MEMS in ECE at CMU

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What is MEMS?

- MEMS have mechanical components with
  - dimensions measured in microns and
  - numbers measured from a few to millions

- MEMS is a way to make both mechanical and electrical components

- MEMS is manufacturing using integrated-circuit batch fabrication processes
Why work on MEMS?

• Miniaturization
  – portable and remote applications
  – Lighter, faster, lower power sensors and actuators

• Multiplicity of devices
  – More complexity allowed
  – arrayed systems (e.g., imagers) possible
  – Cost reduction possible

• Microelectronic integration
  – “smart” and “aware” systems on chip
  – Mixed electrical, mechanical, thermal, optical, fluidic, chemical, biochemical systems
MEMS in Embedded Systems

• Information systems are pervasive in our lives

• Trend is toward
  – portability,
  – autonomy,
  – context awareness

• Creating demand for miniature sensor and actuation systems
  – Ultimately, the embedded system is a MEMS
Bulk (Substrate) Micromachining

• Preferential etching of silicon, glass, and other substrates

• Examples:
  – Grooves for fiber-optic alignment
  – Membranes for pressure sensors, microphones
  – Nozzles for ink-jet printing, drug delivery
Surface (Thin Film) Micromachining

- Mechanics from thin films on surface
- Etching of sacrificial material under microstructure
- Suspended structures for inertial sensing, thermal sensing, resonators, optics, fluidics...

Diagram labels:
- Anchor
- Suspended microstructure
- Electrically insulating layer
- Substrate
- Microchannel
Micromechanical Structural Material

- Survives process steps
- Stiffness
- Yield strength
- Density
- Electrical conductivity or isolation
- Thermal conductivity or isolation
- Residual stress
- Residual stress gradient

structural
Example: Multi-level Polysilicon Processes

- “MUMPS” Process
- Bottom polysilicon interconnect
- Two movable polysilicon layers

www.memscap.com
Post-CMOS Micromachining

- One focus of MEMS research in ECE at CMU
- Structures made starting from CMOS electronics

Post-CMOS Micromachining – Oxide RIE

- Step 1: reactive-ion etch of dielectric layers
- Top metal layer acts as a mask & protects the CMOS
Post-CMOS Micromachining – Si DRIE

- Step 2: DRIE of silicon substrate
- Spacing between structures and silicon is defined
Post-CMOS Micromachining – Release

- Step 3: isotropic etch of silicon substrate
- Structures are undercut & released
CMOS MEMS Structures

- Made from CMOS interconnect layers
- Electronic integration
- Electrostatic and thermal actuation can be added
- Capacitive and resistive sensing can be added

Lateral Low-G Accelerometer

- Low-G accelerometer to study noise sources in CMOS-MEMS
- Limit: air molecules hitting the structure!

sense fingers
proof mass
suspension
Electrothermal Actuators

- Electrically controllable motion on chip
- Microbeams are electrically heated (Power = I²R)
- Beams bend from material expansion

10 µm self actuation
(25°C)

20 µm electrothermal actuation
(178°C)
Electrothermal Comb-Finger Capacitor

- Tunable capacitor in 0.35 μm CMOS
- Dense comb array provides variable capacitance

Electrothermal Micromirrors

- 1 mm by 1 mm by 25 µm-thick mirror
- Thermal actuation of 25° from 0 to 5 mA

H. Xie, Y. Pan, G. K. Fedder, IEEE MEMS 02 & Sensors & Actuators 02
H. Xie, A. Jain, T. Xie, Y. Pan, G. K. Fedder, CLEO 2003
Implantable Bone Stress Imager

• Applications:
  – Measure bone stress in fracture sites
  – Measure stress on implant interface

• Textured surface for osteointegration

• 100’s of stress sensors for statistical data
The Bottom Line

• MEMS spans many levels
  – processing
  – physical transduction
  – devices
  – system-on-chip design
• Work merges ECE areas with other fields
  – e.g., mechanical, chemical, biology
• Emerging area in industry
  – lots of hype, lots of opportunity
Applied Physics – Device Sub-areas, Fall 04

- 18-303: Engineering electromagnetics
- 18-311: Semiconductor devices I
- 18-401: Electro-mechanics design
- 18-410: Physical sensors, transducers and instrumentation
- 18-412: Semiconductor devices II, FETS
- 18-415: MEMS
- 18-578: Mechatronics design
- 18-614: IC fabrication processes
- 18-815: Mechatronics design

Courses are offered as follows:

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Course Content (Abridged Version)

• **18-303 Engineering Electromagnetics I**
  Static electric and magnetic fields in free space and in materials;
  Maxwell’s equations, boundary conditions and potential functions;
  Uniform plane waves, transmission lines, waveguides, radiation and antennas.

• **18-311 Semiconductor Devices I**
  P-N diodes, bipolar transistors, MOSFETs, photodiodes, LEDs and solar cells;
  Doping, electron and hole transport, and band diagrams.

• **18-401 Electromechanics**
  Electromechanical statics and dynamics;
  Energy conversion in synchronous, induction, and commutator rotating machines,
  electromechanical relays, capacitive microphones and speakers, and magnetic levitation.

• **18-410 Physical Sensors, Transducers and Instrumentation**
  Sensor physics, transducers, electronic detection, and signal conversion;
  Case study driven.

• **18-412 Semiconductor Devices II**
  MOSFETs, JFETs, MESFETs, TFTs;
  Device scaling; CCD imagers; active matrix flat panel displays; digital and RF applications.