Lecture 9: Surface Micromachining II

**Announcements:**
- HW#2 due Thursday, 2/15 at 10 a.m.
- Handout online: paper titled “Surface Micromachining for Microelectromechanical Systems”
- Handout online: paper titled “Etch Rates for Micromachining—Part II”
- Kieran out of town; Alper Ozgurluk taking TA duties for this week and next

**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:**
- Looking at stiction in depth
- Now, continue with this

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**Surface Tension**

- A molecule at the liquid surface experiences a net inward force due to surface tension.
- Molecules under the liquid surface attract neighbors from all directions, pulling them in.
- Equilibrium (nothing moves) forces are balanced by the liquid's resistance to compression.
- Result: a liquid squeezer to achieve the smallest surface area (smallest energy state).

**Surface Curvature & Pressure**

- No pressure difference.
- Surface remains flat.
Upon introduction of a differential pressure, the surface curves to generate a net normal force that maintains equilibrium against the pressure.

**Young-Laplace Equation**

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

where \( \Delta p \) = pressure difference

\( \gamma \) = surface tension (force/length)

\( R_x, R_y \) = radii of curvature

\( \Rightarrow \) governs surface curvature

**Contact Angle**

- governed by a balance of surface tensions
- dependent upon the interfaces between different materials

**Example: Hydrophilic Droplet**

- liquid-air surface tension force
- liquid-solid interface tension force
- solid-air surface tension force

**Equilibrium:**

1. horizontal forces cancel
2. vertical forces cancel

\[ f_A = f_{sa} \sin \theta_c \]

\[ f_{sa} = f_{sa} + f_{sa} \cos \theta_c \]

\[ f_{sa} = \frac{\gamma}{\cos \theta_c} \]

Relationship between surface tension is captured by contact angle \( \theta_c \).
Example: Two Plates (cross-section)

Laplace Equation

\[ \Delta P_{\text{la}} = \frac{\partial^2 \phi}{\partial x^2} \]

Surface tension @ liquid-air interface

\[ \Delta P_{\text{la}} = \frac{\gamma_{\text{la}}}{r} \quad \text{radius of curvature of the liquid surface (concave)} \]

Pressure difference @ liquid-air interface

\[ r = \frac{-(g/2)}{\cos \Theta_c} \]

\[ F = -\Delta P_{\text{la}} A = \frac{2\gamma_{\text{la}} \cos \Theta_c}{q} \]

Force needed to keep the plates apart:

\[ + \text{force means } - \text{laplace pressure} \]

Typical MEMS Situation, e.g., accelerometer

- Tether spring
- Top view
- Anchor

Reminders:

1. Reduce A (area)
2. Reduce \( \gamma_{\text{la}} \) (choose the right liquids)
3. Make the gap g large
4. Increase k (stiffness of the support)
5. \( \Theta_c > 90^\circ \)
### Some liquid-solid contact angles[^5]

<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>
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<td></td>
</tr>
<tr>
<td>acetic acid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>water</td>
<td>paraffin wax</td>
<td>107°</td>
</tr>
<tr>
<td></td>
<td>silver</td>
<td>90°</td>
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<tr>
<td>methyl iodide</td>
<td>soda-lime glass</td>
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<tr>
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</tr>
<tr>
<td>mercury</td>
<td>soda-lime glass</td>
<td>140°</td>
</tr>
</tbody>
</table>

[^5]: [Seth Cumpston](http://www.sethcumpston.com)