Introduction to MEMS

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BIOEN 6421, ELEN 5221, MEEN 5960 and 6960

Overview

- What is micromanufacturing and MEMS?
- Why the interest in MEMS?
- IC Fabrication Processes
- Bulk Micromachining Processes
- Surface Micromachining Processes
- Combined Processes
- References

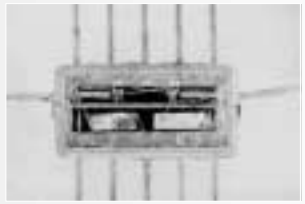
MEMS - evolved from the Microelectronics Revolution

IC Industry Timeline

1947

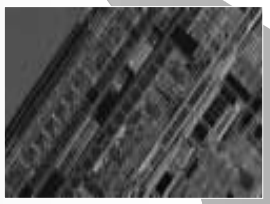
single transistor

1958



first IC

1999



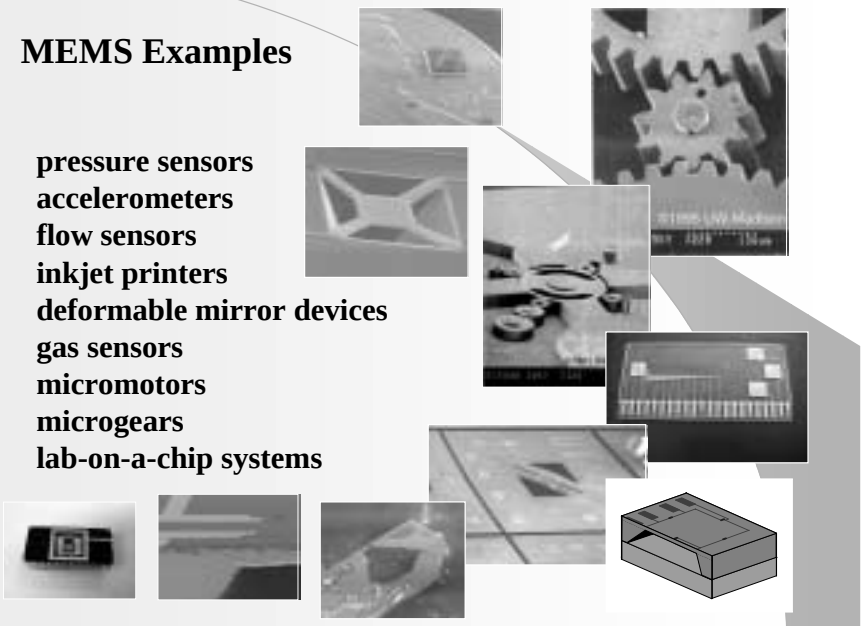
10 million transistors

So what exactly is MEMS?

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common substrate through the utilization of microfabrication technology or "microtechnology".

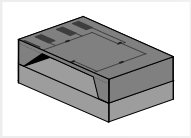
MEMS Examples

pressure sensors
accelerometers
flow sensors
inkjet printers
deformable mirror devices
gas sensors
micromotors
microgears
lab-on-a-chip systems



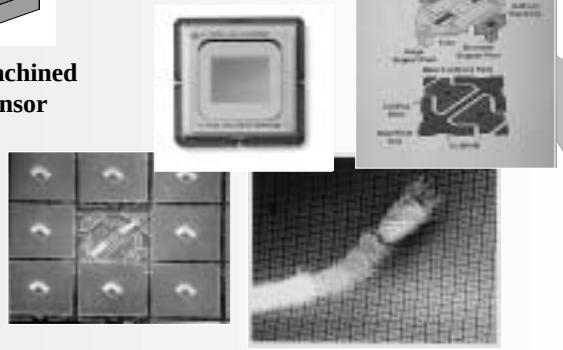
MEMS Timeline

1980



Bulk micromachined pressure sensor

1999

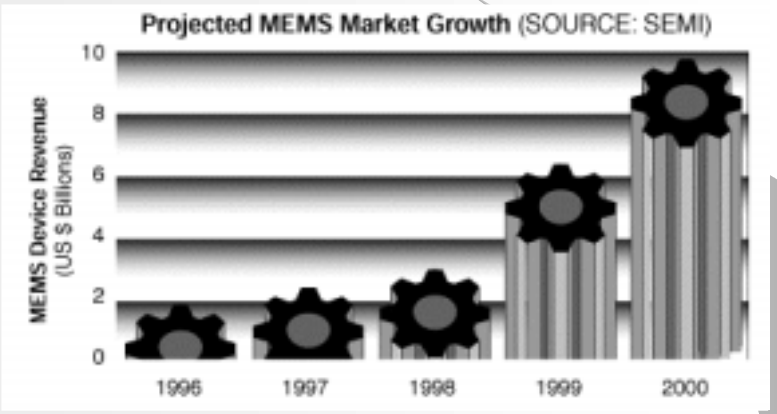


TI DMD
(1.3 million micro-mirrors)

2030

?

The Opportunity of MEMS Technology



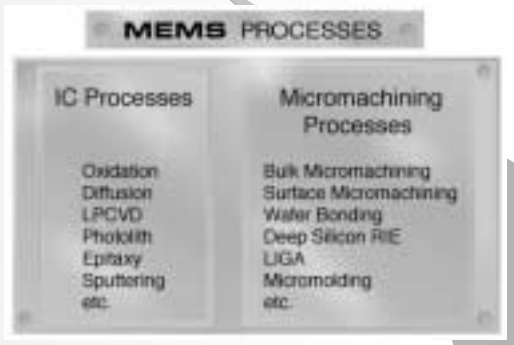
General MEMS Advantages

- Batch fabrication
  - Reduced cost
- Reduced size
  - Is everything better smaller?
- Reduced power
- High precision
- New capabilities?
- Improved performance?

The MicroTechnology/MEMS Tool Set

Cleanroom plus microfab processes

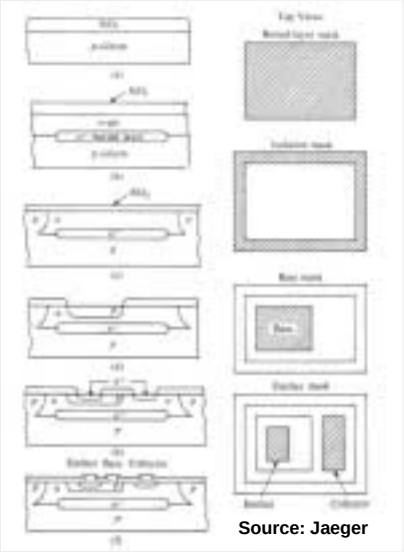
+



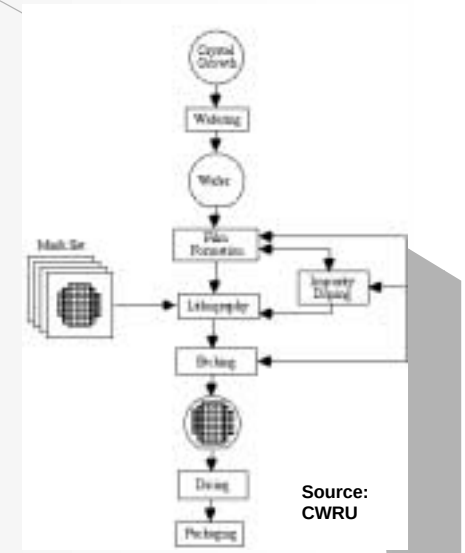
Micromachining Processes

- Standard Integrated Circuit (IC) Processes
  - Identical to those used in IC fabrication
  - Generally used for surface micromachining
- Surface Micromachining
  - Additive processes
- Bulk Micromachining
  - Subractive Process
- Dividing line can become very blurry

Standard IC Processes



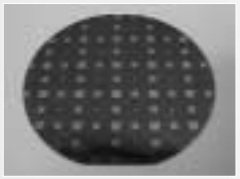
Source: Jaeger



Source: CWRU

Standard IC Processes

Photolithography



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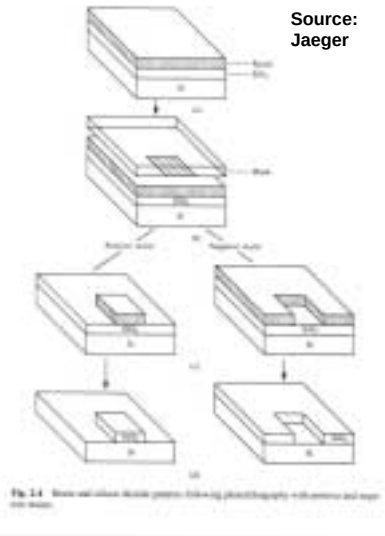


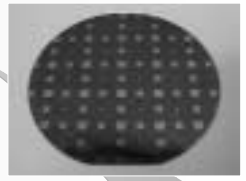
Standard IC Processes

1) Deposit/Grow Thin Films

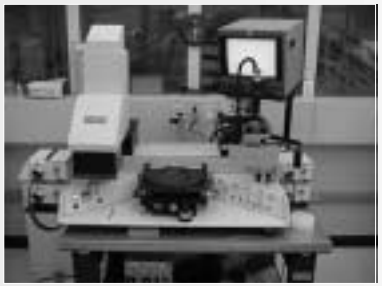
- Sputtering
- Evaporation
- Thermal Oxidation
- CVD
- Spinning
- Epitaxy

Standard IC Processes

2) Pattern Thin Films



- Lithography
- Etching Techniques (wet, dry, RIE)



Standard IC Processes

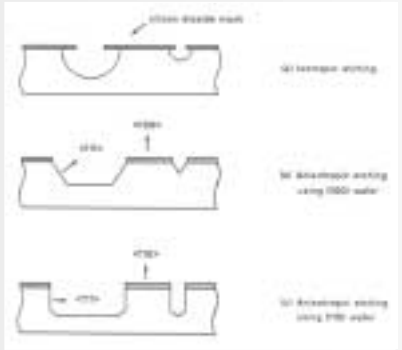
3) Introduce Dopants (to form electrically-active regions for diodes, transistors, etc.)

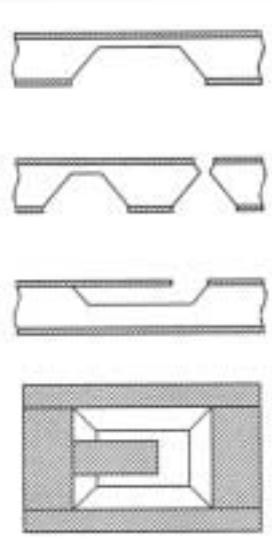
- Thermal Diffusion
- Ion Implantation

Micromachining Processes

Bulk Micromachining

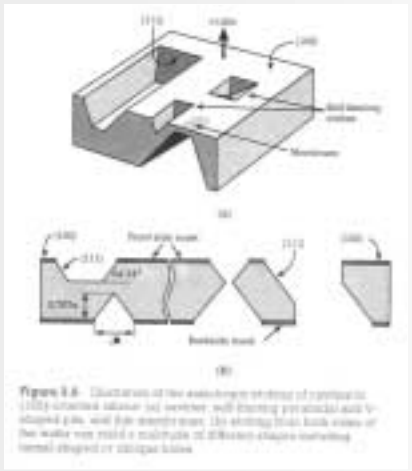
- wet vs dry
- isotropic vs anisotropic
- subtractive process



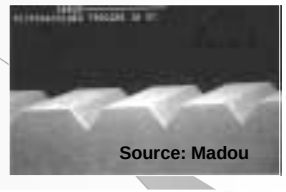


Micromachining Processes

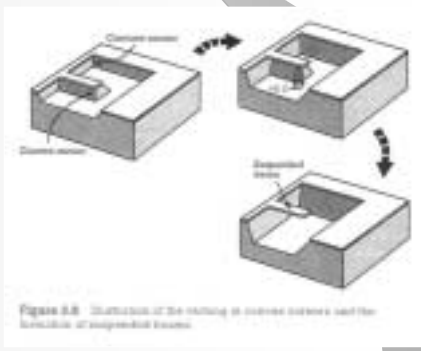
Bulk Micromachining



Source: Maluf



Source: Madou



Source: Maluf

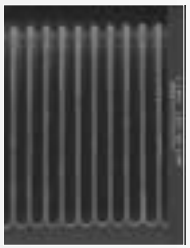
Micromachining Processes

Deep Reactive Ion Etching (DRIE)

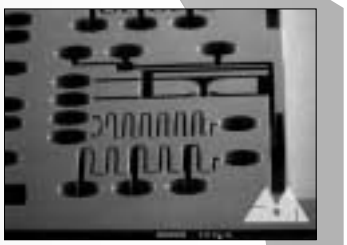
- high density ICP plasma
- high aspect ratio Si structures
- cost: $500K

Source: LucasNova

Source: STS



Source: STS

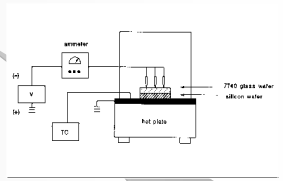


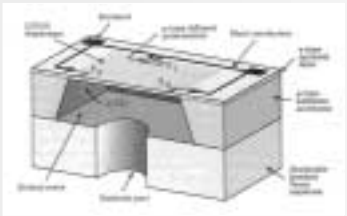
Source: AMMI

Micromachining Processes

Wafer-Level Bonding

- glass-Si anodic bonding
- Si-Si fusion bonding
- eutectic bonding
- low temp glass bonding





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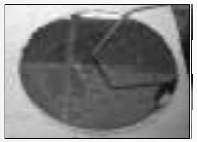
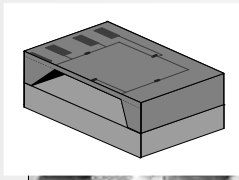


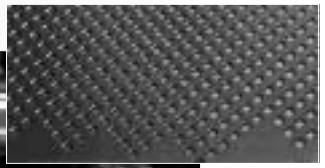
Source: EV

MEMS Examples

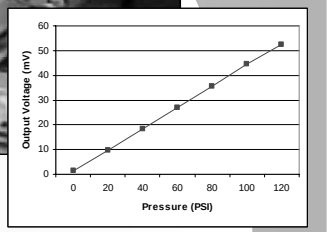
Pressure Sensor (conventional)

Source: NovaSensor





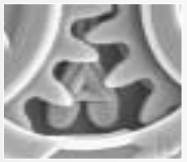
Source: UofL

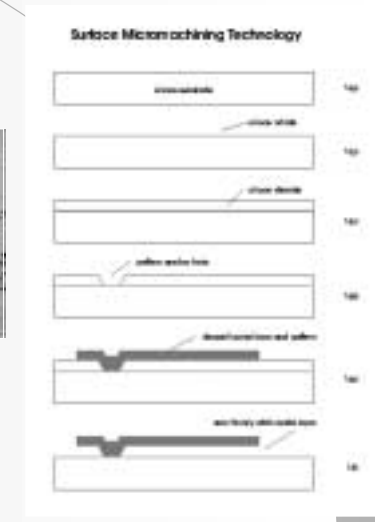


Micromachining Processes

Surface Micromachining

- additive process
- structural & sacrificial layers



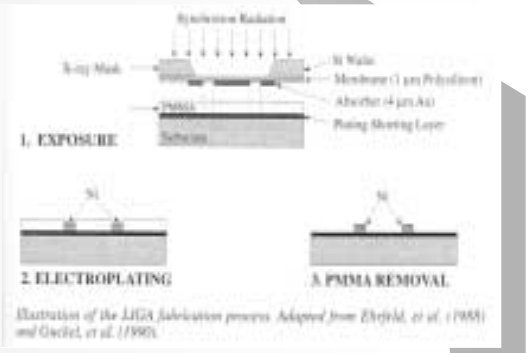


Micromachining Processes

LIGA (lithographie, galvanoformung, abformtechnik)

- uses x-ray lithography (PMMA), electrodeposition and molding to produce very high aspect ratio (>100) micro-structures up to 1000 um tall (1986)

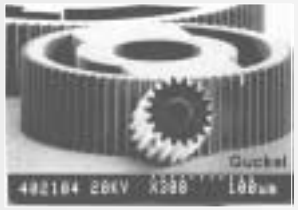
Source: Madou

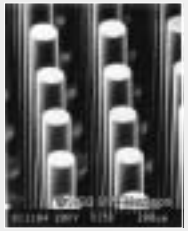


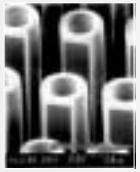
Source: Kovacs

MEMS Examples

Micro-structures using LIGA





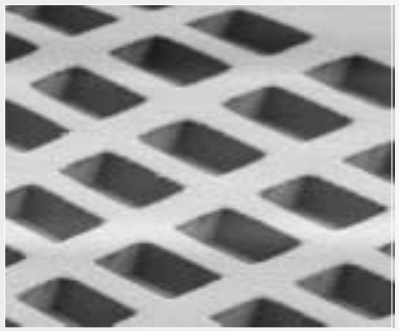


Source: UW

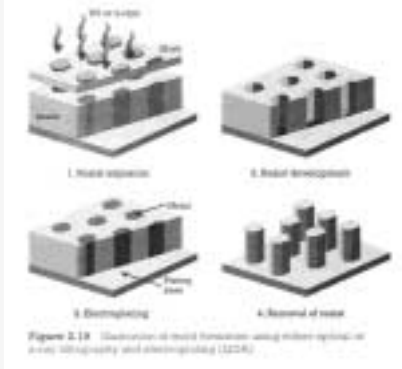
Micromachining Processes

Poor Man's LIGA

- uses optical epoxy negative-resist (SU-8) developed by IBM to produce high aspect ratio micro-structures (1995)



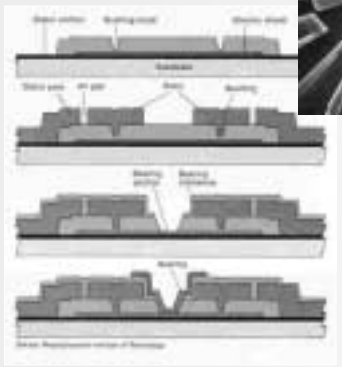
UofL Micro-reaction wells: 150 um wide, 120 um tall, 50 um wall thickness



Source: Maluf

MEMS Examples

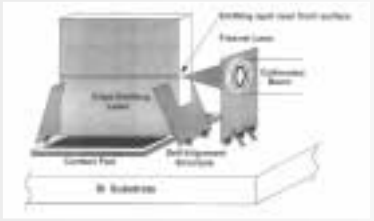
Micromotors

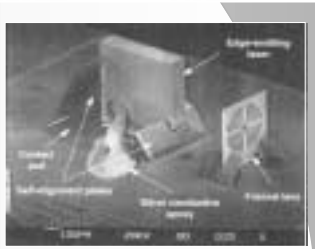


Source: MIT and Berkeley

MEMS Examples

Optical MEMS (MOEMS)

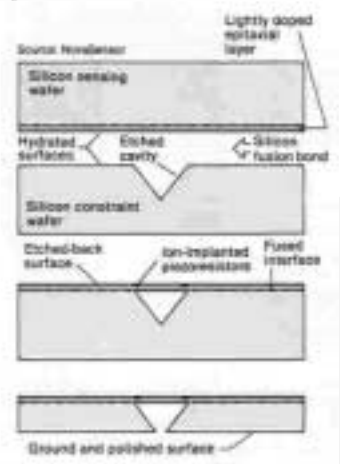




Source: NIST, Simon Fraser, UCLA, and MCNC

MEMS Examples

Pressure Sensor (ultra-miniature)

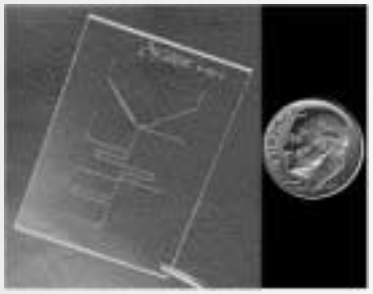


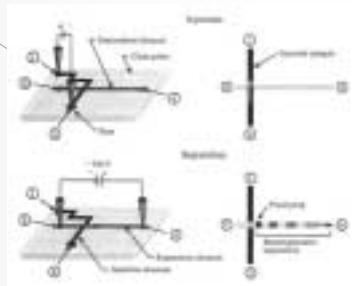
Source: NovaSensor

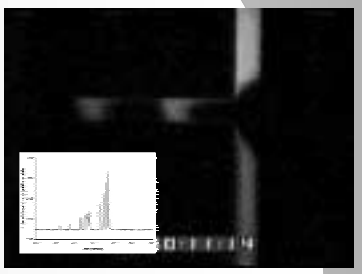
MEMS Examples

Lab-on-a-Chip Systems

- separation
- dilution
- mixing and dispensing
- analysis







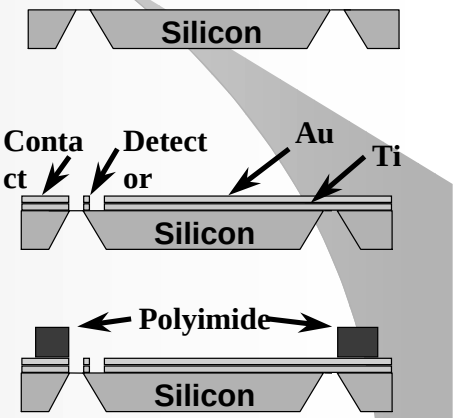
Source: Caliper

Integration

- Micromachining processes may be integrated
- Both bulk and surface micromachining may be performed on a single substrate
- Micromachined structures may be integrated with ICs

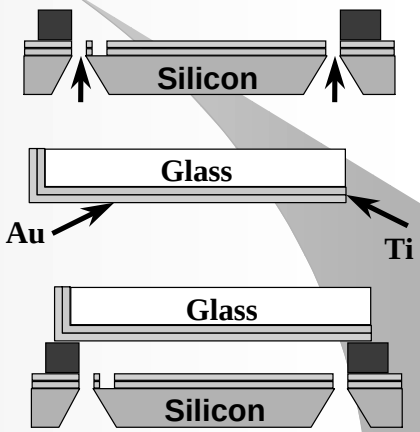
EFFF Fabrication 1

- Anisotropic etching of input and output ports in 20% KOH at 65 C with Si_3N_4 mask
- Deposit and pattern Ti/Au electrodes on front of wafer
- Thick photosensitive polyimide or SU-8 used to define flow channels



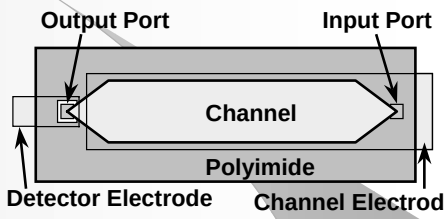
EFFF Fabrication 2

- Remove Si_3N_4 membrane
- Deposit and pattern Ti/Au electrode on glass substrate
- Bond glass substrate to polyimide using biocompatible UV curable adhesive



EFFF Fabrication 3

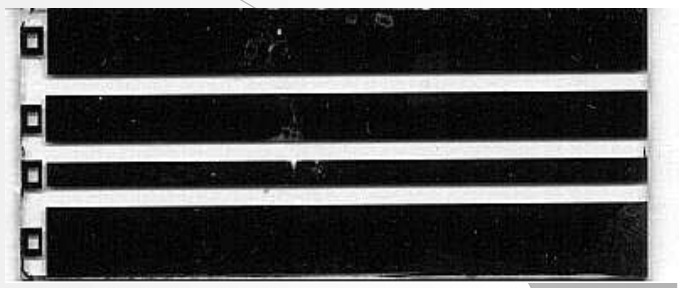
- Completed channel looking from the top



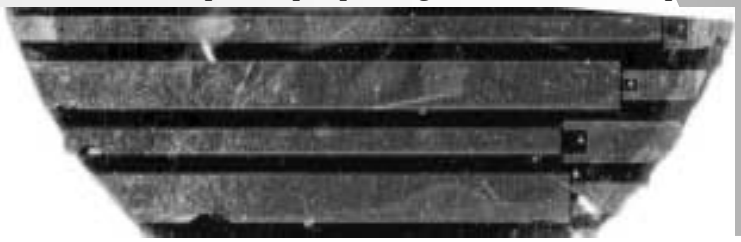
- Cross section through channel showing electrodes, polyimide and substrates

Results- Section Fabrication

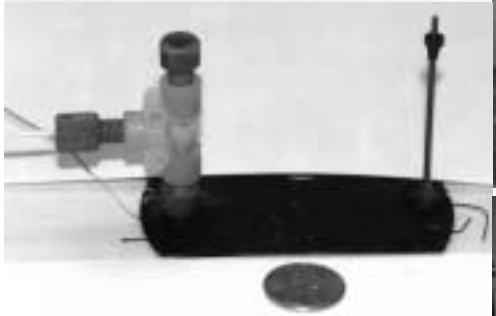
Glass substrate with titanium, gold, and platinum electrode



Silicon substrate with input/output ports, gold electrodes and patterned SU-8

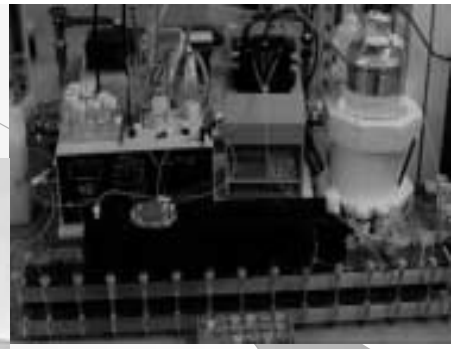


Results- System Assembly



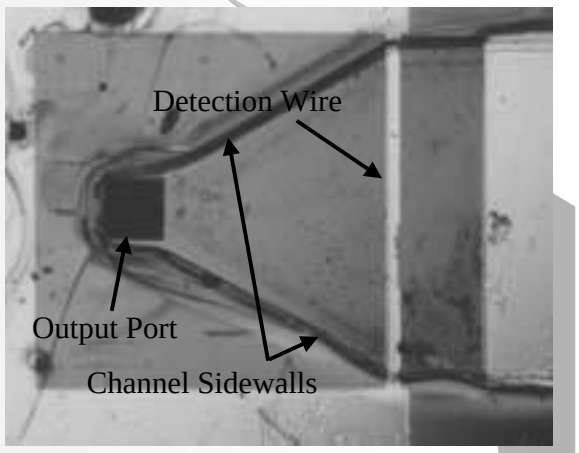
Above- Complete device with input/output port connections

Right- Complete systems with sample and buffer input, μ-EFFF system, and detectors



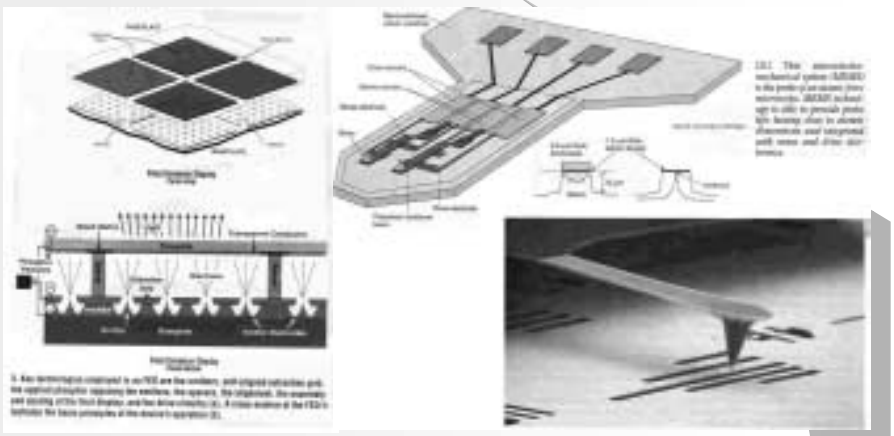
Fabrication Results

- Micrograph of detector wire across channel defined by polyimide
- Wire is 19 μm wide
- Location of wire eliminates all end effects



MEMS Examples

Micromachined Tips for FEDs and AFMs

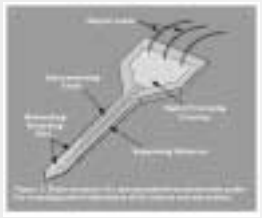


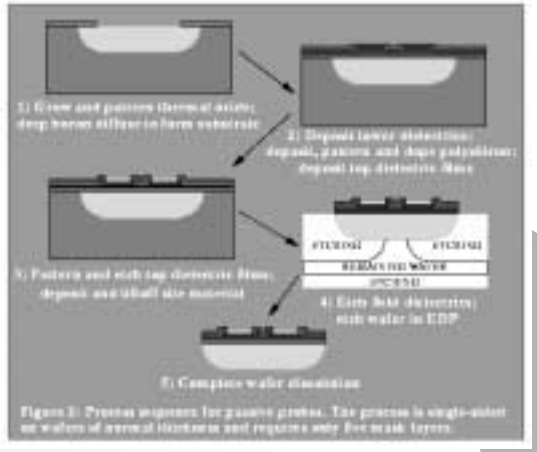
Source: Micron (?)

Source: IBM

MEMS Examples

Neural Probes

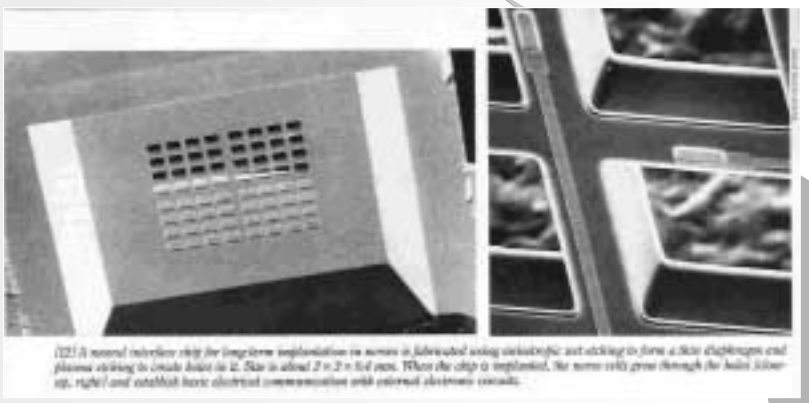




Source: Mich (K. Wise)

MEMS Examples

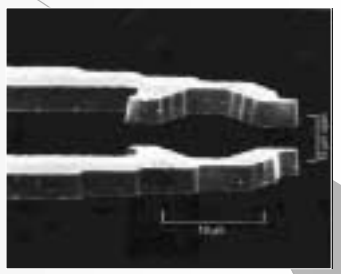
Neural Interface Chip

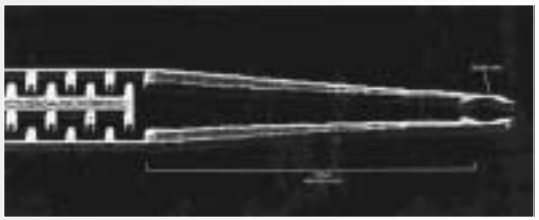


Source: Stanford

MEMS Examples

Micro-Grippers

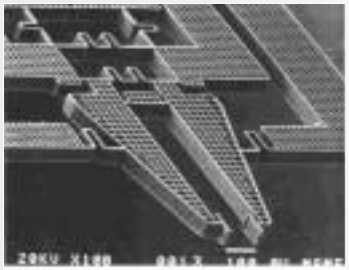


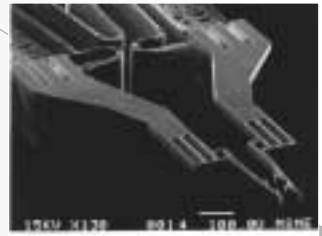


Source: Berkeley

MEMS Examples

Micro-Tweezers

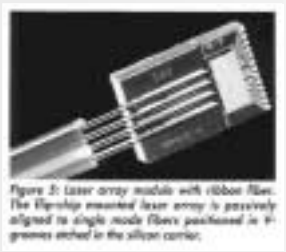


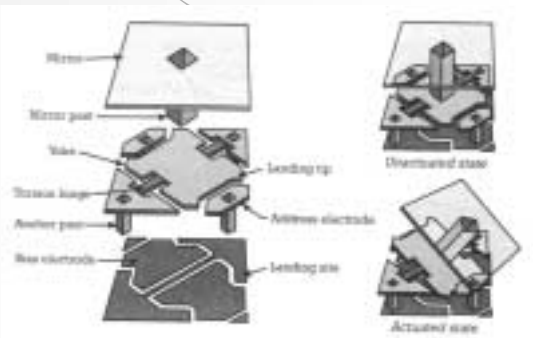


Source: MEMS Precision Instruments

MEMS Examples

Optical MEMS (MOEMS)

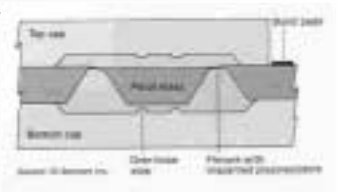


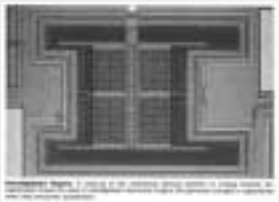


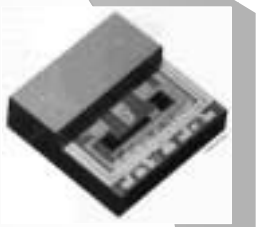
Source: IMC (Sweden), Maluf and TI

MEMS Examples

Accelerometers



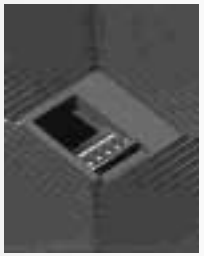


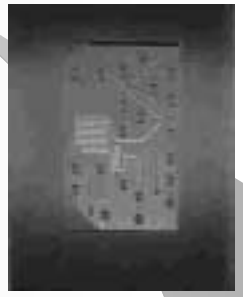


Sources: Analog Devices, Lucas NovaSensor, and EG&G IC Sensors

MEMS Examples

Channels, Nozzles, Flow Structures, and Load Cells





Source: EG&G IC Sensors

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