Lecture 8: Surface Micromachining II

Announcements:
- HW#2 due Thursday, 2/21 at 9 a.m.

Today:
- Reading: Senturia Chpt. 3, Jaeger Chpt. 11, Handouts: “Surface Micromachining for Microelectromechanical Systems”, “Etch Rates for Micromachining—Part II”
- 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 the details of a surface-micromachining process
- Now, continue with this

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
**Surface Micromachining II**

- **Reality:** PR will be stopped
  - Anisotropic Etch (stylolith)
  - sidewall

- **Remarks:**
  1. If want sloped sidewalls → over-expose PR
  2. If want straight sidewalls:
    - Hard mask allows thinner PR → better lithographic resolution
    - Allow thinner SiO₂

- **Substrate:**
  - Substrate: straight polysi sidewall
  - Substrate: S<sub>SiO₂</sub> = high

**Microstructure Sizing**

- **Surface Tension**
  - molecule @ liquid surface
  - = experience a net inward force

- **Liquid Surface**
  - Molecule under the liquid surface
  - pulled in all directions equally
  - not force = zero

- **Equilibrium (nothing moves) → forces balanced**
  - by the liquid's resistance to compression!

- **Result:** Liquid squeezed to achieve the smallest surface area → smallest energy state.
Surface Curvature + Pressure

\[ \text{No Pressure Difference} \]
\[ \text{Surface remains flat} \]

\[ \Rightarrow \text{Upon introduction of a differential pressure, surface curves to generate a net normal force to maintain equilibrium against the pressure} \]

Young-Laplace Equation \( \Rightarrow \) governs the shape of the liquid

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

where \( \Delta p \) = pressure difference

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

\( R_x, R_y \) = radii of curvature

Contact Angle

\( \Rightarrow \) governed by a balance of surface tensions

\( \Rightarrow \) dependent on the interface between different materials

Example: Hypothetical Droplet on Hydrophilic Surface

- \( f_{ls} \) \( \leftarrow \) liquid-air surface tension force
- \( f_{sa} \) \( \leftarrow \) solid-air surface tension force
- \( f_{ls} \) \( \leftarrow \) liquid-solid interface force
- \( f_a \) \( \leftarrow \) adhesion force

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Equilibrium: 1. horizontal forces cancel? 
   2. vertical forces cancel

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

\[ \sigma_{sa} = \sigma_{ls} + \sigma_{la} \cos \theta_c \]

relationship between surface tensions captured by contact angle

If hydrophilic surface - water lowers it↓

\[ \text{droplet} \]

\[ \text{hydrophilic surface} \]

\[ \text{droplet collapses to hug surface} \]

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Example. Two Plates (cross-section)

Laplace Equation

\[ \Delta P_{la} = \frac{\gamma}{r} \]

\[ r = \frac{g/2}{\cos \theta_c} \]

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

\[ (+) \text{force needed to keep plates apart.} \]

\[ (+) \text{force means (+) Laplace pressure} \]
Liquid | Solid | Contact angle
--- | --- | ---
water | soda-lime glass | 0°
ethanol | lead glass | 0°
diethyl ether | fused quartz | 0°
carbon tetrachloride | | 0°
glycerol | | 0°
acetic acid | | 0°
water | paraffin wax | 107°
silver | | 90°
methyl iodide | soda-lime glass | 29°
lead glass | 30°
fused quartz | 33°
mercury | soda-lime glass | 140°

Some liquid-solid contact angles\(^5\)

Remarks:
1. To prevent stiction
   - reduce \(A\) (wetted area)
   - reduce \(\gamma_{1a}\) → choose the right liquid & solids
   - make \(g\) large
   - increase \(k\) → make thing thicker & stiffer
   - \(\theta_c > 90^\circ\)