MEMS Overview

SPEAKER
- Andrew Mason, Asst. Professor in Electrical and Computer Engineering

TOPIC
- Overview of Micro-Electro-Mechanical Systems (MEMS)

OUTLINE
- Overview of MEMS & Microsystems
- Micromachining & MEMS process technology
- Micro-electro-mechanical devices & microsensors
  - Inertial sensors
  - Pressure sensors
  - Bio-sensors
  - Shock sensors
- Integrated Microsystems

What is MEMS?

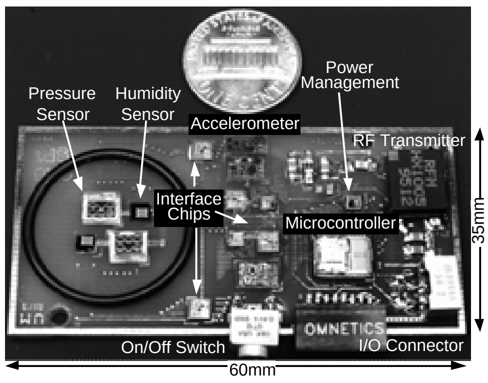
- MEMS = Micro-Electo-Mechanical Systems
  - creation of 3-dimensional structures using integrated circuits fabrication technologies and special micromachining processes
  - typically done on silicon or glass (SiO_2) wafers
- MEMS Devices and Structures
  - transducers
    - microsensors and microactuators
  - mechanically functional microstructures
    - microfluidics: valves, pumps, flow channels
    - microengines: gears, turbines, combustion engines
- Integrated Microsystems
  - integrated circuitry and transducers combined to perform a task autonomously or with the aid of a host computer
  - MEMS components provide interface to non-electrical world
    - sensors provide inputs from non-electronic events
    - actuators provide outputs to non-electronic events

Why Use MEMS?

- Motivation and Benefits
  - Small Size
  - Light Weight
  - Enhanced Performance & Reliability
    - high resolution devices
    - array of devices
  - Low Cost (from batch fabrication)
- Applications
  - Automotive System
  - Health Care
  - Automated Manufacturing
  - Instrumentation
  - Environmental Monitoring & Control
  - Consumer Products
  - Aerospace
- MEMS-based Microsystems
  - highly integrated systems
  - sensing
  - actuation
  - computation
  - control
  - communication

Example MEMS-Based Microsystem

"Micro Cluster" Environmental Monitoring Microinstrument
(developed at U-Mich in the 1990s, A. Mason, K. Wise, et. al.)



Integrated Features
- **Control**
  - **Microcontroller**
  - **Power Management**
- **Communication**
  - **RF Transceiver**
- **Sensing**
  - **Pressure**
  - **Humidity**
  - **Temperature**
  - **Vibration**
- **Packaging**

MEMS Fabrication Technologies

- Applying Micromachining to create 3-D structures using 2-D processing

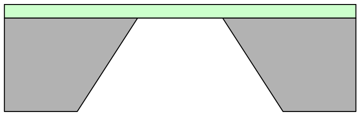
2-D IC fabrication technology → 3-D structures

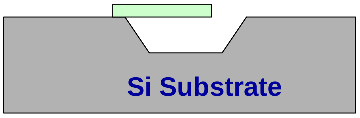
micromachining

- Micromachining Processes
  - bulk and surface micromachining
  - isotropic etching
  - anisotropic etching
  - dissolved wafer process
  - deep reactive ion etching
  - anodic and fusion bonding
  - micromolding

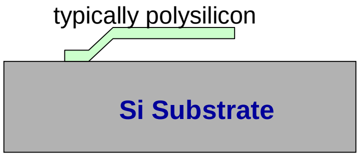
Surface vs. Bulk Micromachining

Bulk Micromachining: Backside etch





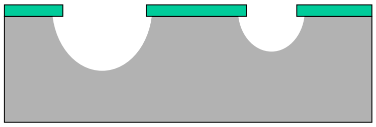
Bulk Micromachining: Front-side Etch pit



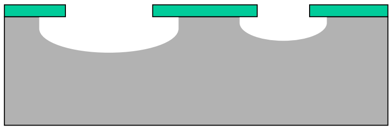
Surface Micromachined Structure

Isotropic Etching of Silicon

- Isotropic etchant
  - etches in all directions
  - forms rounded pits in surface of wafer
- Most common solution
  - HNA: *Mixture of HF, HNO3, Acetic acid (CH3COOH)*



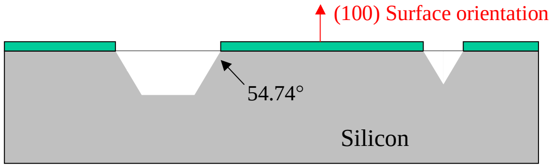
With agitation:
Good reactant mass transport



Without agitation

Anisotropic Etching of Silicon

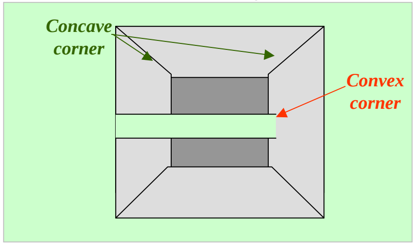
- Anisotropic etchant
  - directional-dependant etch; based on crystal planes
  - forms flat-surface pits in surface of wafer
- Common anisotropic etchants
  - EDP, KOH, TMAH

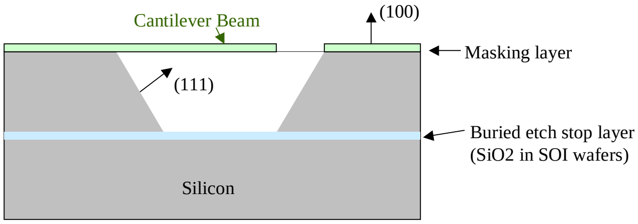


Anisotropic wet etching using EDP, KOH: (100) surface
- Etch stop on (111) plane

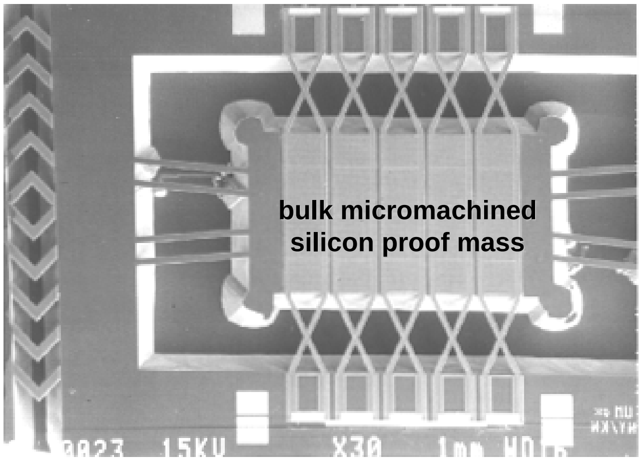
Anisotropic Etching: Convex vs. Concave Corners

masking layer not attacked by Si etchant





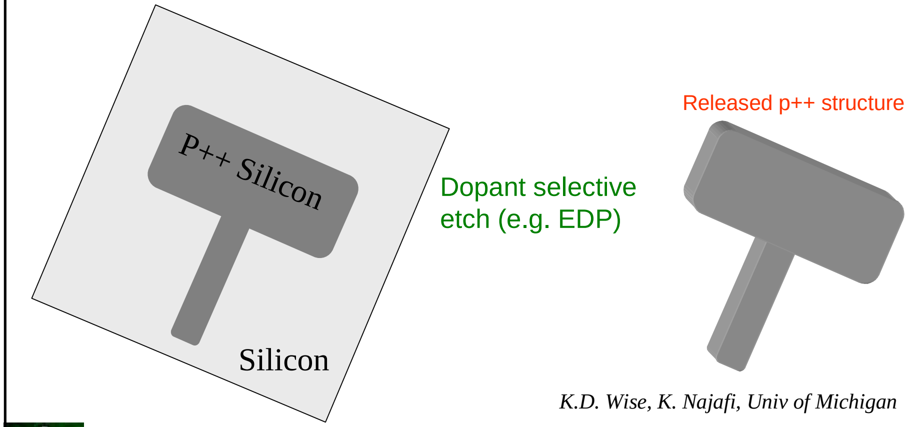
Anisotropic Etching of Silicon: Example



bulk micromachined silicon proof mass

Dissolved Wafer Process

- Structure created by "diffusion masking layer"
  - heavily p-dope silicon (p++)
- Dissolve bulk of silicon to release the p++ structure



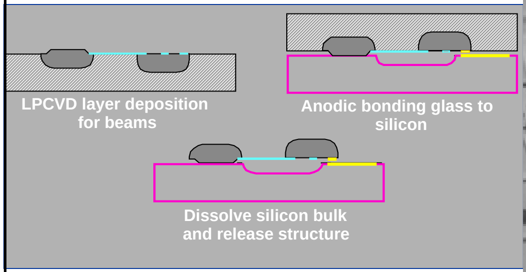
Released p++ structure

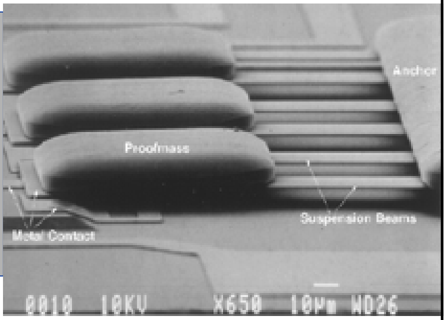
Dopant selective etch (e.g. EDP)

K.D. Wise, K. Najafi, Univ of Michigan

Dissolved Wafer Process Example

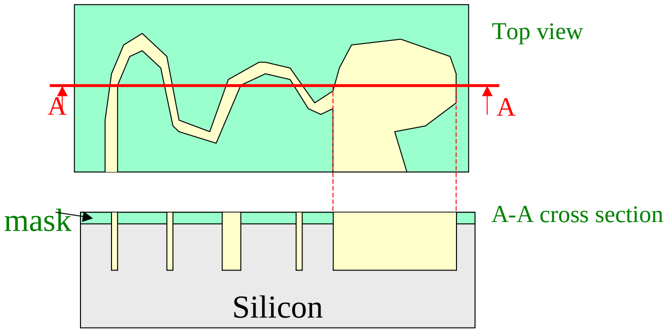
- Shock Switch
  - weighted cantilever beam with contacts that close by acceleration (shock)
- Fabrication Flow
  - create anchor, weight, support beam, and contact on Si
  - create cavity and contact on glass
  - bond wafers and then dissolve the Si wafer





Deep Reactive Ion Etching (DRIE)

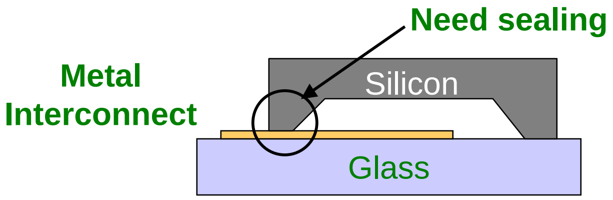
- Reactive Ion Etching = RIE
  - mechanical (ion) etching in plasma for chemical selectivity
- Deep RIE
  - creates high aspect ratio patterns, narrow and deep



- Trench-Refill process
  - can fill the etched “trench” with another material

Glass-Si Anodic Bonding

- Bonding a glass wafer to a silicon wafer
  - both wafer can (and generally are) patterned with structures
- Application
  - creating sealed cavities on a wafer surface
    - can be sealed in vacuum
  - hermetic packaging
- Lead Transfer
  - need to bring the metal leads out of from sealed cavities



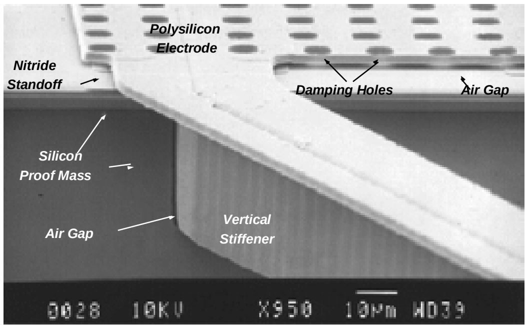
Silicon-Silicon Fusion Bonding

- Two silicon wafer with/without SiO2 can be bonded
- Advantages: No thermal mismatch
- Needs contamination free, smooth, and flat wafers (e.g. surface roughness ~5°A)

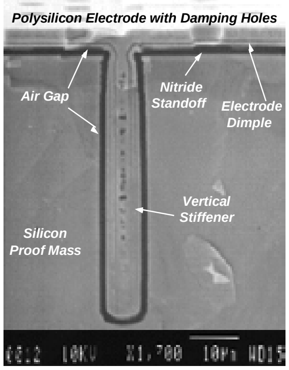
- Process Flow
  - Clean wafers
  - Make the surfaces hydrophilic (e.g. dip in Nitric Acid)
  - Rinse-Dry
  - Place the wafers together apply pressure
  - H2 or N2 anneal at 800-1000°C

Combined Bulk-Surface Process: Molding

- Etch silicon with high aspect ratio (e.g., DRIE)
- Refill partially with *sacrificial* layer (e.g. silicon oxide)
- Refill completely with structural layer (e.g. polysilicon)
- Example: U-Mich Precision Inertial Sensor

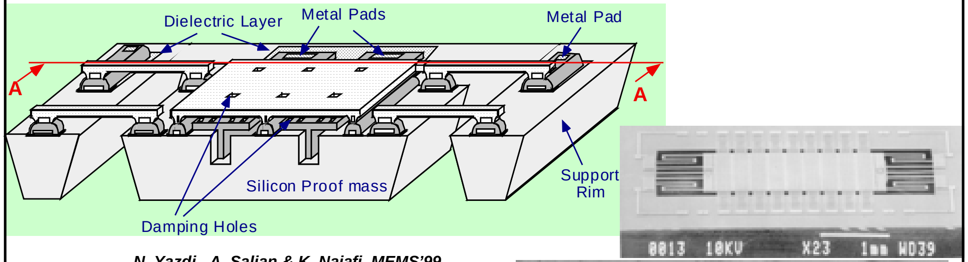


N. Yazdi & K. Najafi, Transducers'97.

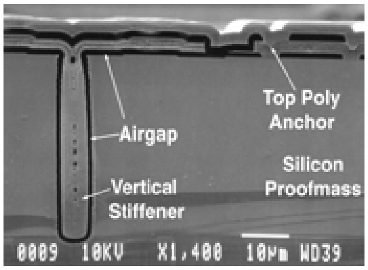


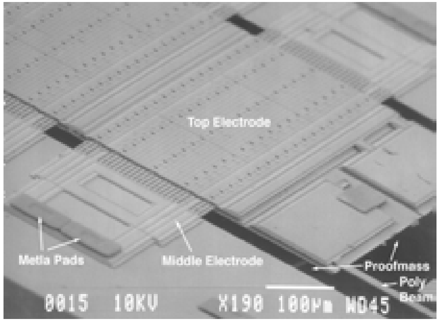
Combined Bulk-Surface Process:

Precision Inertial Sensors



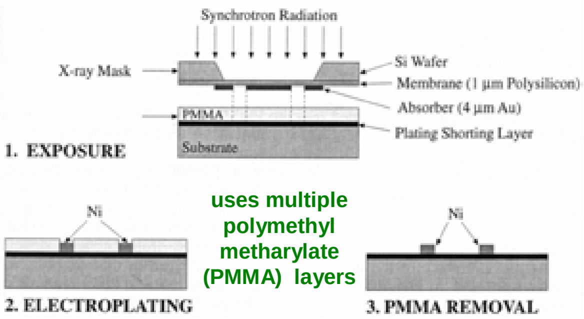
N. Yazdi , A. Salian & K. Najafi, MEMS'99.





LIGA Process

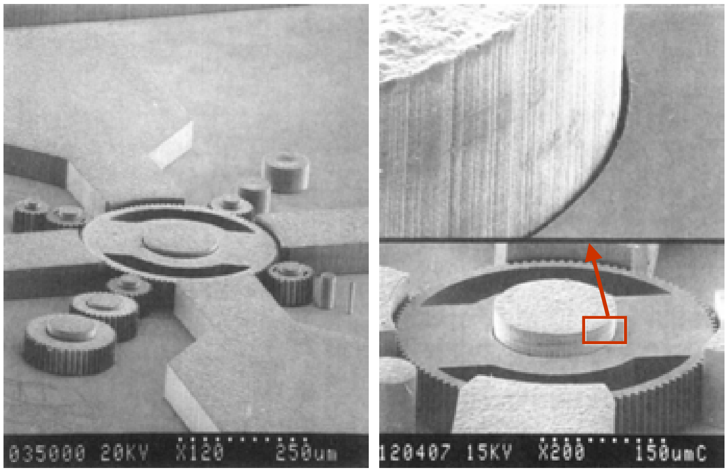
- LIGA: Lithographie, Galvanoformung, Abformung
- Form high aspect ratio structures on top of wafer
- Uses molding and electroplating
- Synchrotron Radiation (X-Ray) used



uses multiple polymethyl metharylate (PMMA) layers

- Features
  - Aspect ratio: 100:1
  - Gap: 0.25µm
  - Size: a few millimeters

LIGA Process: Example



Guckel, IEEE Proceedings, Aug. 1998.

Monolithic Integration of MEMS and ICs

Why Monolithic?

Performance:

- Reduce parasitics due to interconnecting devices
- Reduce noise & crosstalk

Size:

- Reduce pin count
- Reduce package volume

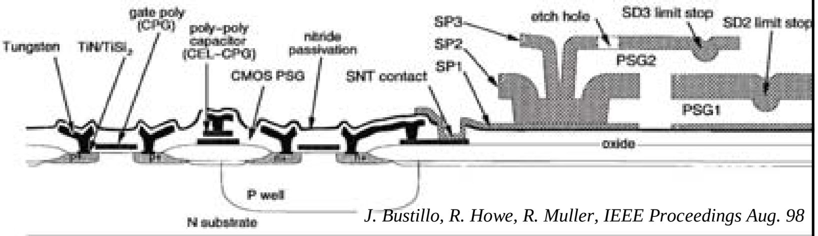
Cost:

- Integration with signal-processing → better functionality
- Reduce packaging cost
- Self test & calibration at wafer level

IC + MEMS Process Examples

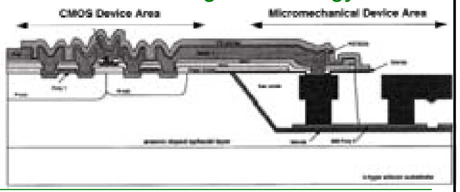
UC Berekely Integrated CMOS & surface micromachining technology

- CMOS first and MEMS second
- CMOS circuit passivated using silicon nitride
- Tungsten interconnects for CMOS



J. Bustillo, R. Howe, R. Muller, IEEE Proceedings Aug. 98

- Sandia Integrated CMOS & surface micromachining technology
  - MEMS first in recessed cavity
  - CMOS second after planarization

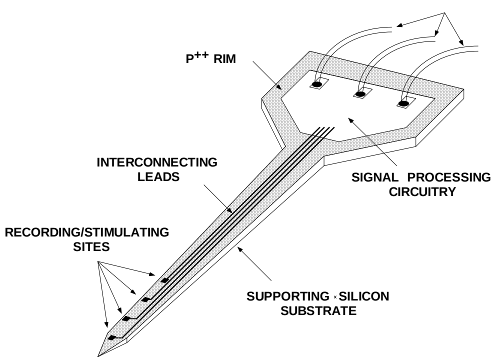


J. Smith et. al., IEDM'95

MEMS Examples

Neural Recording Probes

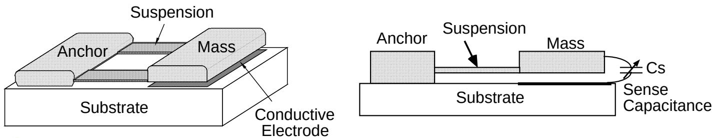
- Monolithic Integration of Wafer-Dissolved Process and IC Technology



Najafi, Wise, JSSC-21 (6), May 1986

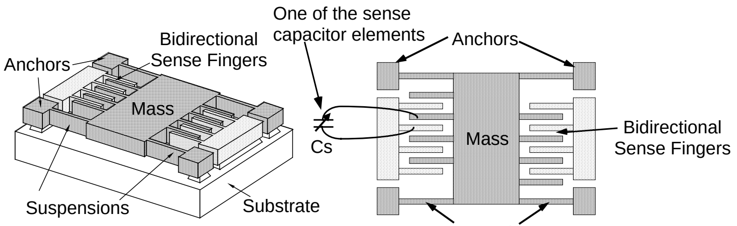
Example: Capacitive Accelerometer

Vertical accelerometer



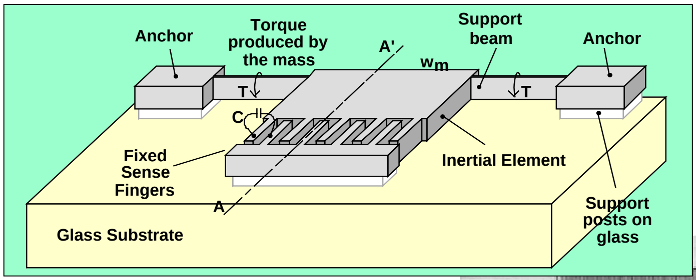
(a) (b)

Lateral accelerometer

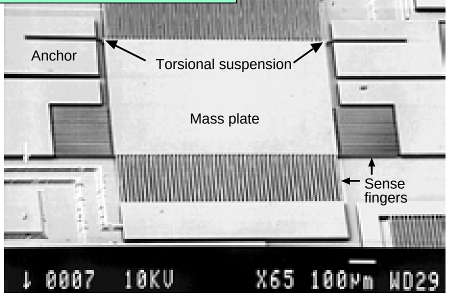


(a) (b)

Example: Z-Axis Torsional Accelerometer

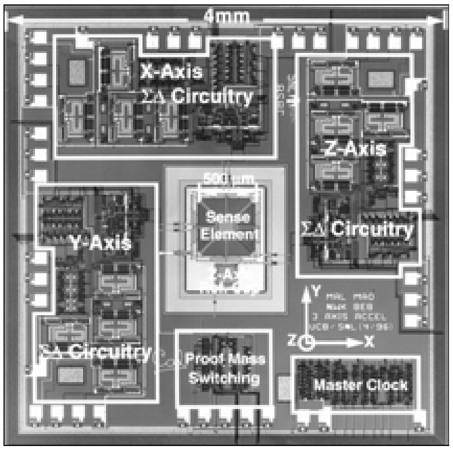


Selvakumar, Najafi, JMEMS 1998.



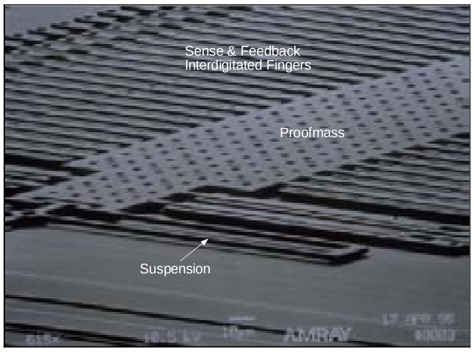
Capacitive Accelerometer

3-Axis Monolithic Surface Micromachined Accelerometer



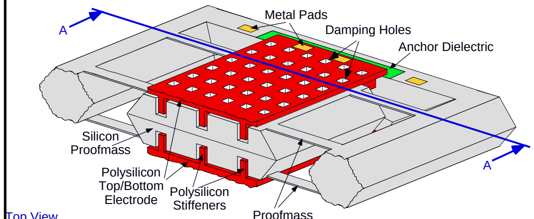
Courtesy of Lemkin, Boser, Trasnducers'97.

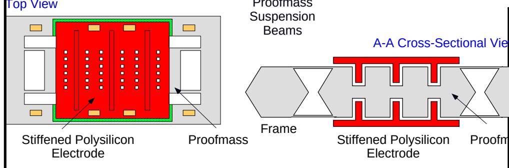
Analog Devices ADXL50

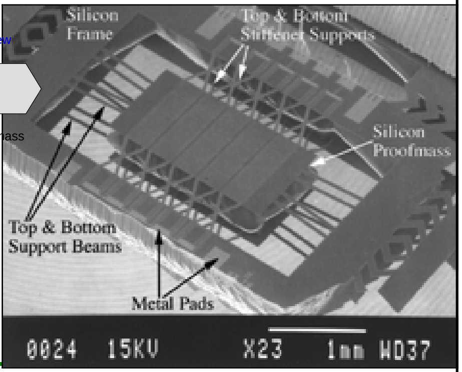


Courtesy of Kevin Chau, Analog Devices Inc.

All-Silicon Micro-G Accelerometer



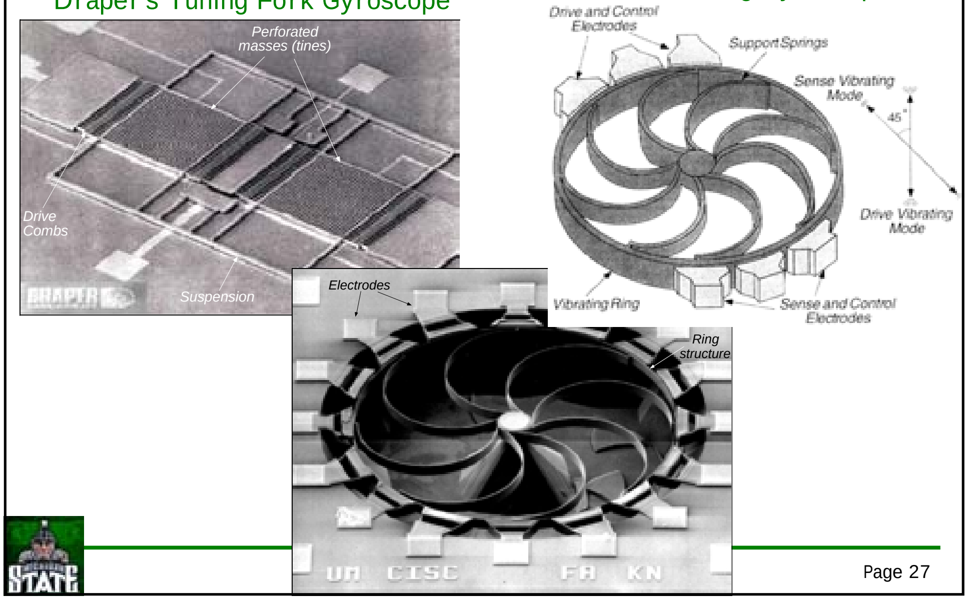




MEMS Gyroscopes

Draper's Tuning Fork Gyroscope

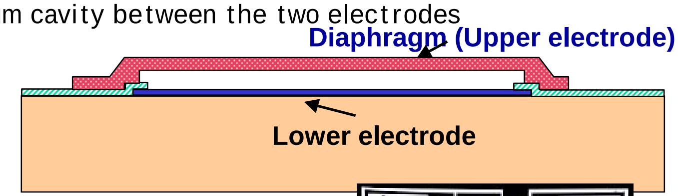
GM & UM Ring Gyroscope

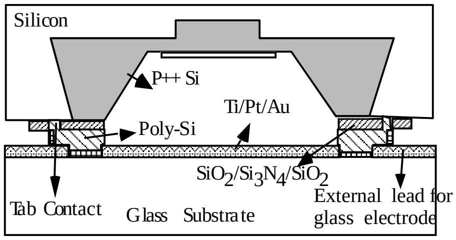


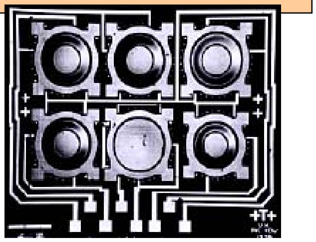
Capacitive Pressure Sensors

Consists of two components:

- Fixed electrode
- Flexible diaphragm forming a moving electrode
- Sealed vacuum cavity between the two electrodes



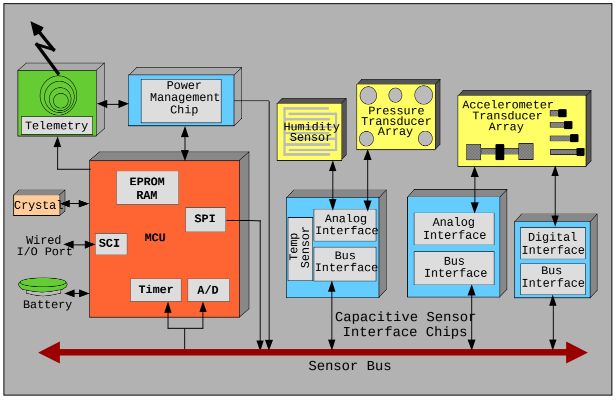




A. Chavan, K.D. Wise, Transducers'97

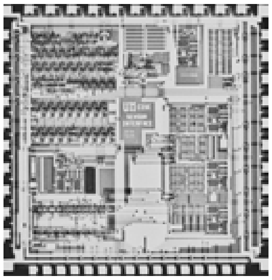
Integrated Microsystems Architecture

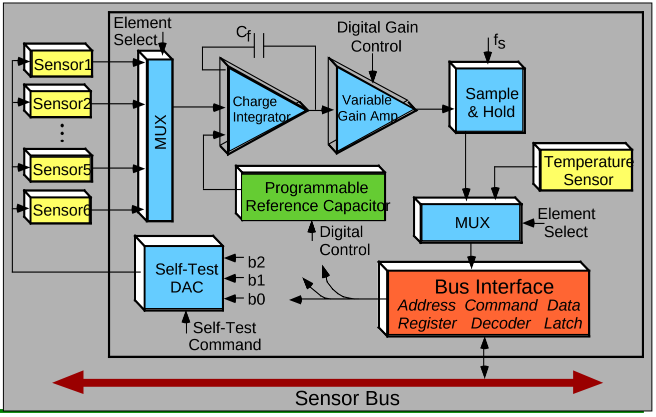
- Flexible Architectures
  - reconfigurable
    - new/different sensors can be added
  - sensor bus



Microsystem Component: Interface Circuit

- Generic capacitive sensor interface
  - sensor readout
  - sensor bus communication
  - programmable operation –useful for range of sensors





Microsystem Component: Shock switch

- System wake-up switch
  - allows events to be captured while system is in sleep mode
  - useful for system-level power management
  - implements several shock thresholds