Surface Micromachining

An IC-Compatible Sensor Technology

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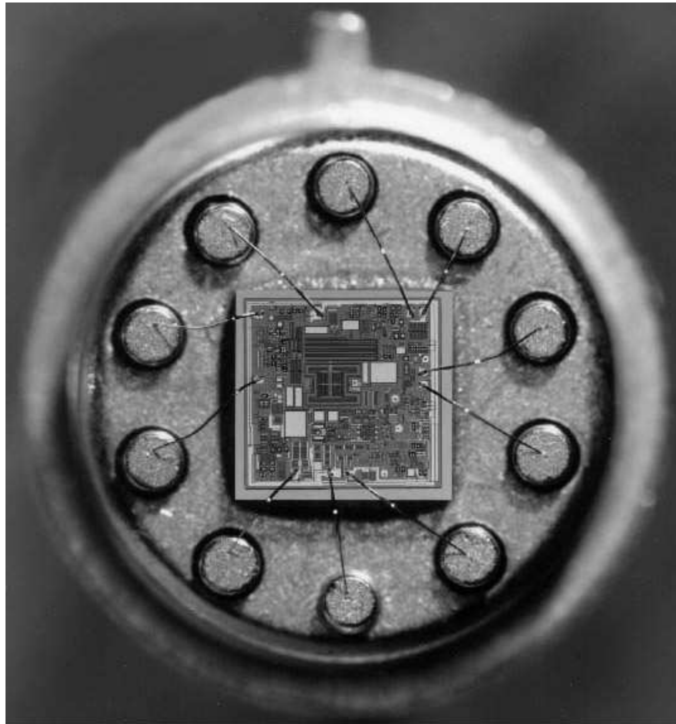
Sensor Applications ...

- pressure
- chemical
- inertial
- image
- temperature
- ...

Surface Micromachining



Ref: Analog Devices ADXL-50

IC fabrication technology:

- electronics
- mechanics
  (processing on chip surface)

⇒ Micro-Electro-Mechanical System (MEMS) on a chip

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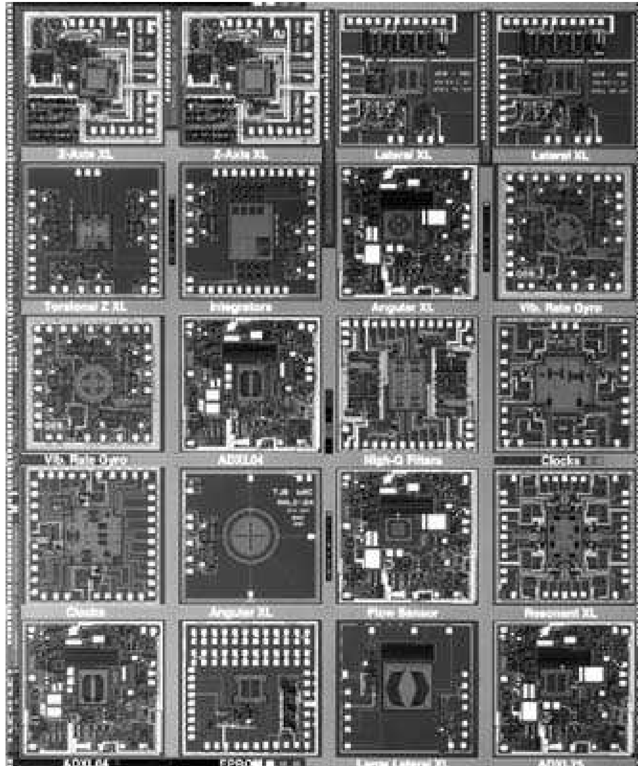
Versatile Sensor Technology



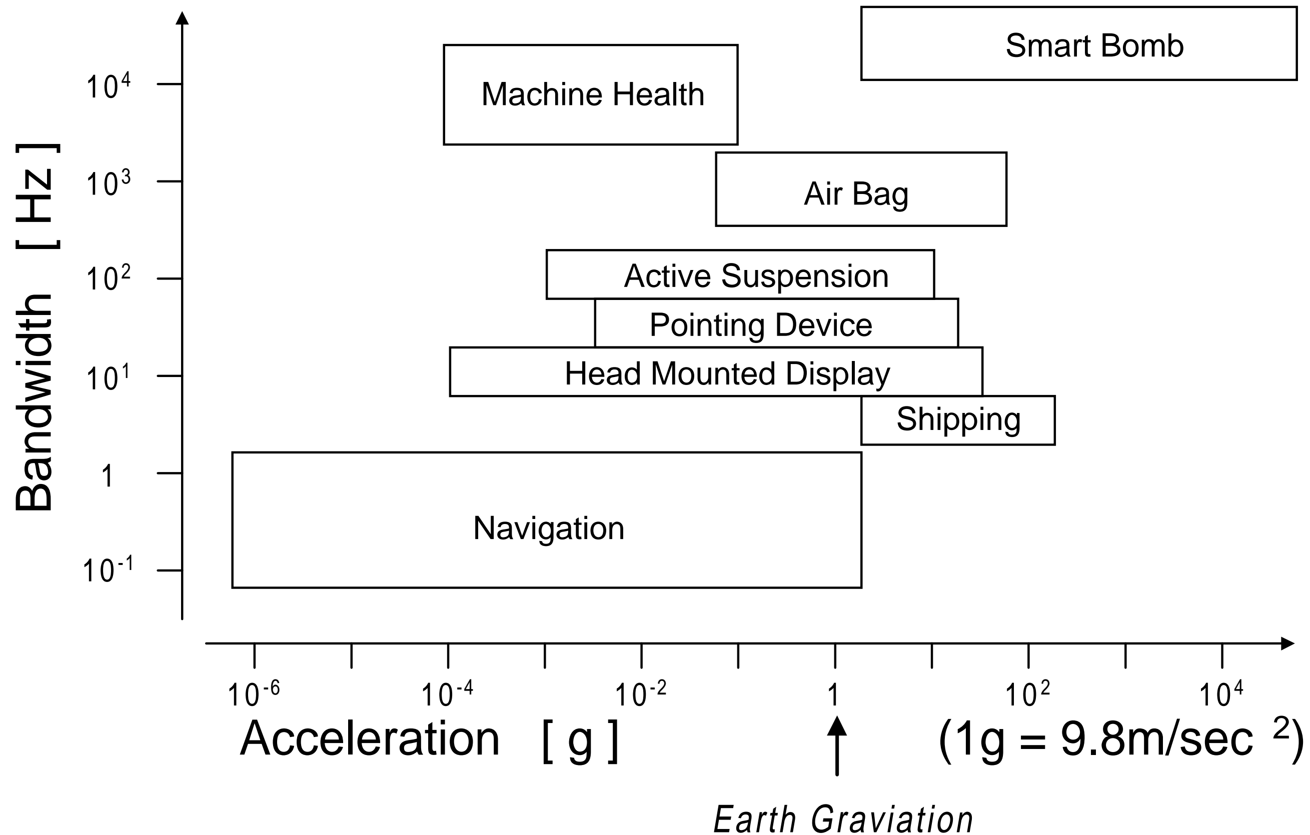
Ref: ADI / UCB Multiproject Run (BiMEMS)

- 4 µm BiCMOS
- 3 x 3 mm^2 chip size
- polysilicon sensors
- devices:
  - accelerometers
  - gyroscopes
  - resonant force sensor
  - high-Q filters
  - clocks

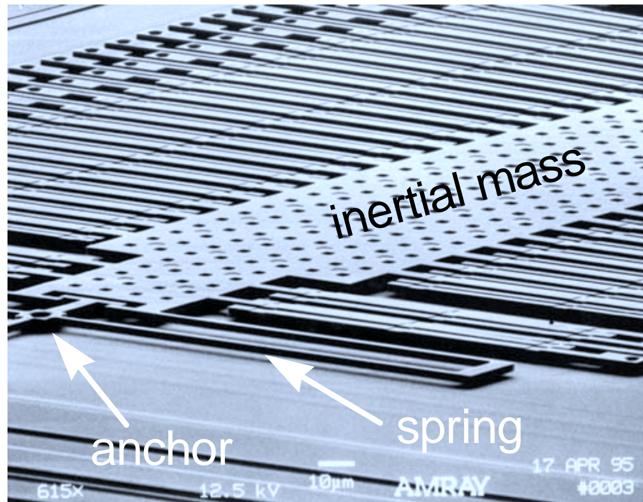
Outline

☞Accelerometer Example
  - performance versus application
  - mechanical sensing element
  - electronic interface
- Fabrication Technology
- MEMS Applications
- Summary

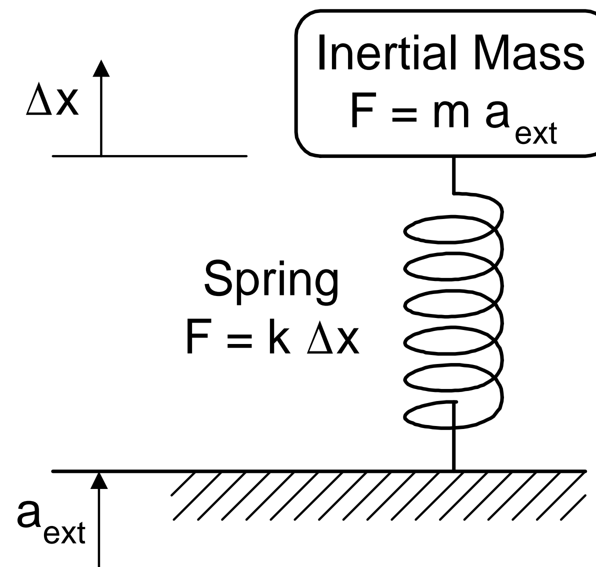
Acceleration Sensors



Acceleration Sensing Principle



Ref: Analog Devices ADXL05



Inertial Mass, m	0.1 μgrams
Plate Thickness	2 μm
Spring Width	1 μm
Air Gap (to substrate)	1.6 mm
Resonant Frequency	10 kHz

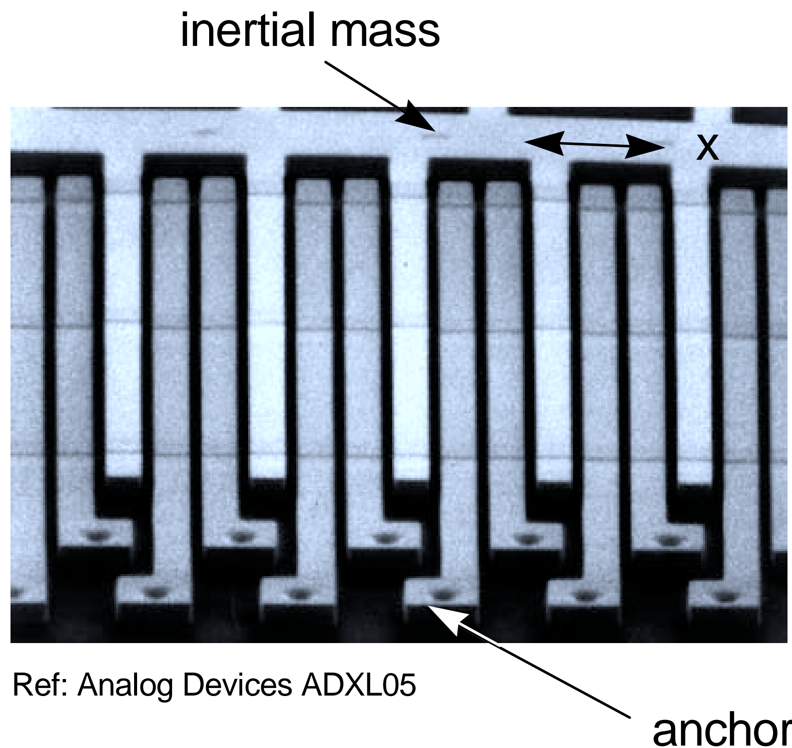
$m\,a_{ext} = k\,\Delta x$

$\Delta x = a_{ext}\,m/k = a_{ext} / \omega_r^2$

$= 1\text{ mg} / (2\pi\ 10\text{kHz}) = \underline{0.025\ \text{Å}}$

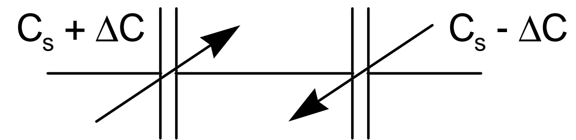
Capacitive Δx Sensing

inertial mass



Ref: Analog Devices ADXL05

anchor

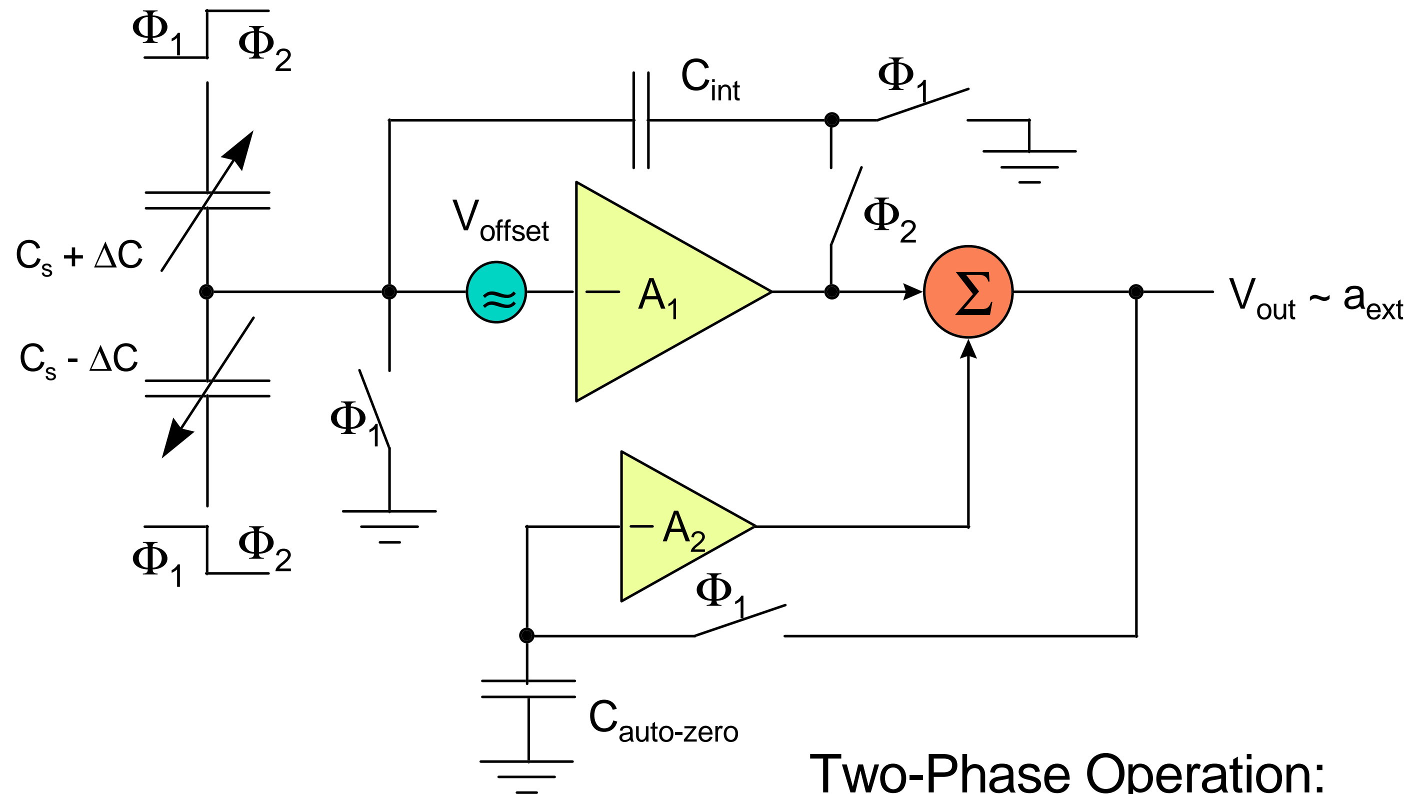


Sense Fingers:

• length	150 μm
• gap	1 μm
• number	40
• capacitance	3 fF/finger
• total cap	120 fF
• sensitivity ΔC/Δx	12 aF/Å

$\underline{\Delta C = 0.3\ \text{aF}}$ for $a_{ext} = 1$ mg

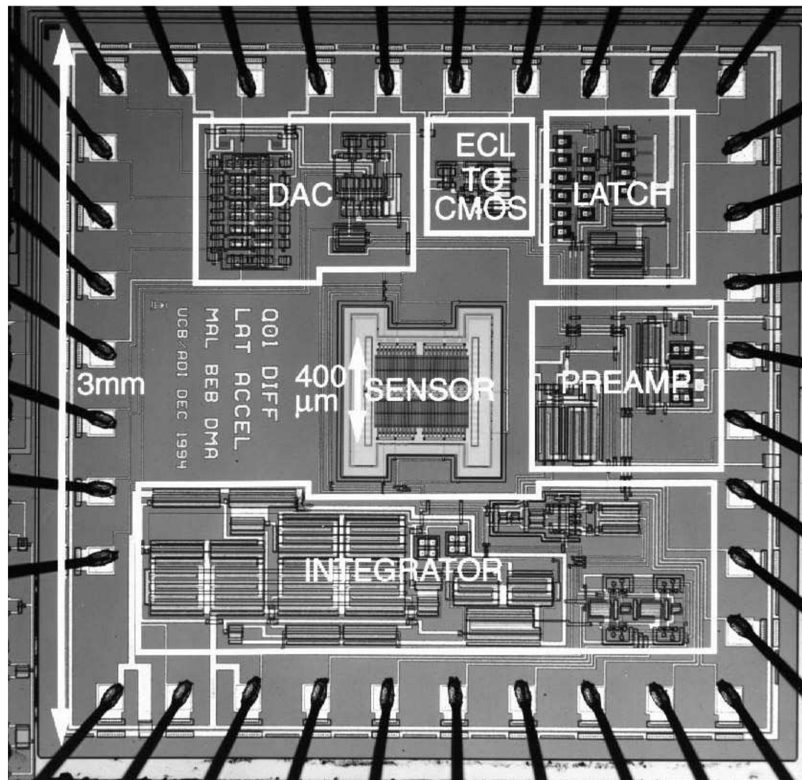
Sense Electronics



Two-Phase Operation:

- Φ_1 offset & 1/f noise cancellation
- Φ_2 position sense

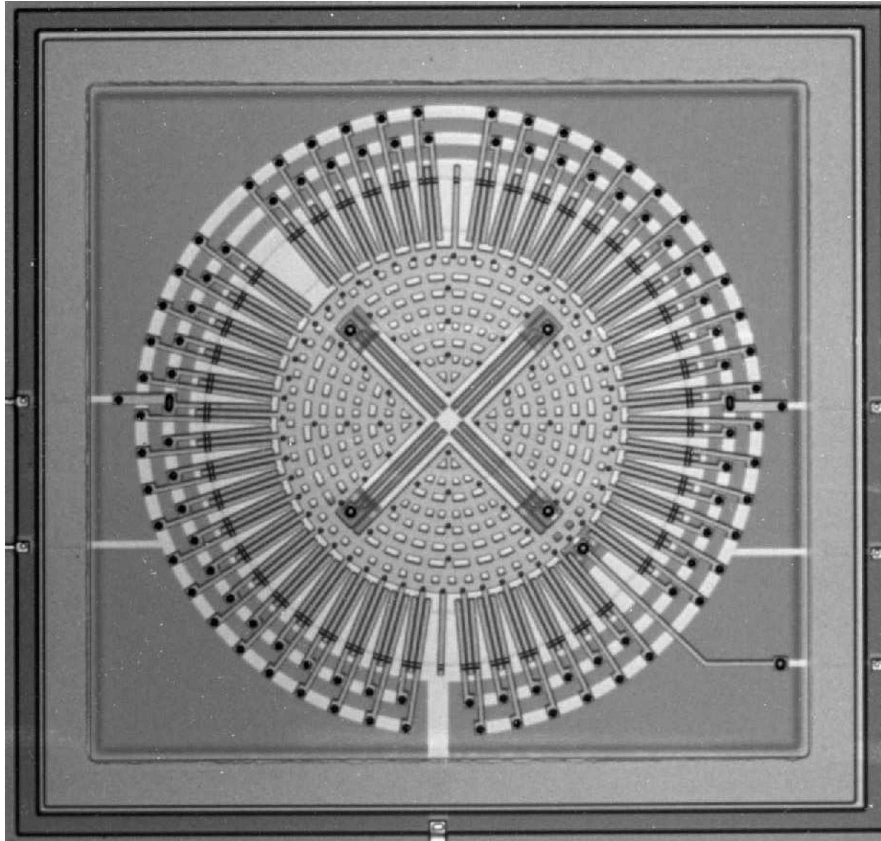
MEMS Accelerometer



• Die size	3 x 3mm^2
• Supply current	3.7mA @ 5V
• Bandwidth	50 Hz
• Full scale input	$\pm$ 5g
• Resolution	1mg
• Digital output	

Ref.: M. A. Lemkin et al., “A fully differential surface micromachined lateral accelerometer”, CICC, Atlanta, 1996.

Angular Accelerometer



- same electronics
- sensitive to acceleration about the z-axis
- applications: hard-disk drives

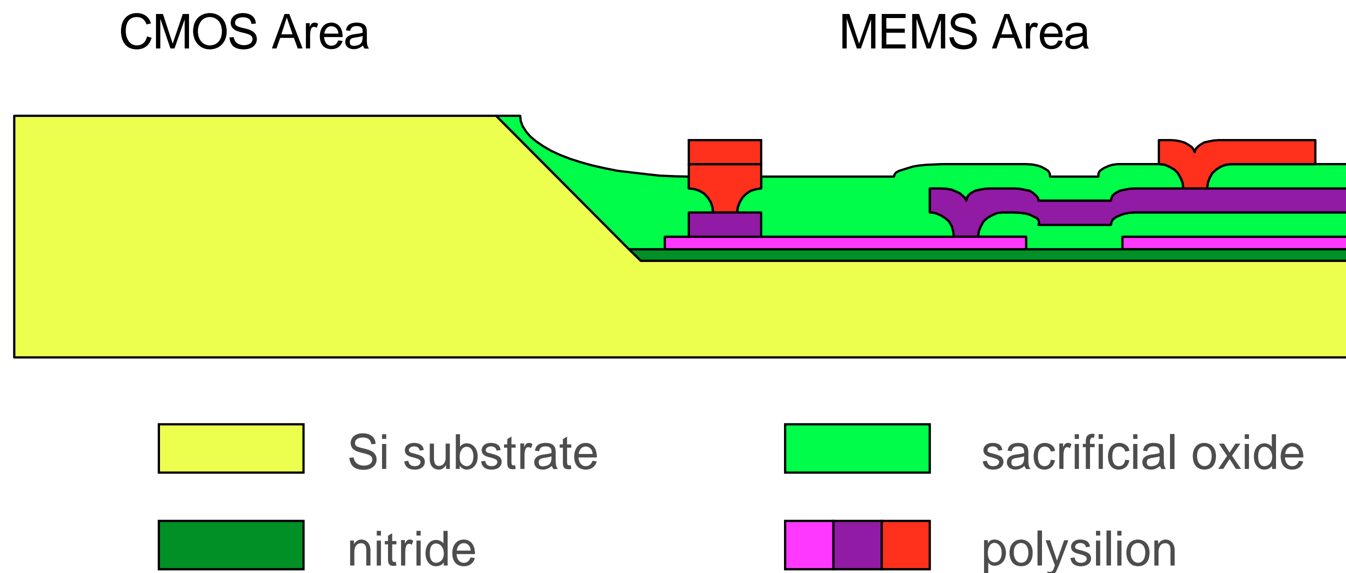
Ref: T. J. Brosnihan et al, “Surface Micromachined Angular Accelerometer with Force Feedback”, Digest ASME Int. Conf. and Expo, San Francisco, Nov. 1995.

Outline

- Accelerometer Example
- ☞ Fabrication Technology
  - – MEMS Device Fabrication
  - – Electronic Devices
  - – Release
- MEMS Applications
- Summary

Mechanical Device Fabrication

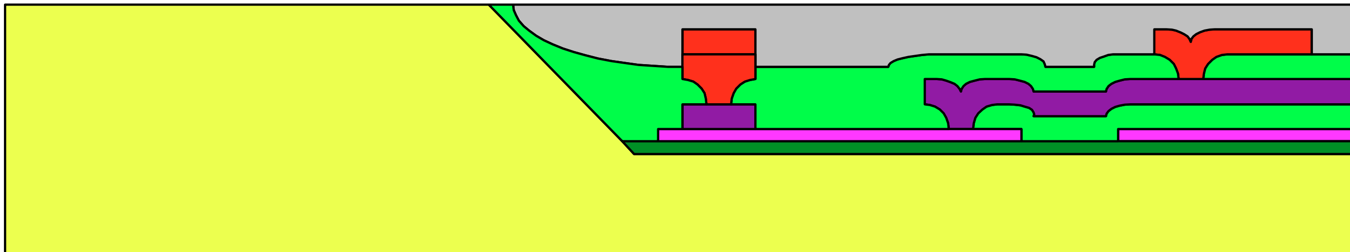
- MEMS-first $\rightarrow$ avoids degradation of CMOS



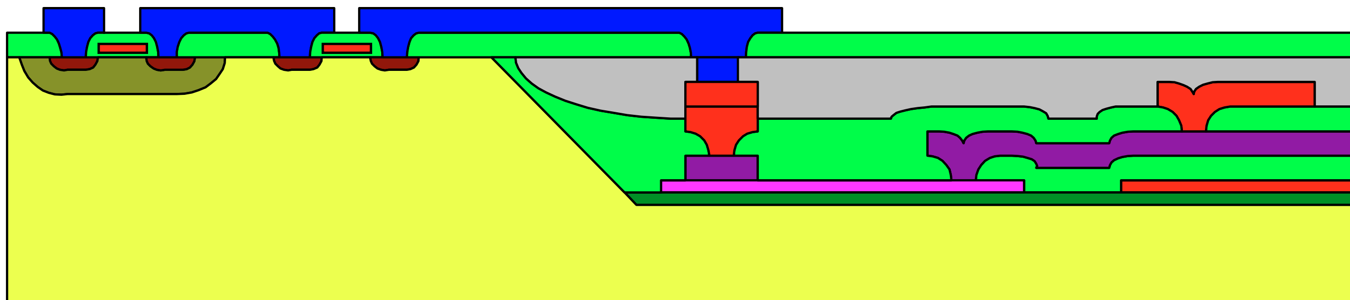
Ref.: J. H. Smith et al, “Embedded Micromechanical Devices for the Monolithic Integration of MEMS with CMOS”, Digest IEDM, Dec. 1995, pp. 609-612.

CMOS Device Fabrication

- fill trench with oxide, planarize (CMP)

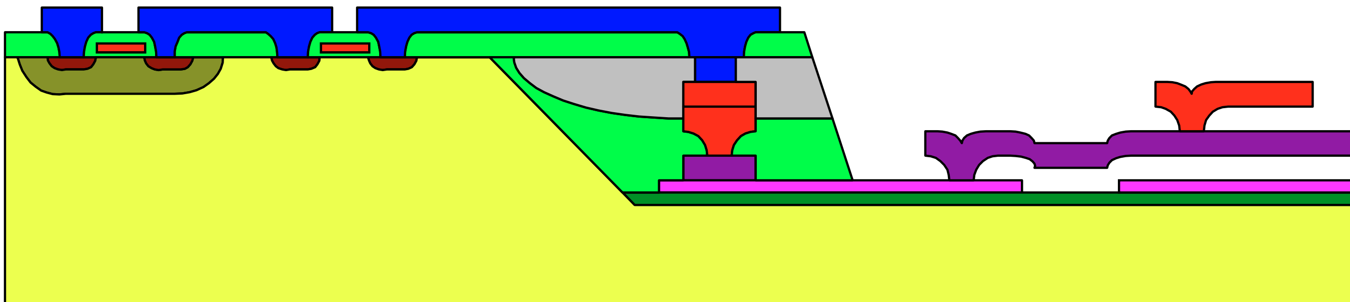


- standard CMOS device fabrication

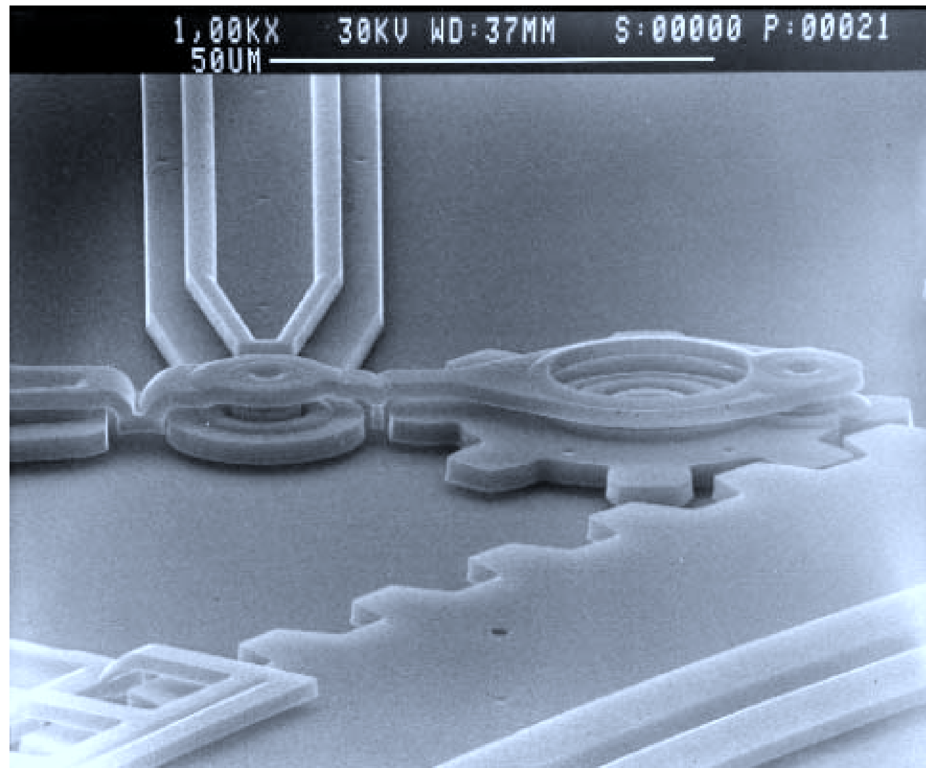


Release

- etch sacrificial oxide in MEMS area



Released Mechanical Elements



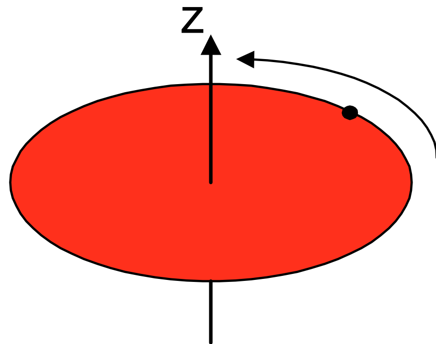
Ref.: J. J. Sniegowski et al., “Monolithic geared mechanisms driven by a polysilicon surface-micromachined on-chip electrostatic microengine”, Digest Solid-State Sensor and Actuator Workshop, Hilton Head, June 1996, pp. 178-182.

Outline

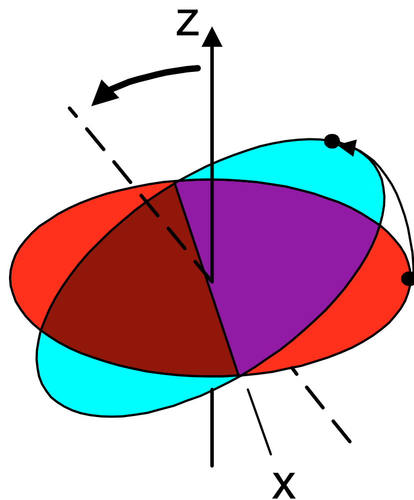
- Accelerometer Example
- Fabrication Technology

☞MEMS Applications & Technology
  - Gyroscopes
  - Displays
  - 3D MEMS (Fiber-Optic Interface)
  - Packaging
- Summary

Gyroscope Principle



- spin disk around z-axis



- input: rotation about x-axis
- measure: torque on z-axis

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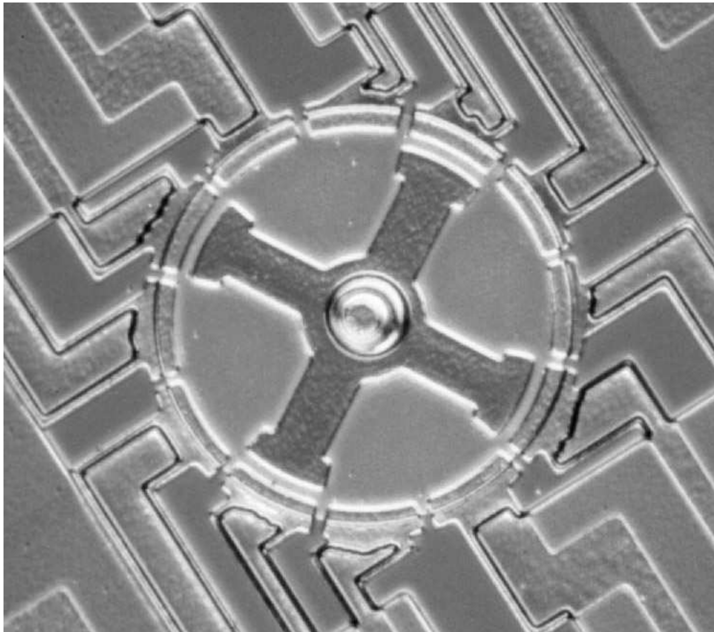
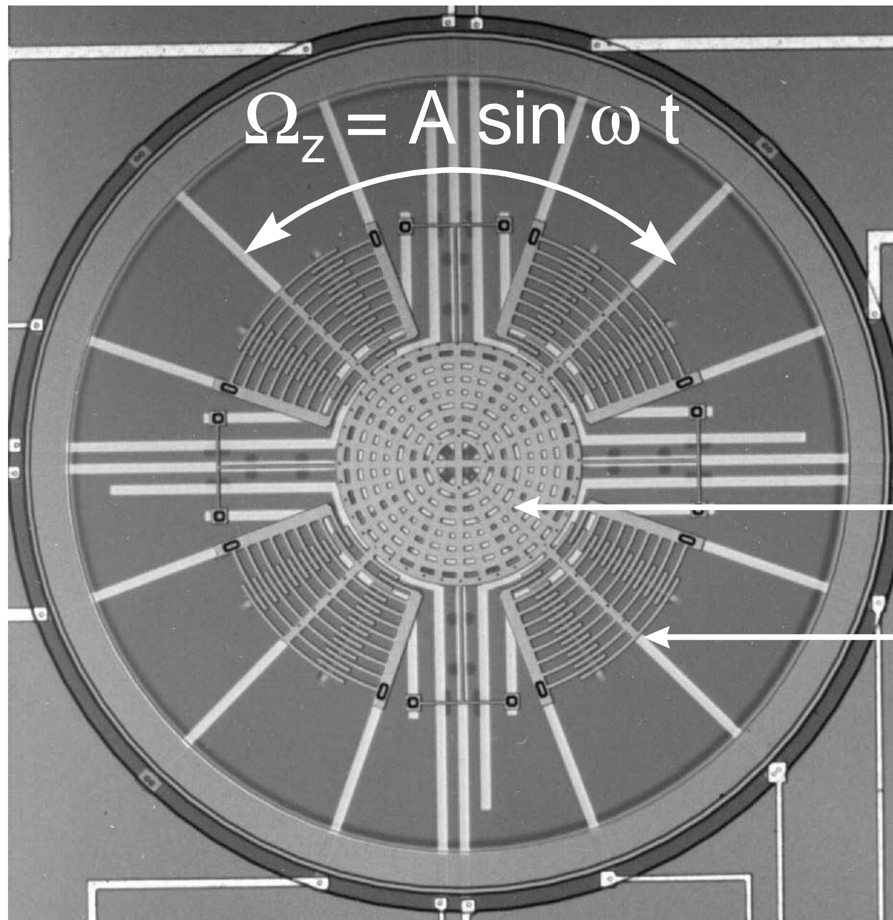
Electrostatic MEMS Motor



Problem:
no high-quality bearings

Two-Axis Angular Rate Sensor



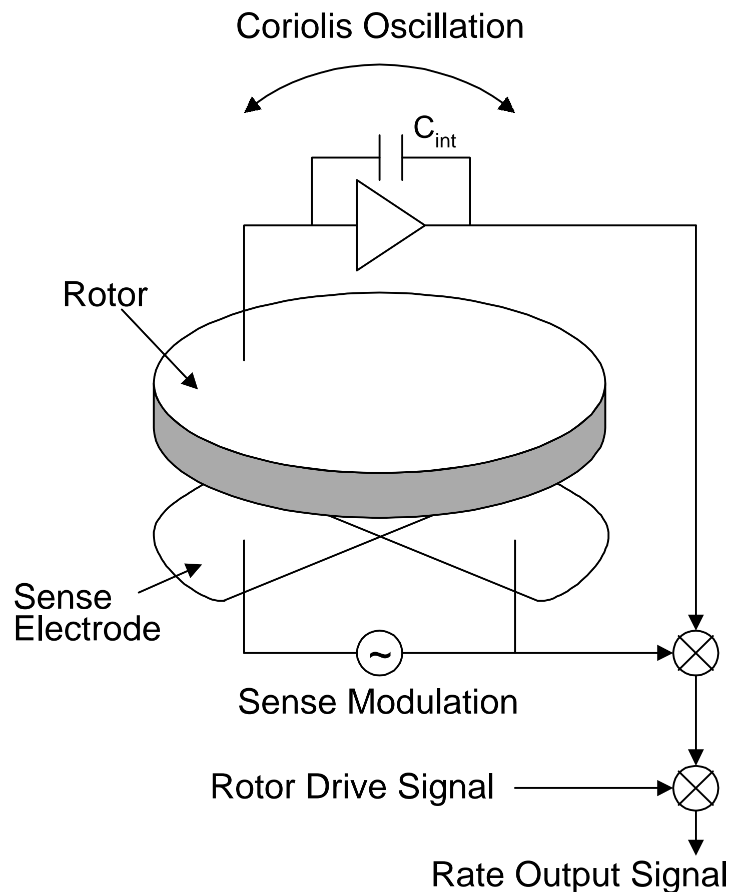
- "vibrate" around z-axis (electrostatic actuation)
- sensitive to x- and y-axis inputs

rotor

electrostatic drive combs

Ref: T. Juneau et al., "Micromachined Dual Input Axis Angular Rate Sensor", Solid-State Sensor and Actuator Workshop, Hilton Head, SC, June 1996.

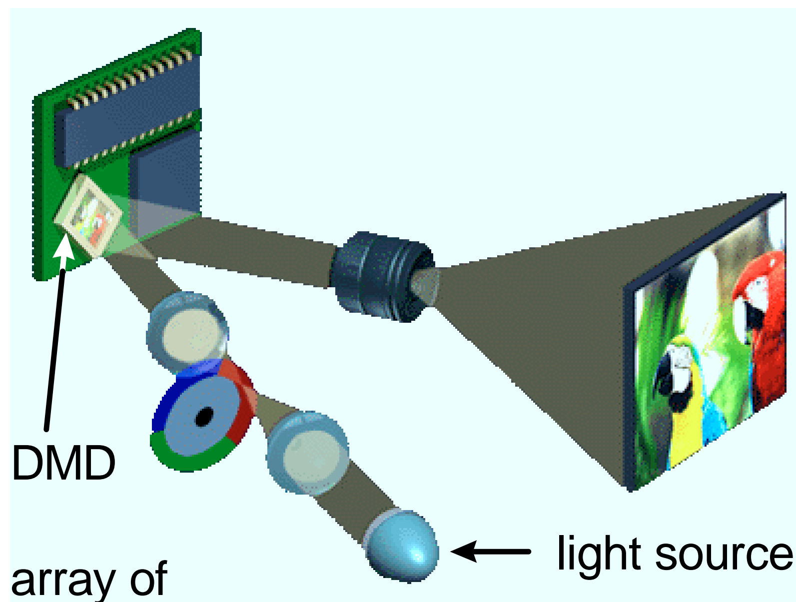
Gyro Sense Electronics



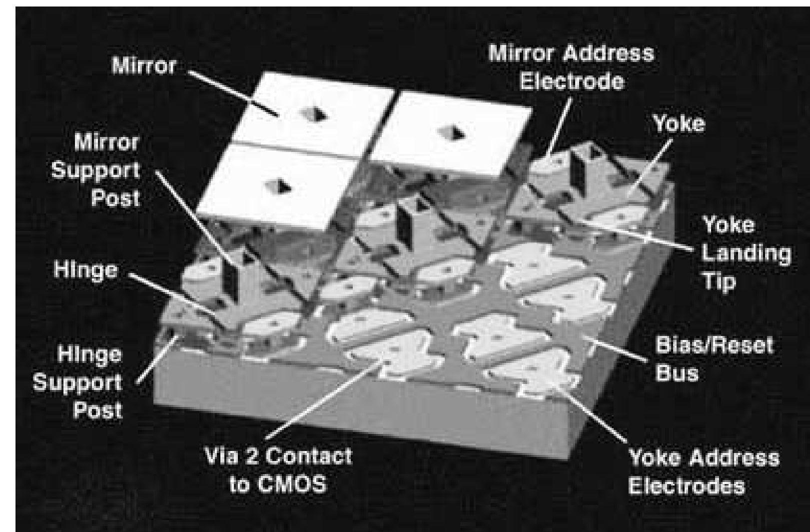
- Q = 1000 in 60mT vacuum
- Rotor resonance 28 kHz
- Bandwidth 25 Hz
- Resolution 1 deg/sec

- Applications:
  - automotive
  - head-mounted displays
  - input devices

Digital Mirror Display (DMD)



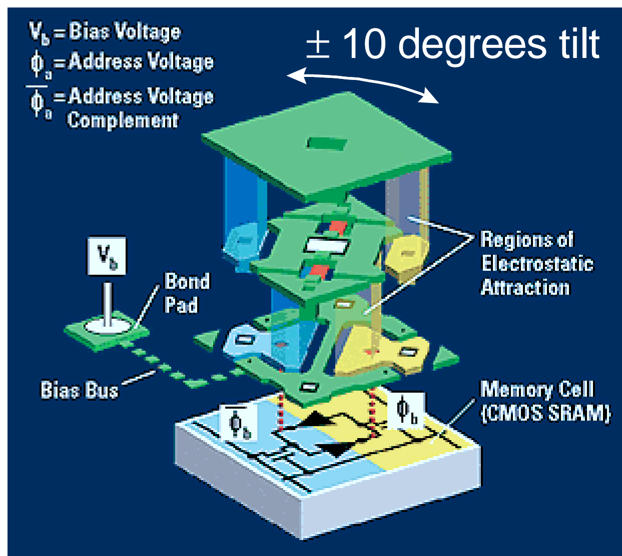
array of movable mirrors direct light to or off screen

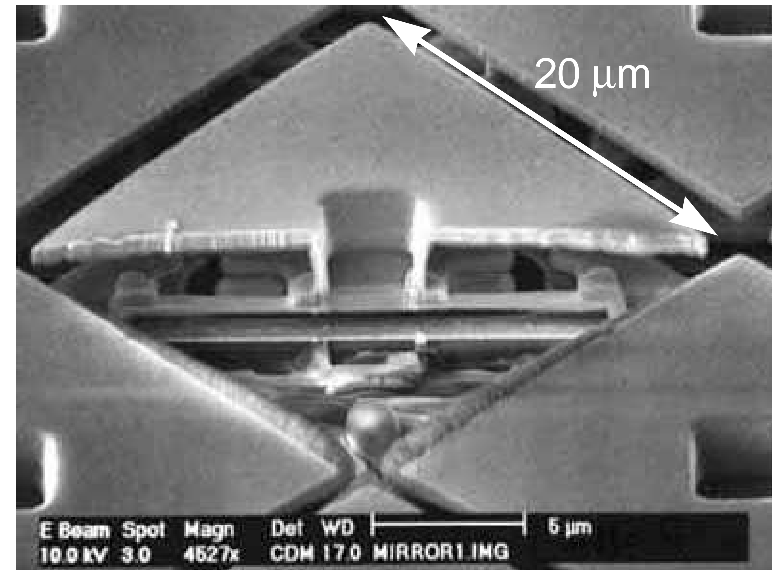


DMD concept

Ref: http://www.ti.com/dlp

DMD Pixel

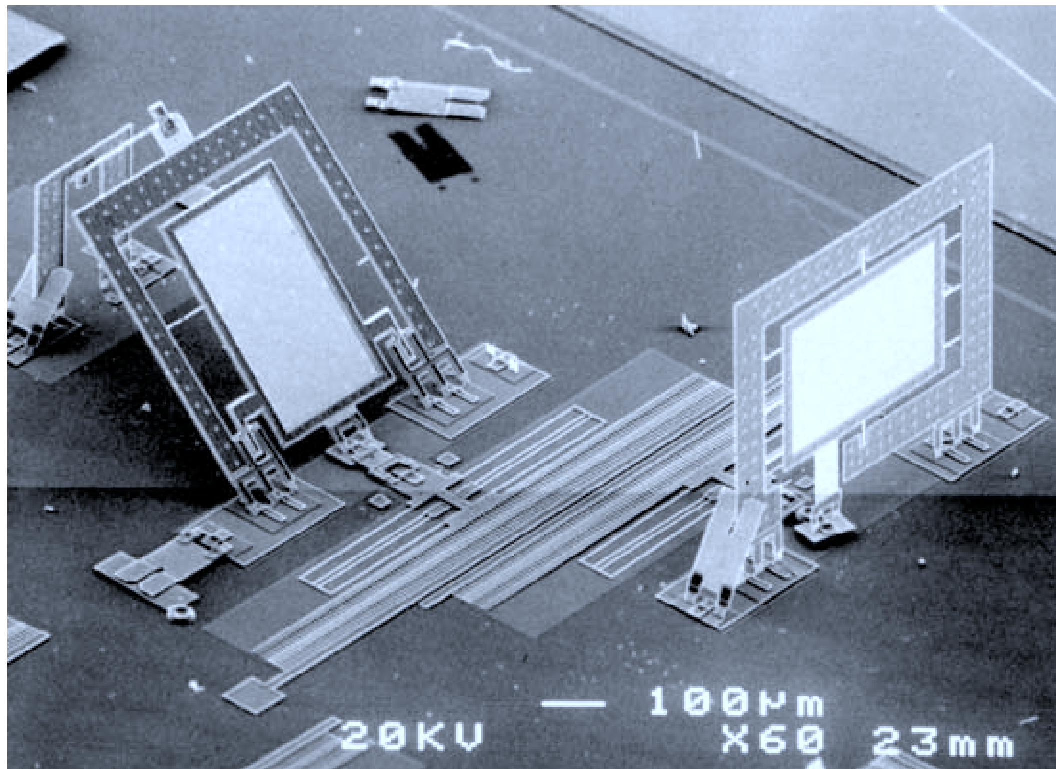




Pixel anatomy:
- SRAM cell
- Al mirror
  (electrostatic actuation)

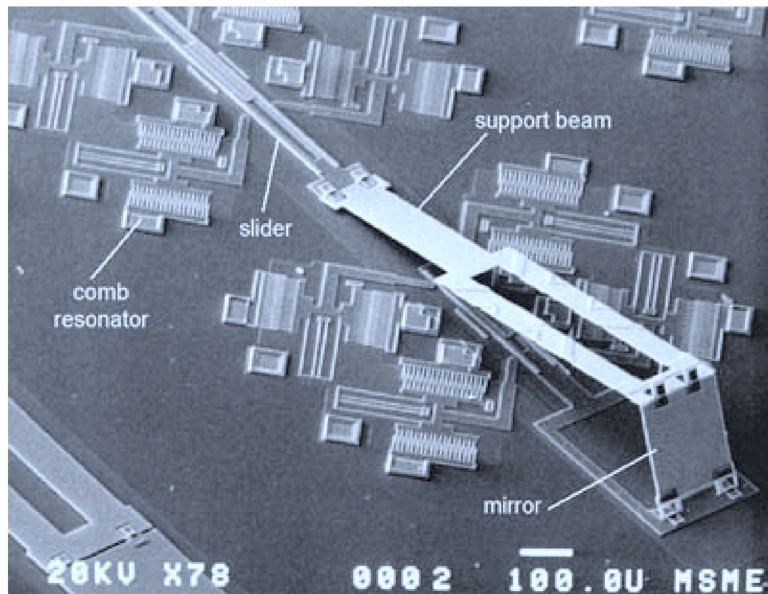
SEM of cleaved pixel

3D MEMS Structures

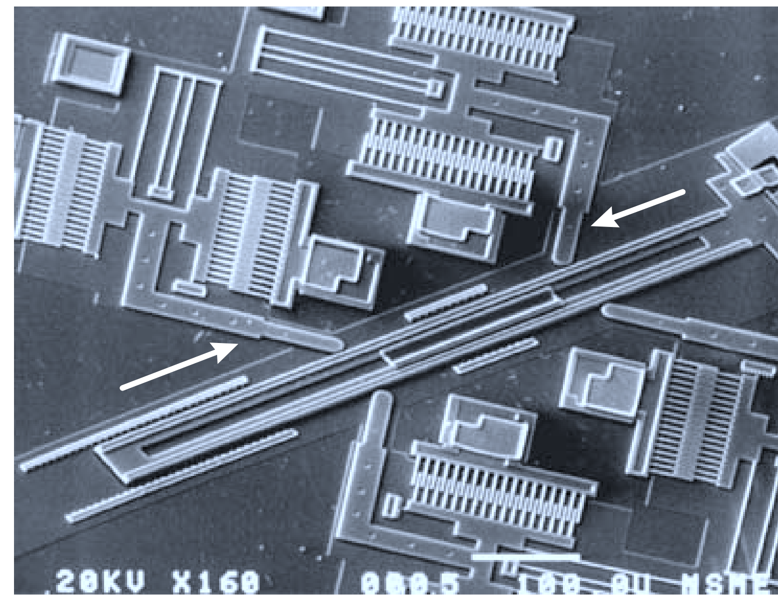


- fold-up structures add 3D capability
- latches hold structure in place

Fiber-Optical Interface



actuated microreflector

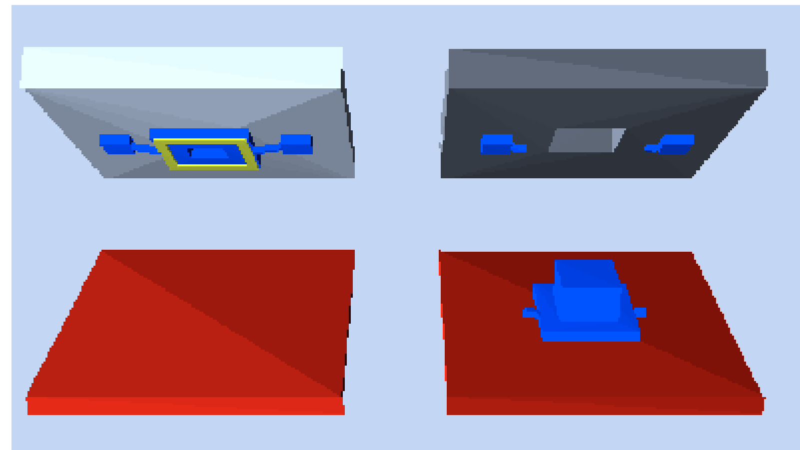


vibromotor actuator (closeup)

Ref.: M. J. Daneman et al., "Linear Vibromotor Actuated Micromachined Microreflector for Integrated Optical Systems", Solid-State Sensor and Actuator Workshop, Hilton Head, 1996, pp. 109-112.

MEMS Packaging

- packaging issues:
  - controlled ambient (e.g. vacuum)
  - protect from plastic injection molding
- solution:
  - MEMS caps
    - fabricate on donor wafer
    - batch transfer



Ref.: M. B. Cohn et al.: "Wafer-to-wafer transfer of microstructures for vacuum packaging", Solid-State Sensor and Actuator Workshop, Hilton Head, 1996.

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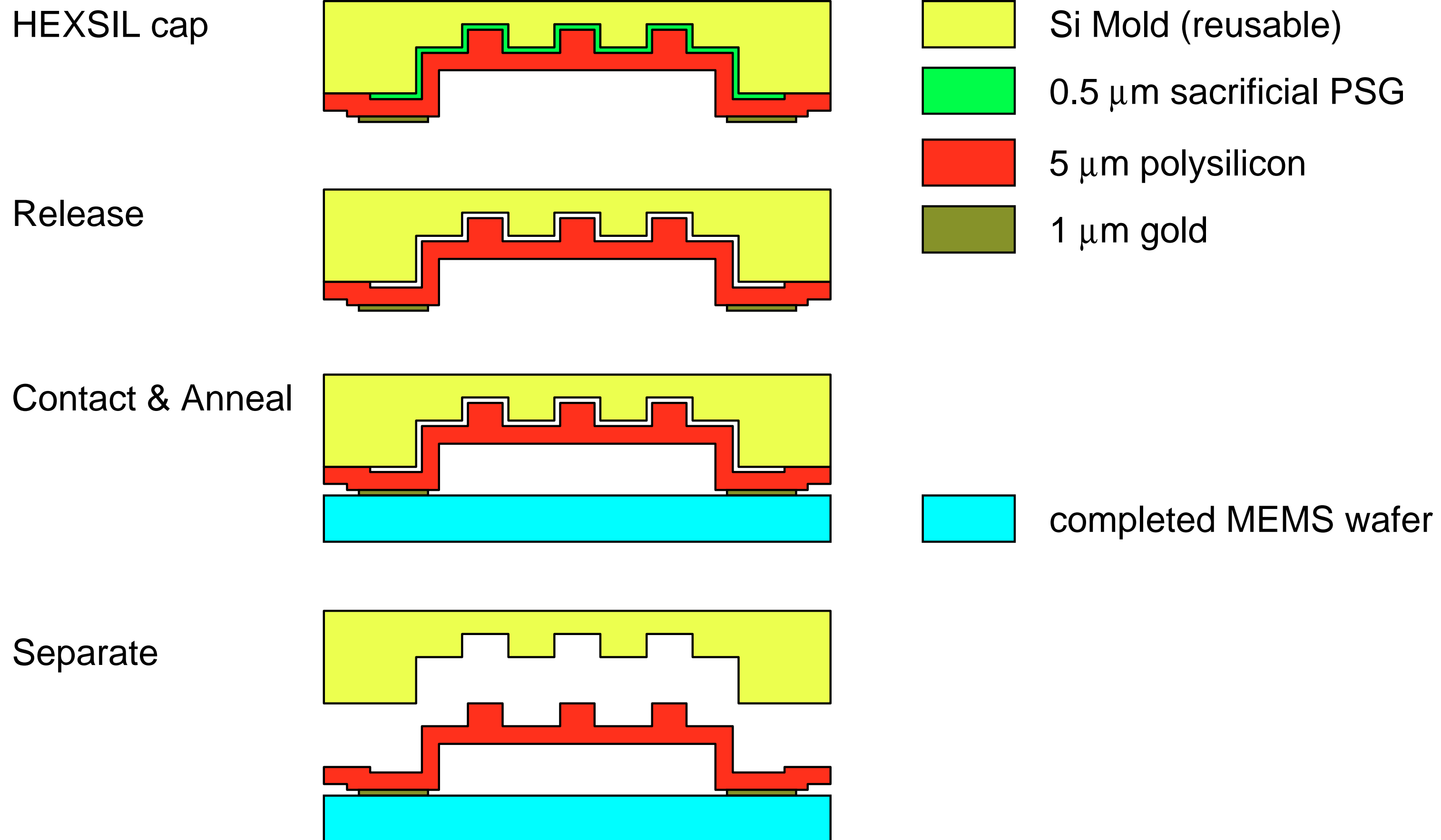
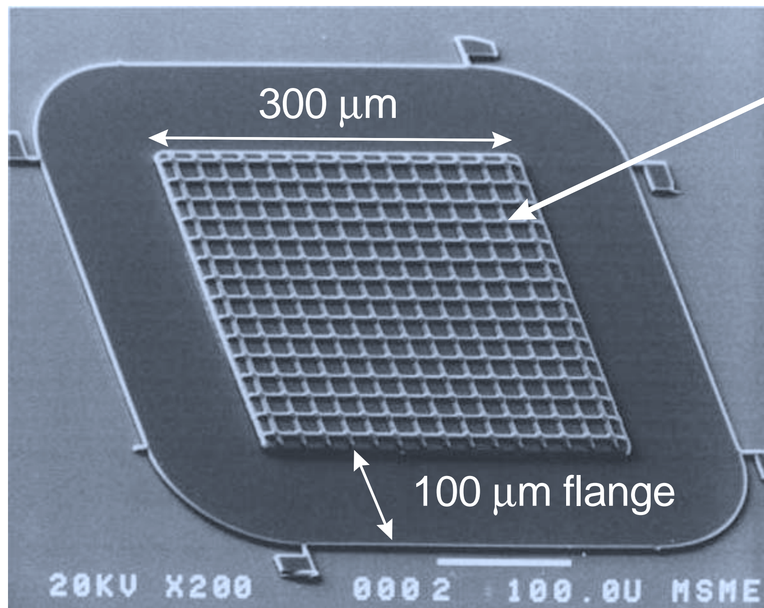
Vacuum Cap Fabrication

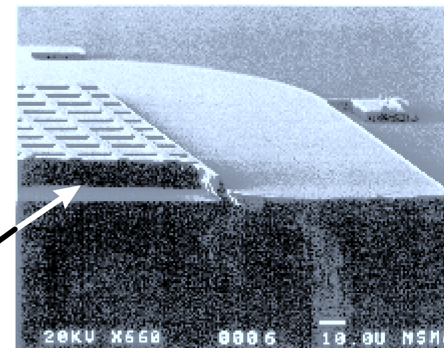


Vacuum Caps



stiffening ribs

4 μm cavity



Ref.: M. B. Cohn et al.: "Wafer-to-wafer transfer of microstructures for vacuum packaging", Solid-State Sensor and Actuator Workshop, Hilton Head, 1996.

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Surface Micromachining Summary

- IC compatible processing
- Versatile:
  - inertial sensors
  - displays
  - optical bench
  - vacuum encapsulation

  \+ RF components

  \+ disk-drive R/W arm assembly

  \+ . . .