微小世界是如何運作的

--- 微機電系統

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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

Year


10^{-3} 10^{-1} 10^{1} 10^{3} 10^{5} 10^{7} 10^{9} 10^{11} 10^{12}

mips T/Die

10^{-3} 10^{2} 10^{4} 10^{6} 10^{8} 10^{10} 10^{12}

Design Rule [m]

30T 160G 6nm

55G 20M 0.18\mu m 4nm

0.03 3K 10\mu m 200nm

Courtesy Yoram Shapira, TAU
Structure of microchips

Interconnect network - 6-7 layers of metallization

Active device layer (1-2 μm)

Silicon substrate (600-800 μm)
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
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

- Wafer Surface
- Cantilevers
- Bridge
- Trench
- Cavity
- Nozzle
- Membrane
Non crystal **Bulk** Micromachining

- Surface
- Cantilevers
- Bridge
- Cavity
- Nozzle
- Trench
- Membrane
# The More Mechanical Levels

The More Sophisticated The Device

<table>
<thead>
<tr>
<th>2-Level</th>
<th>3-Level</th>
<th>4-Level</th>
<th>5-Level</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
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</table>

### Sensors
- Advanced Sensors
- Simple Actuators

### Actuators
- Advanced Actuators
- 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

3-Level

4-Level

5-Level

Motor

Silicon Substrate

Polysilicon Level #1

Polysilicon Level #1

Polysilicon Level #2

Polysilicon Level #1

Polysilicon Level #2

Polysilicon Level #3

Polysilicon Level #4

Motor

Silicon Substrate

Motor

Silicon Substrate

Motor

Silicon Substrate

Silicon Substrate

Motor

Silicon Substrate

Motor

Silicon Substrate

Moveable Plate

Polysilicon Level #1

Polysilicon Level #2

Polysilicon Level #3

Polysilicon Level #4

Sensors

Advanced Sensors

Simple Actuators

Advanced Actuators

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 2 $\mu$m of polysilicon
- Coat with resist, expose
- Etch with RIE (reactive ion etch)
2nd sacrificial (oxide) layer

- Deposit 0.75 μm 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

- 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
LIGA*, Deep UV

Absorber structure

Irradiation

Synchrotron

Resist

Mask membrane

Substrate

Development

Resist structure

Electroforming

Metal

Substrate

Mold Insert

Mold Filling

Mold cavity

Plastic mold material

Mold Separation

Plastic structure

Source: IMM (Mainz Institute for Microtechnology)

*Lithographie, Galvanoformung, Abformung
Fig. 2: PMMA mold of an electrostatic actuator manufactured 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

Create etch stops and gap in back
Fuse silicon
Process top and etch mass
Etch beam and bond Pyrex

Mass wafer
Device wafer
Mass wafer

Sensing elements and interconnections
Air gap for squeeze film damping
Built-in over-acceleration stops
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)
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

<table>
<thead>
<tr>
<th>氣體</th>
<th>TLV (ppm)</th>
<th>氣體</th>
<th>TLV (ppm)</th>
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<td>50</td>
<td>HCN</td>
<td>10</td>
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<tr>
<td>NH₃</td>
<td>25</td>
<td>HCl</td>
<td>5</td>
</tr>
<tr>
<td>H₂S</td>
<td>10</td>
<td>AsH₃</td>
<td>0.05</td>
</tr>
<tr>
<td>Cl₂</td>
<td>1</td>
<td>NO</td>
<td>25</td>
</tr>
<tr>
<td>SO₂</td>
<td>5</td>
<td>NO₂</td>
<td>3</td>
</tr>
<tr>
<td>C₆H₆</td>
<td>10</td>
<td>CO₂</td>
<td>5000</td>
</tr>
<tr>
<td>CH₃Br</td>
<td>20</td>
<td>O₃</td>
<td>0.1</td>
</tr>
<tr>
<td>CH₂CH₂O</td>
<td>50</td>
<td>C₂H₅OH</td>
<td>1000</td>
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</table>
圖4-2 不同厚度SnO₂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

$La_{0.8}Sr_{0.2}Co_{0.5}Ni_{0.5}O_3$
單層氧化物薄膜與異質接合薄膜對CO感測特性之比較

![Graph showing CO sensitivity comparison for SnO_2 and La_{0.8}Sr_{0.2}Co_{0.5}Ni_{0.5}O_{3-δ} at 200°C.](image-url)
SnO$_2$/LSCNO異質接合薄膜在室溫下之I-V曲線
Gyroscopes
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.

\[ \Delta v = \frac{4A}{\lambda p} \Omega \]

- \( A \) – 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

1. Pressure (Relative to Cavity)

2. Bends Thin Membrane

**MEMS accelerometers market**

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

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</thead>
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<tr>
<td>Market size</td>
<td>240 M$</td>
<td>400 M$</td>
<td>560 M$</td>
<td>800 M$</td>
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</tbody>
</table>

**Annul growth**

- 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 2009”
- Yole: “World MENS inertial sensors”

Accelerometer
Fig. 4: 3D accelerometer micromachined by the author in Dresden University of Technology, Dresden, Germany.
Zinc oxide acoustic sensor

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 device.
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
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.
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Power consumption (W)</td>
<td>0.1</td>
<td>0.5</td>
<td>12 V</td>
<td>1.03</td>
<td>16</td>
<td>0.56</td>
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<tr>
<td>Active area for deflection (mm²)</td>
<td>1</td>
<td>NA</td>
<td>9</td>
<td>64</td>
<td>25</td>
<td>16</td>
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<tr>
<td>Deflection (µm)</td>
<td>94</td>
<td>72</td>
<td>72</td>
<td>NA</td>
<td>100</td>
<td>5</td>
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<tr>
<td>Actuation speed (ms)</td>
<td>56</td>
<td>100</td>
<td>200</td>
<td>100</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Package size (mm³)</td>
<td>NA</td>
<td>6.8</td>
<td>NA</td>
<td>2.3</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

* The driving power was supplied through dc voltage pulses.
Micro-pump and valves

Piezobimorph-Membran

Pumpkammer

antiparallel angeordnete dynamische passive Ventile als Ein- und Auslaß

(2x2 ... 10x10)mm²
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
Magnetic read/write heads for hard drives.
Optobionics: Retinal Implant
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.
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.
Macro – Micro - Nano

Macro or Conventional Machines

Micromachines

(0.1 mm - 0.1 μm)

Nanosystems

(100-1 nm)