Lecture 10: Surface Micromachining I

- Announcements:
- This is our make-up lecture for Thursday
  - For those who couldn't make it, the video will be online as usual
- HW#3 online
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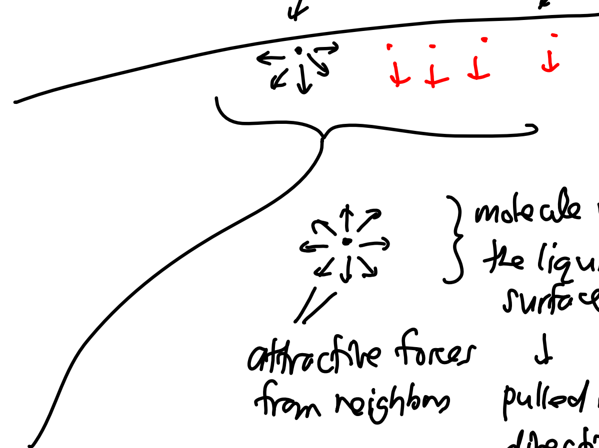
- Today:
- Reading: Senturia Chpt. 3, Jaeger Chpt. 11, Handout: "Surface Micromachining for Microelectromechanical Systems"
- Lecture Topics:
  - Polysilicon surface micromachining
  - Stiction
  - Residual stress
  - Topography issues
  - Nickel metal surface micromachining
  - 3D "pop-up" MEMS
  - Foundry MEMS: the "MUMPS" process
  - The Sandia SUMMIT process
- ---------------------------------------
- Last Time:
- Going through Start Module 5 on "Surface Micromachining"

Microstructure Stiction

Surface Tension

molecule @ liquid surface
⇒ experiences a net inward force

liquid surface

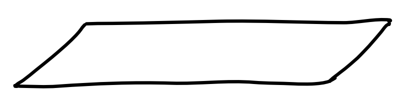


molecule under the liquid surface
↓
pulled in all directions
↓
net force is zero!

attractive forces from neighbors

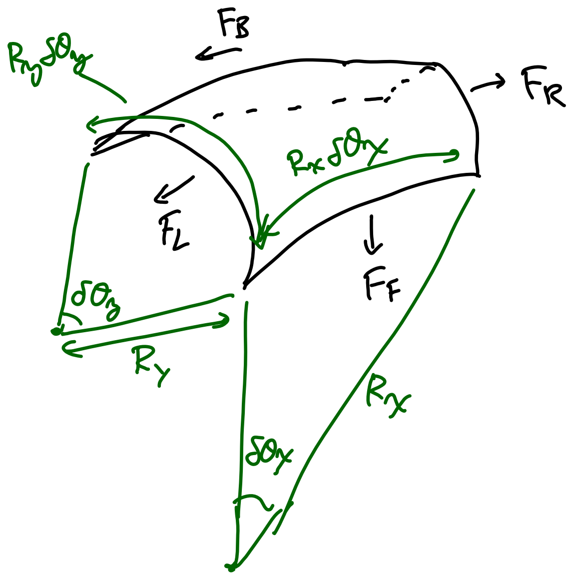
Equilibrium (nothing is moving)
↓
forces balanced out by liquid's resistance to compression
⇒ Result: liquid squeezes to achieve the smallest surface area (smallest energy state)

Surface Curvature & Pressure



No pressure difference
↓
surface remains flat

⇒ introduce a differential pressure:
↳ surface curves to generate a net normal force to maintain equilibrium against the pressure



Young-Laplace Equation

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

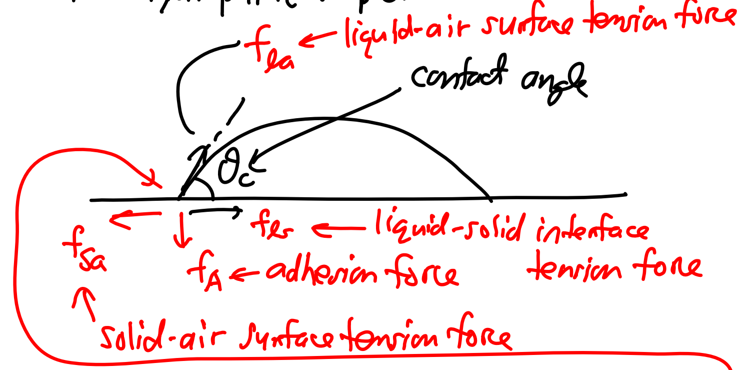
where $\Delta p \triangleq$ pressure difference

$\gamma \triangleq$ surface tension (force/length)

R_x & $R_y \triangleq$ radii of curvature

Contact Angle → governed by a balance of surface tensions
↳ usually property dependent on the interface between different materials

Example: Hydrophilic Droplet



Equilibrium: ① horizontal forces cancel ② vertical forces cancel } @ the contact pt.

$f_A = f_{la}\sin\theta_c$

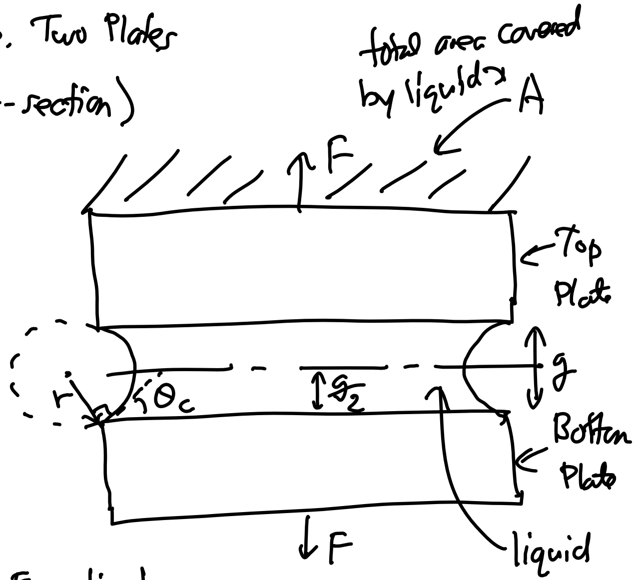
$f_{sa} = f_{ls} + f_{la}\cos\theta_c$ → $\gamma_{sa} = \gamma_{ls} + \gamma_{la}\cos\theta_c$

[for all γ]

↑ Relationship between surface tensions captured by contact angle.

Example. Two Plates

(cross-section)



Laplace Equation

$$\Delta p_{la} = \frac{\gamma_{la}}{r}$$

γ_{la} ← surface tension @ the liquid-air interface

r ← radius of curvature of the liquid [(−) if convex]

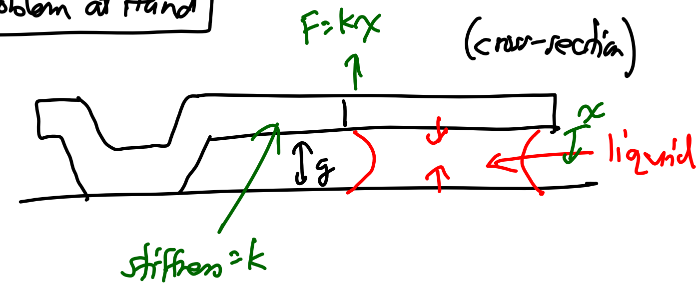
$$\left[r = \frac{-(g/2)}{\cos\theta_c} \right] \Rightarrow \boxed{F = -\Delta p_{la} A = \frac{2A\gamma_{la}\cos\theta_c}{g}}$$

Force needed to keep the plates apart

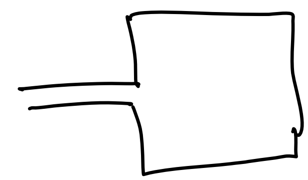
⇒ (+) force means (−) laplace pressure

Problem at Hand

(cross-section)



(top-view)



Remarks

1. To prevent stiction:
   - ⇒ reduce A (wetted area)
   - ⇒ reduce γ_{la} → choose the right liquids (& solids)
   - ⇒ make g large
   - ⇒ increase k → make things thicker
   - ⇒ $\theta_c > 90°$