Fundamentals of MEMS

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Who Cares About MEMS?
Overview

- What is micromanufacturing and MEMS?
- Why the interest in MEMS?
- IC Fabrication Processes
- Bulk Micromachining Processes
- Surface Micromachining Processes
- Combined Processes
- References
Electrostatic Micromotor
MEMS from the Microelectronics Revolution

IC Industry Timeline

1947: single transistor
1958: first IC
2007: Billions of transistors
1980

Bulk micromachined pressure sensor

1999

TI DMD

(1.3 million micro-mirrors)

2020

Medical MEMS?
Top 30 Worldwide MEMS Companies Ranking - 2009 Revenues

(Yole Développement Estimates $M – February 2010)
Top 20 MEMS Foundries

TOP 20 MEMS Foundries - 2009 revenues

Million US$
Accelerometer, Gyroscope, and IMU’s led by Consumer Electronics

2008-2013 market evolution for MEMS inertial sensors per field of application
Beginning of arrow: is 2008. End of arrow is 2013
MEMS Forecast
(Courtesy from Yole Development)
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
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

IC Processes
- Oxidation
- Diffusion
- LPCVD
- Photolith
- Epitaxy
- Sputtering
- etc.

Micromachining Processes
- Bulk Micromachining
- Surface Micromachining
- Wafer Bonding
- Deep Silicon RIE
- LIGA
- Micromolding
- etc.
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
  - Subtractive Process
- Dividing line can become very blurry
Standard IC Processes

Source: CWRU

Source: Jaeger
Standard IC Processes

Photolithography

Source: Jaeger
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

Figure 3.6 Illustration of the anisotropic etching of cavities in (100)-oriented silicon: (a) cavities, self-limiting pyramidal and V-shaped pits, and thin membranes; (b) etching from both sides of the wafer can yield a multitude of different shapes including funnel-shaped or oblique holes.

Source: Maluf

Figure 3.8 Illustration of the etching at convex corners and the formation of suspended beams.

Source: Maluf
Micromachining Processes

Deep Reactive Ion Etching (DRIE)

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

Source: STS
Source: STS
Source: AMMI
Source: LucasNova
Micromachining Processes

Surface Micromachining
• additive process
• structural & sacrificial layers

Source: Sandia
Micromachining Processes

LIGA (lithographie, galvanoformung, abformtechnik)

- uses x-ray lithography (PMMA), electrodeposition and molding to produce very high aspect ratio (>100) microstructures up to 1000 µm tall (1986)
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
Micromachining Processes

Wafer-Level Bonding

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

Source: Maluf

Source: EV
MEMS Examples

Pressure Sensor (conventional)

Source: NovaSensor

Source: UofL
MEMS Examples

Micromotors

Source: MIT and Berkeley
MEMS Examples

Optical MEMS (MOEMS)

The MUMPs infrastructure programs at MCNC are designed to provide low-cost access to MEMS process technology. Hundreds of users from the domestic industry, government, and academic communities have used MCNC to access MUMPs. The Multi-user MEMS Processes (MUMPs) process is a regularly scheduled, low-cost solution for access to this emerging technology with a flexible fee/award of proven success.

MUMPs is the contraction of our popular Multi-user MEMS Processes. Low-cost and easy access to MUMPs offers a low-risk, prototyping/ua-communication pathway for small businesses and industry. The "tagging" process is a single-layer process/that surface micromachining technology. Devices such as X-ray detector, more optical sensors, actuators, and sensors can be produced using MUMPS.

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
MEMS Examples

Micromachined Tips for FEDs and AFMs

3. Key technologies employed in an FED are the emitters, self-aligned extraction grid, the applied phosphor opposing the emitters, the spacers, the alignment, the assembly and sealing of the final display, and the drive circuitry. A cross-section of the FED illustrates the basic principles of the device's operation.

Source: Micron (?)  
Source: IBM
MEMS Examples

Neural Probes

Source: Mich (K. Wise)
[12] A neural interface chip for long-term implantation in nerves is fabricated using anisotropic wet etching to form a thin diaphragm and plasma etching to create holes in it. Size is about $3 \times 3 \times 0.4$ mm. When the chip is implanted, the nerve cells grow through the holes (close-up, right) and establish basic electrical communication with external electronic circuits.

Source: Stanford
MEMS Examples

Micro-Grippers

Source: Berkeley
MEMS Examples

Micro-Tweezers

Source: MEMS Precision Instruments
MEMS Examples

Optical MEMS (MOEMS)

**Figure 3:** SEM picture of the microstructured silicon carrier with electrodes (solder pads), connection lines and probing pads.

**Figure 5:** Laser array module with ribbon fiber. The flip-chip mounted laser array is passively aligned to single mode fibers positioned in V-grooves etched in the silicon carrier.

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
Microreactor
SU8 High AR Structures
PZT Cantilever BEAM

- thickness 4.5 mm
- width 300 mm
- length 1000 mm
- 15 m at 10 V

OTS coating to prevent from stiction
Micropump

- Bimetallic thermal actuation
- Three-layer silicon
- Middle layer has 2 check valves
- Flowrate 190 mL/min
- Back pressure 80 mm H₂O
MEMS References

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MEMS and Nanotechnology Clearinghouse: www.memsnet.org