Lecture 1:

Intro to MEMS

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What is MEMS ?

- Different physics in nano and micro scales
  - High viscosity (> inertia), stiction, friction & surface tension are dominant in micro world

From *Scientific American*, November 1992

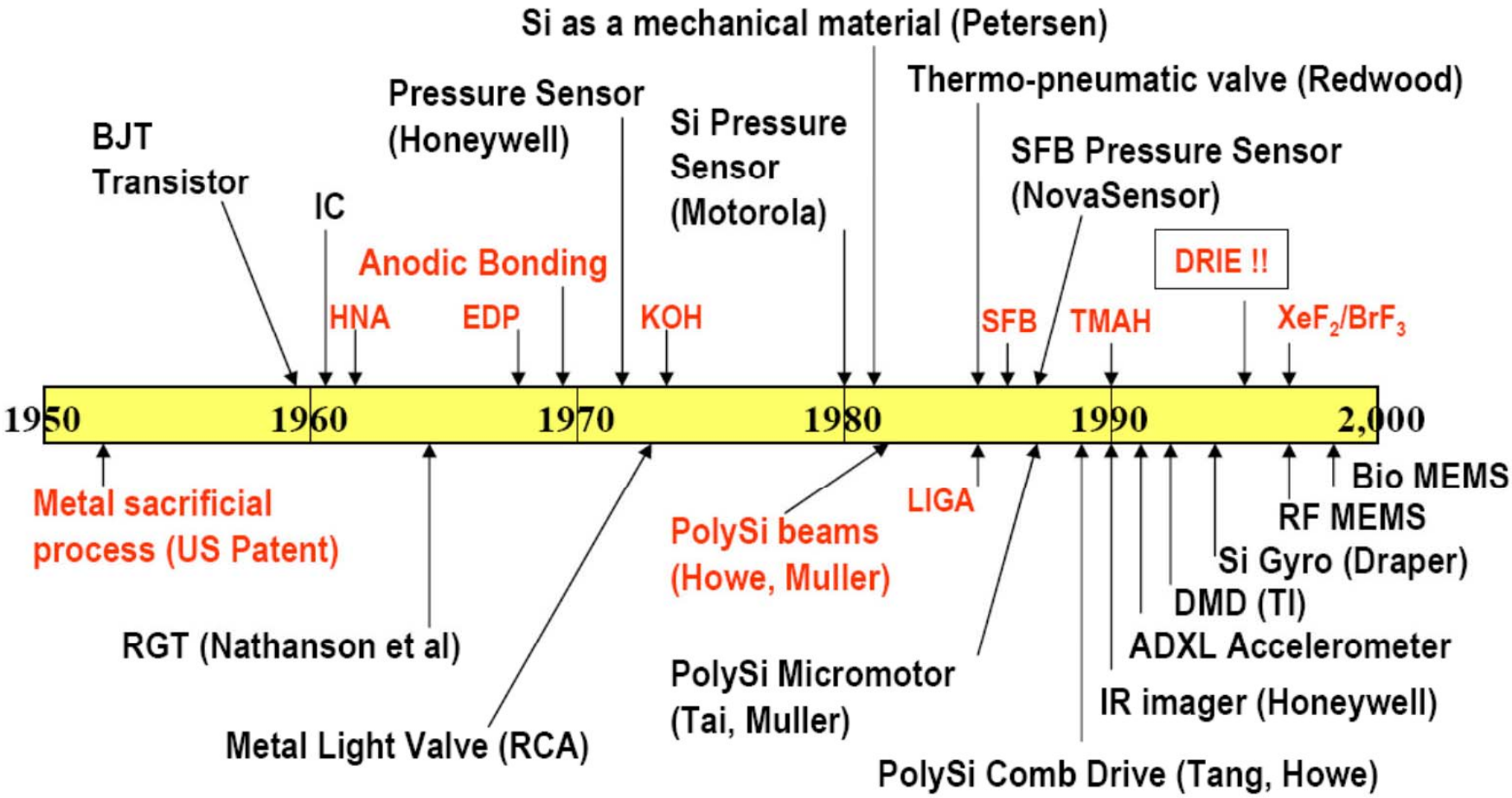
Antz, Dreamworks

What is MEMS ?

- **MicroElectroMechanical Systems**
- The fabrication of devices with at least some of their dimensions in the micrometer range.
- Increase performance and decrease cost.
- Application for *electronics, communications, mechatronics, medicine, military*
- Commercial product : an accelerometer sensor for the car air-bag, an inkjet printer header, a pressure sensor, components of RF and Optics
- As a new solution for IT, BT, ET, and NT many countries investment MEMS.

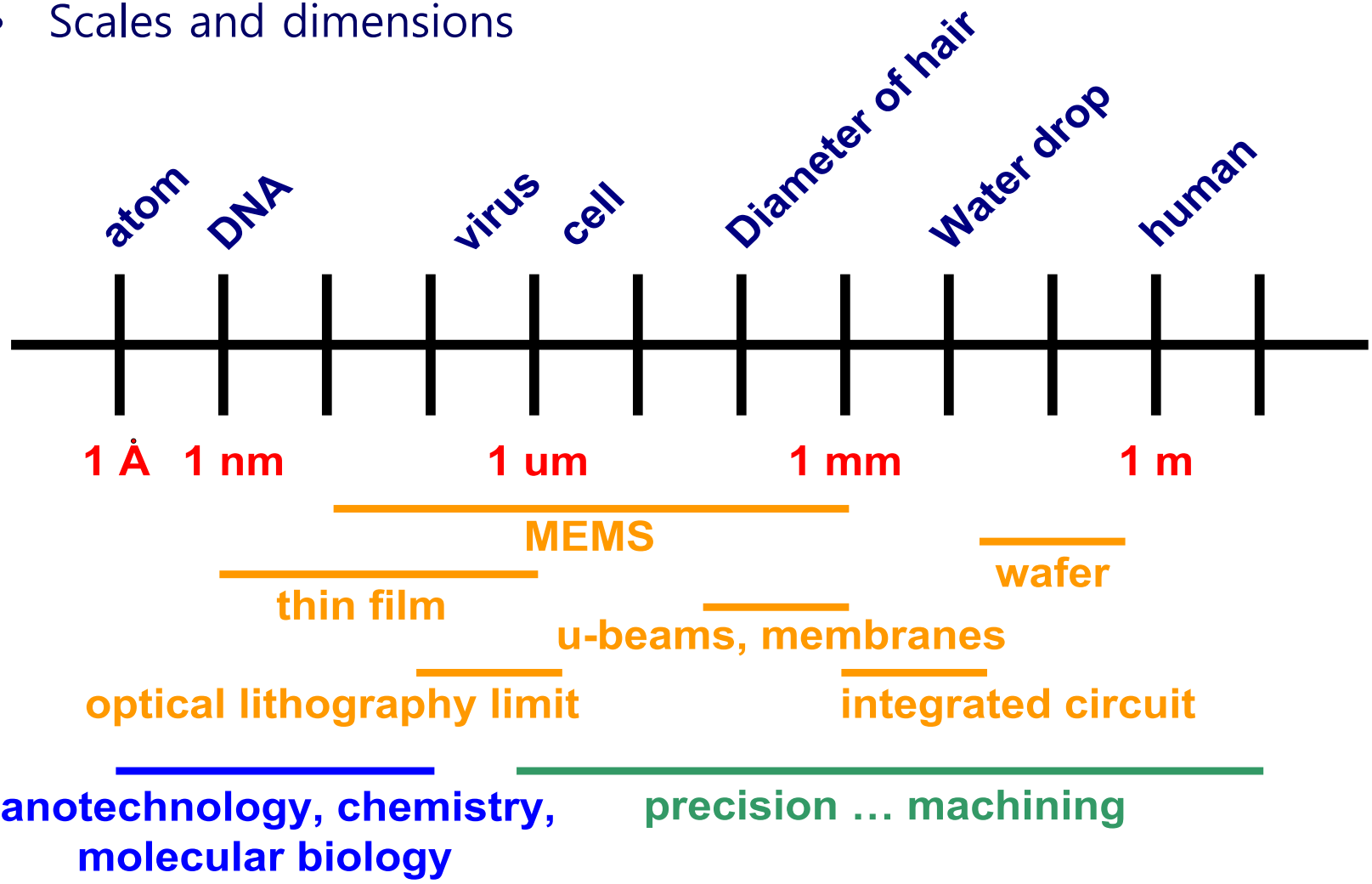
What is MEMS ?

- A brief MEMS history



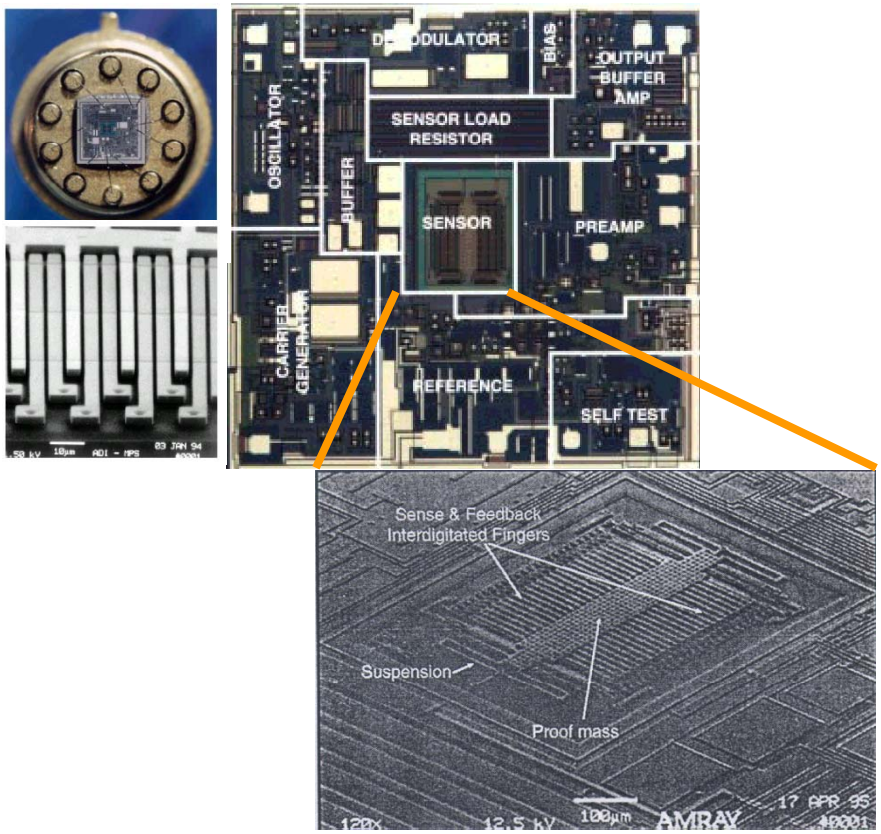
What is MEMS ?

- Scales and dimensions

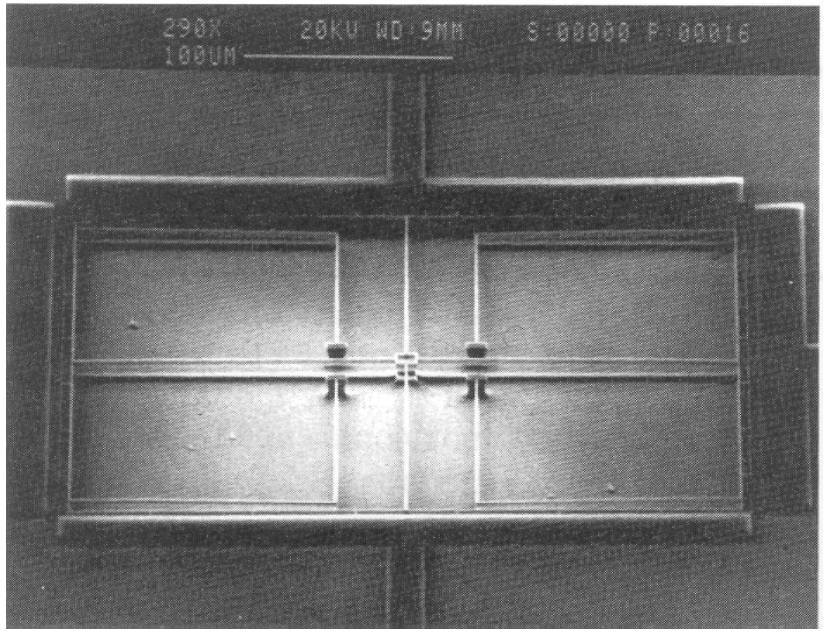


What is MEMS ?

- Uses IC manufacturing techniques to fabricate moving structures in micro scale



(Http://www.analog.com)



(Cornell)

What is MEMS ?

- Scaling law
  - As system becomes smaller, the scaling of the force also determines the acceleration, a; transit time, t; power per unit volume P/V_O generated and dissipated
  - the mass of a system : m, scales as (S^3)
  - for generalized case with a force F scaling as (S^F)
  - where x = distance

$$F = \begin{bmatrix} S^1 \\ S^2 \\ S^3 \\ S^4 \end{bmatrix} \qquad a = \frac{F}{m} = [S^F][S^{-3}] \qquad t = \sqrt{\frac{2xm}{F}} = \left([S^1][S^3][S^{-F}]\right)^{\frac{1}{2}}$$

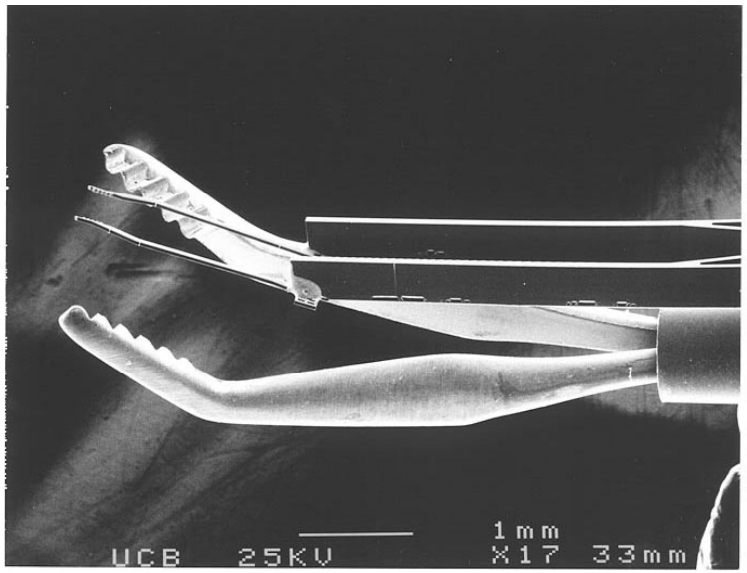
$$\frac{P}{V_O} = \frac{Fx}{tV_O}$$

$$F = \begin{bmatrix} S^1 \\ S^2 \\ S^3 \\ S^4 \end{bmatrix} \Rightarrow a = \begin{bmatrix} S^{-2} \\ S^{-1} \\ S^0 \\ S^1 \end{bmatrix} \Rightarrow t = \begin{bmatrix} S^{1.5} \\ S^1 \\ S^{0.5} \\ S^{2.0} \end{bmatrix}$$

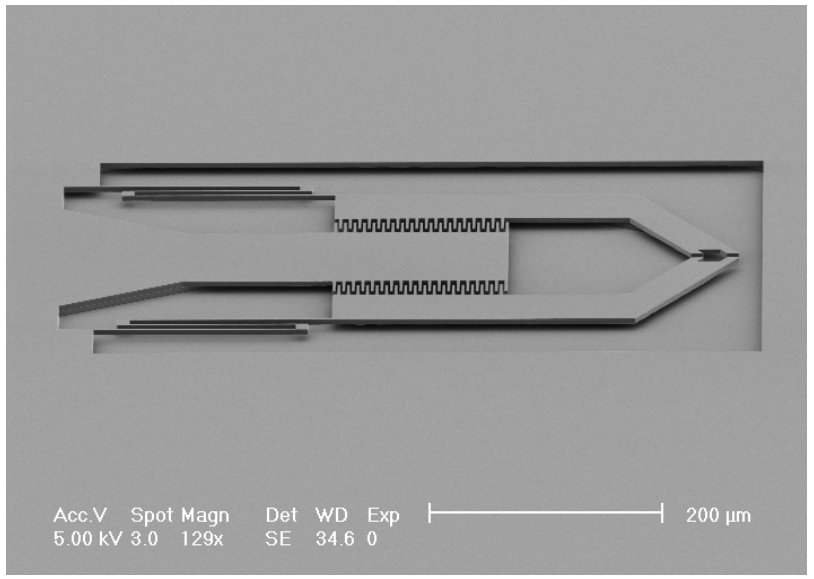
$$\frac{P}{V_O} = \begin{bmatrix} S^{-2.5} \\ S^{-1} \\ S^{0.5} \\ S^2 \end{bmatrix}$$

What is MEMS ?

- Long slender beams are very strong in micro scale



Http://www.memspi.com



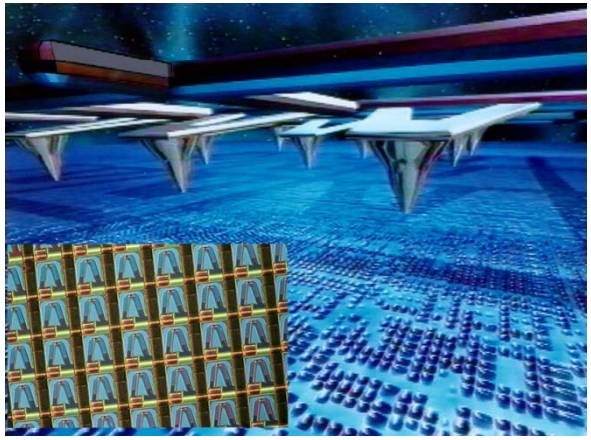
Nano/Micro Systems & Controls Lab, SNU

- But moving through air in micro scale is difficult (like swimming in molasses)

What are MEMS driving forces ?

- **M**iniaturization
  - Small feature: fast, precise, gentle, reach narrow space
- **M**ultiplicity
  - Batch fabrication: mass production, low cost
  - Pre-assembled system and parallel processing: high density
- **M**icroelectronics
  - Integration with electronic circuits

Wearable PC

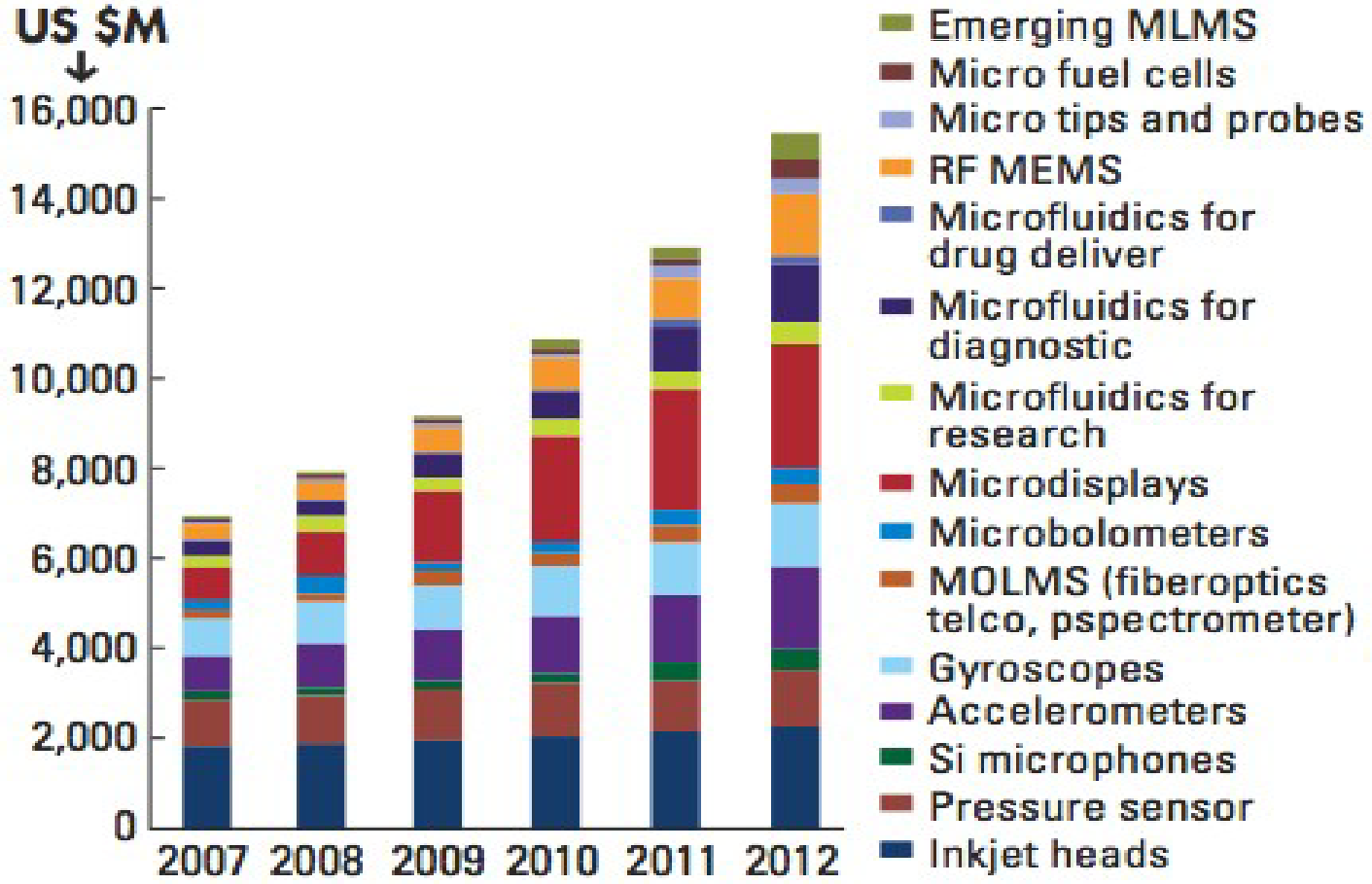


IBM Millipede (800 Gbit/in^2)

HDD: 230 Gbit/in^2
DRAM: 10 Gbit/in^2
Fresh RAM: 250 Mbit/in^2

MEMS Market

MEMS Market Forecast, 2007-2012

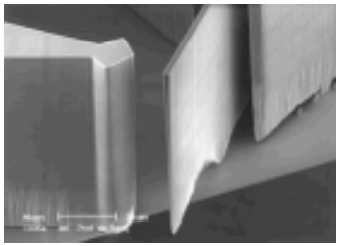


Source: Yole Développement, July 2008

Intro to Micromachining

1991
IOP JMM

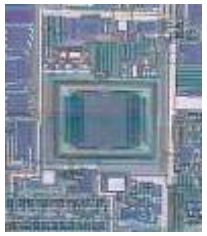
1992
J of MEMS



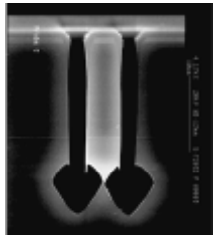
~1995
SOI process

"MEMS" coined

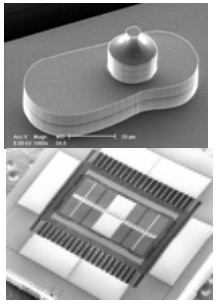
1988
UC Berkley micromotor:
Beginning of
the surface micromaching



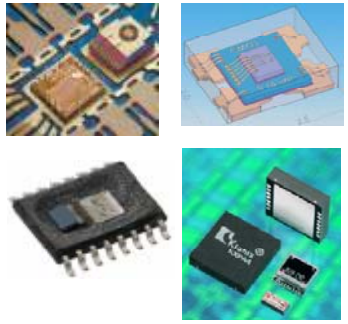
1992
ADI accelerometer



1993
Cornell
SCREAM process



1997
SNU
SBM process

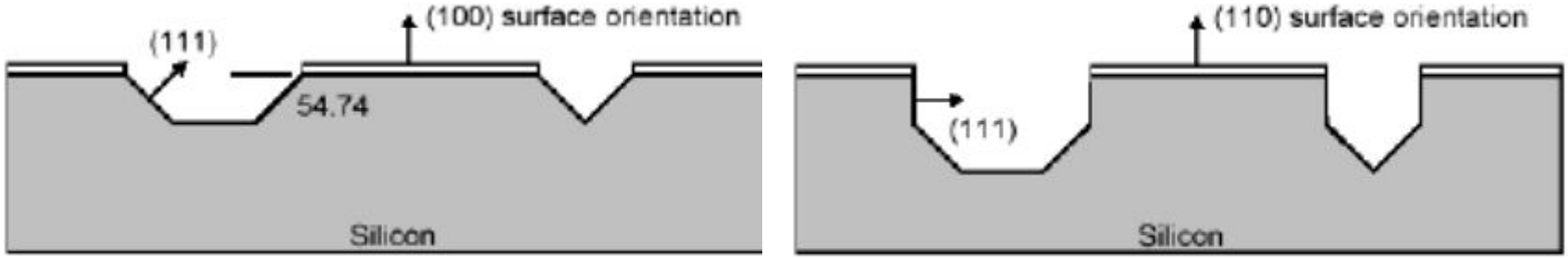


Multi Chip Packaging

1980 1990 2000

Bulk Micromachining (70's)

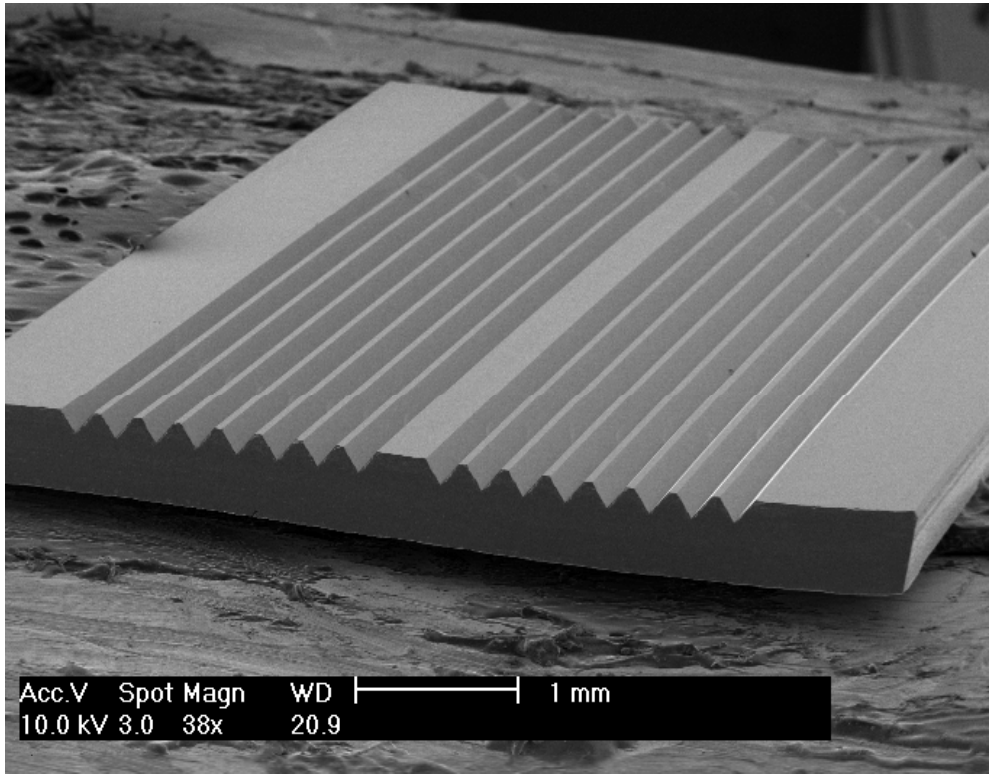
- Anisotropic wet etching
  - Anisotropic etchants etch much faster in one direction than in another
    → Exposing the slowest etching crystal planes over time
    → (111) planes have the slowest etch rate
  - Several solutions: Alkalic OH (KOH, NaOH), TMAH, EDP
  - Etching at concave corners on (100), stop at (111) intersections, convex corners are under cut



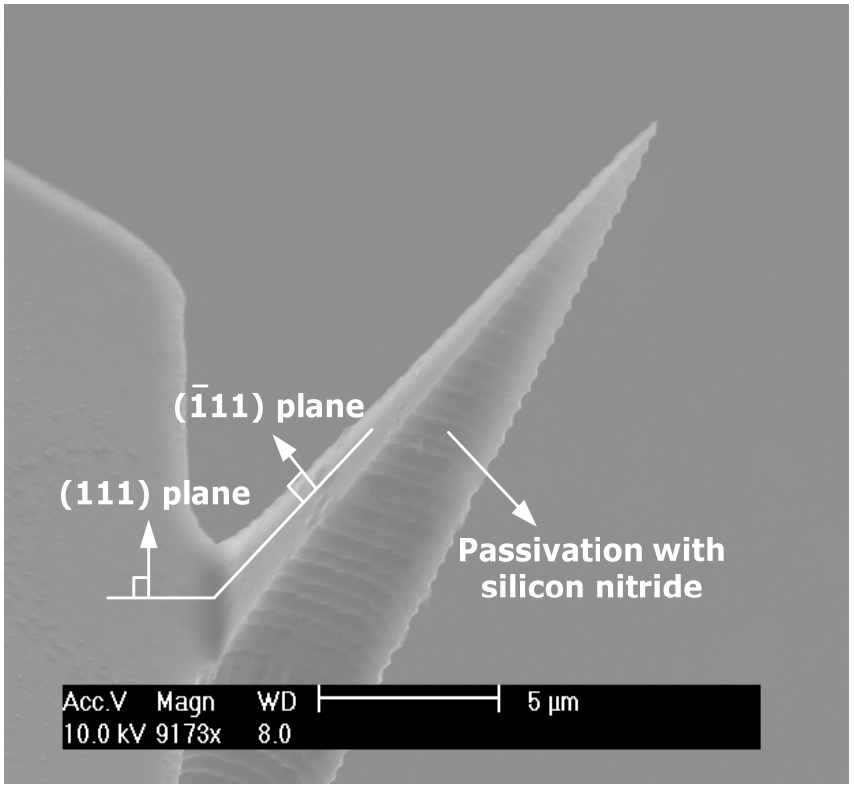
Silicon anisotropic wet etching of (100) and (110) silicon

Bulk Micromachining (70's)

- Anisotropic silicon etching



Optical bench using (100) silicon

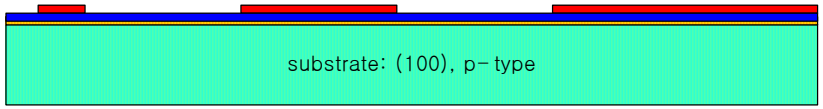


Silicon tip using (111) silicon

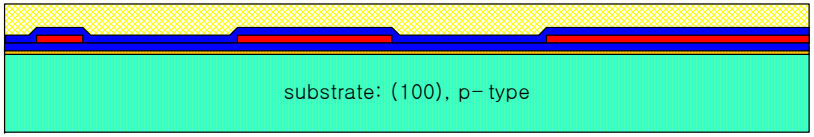
(SNU NML)

Surface Micromachining ('85-'95)

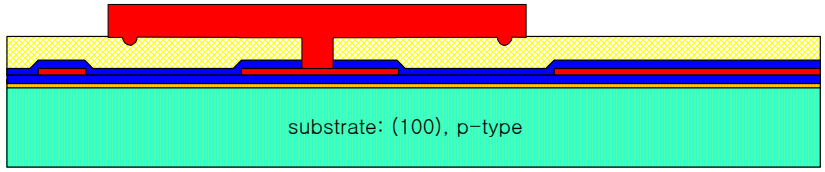
- Typical surface micromachining process steps
  - In HF, oxide etches fast for sacrificial release



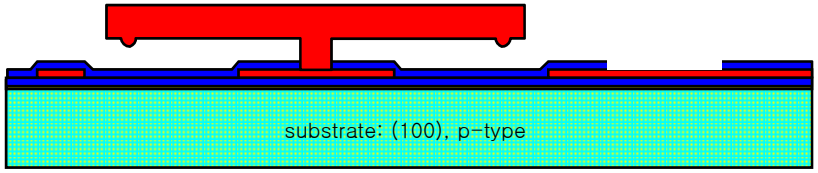
(a) oxide/nitride deposition, polysilicon deposition & patterning



(b) nitride deposition, sacrificial oxide deposition



(c) anchor patterning, polysilicon deposition & patterning

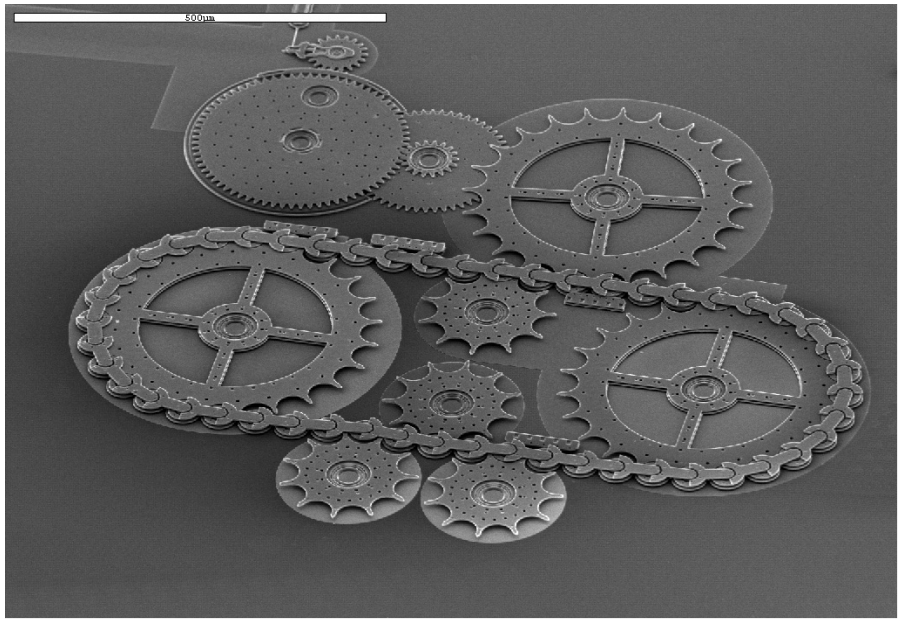


(d) sacrificial wet etch in HF

(SNU MEMS MPC)

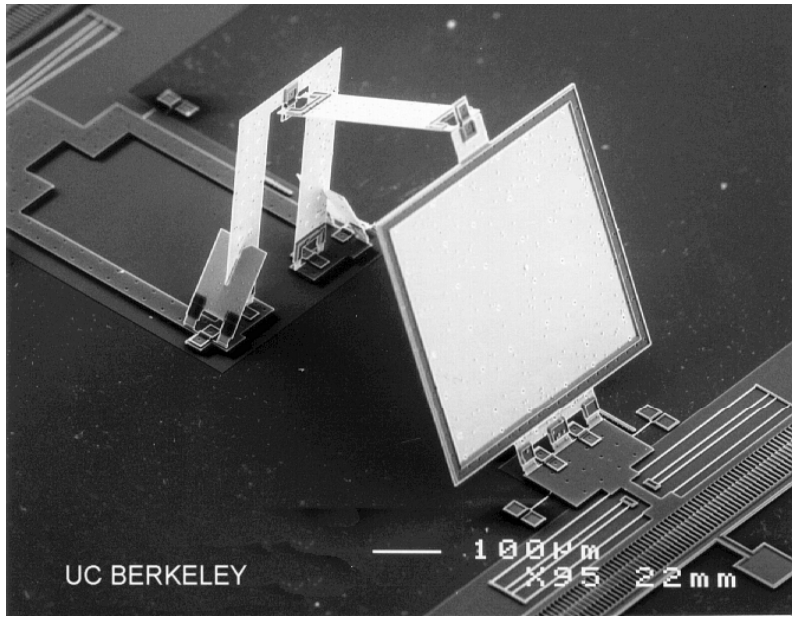
Surface Micromachining ('85-'95)

- Micro gear chain
  (four polysilicon)



(Sandia Lab.)

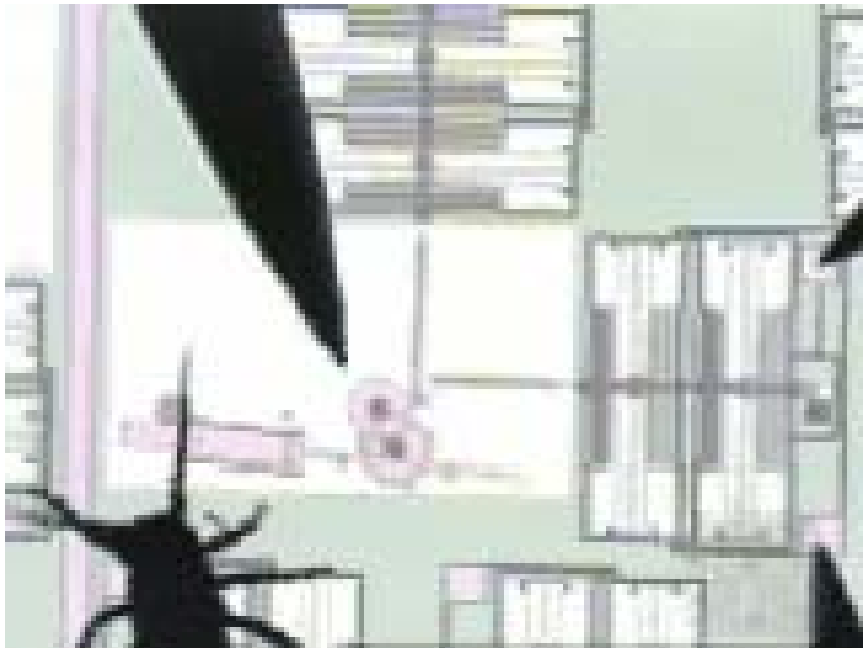
- Actuated micromirrors
  (three polysilicon hinge structure)



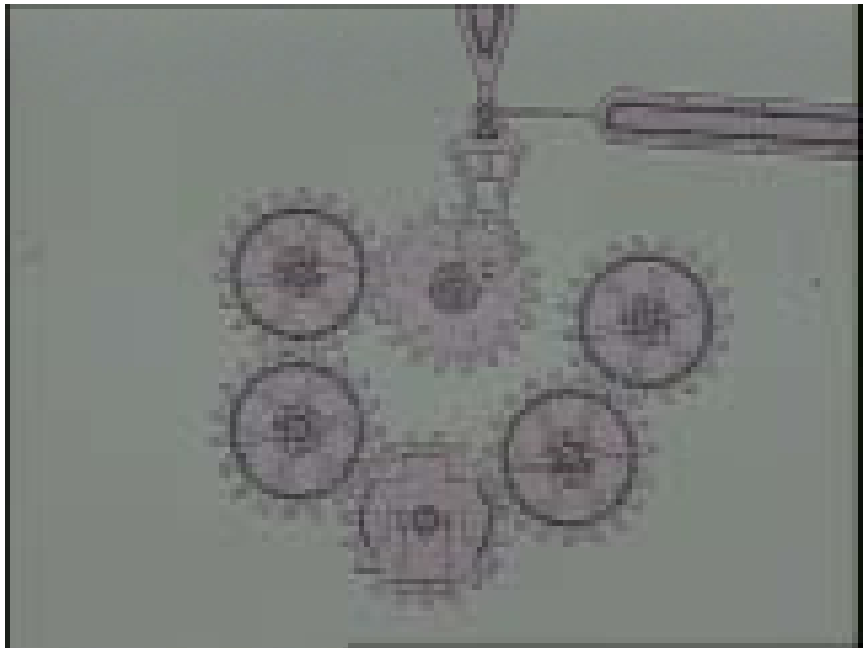
(UC Berkeley, Pister Ph.D. thesis)

Surface Micromachining ('85-'95)

- Aphid on mirror



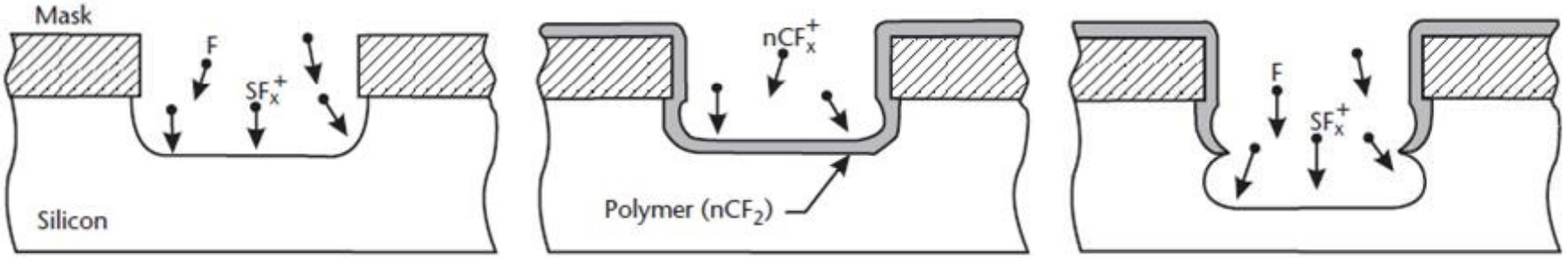
- 6 gears



(Sandia Lab.)

Deep Silicon Reactive Ion Etching ('90-)

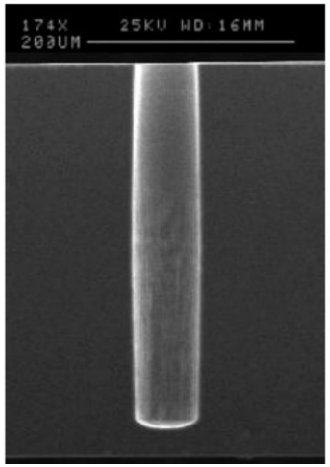
- Uses high density plasma to alternatively etch silicon and deposit etch resistant polymer on sidewall
  - Unconstrained geometry 90^{O} side walls
  - High aspect ratio 1:30
  - Easily masked (PR, SiO_2)
- Bosch process: sidewall passivation → etch → sidewall passivation → etch …



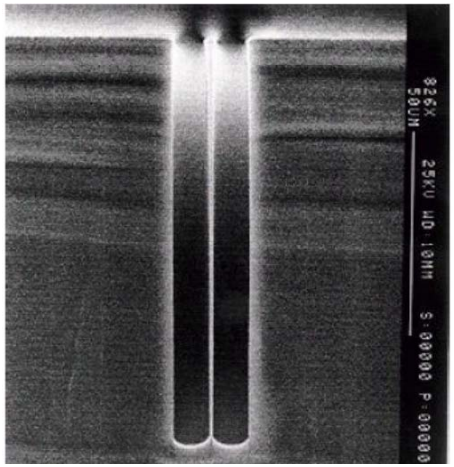
Etch Deposit polymer Etch

Deep Silicon Reactive Ion Etching ('90-)

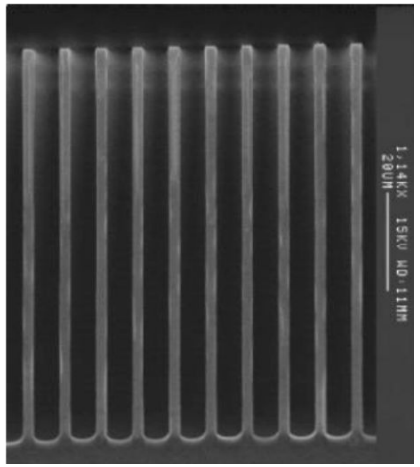
- Fabrication example



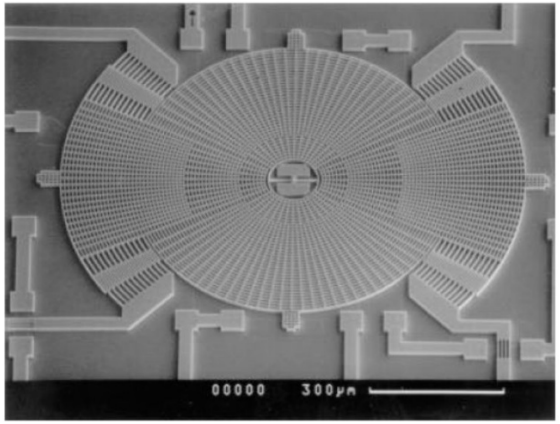
350 μm depth



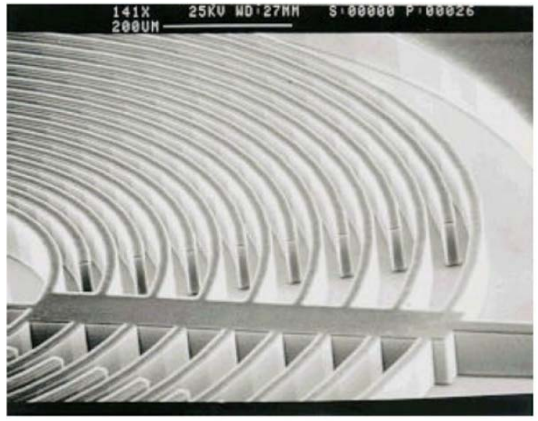
100 μm depth



80 μm depth, 4.5 μm space width, 2 μm line width



Gyroscope

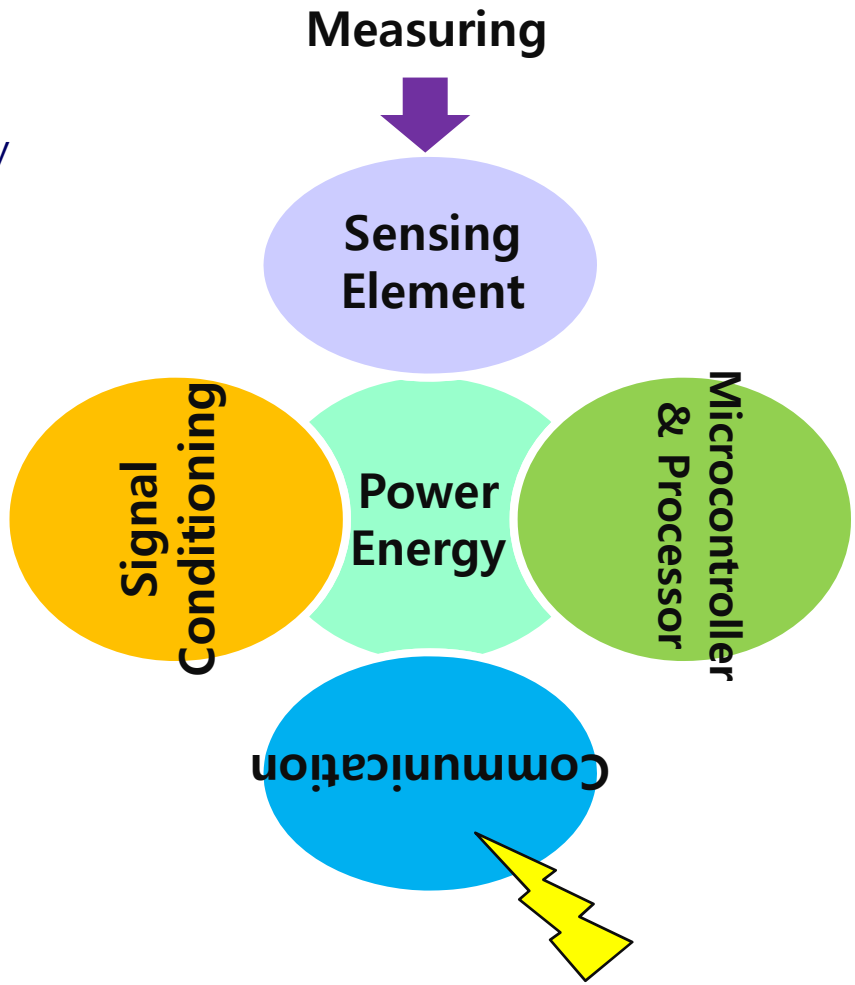


Accelerometer (170 μm depth)

Applications – Smart Sensors

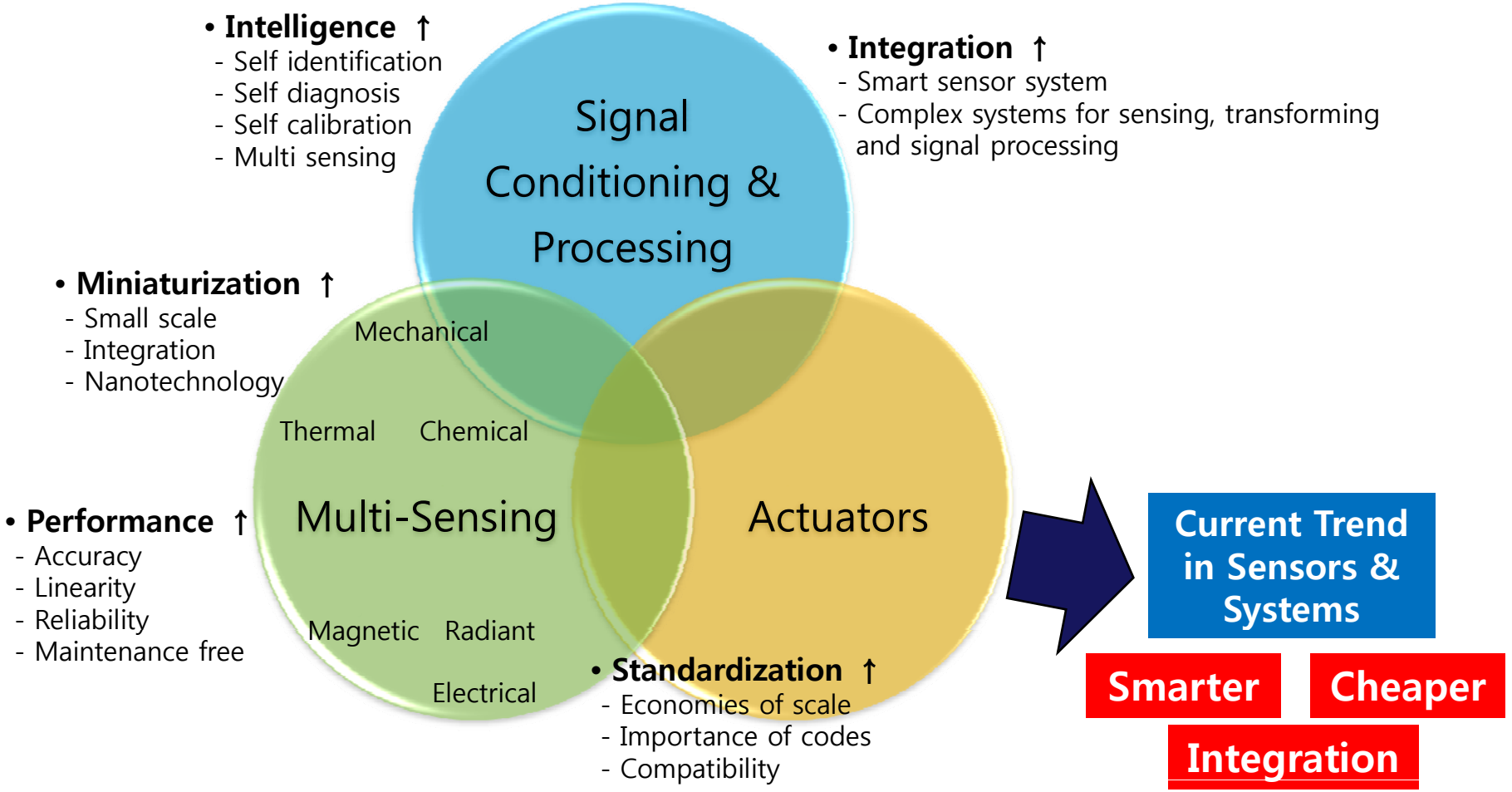
- Smart sensor
  - A sensor with built-in intelligence
  - The intelligence is partially or fully integrated on a single chip

- Smart sensor architecture
  - Sensing element
  - Interface element for signal conditioning and data conversion
  - Processing element (this includes a microcontroller with an associated memory and software)
  - Communication element
  - Power source



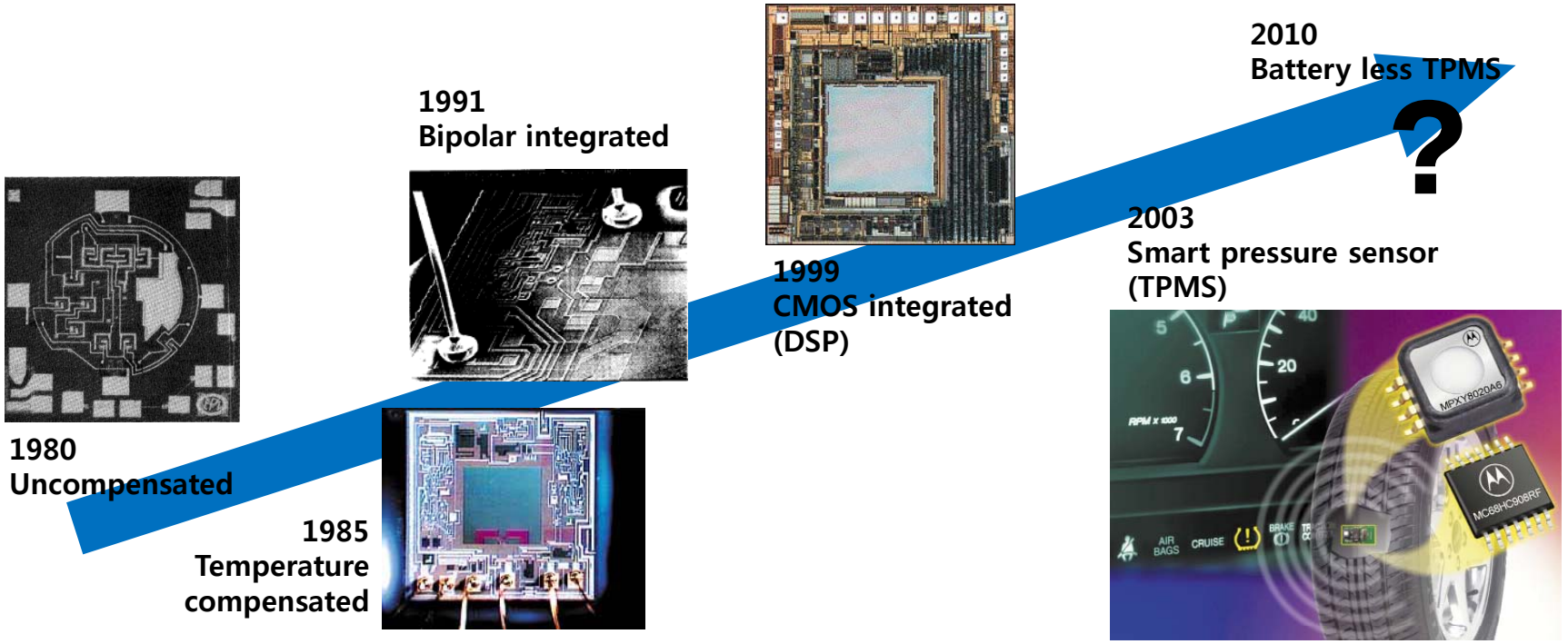
Applications – Smart Sensors (cont'd)

- Trend of the smart sensors



Applications – Smart Sensors (cont'd)

- Smart pressure sensors: piezoresistive or capacitive
  - Sensor + Electronics → Smaller & Cheaper
  - Key trends
    - The growth of the medical and automotive business is stable
    - New application like the TPMS are boosting this market

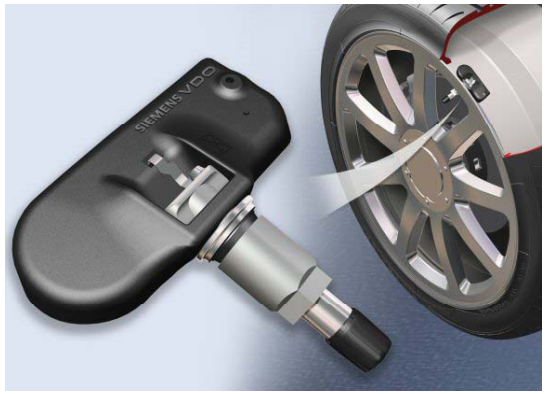


Applications – Smart Sensors (cont'd)

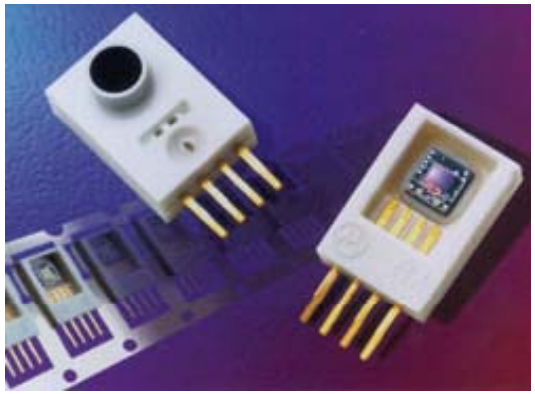
- Smart pressure sensors application
  - Engine optimization, emission control, and safety enhancement
    - Manifold intake air pressure (MAP) and barometric air pressure (BAP) for the engine control unit
    - Tire pressure monitoring system (TPMS) and side airbag pressure sensor
  - Medical applications
    - Sleep apnea, asthma monitoring, blood pressure meter

MAP sensor (Delphi)


Airbag pressure sensor (Bosch)

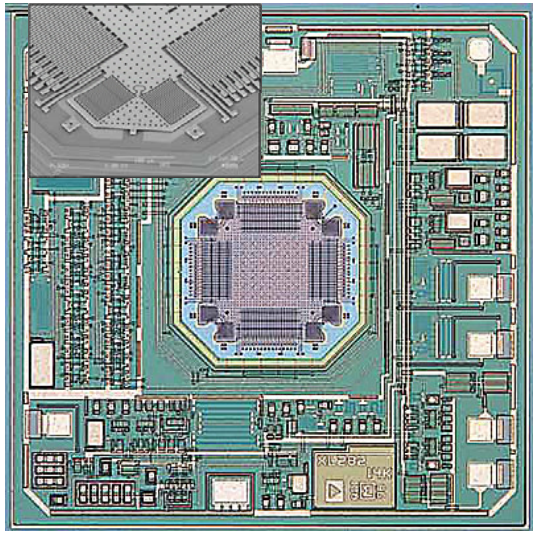


Wheel mounted TPMS (Siemens)

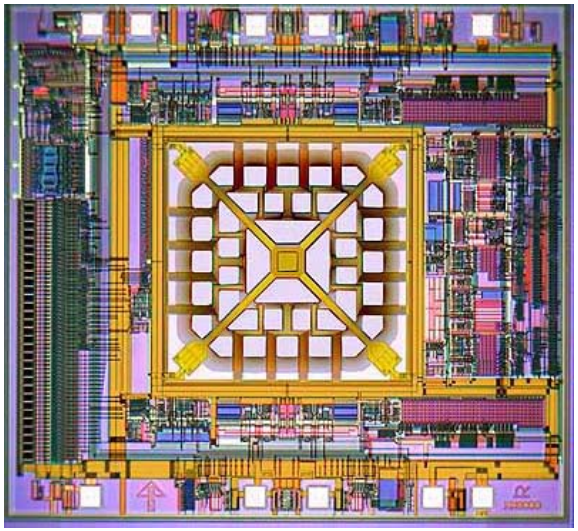

Blood pressure meter (Motorola)

Applications – Smart Sensors (cont'd)

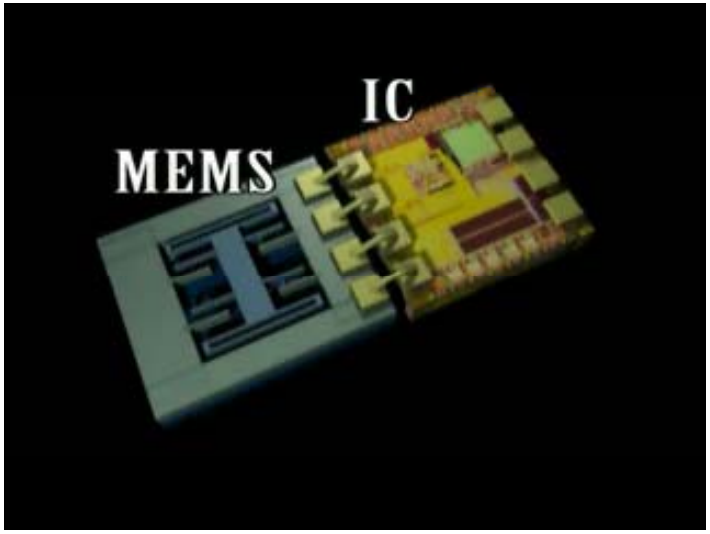
- Smart accelerometer: capacitive or thermal
  - Smaller devices with multiple axis sensing
  - Key trends
    - The automotive business is increasing rapidly with the growth of ESP
    - Consumer applications have really started use MEMS sensors in volume for application like mobile phone, GPS, and game controller



Capacitive accelerometer
(ADI)



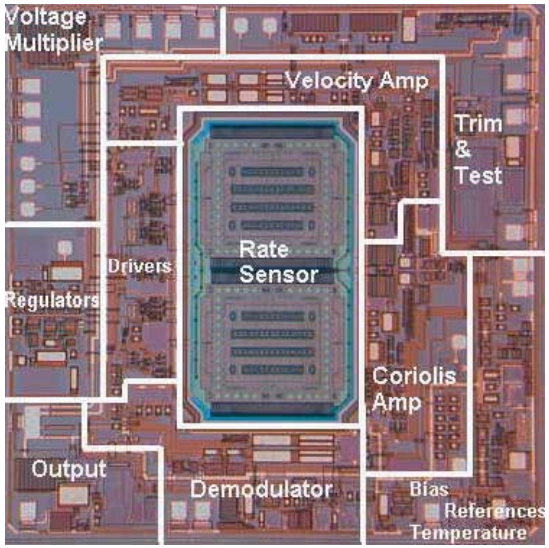
Dual-axis thermal accelerator
(MEMSIC)



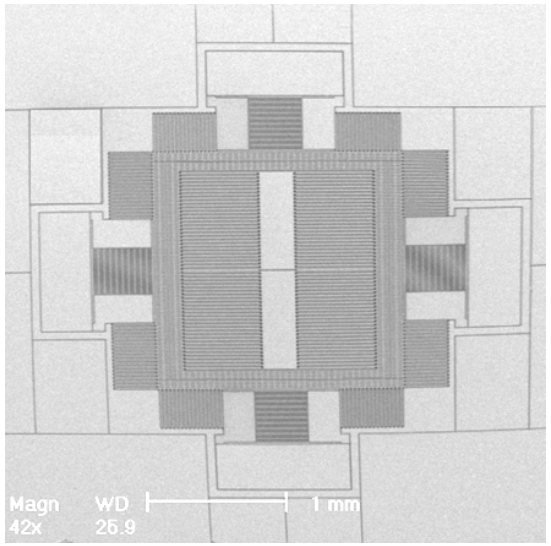
MEMS accelerometer with IC
(NML SNU)

Applications – Smart Sensors (cont'd)

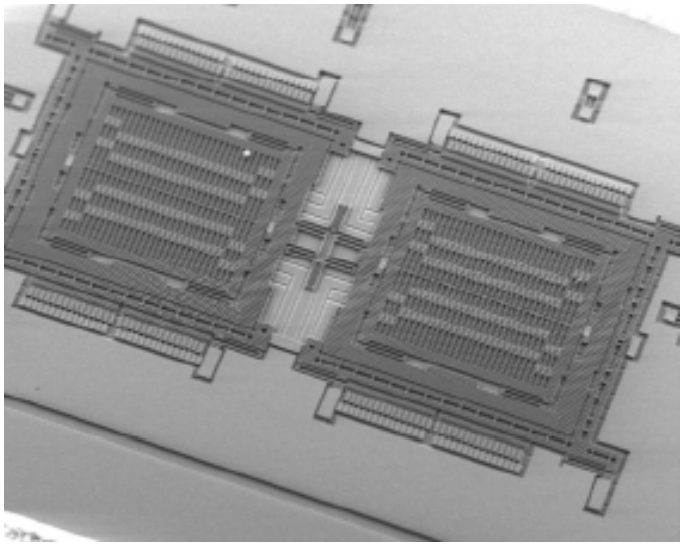
- Smart gyroscope : capacitive or piezoelectric
  - Smaller devices with multiple axis sensing
  - Key trends
    - The ESP market is growing very fast, with adoption of the system in medium end cars. (Silicon vs. Quartz)
    - GPS is another growth area, both for automotive and autonomous systems



iMEMS ADXRS
(ADI)



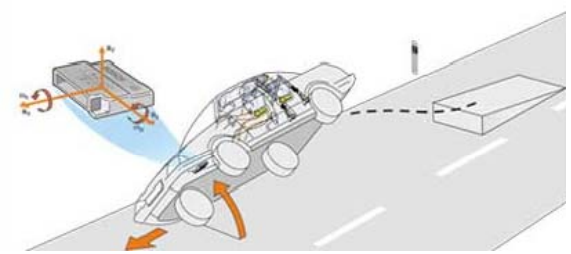
X-axis gyroscope
(SNU, NML)



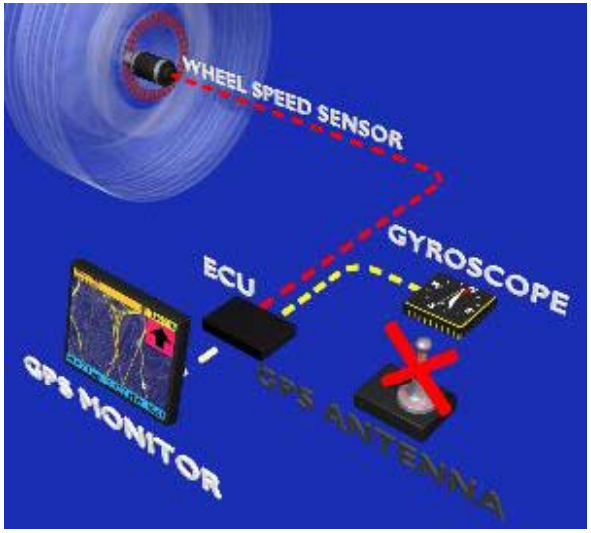
Z-axis gyroscope
(Motorola)

Applications – Smart Sensors (cont'd)

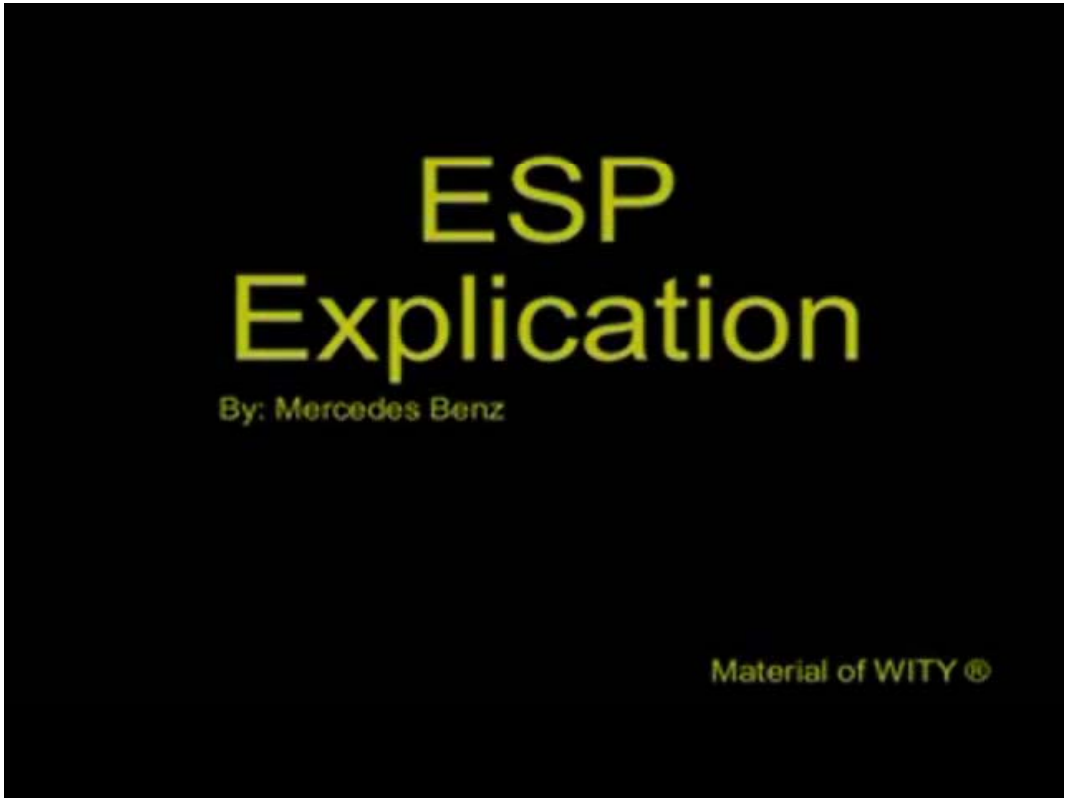
- Smart accelerometer & gyroscope for automotive applications
  - Crash accident recording, Rollover sensing, ESP, GPS



Rollover sensing



High performance GPS navigation with gyroscope

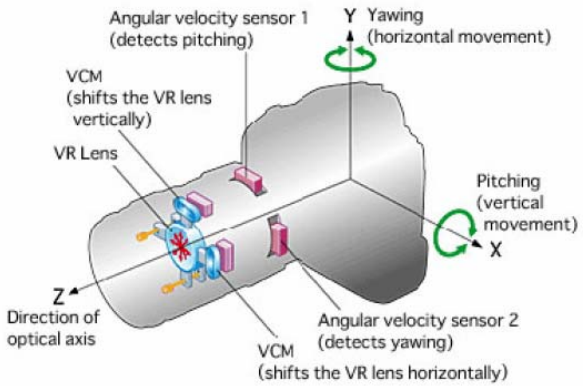


Electronic Stability Programs/Vehicle Dynamic Control (ESP/VDC)

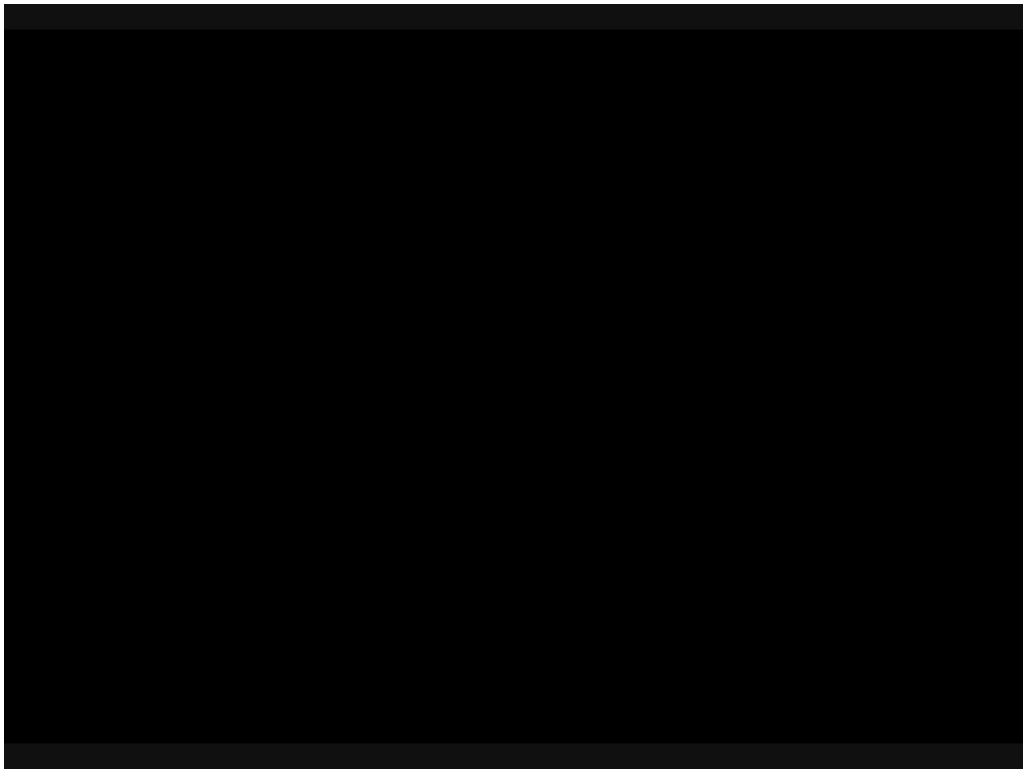
Applications – Smart Sensors (cont'd)

- Smart accelerometer & gyroscope for consumer electronics
  - Video game controller, camera image stabilization, HDD protection, mobile phone, human computer interface

Video game controller (Nintendo)



Lens shifting type (Nikon)

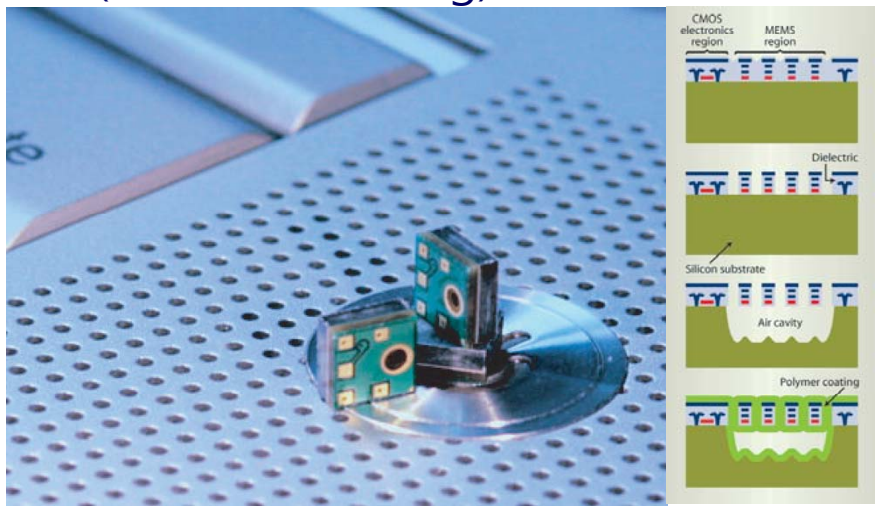


iPhone (Apple)

Applications – Smart Sensors (cont'd)

- MEMS microphone
  - Since 2004, the industry has seen increasing sales of MEMS devices across multiple consumer applications, with MEMS microphones for cell phones leading the pack.
  - The market for overall MEMS microphones will be 432 million units in 2008, according to Yole report.
- MEMS microphone applications: mobile phone, PDA, digicam, camcorder, lab-top, automotive (hand-free calling)

Silicon microphone
(Knowles Acoustics)



Surface mountable monolithic digital microphone &
Fabrication process for MEMS microphone (Akustica)

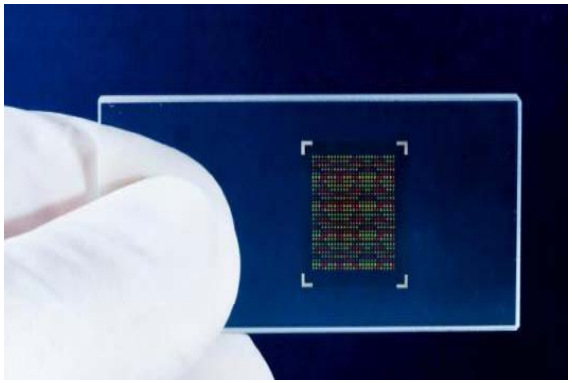
Applications – Smart Sensors (cont'd)

- Smart biomedical sensors
  - Biomedical sensors with integrated circuitry
  - Implanted in the human body or wearable
  - Will improve people's health, comfort and safety
  - Typical future sensor node
- Example applications
  - Glucose level monitor
  - Transplant organ viability monitor
  - Blood monitor
  - Cancer detection/monitor
  - Health monitor
  - Retinal and cortical prosthesis

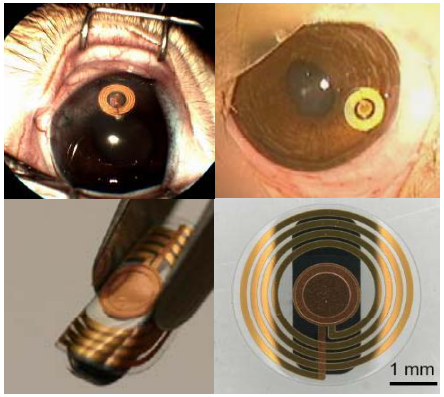
Hand-Held Device
(receiver unit)

Wireless Body Area Network (WBAN)

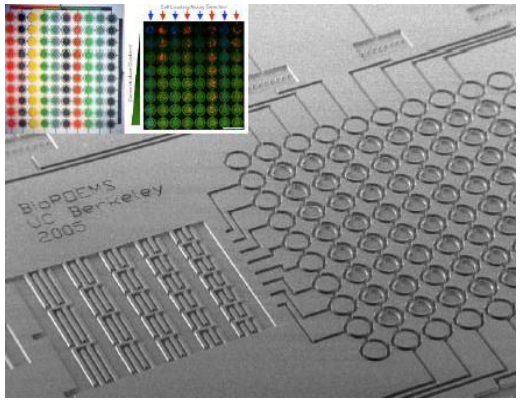
Applications – Fluidics and BioMEMS



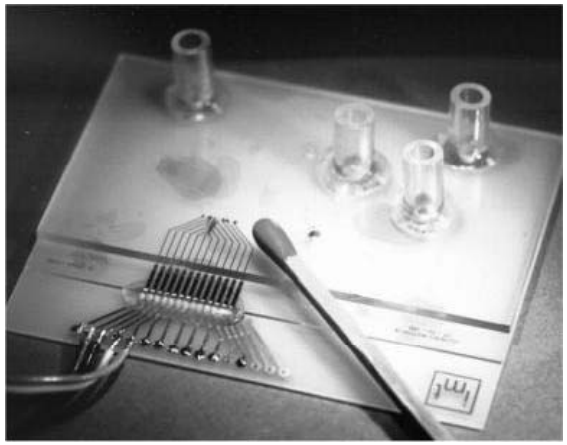
DNA chip (TorreyPath)



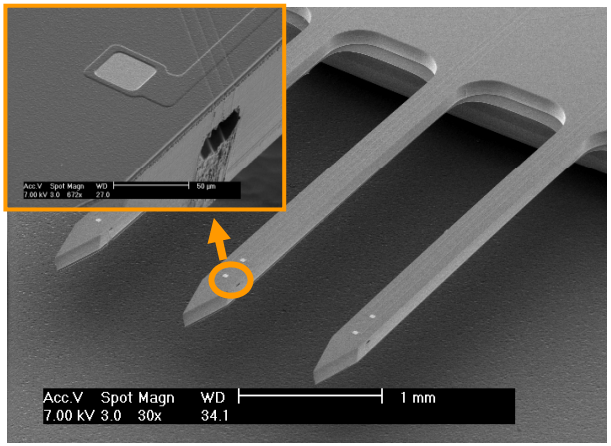
Presure sensor (Caltech)



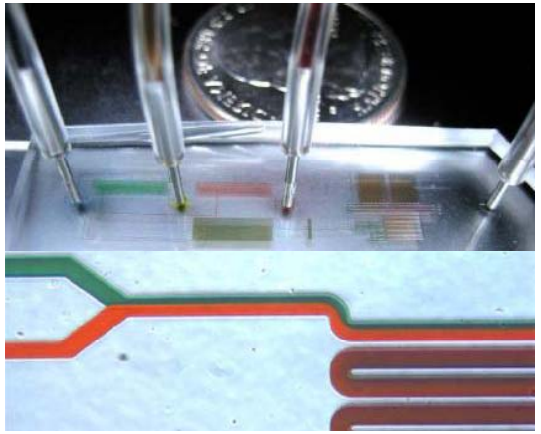
Dynamic cell culture array (U.C. Berkeley)



Nanopump (De GENEVE Univ.)



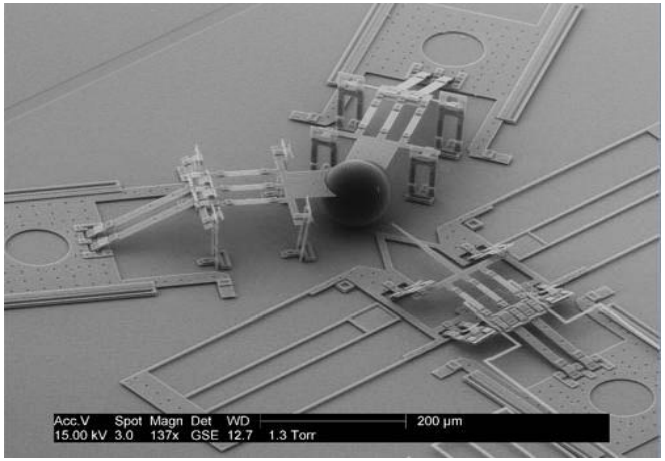
Microneedle (NML SNU)



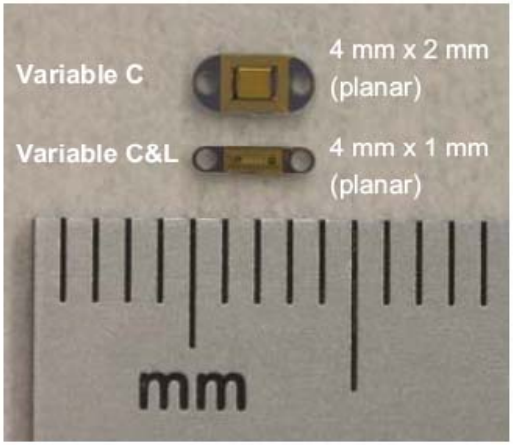
Microfluidic system (U.C. Berkeley)

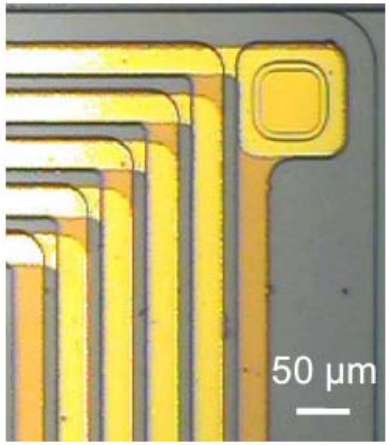
Applications – Fluidics and BioMEMS (cont'd)

DNA chip (Roche)

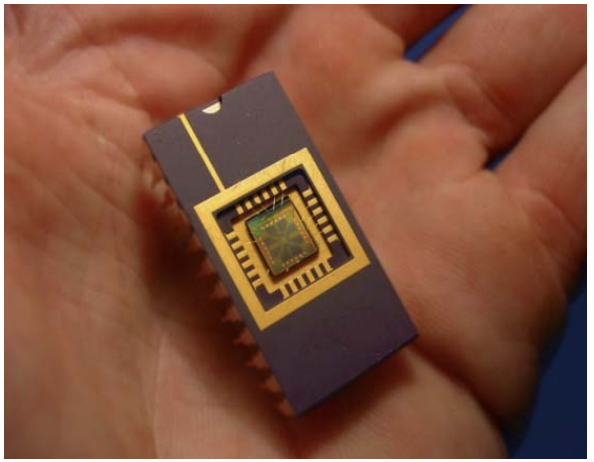


Bio-MEMS Gripper(BYU)





Wireless intraocular pressure sensor (Doheny Eye Institute)



Biosensor (IMEC)

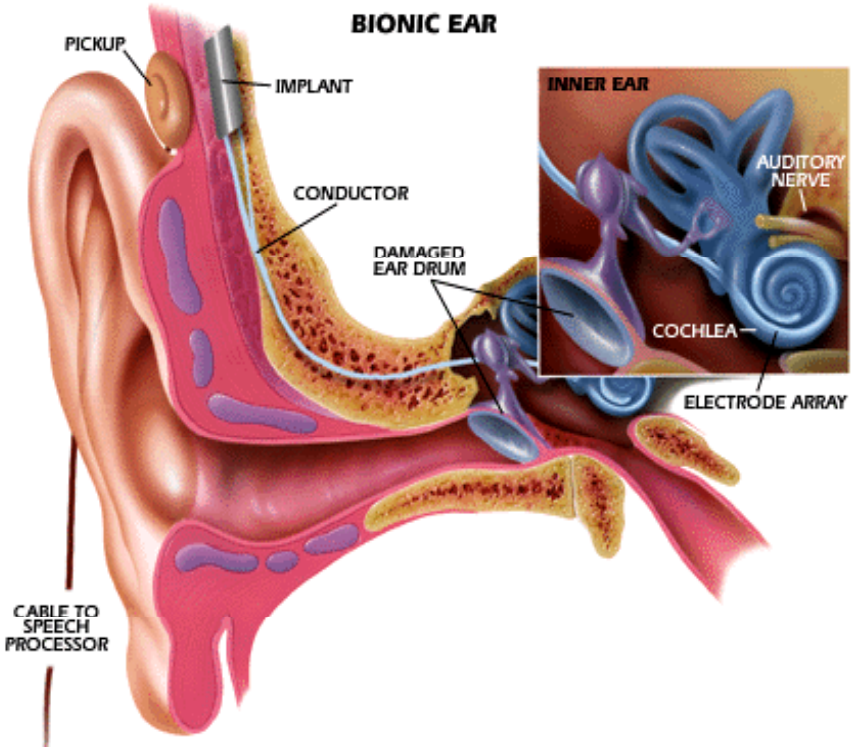
Applications – Fluidics and BioMEMS (cont'd)

- Neural Chip - The New Bionic Man
  - Retina Implant
  - Cochlear Implant
  - Edinburgh Arm
  - Heart Assist Pump
  - Nose on a chip
  - Electronic Tongue
  - NCP (NeuroCybernetic Prosthesis) : relief for the epileptic seizures, VNS (Vagus Nerve Stimulation)
  - Plastic muscle
  - Silicon Sensor

(Science, 8 February, 2002)

Applications – Fluidics and BioMEMS (cont'd)

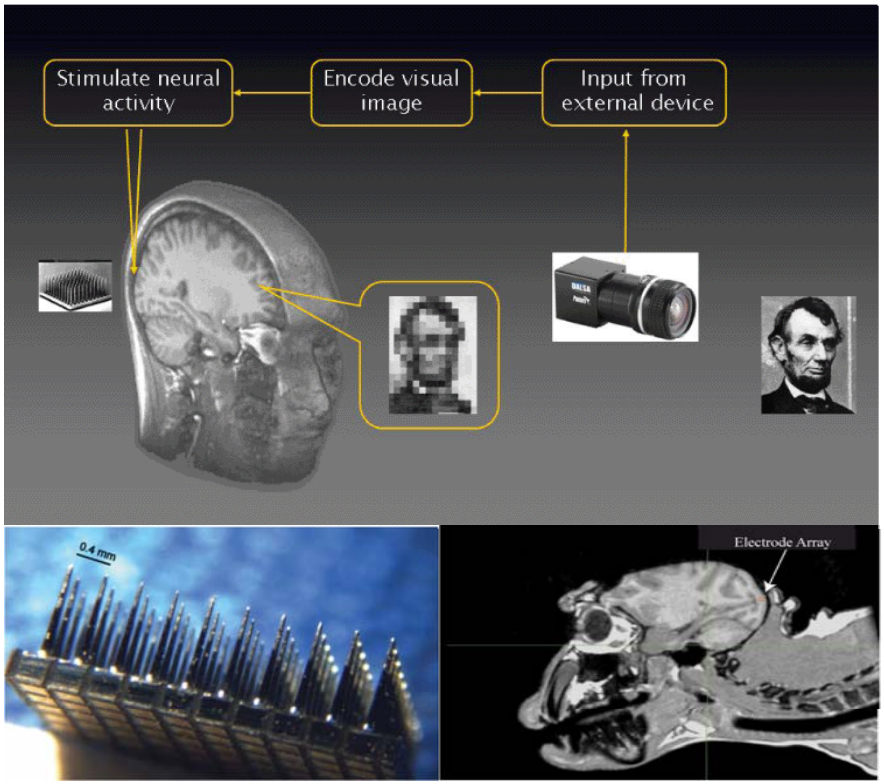
- Cochlea prosthesis



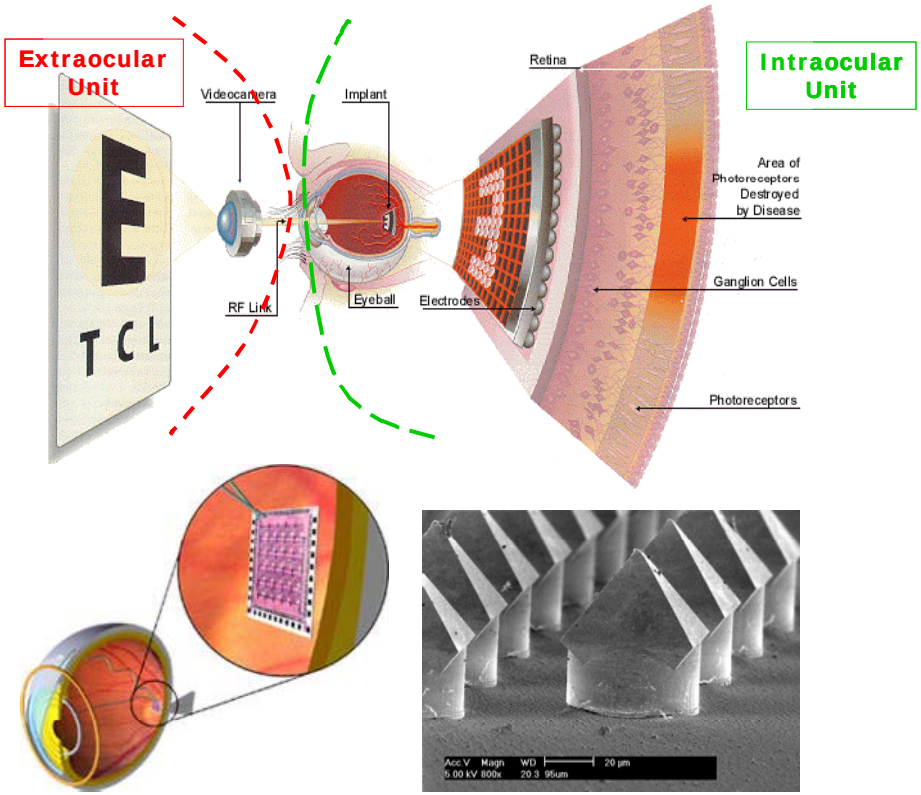
Cochlear Inc.

Applications – Fluidics and BioMEMS (cont'd)

- Vision prosthesis



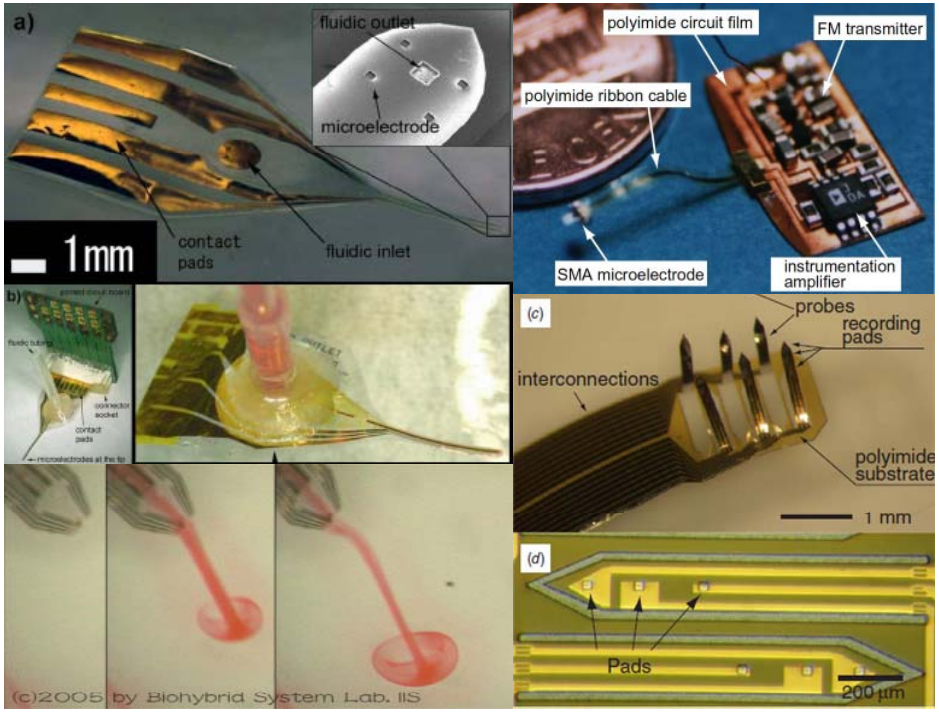
(The Univ. of Utah)



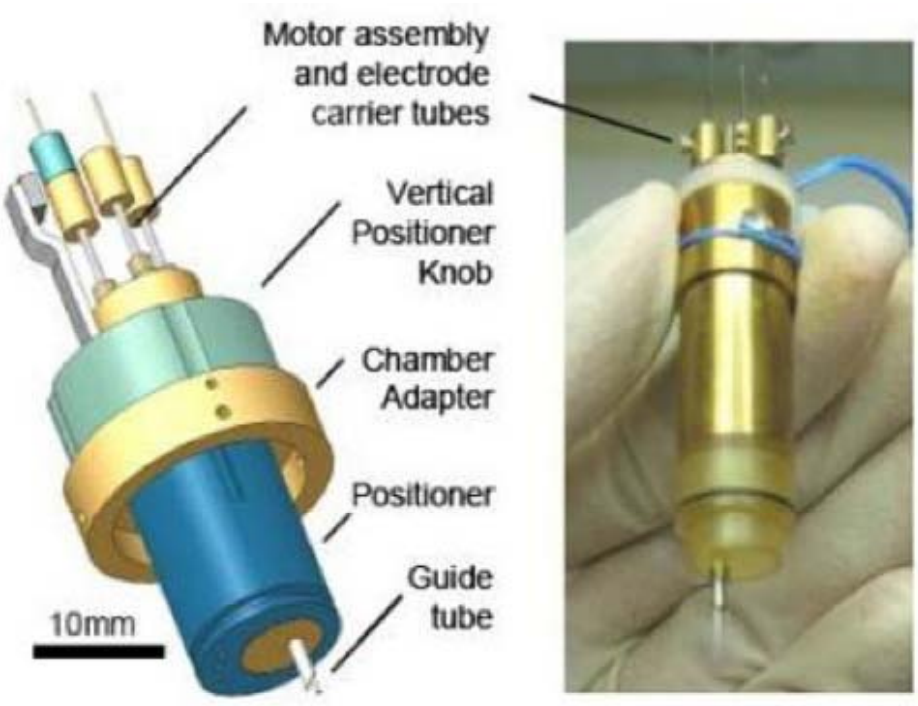
(Arrow-head Micro Electro Array, SNU)

Applications – Fluidics and BioMEMS (cont'd)

- MEMS Neural probe



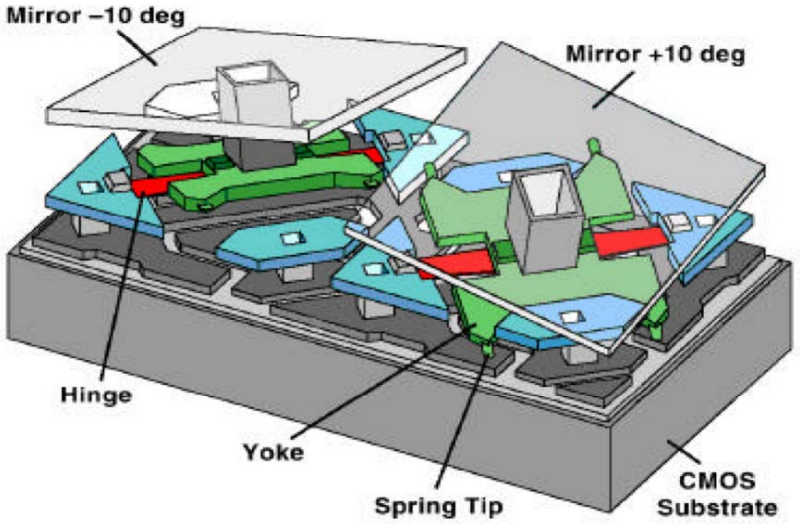
(The Univ. of Tokyo)

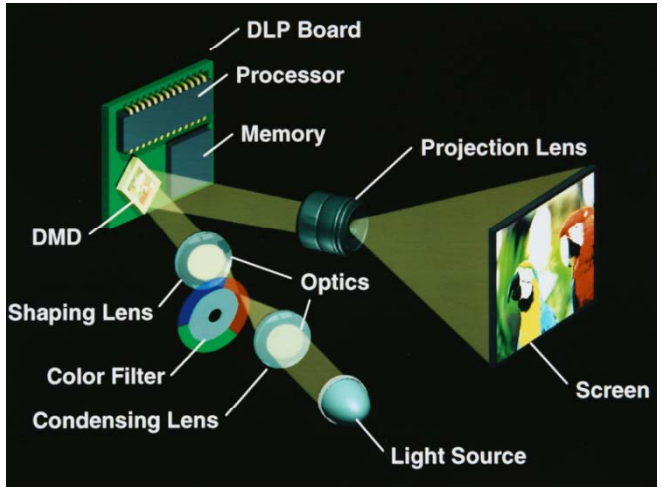


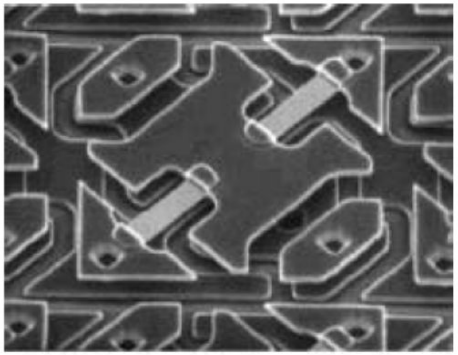
(Caltech)

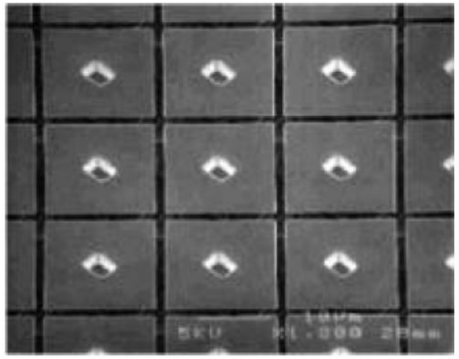
Applications – OMEMS (cont'd)

- DLP(digital light processing)







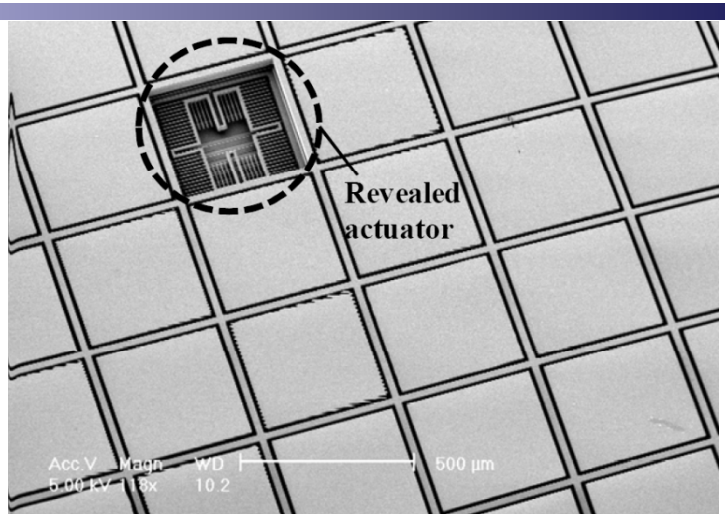


DLP Pico Projector Phone

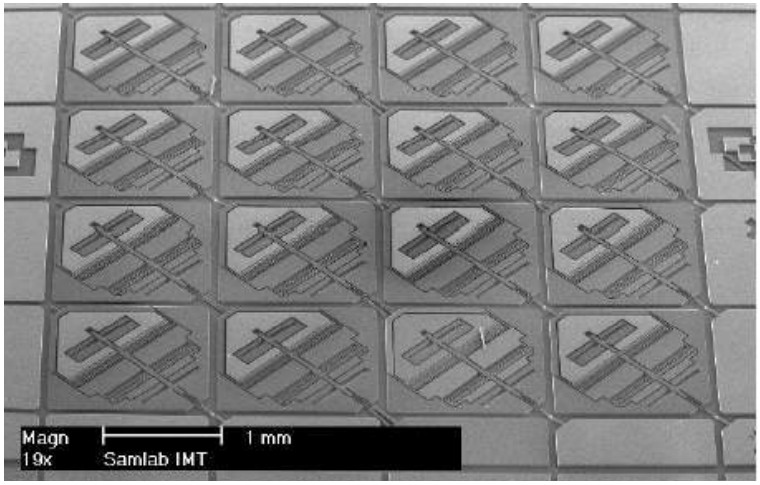
(http://www.dlp.com)

Applications – OMEMS (cont'd)

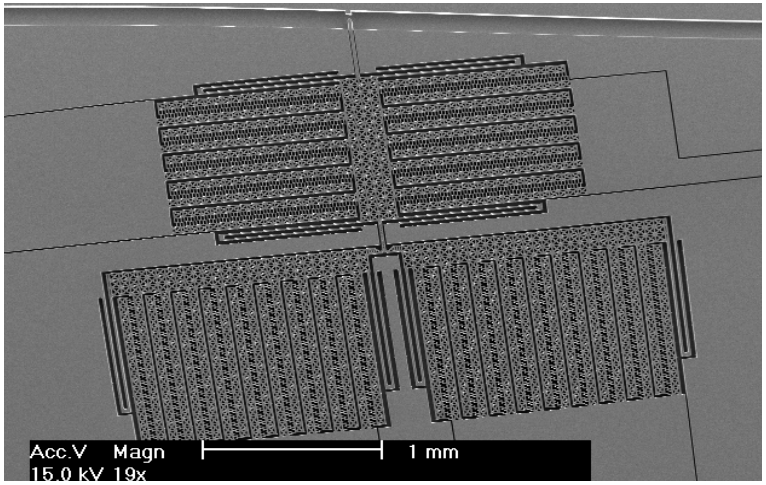
Micro-Lens Scanner (UC Berkeley)



Micromirror array for telescope (SNU)



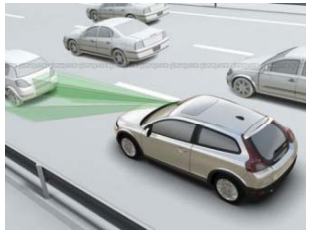
4×4 matrix switch for optical fiber switching (Neuchatel Univ.)



Fast on/off optical switch (NML SNU)

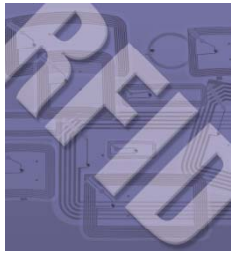
Applications – RF MEMS

Satellite Communications



Electronics (77 GHz anti-collision Radar, on-board GPS)

Improved millimetric sensors (MMW)
RFID (TAGS)



Adjustable antennas

RF MEMS

Tranmission/reception
- Handsets
- Basestations

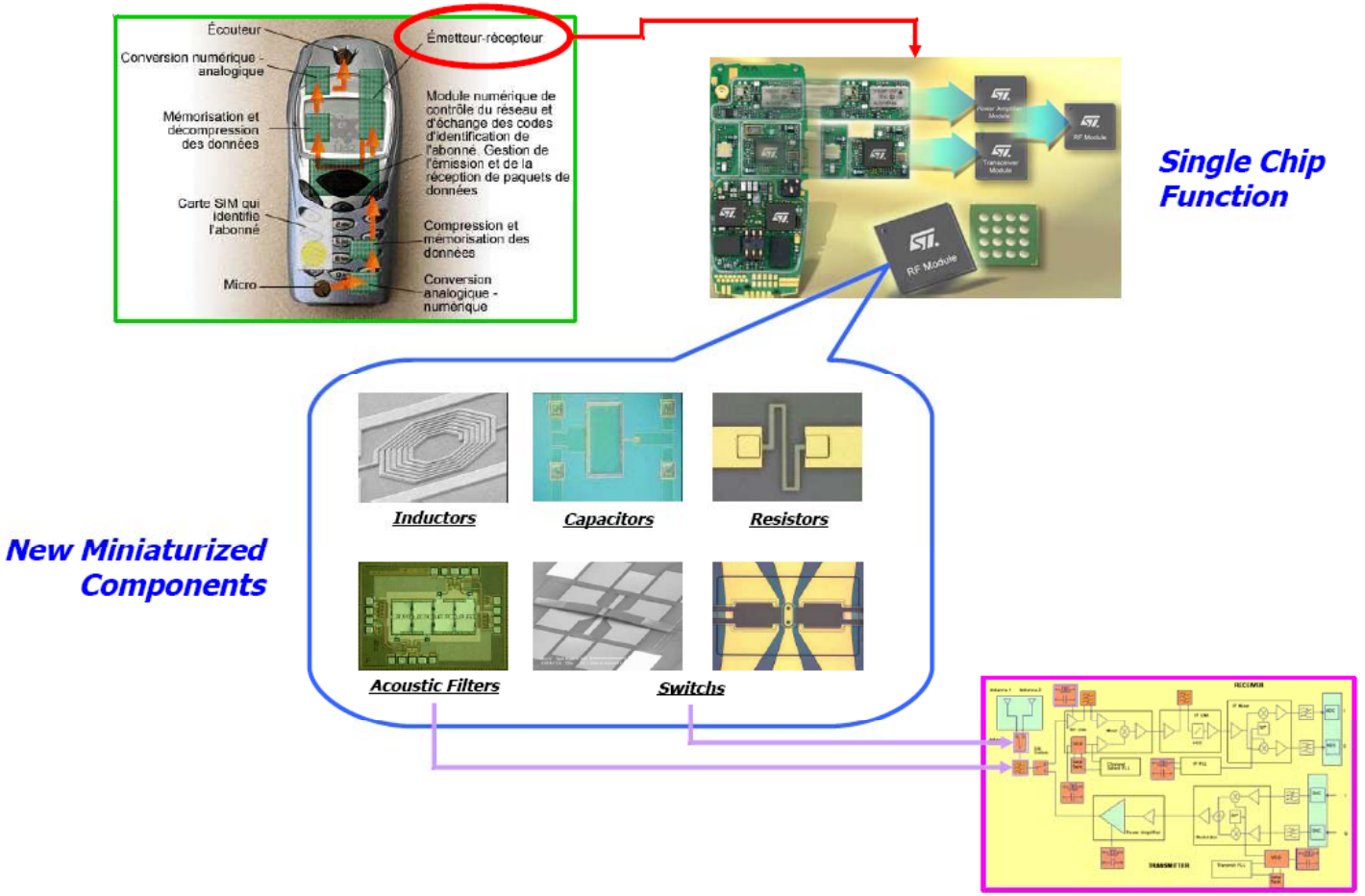
LANs: intelligent housing (2.4 GHz and 5.2 GHz) local radio loop for SOHO internet connections (5 GHz to 30 GHz)

Other wireless products (portable PCs, GPS)

Radar systems (phase-delay systems)

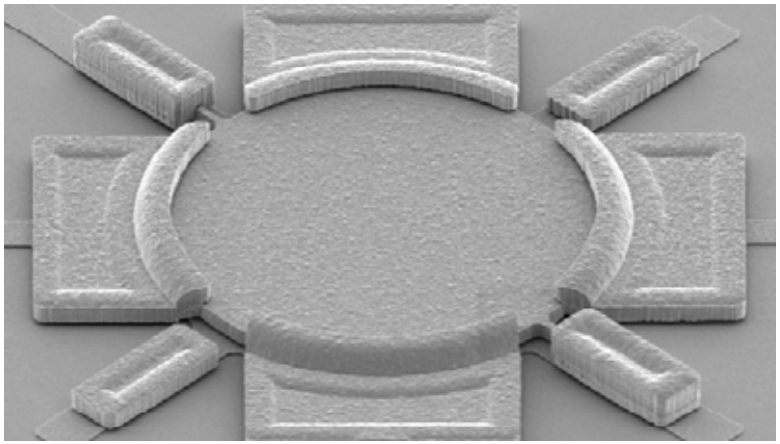
Applications – RF MEMS (cont'd)

- RF MEMS components for wireless devices

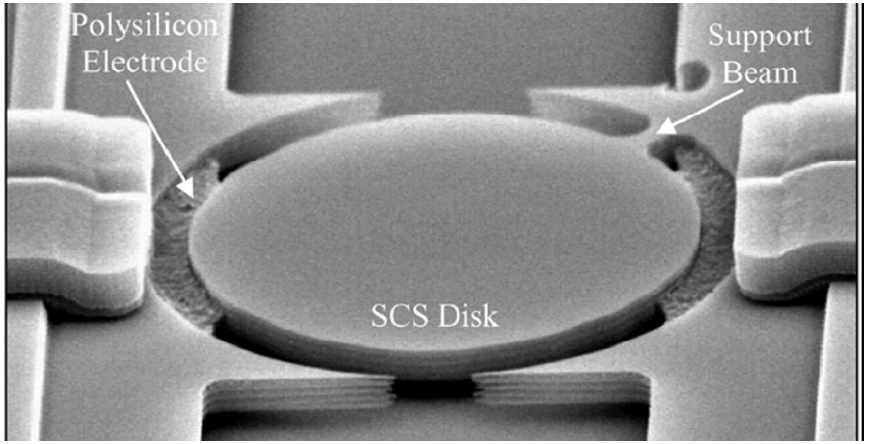


Applications – RF MEMS (cont'd)

- Vibrating RF MEMS devices

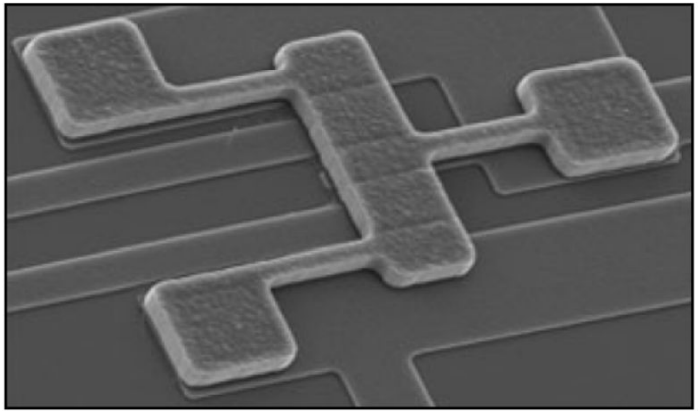


60-MHz wine-glass disk resonator (Michigan)

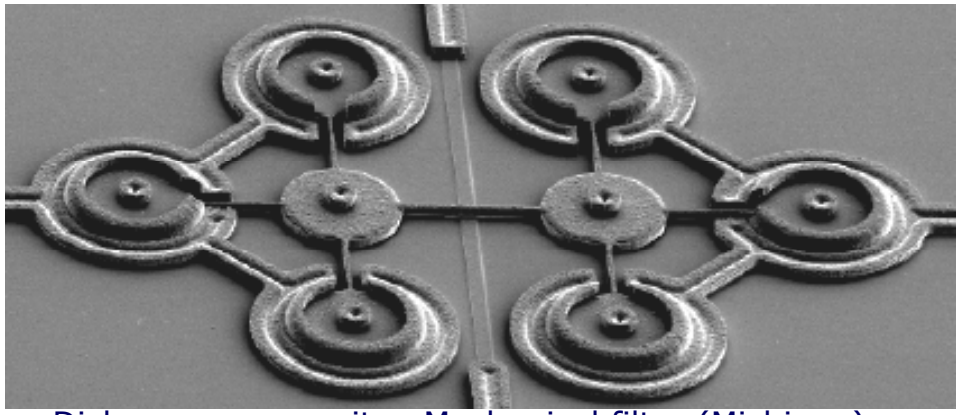


Side-supported SCS disk resonator (Georgia Tech.)

- Filters



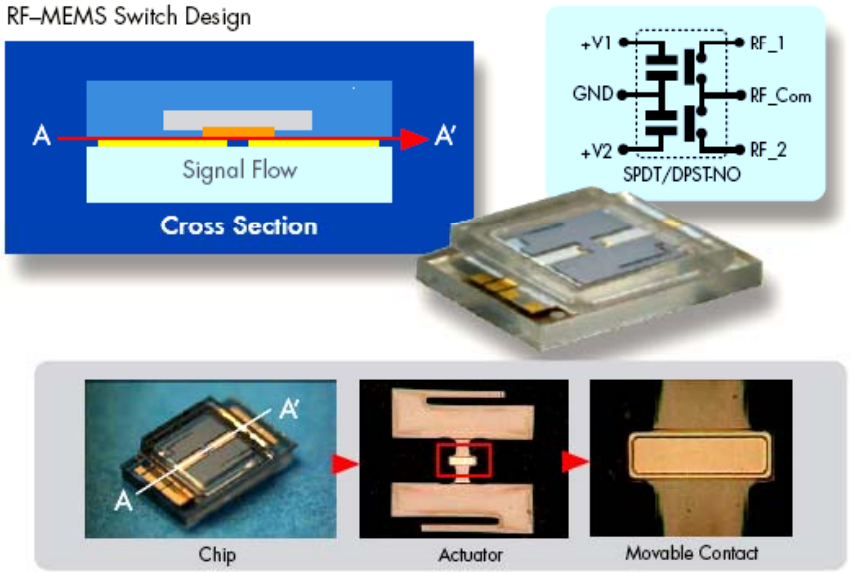
Quadrature mixer-filter (Michigan)

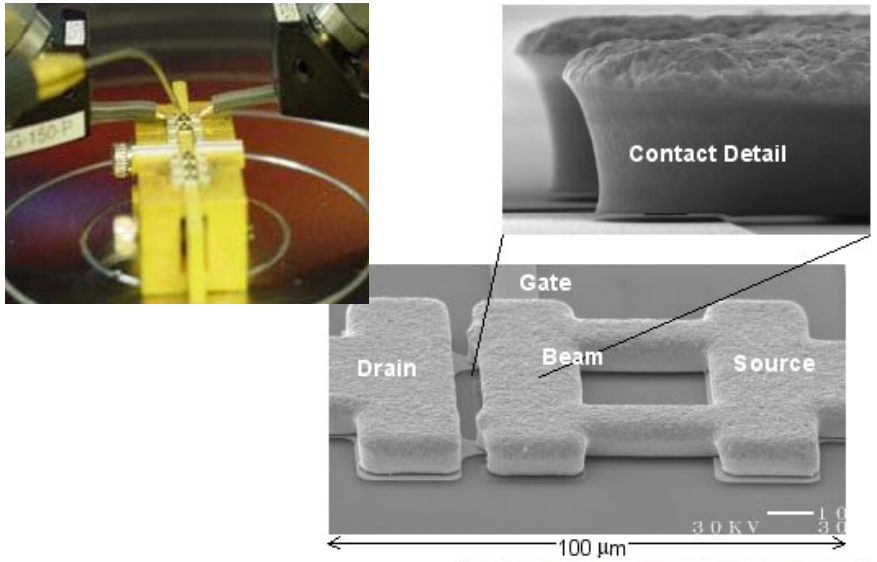


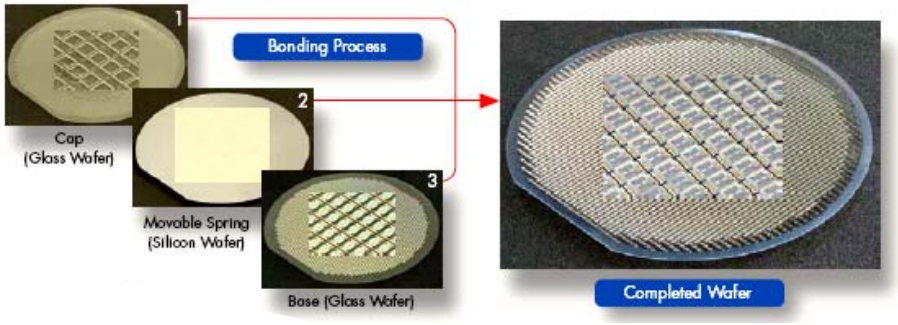
Disk array composite μMechanical filter (Michigan)

Applications – RF MEMS (cont'd)

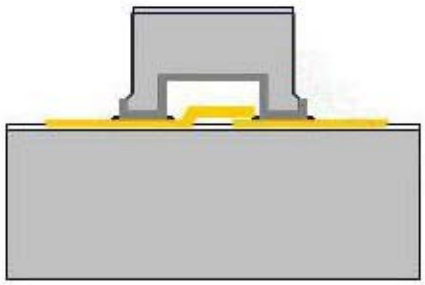
- MEMS switch

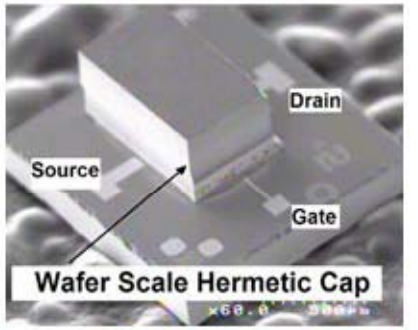






(Omron)

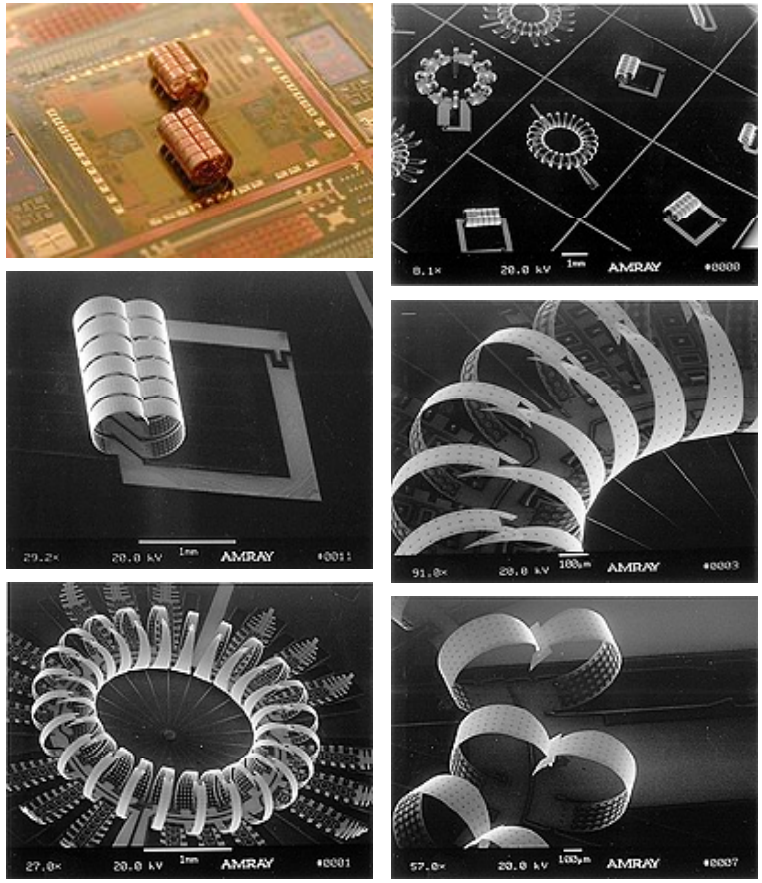




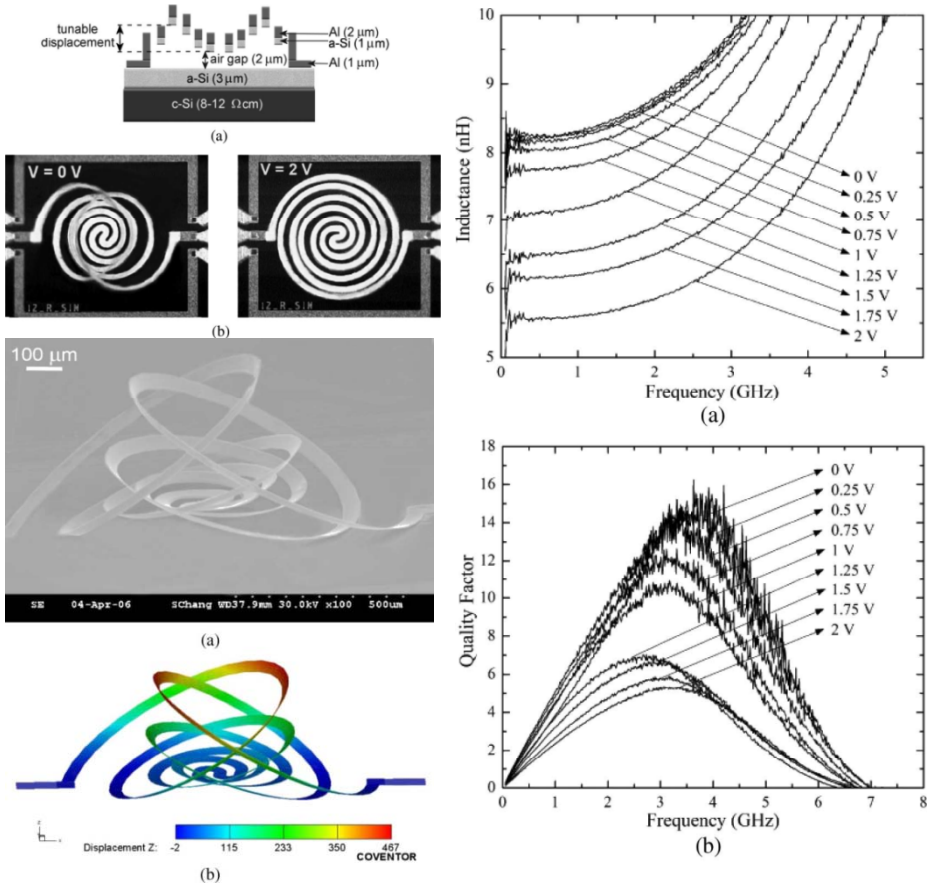
(RadantMEMS)

Applications – RF MEMS (cont'd)

- MEMS inductor



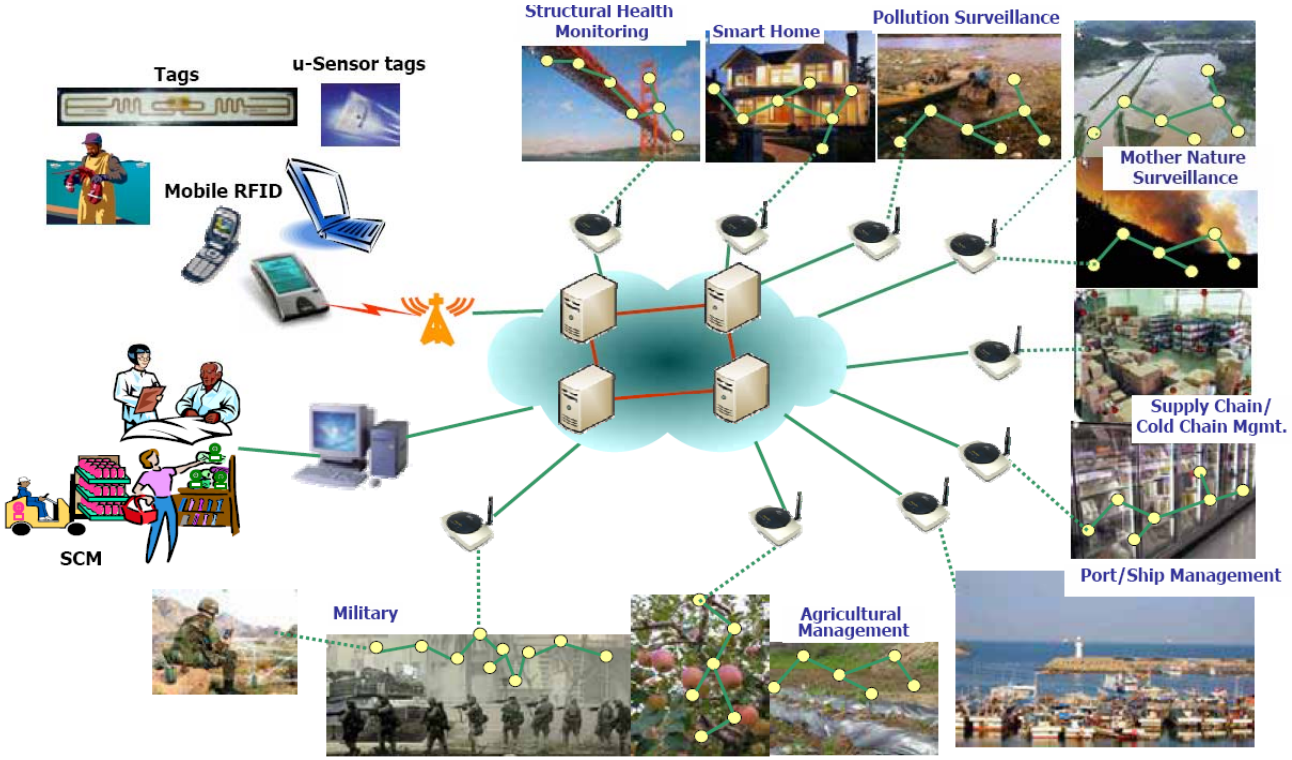
Stressedmetal (PARC)



Tunable inductor (Univ. of Waterloo)

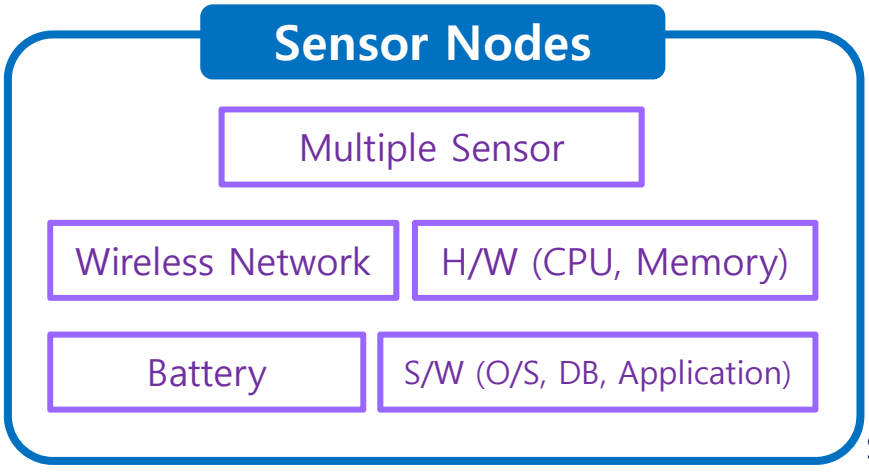
Applications – USN

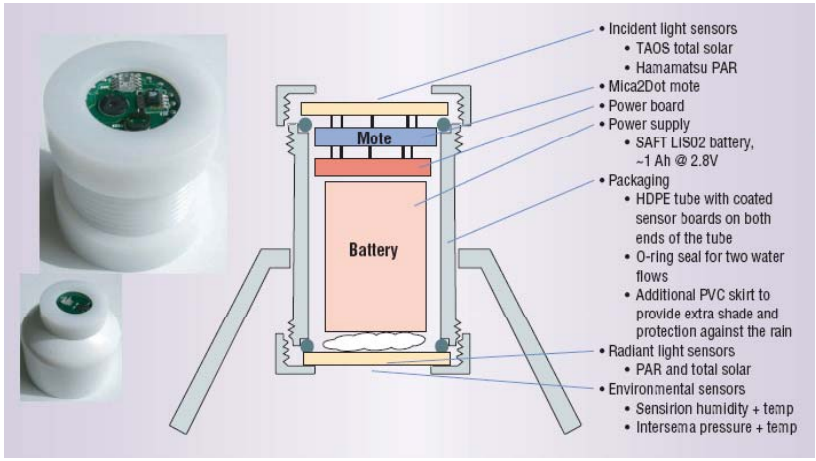
- USN (Ubiquitous Sensor Network)
  - Everywhere, everything with RFID tags → Ubiquitous
  - Sensing ID and environmental information → Sensor
  - Real-time monitoring & control via network → Network



Applications – USN (cont'd)

- Sensor network and sensor nodes
  - Sensor network is composed of a large number of sensor nodes with sensing, processing & wireless communication capabilities
  - Sensor nodes are small, low cost, low-power devices that have following functionality:
    - Communication on short distances due to power limitation
    - Sense environment data
    - Perform limited data processing
  - Network usually also contains "sink" node which connects it to the outside world

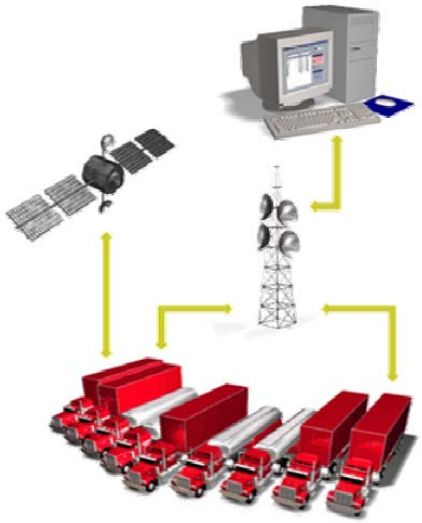




Self-organizing wireless sensor network nodes: Mote (Intel)

Applications – USN (cont'd)

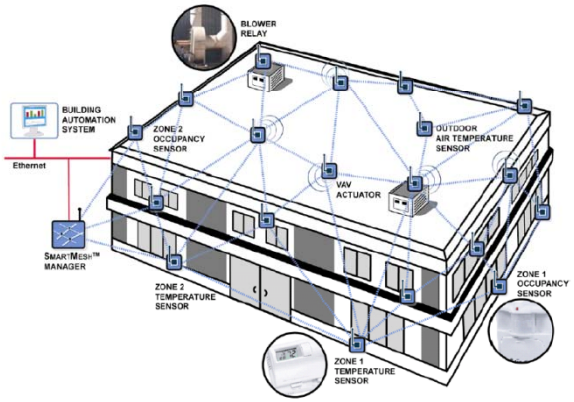
- Sensor Network Applications
  - Military Applications
  - Environment and Habitat Monitoring
  - Manufacturing
  - Transportation
  - Seismic Study
  - Health Care
  - Home Network



Transportation

Military applications

Soil moisture sensor nodes



Building automation system