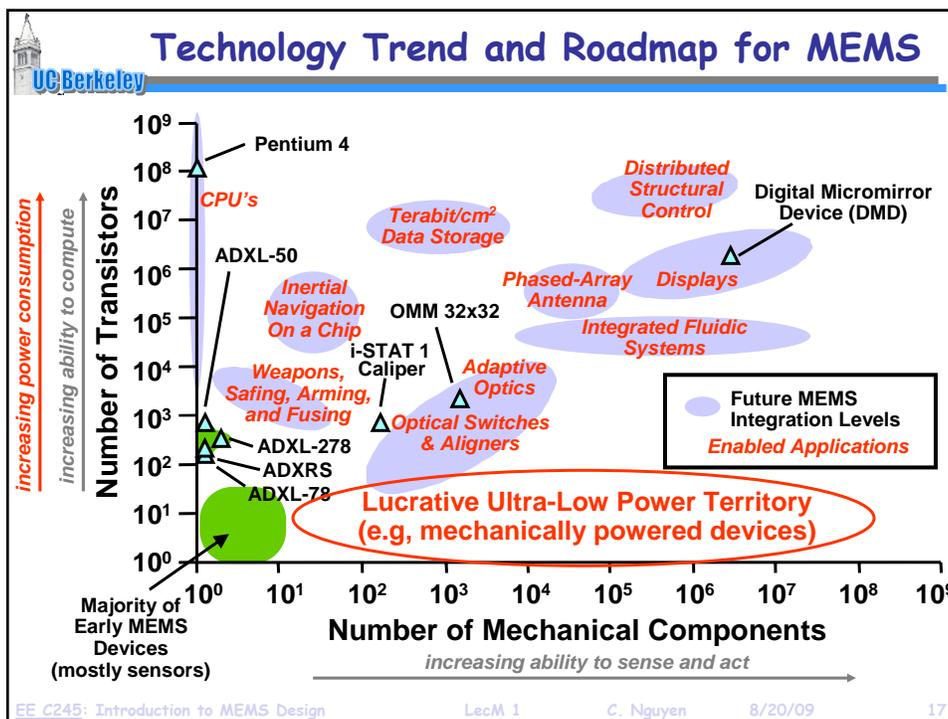
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### Technology for MEMS

Device	Number of Mechanical Components	Advantages
Caliper Microfluidic Chip	~10 <sup>2</sup>	Adv.: small size, small sample, fast analysis speed
ADXL 78	~10 <sup>3</sup>	Adv.: small size
OMM 8x8 Optical Cross-Connect Switch	~10 <sup>3</sup>	Adv.: faster switching, low loss, larger networks
TI Digital Micromirror Device	~10 <sup>4</sup>	Adv.: low loss, fast switching, high fill factor
Digital Micromirror Device (DMD)	~10 <sup>5</sup>	Adv.: low loss, fast switching, high fill factor

Other devices shown: Analog Devices ADXRS Integrated Gyroscope, i-STAT 1 Caliper, Adaptive Optics, Optical Switches & Aligners, Integrated Fluidic Systems, Future MEMS.

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### Benefits of Size Reduction: MEMS

- 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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