EE C245 – ME C218
Introduction to MEMS Design
Fall 2011

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Lecture Module 1: Admin & Overview

Instructor: Prof. Clark T.-C. Nguyen

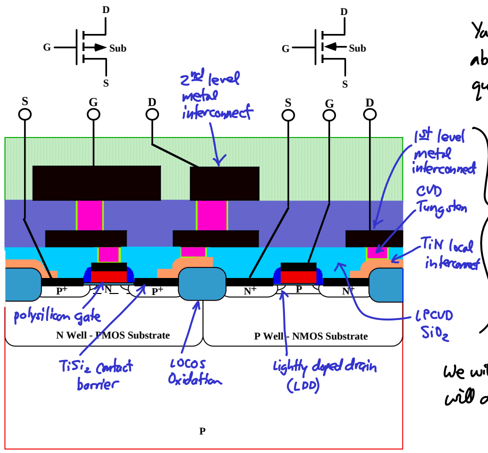
- *Education*: Ph.D., University of California at Berkeley, 1994
- *1995*: joined the faculty of the Dept. of EECS at the University of Michigan
- *2006*: (came back) joined the faculty of the Dept. of EECS at UC Berkeley
- *Research*: exactly the topic of this course, with a heavy emphasis on vibrating 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

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 2011
- 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

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.

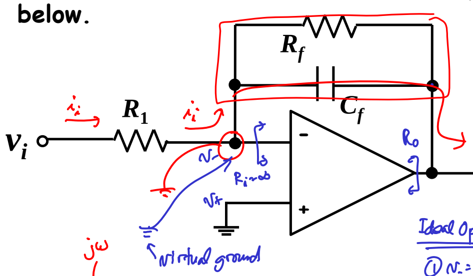
② How to pattern or otherwise form the shapes of the layers shown.

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!

What Should You Know?

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



Ideal Op Amp: (apply when have neg. FB)

① $v_- = v_+$
② $R_i \to \infty$
③ $A_o = \text{gain} = \infty$
④ $R_o = 0$

$$v_o = -i_i\left(R_f \,\|\, \frac{1}{\overset{j\omega}{s}C_f}\right) = -\frac{v_i}{R_1}\left(\frac{R_f}{1+sR_fC_f}\right)$$

$$\left[i_i = \frac{v_i}{R_1}\right]$$

$$\frac{v_o}{v_i}(s) = -\frac{R_f}{R_1}\,\frac{1}{1+sR_fC_f} = -\frac{R_f}{R_1}\,\frac{1}{1+\frac{s}{\omega_o}} \leftarrow \omega_o = \frac{1}{R_fC_f}$$

Course Overview

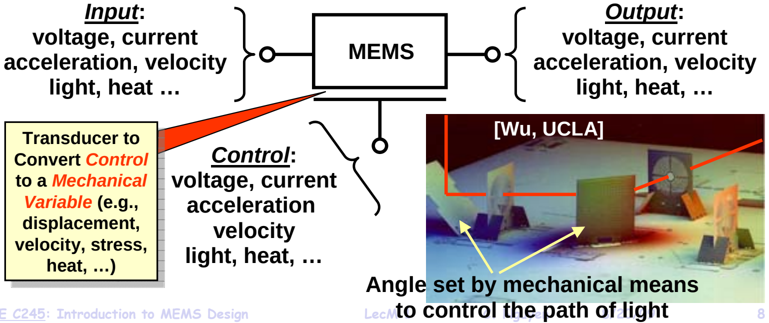
- The mechanics of the course are summarized in the course handouts, given out in lecture today
  - Course Information Sheet
    - Course description
    - Course mechanics
    - Textbooks
    - Grading policy
  - Syllabus
    - Lecture by lecture timeline w/ associated reading sections
    - Midterm Exam: tentatively set for Thursday, Oct. 28
    - Final Exam: Friday, Dec. 17, 7-10 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

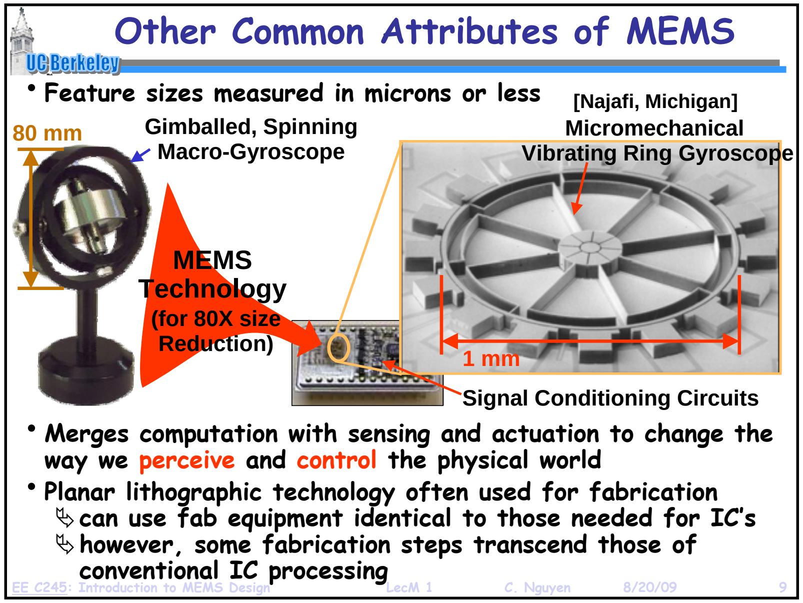
Output: voltage, current acceleration, velocity light, heat, …

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

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

[Wu, UCLA]

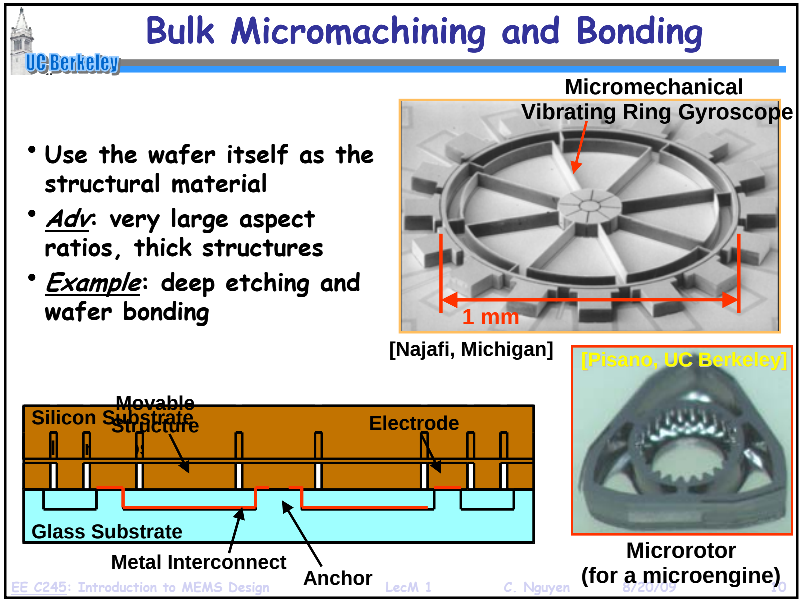
Angle set by mechanical means to control the path of light



Other Common Attributes of MEMS

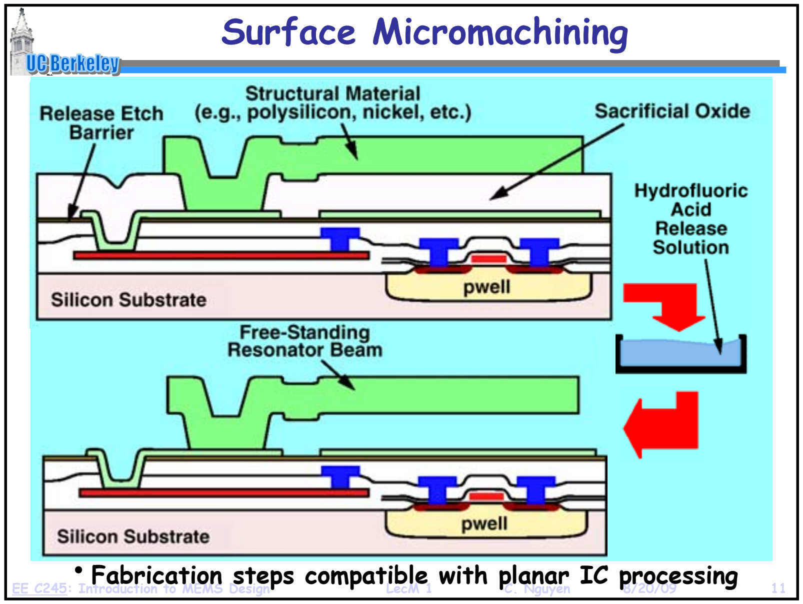
- Feature sizes measured in microns or less

- 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



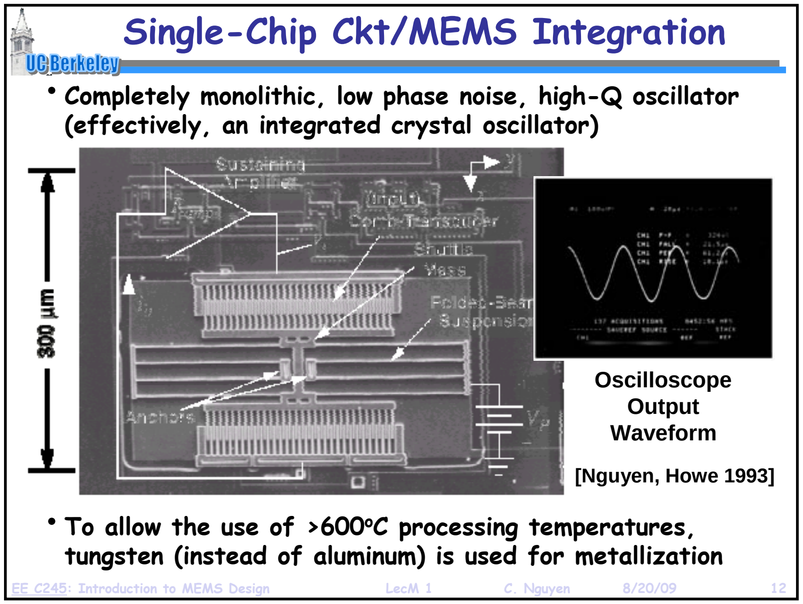
Bulk Micromachining and Bonding

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



Surface Micromachining

- Fabrication steps compatible with planar IC processing

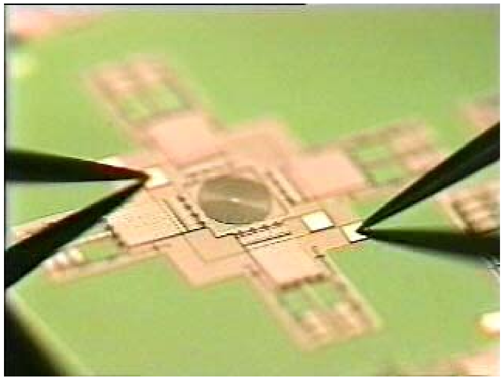


Single-Chip Ckt/MEMS Integration

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

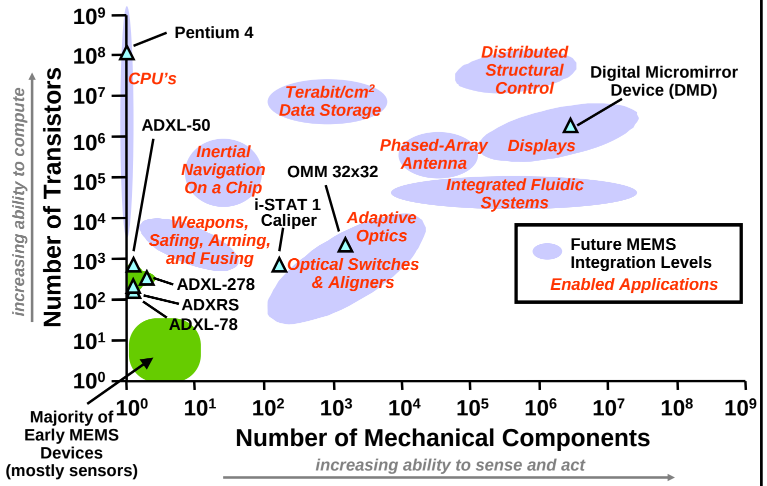
- To allow the use of >600°C processing temperatures, tungsten (instead of aluminum) is used for metallization

3D Direct-Assembled Tunable L



[Ming Wu, UCLA]

Technology Trend and Roadmap for MEMS

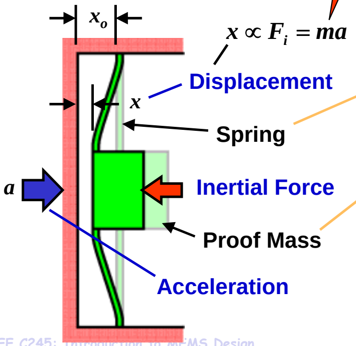


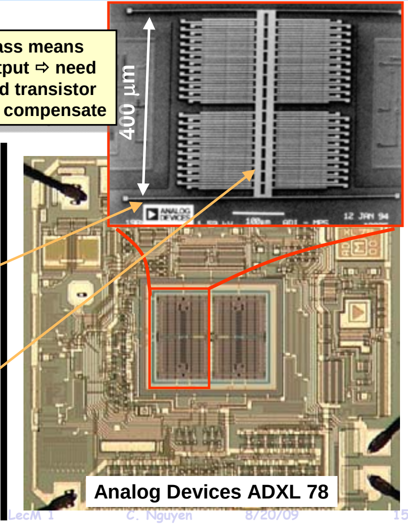
Example: Micromechanical Accelerometer

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

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

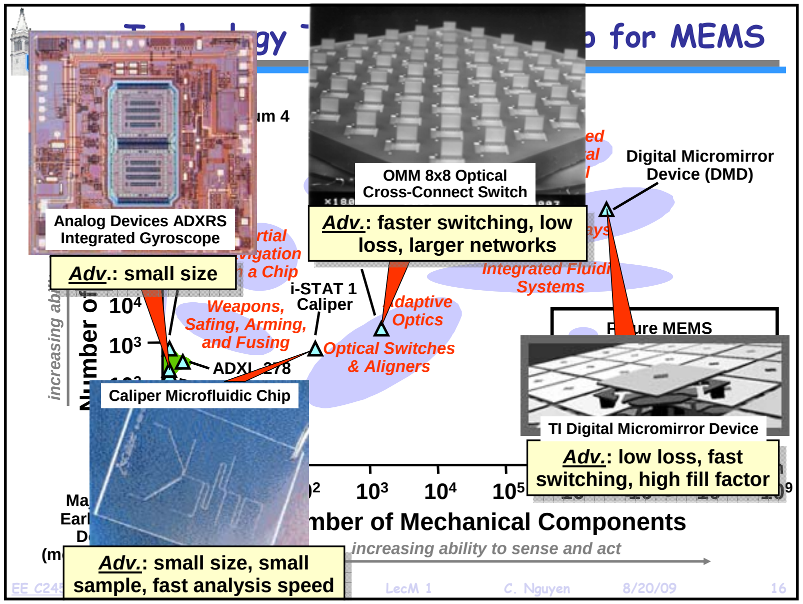
Basic Operation Principle





Analog Devices ADXL 78

Technology Trend and Roadmap for MEMS



Analog Devices ADXRS Integrated Gyroscope

Adv.: small size

OMM 8x8 Optical Cross-Connect Switch

Adv.: faster switching, low loss, larger networks

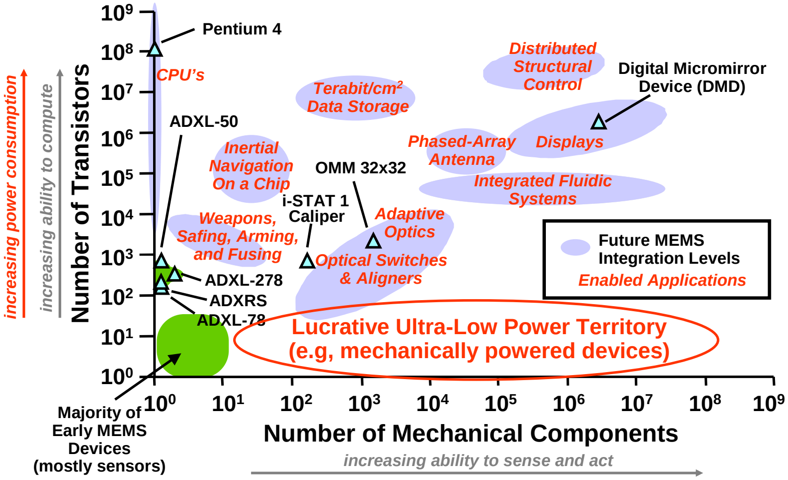
Caliper Microfluidic Chip

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

TI Digital Micromirror Device

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

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

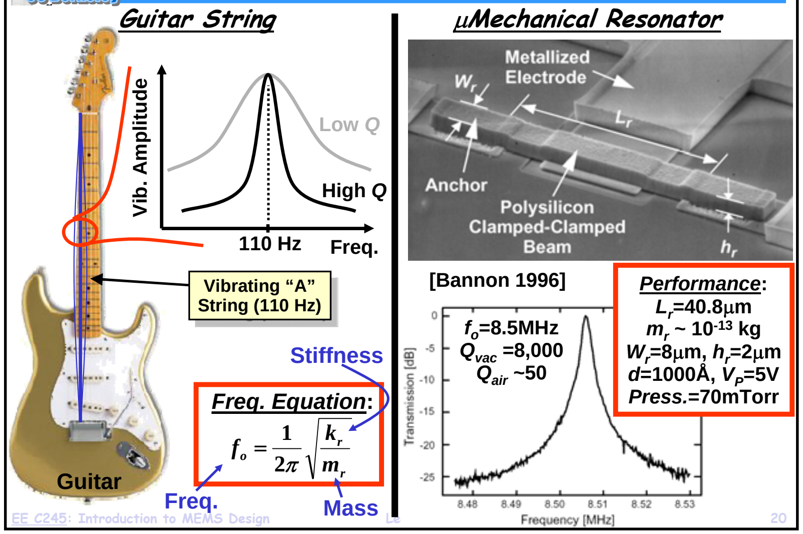
Performance enhancements for application domains beyond those satisfied by electronics in the same general categories

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 ↑

Vibrating RF MEMS

Basic Concept: Scaling Guitar Strings

Guitar String ***μMechanical Resonator***



[Bannon 1996]

Freq. Equation:

$$f_o = \frac{1}{2\pi}\sqrt{\frac{k_r}{m_r}}$$

Performance:
L_r=40.8μm
m_r ~ 10^{-13} kg
W_r=8μm, h_r=2μm
d=1000Å, V_P=5V
Press.=70mTorr