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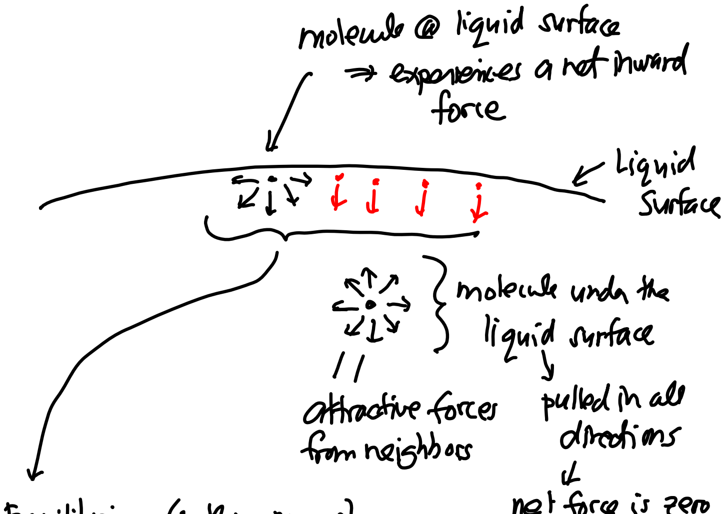
- Last Time:
- Looking at stiction in depth
- Now, continue with this

Microstructure Stiction

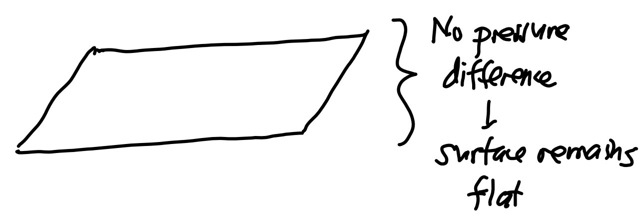
Surface Tension



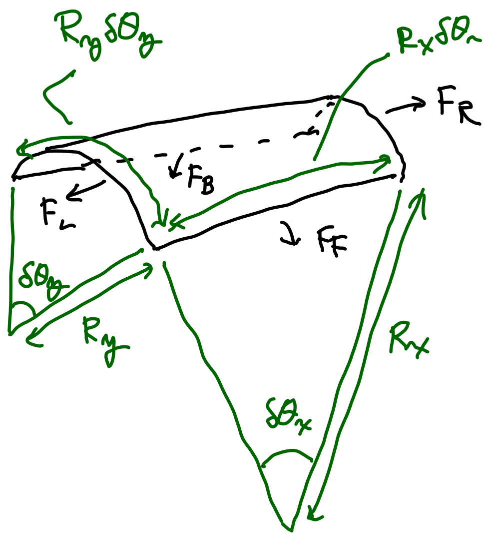
Equilibrium (nothing moves)
↳ forces balanced out by liquid's resistance to compression

→ Result: liquid squeezes to achieve the smallest surface area (smallest energy state)

Surface Curvature & Pressure



⇒ upon introduction of a differential pressure:
↳ surface curves to generate a net normal force that maintains equilibrium against the pressure



Young-Laplace Equation

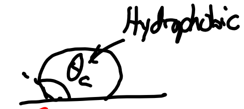
$$\Delta p = \gamma\left(\frac{1}{R_x} + \frac{1}{R_y}\right)$$

where $\Delta p \triangleq$ pressure difference
$\gamma \triangleq$ surface tension (force/length)
R_x & $R_y \triangleq$ radii of curvature

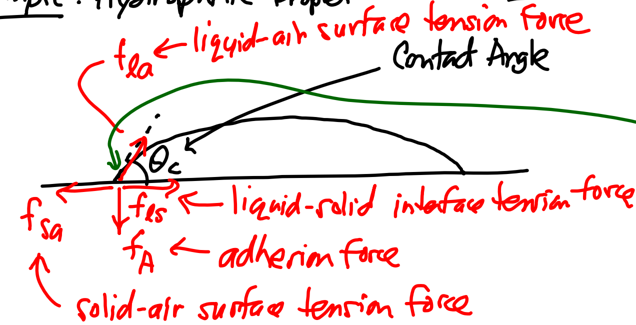
⇒ Governs surface curvature

Contact Angle

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



Example: Hydrophilic Droplet



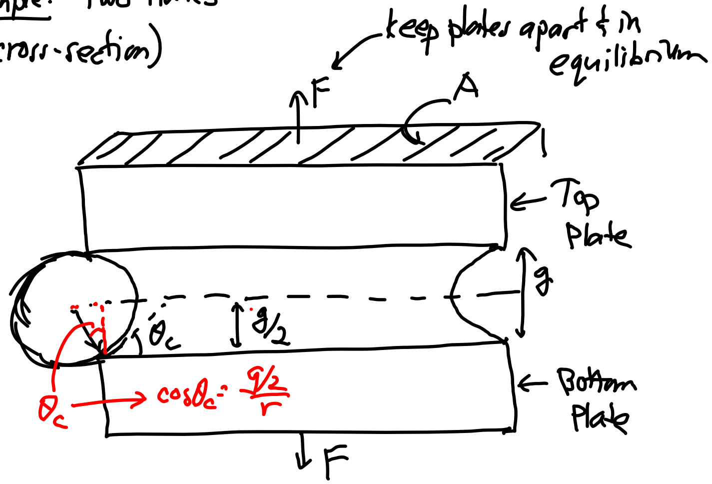
Equilibrium: ① horizontal forces cancel } @ the contact pt.
② vertical forces cancel

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

$f_{sa} = f_{ls} + f_{la}\cos\theta_c$ → [for γ] $\boxed{\gamma_{sa} = \gamma_{ls} + \gamma_{la}\cos\theta_c}$

↑ Relationship between surface tension is captured by contact angle θ_c.

Example. Two Plates
(cross-section)



Laplace Equation

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

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

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

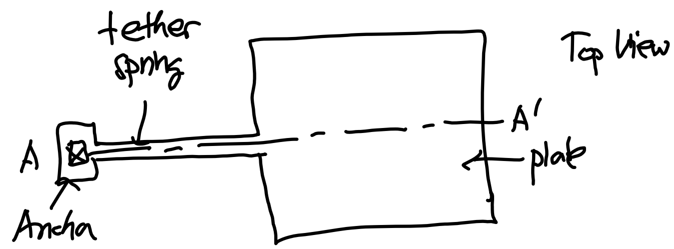
ΔP_{la}: Pressure Difference @ Liquid-Air Interface

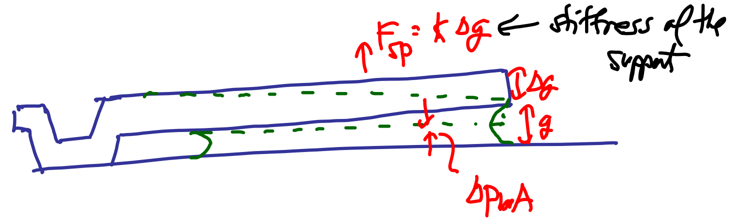
$$\left[r = \frac{-(g/2)}{\cos\theta_c} \right] \Rightarrow \boxed{F = -\Delta P_{la} A = \frac{2A\gamma_{la}\cos\theta_c}{g}}$$

Force needed to keep the plates apart.

→ (+) force means (-) laplace pressure

Typical MEMS Situation | e.g., accelerometer





Remarks. To prevent stiction:

1. Reduce A (area)
2. Reduce γ_{la} ← choose the right liquids
3. Make the gap g large
4. Increase k (stiffness of support(s))
   ↳ make the structure thicker
5. $\theta_c > 90°$

Liquid	Solid	Contact angle
water	soda-lime glass	0°
ethanol	lead glass	
diethyl ether	fused quartz	
carbon tetrachloride		
glycerol		
acetic acid		
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]

Which Layer to Align To?