MEMS in ECE at CMU

Gary K. Fedder
Department of Electrical and Computer Engineering
and The Robotics Institute
Carnegie Mellon University
Pittsburgh, PA 15213-3890

fedder@ece.cmu.edu
http://www.ece.cmu.edu/~mems

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What is MEMS?

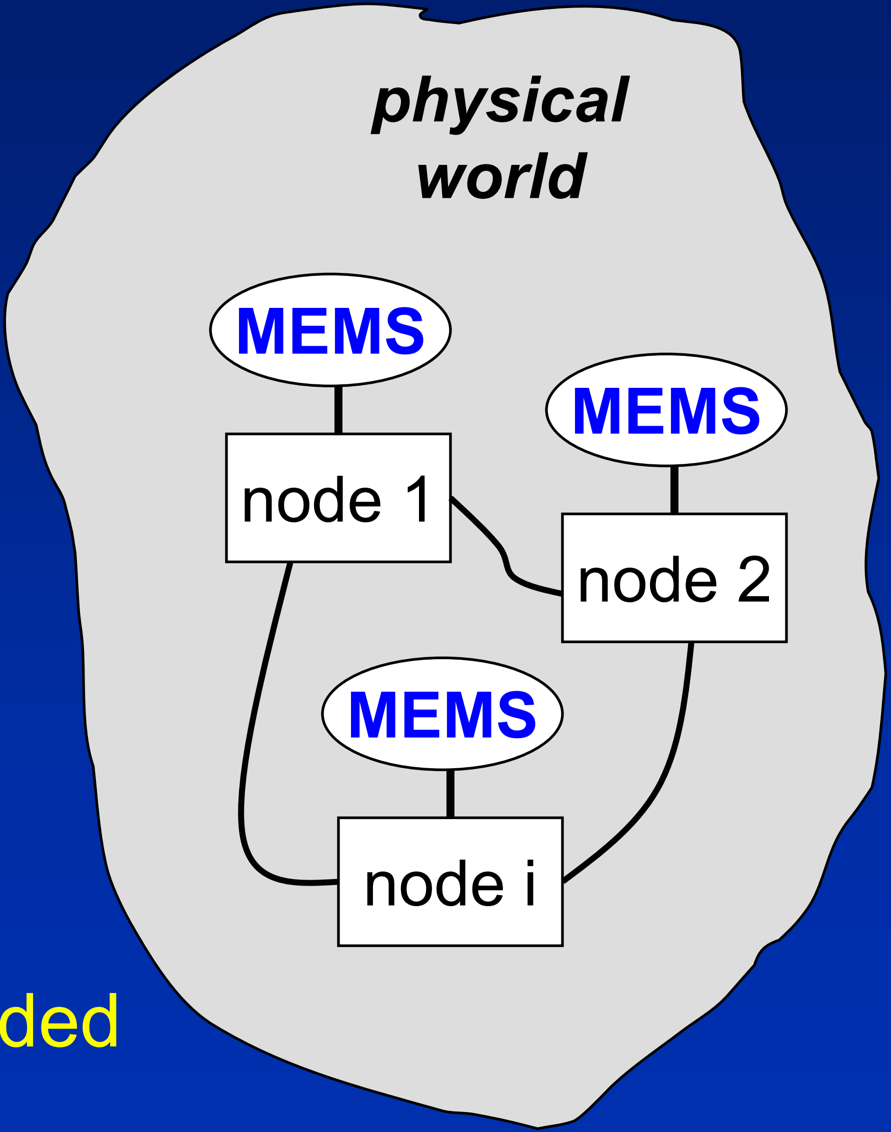
- MEMS have mechanical components with
  - dimensions measured in microns and
  - numbers measured from a few to millions
- MEMS is a way to make both mechanical and electrical components
- MEMS is manufacturing using integrated-circuit batch fabrication processes

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

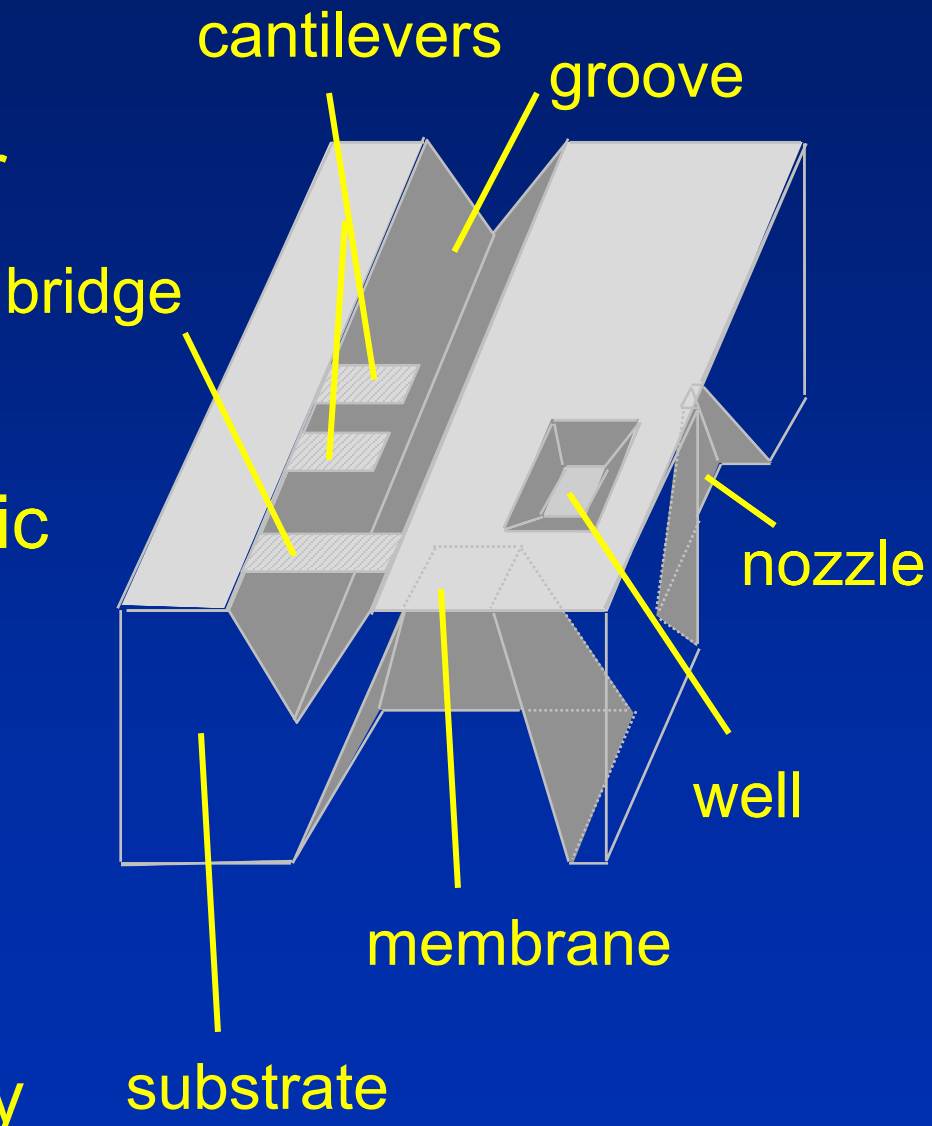
MEMS in Embedded Systems

- 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



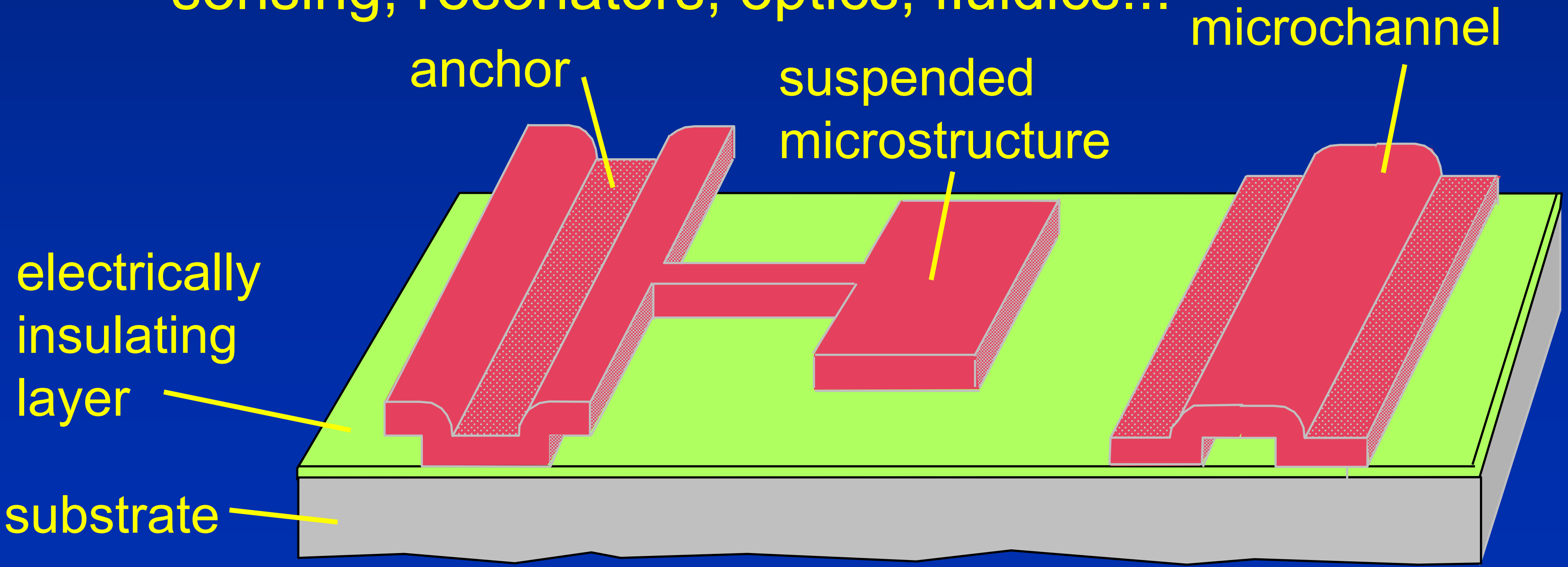
Bulk (Substrate) Micromachining

- 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



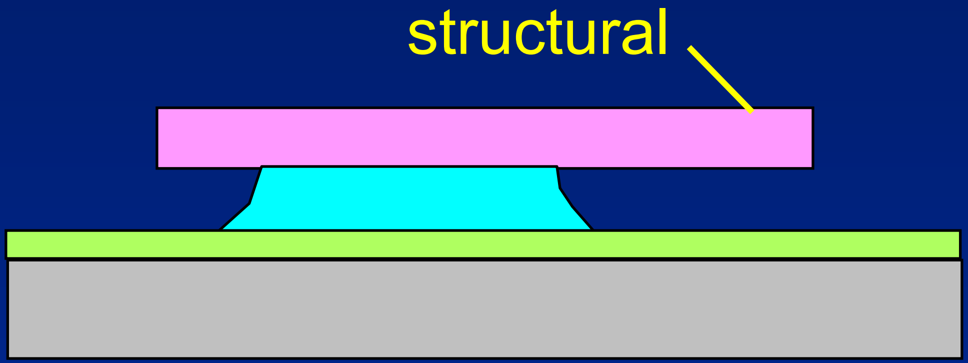
Surface (Thin Film) Micromachining

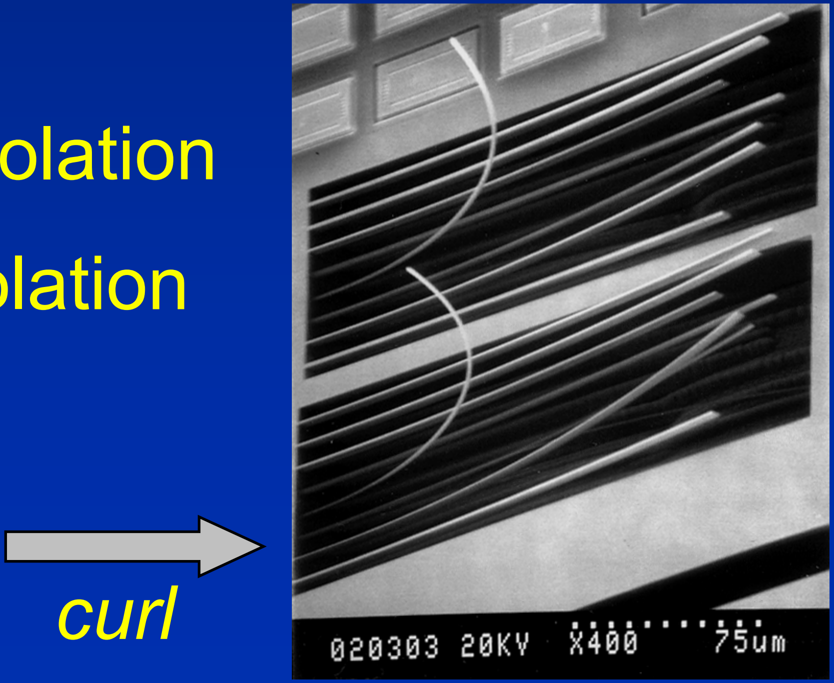
- Mechanics from thin films on surface
- Etching of sacrificial material under microstructure
- Suspended structures for inertial sensing, thermal sensing, resonators, optics, fluidics...



Micromechanical Structural Material

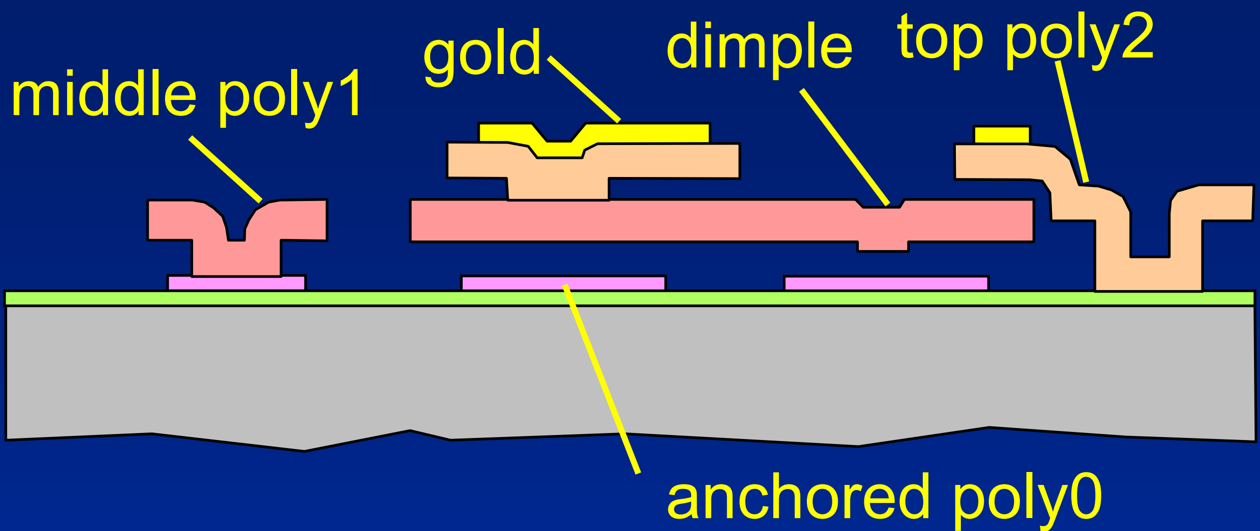
- Survives process steps
- Stiffness
- Yield strength
- Density
- Electrical conductivity or isolation
- Thermal conductivity or isolation
- Residual stress
- Residual stress gradient

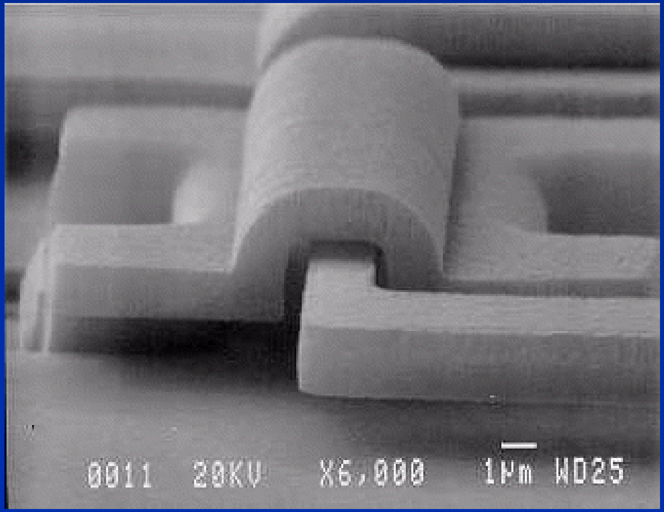




Example: Multi-level Polysilicon Processes

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

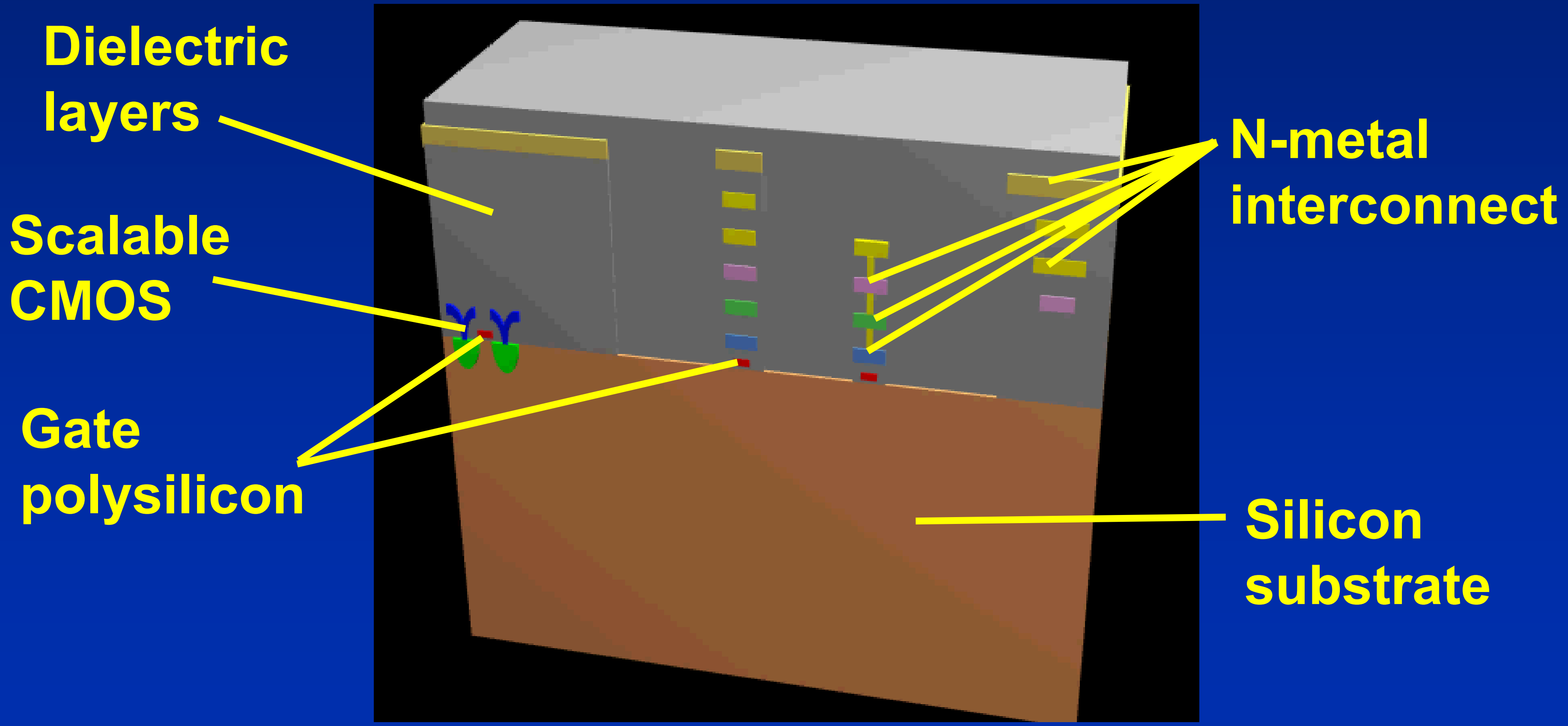




www.memscap.com

Post-CMOS Micromachining

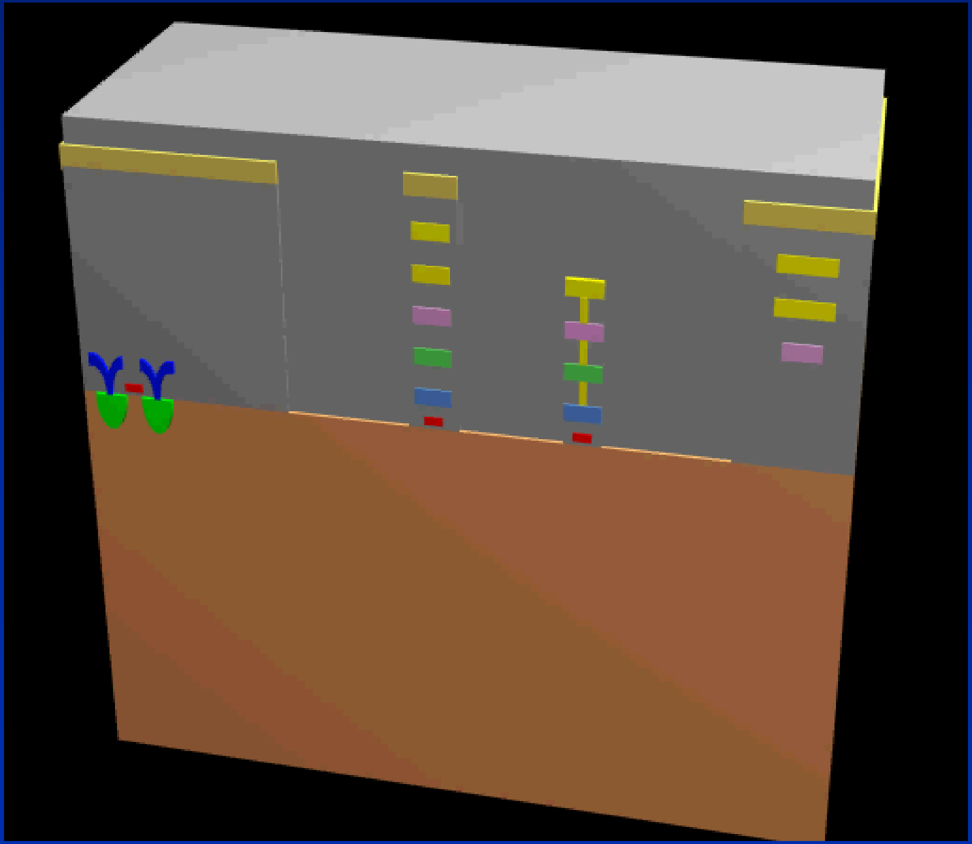
- One focus of MEMS research in ECE at CMU
- Structures made starting from CMOS electronics



G. Fedder *et al.*, Sensors & Actuators A, v.57, no.2, 1996

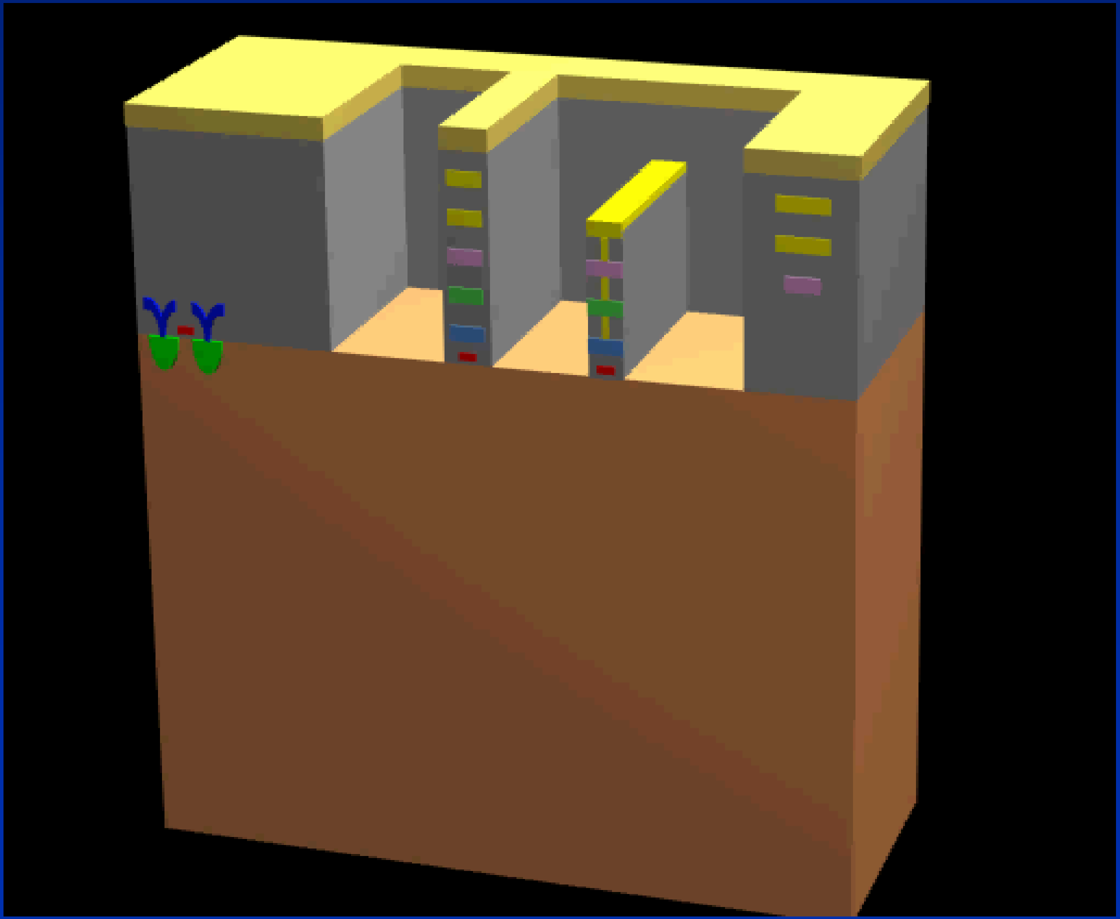
Post-CMOS Micromachining – Oxide RIE

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



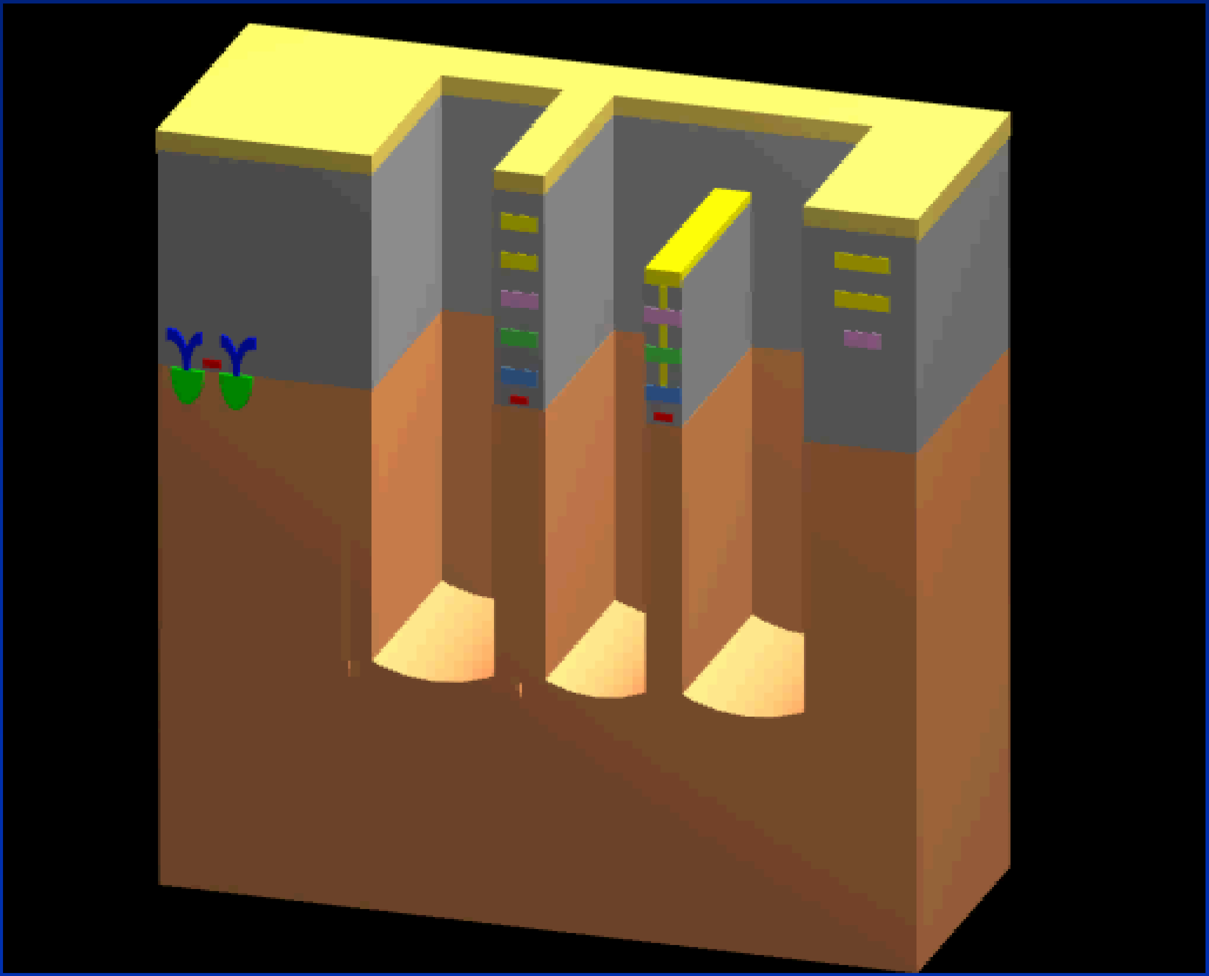
Post-CMOS Micromachining – Si DRIE

- Step 2: DRIE of silicon substrate
- Spacing between structures and silicon is defined



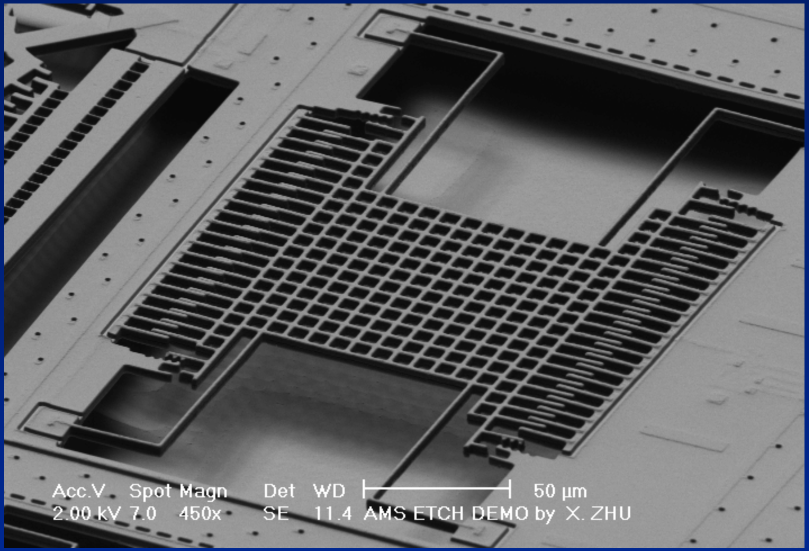
Post-CMOS Micromachining – Release

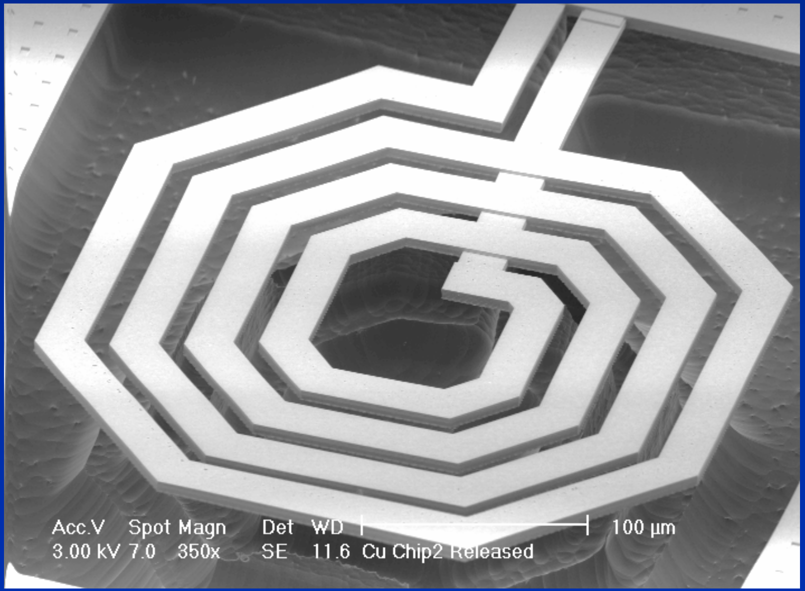
- Step 3: isotropic etch of silicon substrate
- Structures are undercut & released



CMOS MEMS Structures

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

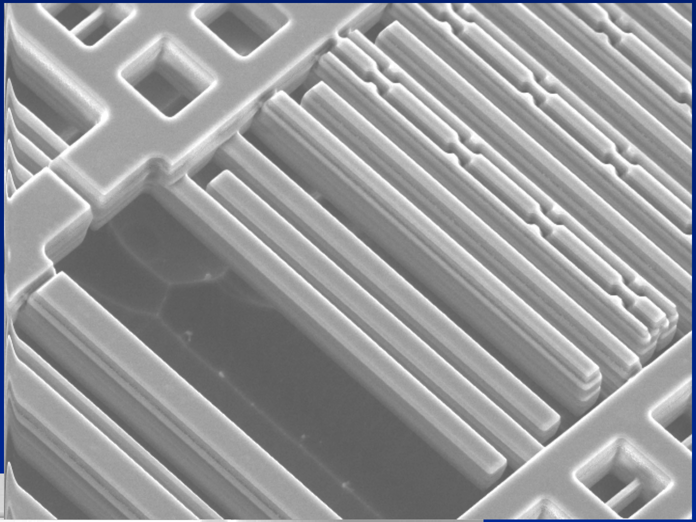


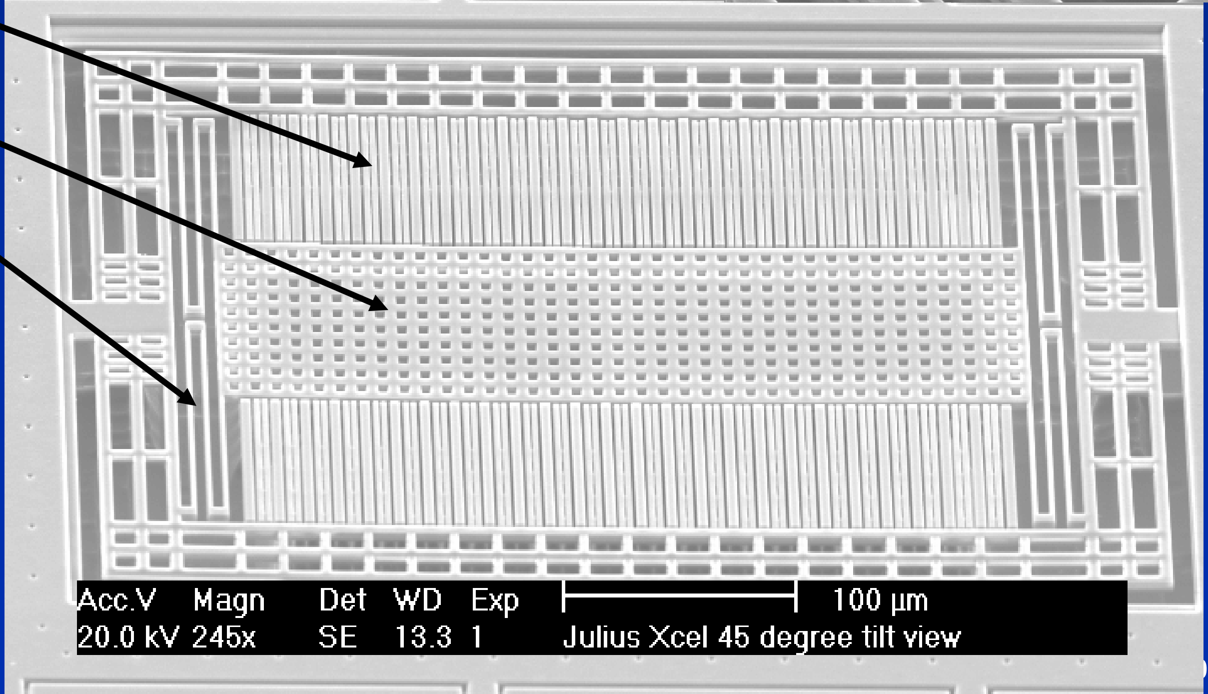


H. Lakdawala, et al., JSSC Mar. 2002.

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

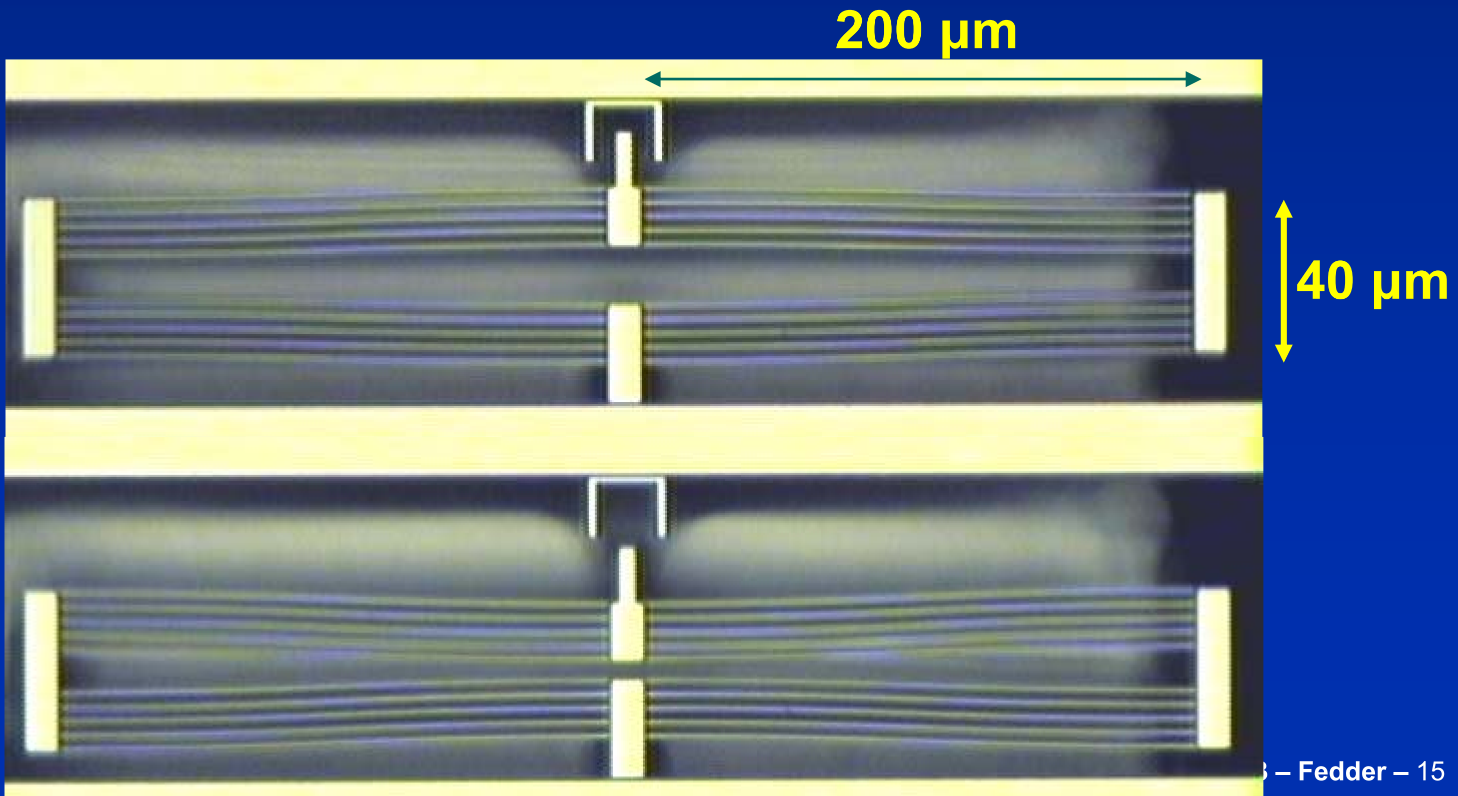
- Electrically controllable motion on chip
- Microbeams are electrically heated (Power = I^2R)
- Beams bend from material expansion

10 µm self actuation

(25°C)

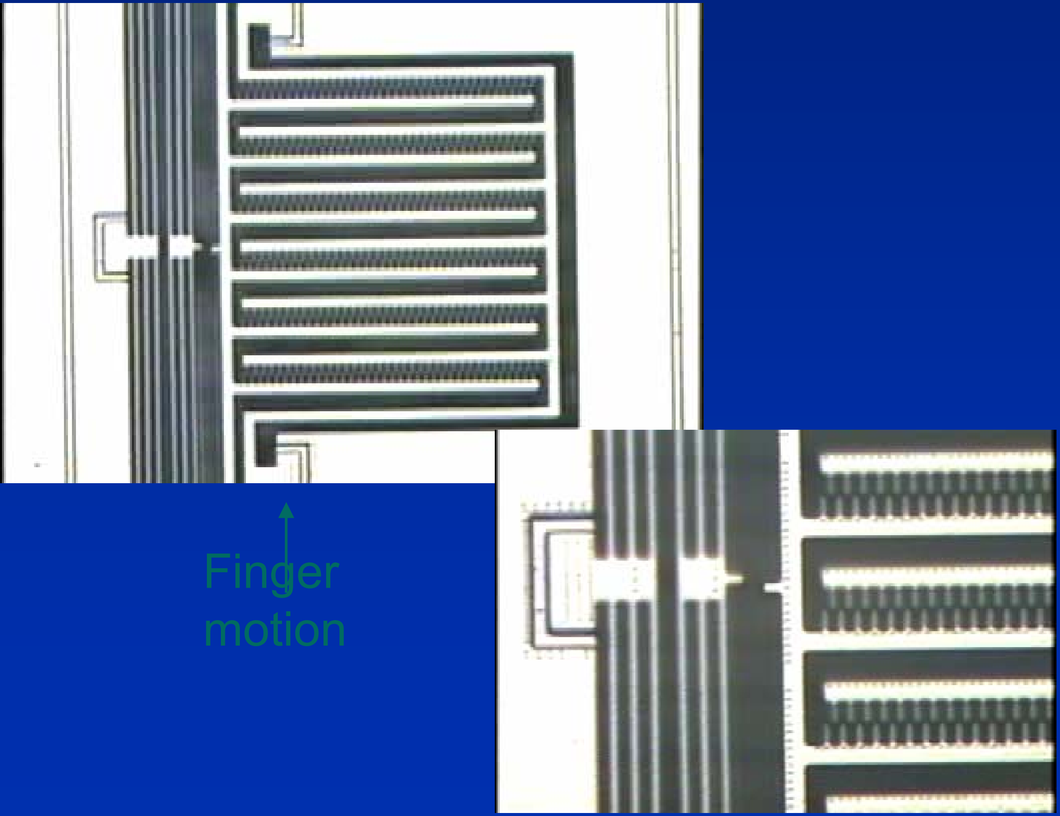
20 µm electrothermal actuation

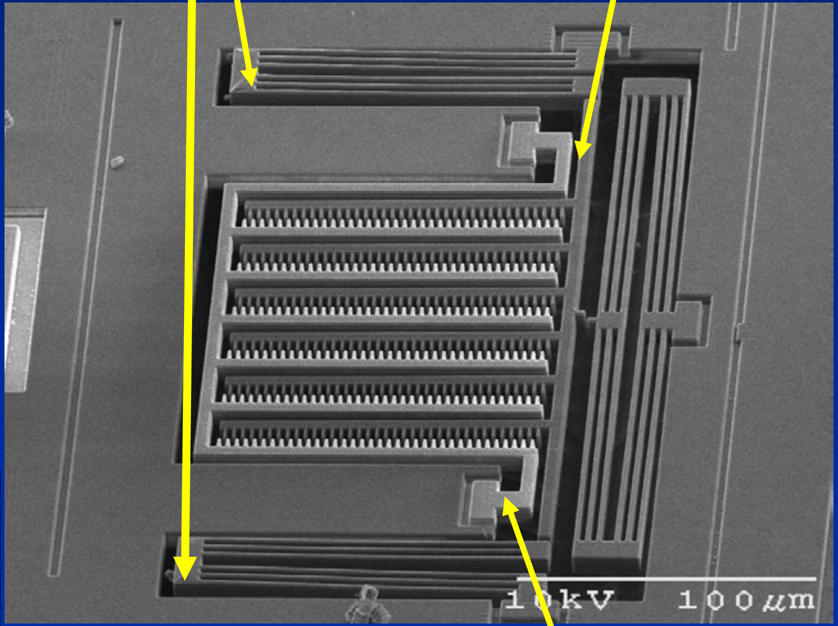
(178°C)



Electrothermal Comb-Finger Capacitor

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

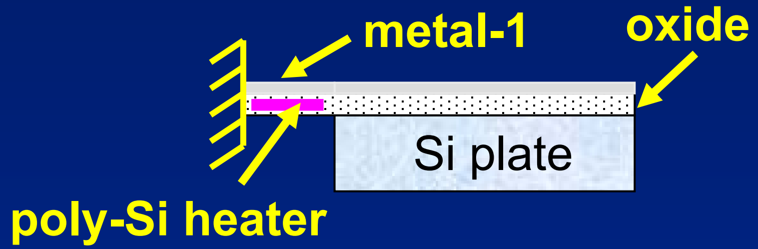




A. Oz, G. K. Fedder, IEEE Transducers 2003 & MTT-S RFIC 2003, June 2003

Electrothermal Micromirrors

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

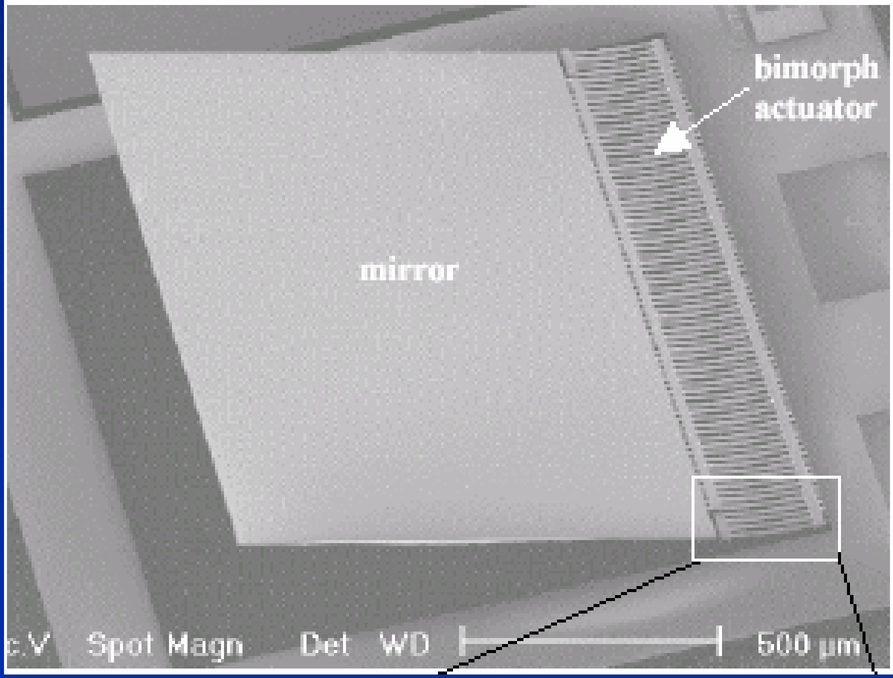


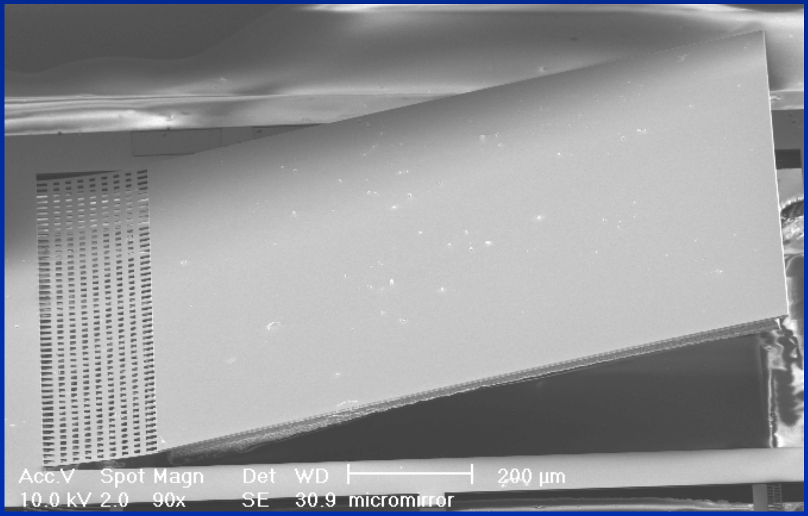
metal-1

oxide

Si plate

poly-Si heater



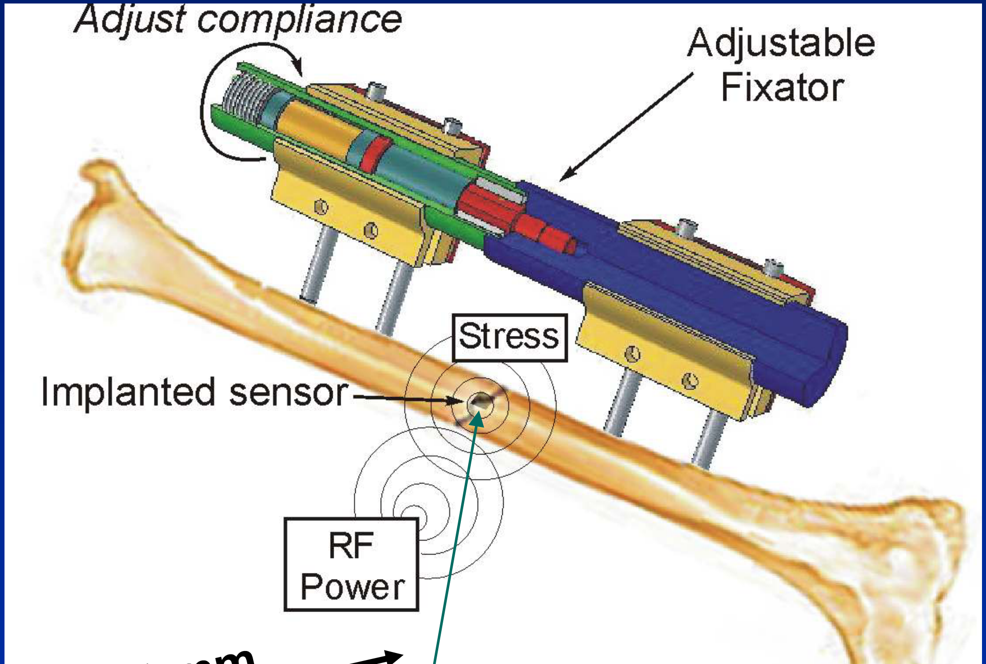


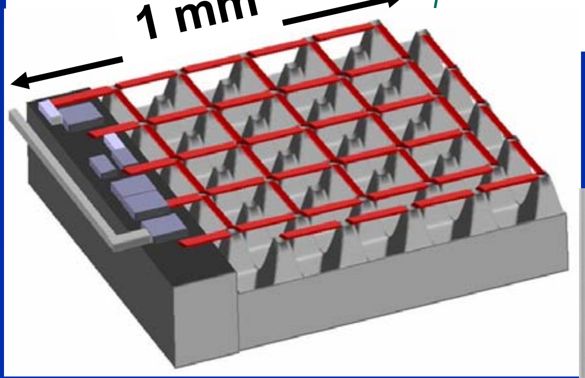
H. Xie, Y. Pan, G. K. Fedder, IEEE MEMS 02 & Sensors & Actuators 02

H. Xie, A. Jain, T. Xie, Y. Pan, G. K. Fedder, CLEO 2003

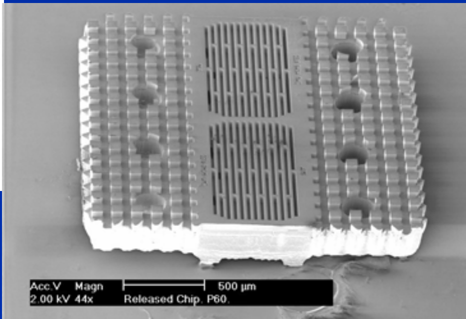
Implantable Bone Stress Imager

- Applications:
  - Measure bone stress in fracture sites
  - Measure stress on implant interface
- Textured surface for osteointegration
- 100's of stress sensors for statistical data





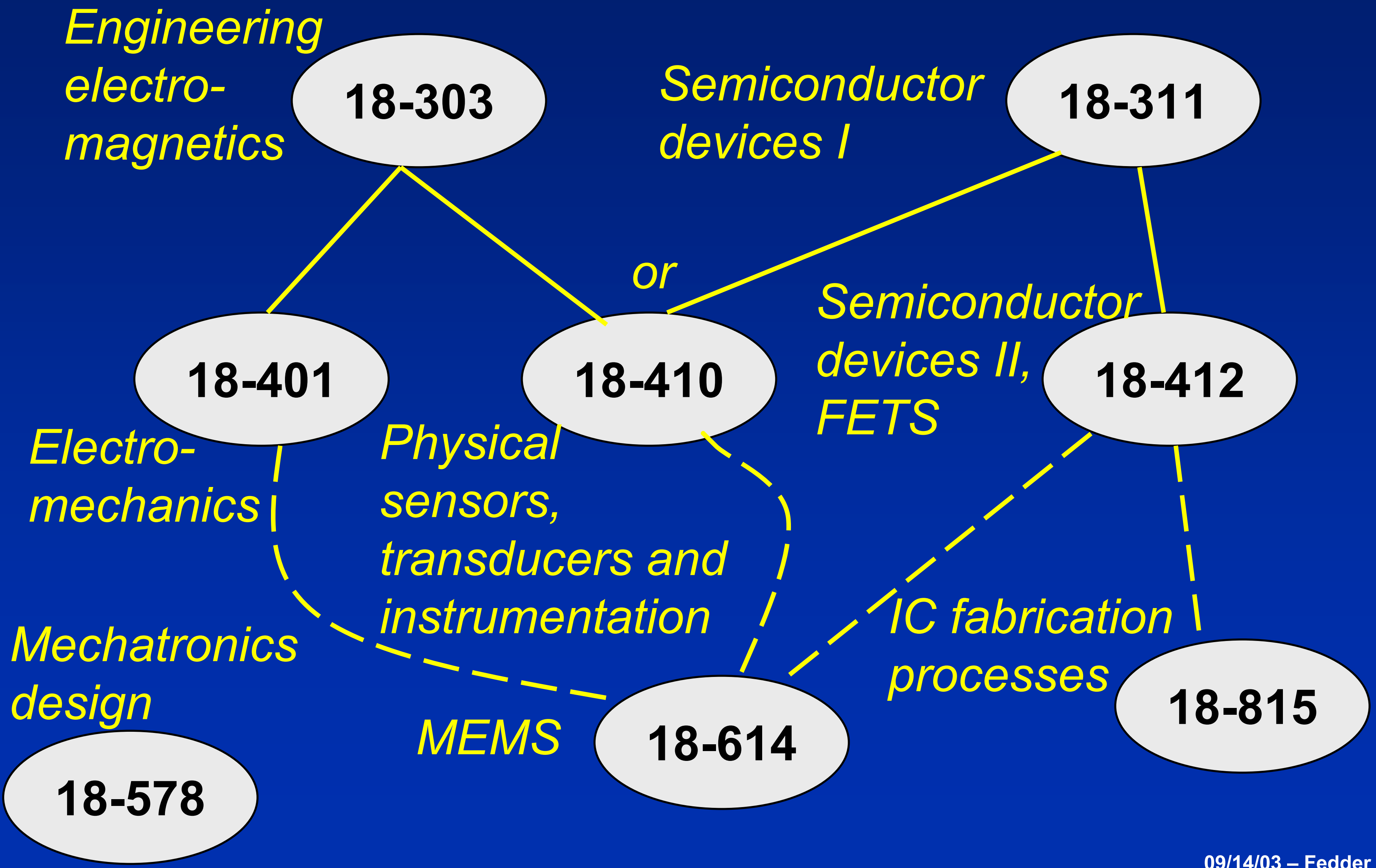
1st gen chip



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



Engineering electro-magnetics
18-303

Semiconductor devices I
18-311

or

18-401

18-410

Semiconductor devices II, FETS
18-412

Electro-mechanics

Physical sensors, transducers and instrumentation

Mechatronics design
18-578

MEMS
18-614

IC fabrication processes
18-815

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.