


EE C247B - ME C218 Introduction to MEMS Design Spring 2017

Prof. Clark T.-C. Nguyen

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 & 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)

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What Should You Know?

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

1st level metal interconnect
2nd level metal interconnect
CVD Tungsten
TiN local interconnect
LPCVD SiO₂
polysilicon gate
N Well - PMOS Substrate
P Well - NMOS Substrate
TiSi₂ Contact barrier
LOCOS Oxidation
Lightly doped drain (LDD)

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

- How to deposit or grow these 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?

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

Ideal Op Amp:

- $A_o = \infty$
- $N_+ = N_-$
- $R_i = \infty \Rightarrow i_- = i_+ = 0$
- $R_o = 0$

Handwritten Analysis:

$$i_i = \frac{(v_i - 0)}{R_1} = \frac{v_i}{R_1}$$
$$v_o = -i_i (R_f \parallel \frac{1}{sC_f}) = -\frac{v_i}{R_1} \left(\frac{R_f}{1 + sR_fC_f} \right)$$
$$\left[i_i = \frac{v_i}{R_1} \right] \quad \frac{v_o}{v_i} = -\frac{R_f}{R_1} \frac{1}{1 + sR_fC_f} = -\frac{R_f}{R_1} \frac{1}{1 + \frac{s}{\omega_0}} = \frac{N_o(s)}{D_o(s)}$$

$\omega_0 = \frac{1}{R_fC_f}$

$v_o = A_o(v_+ - v_-)$
 $\text{finite} = \infty(v_+ - v_-)$
 $\text{in neg FB} \Rightarrow v_+ = v_- = 0$

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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, ...

[Wu, UCLA]

Angle set by mechanical means to control the path of light

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Other Common Attributes of MEMS

- Feature sizes measured in microns or less

80 mm

Gimballed, Spinning Macro-Gyroscope

MEMS Technology (for 80X size Reduction)

Signal Conditioning Circuits

1 mm

Vibrating Ring Gyroscope

[Najafi, Michigan]

- 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

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

1 mm

Micromechanical Vibrating Ring Gyroscope

[Najafi, Michigan]

Microrotor (for a microengine)

[Pisano, UC Berkeley]

Silicon Substrate

Movable Structure

Electrode

Glass Substrate

Metal Interconnect

Anchor

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Surface Micromachining

Release Etch Barrier

Structural Material (e.g., polysilicon, nickel, etc.)

Sacrificial Oxide

Hydrofluoric Acid Release Solution

Silicon Substrate

pwell

Free-Standing Resonator Beam

- Fabrication steps compatible with planar IC processing

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Single-Chip Ckt/MEMS Integration

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

300 μ m

Sustaining Amplifier

(Input) Comb-Transducer

Shuttle Mass

Folded-Beam Suspension

Anchor

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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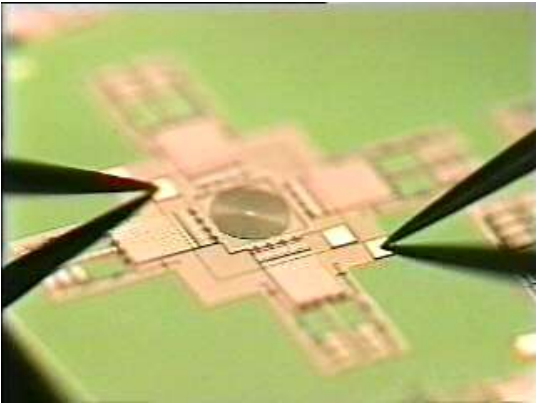
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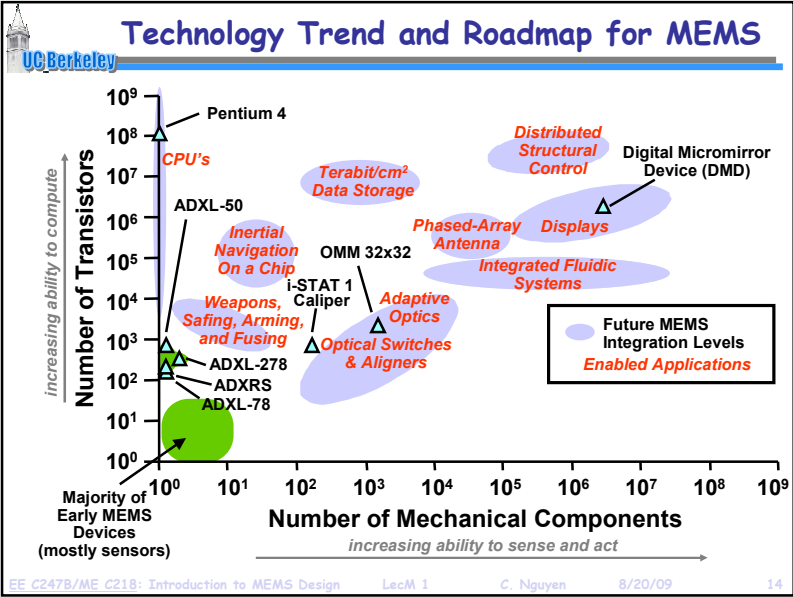
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3D Direct-Assembled Tunable L



[Ming Wu, UCLA]

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Example: Micromechanical Accelerometer

- The MEMS Advantage:
 - >30X size reduction in accelerometer mechanical components
 - allows integration of electronics

Tiny mass means small output \Rightarrow need integrated transistor circuits to compensate

Basic Operation Principle

$x \propto F_i = ma$

Displacement

Spring

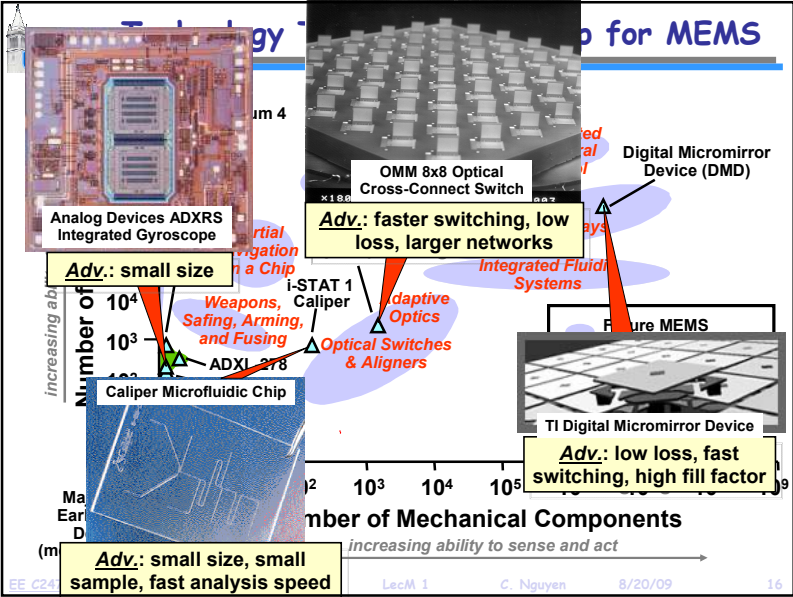
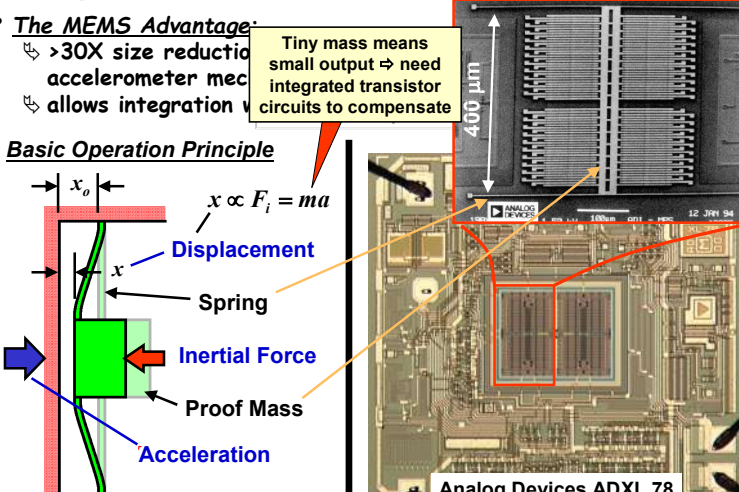
Inertial Force

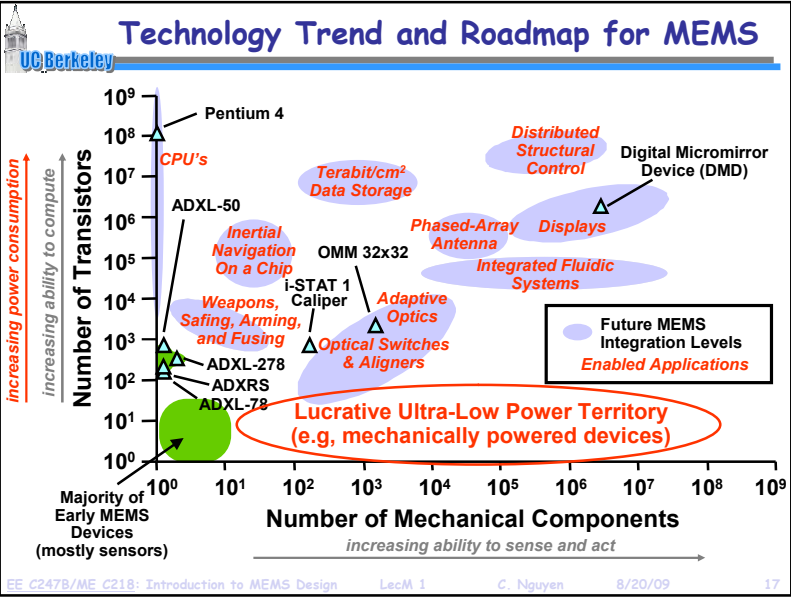
Proof Mass

Acceleration

400 μm

Analog Devices ADXL 78





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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Vibrating RF MEMS

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