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EE C247B – ME C218
Introduction to MEMS Design
Spring 2017

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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 2017
- 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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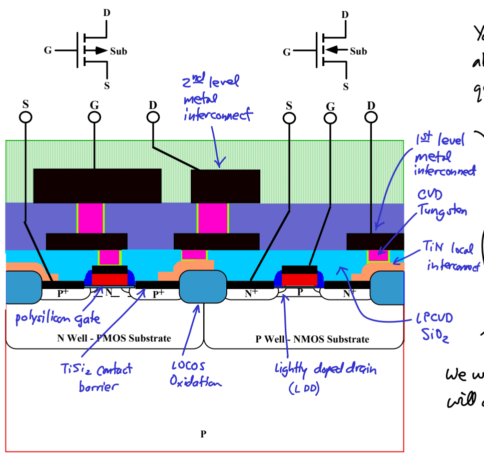
Course Overview

- The mechanics of the course are summarized in the course handouts, described in lecture today
  - Course Information Sheet
    - Course description
    - Course mechanics
    - Textbooks
    - Grading policy
  - Syllabus
    - Lecture by lecture timeline w/ associated reading sections
    - Midterm Exam: Tuesday, March 21
    - Final Exam: Friday, May 12, 7-10 p.m. (Group 20)
    - Project due date TBD (but near semester's end)

What Should You Know?

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



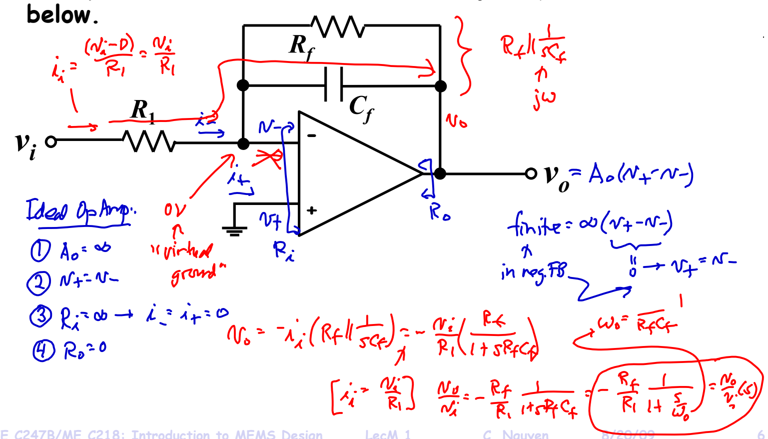
You should either already know or be able to learn independently & very quickly:

1. How to deposit or grow these 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 $v_o(s)/v_i(s)$ of the circuit below.

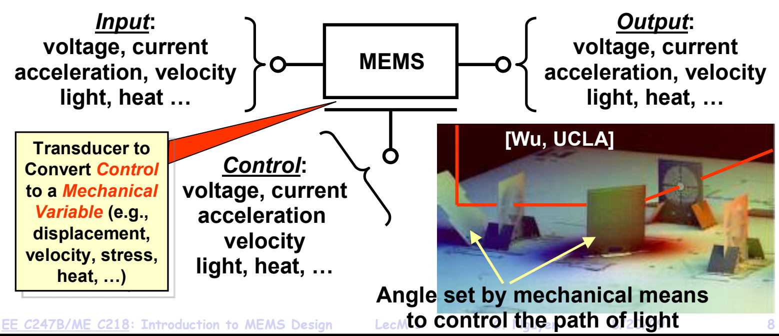


Lecture Outline

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

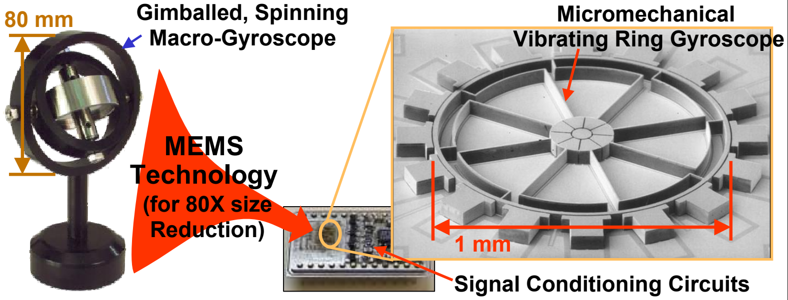
MEMS: Micro Electro Mechanical System

- 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



Other Common Attributes of MEMS

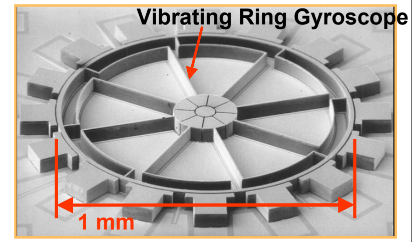
- Feature sizes measured in microns or less



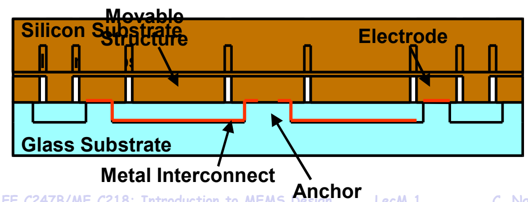
- Merges computation with sensing and actuation to change the way we perceive and control the physical world
- Planar lithographic technology often used for fabrication
  - can use fab equipment identical to those needed for IC's
  - however, some fabrication steps transcend those of conventional IC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

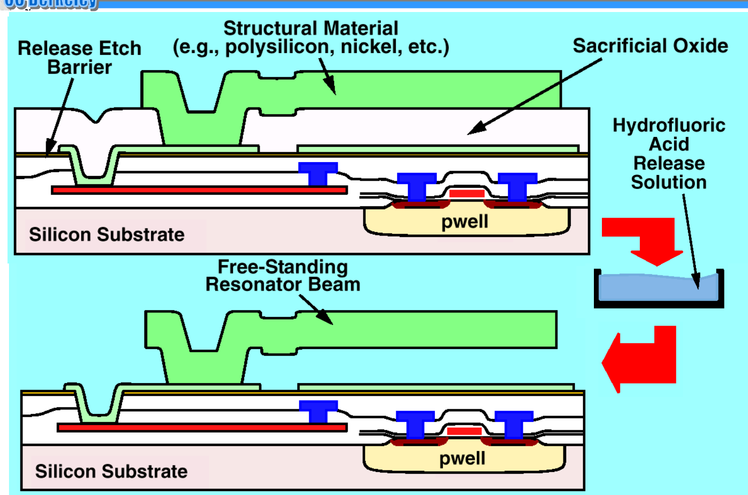


[Najafi, Michigan]



Microrotor
(for a microengine)

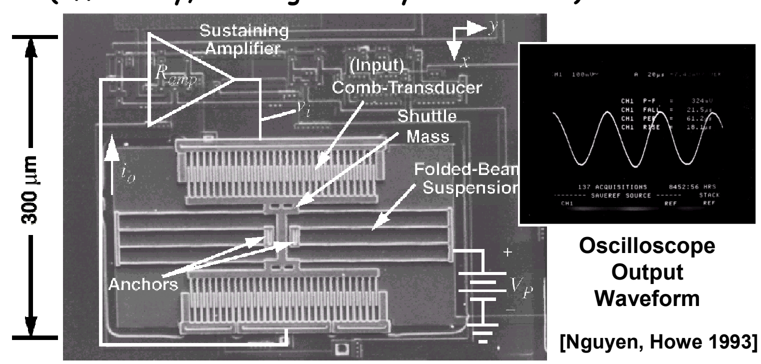
Surface Micromachining



- 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)

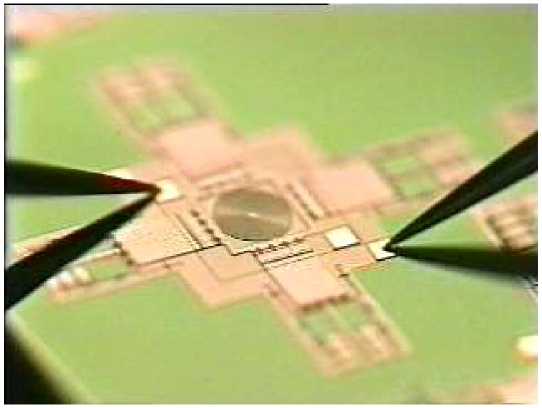


Oscilloscope
Output
Waveform

[Nguyen, Howe 1993]

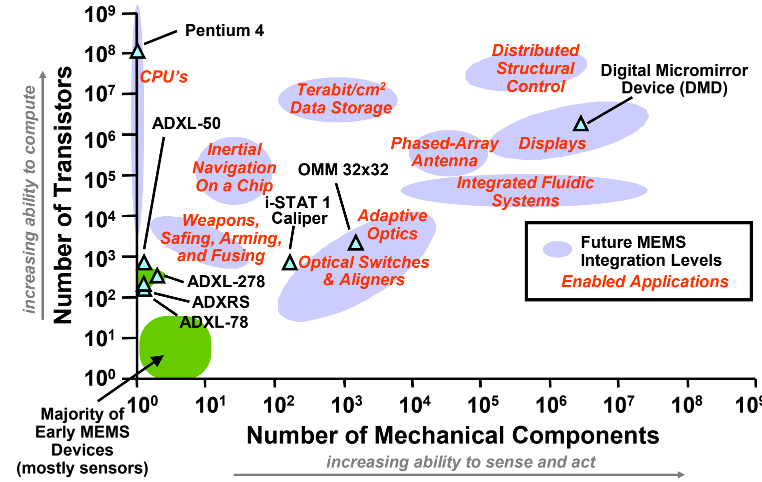
- To allow the use of >600°C processing temperatures, tungsten (instead of aluminum) is used for metallization

3D Direct-Assembled Tunable L



[Ming Wu, UCLA]

Technology Trend and Roadmap for MEMS



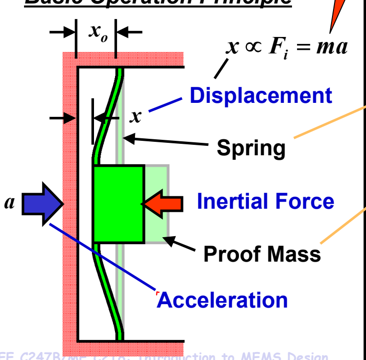
Example: Micromechanical Accelerometer

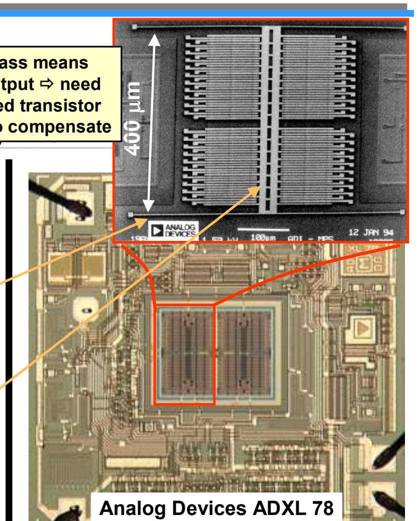
- *The MEMS Advantage:*
  - >30X size reductio[n for] accelerometer mec[hanical element]
  - allows integration w[ith transistor circuits]

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

Basic Operation Principle

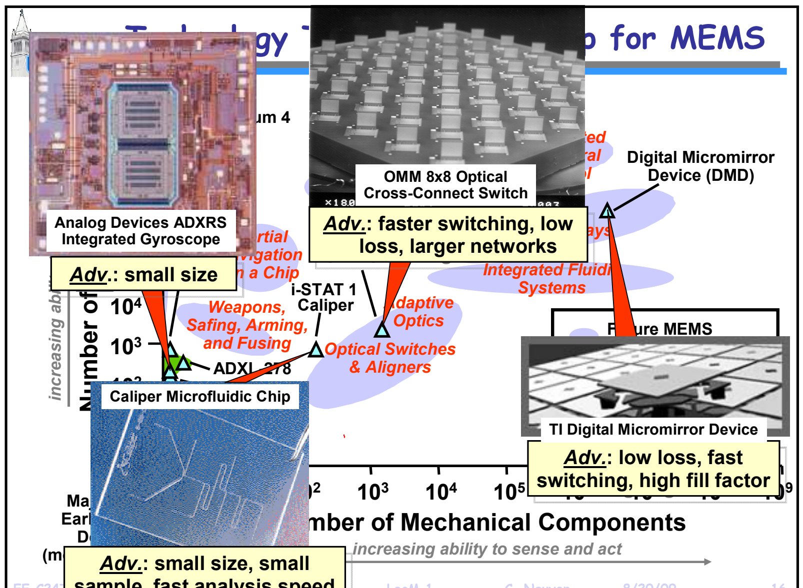
$x \propto F_i = ma$



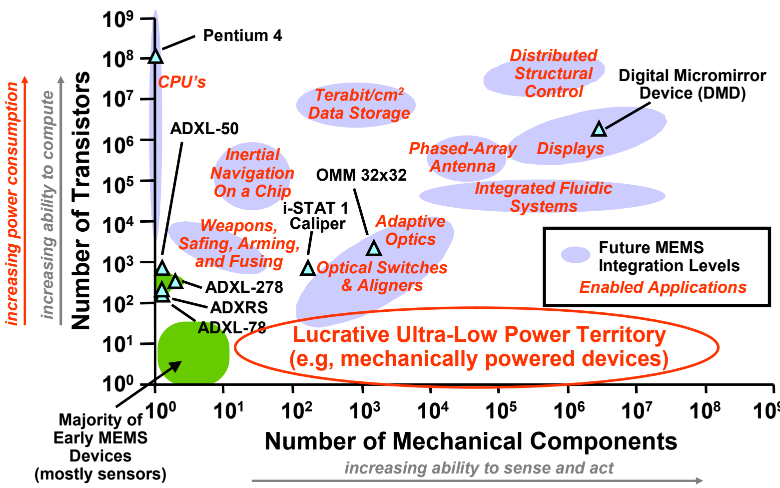


Analog Devices ADXL 78

Technology Trend and Roadmap for MEMS



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

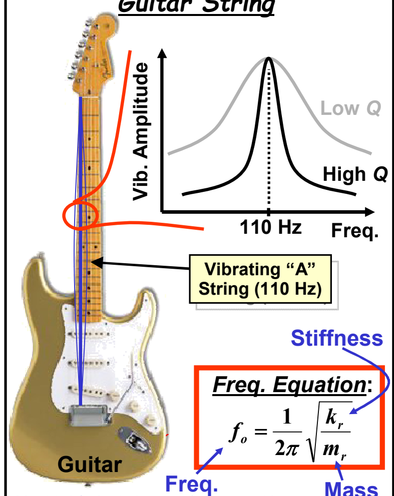
Performance enhancements for application domains beyond those satisfied by electronics in the same general categories

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

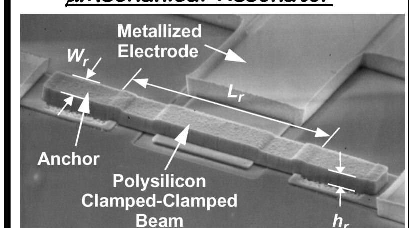
Guitar String



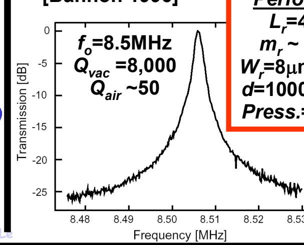
Freq. Equation:

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

μMechanical Resonator



[Bannon 1996]



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