Lecture 1: Definition and Incentives for MEMS
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, from undergraduate to graduate
- **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 2008

• Related courses at UC Berkeley:
   EE 143: Microfabrication Technology
   CS 194 (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
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. 23
    - Final Exam: Saturday, Dec. 20, 12:30-3:30 p.m.
    - Change this Final Exam time?
    - Project due date TBD (but near semester's end)
• Reading: Senturia, Chapter 1

• Lecture Topics:
  - Definitions for MEMS
  - MEMS roadmap
  - Benefits of Miniaturization
  - Examples
    - GHz micromechanical resonators
    - Chip-scale atomic clock
    - Micro gas chromatograph
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, ...

**Control:**
- 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, ...)

[Angle set by mechanical means to control the path of light]

[Image: [Wu, UCLA]
Other Common Attributes of MEMS

- Feature sizes measured in microns or less

• Gimbaled, Spinning Macro-Gyroscope
  
[Najafi, Michigan]
Micromechanical Vibrating Ring Gyroscope

• 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

MEMS Technology
(for 80X size Reduction)
Bulk Micromachining and Bonding

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

[Image of Micromechanical Vibrating Ring Gyroscope]

1 mm

[Najafi, Michigan] [Pisano, UC Berkeley]

Silicon Substrate

Glass Substrate

Metal Interconnect

Anchor

Microrotor (for a microengine)
Surface Micromachining

Fabrication steps compatible with planar IC processing

- Fabrication steps compatible with planar IC processing

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

- Release Etch Barrier

- Sacrificial Oxide

- Hydrofluoric Acid Release Solution

- Free-Standing Resonator Beam

- Silicon Substrate

- pwell
Single-Chip Ckt/MEEMS 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

[Nguyen, Howe 1993]
3D Direct-Assembled Tunable

[Ming Wu, UCLA]
Technology Trend and Roadmap for MEMS

Number of Mechanical Components

Number of Transistors

Majority of Early MEMS Devices (mostly sensors)

 increasing ability to sense and act

Future MEMS Integration Levels Enabled Applications

Terabit/cm² Data Storage

Distributed Structural Control

Digital Micromirror Device (DMD)

Integrated Fluidic Systems

Displays

Phased-Array Antenna

Optical Switches & Aligners

Adaptive Optics

OMM 32x32

Weapons, Safing, Arming, and Fusing

Inertial Navigation On a Chip

ADXL-278

ADXLS

ADXL-50

ADXL-78

CPU’s

Pentium 4

EE C245: Introduction to MEMS Design
Benefits of Size Reduction: IC’s

• Numerous benefits attained by scaling of transistors:
  - Higher Current Drive
  - Lower Capacitance
  - Higher Integration Density
  - Lower Supply Voltage

Lower Power \{ \text{Higher Circuit Complexity & Economy of Scale} \}

\{ \text{Faster Speed} \}

• But ... some drawbacks:
  - poorer reliability (e.g., hot e- effects)
  - lower dynamic range (analog ckts suffer)
Example: Micromechanical Accelerometer

- **The MEMS Advantage:**
  - >30X size reduction for accelerometer mechanical element
  - allows integration with IC's

**Basic Operation Principle**

- Displacement $x$
- Spring
- Proof Mass
- Inertial Force $F_i = ma$
- Acceleration $a$

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

Analog Devices ADXL 78