微小世界是如何運作的

---微機電系統

國立成功大學
材料科學及工程學系
特聘教授
張炎輝

- Introduction
- Surface micromachining
- Bulk micromachining
- Applications
- Conclusion

Micro and Nano technologies - status

- *Micro technologies*
- 1/1,000,000 of a meter
- Devices dimensions today in the Microelectronics industry ~0.065 μm
- The dimensions will reach 0.035 μm in 2010
- ~9000 million devices on a chip

•*Nano technologies*
•1/1,000,000,000 of a meter
•1000 Billion devices on a chip
•Atomic scale devices
•Not in production….. yet

Microsystem Technology

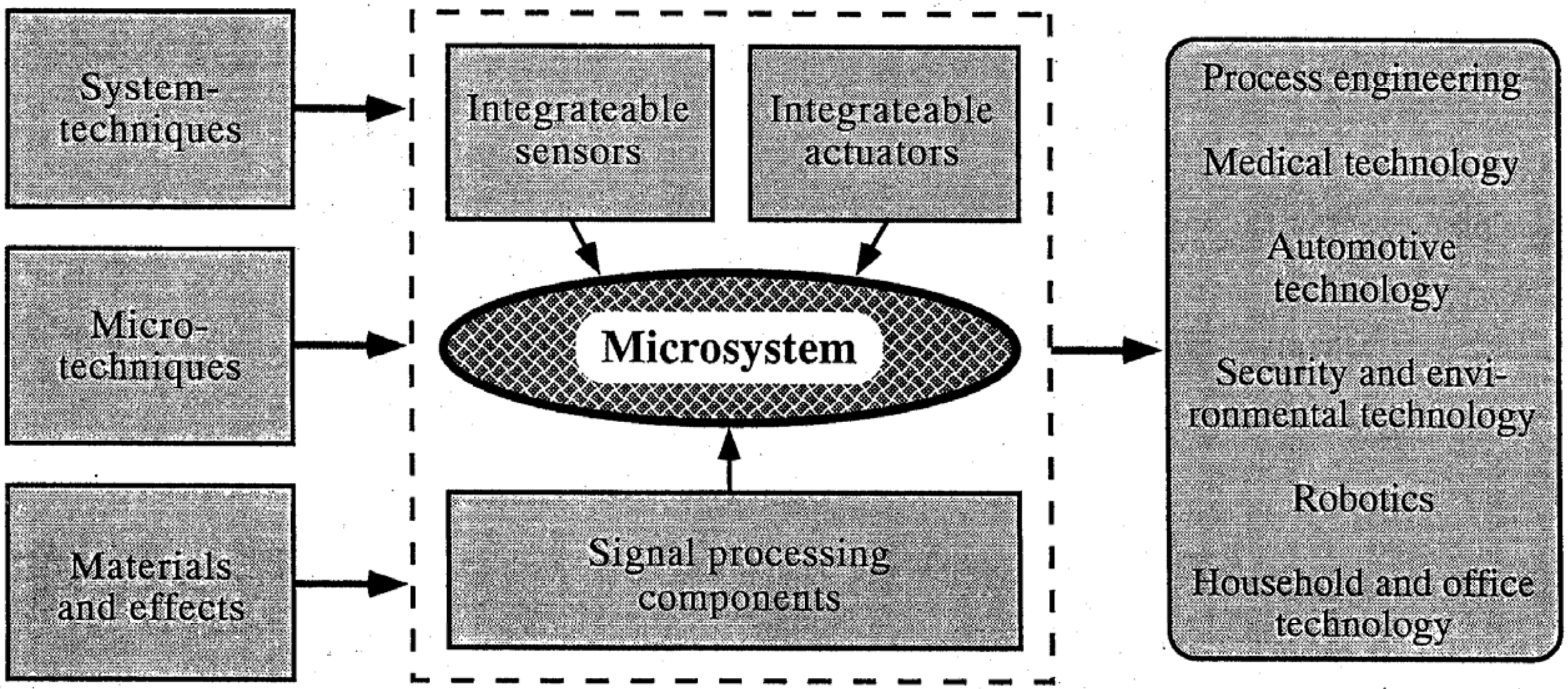
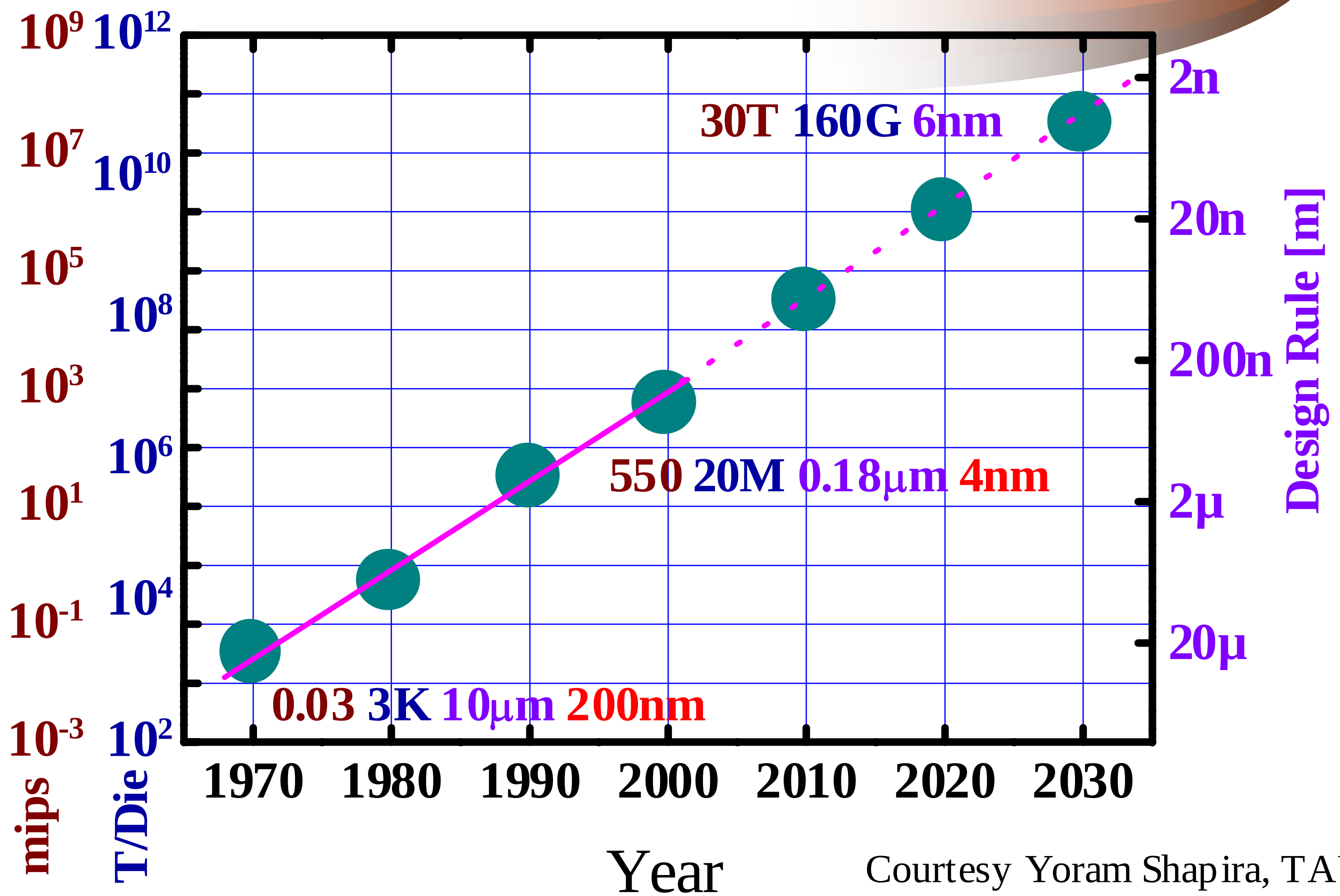


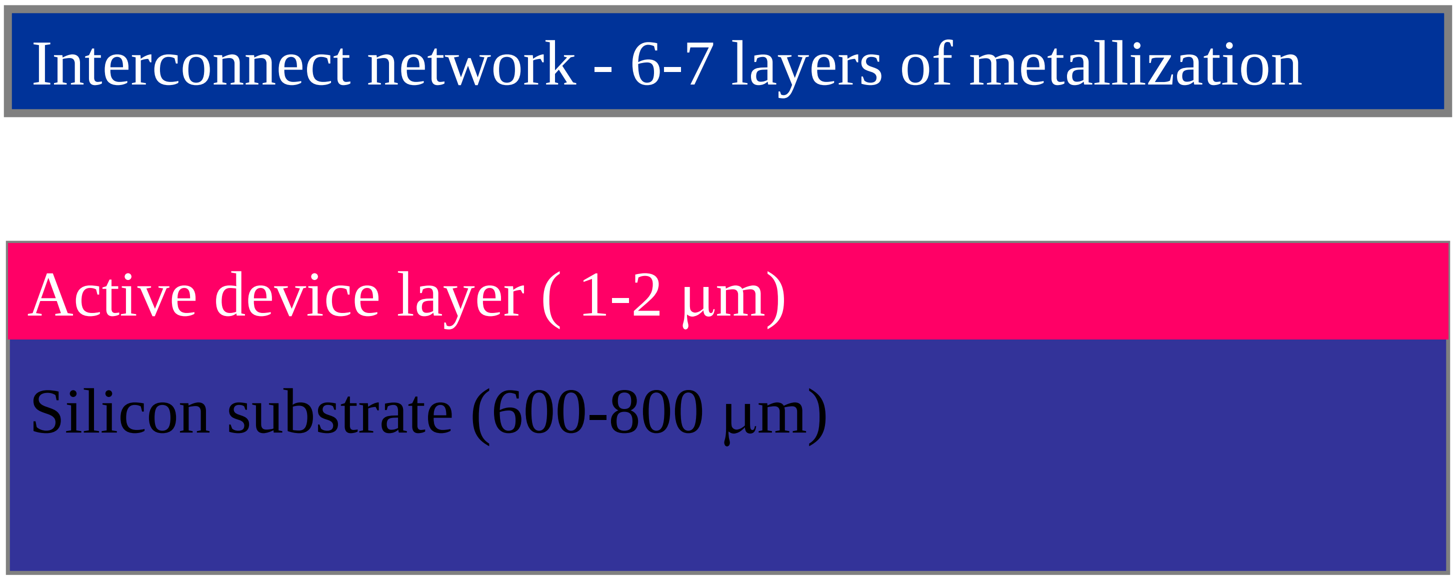
Fig. 1.1: Overview of the MST

Materials Characterization

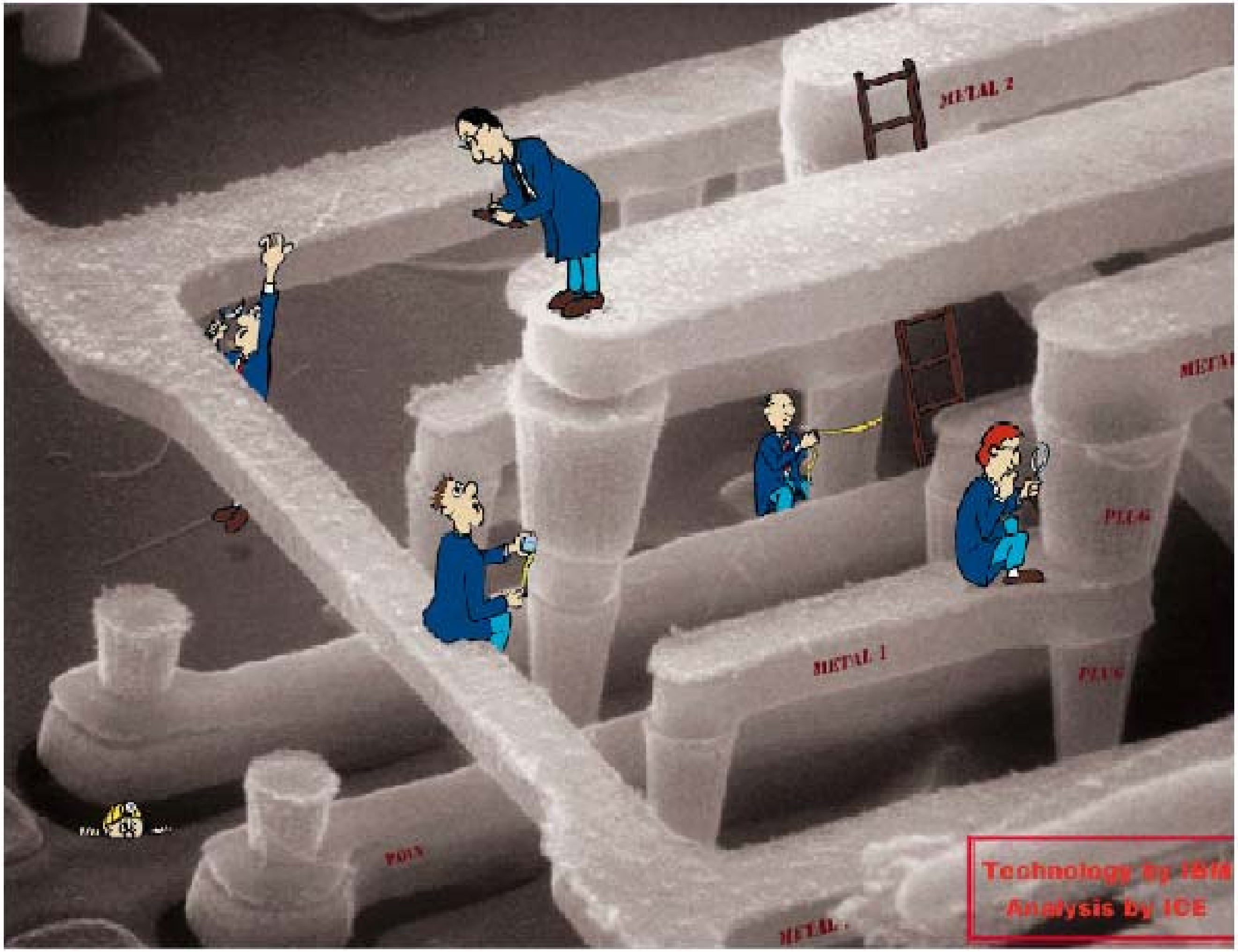


Courtesy Yoram Shapira, TAU

Structure of microchips

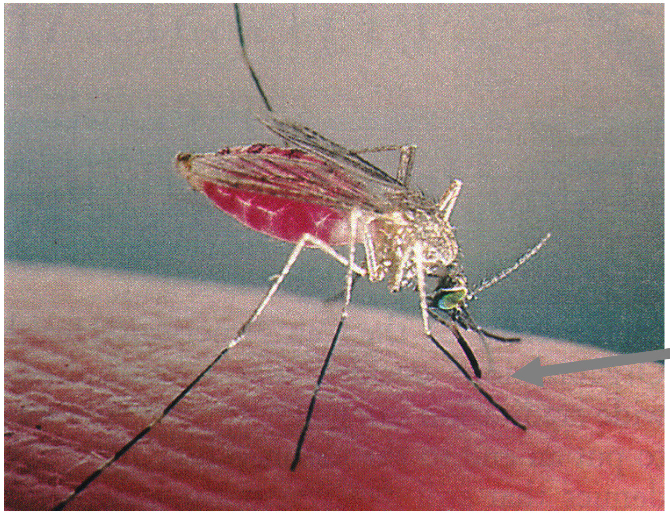


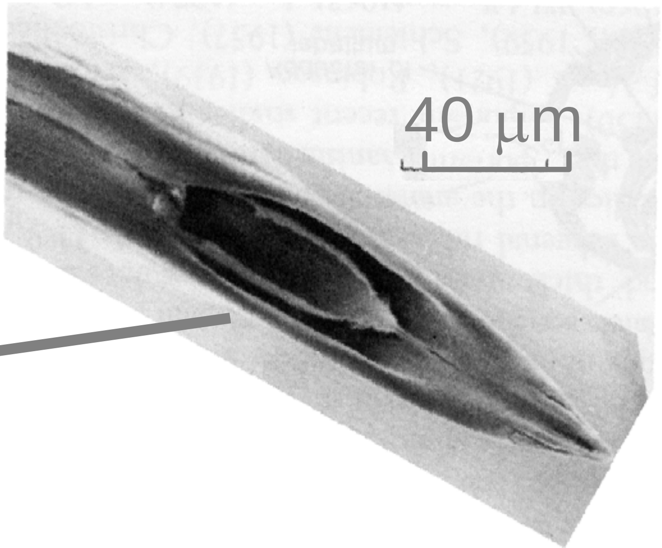
Multi-level metallization

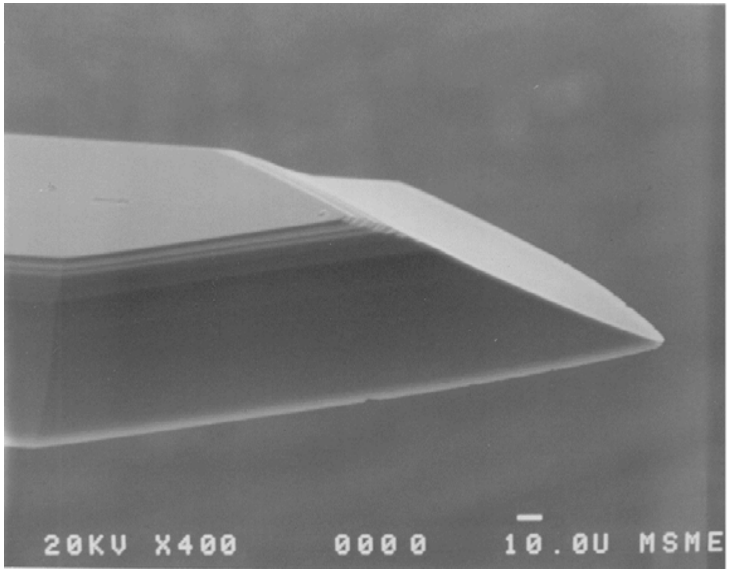


What can we put on a silicon chip ?

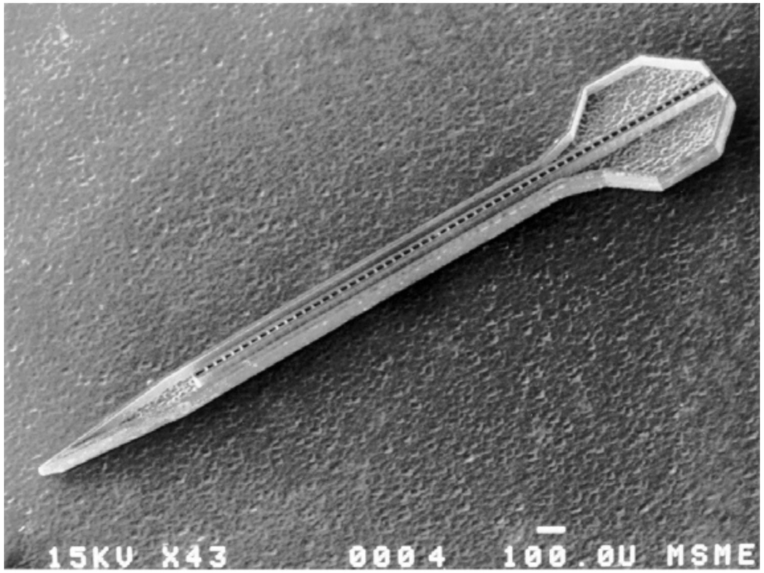
- MEMS - Micro Electro Mechanical Systems
- MEOMS - Micro Electro Optical Mechanical Systems
- Micro-biological systems
- Micro-Chemistry, and
- Microelectronics…..



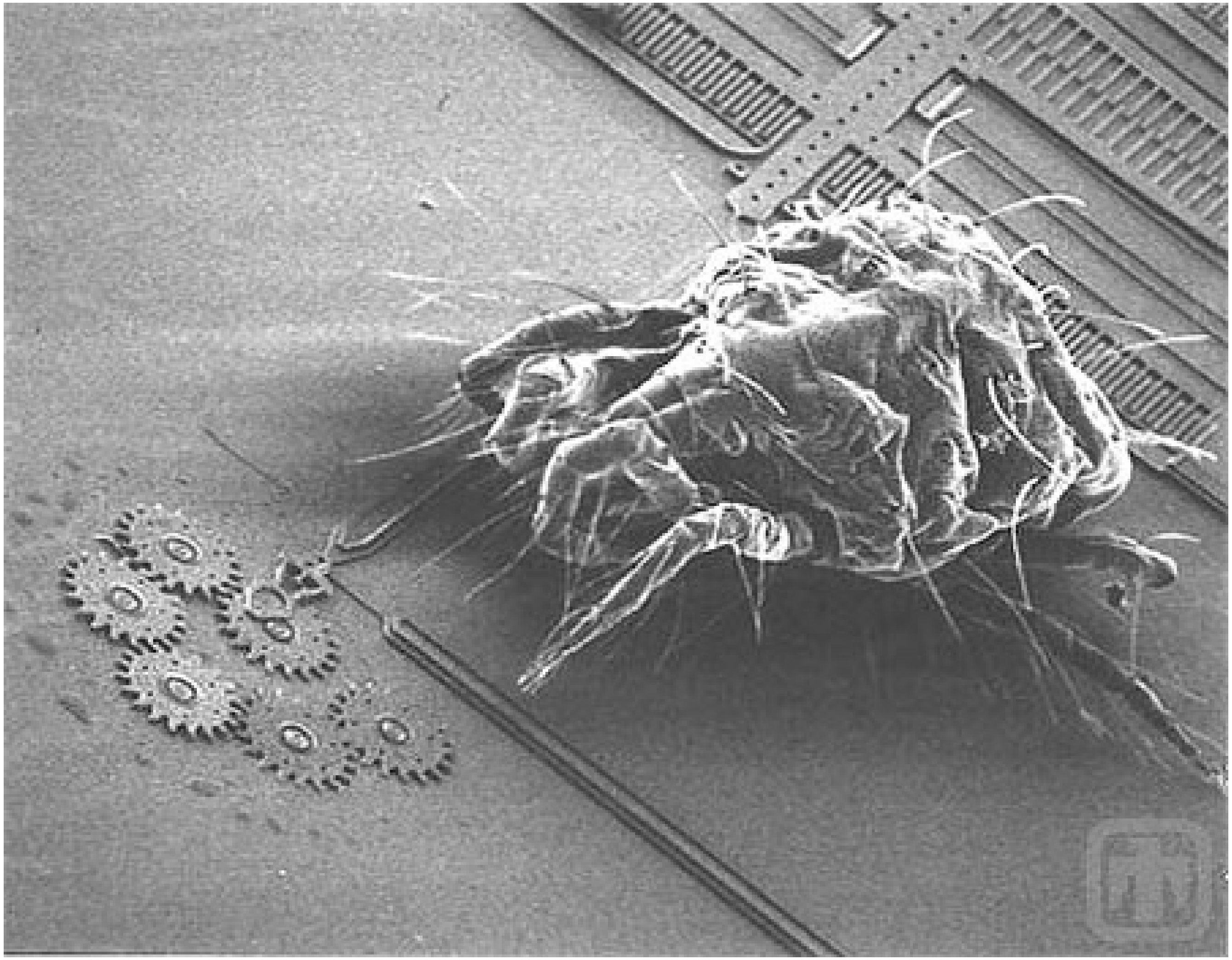


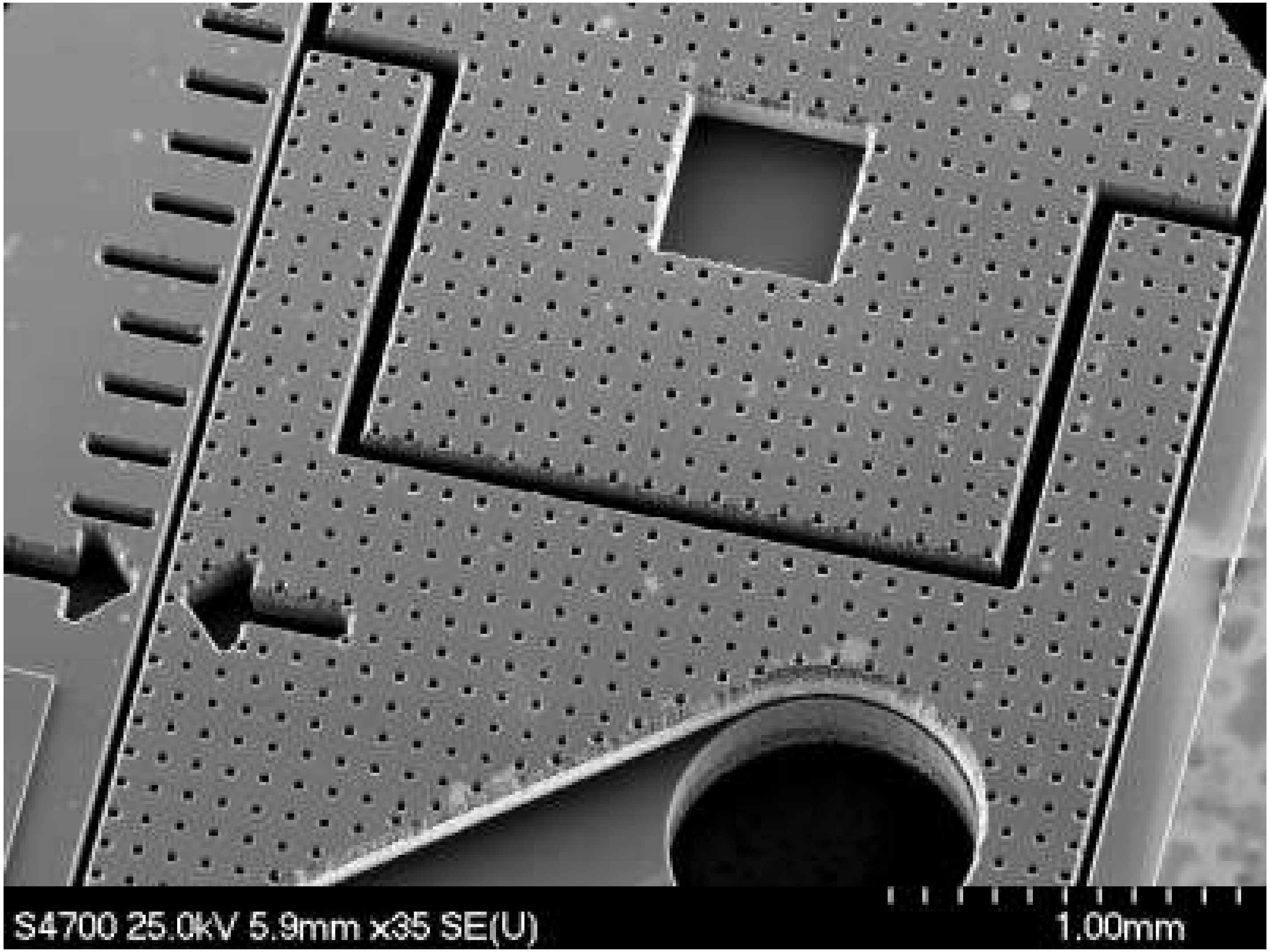


Lancet width = 170 μm



Needle width = 150 μm




S4700 25.0kV 5.9mm x35 SE(U)
1.00mm

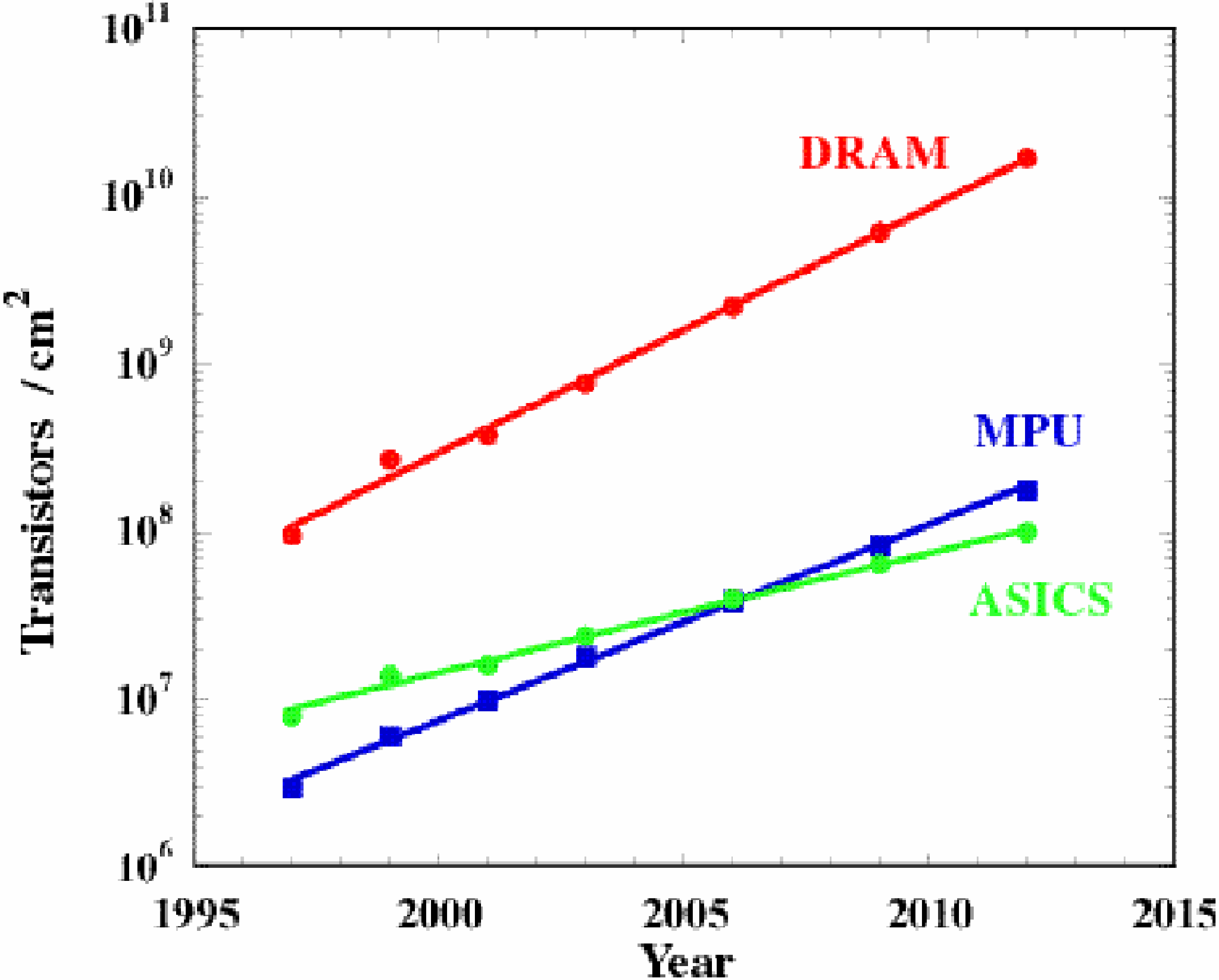
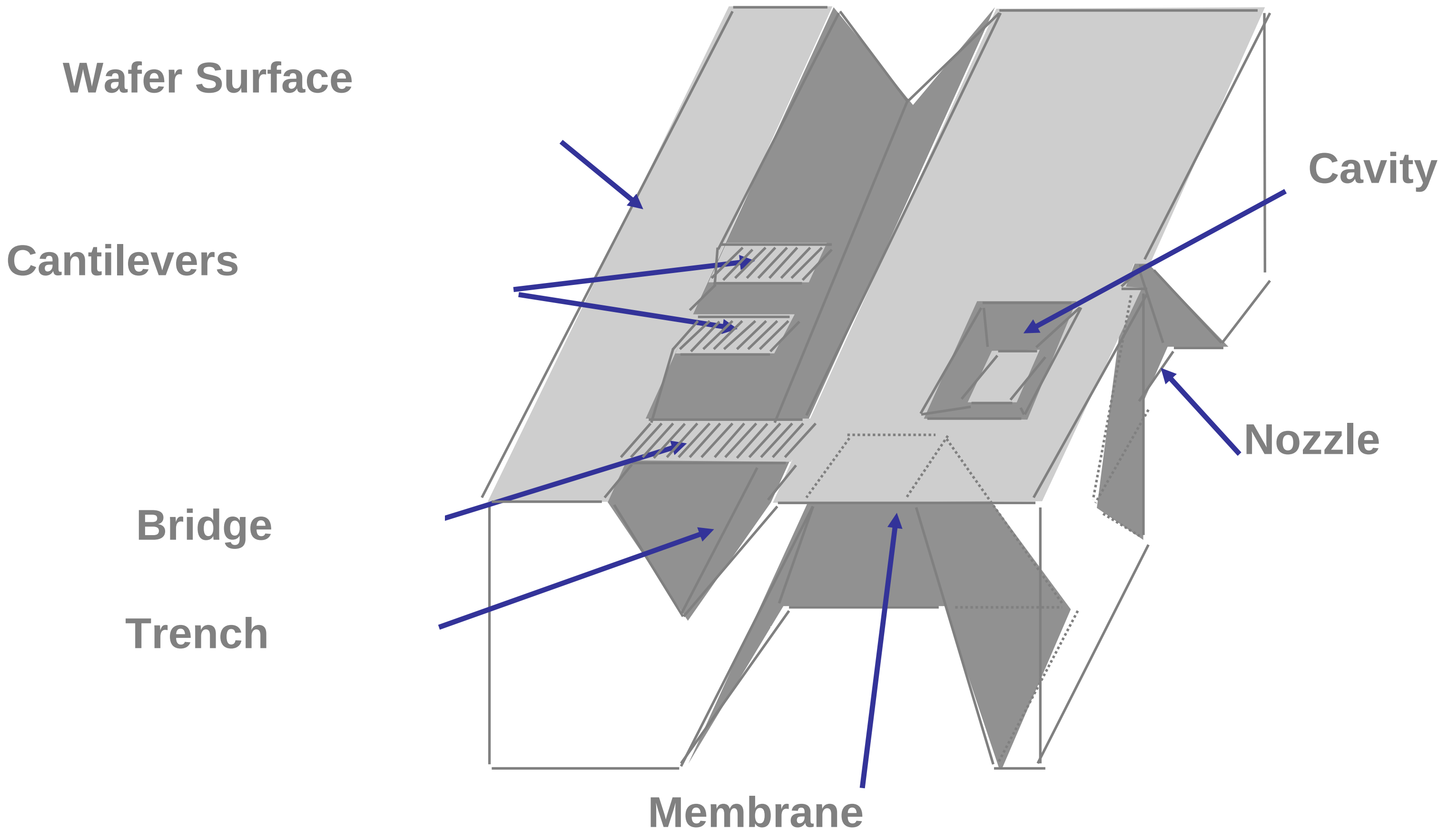


Figure 1.2:- The number of transistors per cm² plotted against the year of first manufacture.

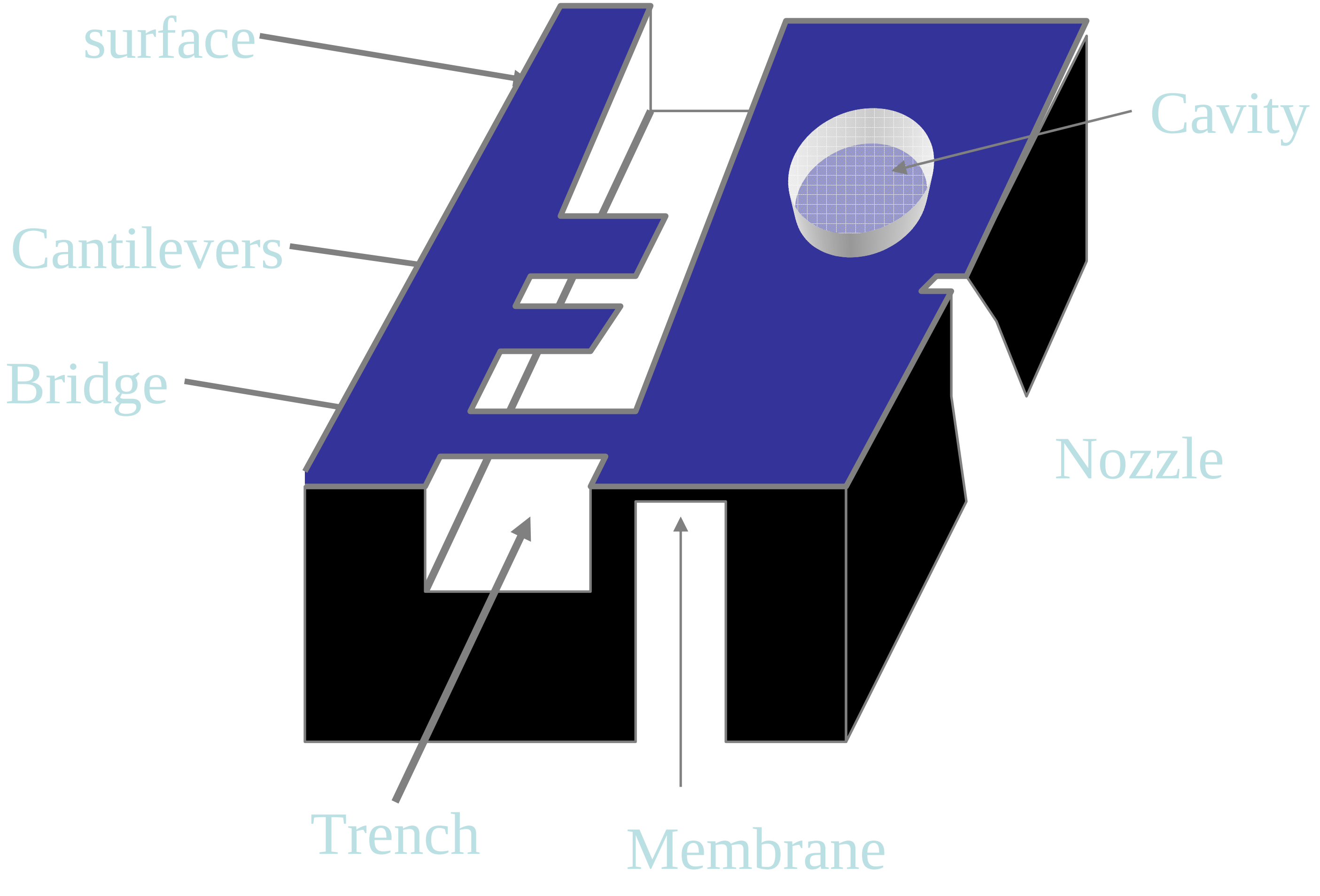
Fabrication

- Bulk micro-machining
  - etch into the substrate
- Surface micro-machining
  - build up layers above the substrate and etch
- LIGA
  - deep structures

Single crystal Bulk Micromachining

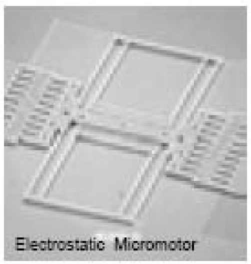


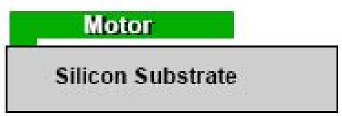
Non crystal Bulk Micromachining



The More Mechanical Levels
The More Sophisticated The Device

2-Level

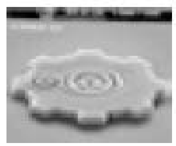


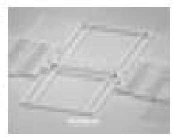


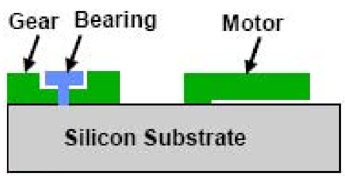
- Polysilicon Level #1

Sensors

3-Level



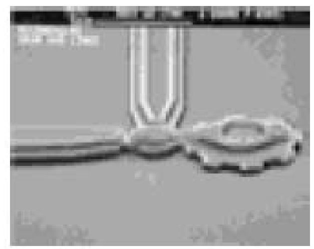


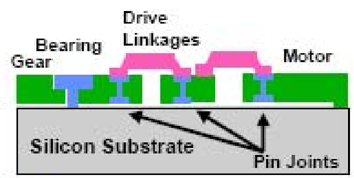


- Polysilicon Level #1
- Polysilicon Level #2

Advanced Sensors
Simple Actuators

4-Level

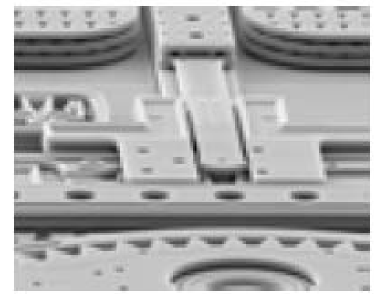


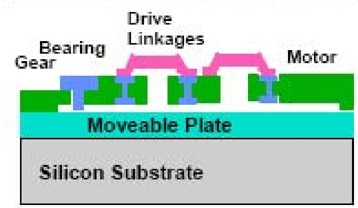


- Polysilicon Level #1
- Polysilicon Level #2
- Polysilicon Level #3

Advanced Actuators

5-Level





- Polysilicon Level #1
- Polysilicon Level #2
- Polysilicon Level #3
- Polysilicon Level #4

Complex Systems

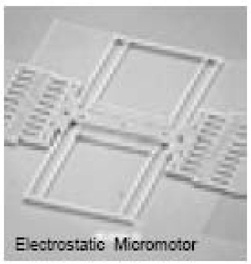
Surface micromachining

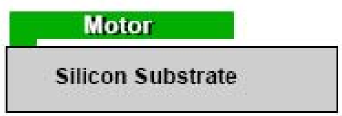
- Specifically - MUMPS (Multi-User MEMS Processes)[1]
  - MUMPS has been called “MOSIS for MEMS”
  - Three poly layer process derived from Berkeley Sensors and Actuators Center
  - Seven total material layers
  - N mask steps

[1] Figures are plagiarized from MUMPS , MCNC.

The More Mechanical Levels
The More Sophisticated The Device

2-Level

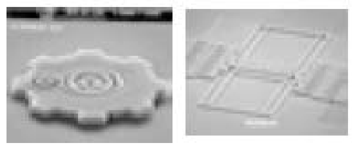


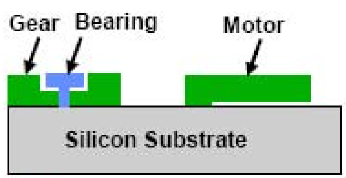


- Polysilicon Level #1

Sensors

3-Level

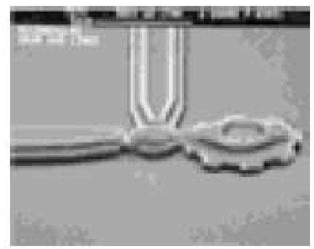


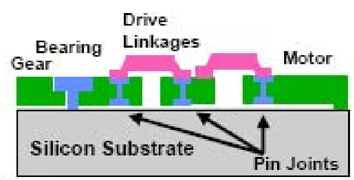


- Polysilicon Level #1
- Polysilicon Level #2

**Advanced Sensors
Simple Actuators**

4-Level

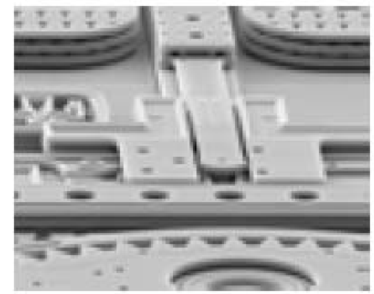


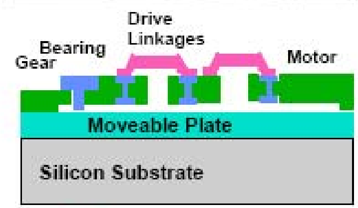


- Polysilicon Level #1
- Polysilicon Level #2
- Polysilicon Level #3

Advanced Actuators

5-Level



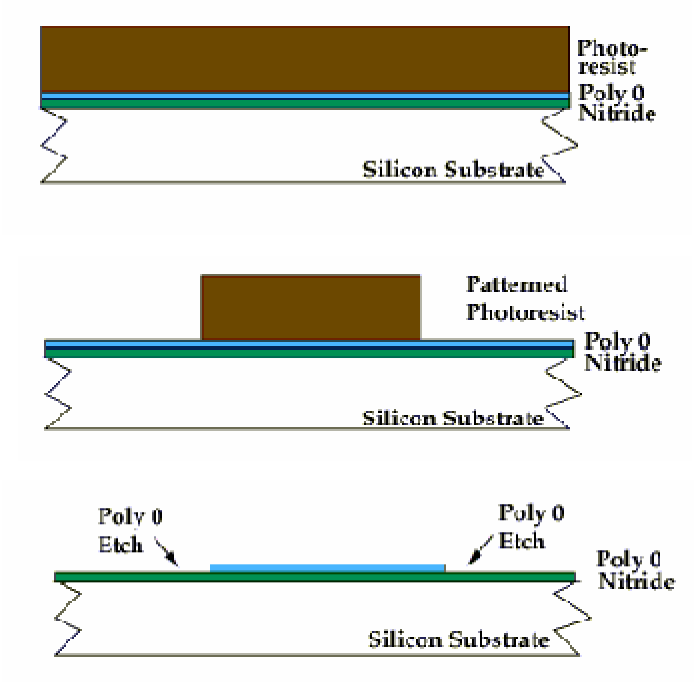


- Polysilicon Level #1
- Polysilicon Level #2
- Polysilicon Level #3
- Polysilicon Level #4

Complex Systems

Patterning Poly 0

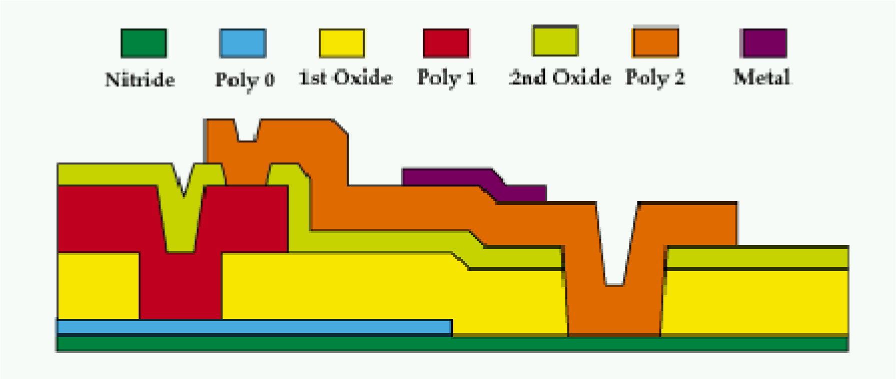
- Initial layers:
  - substrate/nitride/poly0/ resist
- Expose resist
- Dissolve exposed resist
- Etch poly0
- Wash remaining resist



Poly0 is an electrical layer.

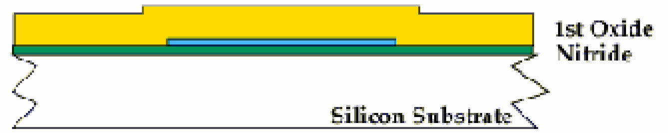
Processing Layers

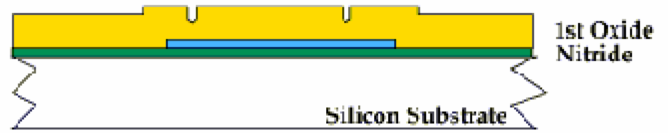
- 7 material layers/
  - isolation
  - conductor (poly)
  - 1st sacrificial (oxide)
  - 1st structural (poly)
  - 2nd sacrificial (oxide)
  - 2nd structural (poly)
  - metal

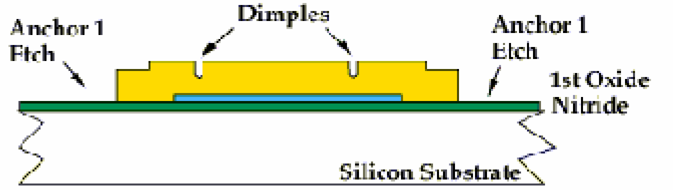


First Sacrificial (oxide) Layer

- This layer will eventually be dissolved. Its purpose is to support the structural layer (poly1) above it.
- Note: all layers are conformal
- Two timed etches - short for dimples, longer for anchor

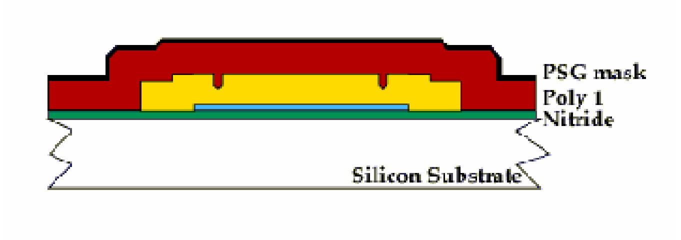


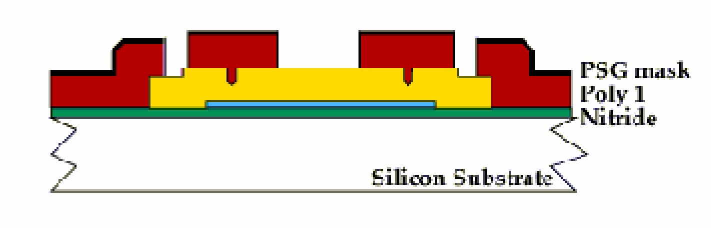




First structural (poly1) layer

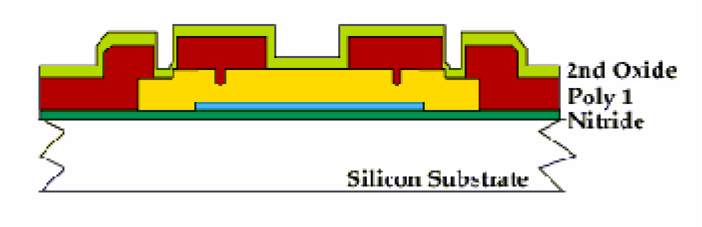
- Deposit 2μm of polysilicon
- Coat with resist, expose
- Etch with RIE (reactive ion etch)

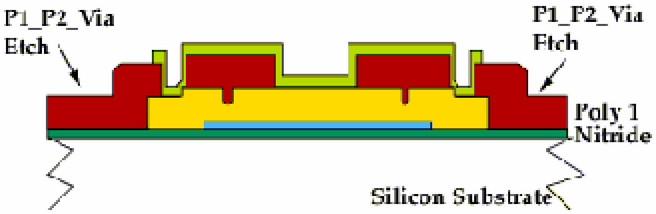


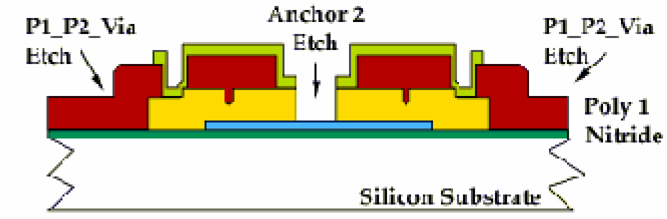


2nd sacrificial (oxide) layer

- Deposit 0.75μm oxide
- Two etch steps - first contacts poly1, second contacts substrate

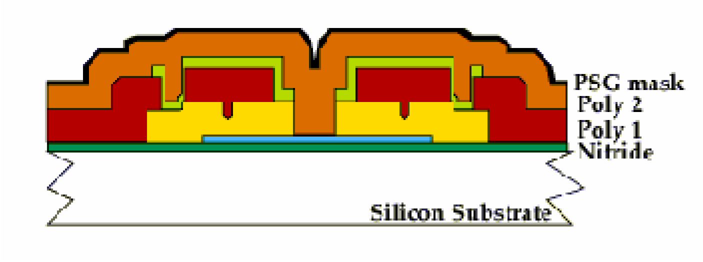


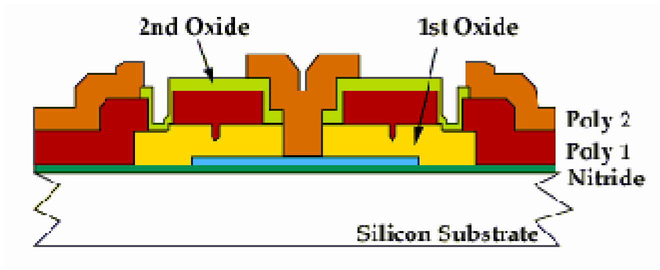


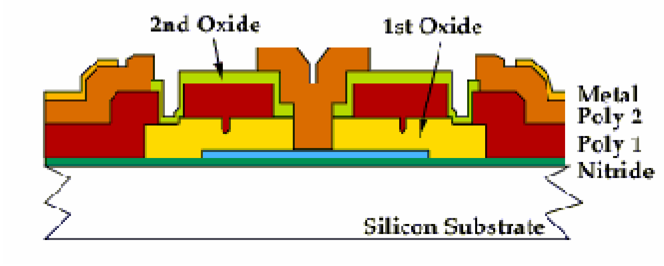


2nd structural (poly2) layer + metal

- Deposit second poly layer
- Apply resist and etch (RIE)
- Apply resist and etch
- Deposit metal, gold in MUMPS

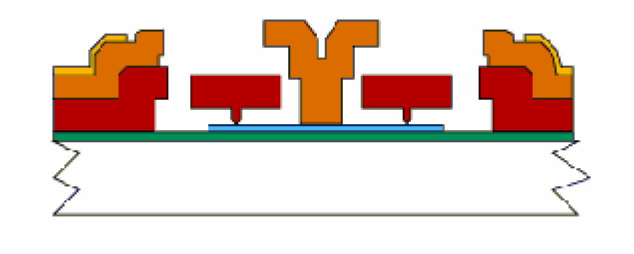


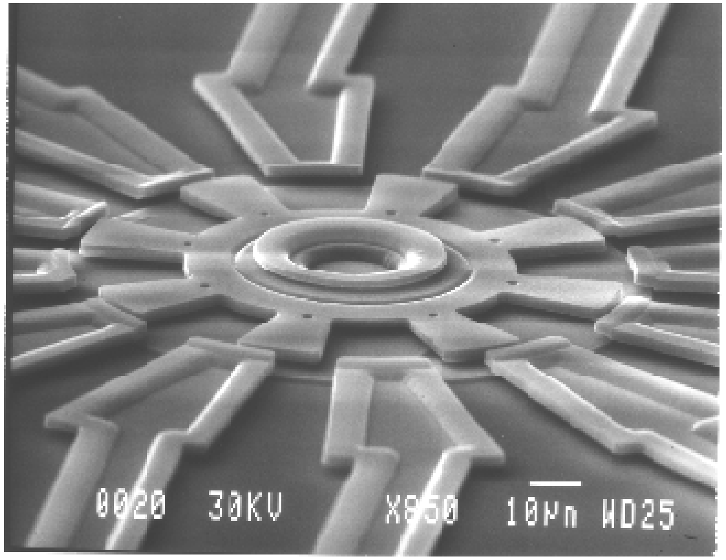




Released mechanism

- Rinse in solvent to remove resist and overlying metal
- Soak 2 minutes in concentrated HF to dissolve sacrificial oxide layers

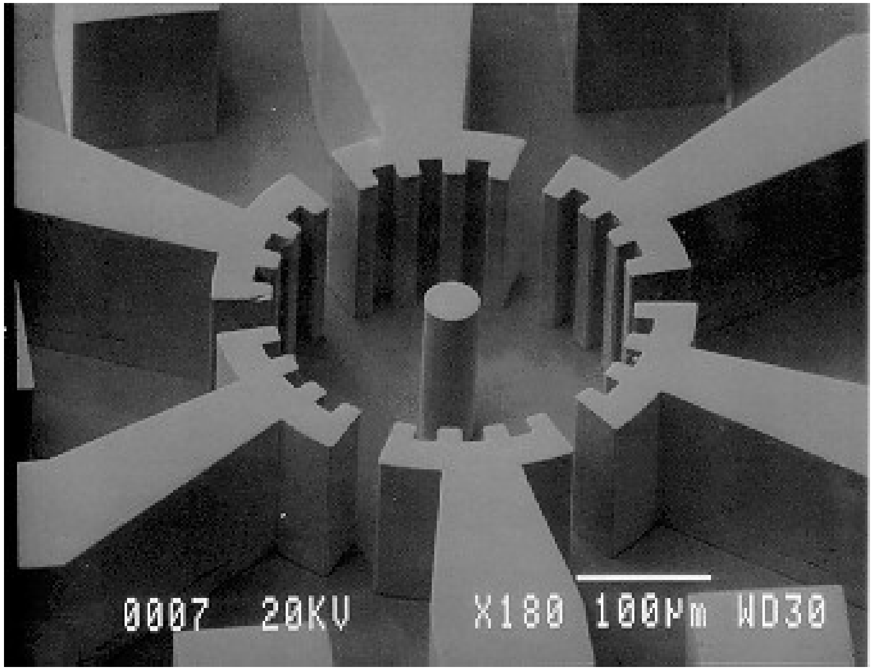




LIGA

Lithograpie, Galvanoformung, Abformung

- 200μm deep structures
- Coat with thick resist
- Pattern with Xrays
- Electroplate exposed area with Ni
- Machine to +-5μm
- Use titanium and Cu as sacrificial layers



MCNC

LIGA

Lithograpie, Galvanoformung, Abformung

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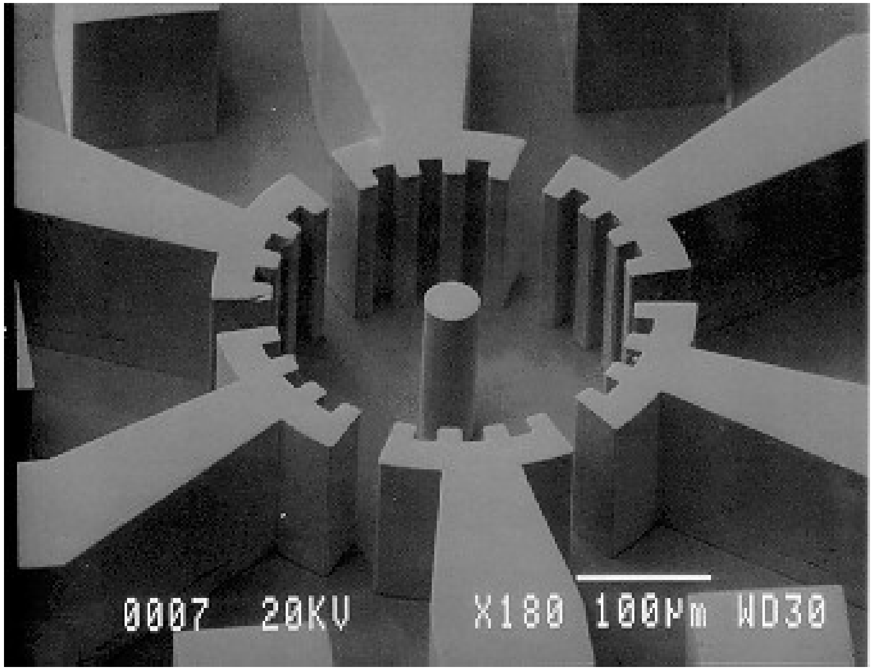
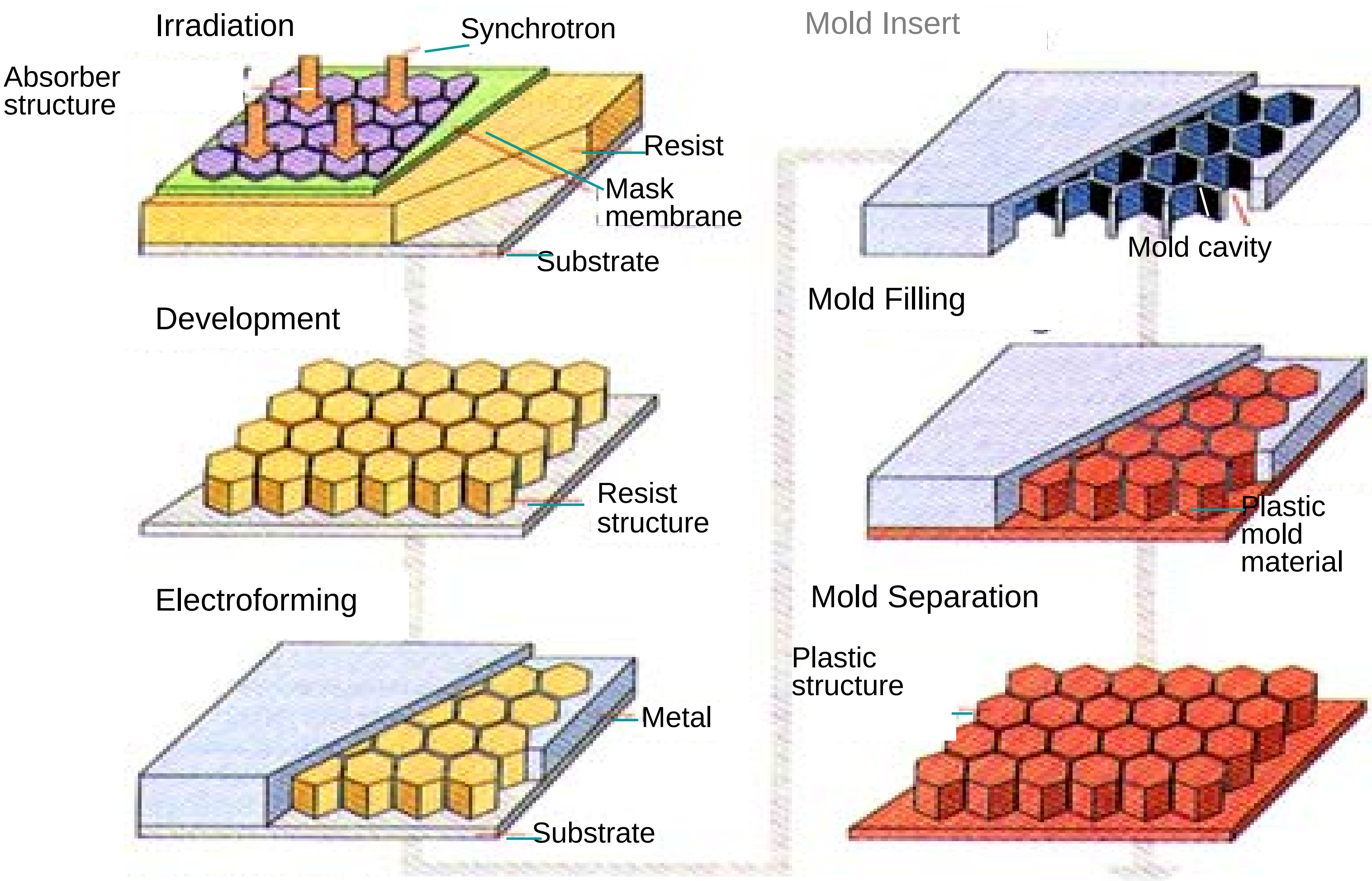


MCNC

LIGA*, Deep UV



Source: IMM (Mainz Institute for Microtechnology)

*Lithographie, Galvanoformung, Abformung

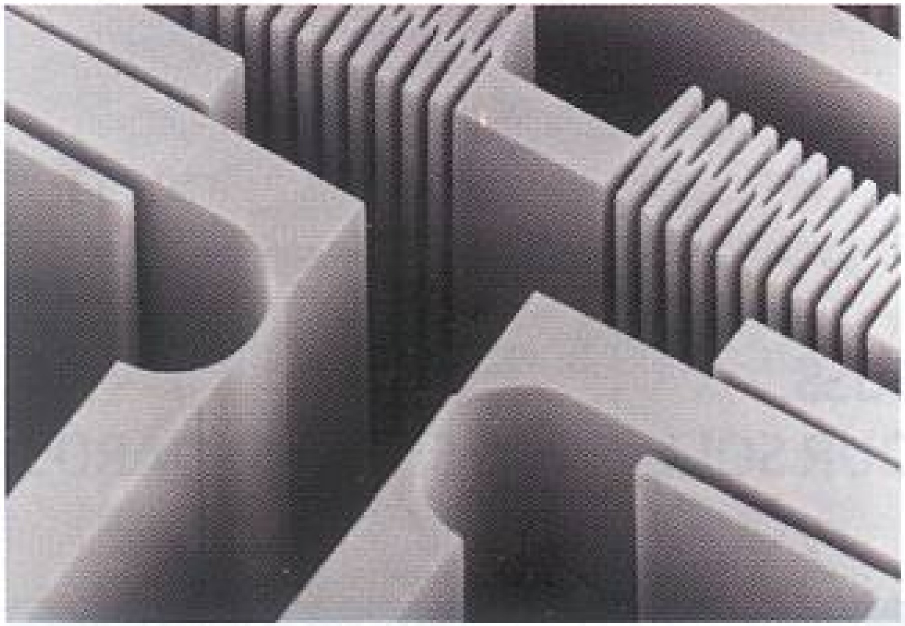


Fig. 2: PMMA mold of an electrostatic actuator manu-factured by X-ray deep lithography before the electro-deposition of nickel. The height is 100 µm, the smallest lateral dimension 1 µm.

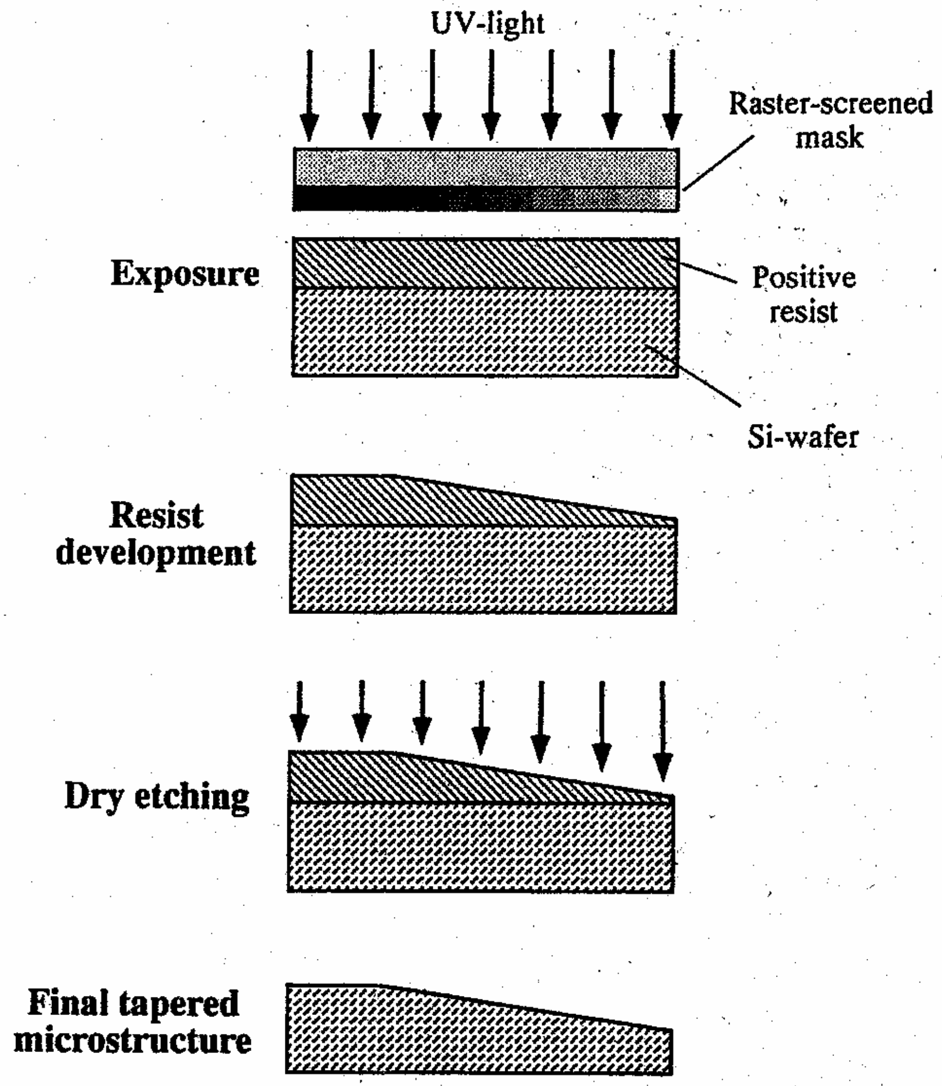
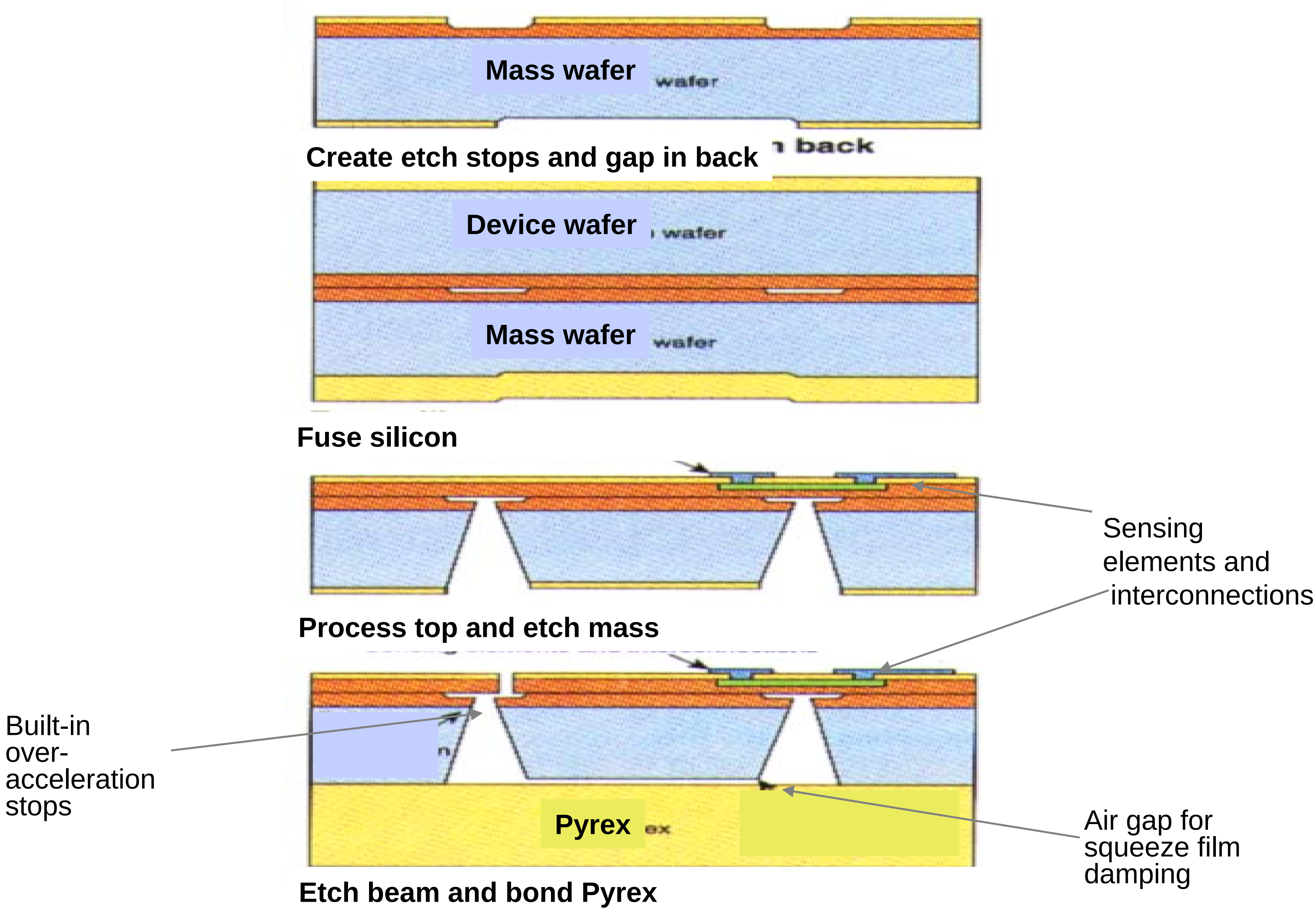


Fig. 4.4: Principle of gray-tone lithography. According to [Weng94]

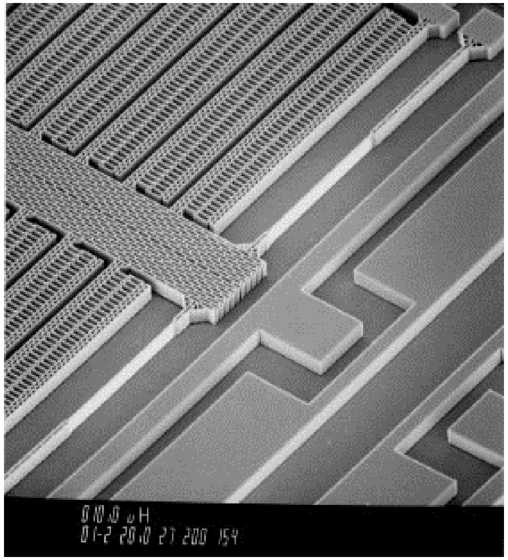
Fig. 1: parallel-produced impellers for flow sensors

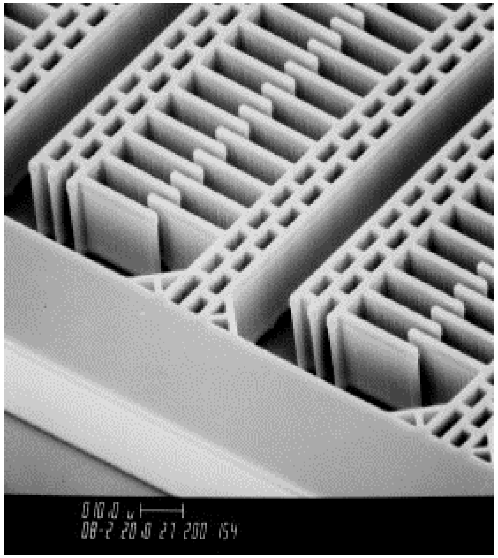
Wafer-to-Wafer Bonding



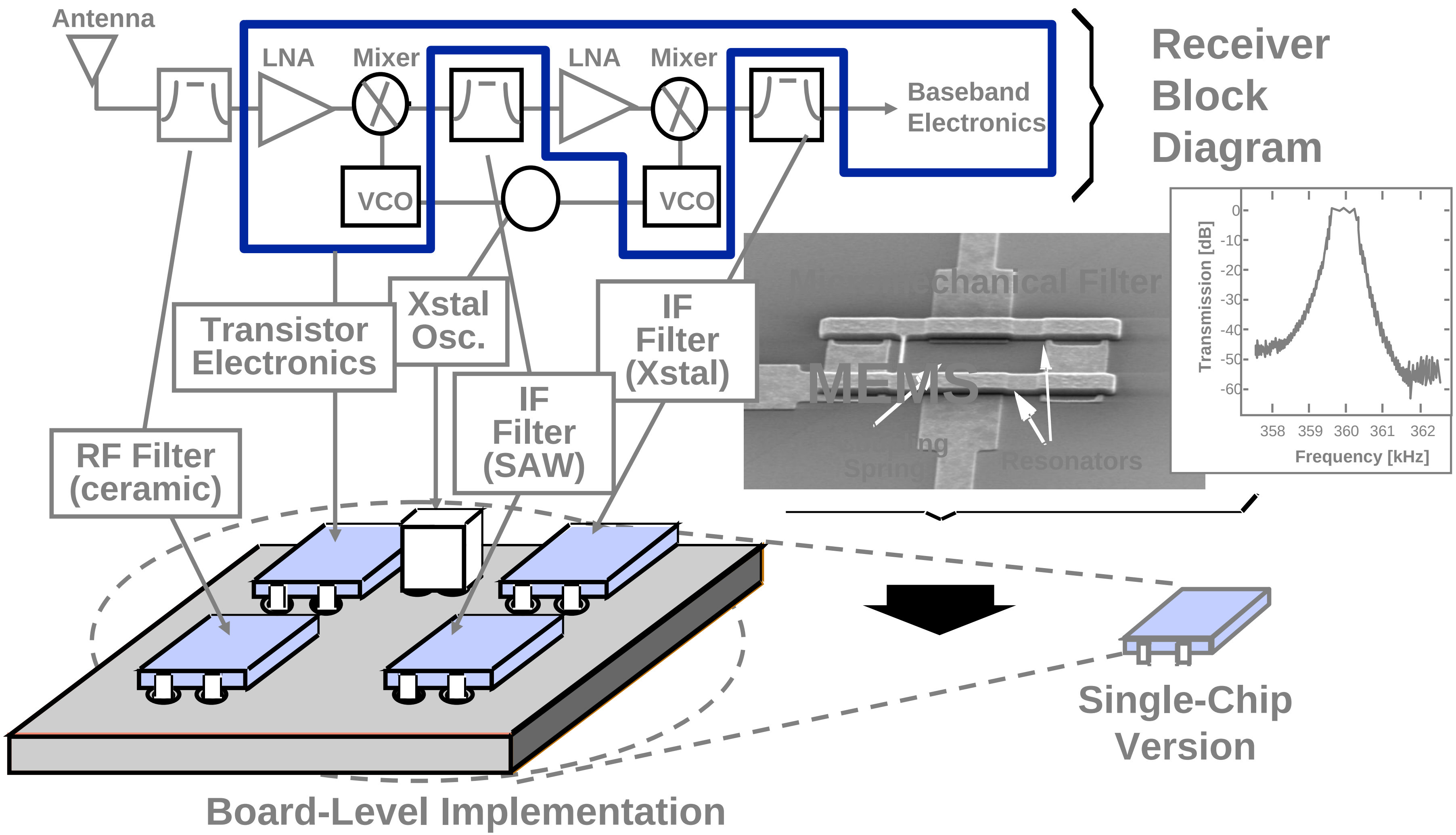
Highlights of the Rockwell MEMS Tunable Capacitor

- Single Crystal Silicon
- Superior Mechanical Properties
- High Aspect Ratio (20 to 1)
- Higher Linearity
- Large Tuning Ratio (> 6.5 to 1)





Wrist Communicator

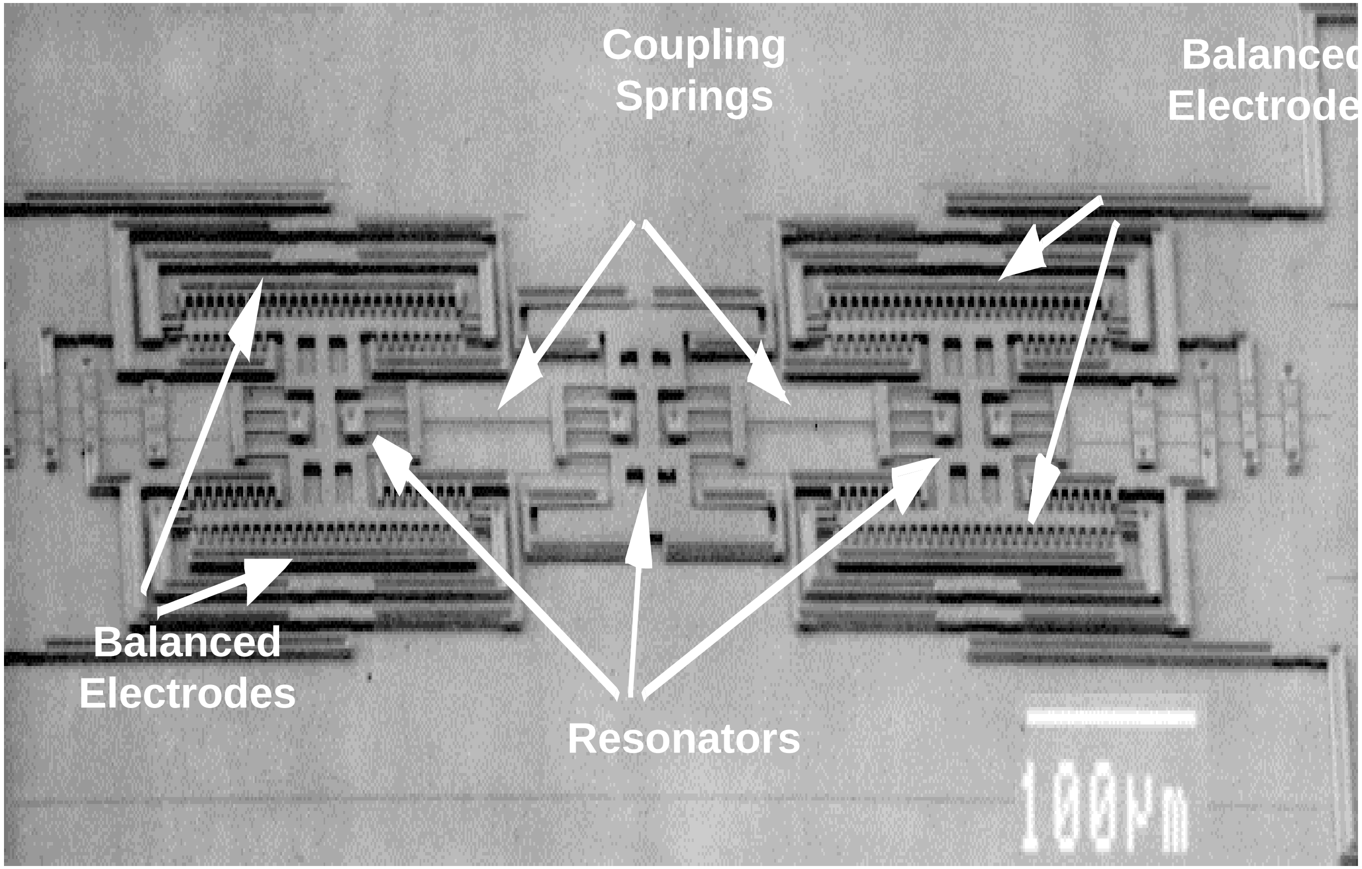


- Off-chip high-Q mechanical components present bottlenecks to miniaturization ➡ replace them with μmechanical versions

Wrist Communicator

Sixth-Order Bandpass Filter in MEMS Technology

(200 x 700 μm)



Applications

Sensors: CO, Gyroscopes, …….

Actuators: Micromotors, …….

Optobionics: Retinal Implant, Drug
Delivery Systems, ……..

Optical mems

Sensors

Sensors applications:

* environmental monitoring of water and air
* gas sensor
* gyroscope
* pressure sensor
* accelerometer
* acoustic sensor
* SW devices sensor

Chemical analysis
Water analyzer

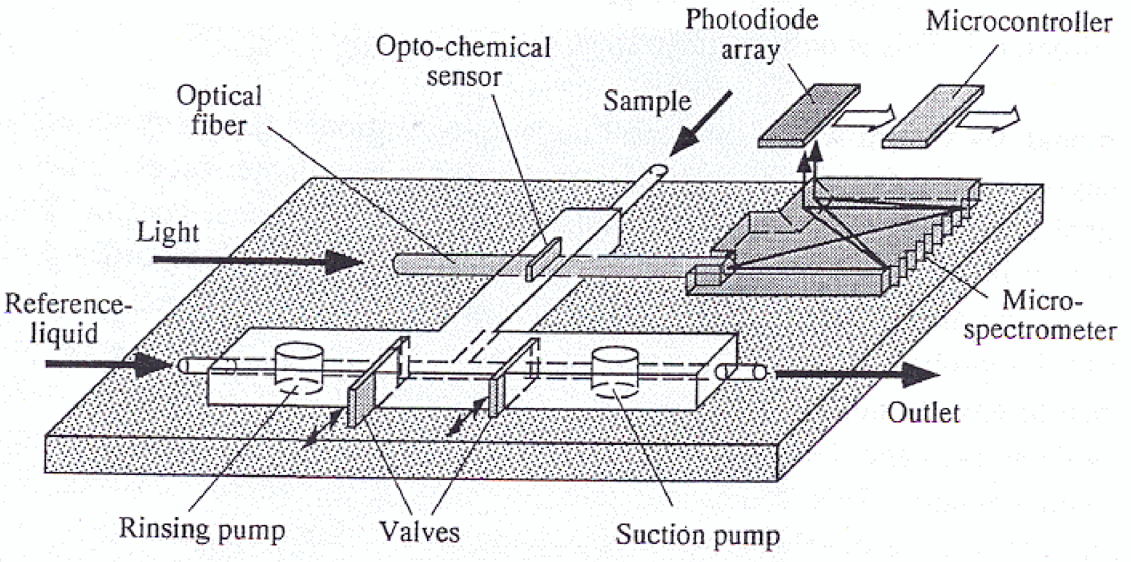


Fig. 2.9: Contaminant analyzer using an optical principle. According to [Schom93]

Threshold limited values of toxic gases

氣體	TLV (ppm)	氣體	TLV (ppm)
CO	50	HCN	10
NH_3	25	HCl	5
H_2S	10	AsH_3	0.05
Cl_2	1	NO	25
SO_2	5	NO_2	3
C_6H_6	10	CO_2	5000
CH_3Br	20	O_3	0.1
CH_2CH_2O	50	C_2H_5OH	1000

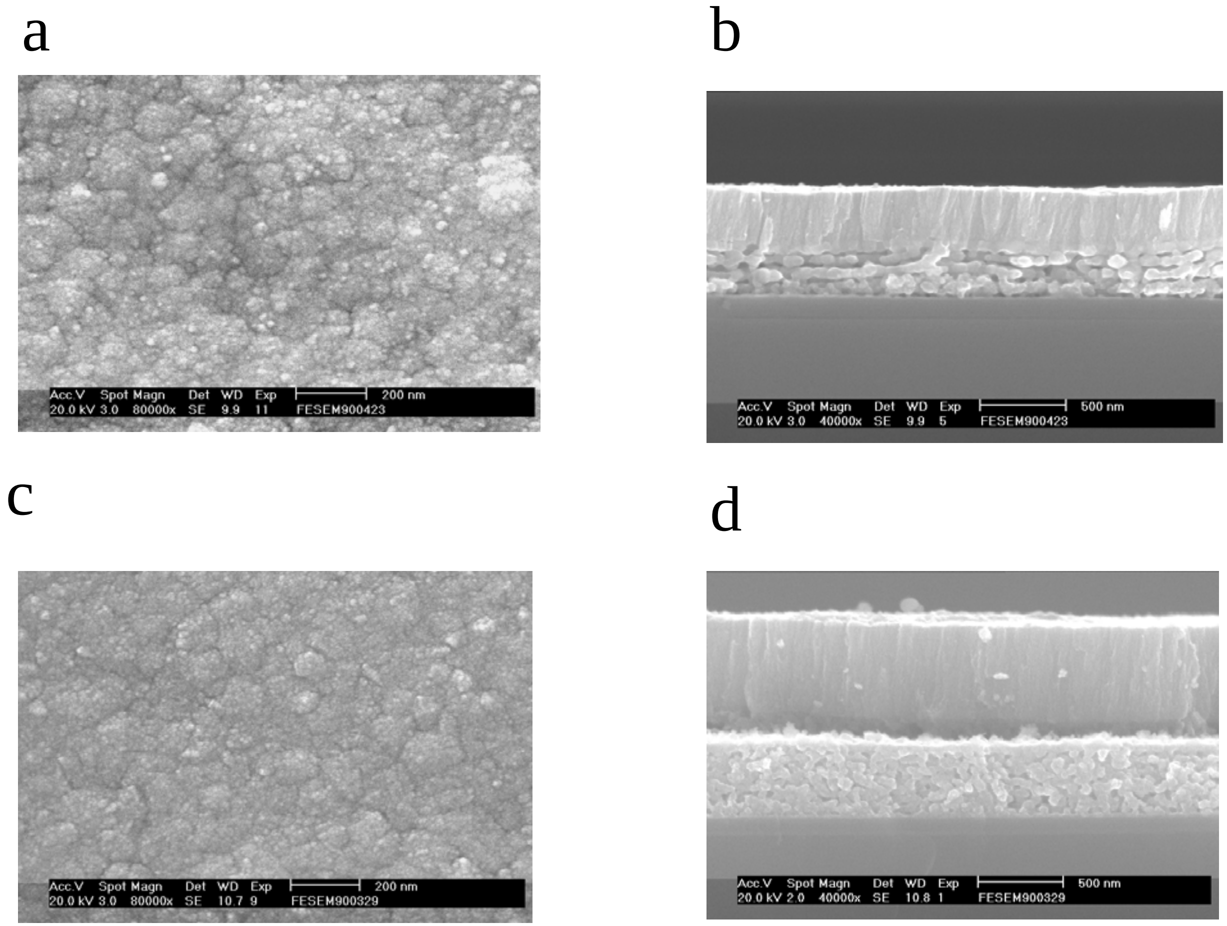


圖4-2 不同厚度SnO_2薄膜與LSCNO異質接合之表面及其橫截面之SEM顯微結構(a、b)400nm，(c、d)800nm

異質接合之幾何型態如下圖:

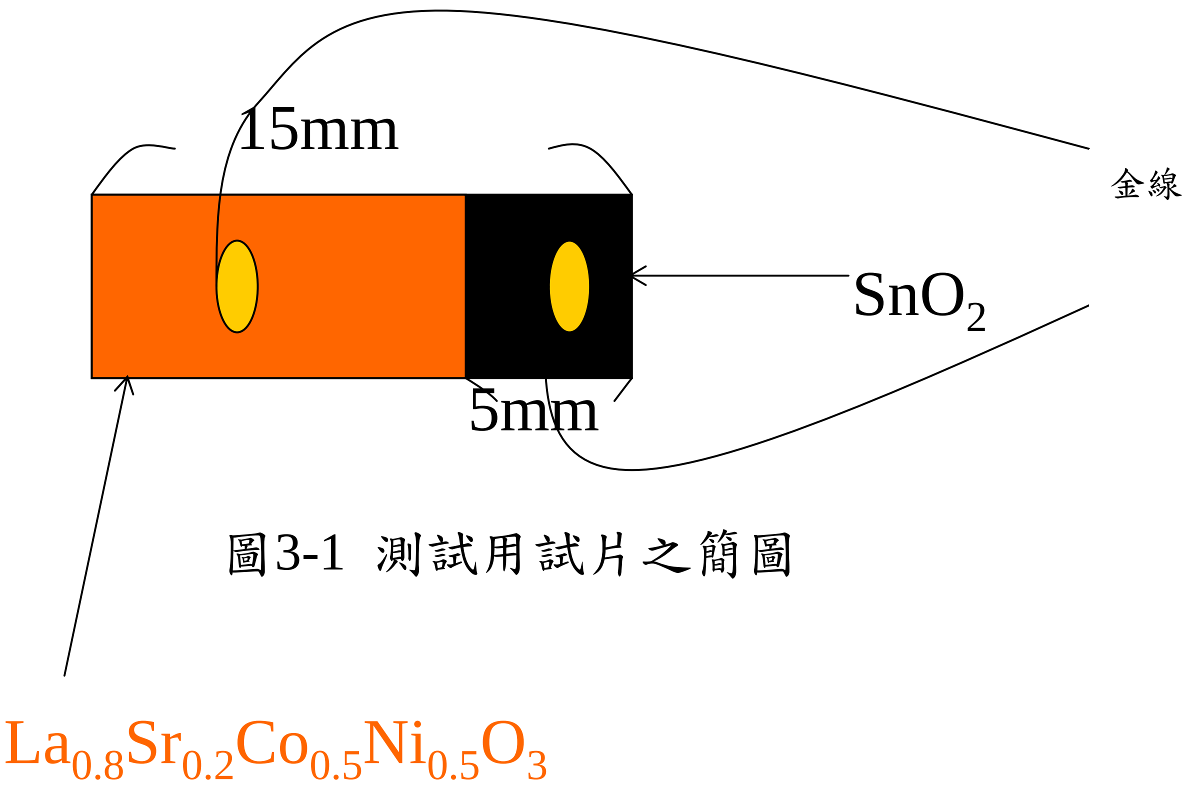
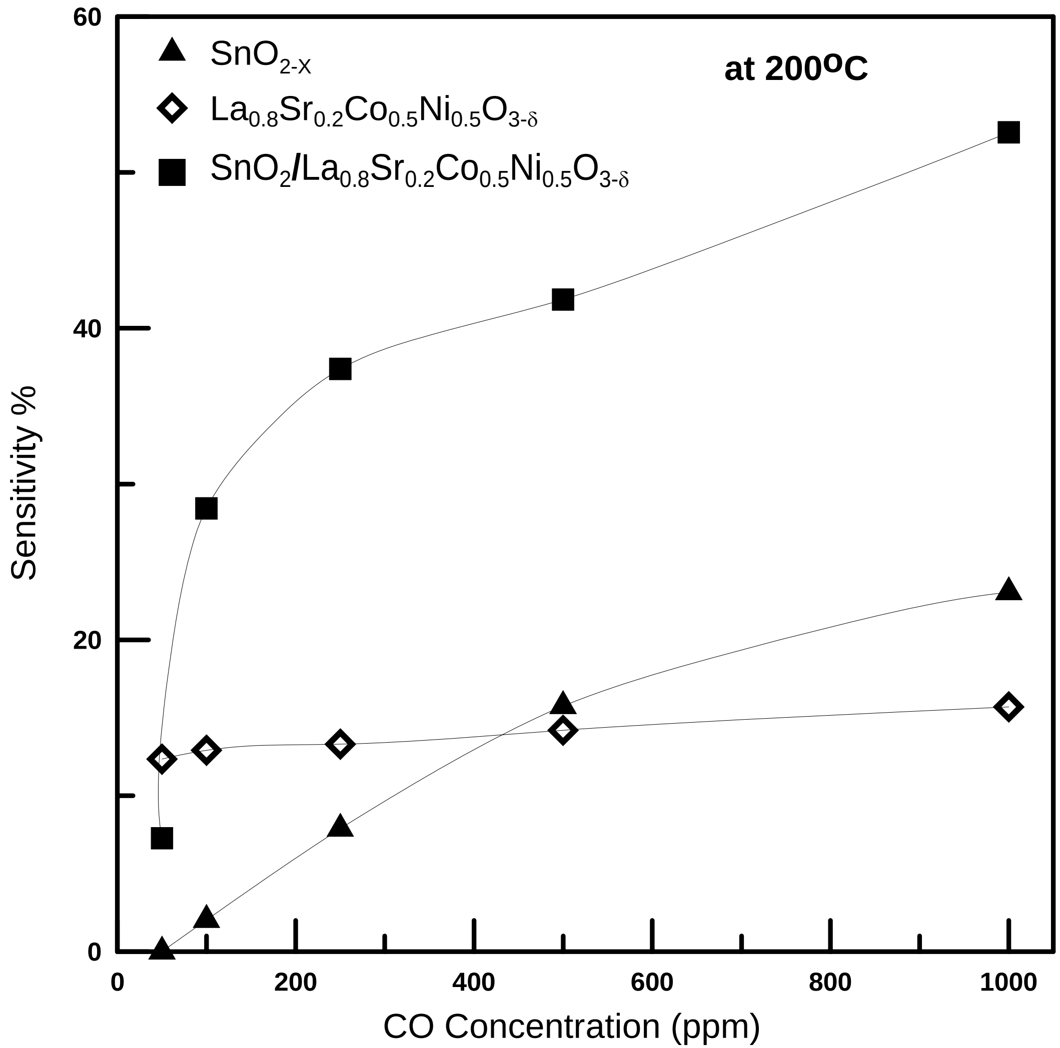
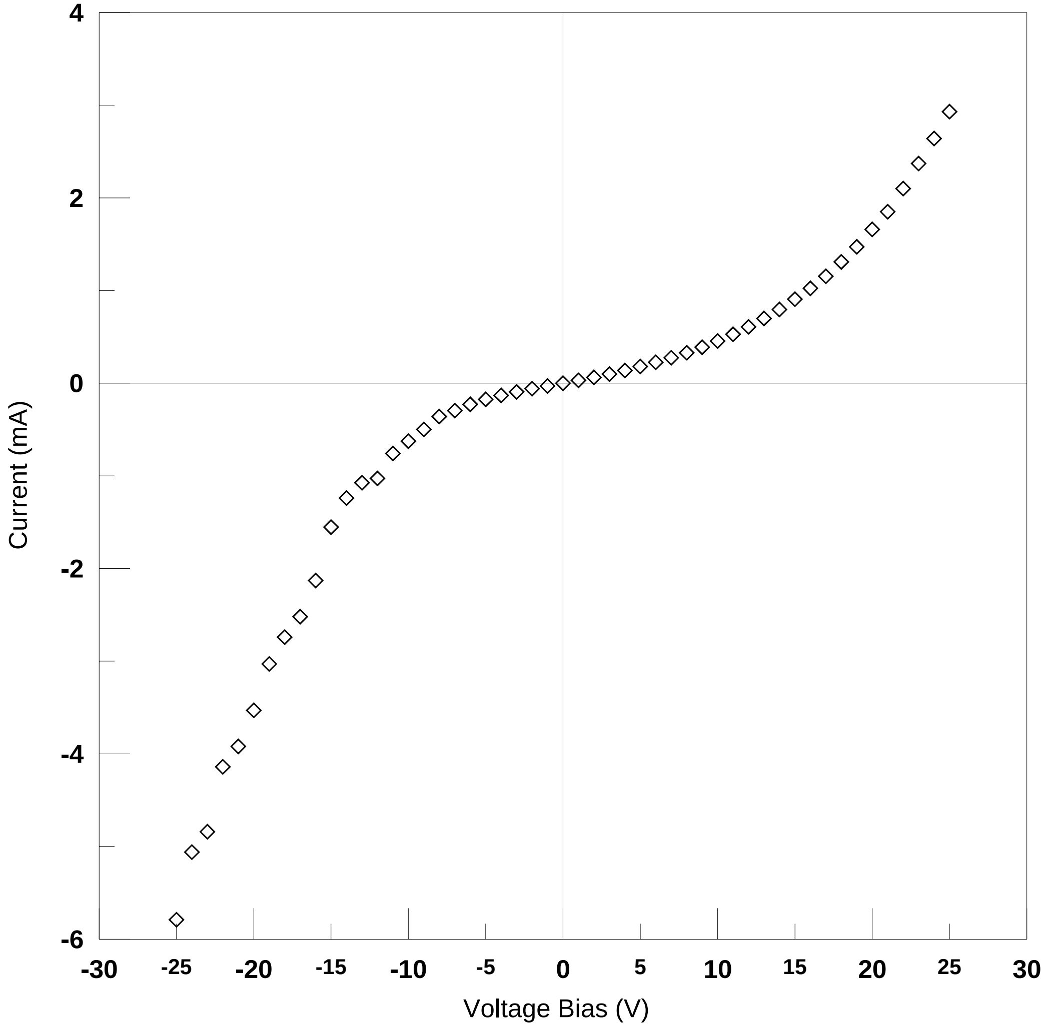


圖3-1 測試用試片之簡圖

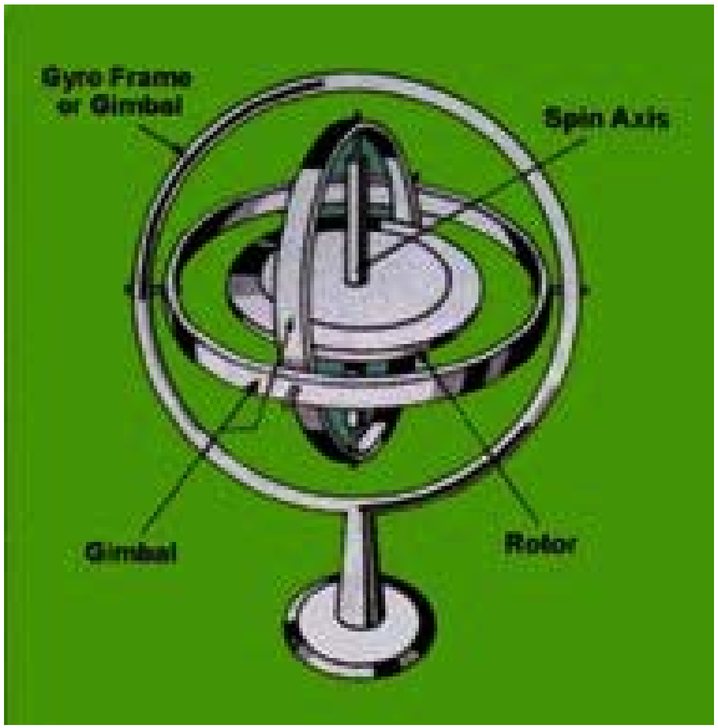
單層氧化物薄膜與異質接合薄膜對CO感測特性之比較



SnO_2/LSCNO異質接合薄膜在室溫下之I-V曲線



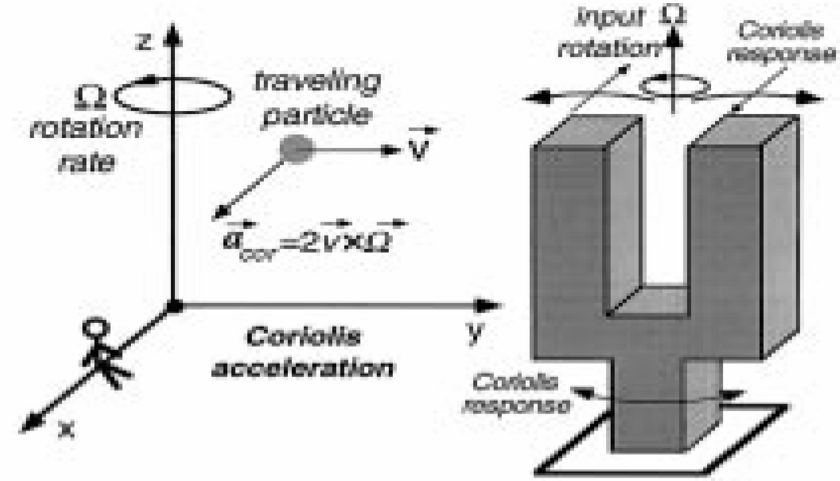
Gyroscopes

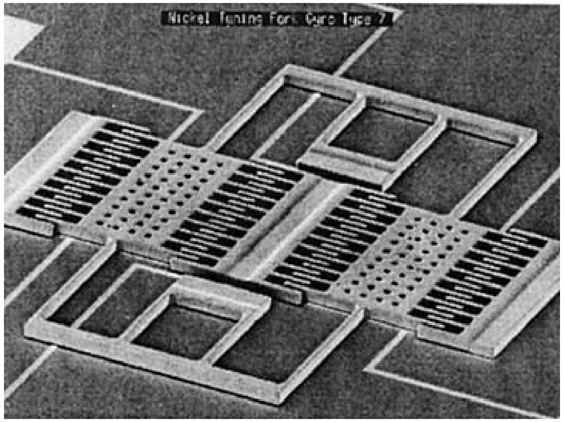

Gyro Frame
or Gimbal
Spin Axis
Gimbal
Rotor


（株）シリコンセンシングシステムズジャパン

Draper Tuning Fork Gyro

- The rotation of tines causes the Coriolis Force
- Forces detected through either electrostatic, electromagnetic or piezoelectric.
- Displacements are measured in the Comb drive

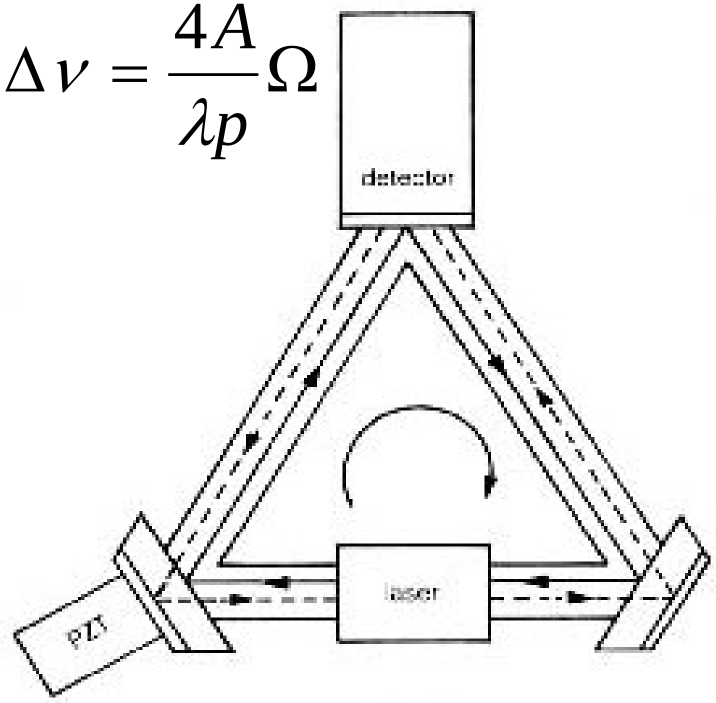




Laser Ring Gyroscopes

- Two signals sent around ring
- Different path lengths create a beat frequency.

$$\Delta \nu = \frac{4A}{\lambda p}\Omega$$

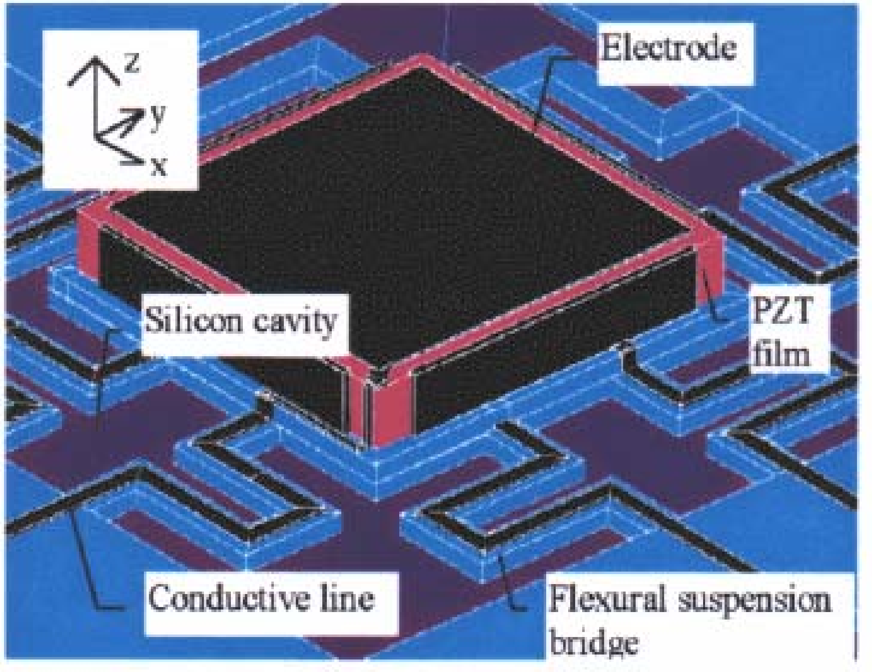


Active

- *A* – area of ring
- P – perimeter of ring

Piezoelectric Gyroscopes

- Basic Principles
  - Piezoelectric plate with vibrating thickness
  - Coriolis effect causes a voltage from the material
  - Very simple design and geometry



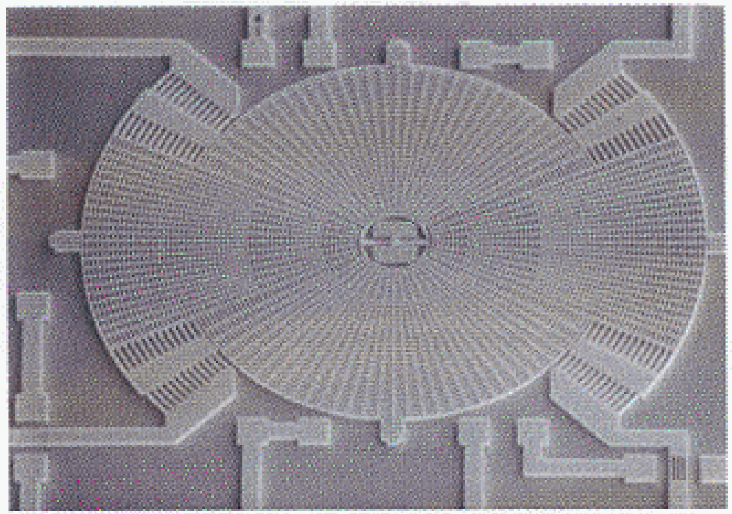


Fig. 1a: Gyrometer chip manufactured using the described Bosch Si-surface micromachining process.

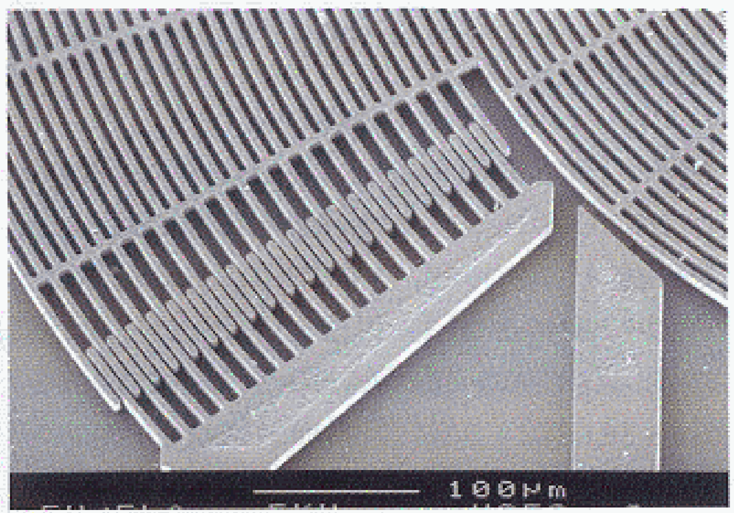
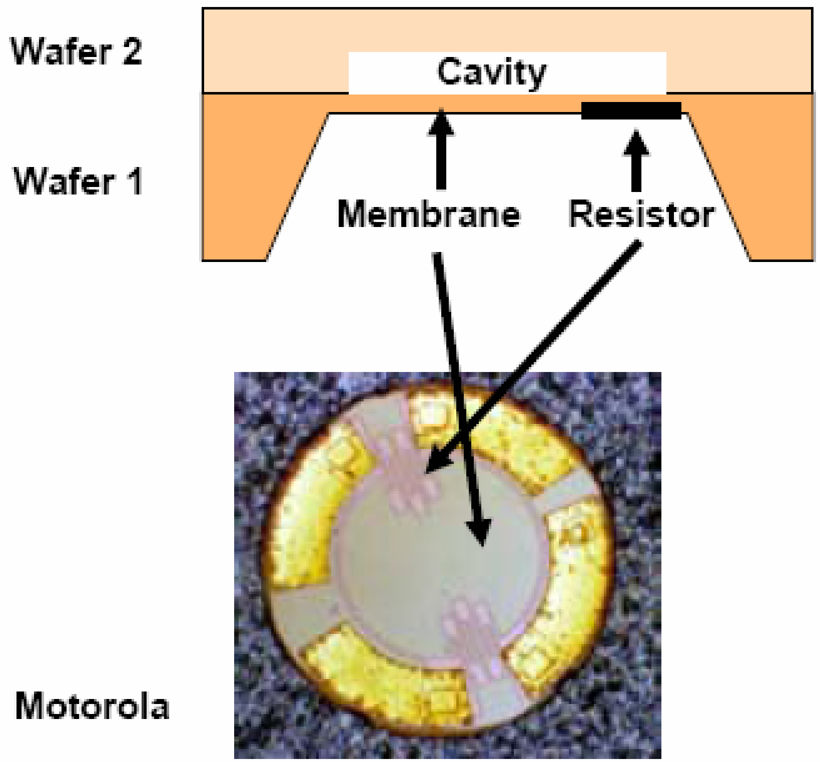


Fig. 1b: Details of an accelerometer comb-structure.

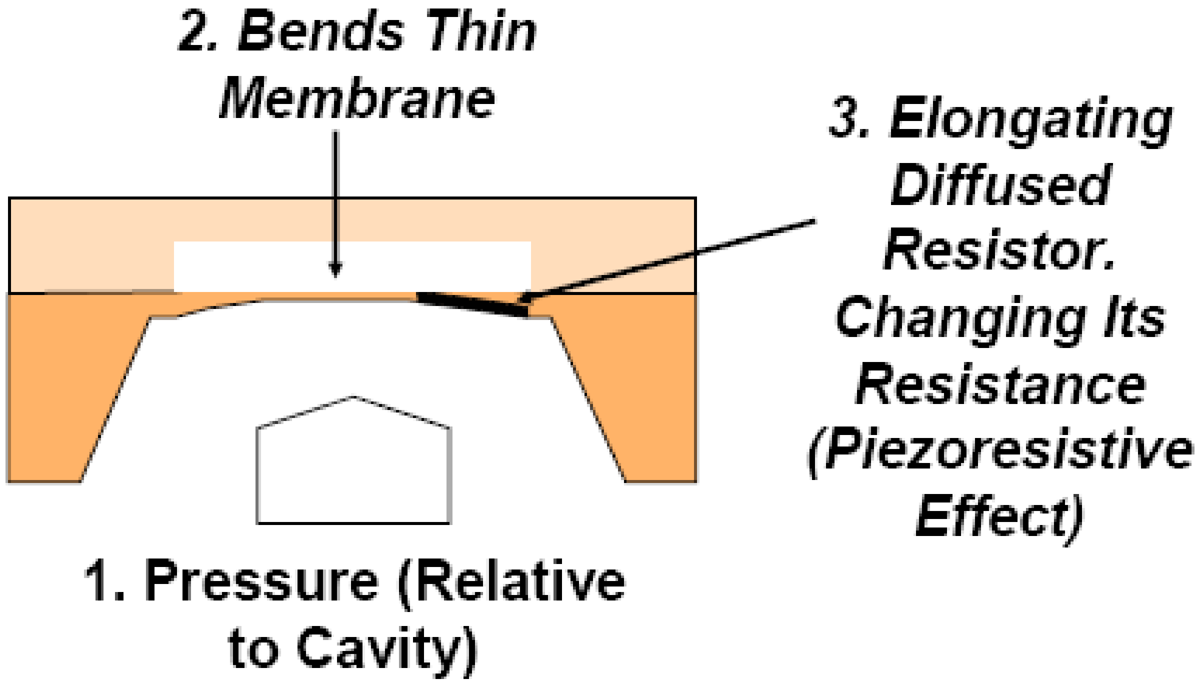
Applications of gyroscope

* Anti-Lock Brakes
* Military Munitions
* Inertial Measurement Unit
* Gait-Phase Detection Sensor
  Embedded in a Shoe Insole

Micromachined Pressure Sensor



Operation of pressure sensor



Accelerometer

MEMS accelerometers market

- Success of MEMS accelerometers is pushed by a general growth of all the marketplaces.

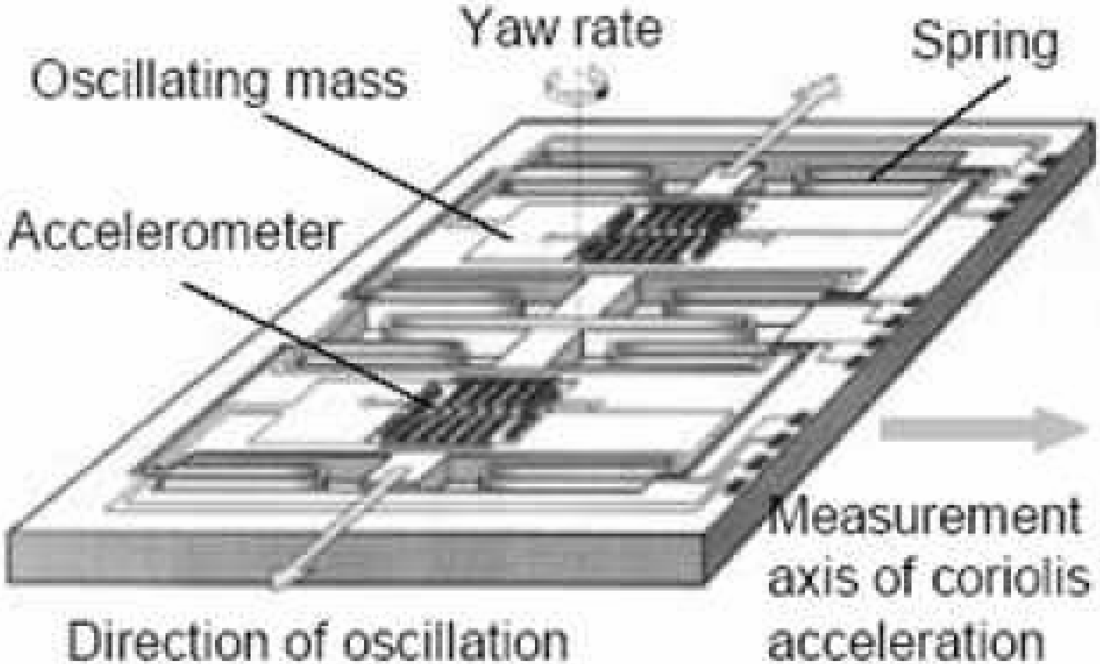
Year	1996	2002	2005	2008
Market size	240 M$	400 M$	560 M$	800 M$
Annul growth		+10%	+12%	+12%

- Automotive : 80%
- Avionic and defense : 8%
- Agriculture : 3%
- Seismic : 3%
- Tilt et stabilization : 2.5%
- Various : 3.5%

Values inherited from following market studies:

- NEXUS: "market studies from 1996 to 2002"
- Intechno Consulting's: "Sensor Markets 2008"
- Yole: "World MEMS inertial sensors"

iMEMS® Accelerometer



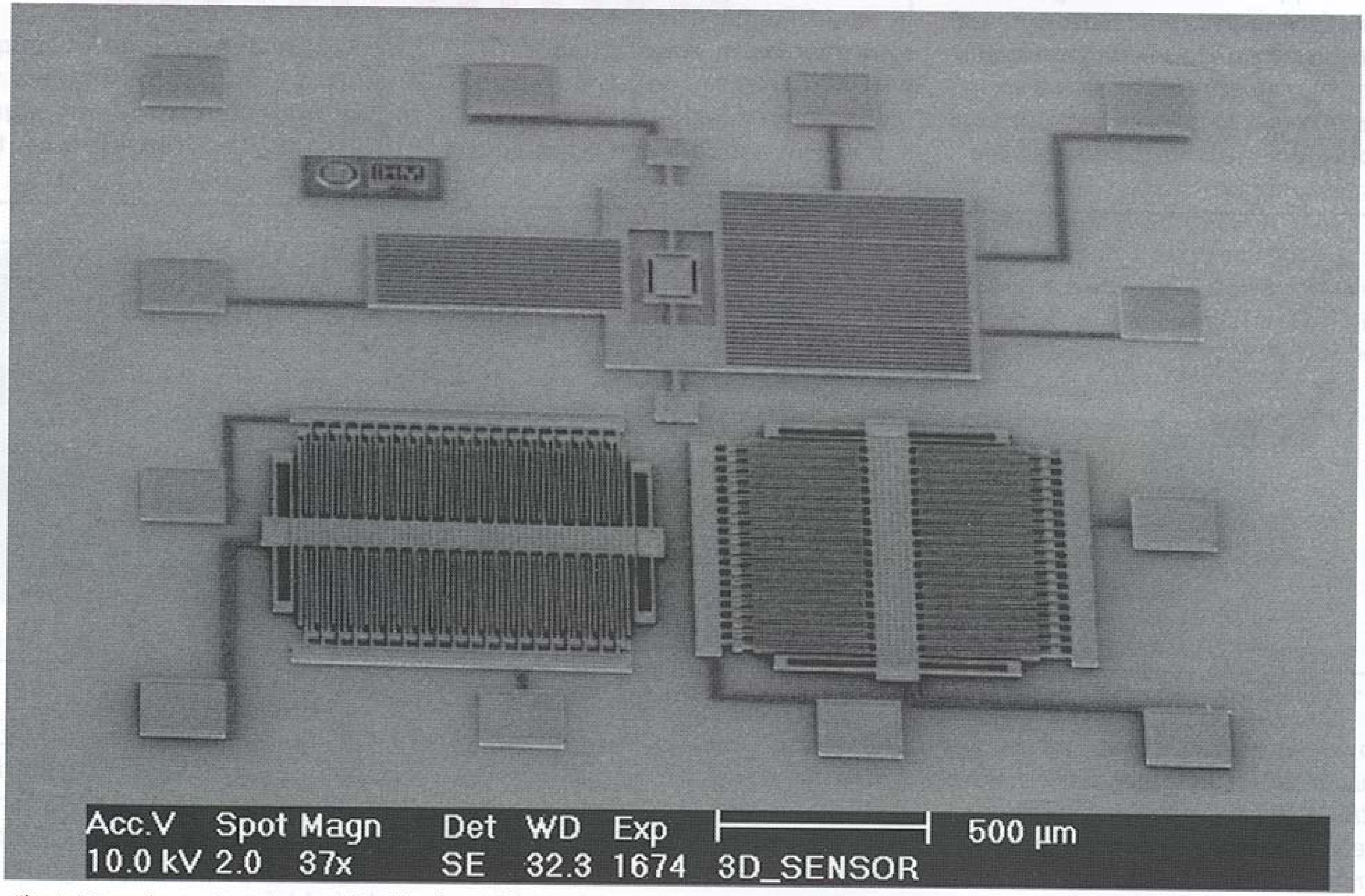


Fig. 4: 3D accelerometer micromachined by the author in Dresden University of Technology, Dresden, Germany.

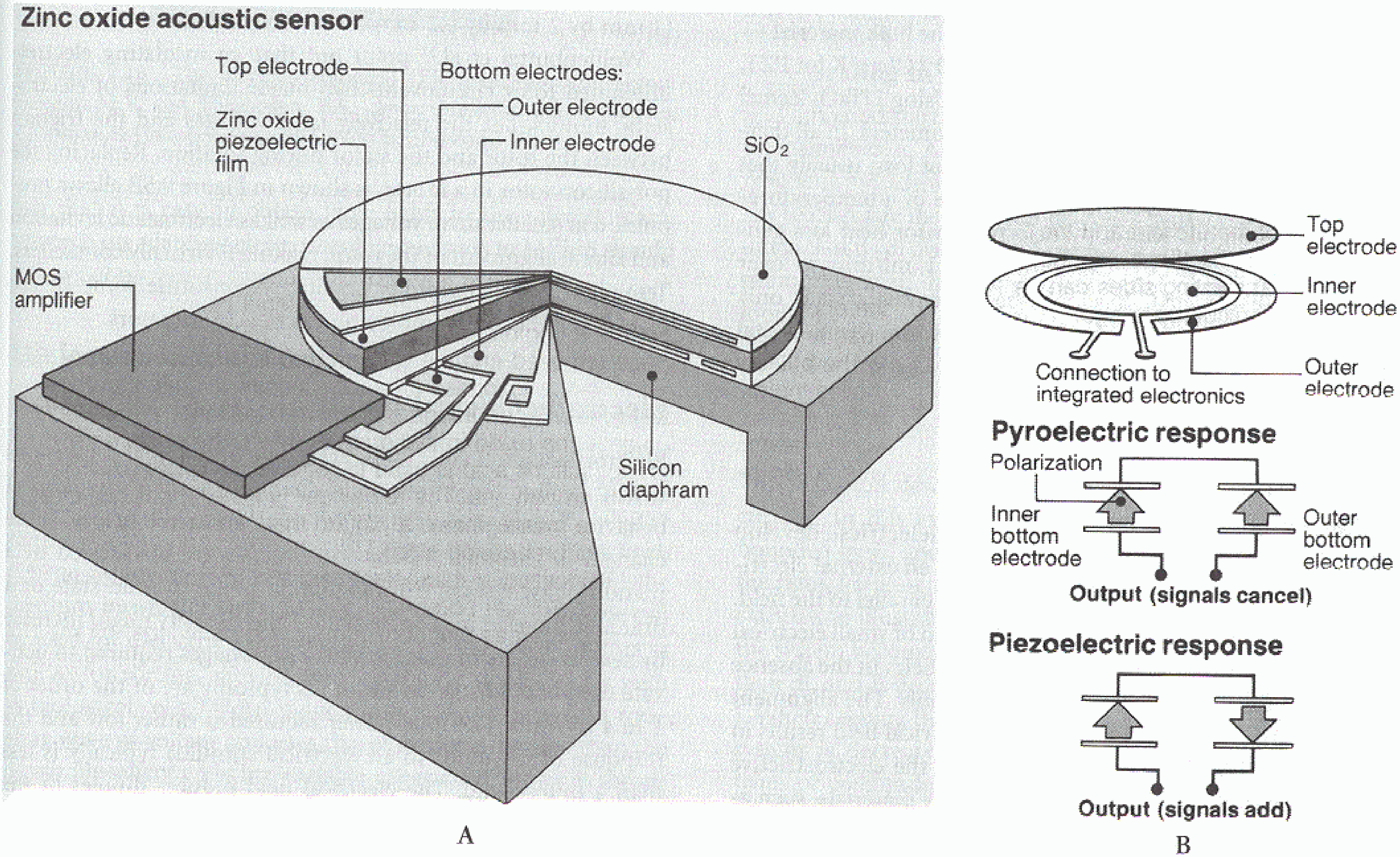


FIGURE 9.9 Zinc oxide acoustic sensor. Two parallel plate electrodes in Honeywell's acoustic sensor act as capacitors. Voltages due to temperature variations (pyroelectric effect) on zinc oxide film cancel, while those due to pressure add, doubling the output. (From Allen, R., Sensors in Silicon, *High Technology*, 43–81, 1984. With permission.)

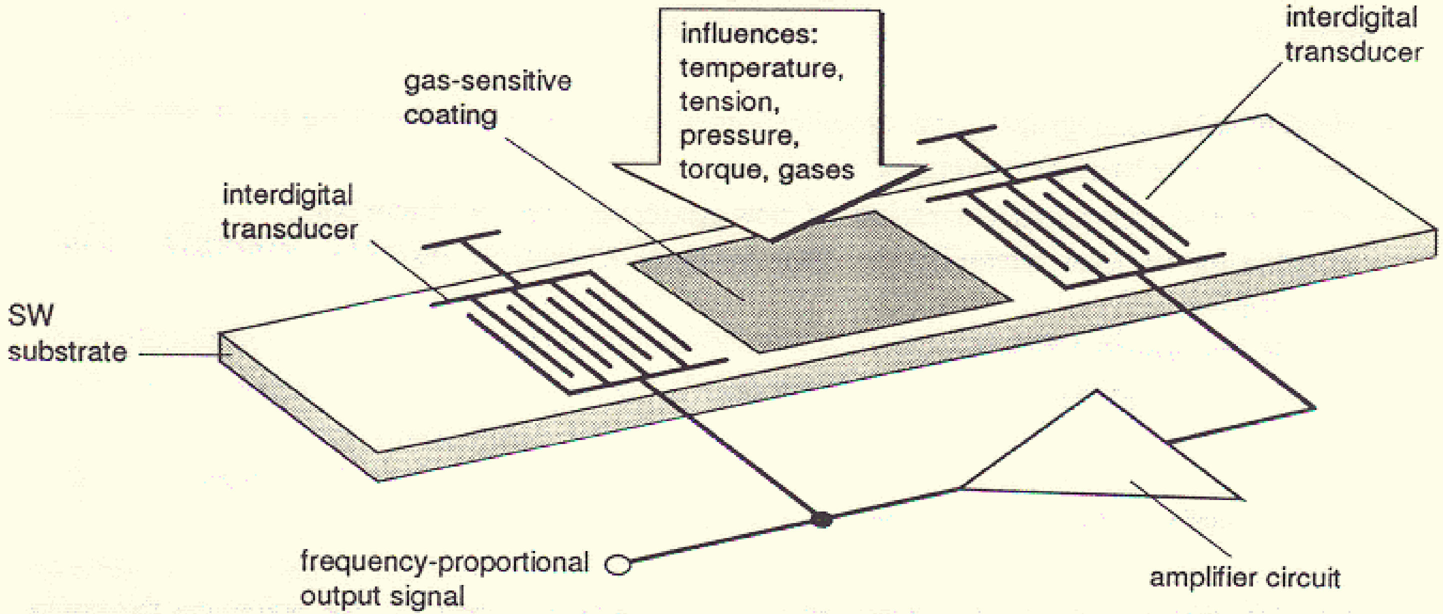


Figure 1-2. SW (surface-wave) sensors: changes in the parameters of SW propagation are converted into frequency changes of an oscillator.

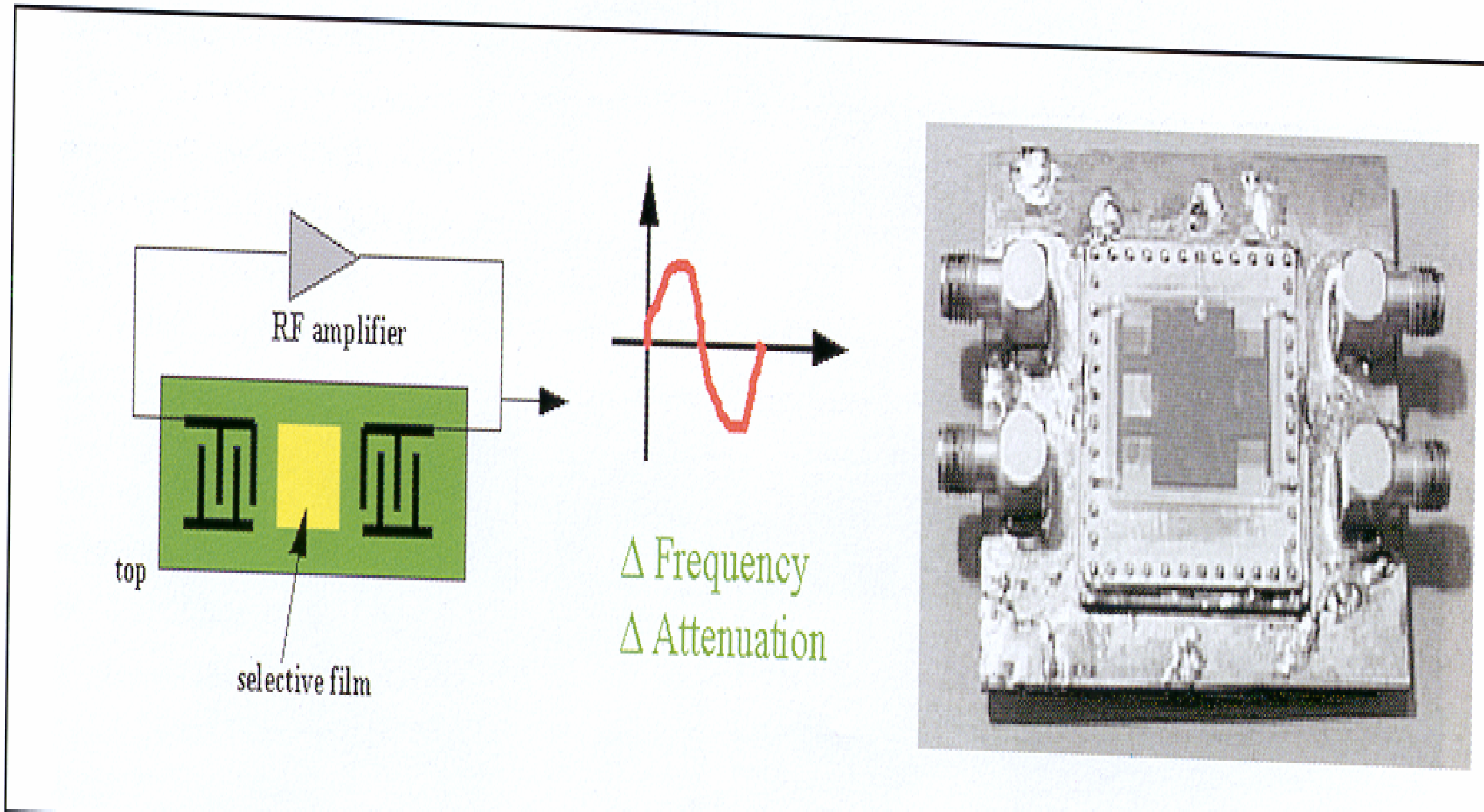


Fig. 1: Principle and assembly of a SH-SAW sensing deveice.

Actuators

Micromotors: Electrostate,

Emectromagnetics…..

Diaphragm pump

Micro-tweezer

Ink jet

Magnetic head driver

……………………

微型制動器使用之材料:

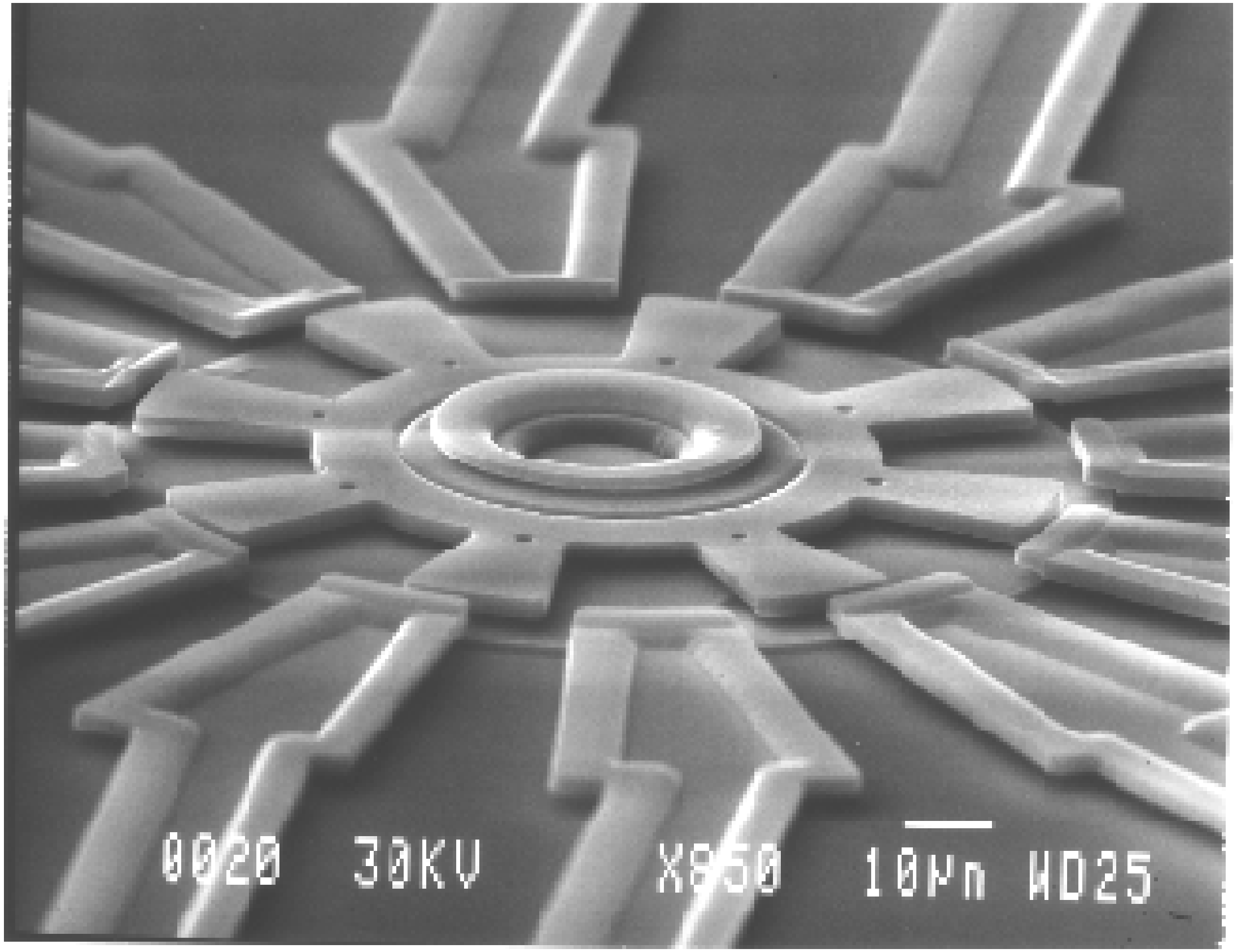
電磁式---軟硬磁組合, 磁伸縮材料

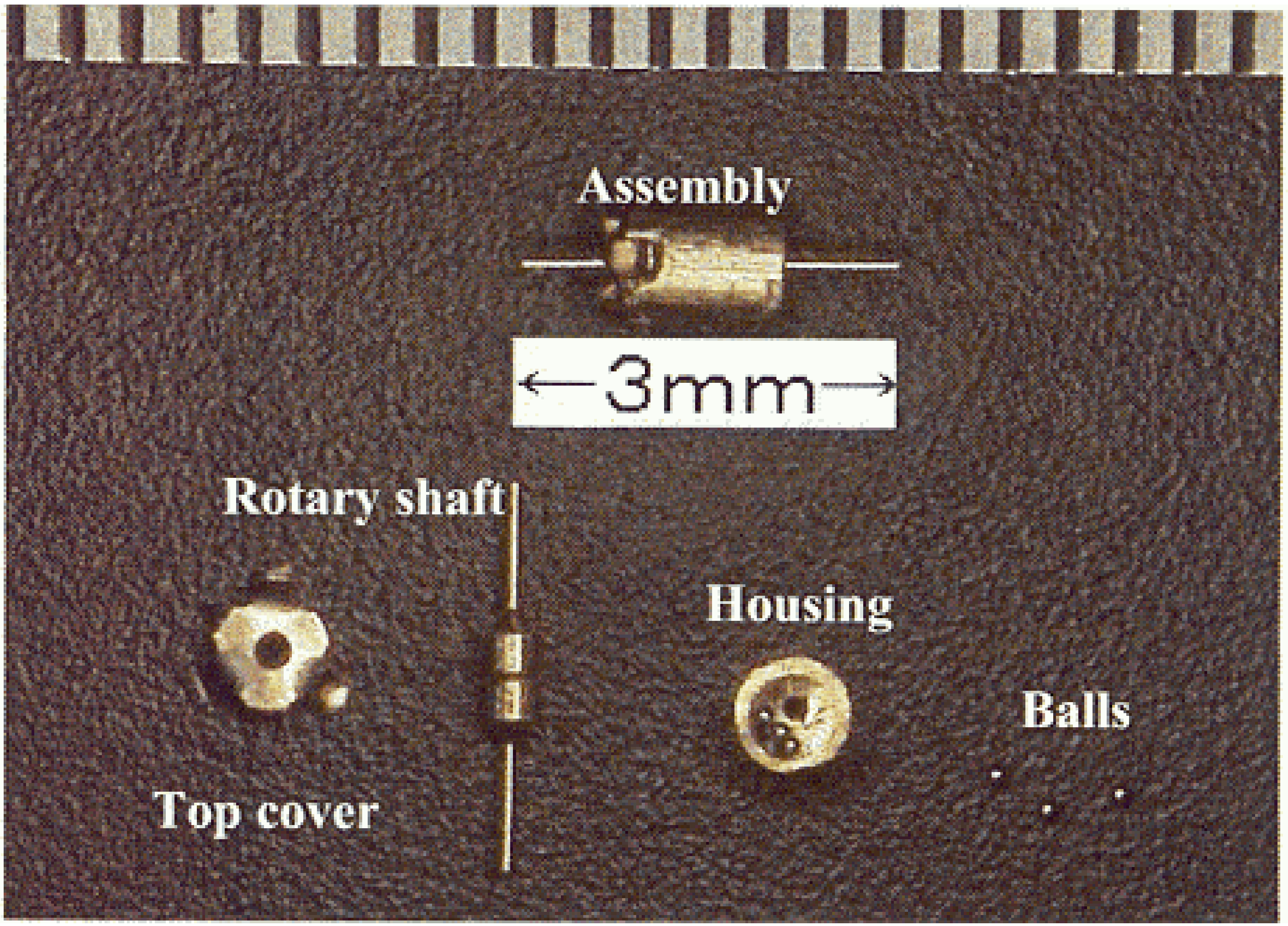
壓電式---PZT

SMA----TiNi alloy

熱驅動式--- Bimetal （熱膨脹式）

Electrostatic motor




Assembly
←3mm→
Rotary shaft
Housing
Balls
Top cover

Diaphragm pump

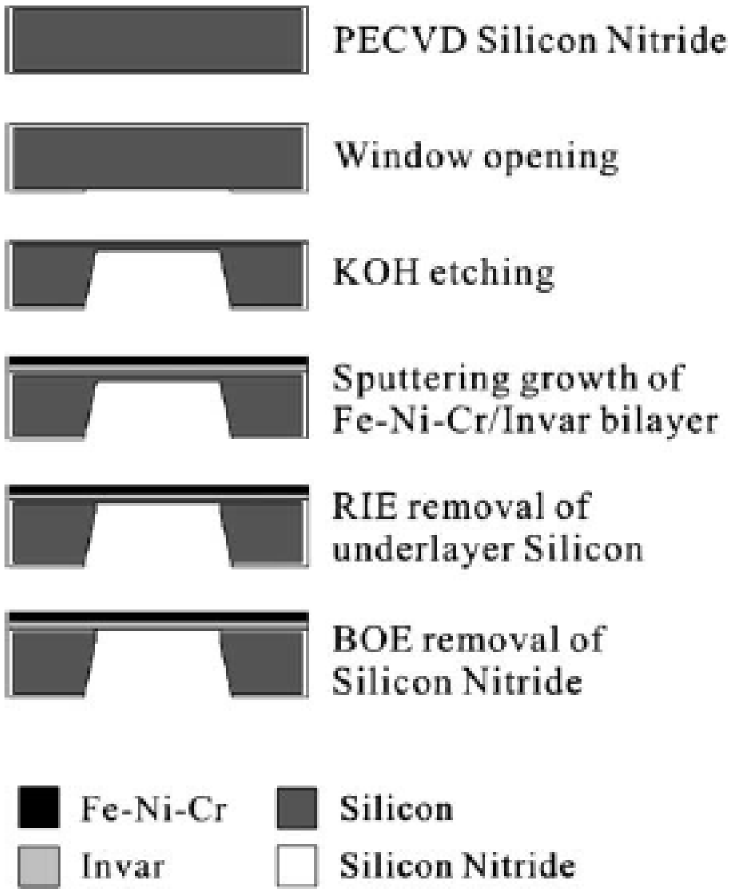


Fig. 1. Fabrication process for freestanding membrane.

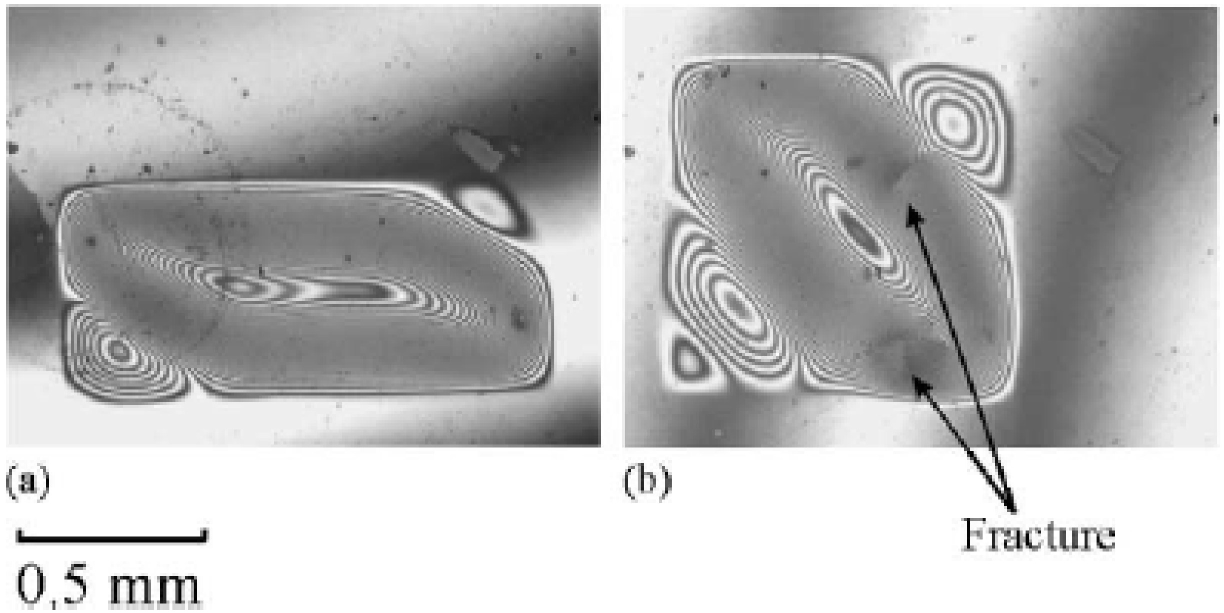
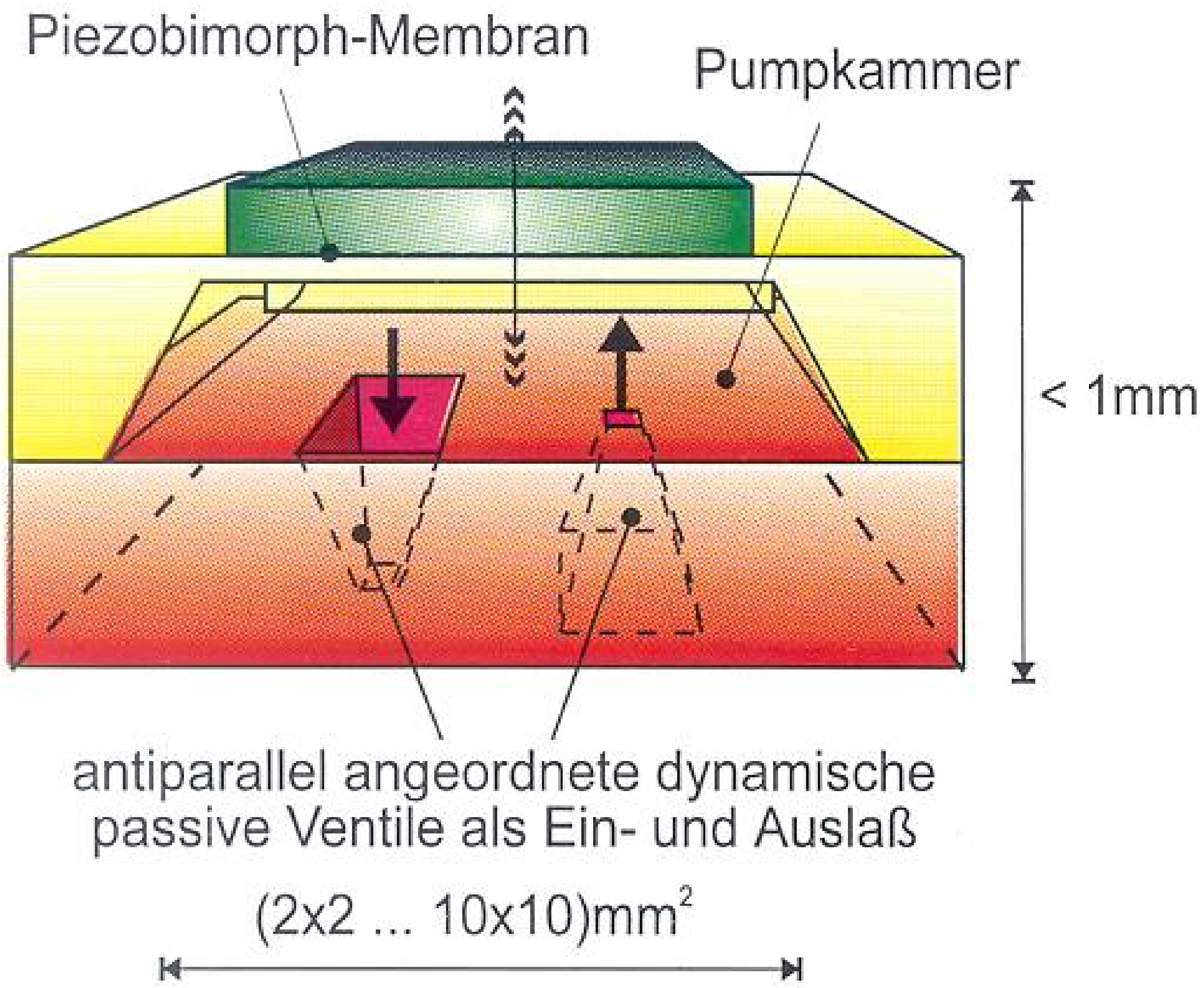


Fig. 4. Compressive residual stress induced postbuckling and fracture for the freestanding bimetal membrane. Top-view of the FNC (upper layer)/ Invar membrane: (a) 40 mTorr deposition pressure; (b) 25 mTorr deposition pressure.

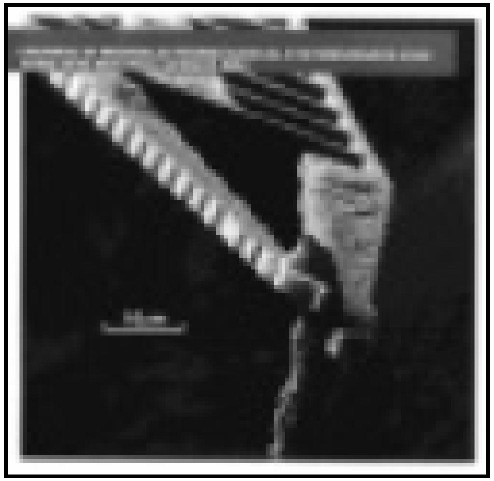
Performance parameters	This study	Other studies				
	FNC/Invar	Al/silicon [22]	Al/poly Si/silicon [4]	Ni/silicon [22]	SMA [23]	Al/SiN_x/poly Si/Si [24]
Power consumption (W)	0.1	0.5	*12 V	1.03	16	0.56
Active area for deflection (mm^2)	1	NA	9	64	25	16
Deflection (μm)	94		72	NA	100	5
Actuation speed (ms)	56	100	NA	200	100	NA
Package size (mm^3)	NA	6.8	NA	2.3	NA	NA

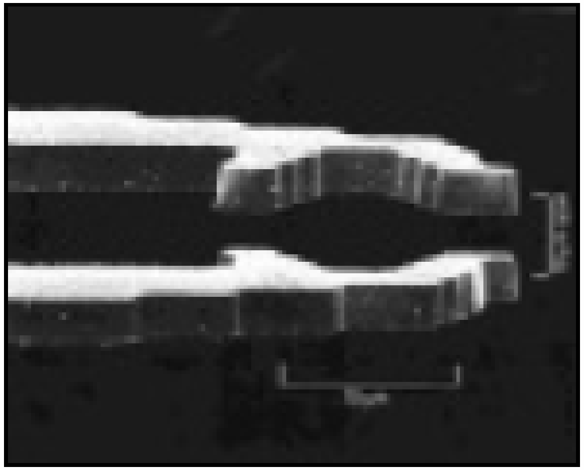
* The driving power was supplied through dc voltage pules.

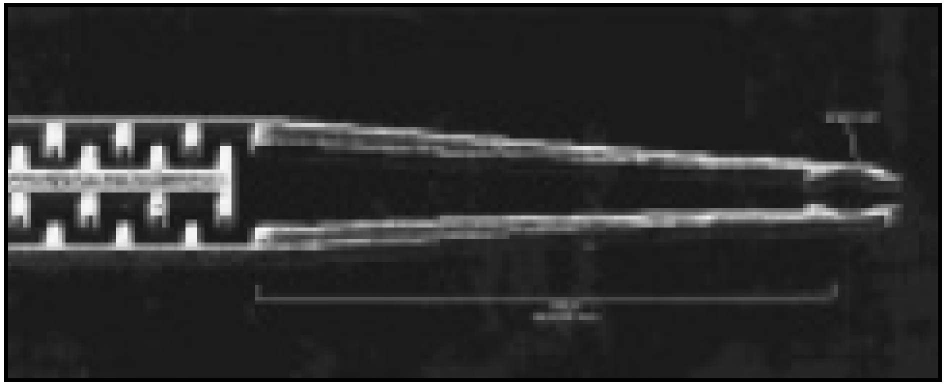
Micro-pump and valves



Micro-Grippers

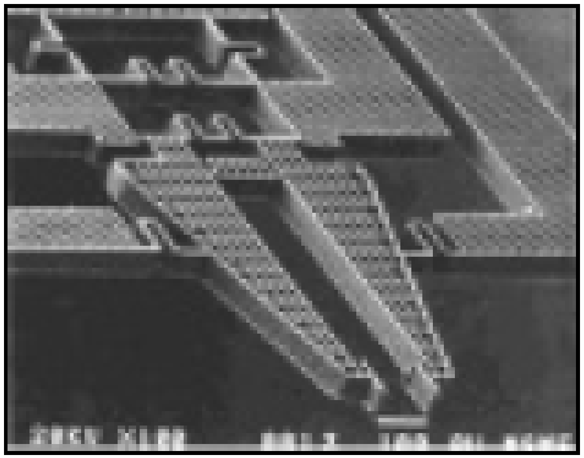


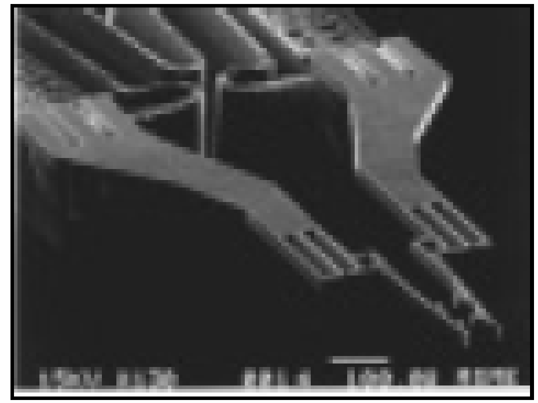


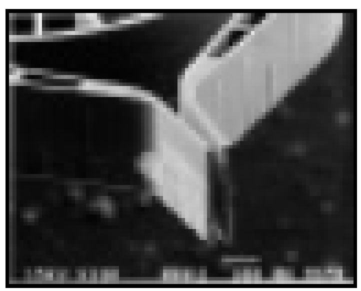


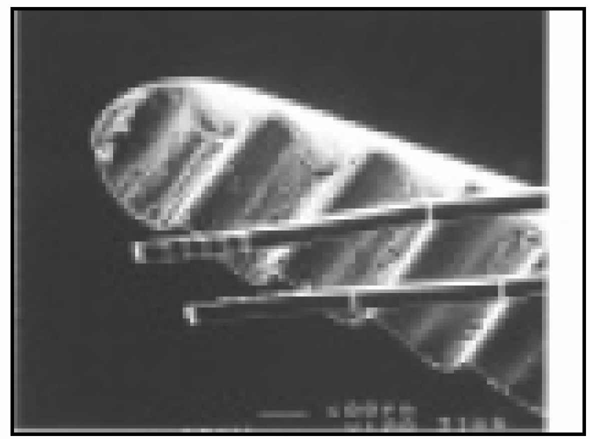
Source: Berkeley

Micro-Tweezers



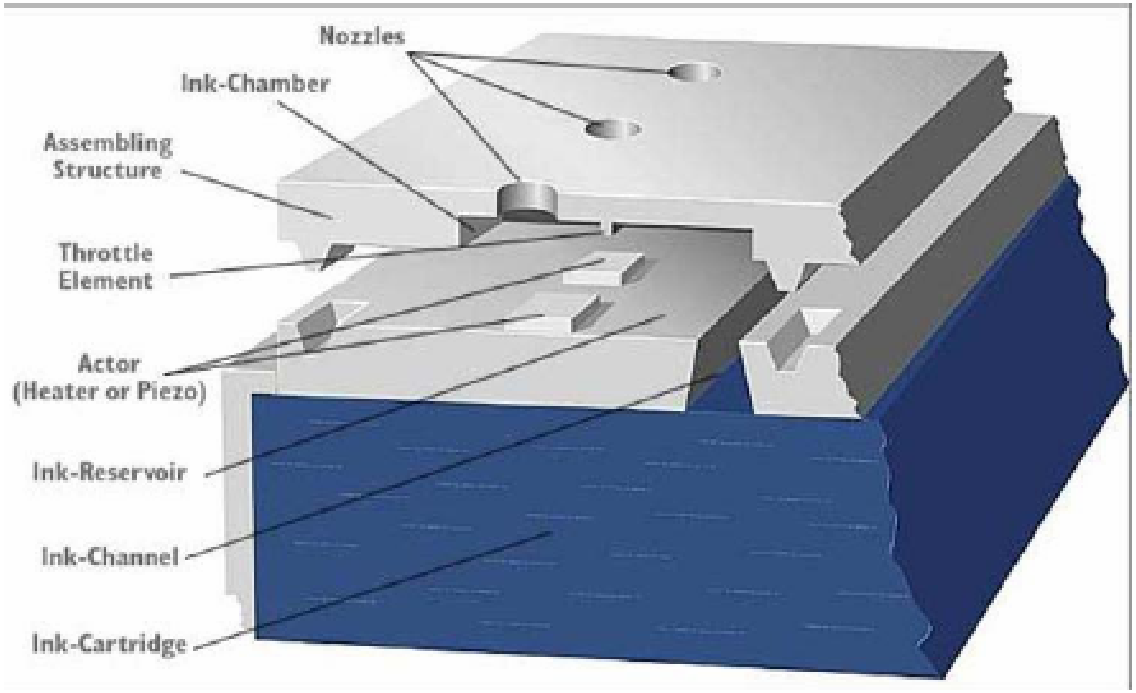




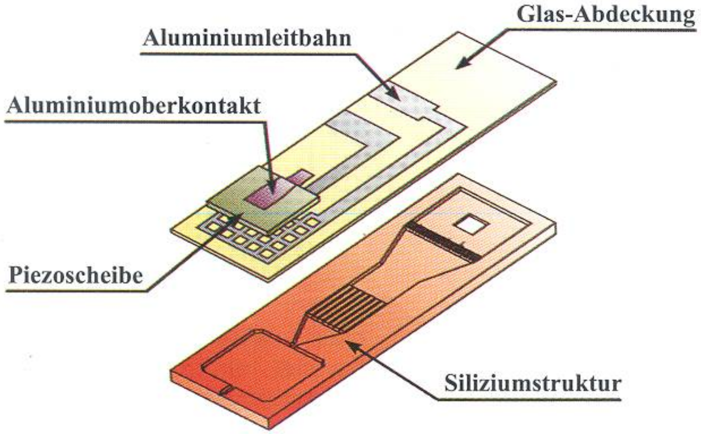


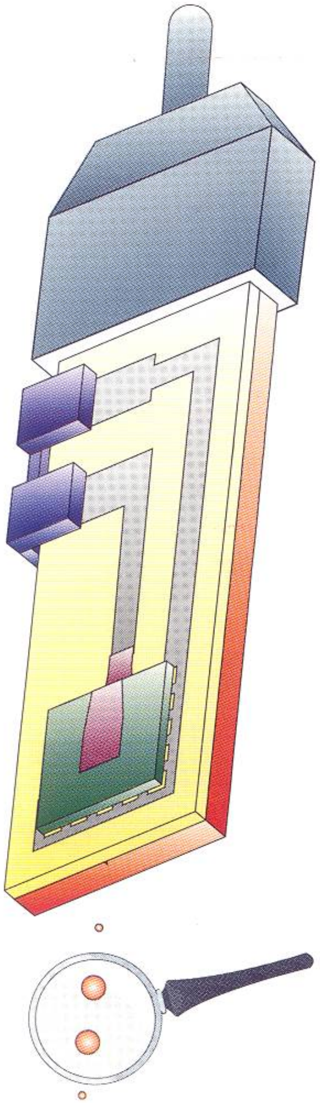
Source: MEMS Precision Instruments

- Ink jet printers are MEMS based – late 1970's, IBM and HP

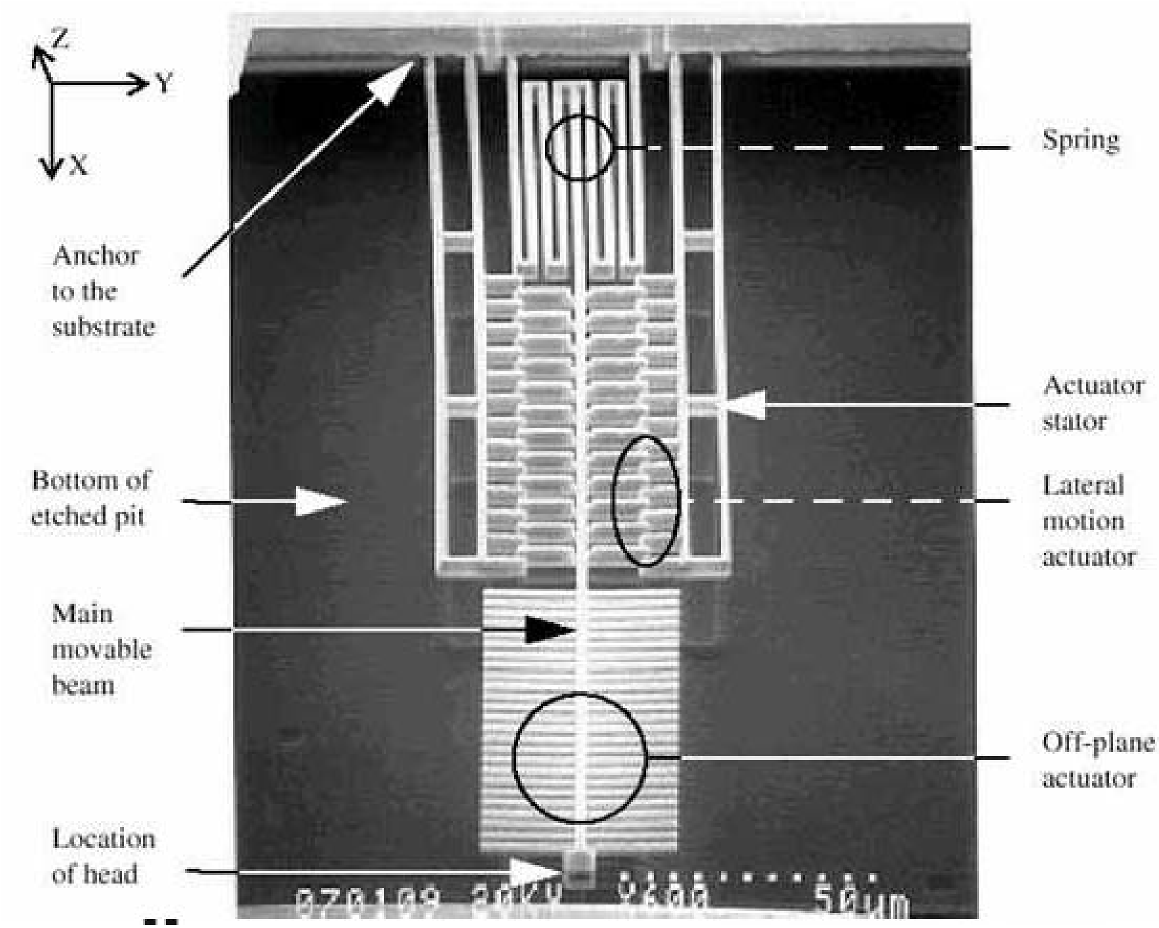


噴墨頭示意圖

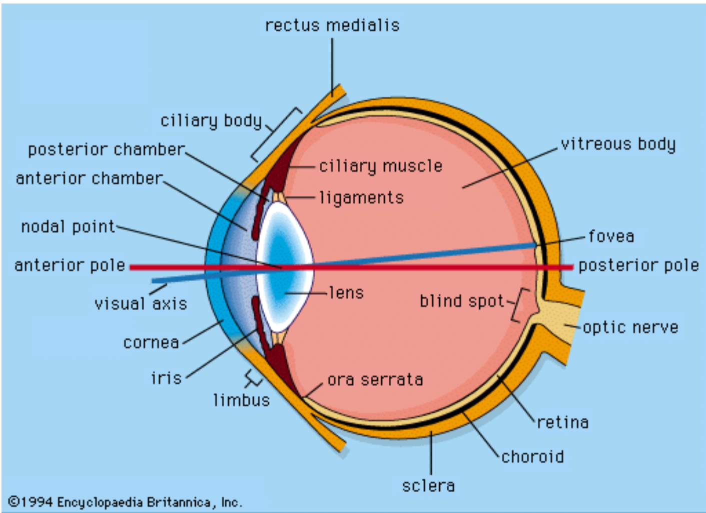

Glas-Abdeckung
Aluminiumleitbahn
Aluminiumoberkontakt
Piezoscheibe
Siliziumstruktur

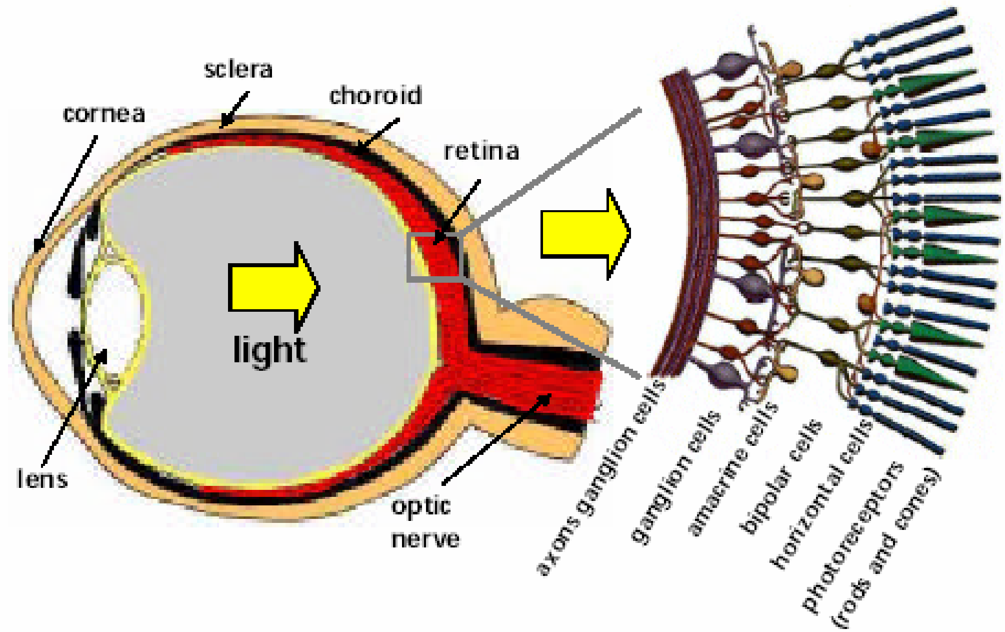


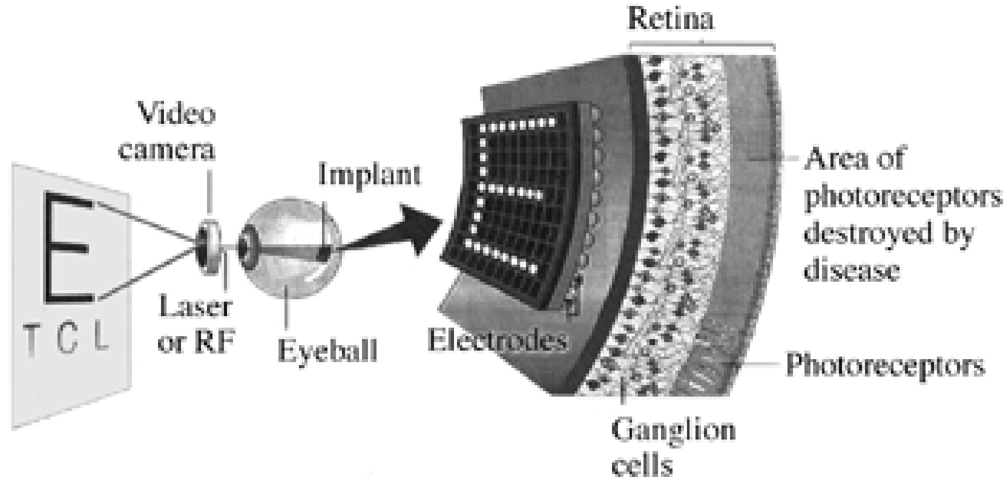
Magnetic read/write heads for hard drives.



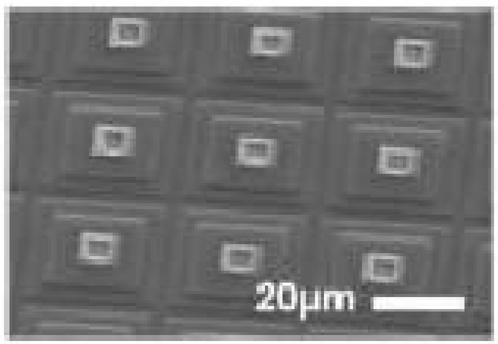
Optobionics: Retinal Implant



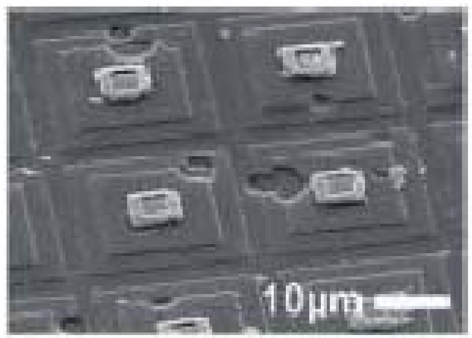




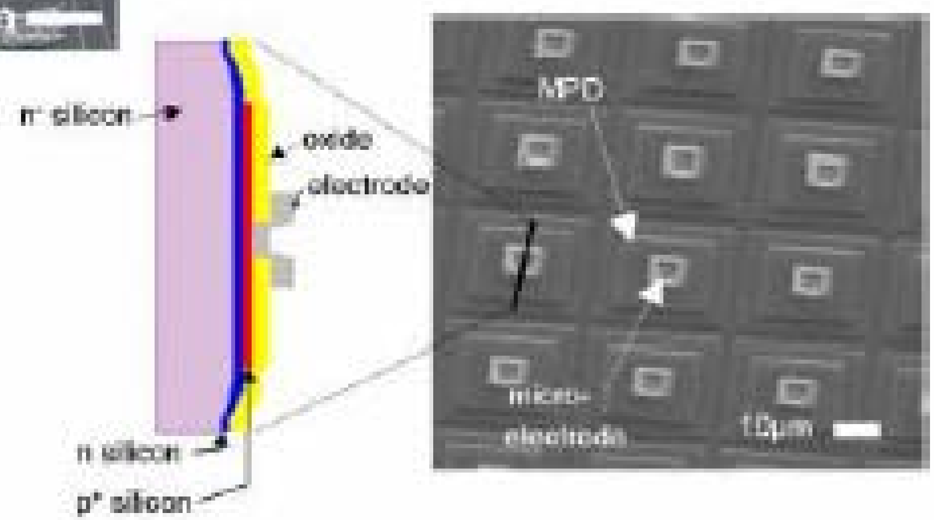
Retina
Video camera
Implant
Area of photoreceptors destroyed by disease
Laser or RF
Eyeball
Electrodes
Photoreceptors
Ganglion cells
T C L



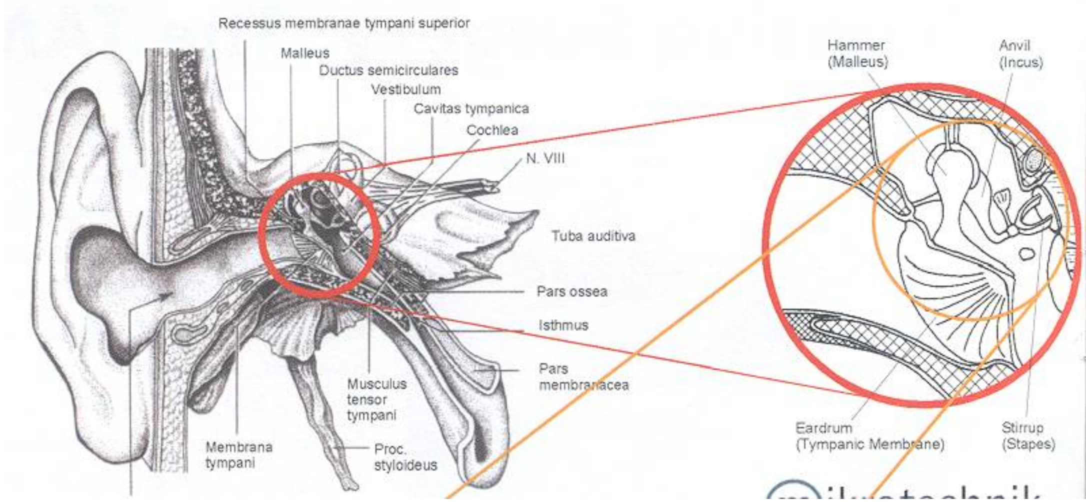
20µm

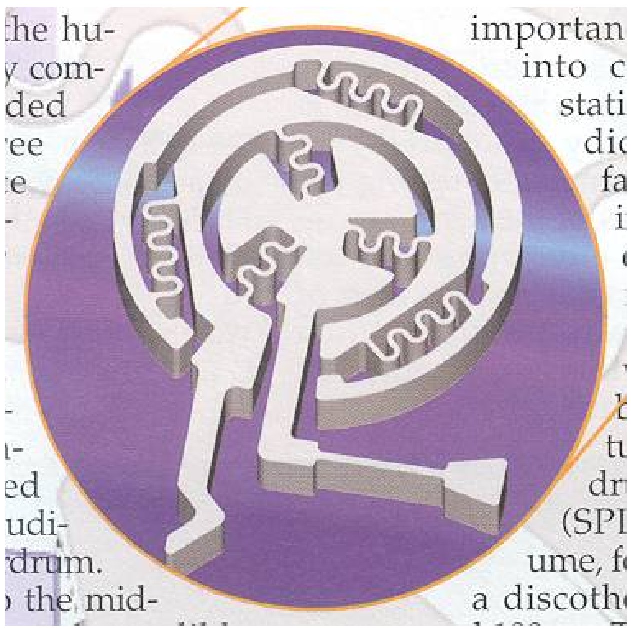


10µm

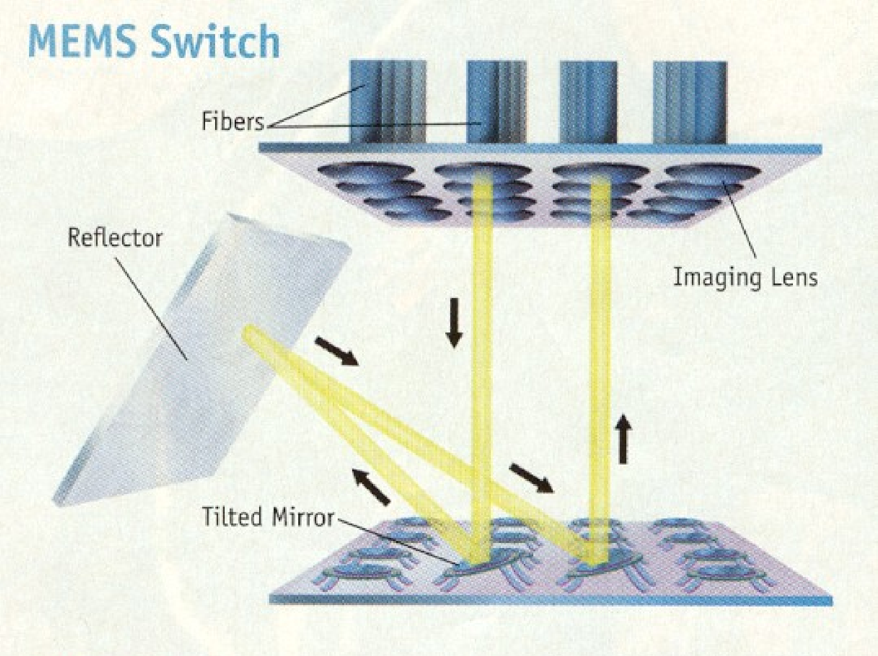


n+ silicon
oxide
electrode
n silicon
p+ silicon
MPD
micro-electrode
10µm

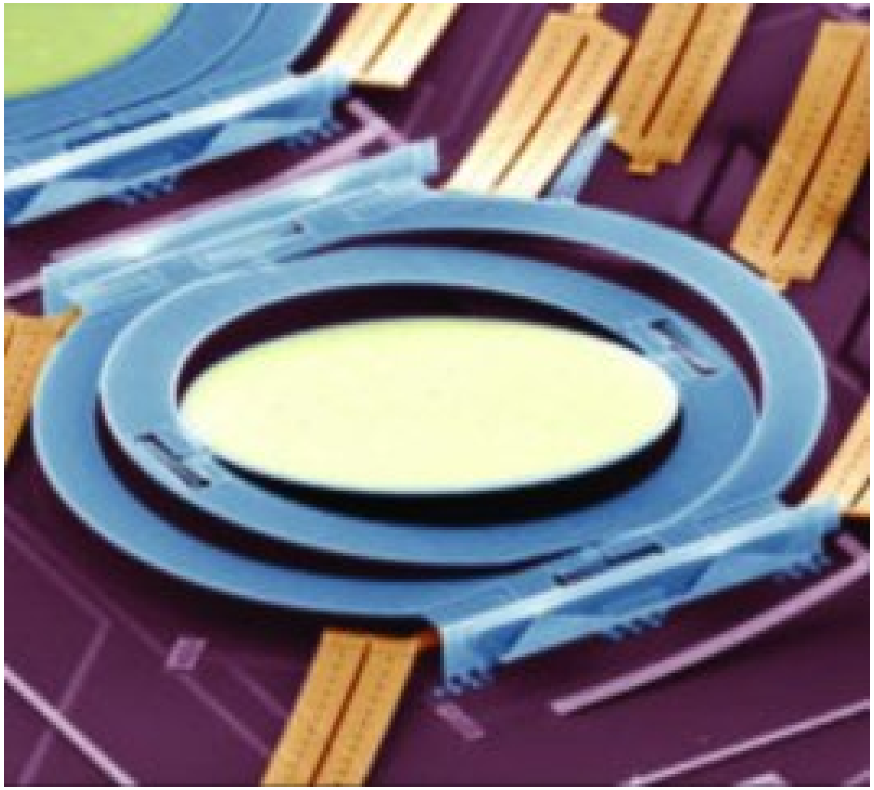

Recessus membranae tympani superior
Malleus
Ductus semicirculares
Vestibulum
Cavitas tympanica
Cochlea
N. VIII
Tuba auditiva
Pars ossea
Isthmus
Pars membranacea
Musculus tensor tympani
Membrana tympani
Proc. styloideus
Hammer (Malleus)
Anvil (Incus)
Eardrum (Tympanic Membrane)
Stirrup (Stapes)

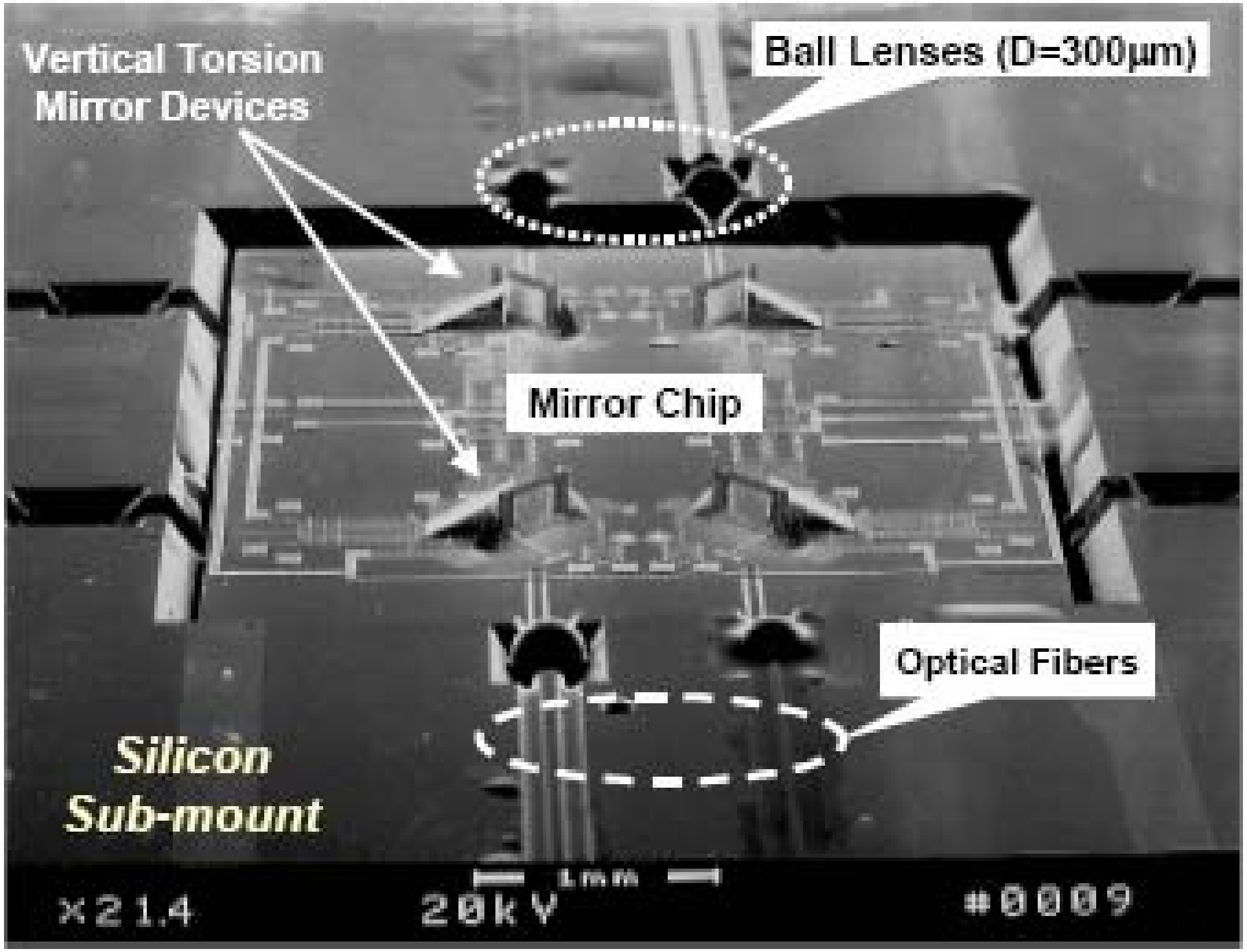


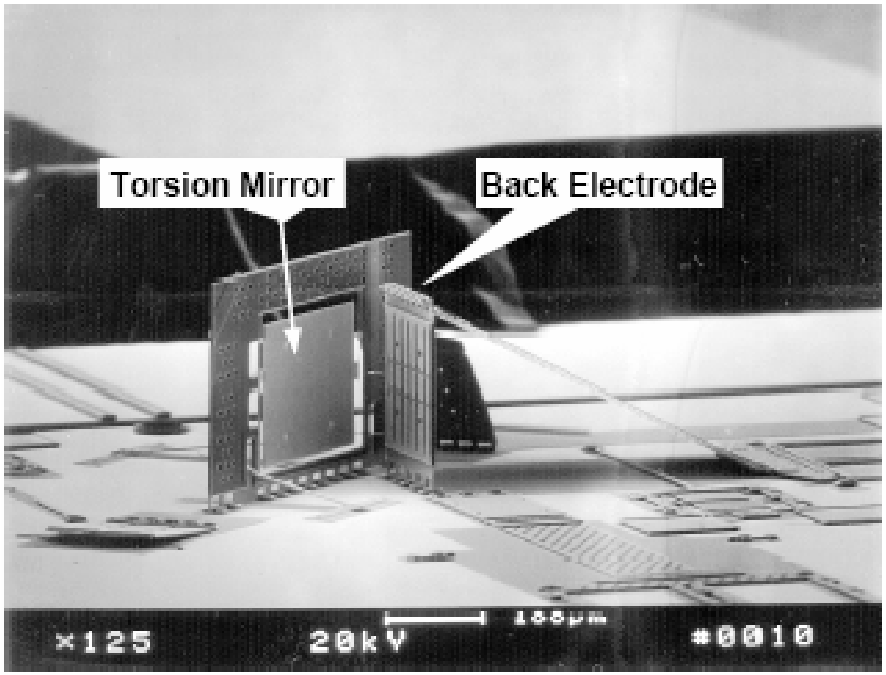
Two Axis Micro-mirror

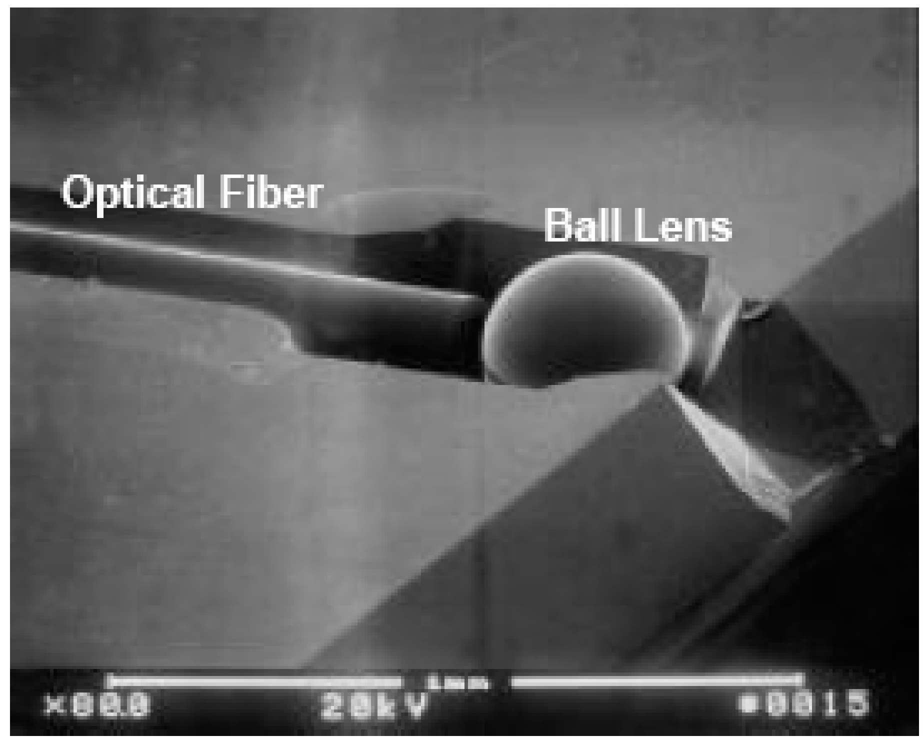


TILTED MIRROR in a MicroElectroMechanical System (MEMS) switch (*photograph shows close-up*) bounces a lightwave from an incoming fiber onto a reflector, off another mirror and into an outgoing fiber.

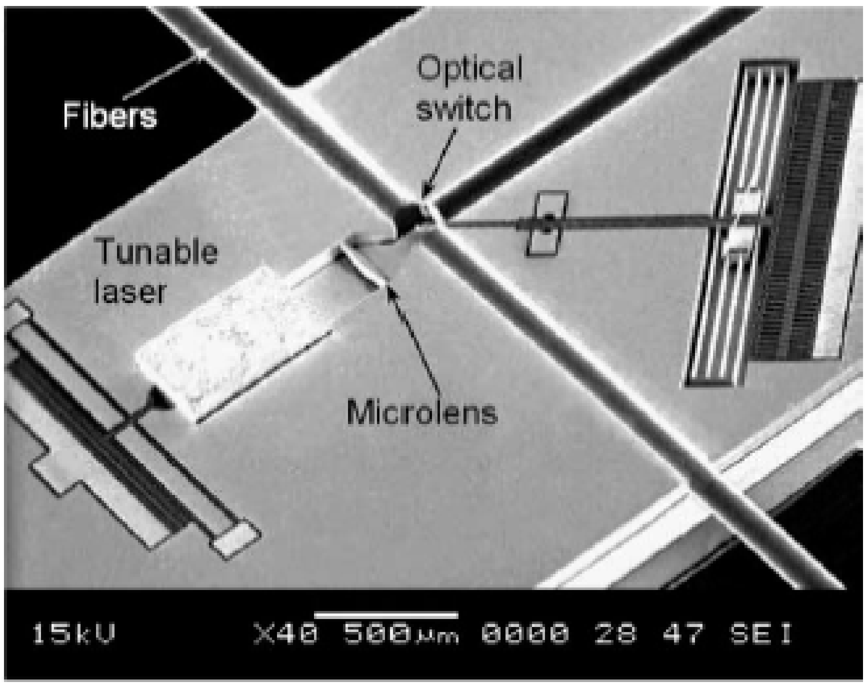


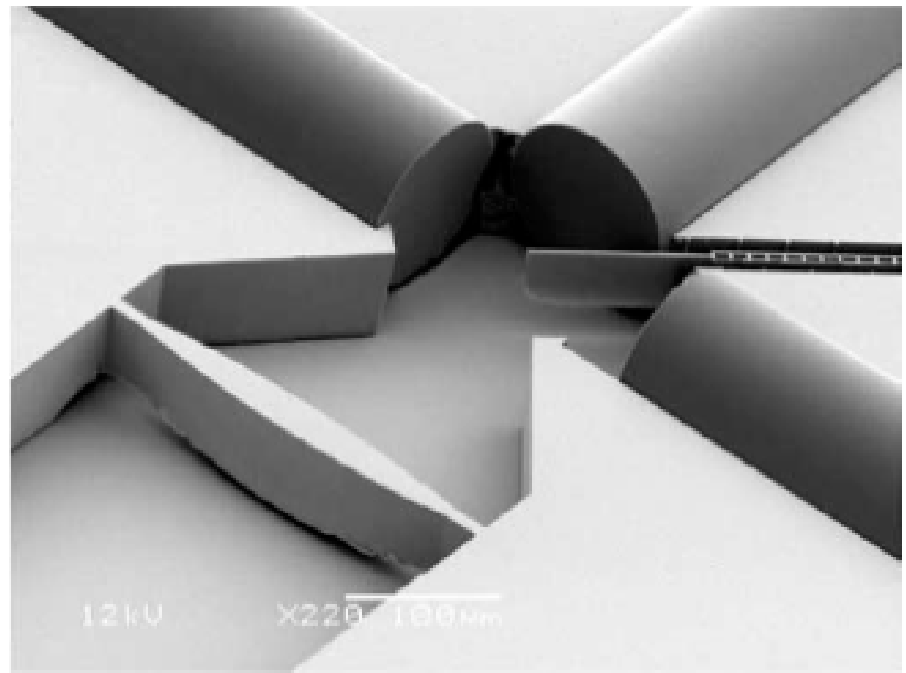

Vertical Torsion
Mirror Devices
Ball Lenses (D=300µm)
Mirror Chip
Optical Fibers
Silicon
Sub-mount
1mm
x21.4
20kV
#0009


Torsion Mirror
Back Electrode
×125
20kV
#0010

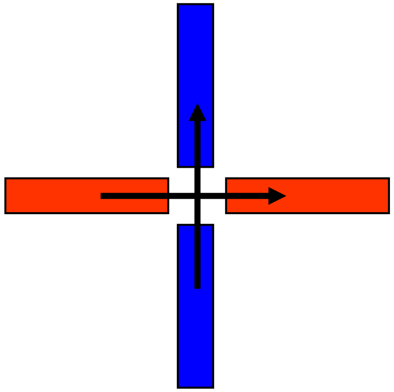

Optical Fiber
Ball Lens
20kV
#0015

Optical Switch

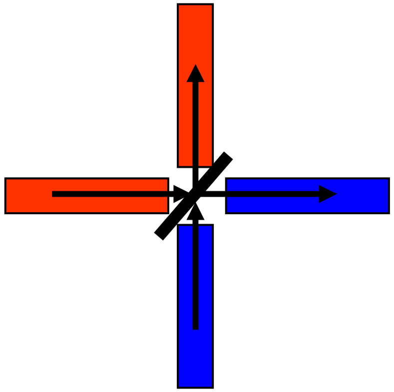




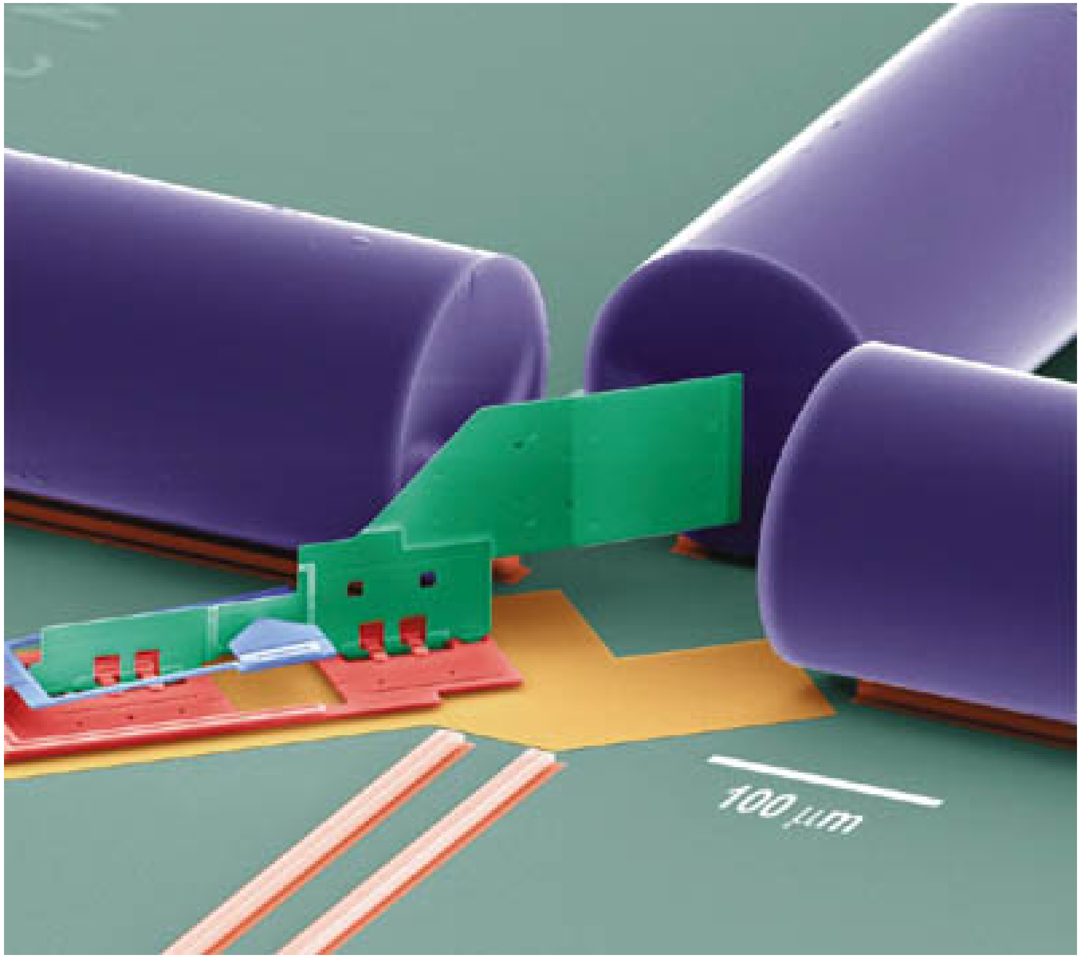
2x2 Optical Switch



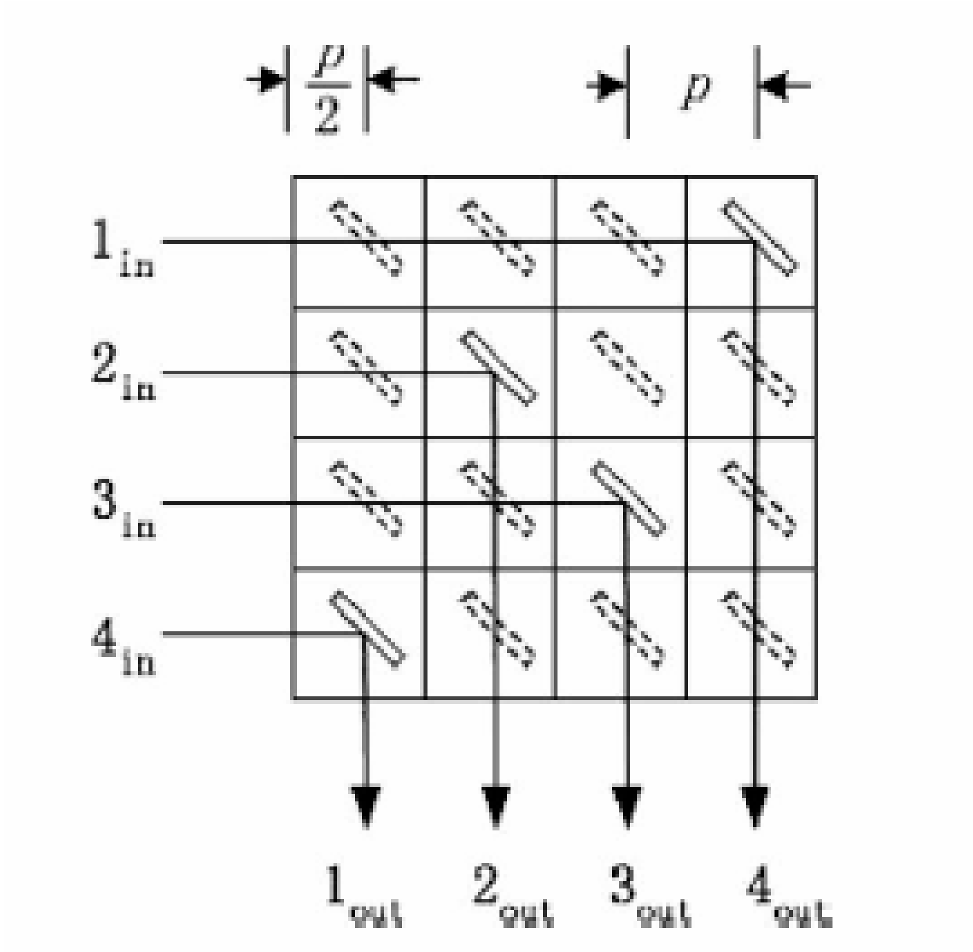
Cross State



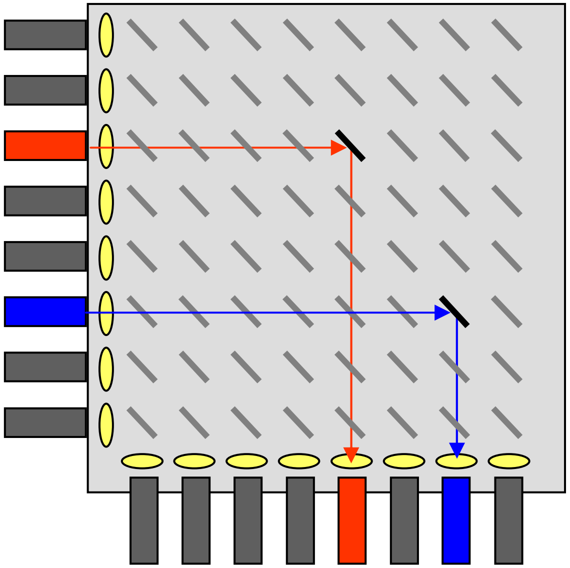
Bar State

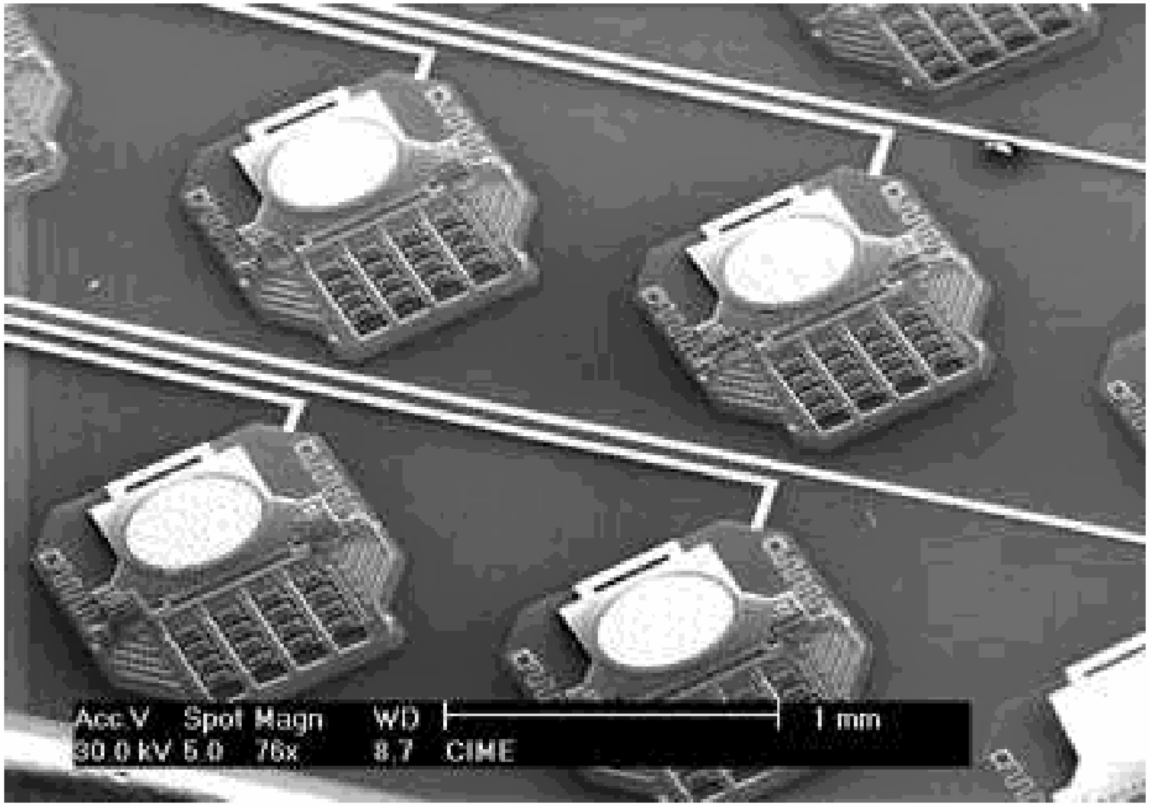


Optical Switch

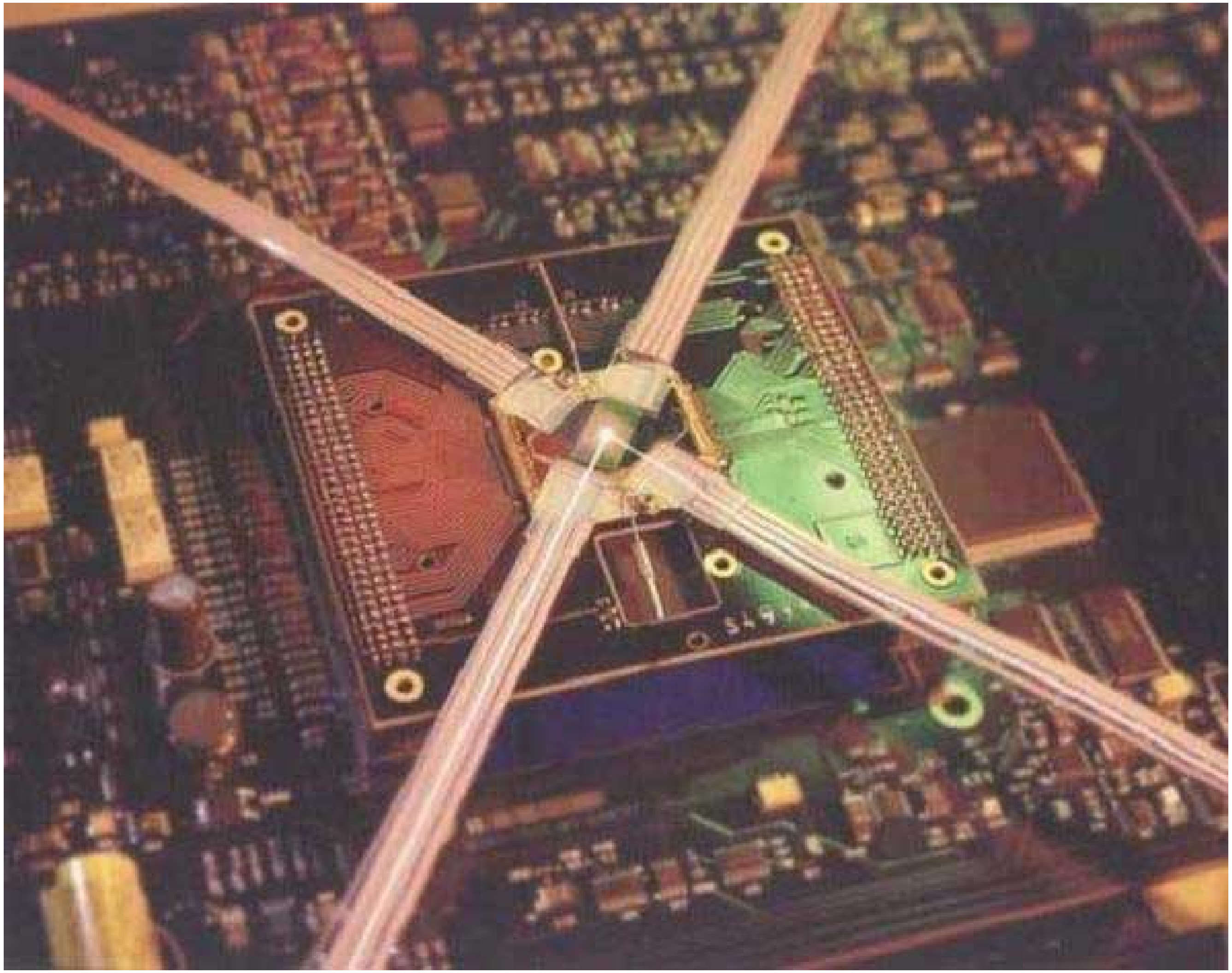


NxN Optical Link





Agilent Bubble Switch



Segmented Mirrors

- Space Optical Telecommunication
  - Reliable, Small in size, Light in weight, & Easy to fabricate
- Air Turbulence causes optical aberrations
- Quick response time, therefore able correct optical aberrations

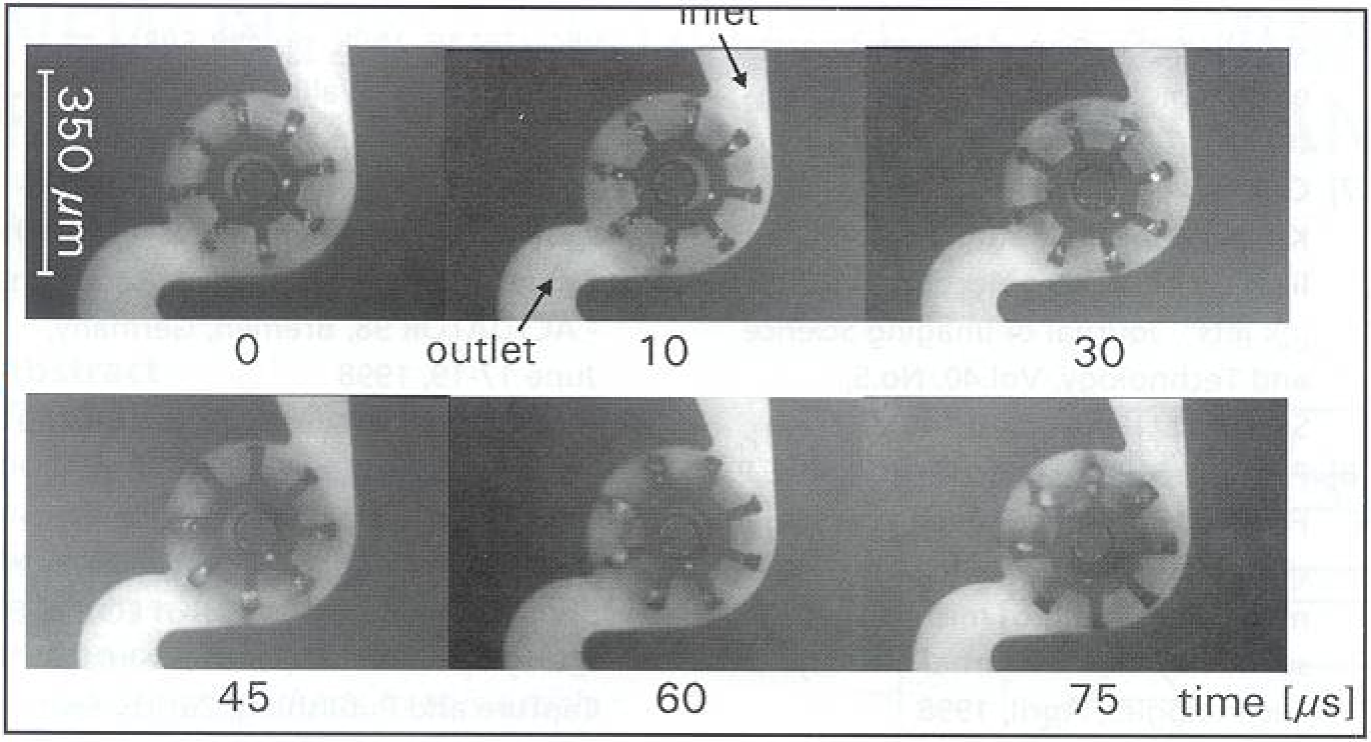
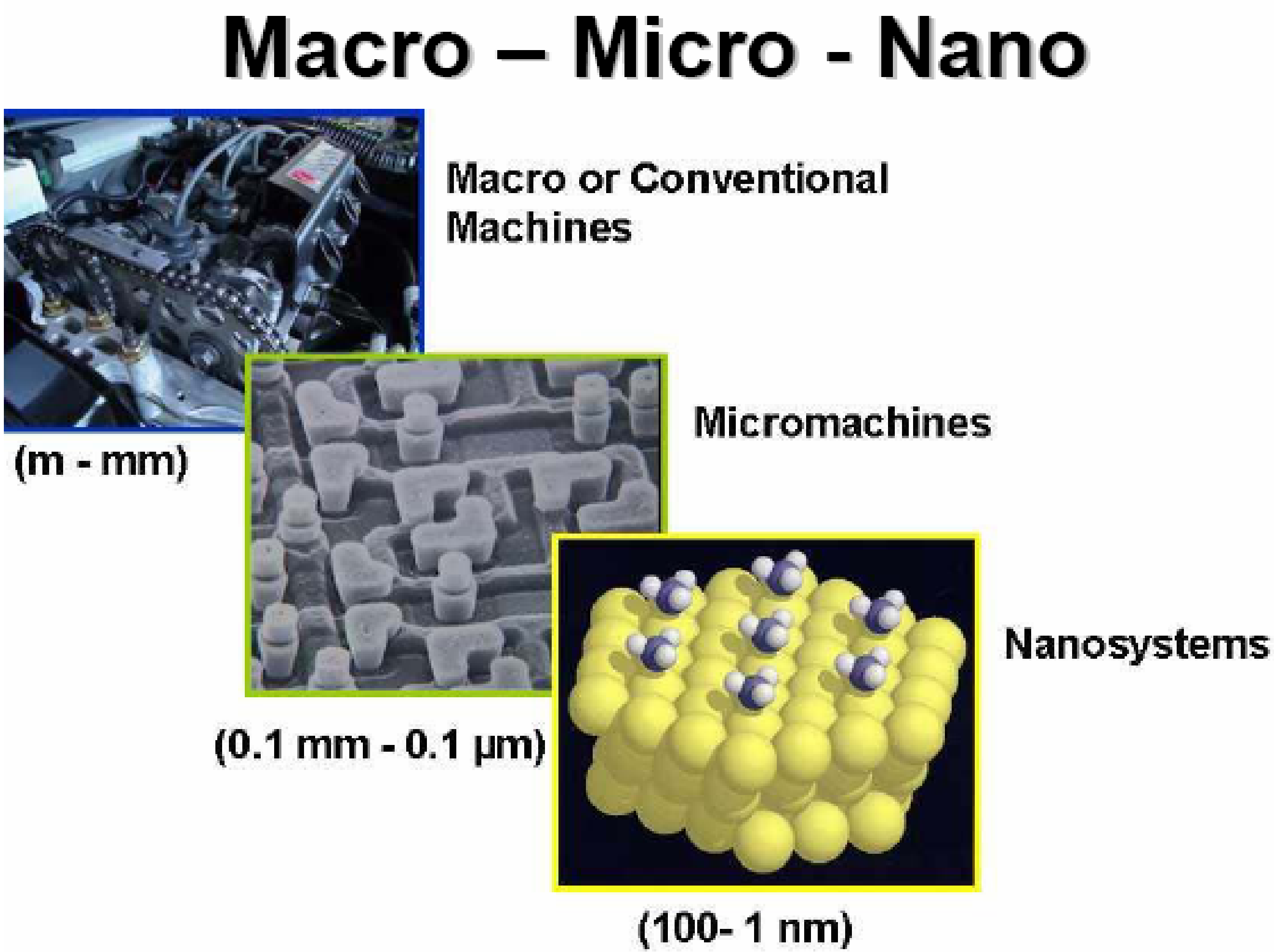
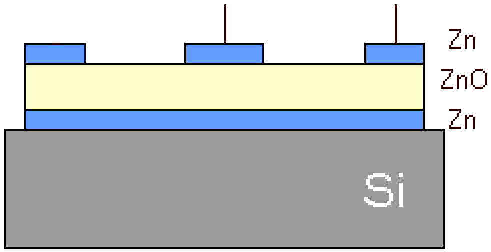


Fig.3: Visualization of the stationary rotation of a pneumatic driven microturbine.

結　語


Macro – Micro - Nano
Macro or Conventional Machines
(m - mm)
Micromachines
(0.1 mm - 0.1 μm)
Nanosystems
(100- 1 nm)


Zn
ZnO
Zn
Si