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 2021
  - 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

* The mechanics of the course are summarized in the course handouts, described in lecture today
  - Syllabus (Course Information Sheet)
    - Course description
    - Course mechanics
    - Textbooks
    - Grading policy
  - Schedule
    - Lecture by lecture timeline w/ associated reading sections
    - Consult this sheet for readings, which are not in the lecture table
    - Midterm Exam: Thursday, March 18
    - Final Exam: Wednesday, May 12, 11:30 a.m.-2:30 p.m. (Group 10)
    - Project due date TBD (but near semester's end)
What Should You Know?

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

1. How to design in your chosen design tool.
2. How to simulate a device from the shapes of the layout shown.
3. What determines the order by which different layers are formed, e.g., temperature, time, doping, and... we will review these things but we will do this very fast.

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, ...

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
**Technology Trend and Roadmap for MEMS**

- **Increasing ability to compute**
  - CPU's
- **Increasing ability to sense and act**
  - Terabit/cm² Data Storage
  - Distributed Structural Control
  - Digital Micromirror Device (DMD)
  - Displays
  - Phased-Array Antenna
  - Integrated Fluidic Systems
  - Adaptive Optics
  - Optical Switches & Aligners

**Number of Transistors**

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**Number of Mechanical Components**

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**Example: Micromechanical Accelerometer**

- **The MEMS Advantage:**
  - >30X size reduction vs accelerometer mechanical element
  - allows integration

- **Basic Operation Principle**
  - $x = F/m = ma$

- **Advantages:**
  - Small mass means small output vs need for integrated transistor circuits to compensate

- **Microfluidic Chip Adv.**
  - Small size, small sample, fast analysis speed

- **Caliper Microfluidic Chip Adv.**
  - Faster switching, low loss, larger networks
  - Low loss, fast switching, high fill factor

- **OMM 32x32 Optical Cross-Connect Switch Adv.**
  - Faster switching, low loss, larger networks

**Future MEMS Integration Levels Enabled Applications**

- **OMM 8x8 Optical Cross-Connect Switch**
  - Faster switching, low loss, larger networks
  - Low loss, fast switching, high fill factor

- **TI Digital Micromirror Device**
  - Faster switching, low loss, larger networks
  - 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 ↑

Basic Concept: Scaling Guitar Strings

Vibrating RF MEMS