CMP Processing Issues for MEMS Fabrication Technology

Dale Hetherington, Ph.D.
Sandia National Laboratories
Albuquerque, NM
Miniaturization Micro-robot, 2001
Microengine Drive Gear

80 microns

Human Hair

100 microns

80 microns
Microengine Gear Teeth are the Size of Red Blood Cells

9 microns

2.5 microns
MEMS: It’s Not About Making Things Small

- The microelectronics revolution changed the world because of cost, not size
- MEMS offers a way to make complex electromechanical systems at low cost
- In order to fully realize the potential benefits of MEMS, cost must be the driver
- Cost Issues:
  - Maintain batch fabrication
  - Use standard IC materials
  - Leverage “standard” technologies and processes
Why Should IC Manufacturers Care About MEMS?

- New products in old fabs
- Seamless integration into existing fabs
- Don’t have to buy anything new
- Risk is low
- Logical next step
Successful MEMS Commercialization: The Challenges

The Chicken and Egg Problem

MEMS Developers

“Call Me When You Can Order a Million a Month”

Manufacturers

System Integrators

“Call Me When I Can Place an Order”
MEMS Challenges:
No Industry Standard Technologies

- Technologies are application-specific
- Pressure sensors, accelerometers, Displays, and inkjet print heads all use different technologies
- No synergy or cooperation in design, packaging, qualification, and tool development

TI DMD

Pressure Sensor
Transistor: Basic Building Block for IC’s

Moore's Law

Source: www.intel.com

No equivalent basic building block for MEMS
## Integrated Circuit Vs. MEMS Technology

<table>
<thead>
<tr>
<th></th>
<th>ICs</th>
<th>MEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Film Thickness ((\mu m))</td>
<td>&lt;1</td>
<td>2-6</td>
</tr>
<tr>
<td>Critical Dimension ((\mu m))</td>
<td>&lt; 0.1 (\mu m)</td>
<td>1</td>
</tr>
<tr>
<td>Topography ((\mu m))</td>
<td>&lt;1</td>
<td>2-10</td>
</tr>
<tr>
<td>Device Size ((\mu m))</td>
<td>&lt;1</td>
<td>100</td>
</tr>
</tbody>
</table>

### Processing Issues...

- Intrinsic Film Stress
- Thermal Budget
- Stiction
- Planarization
MEMs Dimensions

- atom
- DNA
- cell
- water drop

- 1 Å
- 1 nm
- 1 μm
- 1 mm
- 1 m

- MEMS
- thin films
- chip
- IC litho limit
- wafer
- transistor

[Image of a diagram showing a scale from 1 Å to 1 m with various labels and categories]
MEMS Allows Two Primary Functions: Sensing and Actuation

Sensors: Learn something about the environment

Actuators: Change something about the environment
MEMS Applications

• Sensing Applications
  – Medical Pressure Sensors
  – Automotive Pressure Sensors
  – Smart Tires
  – Airbag Accelerometers
  – ABS Sensors
  – Auto Navigation Gyros
  – Pacemakers
  – Machine Monitoring

• Actuation Applications
  – Optical Switches/Modulators
  – Optical Scanners
  – Disk Drives
  – Microbiology/Microsurgery
  – Infusion Pumps
  – Industrial Valves
  – Micro Aerodynamic Flaps
  – Ink-jet Print Heads
  – Semiconductor Assembly
More Advanced MEMs Concepts

- Inertial Measurement
- RF
- More Advanced MEMs Concepts
- Optics
- Waveguide Switch
- Micropump
- Microfluidics
- Channels with electrodes
Example of Advanced Commercial Applications

Optical Switches
MICROSTAR® MIRROR ARRAY

PROTOTYPE MICROSTAR® OPTICAL CROSSCONNECT (8x8)
Bell Labs’ MicroStar® Technology

Projection Systems

DMD™ with Mirror Removal

Texas Instruments’ Digital Light Processing (DLP™)

Bell Labs’ MicroStar® Technology

Packaged DMD™
MEMS Fabrication Technologies

1. Bulk MEMS
   Wet and/or dry etching of silicon substrate.

2. LIGA
   X-ray lithography and electroplating.

3. Surface MEMS
   Polysilicon deposition and etching of sacrificial films.

4. Modular MEMS/CMOS
   a) CMOS first/MEMS last
   or
   b) MEMS first/CMOS last

TI Digital Micromirror
Bulk Silicon Micromachining

- Directional etching along crystal planes
- Deep Reactive Ion Etching

Etch Mask (Photoresist)

Examples of Bulk Micromachine Structures Formed Using KOH Etches

Example of Deep silicon etch using Bosch etcher
Bulk Micromachining: Inkjet Printers
Chemical Separation Using a Gas Chromatograph Column

-A mixture of analytes is injected into the column
-A carrier gas (air) carries the mixture thru the column
-Analytes are repeatedly absorbed/desorbed by a coating (stationary phase)
-Different coating/analyte affinities cause separation
Single level Surface Micromachining

Poly Groundplane

PSG Deposition and Patterning
- Anchor Cut
- Dimple

Structural Polysilicon Deposition

Release in Hydrofluoric Acid

Analog Devices, ADXL-50
⇒ Early Commercial Surface Micro-Machined Device
⇒ 2-µm BiCMOS Fab Line

Source: Analog Devices
Multi-level Surface Micromachining

SUMMiT™ – Sandia’s Ultra-planar Multi-level MEMS Technology
Modular MEMS-CMOS Process*

Build-up MEMS structure on wafer. Pattern & etch area to leave encapsulated MEMS island.

Grow selective epi around MEMS module and planarize with CMP. Foundry CMOS electronics with contacts to MEMS poly layer.

Pattern and release beams.

Modular MEMS-CMOS Process*

Polysilicon layer making electrical contact to CMOS circuits (not shown).

Etch holes

SEM of a integrated z-axis microgyroscope fabricated device.

How Is CMP Used in MEMS Fabrication?

Planarization of Sacrificial Oxide

Pre CMP

Post CMP

Oxide

Polysilicon

Planarized Surface

Polysilicon

Sandia National Laboratories
CMP eliminates design constraints

Without CMP

Design Interference

Planarized with CMP

Planar linkage arm

Microgear, Linkage, and Hub Assembly
Oxide step height reduction

![Graph showing step height reduction before and after polishing.](image-url)
Silicon Wafer

Polyurethane Pad

SEM Photo - P. Shea, Sandia National Labs
CMP Processing Issues

• Consumables
  – Pad
    • Pad wear – conventional IC pad lifetime is short
    • Conditioning – need aggressive conditioning
    • Asperity interaction with step height – microscale slurry transport problems
  – Slurry
    • Removal rate – conventional oxide slurry RR is low
    • Desire high RR while maintaining good uniformity

• Equipment
  – Wafer handling
    • Carriers must accommodate increased bow/warp
  – Metrology
    • Measurement of thick films

• Pattern density
  – Tolerances for within die uniformity are not as stringent as conventional IC tolerances for certain applications
Polysilicon Micro-Mirror Structure*

* Phillips USAF Research Laboratory
Polysilicon layer CMP

• CMP polysilicon micromirror surface to eliminate print-through effect

Electrostatic Actuation

Comb Drives
1300 µm X 1100 µm
Tortional Ratchet Actuator
Positionable Mirror
Pin-in-maze Operation
Coupling Complete
Surface Micromachined Cell Smasher

By using silicon nitride channels with integrated polysilicon structures, mechanical systems can be integrated with electrical and optical systems, as well as microfluidics.

Application – mechanical cell permeation device.
Summary

MEMS has considerable processing challenges including planarization.

CMP has enabled MEMs multilayered polysilicon structures resulting in complex device functionality and performance.