Micro/Nano Engineering Lab

“MEMS (Micro Electro-Mechanical Systems)”

2.674
Sang-Gook Kim

- Lab sections
- Lab manual (Module #1 and #2)
- Lab safety training certificate, due Feb. 16, 12 PM.
- Reading suggestions
  - Feynman Lecture, ”Plenty of Room at the Bottom”
  - Intro MEMS
  - C. Liu, Foundations of MEMS, Prentice Hall, 2006
Great Engineering Achievements of the Century, NAE

1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. Petroleum and Petrochemical Technologies
18. Laser and Fiber Optics
19. Nuclear Technologies
20. High-performance Materials

http://www.greatachievements.org
No limit in the scale of integration

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Silicon Valley: A Movie

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-pitch ✓
-roll
-yaw

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Inertial Navigation System

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Please see http://volamar.ru/audio_video/foto/03/giroskop/crs4_rng1.jpg.

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$F_c = -2m(\omega \times v)$
History of MEMS

1960
- Gas MEMS
- Draper

1970
- Si Pressure Sensor (Motorola)
- Pressure Sensor (Honeywell)
- Metal Light Valve (RCA)
- JIGT (Nathanson et al)
- Metal Sacrificial Process (US Patent)

1980
- RF MEMS
- Si Gyro (Draper)
- BJT Transistor
- IC
- Pressure Sensor (Motorola)
- Metal Light Valve (RCA)
- JIGT (Nathanson et al)

1990
- MEMS
- Si Gyro (Draper)
- BJT Transistor
- IC
- Pressure Sensor (Motorola)
- Metal Light Valve (RCA)
- JIGT (Nathanson et al)

2000
- MEMS
- Si Gyro (Draper)
- BJT Transistor
- IC
- Pressure Sensor (Motorola)
- Metal Light Valve (RCA)
- JIGT (Nathanson et al)

Comb Drive Designs

Linear

- Grating beams
- Flexures
- Electrostatic comb-drives

Barbastathis and Kim group, MIT
Airbag Accelerometers

- Airbag accelerometer looks like a silicon circuit, but with moving parts.
- In a crash, your car decelerates very quickly
- A spring, damper and mass can measure the deceleration.

**Analog devices**

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ADXL-50
Full range: 0-50g
sensitivity: 200mV/g
resolution: 5 mg at 100 Hz
noise floor: 0.5 mg/(Hz)^{1/2}

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Micro Technology ...

- Path 1: Better and better integrated circuits (CPUs, VLSI, Flash etc.)
- Path 2: Micro-Electro-Mechanical Systems (MEMS)
  - Why only make electronics, when you could make little silicon structures that bend, move, and process electrical signals for various purposes?
  - Or make micrometer scale flow channels for rapid DNA analysis?
  - Either way, you need to create empty spaces beneath some of your device elements
  - Vast possibilities enabled by a vast range of manufacturing technologies
Why shrink things? – scaling law

- Shock and impact
- Scale and form factor
- Load carrying capability
  - Gravity
- Surface/Volume
  - Heat loss/generation
  - Cold blooded

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Frog, Water Strider, Gecko

Mass/surface tension

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· Thermal jet by HP
· Superheat ink 250°C
· Peak pressure 1.4 MPa

Microscopic view under stroboscopic illumination
- Up to 36,000 vapor bubble cycles per second

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Tiny Products

- DLP (Digital Light Processing, TI)

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Typical integrated circuit cross-section

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http://www.aero.org/publications/crosslink/summer2003/03.html

- Simplified integrated circuit cross-section (real ones often have more layers of metal interconnects)
- Very complex, small features stacked on top of each other – but only the kinds of features that are needed for integrated circuits
• The most common wafers are silicon wafers, as shown above
• Other wafers (glass, quartz, etc.) are also available
• Silicon wafers come in sizes from a 2” to 12”
• Plain, unpatterned wafers are then patterned into an array of small, repeated structures called dies
**Technique 1: Add material everywhere**

Top view: Add material everywhere

Side view (cross-section): Thin film deposition

**Technique 2: Remove material everywhere**

Top view: Remove material everywhere

Side view (cross-section): Etching (can etch thin film or substrate wafer)
Technique 3: Define a “stencil” pattern

Top view

Side view (cross-section)

Photolithography (more details to follow)

Technique 4: Remove only exposed material

Top view

Side view (cross-section)

Patterned etching
Technique 5: Add material in exposed areas

Top view

Side view (cross-section)

Thin film lift-off

Masks

“Real” masks: patterned chrome on quartz or glass (expensive but high resolution)

Transparency masks: patterns printed from a high resolution printer onto transparency film (cheap, fast, lower resolution)

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Lithography (Greek, “stone-writing”)  

- Pattern Transfer
  - Application of photosensitive PR
  - Optical exposure to transfer image from mask to PR
  - Remove PR \rightarrow binary pattern transfer

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Photolithography with Positive Resist

- Spin a photosensitive resist layer onto the wafer surface
- Photoresist is a few micrometers thick
- Expose resist with UV light through a photolithographic mask; wherever the light hits it, the resist molecules get chopped up
- Developer removes exposed resist
- Forms a stencil that determines which parts of the surface are affected by the next process
Photolithography with Negative Resist

- Spin a photosensitive resist layer onto the surface
- Thickness of order 1 micron
- Expose resist with UV light through a mask
- This time, light links the molecules together to make them tougher
- Developer removes unexposed resist

Lab module 1-a: Millifluidics
Mixing in flowing systems - Péclet number

- Péclet number: Compares transport due to advection to transport due to diffusion

\[ t_{\text{adv}} \sim \frac{L}{U} \]

\[ t_{\text{diff}} \sim \frac{W^2}{D} \]

\[ \text{ timescale for diffusion across channel width } \]
\[ \frac{W^2}{D} = \frac{LU}{D} \left( \frac{W}{L} \right)^2 = \text{Pe} \left( \frac{W}{L} \right)^2 \]

\[ L \]

\[ W \]
- $W = k \lambda/NA$ (Rayleigh Eqn.)
- In 1975, 405 nm (Hg line) at an NA of 0.32, a line width of 10 µm, mercury lamps
- deep-UV (248 nm) KrF Excimer laser, 193 nm ArF laser, 157 nm

### Table 1: Wavelength “Generations”

<table>
<thead>
<tr>
<th>Year</th>
<th>Node</th>
<th>Lithography</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>2000nm</td>
<td>i/g-line Steppers</td>
</tr>
<tr>
<td>1984</td>
<td>1500nm</td>
<td>i/g-line Steppers</td>
</tr>
<tr>
<td>1987</td>
<td>1000nm</td>
<td>i/g-line Steppers</td>
</tr>
<tr>
<td>1990</td>
<td>800nm</td>
<td>i/g-line Steppers</td>
</tr>
<tr>
<td>1993</td>
<td>500nm</td>
<td>i/g-line Steppers</td>
</tr>
<tr>
<td>1995</td>
<td>350nm</td>
<td>i-line -&gt; DUV</td>
</tr>
<tr>
<td>1997</td>
<td>250nm</td>
<td>DUV</td>
</tr>
<tr>
<td>1999</td>
<td>180nm</td>
<td>DUV</td>
</tr>
<tr>
<td>2001</td>
<td>130nm</td>
<td>DUV</td>
</tr>
<tr>
<td>2003</td>
<td>90nm</td>
<td>193nm</td>
</tr>
<tr>
<td>2005</td>
<td>45nm</td>
<td>193nm -&gt; 157nm</td>
</tr>
<tr>
<td>2007</td>
<td>32nm</td>
<td>EUV, X-ray</td>
</tr>
<tr>
<td>2009</td>
<td>30nm and below</td>
<td>EUV, X-ray</td>
</tr>
</tbody>
</table>

- Nanoimprinting
  - Soft Lithography
  - Dip Pen Lithography
  - SIM-based patterning

193 nm immersion lithography

- Area 7 in DME
- Fluidics, heat transfer and energy conversion at the micro- and nanoscale
- Bio-micro-electromechanical systems (bio-MEMS)
- Optical-micro-electromechanical systems (optical-MEMS)
- Engineered nanomaterials
- Energy and Nano-Manufacturing
- Course 2A (Nano Track)
- Micro/Nano Area in ME

[http://web.mit.edu/nanomicro](http://web.mit.edu/nanomicro)