EE C245 – ME C218
Introduction to MEMS Design
Fall 2009

Prof. Clark T.-C. Nguyen

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

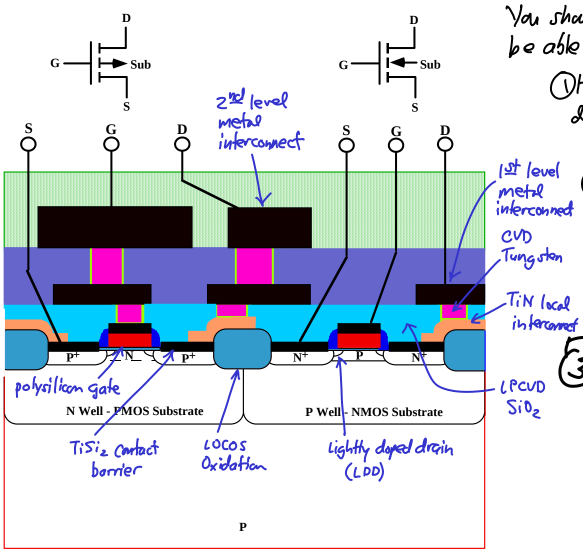
<u>Lecture Module 1</u>: Admin & Overview

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 2009
- Related courses at UC Berkeley:
  - EE 143: Microfabrication Technology
  - CS 194 (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

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 very quickly:

① How the films to the left were deposited or grown?

② How does one pattern these layers or otherwise form them.

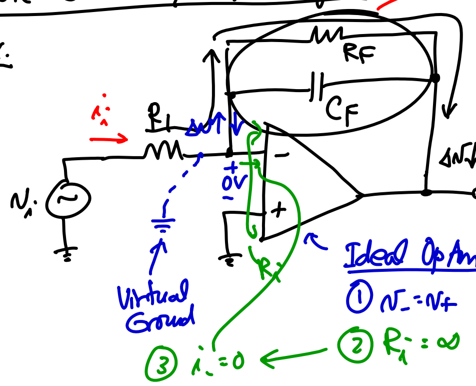
③ What determines the order by which these layers came down?

What Should You Know?

Basic Ckt. Analysis & Design

$z = R_f \| \frac{1}{\underbrace{sC_f}_{j\omega}} = \frac{R_f}{1+sR_fC_f}$

Ex.



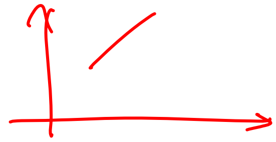
Find the transfer function $\frac{v_o}{v_i}(s)$.

Ideal Op Amp Rules: (hold for neg. FB) ✓

① $v_- = v_+$

② $R_i = \infty$

③ $i_- = 0$



$i_i = \frac{v_i}{R_1}$

$v_o = -i_i\left(R_f \| \frac{1}{sC_f}\right) = -\frac{v_i}{R_1}\left(\frac{R_f}{1+sR_fC_f}\right) \Rightarrow \boxed{\frac{v_o}{v_i}(s) = -\frac{R_f}{R_1}\left(\frac{1}{1+\frac{s}{\omega_b}}\right) \quad \omega_b = \frac{1}{R_fC_f}}$

Course Overview

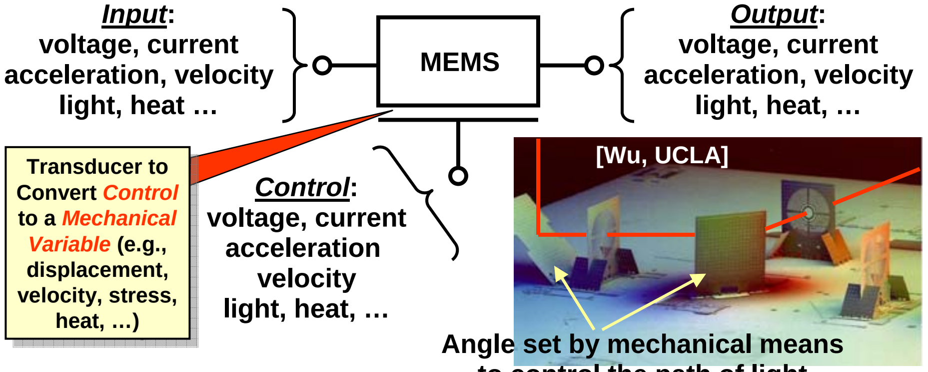
- The mechanics of the course are summarized in the course handouts, given out in lecture today
  - Course Information Sheet
    - Course description
    - Course mechanics
    - Textbooks
    - Grading policy
  - Syllabus
    - Lecture by lecture timeline w/ associated reading sections
    - Midterm Exam: tentatively set for Thursday, Oct. 23
    - Final Exam: Saturday, Dec. 20, 12:30-3:30 p.m.
    - Change this Final Exam time?
    - Project due date TBD (but near semester's end)

Lecture Outline

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

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, …)

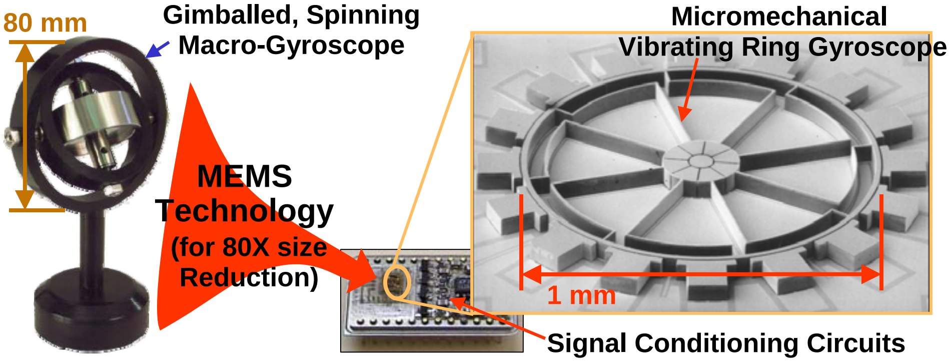
Control: voltage, current acceleration velocity light, heat, …

[Wu, UCLA]

Angle set by mechanical means to control the path of light

Other Common Attributes of MEMS

- Feature sizes measured in microns or less



80 mm

Gimballed, Spinning Macro-Gyroscope

MEMS Technology (for 80X size Reduction)

[Najafi, Michigan] Micromechanical Vibrating Ring Gyroscope

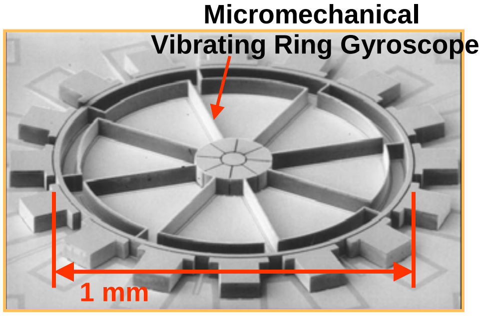
1 mm

Signal Conditioning Circuits

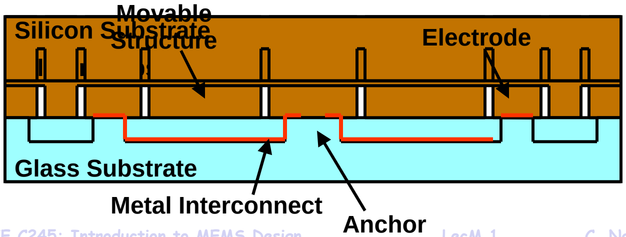
- Merges computation with sensing and actuation to change the way we perceive and control the physical world
- Planar lithographic technology often used for fabrication
  - ↳ can use fab equipment identical to those needed for IC's
  - ↳ however, some fabrication steps transcend those of conventional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

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

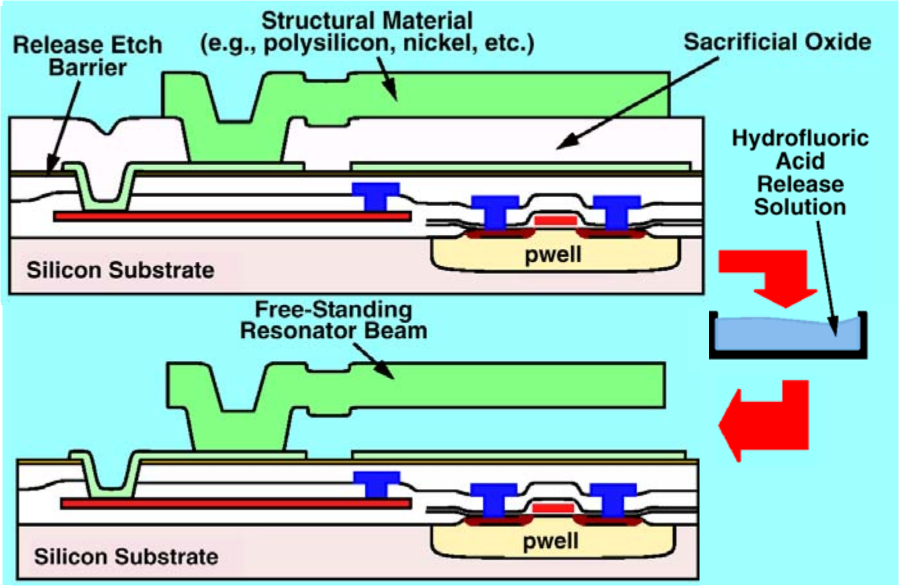


[Najafi, Michigan]



Microrotor
(for a microengine)

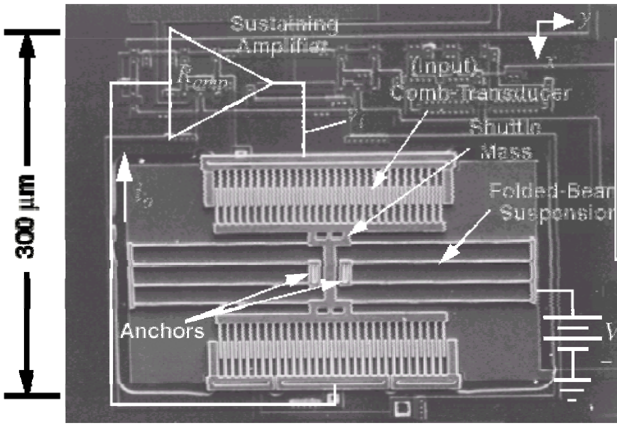
Surface Micromachining

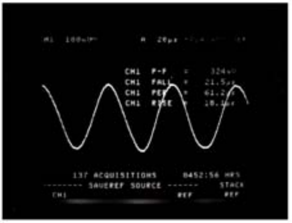


- Fabrication steps compatible with planar IC processing

Single-Chip Ckt/MEMS Integration

- Completely monolithic, low phase noise, high-Q oscillator (effectively, an integrated crystal oscillator)





Oscilloscope Output Waveform

[Nguyen, Howe 1993]

- To allow the use of >600°C processing temperatures, tungsten (instead of aluminum) is used for metallization

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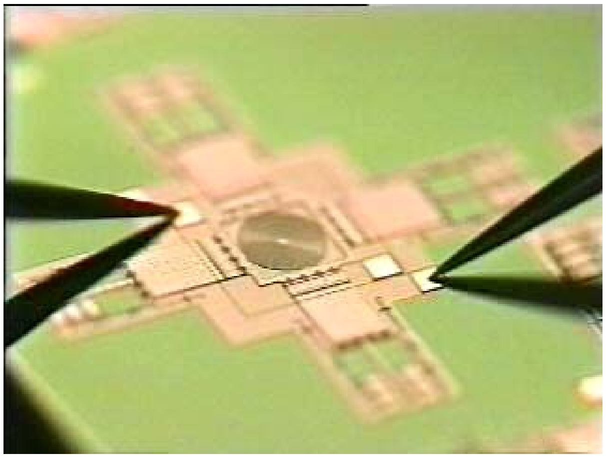
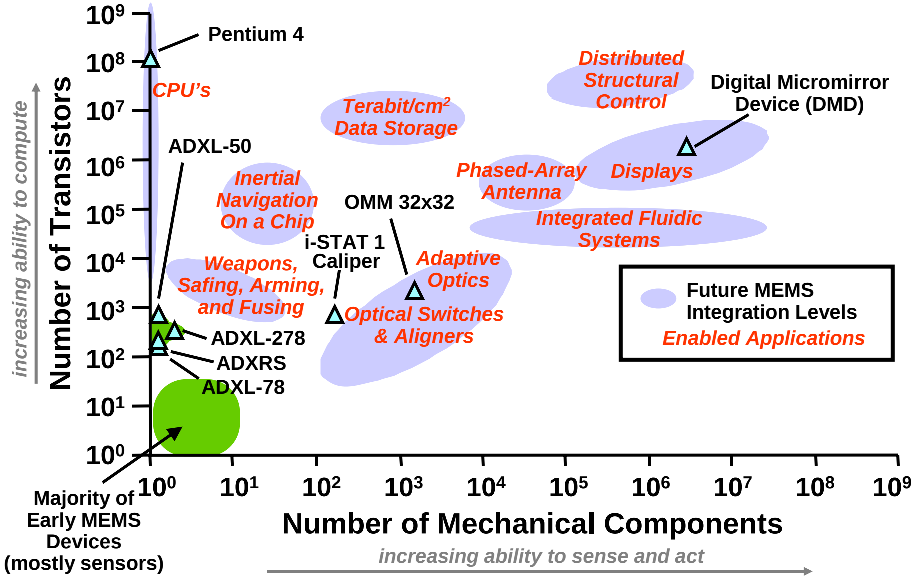
3D Direct-Assembled Tunable *L*



[Ming Wu, UCLA]

Technology Trend and Roadmap for MEMS

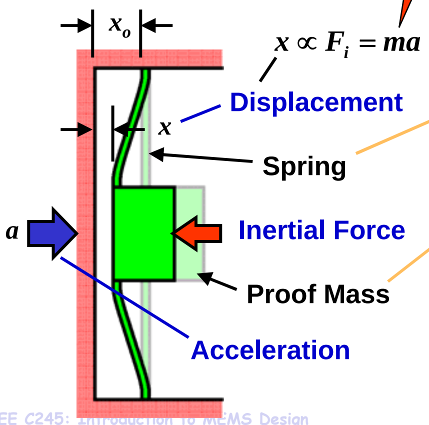


Example: Micromechanical Accelerometer

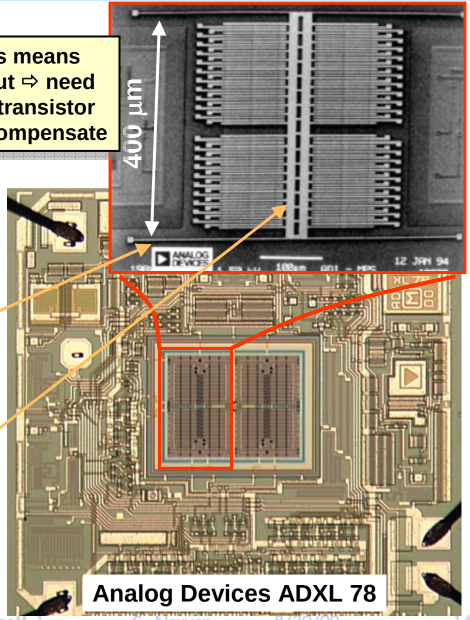
- *The MEMS Advantage:*
  - >30X size reductio
    accelerometer mec
  - allows integration w

Tiny mass means small output ⇨ need integrated transistor circuits to compensate

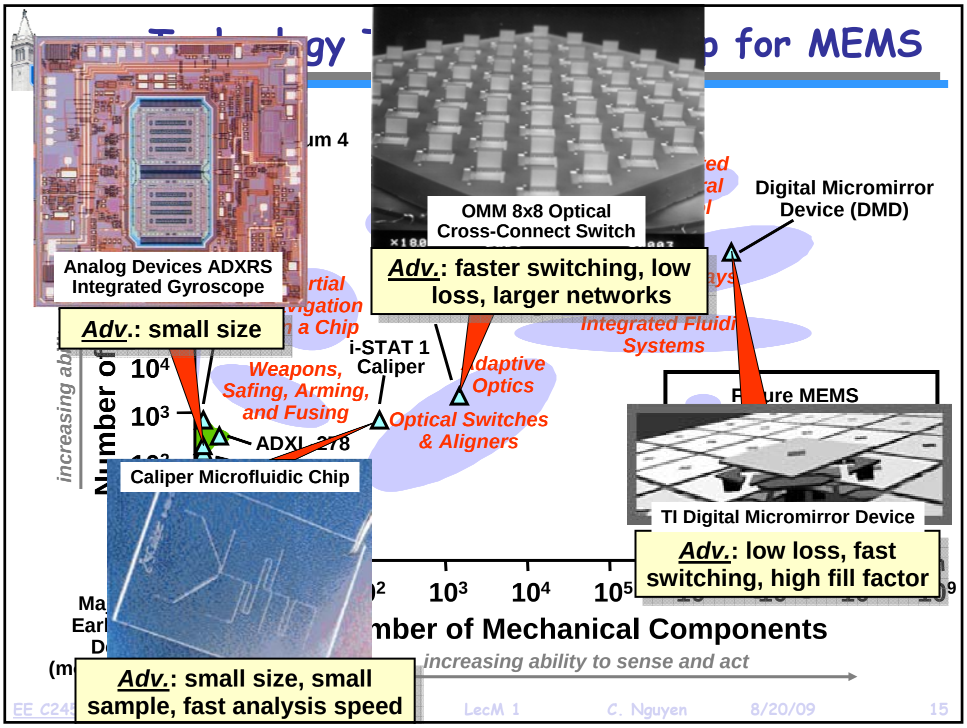
Basic Operation Principle



$x \propto F_i = ma$



Analog Devices ADXL 78



Analog Devices ADXRS Integrated Gyroscope

Adv.: small size

OMM 8x8 Optical Cross-Connect Switch

Adv.: faster switching, low loss, larger networks

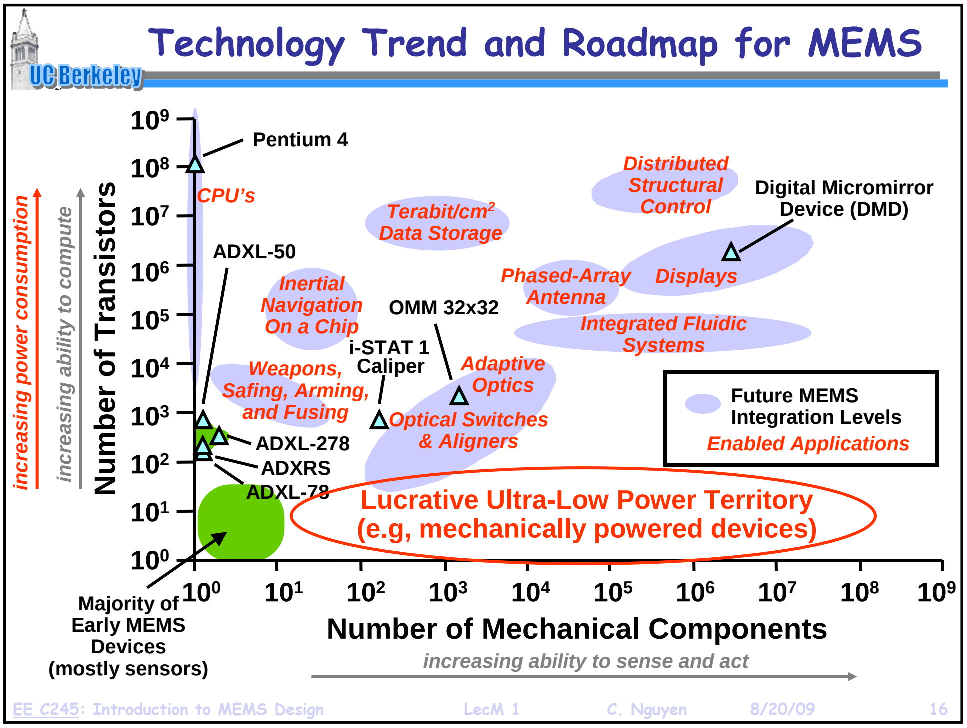
TI Digital Micromirror Device

Adv.: low loss, fast switching, high fill factor

Caliper Microfluidic Chip

Adv.: small size, small sample, fast analysis speed

Technology Trend and Roadmap for MEMS



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 ↑