Lecture 8: Surface Micromachining II

Announcements:
- HW#2 online and due next Friday at 8 a.m.
- I have been traveling since Wednesday; back next Tuesday
- This is Thursday lecture and is a prepared video

Today:
- Reading: Senturia Chpt. 3, Jaeger Chpt. 11, Handout: “Surface Micromachining for Microelectromechanical Systems”
- Lecture Topics:
  - Polysilicon surface micromachining
  - Stiction
  - Residual stress
  - Topography issues
  - Nickel metal surface micromachining
  - 3D “pop-up” MEMS
  - Foundry MEMS: the “MUMPS” process
  - The Sandia SUMMIT process
- Last Time:
  - Going through Module 5 on Surface Micromachining

- Straight or Sloped Sidewalls:
  - Often want sloped sidewalls in order to reduce the sharpness of corners
    - Easier to deposit over
    - Sharp corners concentrate stresses
    - High stress can weaken structures creating a reliability concern
    - High stress can dissipate energy, lowering Q
  - When you want straight sidewalls (e.g., for lateral electrostatic drive), use a hard mask
    - PR can’t last for thick structures
    - A hard mask suppresses angle transfer

Etching to Select Sidewall Type

[Diagram showing etching process]
Surface Micromachining II

What can we do to get straight sidewalls?

$S_{ox}^{PR} = \text{small}$

$S_{ox}^{poly} = \text{large}$

$SiO_2 \leftarrow \text{hard mask}$

$molecule @ \text{liquid surface} = \text{experienced a net inward force}$

$Liquid Surface$

$\text{molecule under the liquid surface}$

$\text{attractive forces from neighbors pulled in all directions}$

$Equilibrium (nothing is moving)$

$\text{forces balanced out by liquid's net force is zero}$

$\text{Result: liquid squeezes to achieve the smallest surface area (smallest energy state)}$

$Surface Curvature \rightarrow \text{Pressure}$

$\text{No pressure difference}$

$\text{surface remains flat}$

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Introduction to MEMS Design

Lecture 8w: Surface Micromachining II

Contact angle is governed by a balance of surface tensions, usually property dependent on the interface between different materials.

Example: Hydrophilic Droplet

- \( f_{la} \) - liquid-air surface tension force
- \( f_{sa} \) - liquid-solid interface tension force
- \( f_{ad} \) - adhesion force

Young-Laplace Equation

\[ \Delta \rho = \gamma \left( \frac{1}{R_x} + \frac{1}{R_y} \right) \]

where \( \Delta \rho \) = pressure difference
\( \gamma \) = surface tension (force/length)
\( R_x, R_y \) = radii of curvature

Equilibrium:
1. Horizontal forces cancel \( \nabla \rho \) at contact point.
2. Vertical forces cancel.

\[ f_A = f_{la} \sin \theta_c \]
\[ f_{sa} = f_{ls} + f_{la} \cos \theta_c \]

End Point Relationship

Surface tensions captured by contact angle.
Example. Two Plates (cross-section)

Laplace Equation

\[
\Delta p_{la} = \frac{\sigma_{la}}{r} \quad \text{surface tension at the liquid-air interface}
\]

\[
F = \Delta p_{la} A = \frac{2\pi \sigma_{la} \cos \theta_c}{g}
\]

- Force needed to keep the plates apart
  - \( F \) force, \( \Delta p_{la} \) Laplace pressure

Problem at Hand (cross-section)

\[
F = kx \quad \text{(cross-section)}
\]

- Stiffness \( k \)

Remark:
1. To prevent sticking:
   - reduce \( A \) (wetted area)
   - reduce \( \sigma_{la} \) choose to right liquids (t suitable)
   - make \( g \) large
   - increase \( k \) make thing thicker

- \( \theta_c > 90^\circ \)

- Water

[Diagram of liquid and plates with arrows and annotations]
### Some liquid-solid contact angles

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Solid</th>
<th>Contact angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>soda-lime glass</td>
<td>0°</td>
</tr>
<tr>
<td>ethanol</td>
<td>lead glass</td>
<td></td>
</tr>
<tr>
<td>diethyl ether</td>
<td>fused quartz</td>
<td></td>
</tr>
<tr>
<td>carbon tetrachloride</td>
<td></td>
<td></td>
</tr>
<tr>
<td>glycerol</td>
<td>paraffin wax</td>
<td>107°</td>
</tr>
<tr>
<td>acetic acid</td>
<td>silver</td>
<td>90°</td>
</tr>
<tr>
<td>methyl iodide</td>
<td>soda-lime glass</td>
<td>29°</td>
</tr>
<tr>
<td>mercury</td>
<td>fused quartz</td>
<td>33°</td>
</tr>
</tbody>
</table>

[5]
Best Alignment Strategy

- Polyo align
- Anchol align
- Poly align
- 2x the possible alignment error!

How can you tell the misalignment?

- 200um offset
- 100um aligned -> 100um offset
- 0um
- 100um
- 200um