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

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 2019
- 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
- Assumed background for EE C247B/ME C218:
  - graduate standing in engineering or physical/bio sciences
  - knowledge of microfabrication technology

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: Thursday, March 21
    - Final Exam: Thursday, May 16, 8-11 a.m. (Group 13)
    - Project due date TBD (but near semester's end)
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.

\[ R_f \]

\[ \frac{v_i}{v_o} \]

What Should You Know?

- Angle set by mechanical means to control the path of light

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

\( \text{Input:} \) voltage, current, acceleration, velocity, light, heat, ...

\( \text{MEMS} \)

\( \text{Output:} \) 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, ...

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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

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]

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**Example: Micromechanical Accelerometer**

*The MEMS Advantage:*
- >30X size reduction of accelerometer means allows integration

**Basic Operation Principle**

\[ x \propto F_i = ma \]

- Displacement
- Spring
- Inertial Force
- Proof Mass
- Acceleration

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

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**Technology Trend and Roadmap for MEMS**

- CPU's
- Pentium 4
- ADXL-50
- Inertial Navigation On a Chip
- Terabit/cm² Data Storage
- ADXL-278
- i-STAT 1 Caliper
- OMM 32x32
- ADXL-78
- Adaptive Optics
- Phased-Array Antenna
- Displays
- Integrated Fluidic Systems
- Digital Micromirror Device (DMD)

**Number of Transistors**

- Increasing ability to compute
- Number of Mechanical Components
- Increasing ability to sense and act

**Majority of Early MEMS Devices (mostly sensors)**

**Future MEMS Integration Levels Enabled Applications**

- Terabit/cm² Data Storage
- Inertial Navigation On a Chip
- Adaptive Optics
- Display
- Integrated Fluidic Systems
- Digital Micromirror Device (DMD)