

Lecture Outline

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

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7

MEMS: Micro Electro Mechanical System

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- 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

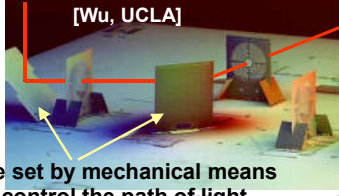
Input:
voltage, current
acceleration, velocity
light, heat ...

MEMS

Output:
voltage, current
acceleration, velocity
light, heat, ...

Control:
voltage, current
acceleration
velocity
light, heat, ...

Transducer to Convert **Control** to a **Mechanical Variable** (e.g., displacement, velocity, stress, heat, ...)



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


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8

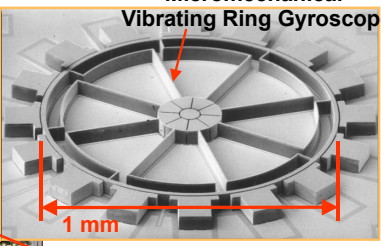
Other Common Attributes of MEMS

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- Feature sizes measured in microns or less [Najafi, Michigan]




80 mm
Gimballed, Spinning
Macro-Gyroscope



1 mm
Vibrating Ring Gyroscope

MEMS Technology
(for 80X size Reduction)



Signal Conditioning Circuits

- 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

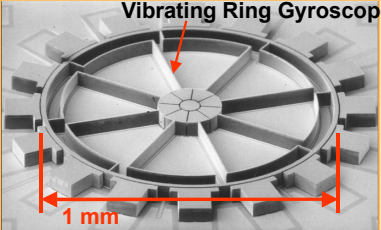
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9

Bulk Micromachining and Bonding

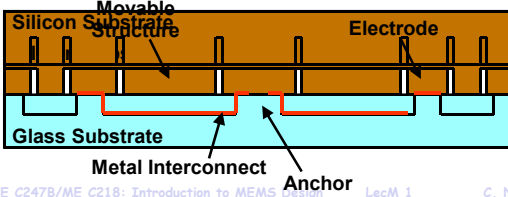
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- Use the wafer itself as the structural material
- **Adv:** very large aspect ratios, thick structures
- **Example:** deep etching and wafer bonding




1 mm
Micromechanical
Vibrating Ring Gyroscope

[Najafi, Michigan]



Movable Structure
Electrode
Glass Substrate
Metal Interconnect
Anchor



Microrotor
(for a microengine)

[Pisano, UC Berkeley]

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10

Surface Micromachining

The diagram illustrates the surface micromachining process in two stages. In the first stage, a silicon substrate with a p-well is coated with a release etch barrier, structural material (e.g., polysilicon, nickel, etc.), and a sacrificial oxide layer. In the second stage, hydrofluoric acid release solution is used to etch away the sacrificial oxide, resulting in a free-standing resonator beam.

- Fabrication steps compatible with planar IC processing

11

Single-Chip Ckt/MEMS Integration

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

The micrograph shows a single-chip Ckt/MEMS integration with a height of 300 μm. Key components labeled include the Sustaining Amplifier, Comb-Transducer, Shuttle Mass, Anchors, and a Folded-Beam Suspension. An inset shows an oscilloscope output waveform.

Oscilloscope Output Waveform
[Nguyen, Howe 1993]

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

12

3D Direct-Assembled Tunable L

The micrograph shows a 3D direct-assembled tunable L device, which is a type of MEMS resonator. The device is shown being held by tweezers.

[Ming Wu, UCLA]

13

Technology Trend and Roadmap for MEMS

The graph plots the Number of Transistors (y-axis, 10⁰ to 10⁹) against the Number of Mechanical Components (x-axis, 10⁰ to 10⁹). It shows the increasing ability to compute (y-axis) and sense and act (x-axis). Key points on the graph include:

- Pentium 4 (CPU's)
- ADXL-50, ADXL-278, ADXR8, ADXL-78 (Majority of Early MEMS Devices (mostly sensors))
- Inertial Navigation On a Chip
- Weapons, Safing, Arming, and Fusing
- OMM 32x32
- i-STAT 1 Caliper
- Optical Switches & Aligners
- Adaptive Optics
- Terabit/cm² Data Storage
- Phased-Array Antenna
- Integrated Fluidic Systems
- Distributed Structural Control
- Displays
- Digital Micromirror Device (DMD)

Legend: Future MEMS Integration Levels (blue oval), Enabled Applications (red oval).

14

Example: Micromechanical Accelerometer

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- The MEMS Advantage:**
 - >30X size reduction
 - accelerometer mechanism
 - allows integration with

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

Basic Operation Principle

$x \propto F_i = ma$

Displacement
Spring
Inertial Force
Proof Mass
Acceleration

Analog Devices ADXL 78

15

Technology Trend and Roadmap for MEMS

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Adv.: faster switching, low loss, larger networks

Adv.: small size

Adv.: low loss, fast switching, high fill factor

Adv.: small size, small sample, fast analysis speed

16

Technology Trend and Roadmap for MEMS

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Increasing power consumption

Increasing ability to compute

Increasing ability to sense and act

Future MEMS Integration Levels Enabled Applications

Lucrative Ultra-Low Power Territory (e.g, mechanically powered devices)

17

Benefits of Size Reduction: MEMS

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- 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 ↑

18