CMP Processing Issues for MEMS Fabrication Technology

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Albuquerque, NM

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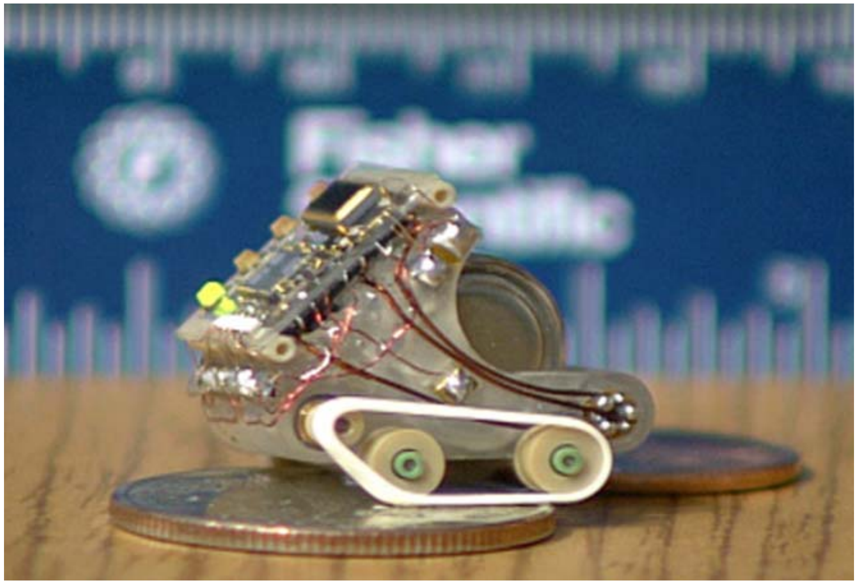
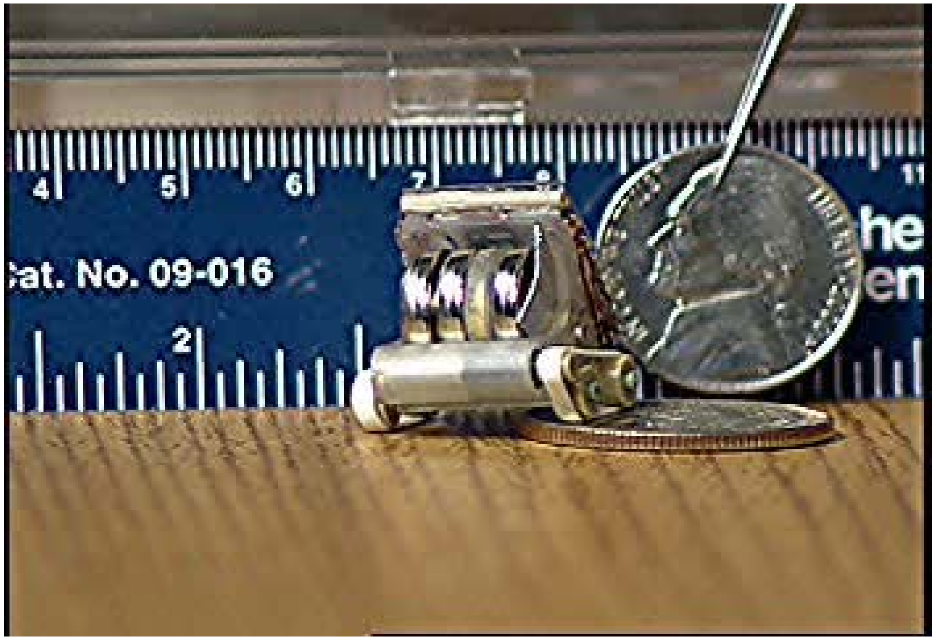
Miniaturization Micro-robot, 2001





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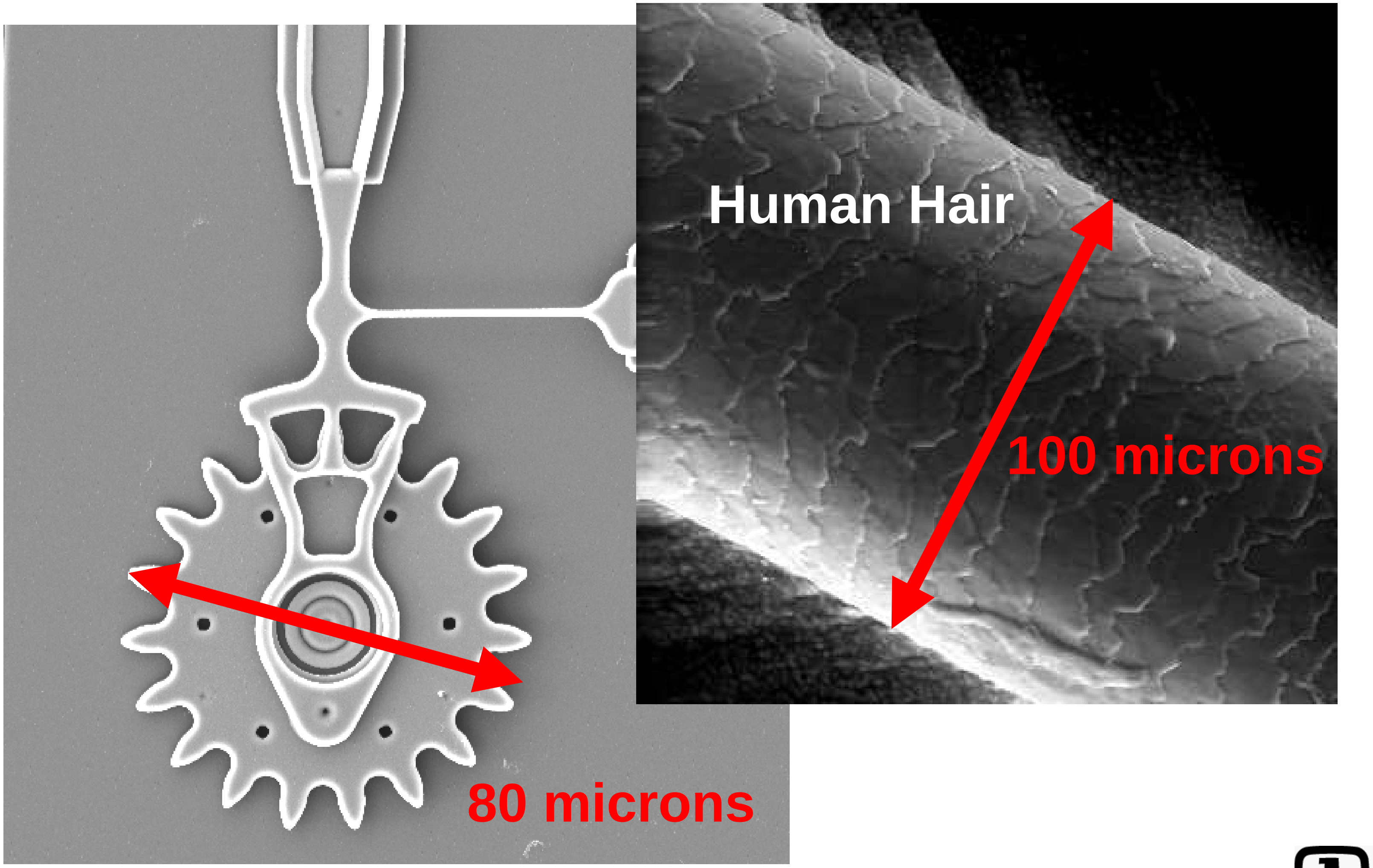
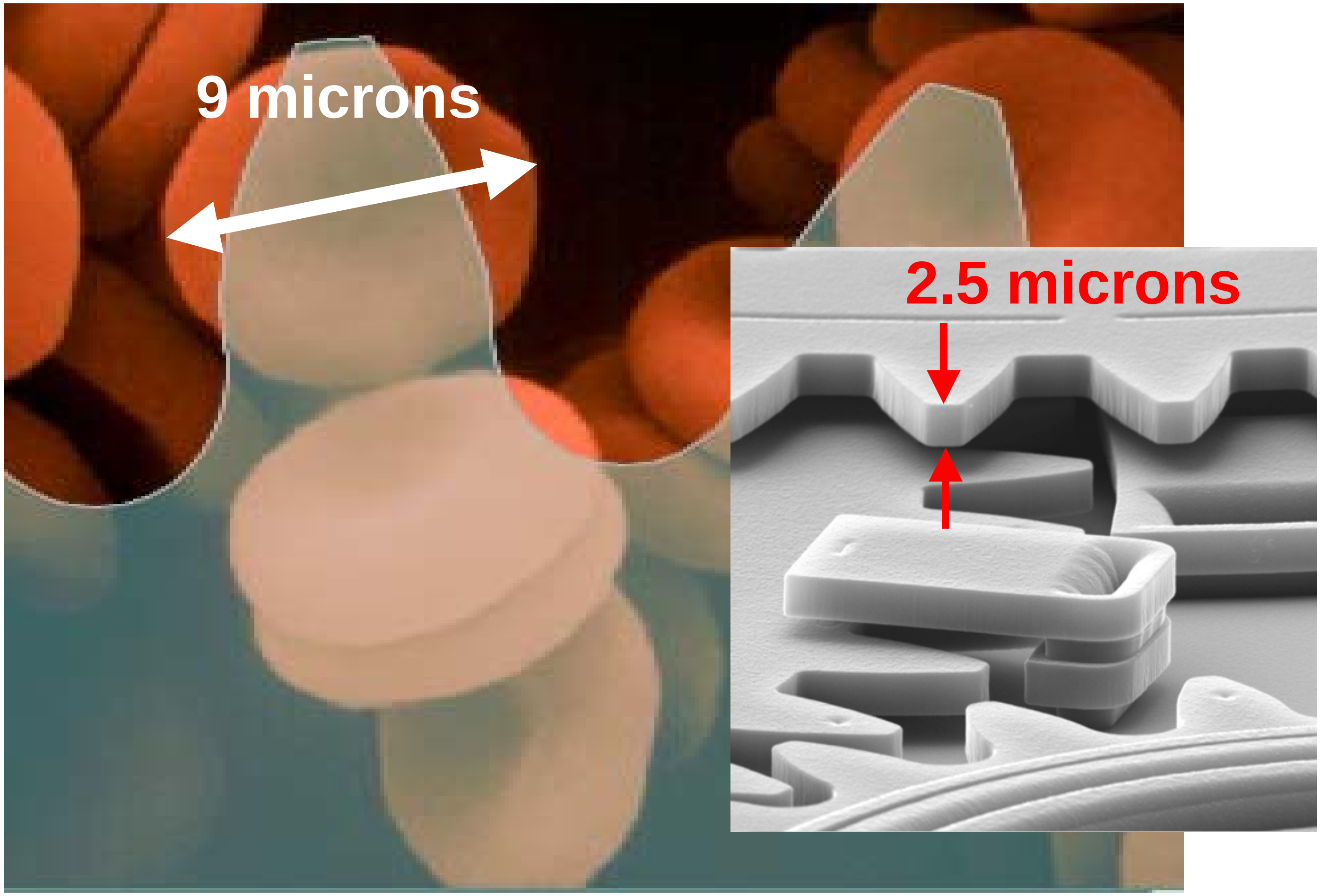
Microengine Drive Gear



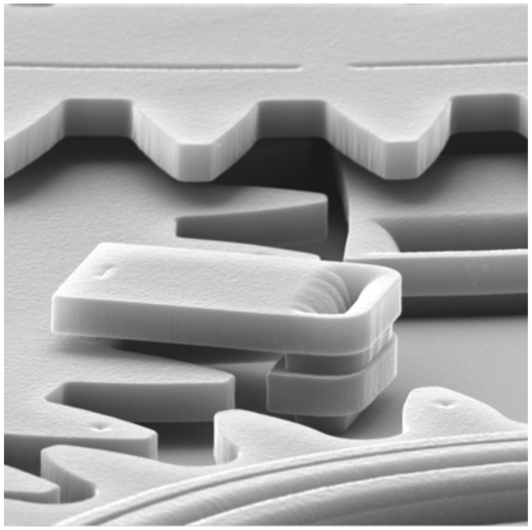
Microengine Gear Teeth are the Size of Red Blood Cells

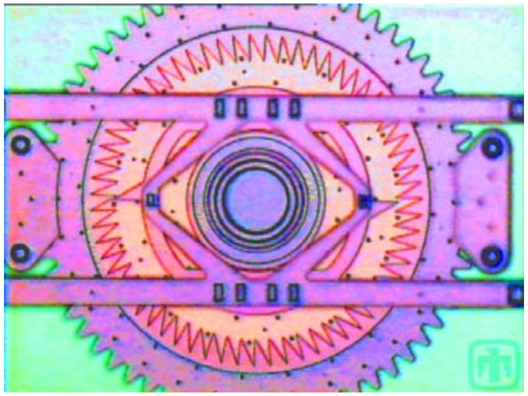


MEMS: It's Not About Making Things Small

- The microelectronics revolution changed the world because of cost, not size
- MEMS offers a way to make complex electromechanical systems at low cost
- In order to fully realize the potential benefits of MEMS, cost must be the driver
- Cost Issues:
  - **Maintain batch fabrication**
  - **Use standard IC materials**
  - **Leverage "standard" technologies and processes**

Why Should IC Manufacturers Care About MEMS?

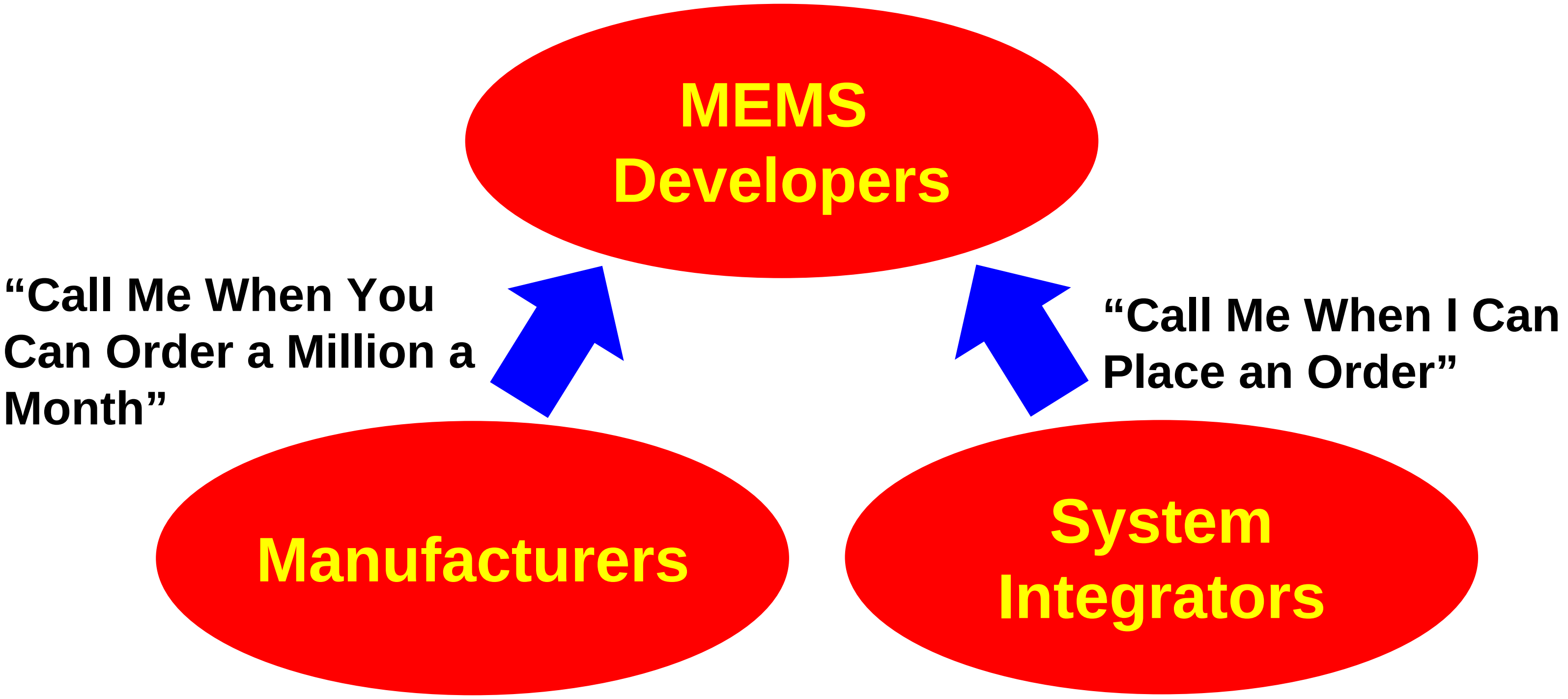




- New products in old fabs
- Seamless integration into existing fabs
- Don’t have to buy anything new
- Risk is low
- Logical next step

Successful MEMS Commercialization: The Challenges

The Chicken and Egg Problem



MEMS Developers

“Call Me When You Can Order a Million a Month”

“Call Me When I Can Place an Order”

Manufacturers

System Integrators

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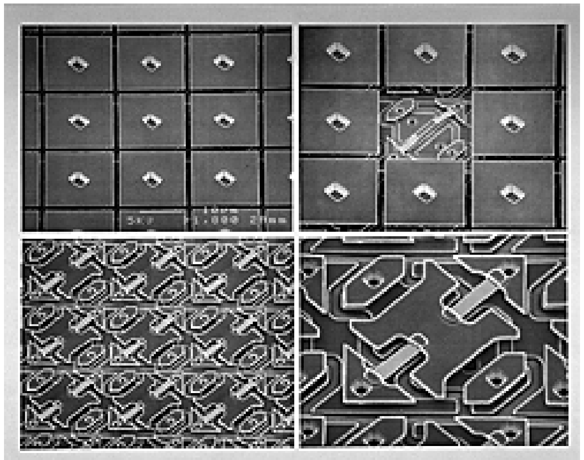
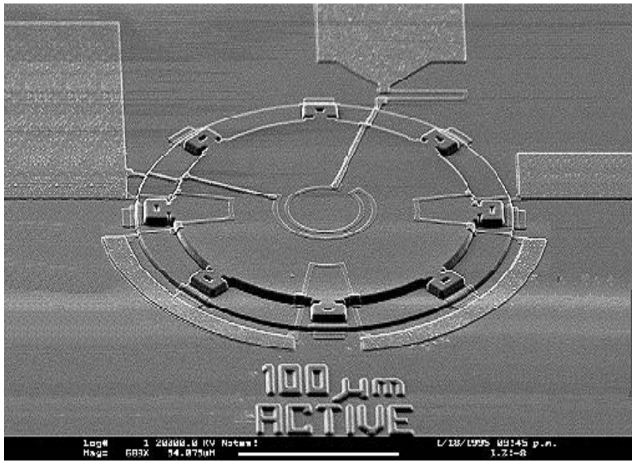
MEMS Challenges:
No Industry Standard Technologies



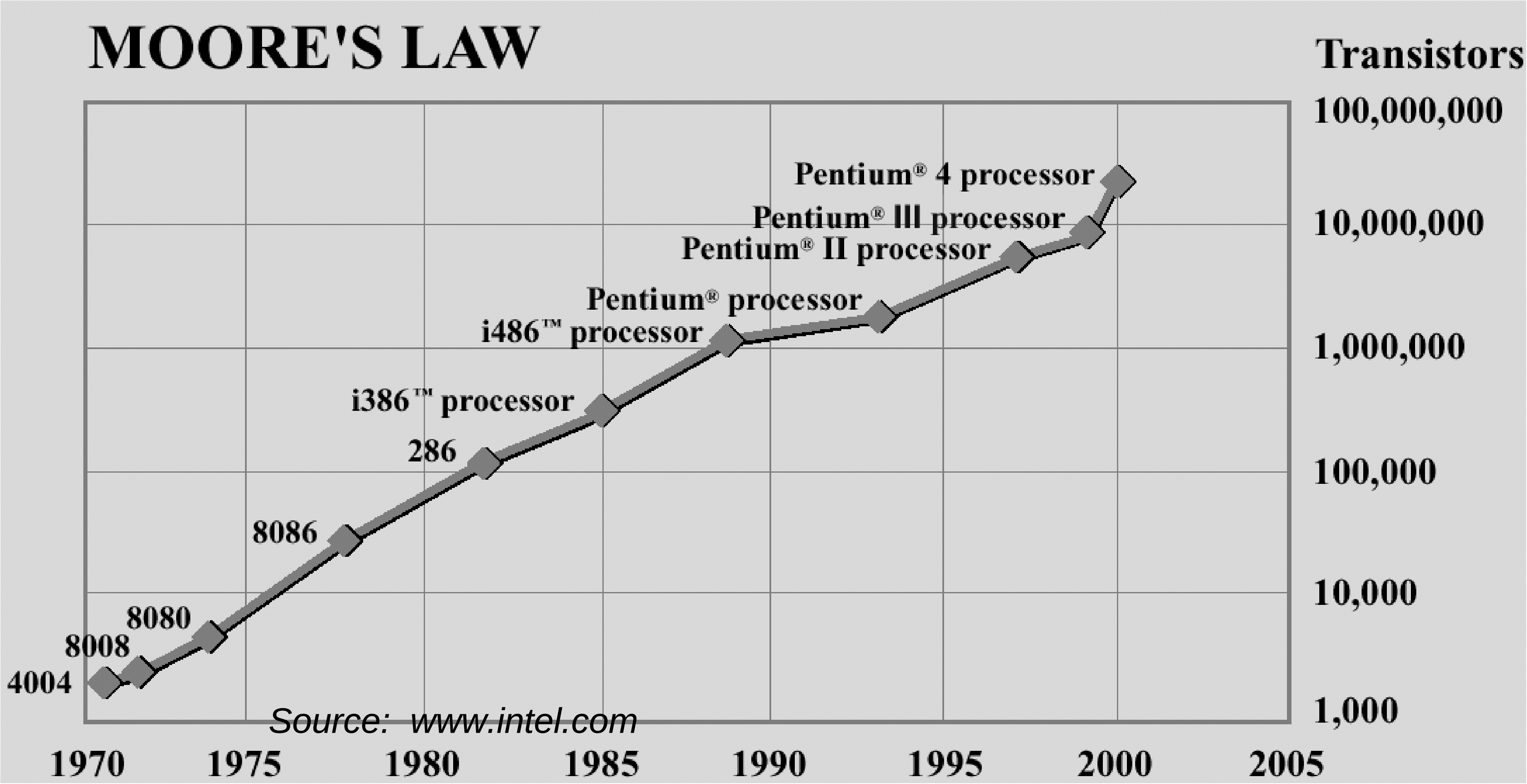
TI DMD



Pressure Sensor

- Technologies are application-specific
- Pressure sensors, accelerometers, Displays, and inkjet print heads all use different technologies
- No synergy or cooperation in design, packaging, qualification, and tool development

Transistor: Basic Building Block for IC's



Source: www.intel.com

No equivalent basic building block for MEMS

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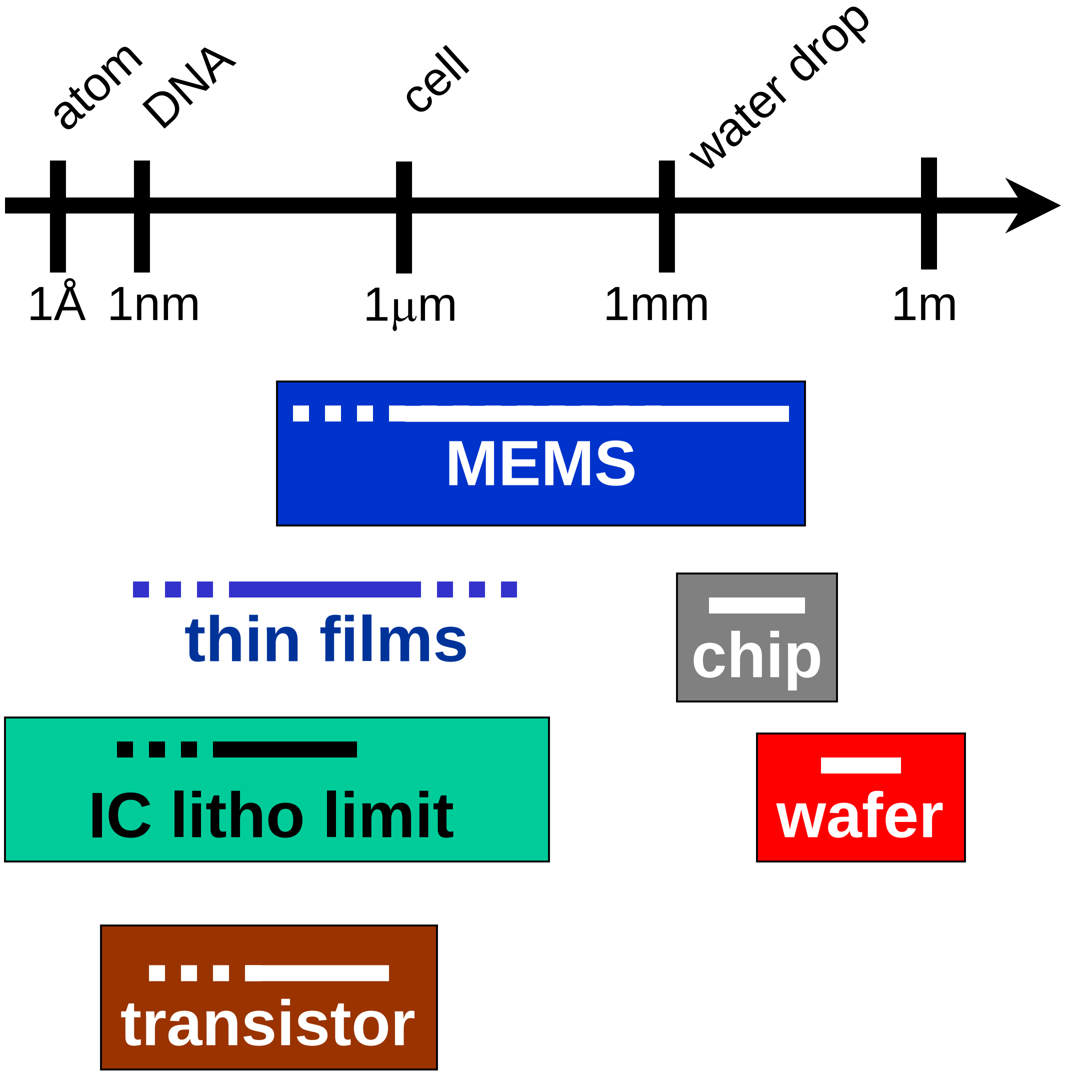
Integrated Circuit Vs. MEMS Technology

	ICs	MEMS
Film Thickness (μm)	<1	2-6
Critical Dimension (μm)	< 0.1 μm	1
Topography (μm)	<1	2-10
Device Size (μm)	<1	100

Processing Issues...

⇒ **Intrinsic Film *Stress***
⇒ **Thermal Budget**
⇒ ***Stiction***
⇒ ***Planarization***

MEMs Dimensions



atom
DNA
cell
water drop

1Å
1nm
1μm
1mm
1m

MEMS

thin films

chip

IC litho limit

wafer

transistor

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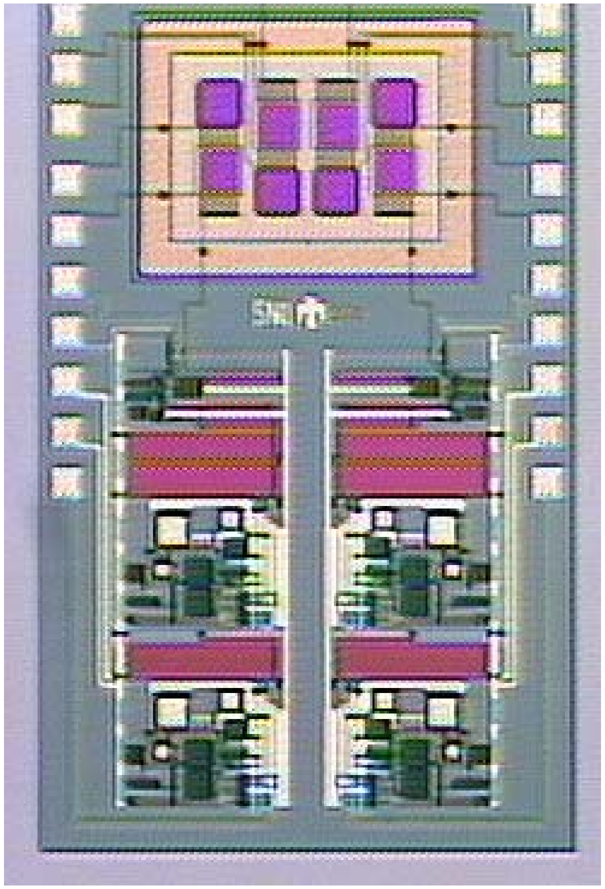
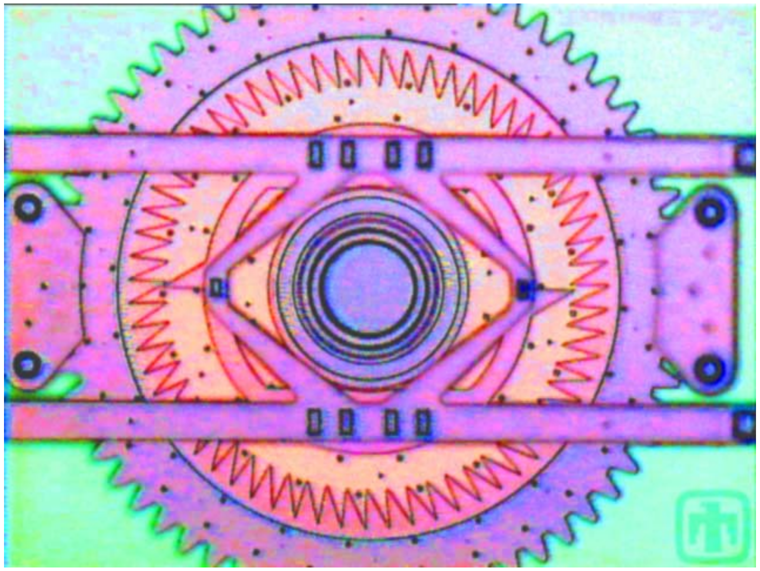
MEMS Allows Two Primary Functions: Sensing and Actuation



Sensors: Learn something about the environment

Actuators: Change something about the environment



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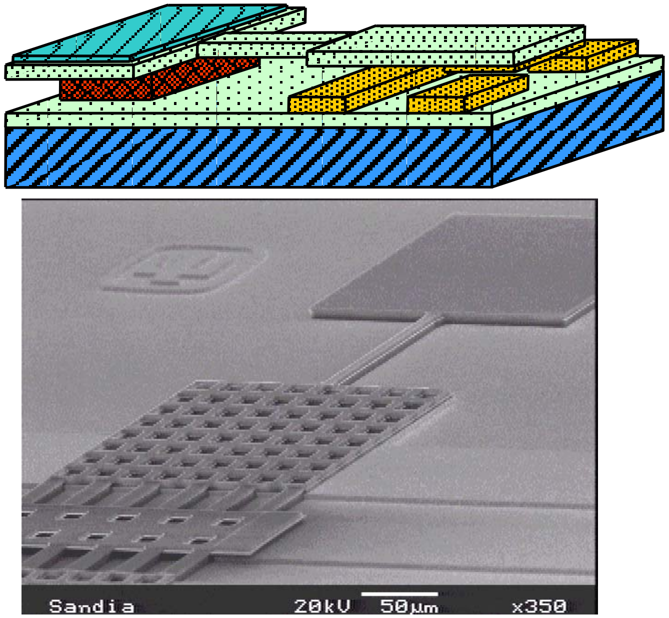
MEMS Applications

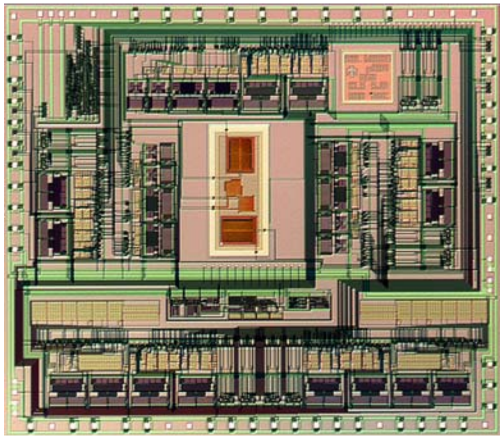
- Sensing Applications
  - Medical Pressure Sensors
  - Automotive Pressure Sensors
  - Smart Tires
  - Airbag Accelerometers
  - ABS Sensors
  - Auto Navigation Gyros
  - Pacemakers
  - Machine Monitoring

- Actuation Applications
  - Optical Switches/ Modulators
  - Optical Scanners
  - Disk Drives
  - Microbiology/Microsurgery
  - Infusion Pumps
  - Industrial Valves
  - Micro Aerodynamic Flaps
  - Ink- jet Print Heads
  - Semiconductor Assembly

More Advanced MEMs Concepts

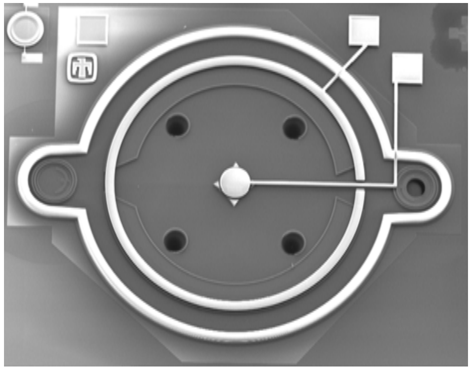
RF



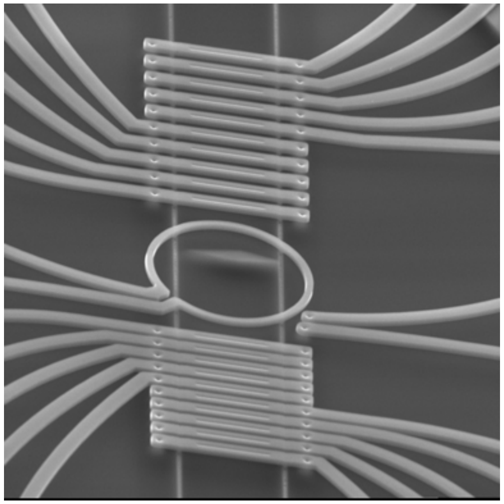


Inertial Measurement

micropump

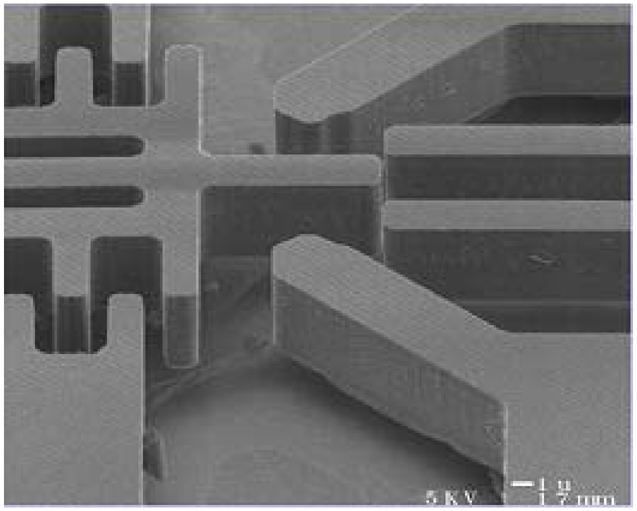


Microfluidics



Channels with electrodes

Optics



Waveguide Switch

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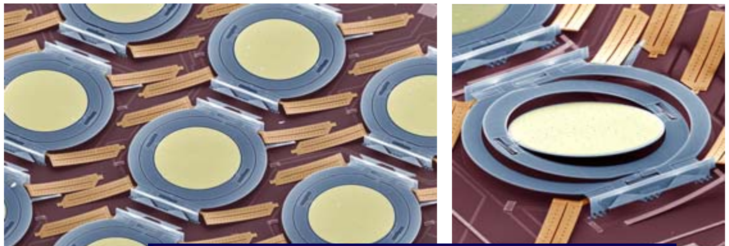
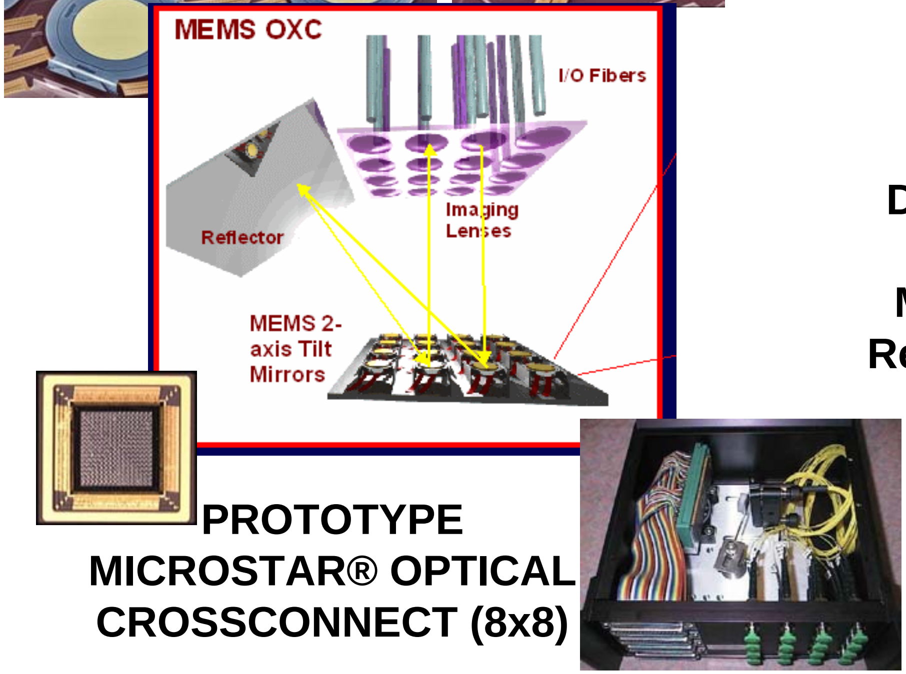
Example of Advanced Commercial Applications

Optical Switches

MICROSTAR® MIRROR ARRAY

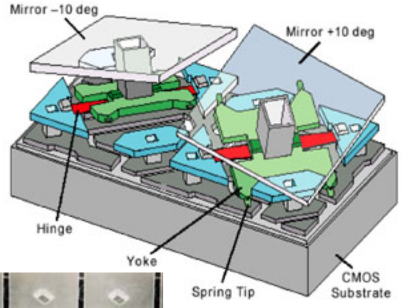




PROTOTYPE MICROSTAR® OPTICAL CROSSCONNECT (8x8)

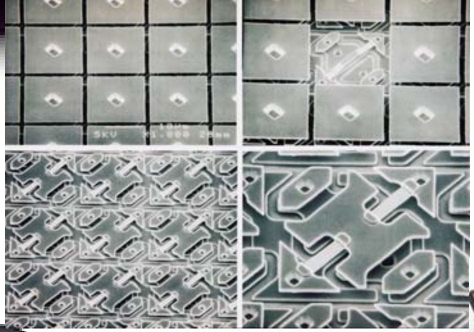
Bell Labs' MicroStar® Technology

Projection Systems



DMD™ Architecture

DMD™ with Mirror Removal



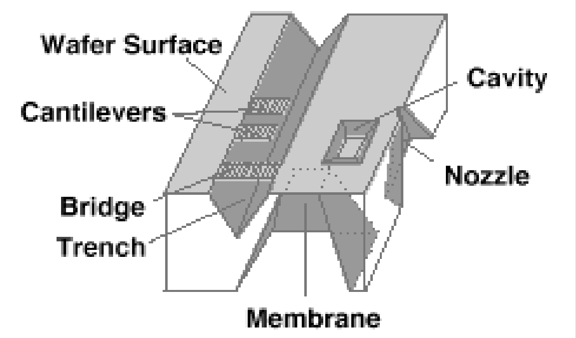
Packaged DMD™

Texas Instruments' Digital Light Processing (DLP™)

MEMS Fabrication Technologies

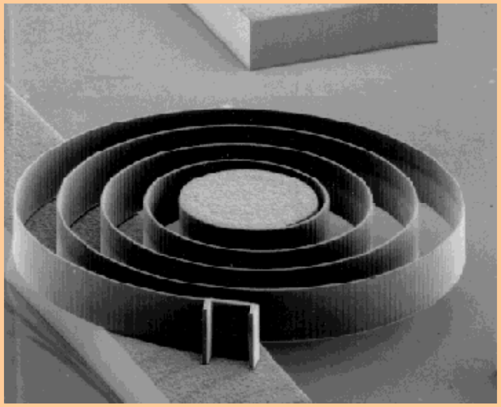
1. Bulk MEMS

Wet and/or dry etching of silicon substrate.



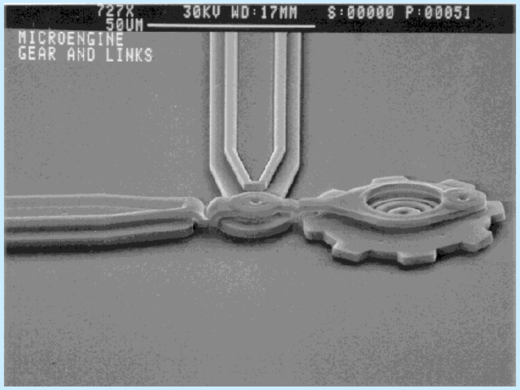
2. LIGA

X-ray lithography and electroplating.



3. Surface MEMS

Polysilicon deposition and etching of sacrificial films.

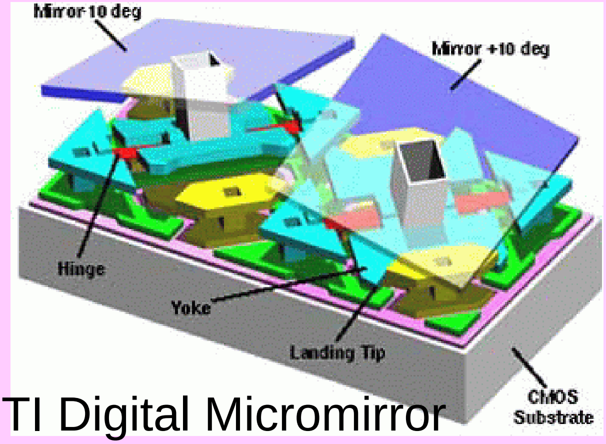


4. Modular MEMS/CMOS

a) CMOS first/MEMS last

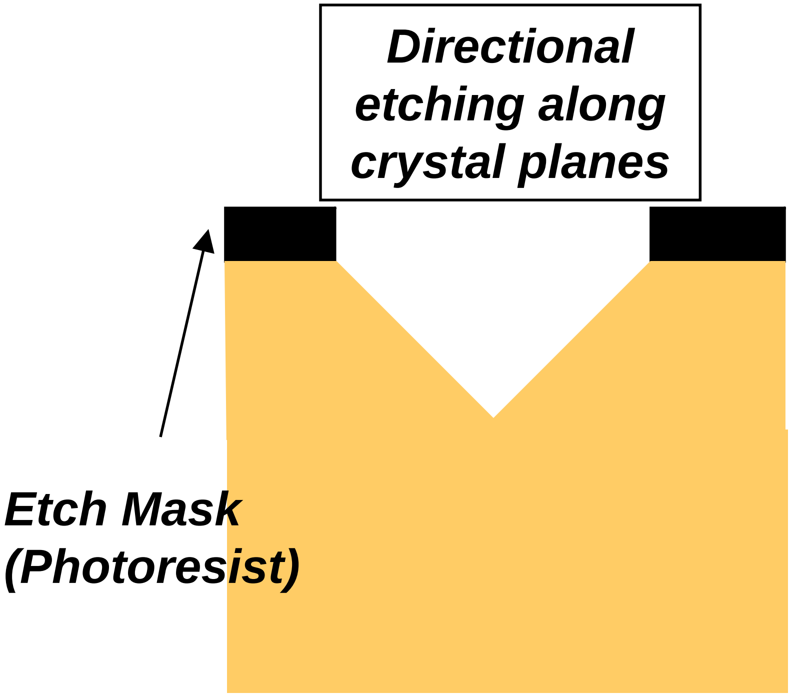
or

b) MEMS first/CMOS last



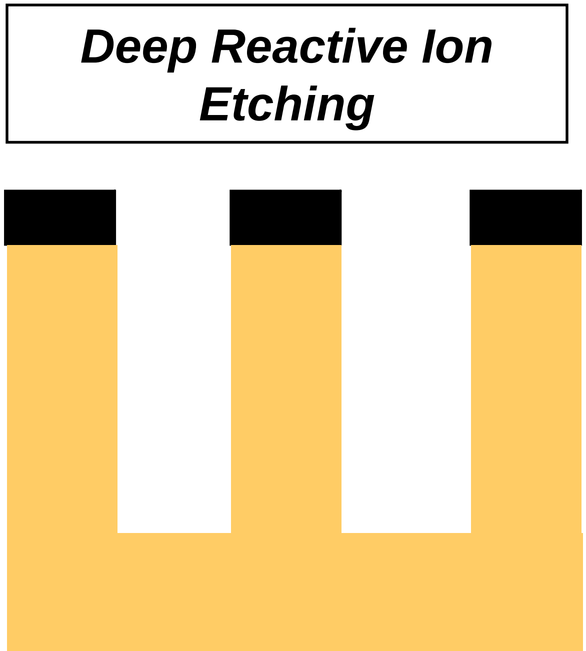
TI Digital Micromirror

Bulk Silicon Micromachining

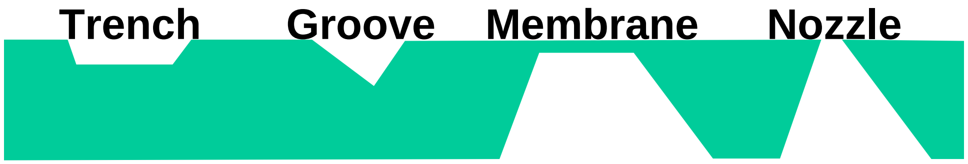


Directional etching along crystal planes

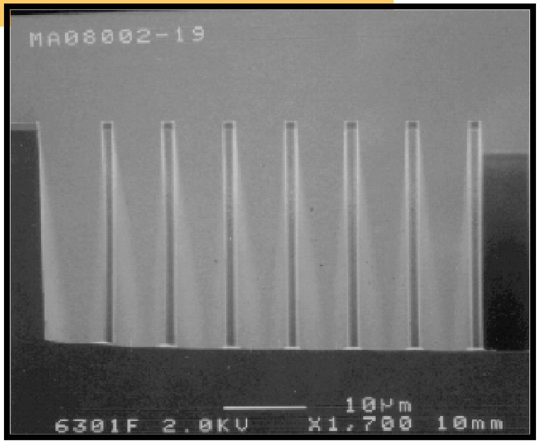
Etch Mask (Photoresist)



Deep Reactive Ion Etching



Examples of Bulk Micromachine Structures Formed Using KOH Etches



Example of Deep silicon etch using Bosch etcher

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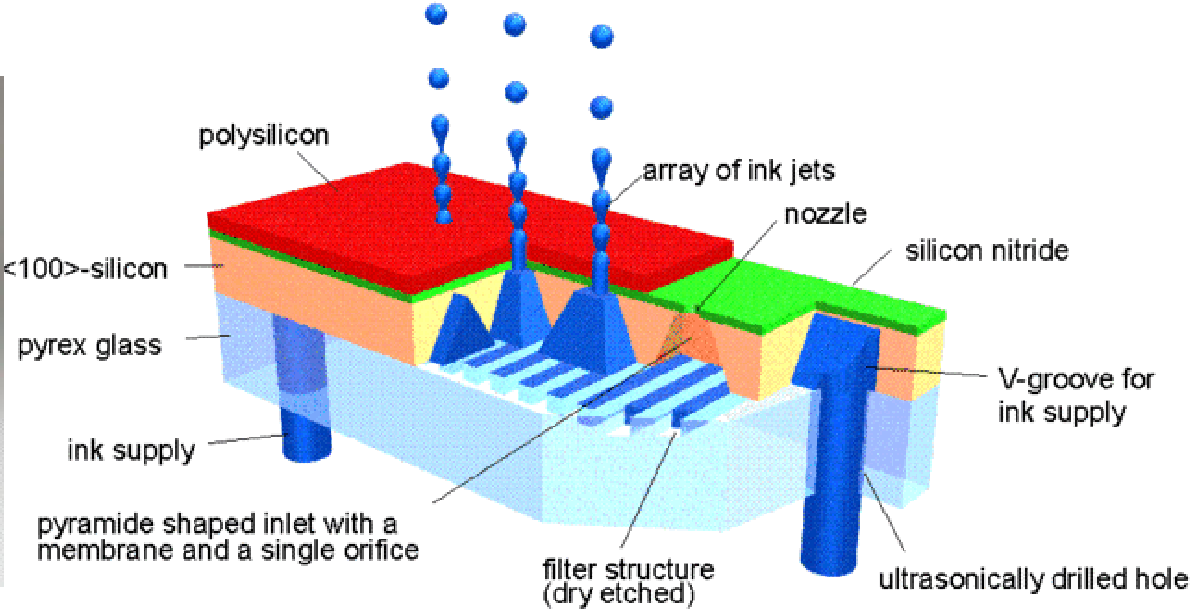
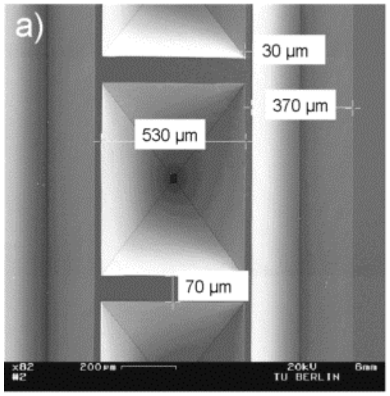
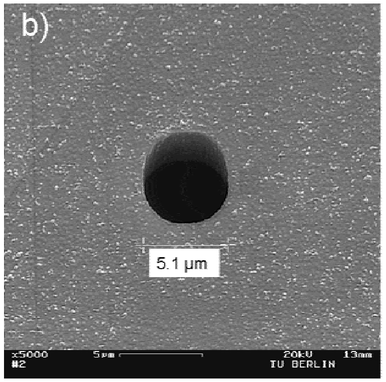
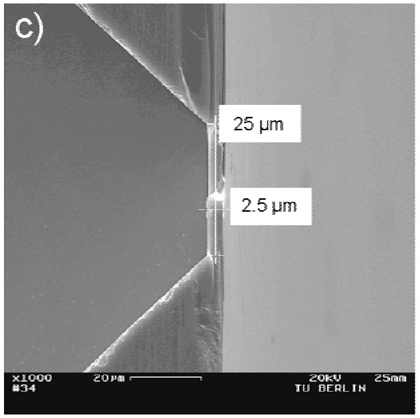
Bulk Micromachining: Inkjet Printers

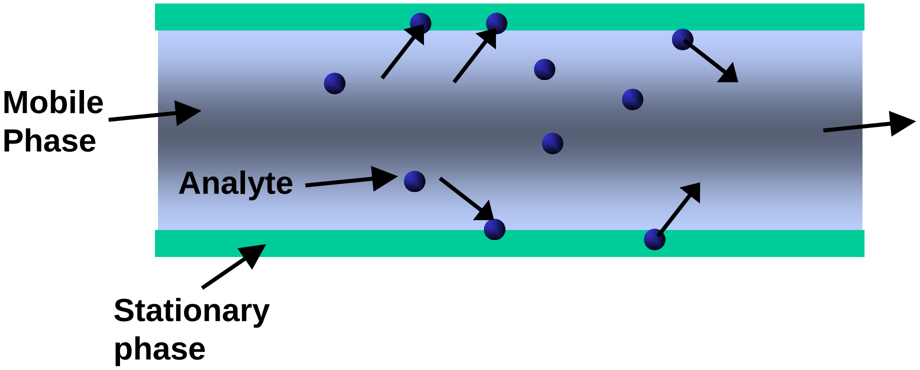








Chemical Separation Using a Gas Chromatograph Column

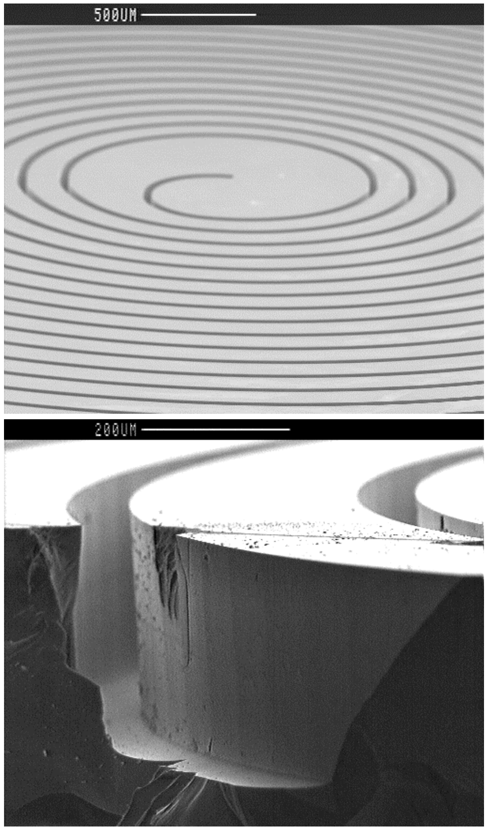


Mobile Phase

Analyte

Stationary phase

Bosch Deep Reactive Ion Etch

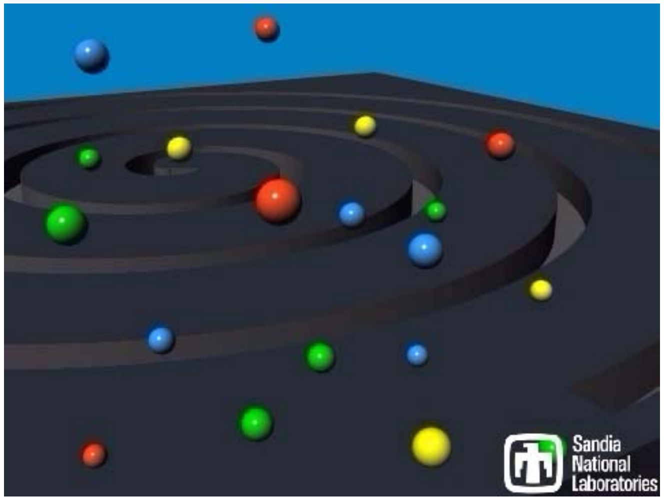


-A mixture of analytes is injected into the column

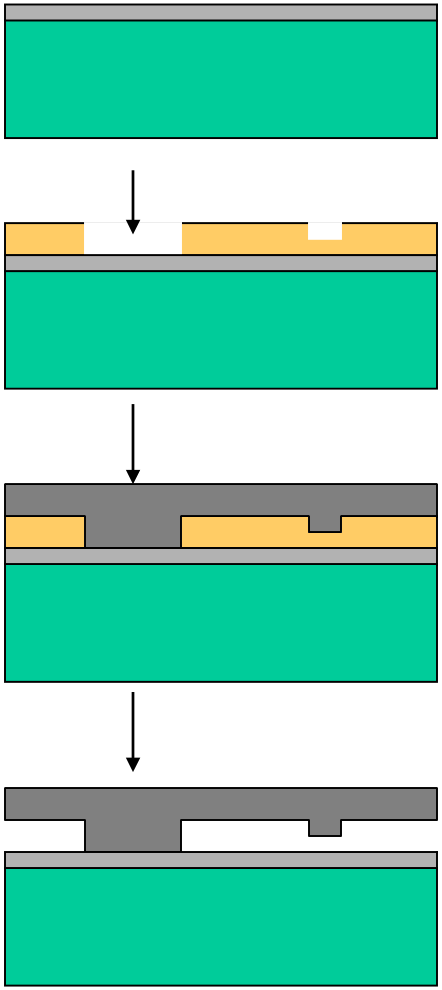
-A carrier gas (air) carries the mixture thru the column

-Analytes are repeatedly absorbed/desorbed by a coating (stationary phase)

-Different coating/analyte affinities cause separation



Single level Surface Micromachining



Poly Groundplane

PSG Deposition and Patterning

- **Anchor Cut**
- **Dimple**

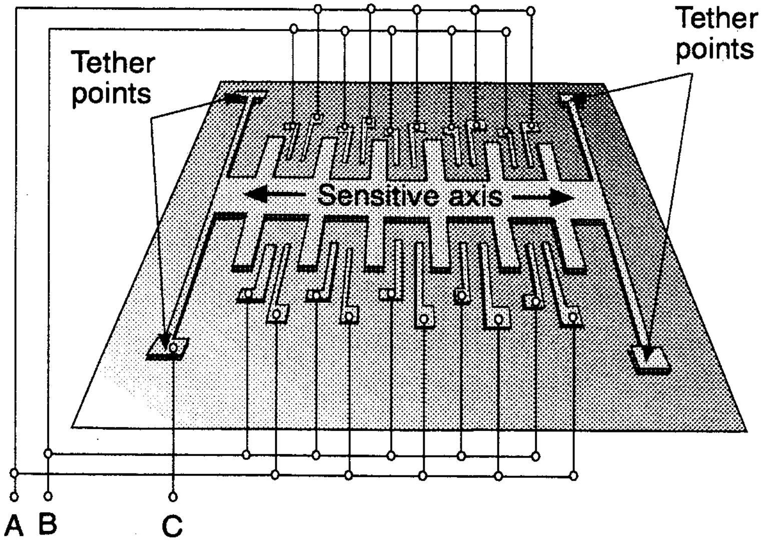
Structural Polysilicon Deposition

Release in Hydrofluoric Acid

Analog Devices, ADXL-50

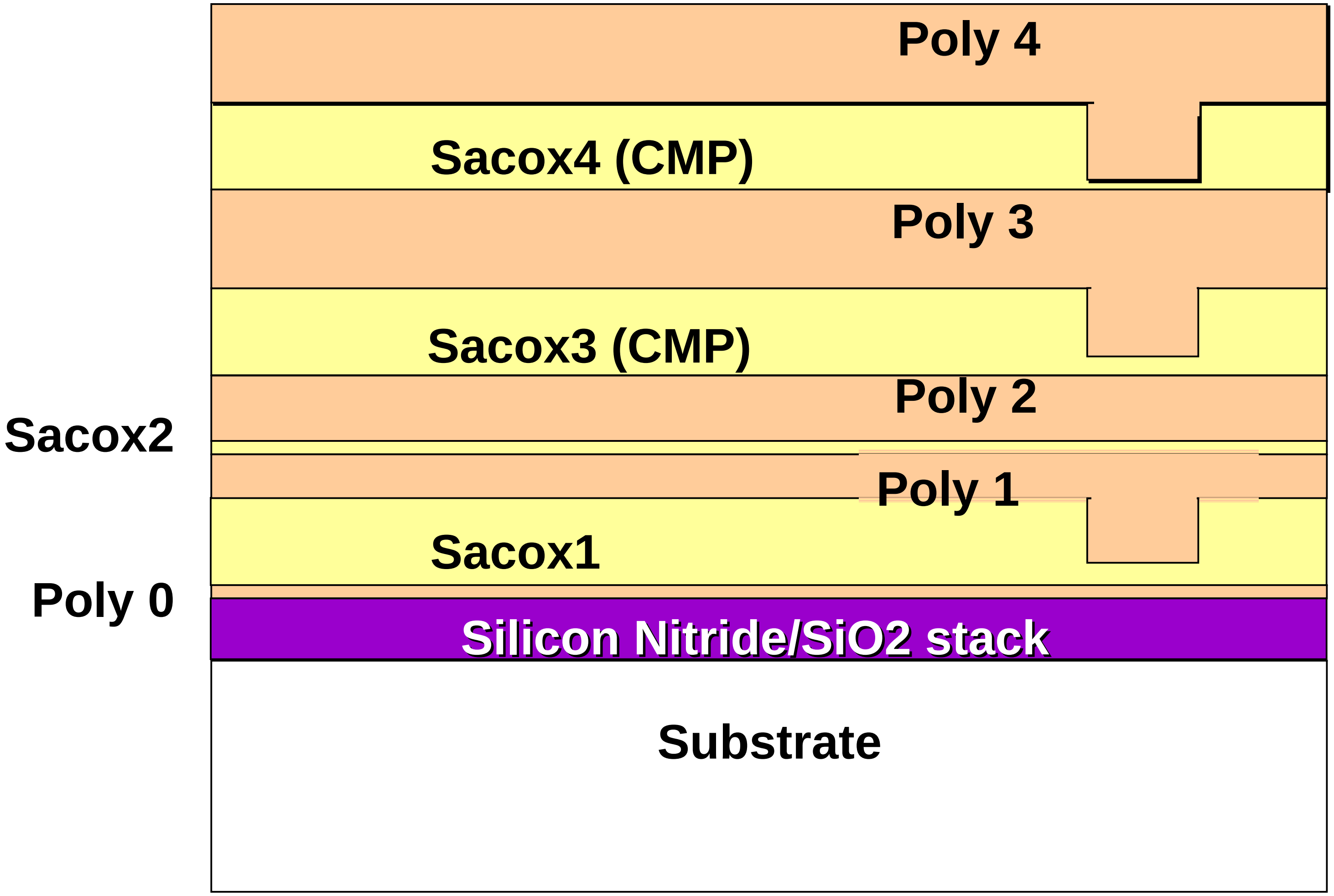
⇒ **Early Commercial Surface Micro-Machined Device**

⇒ **2-µm BiCMOS Fab Line**



Source: Analog Devices

Multi-level Surface Micromachining



SUMMiT™ – Sandia's Ultra-planar Multi-level MEMS Technology

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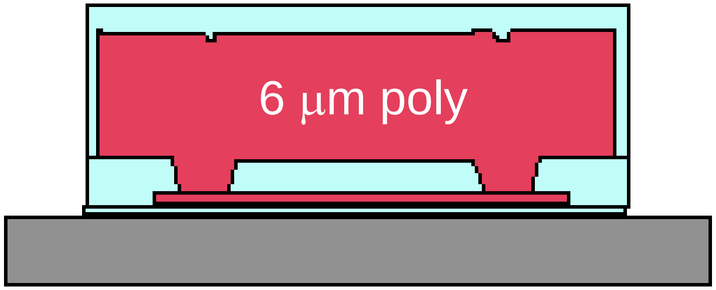
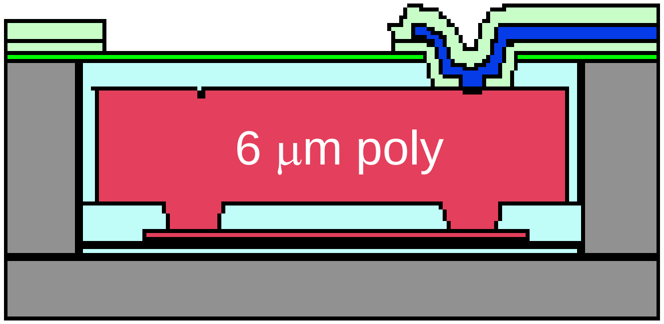
Modular MEMS-CMOS Process*



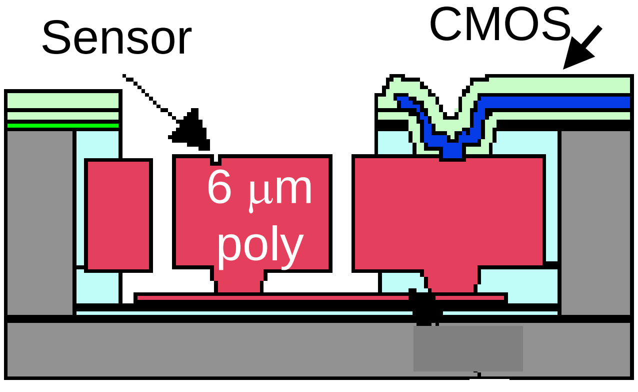
Build-up MEMS structure on wafer. Pattern & etch area to leave encapsulated MEMS island.

↓



Grow selective epi around MEMS module and planarize with CMP. Foundry CMOS electronics with contacts to MEMS poly layer.

↓

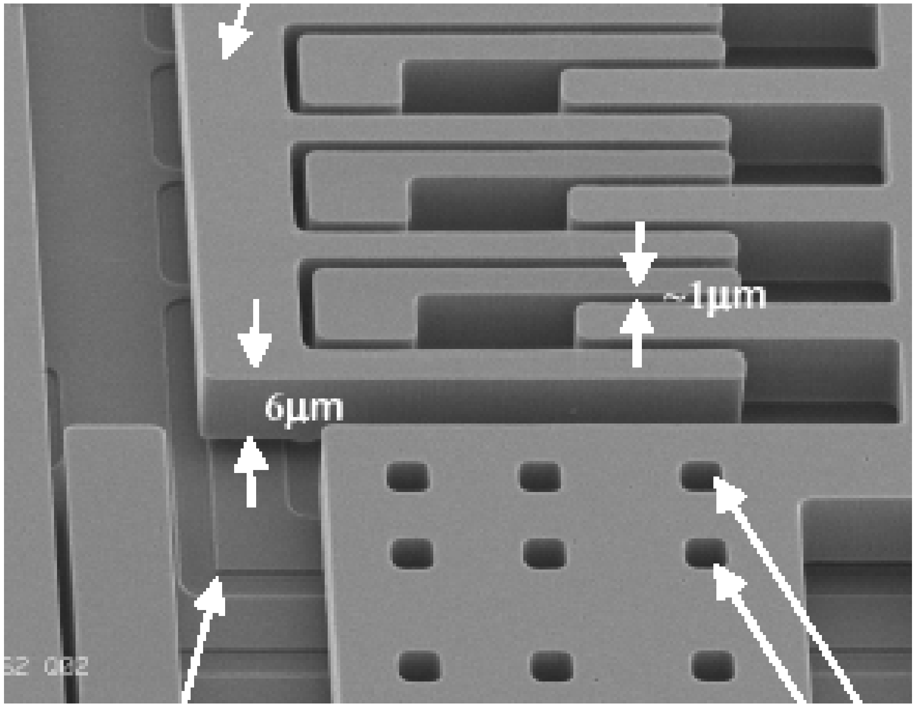


Pattern and release beams.

*M. Palaniapan, et al. IEDM Tech Digest Dec. 2002.

Modular MEMS-CMOS Process*

6 μm poly



SEM of a integrated z-axis microgyroscope fabricated device.

Polysilicon layer making electrical contact to CMOS circuits (not shown).

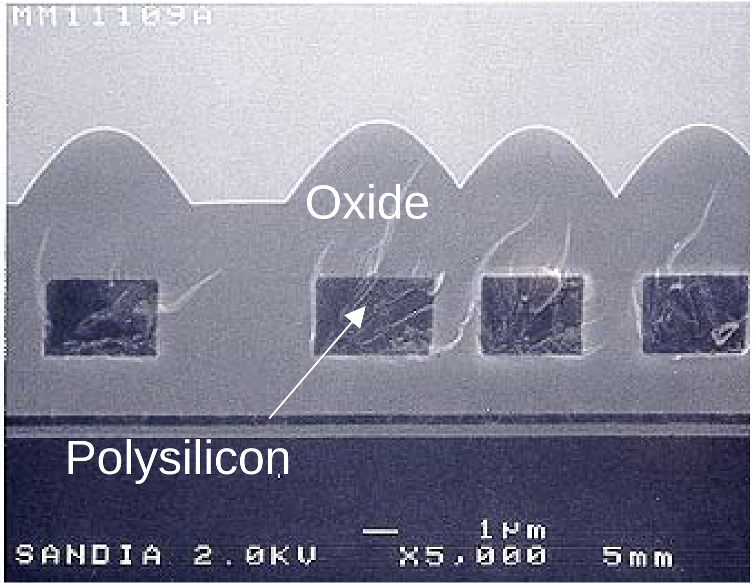
Etch holes

*M. Palaniapan, et al. IEDM Tech Digest Dec. 2002.

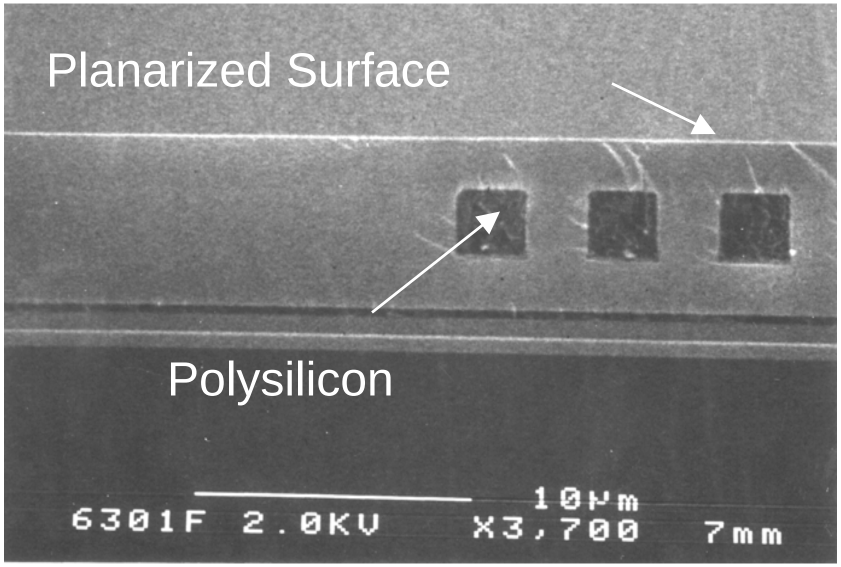
How Is CMP Used in MEMS Fabrication?

Planarization of Sacrificial Oxide

Pre CMP

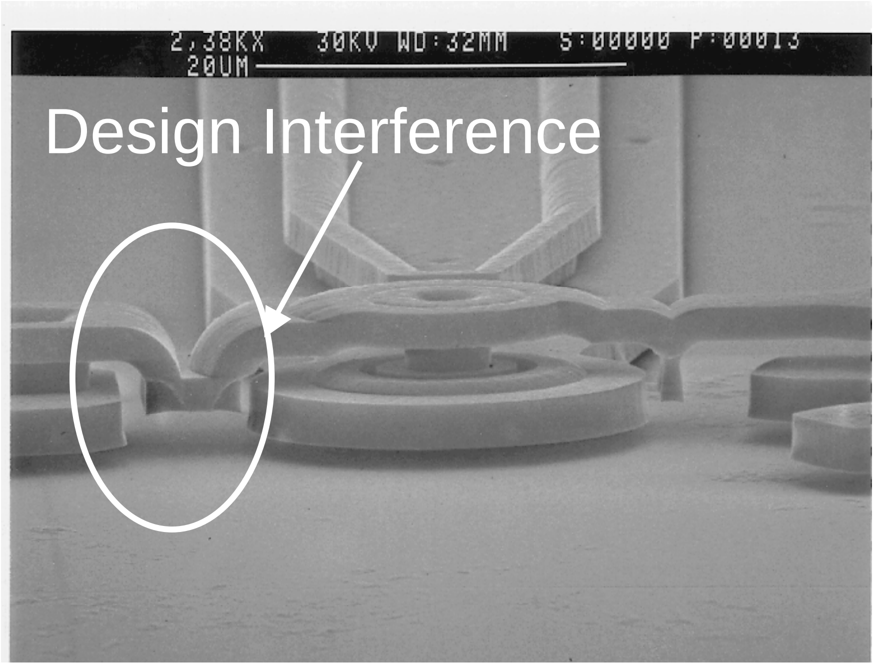


Post CMP



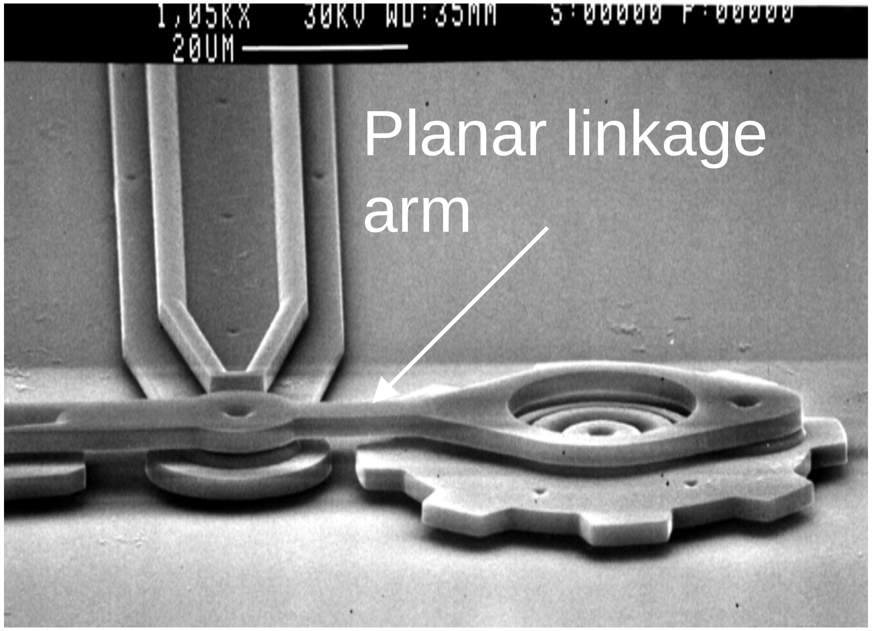
CMP eliminates design constraints

Without CMP



Design Interference

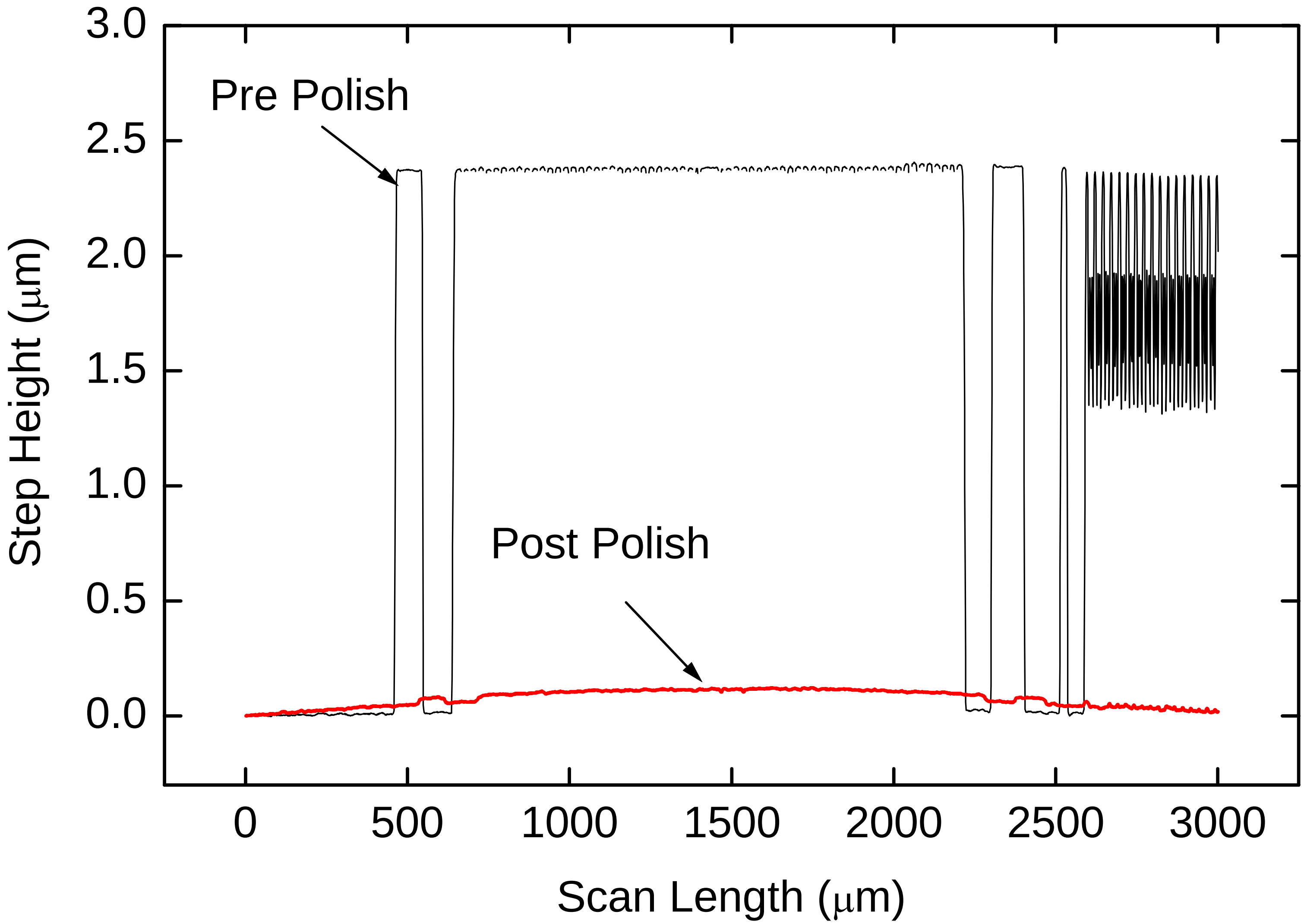
Planarized with CMP



Planar linkage arm

Microgear, Linkage, and Hub Assembly

Oxide step height reduction



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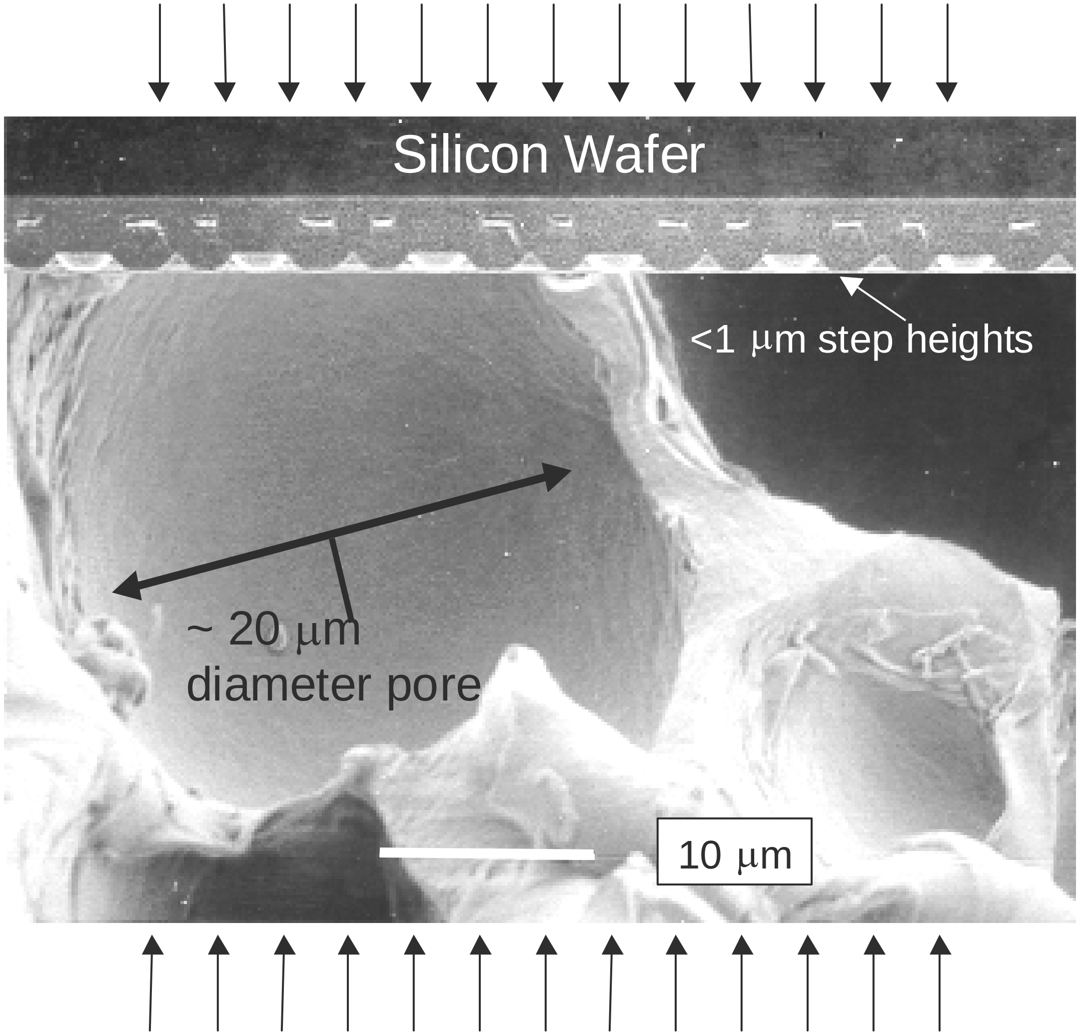


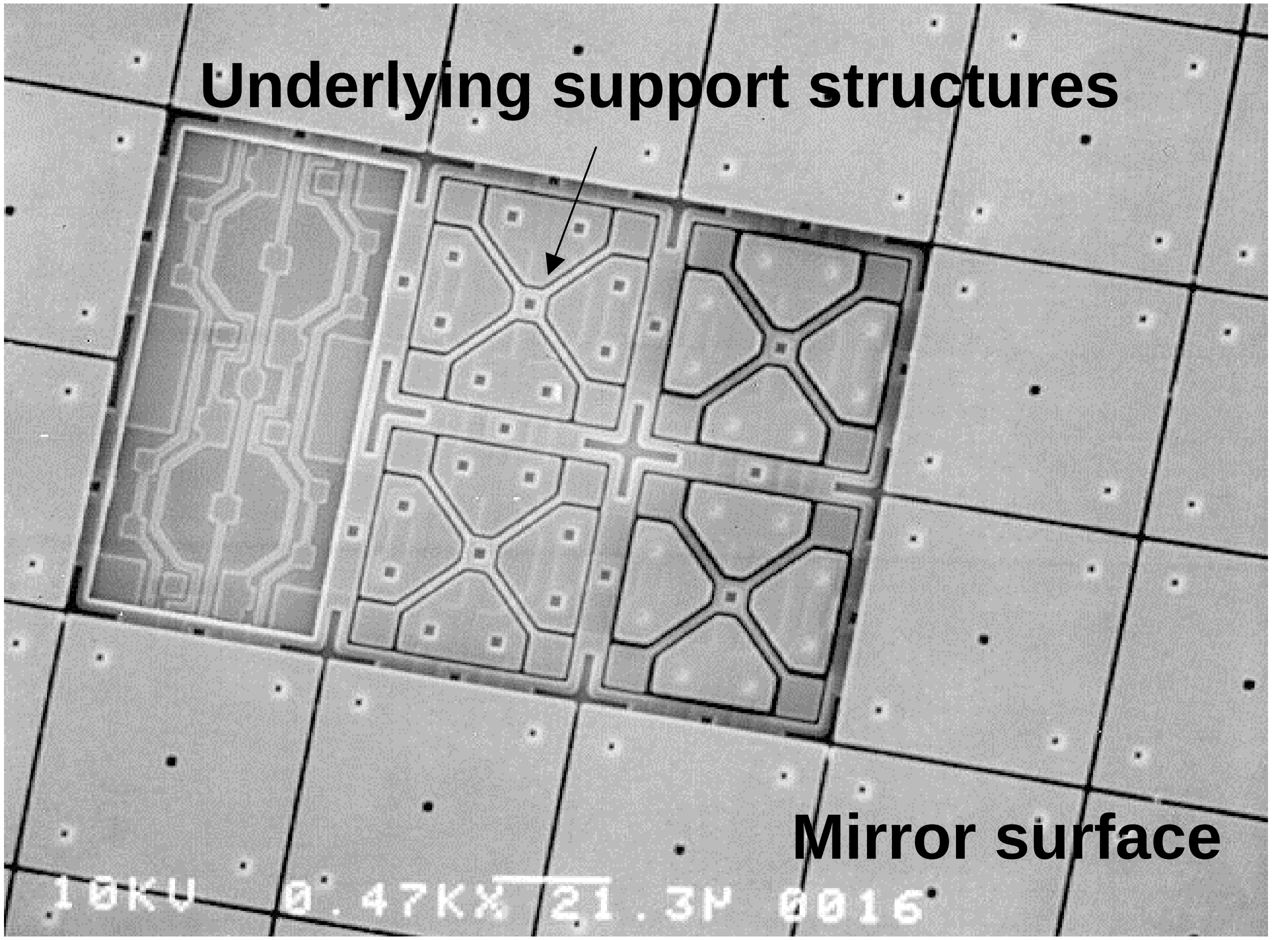
Polyurethane Pad

SEM Photo - P. Shea, Sandia National Labs

CMP Processing Issues

- Consumables
  - Pad
    - Pad wear – conventional IC pad lifetime is short
    - Conditioning – need aggressive conditioning
    - Asperity interaction with step height – microscale slurry transport problems
  - Slurry
    - Removal rate – conventional oxide slurry RR is low
    - Desire high RR while maintaining good uniformity
- Equipment
  - Wafer handling
    - Carriers must accommodate increased bow/warp
  - Metrology
    - Measurement of thick films
- Pattern density
  - Tolerances for within die uniformity are not as stringent as conventional IC tolerances for certain applications

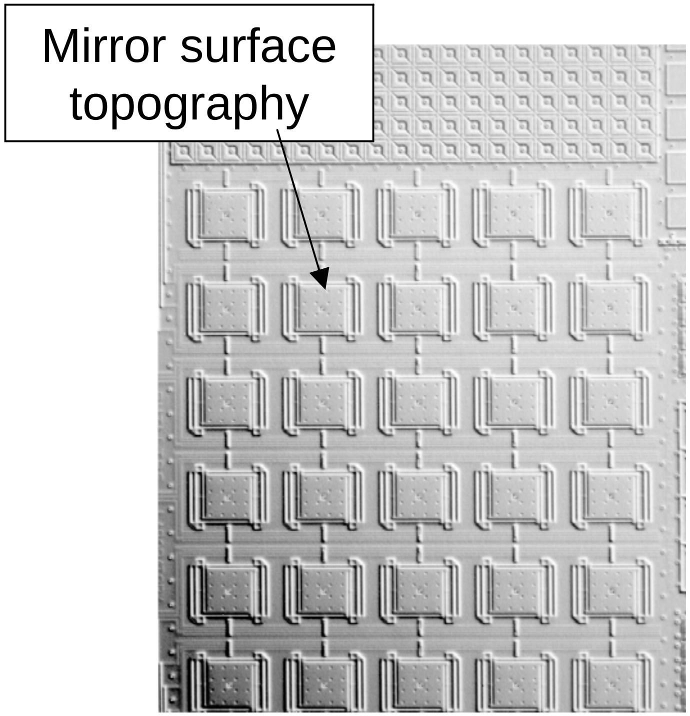
Polysilicon Micro-Mirror Structure*

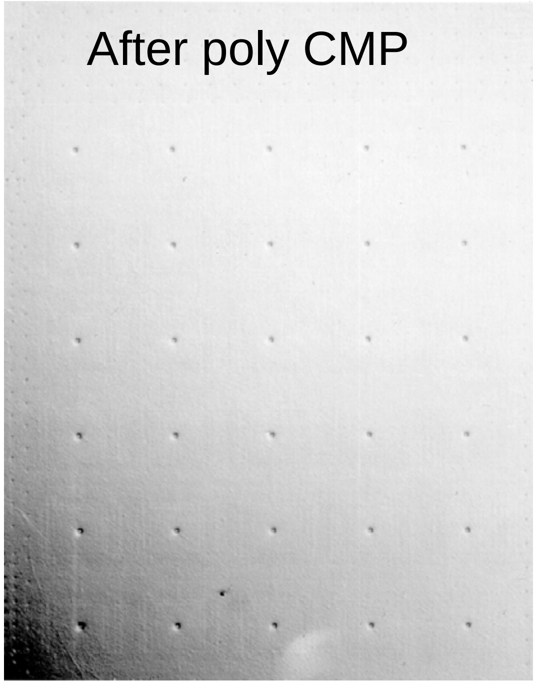


* Phillips USAF Research Laboratory

Polysilicon layer CMP

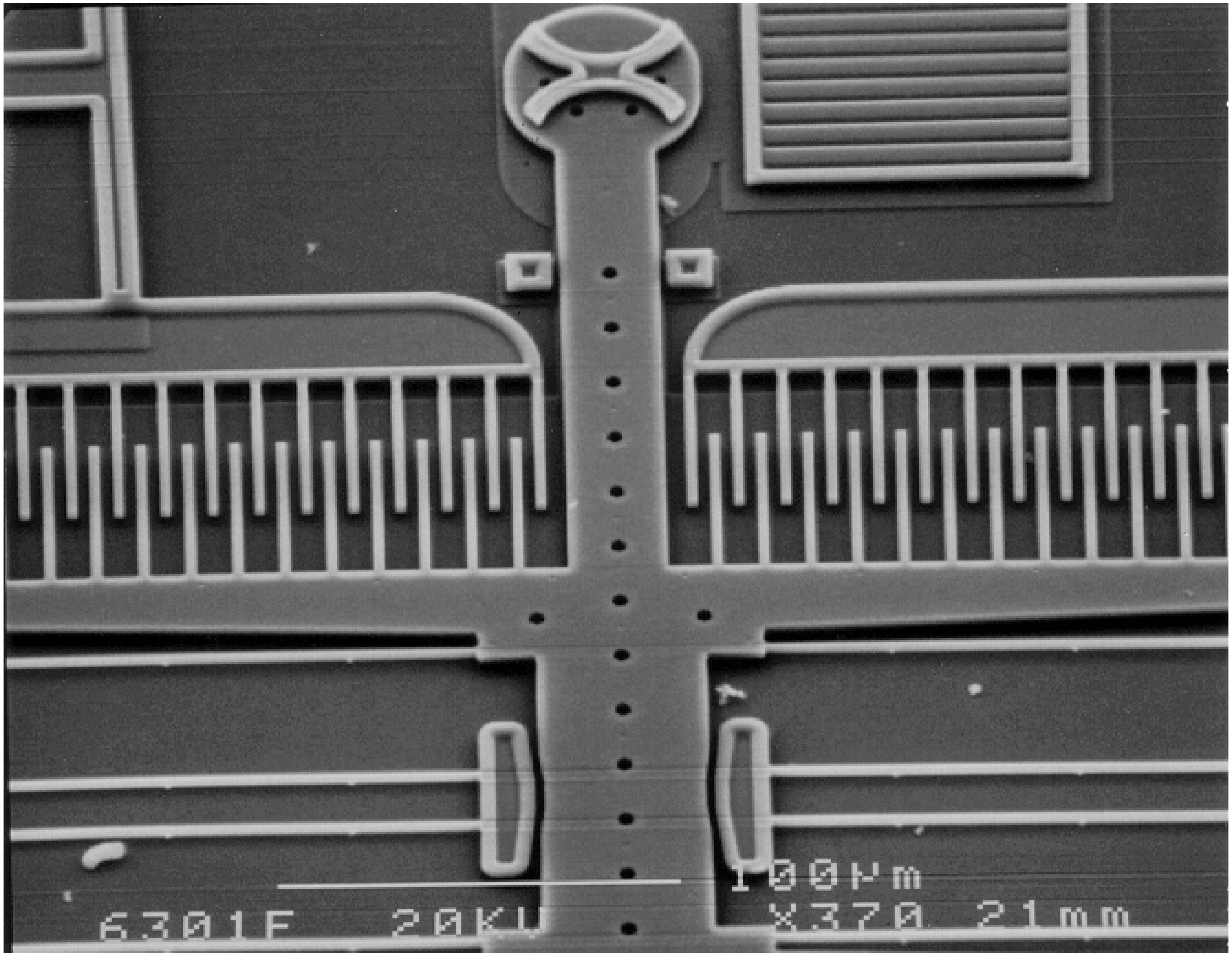
- CMP polysilicon micromirror surface to eliminate print-through effect





D. L. Hetherington, et al., Proceedings of SPIE Volume 3440, July 1998.

Electrostatic Actuation



Comb Drives
1300 µm X 1100 µm

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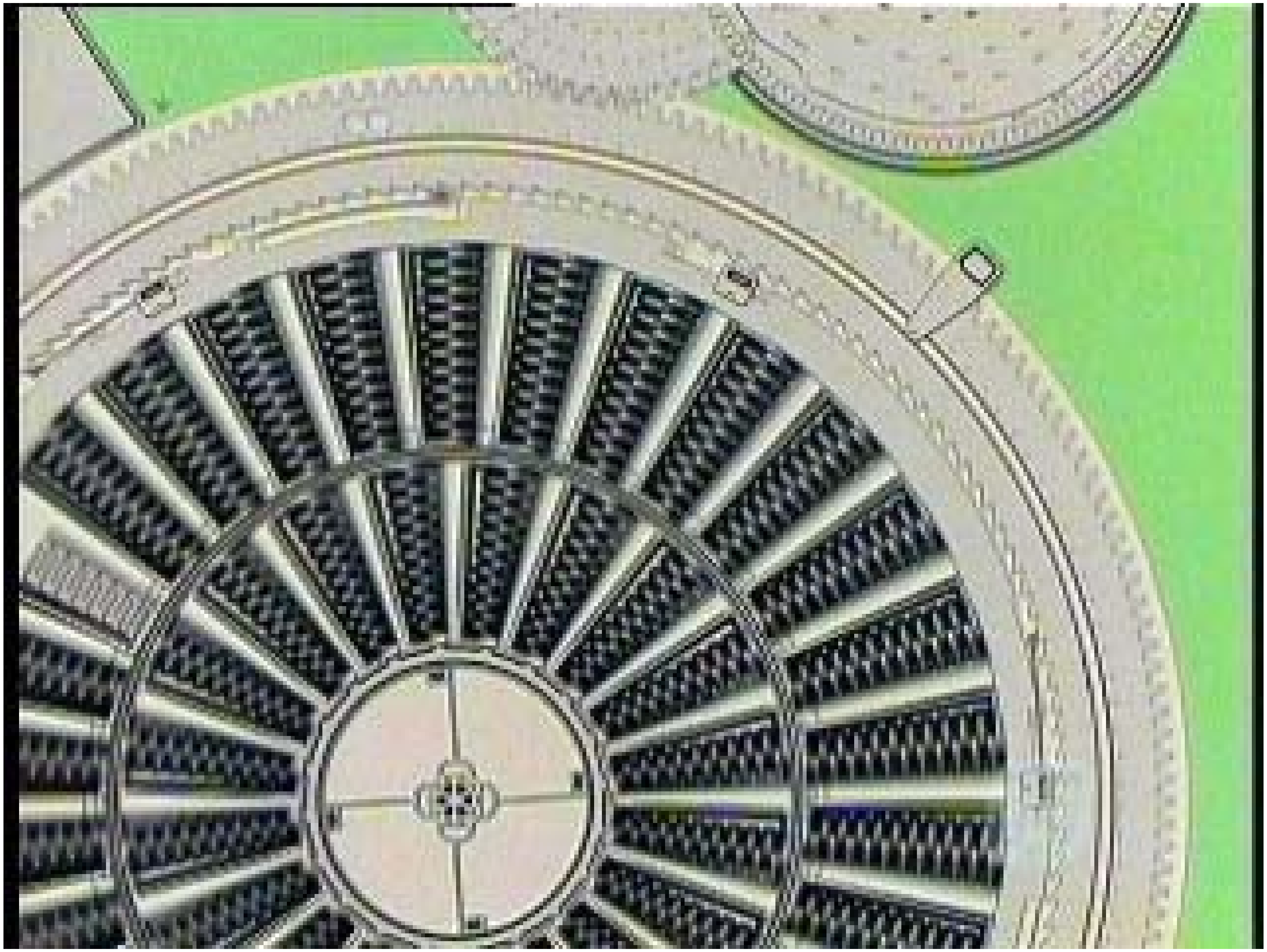
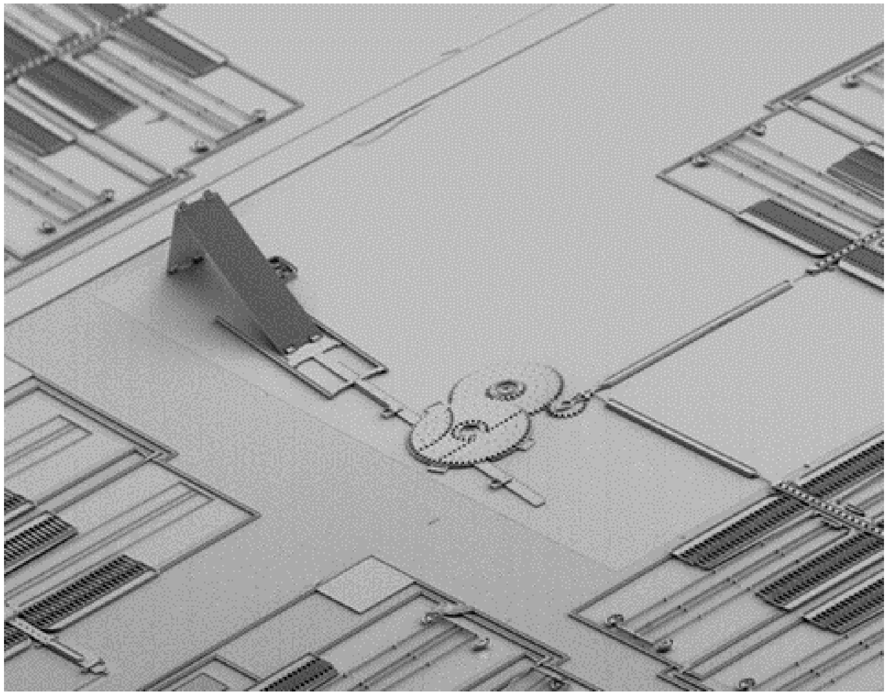
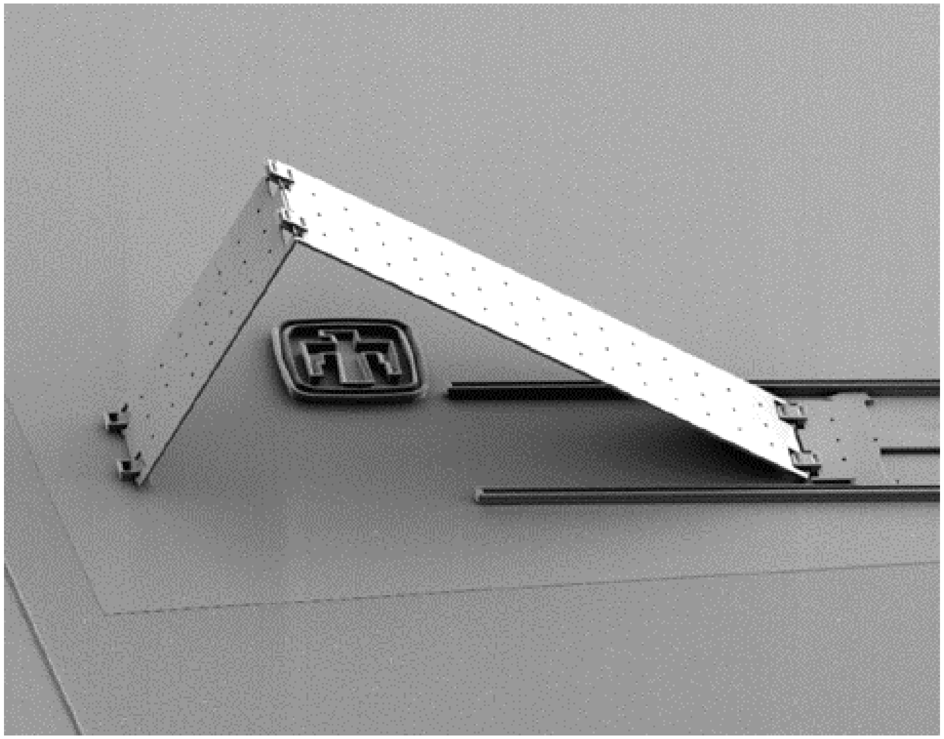
Tortional Ratchet Actuator



Positionable Mirror





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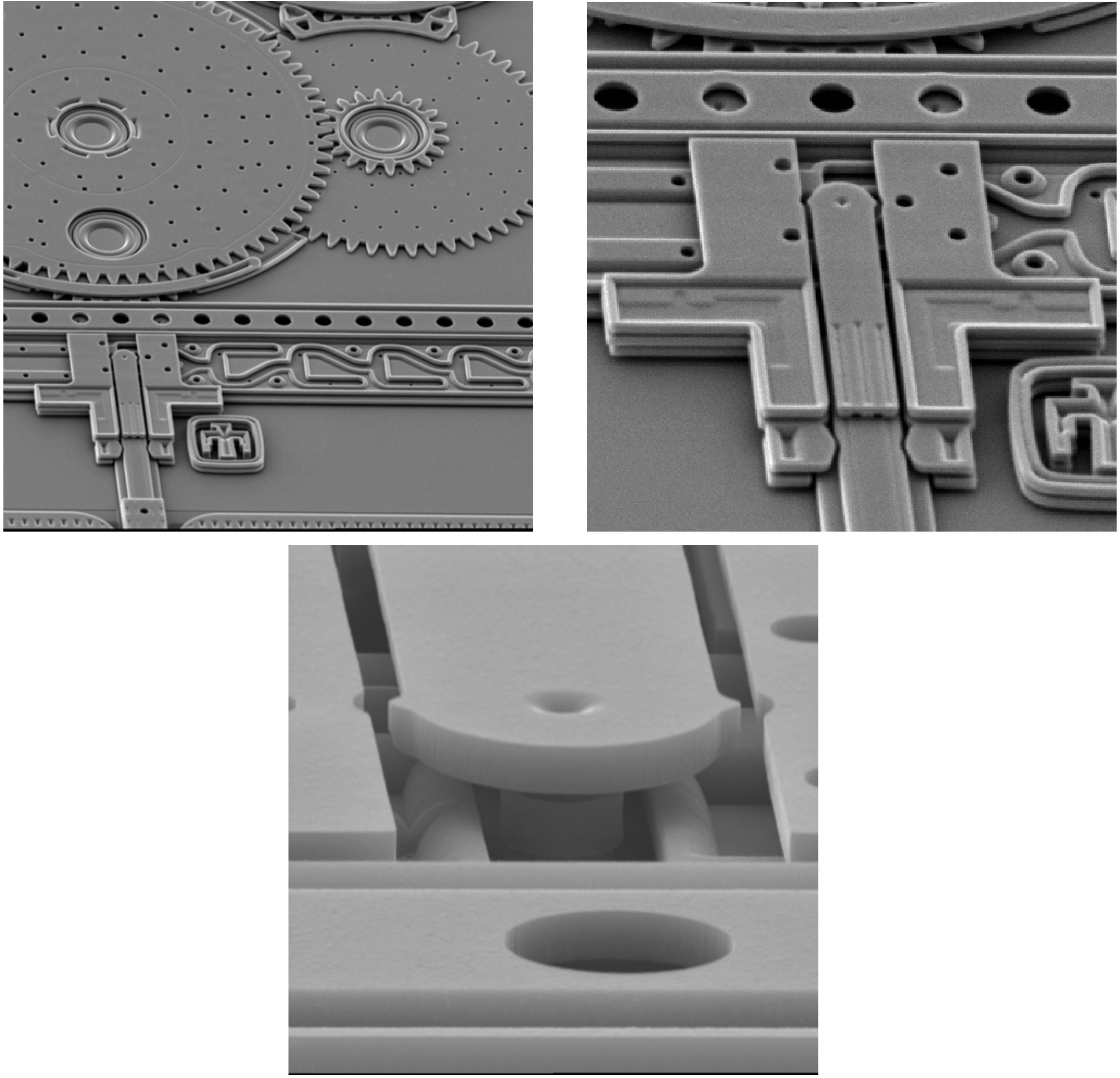
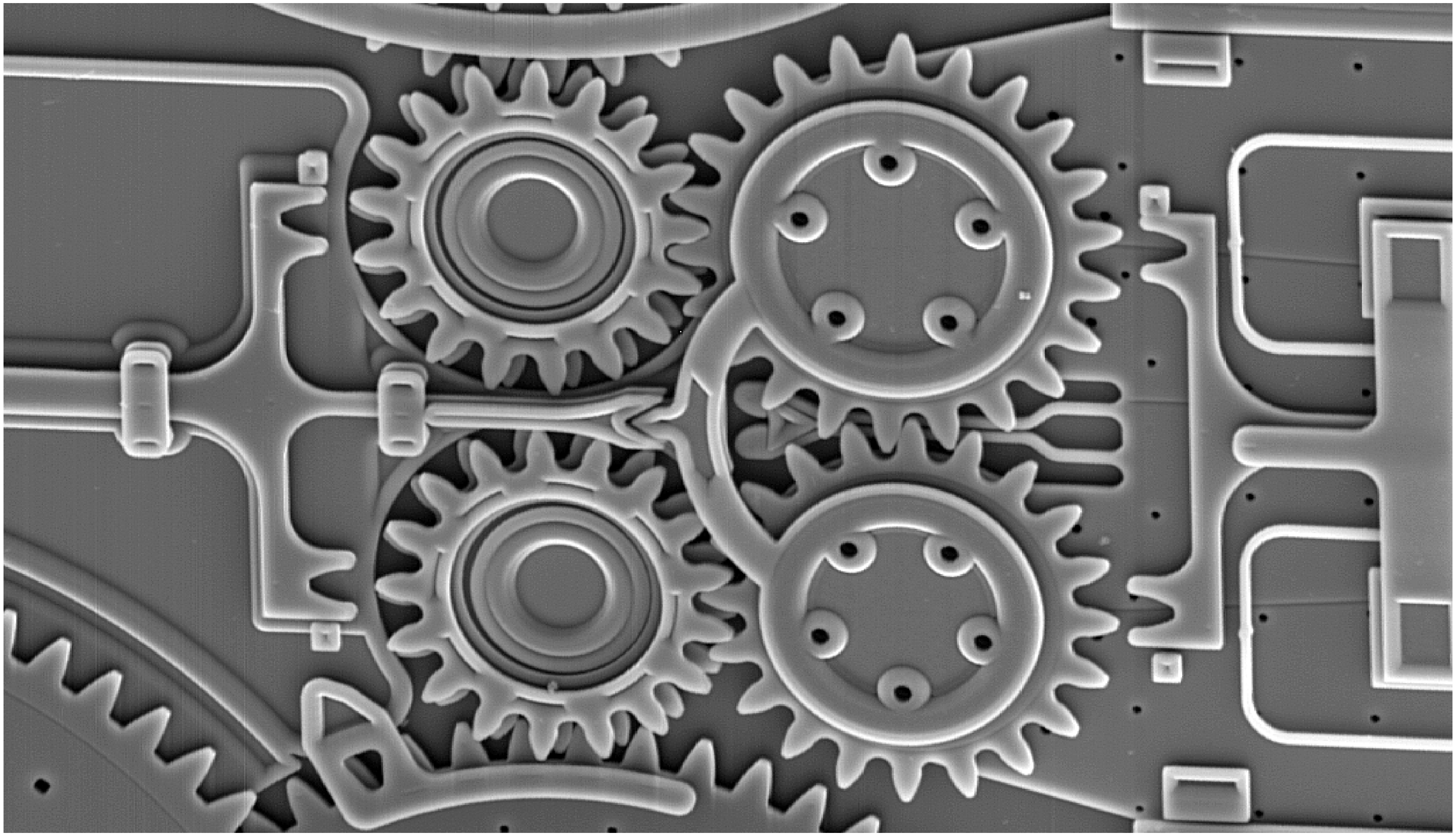
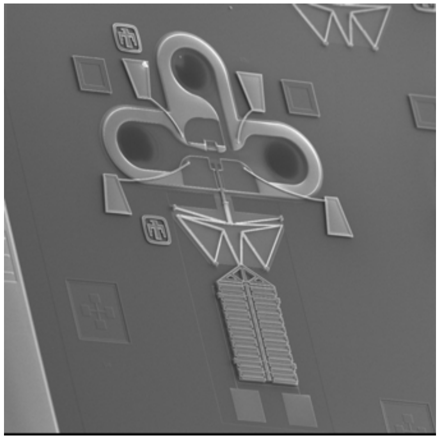
Pin-in-maze Operation



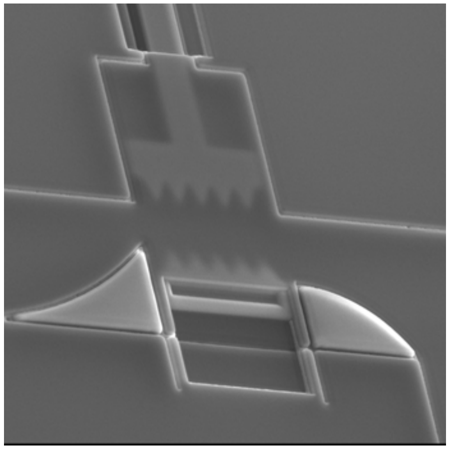
Coupling Complete



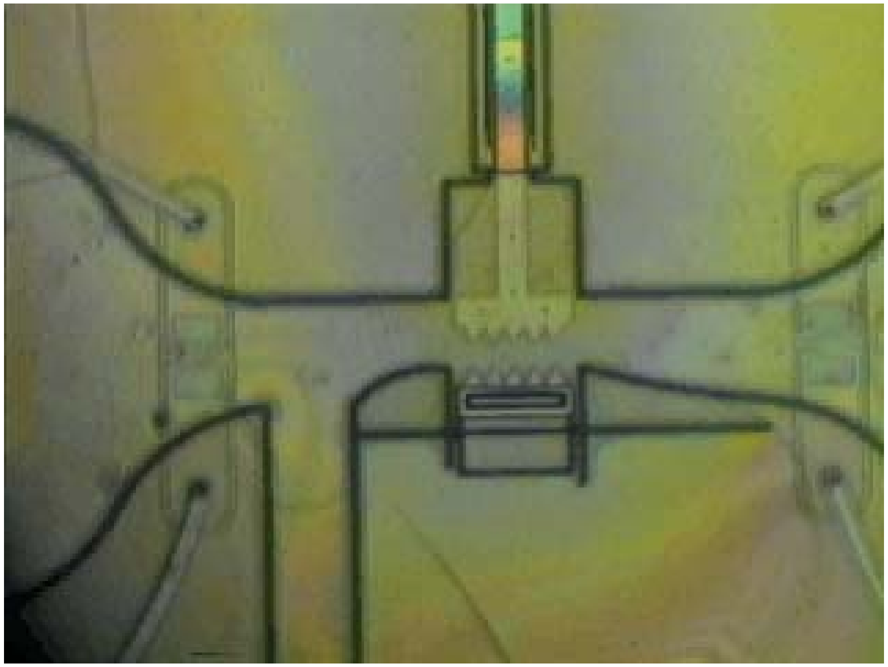
Surface Micromachined Cell Smasher



By using silicon nitride channels with integrated polysilicon structures, mechanical systems can be integrated with electrical and optical systems, as well as microfluidics.



Application – mechanical cell permeation device.



Summary

- MEMS has considerable processing challenges including planarization.
- CMP has enabled MEMs multilayered polysilicon structures resulting in complex device functionality and performance.

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