Lecture 10: Surface Micromachining II

- **Announcements:**
- HW#2: Due today
  - Problem 5 moved to HW#3, so don't turn it in with HW#2
- HW#3: Online soon, due Thursday next week
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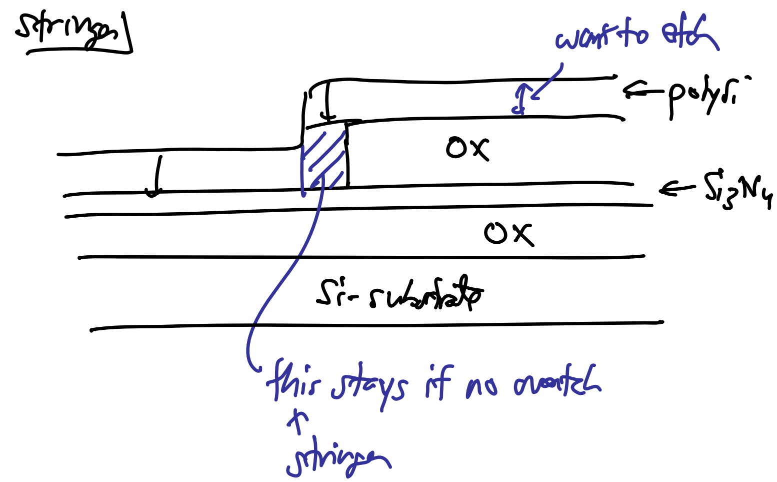
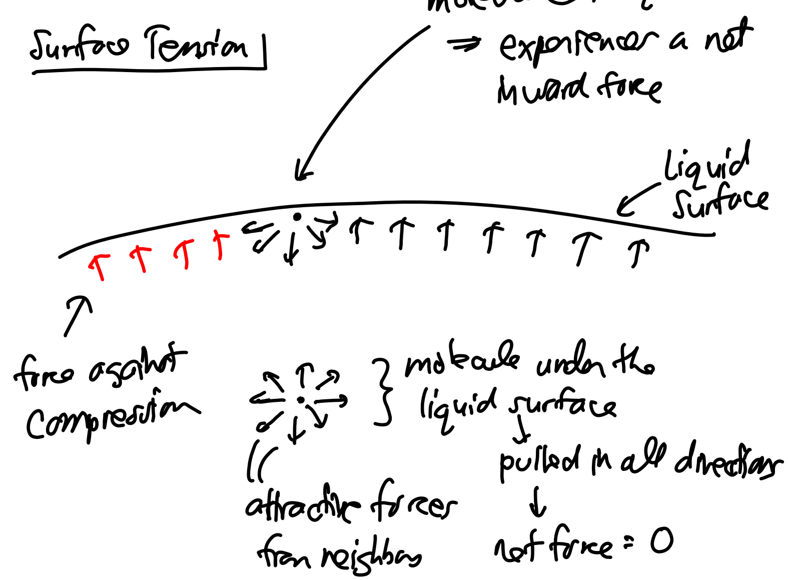
- **Today:**
- Reading: Senturia Chpt. 3, Jaeger Chpt. 11, Handout: "Surface Micromachining for Microelectromechanical Systems"
  - Lecture Topics:
  - Polysilicon surface micromachining
  - Stiction
  - Residual stress
  - Topography issues
  - Nickel metal surface micromachining
  - 3D "pop-up" MEMS
  - Foundry MEMS: the "MUMPS" process
  - The Sandia SUMMIT process
- ------------------------------------
- **Last Time:**
- Going through Module 5 on Surface Micromachining
- Got up to "Issues", which we continue with, now



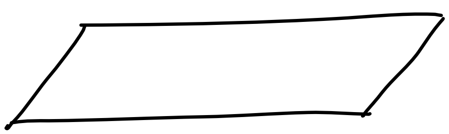
Microstructure Stiction



Equilibrium (nothing is moving)
↳ forces balanced out
↳ by the liquid's resistance to compression

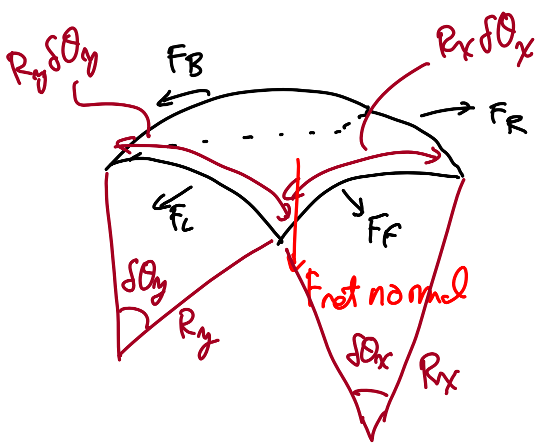
⇒ Result: Liquid squeezes to achieve minimum surface area → minimal energy state

Surface Curvature & Pressure



No Pressure Difference
↓
Surface remains flat

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



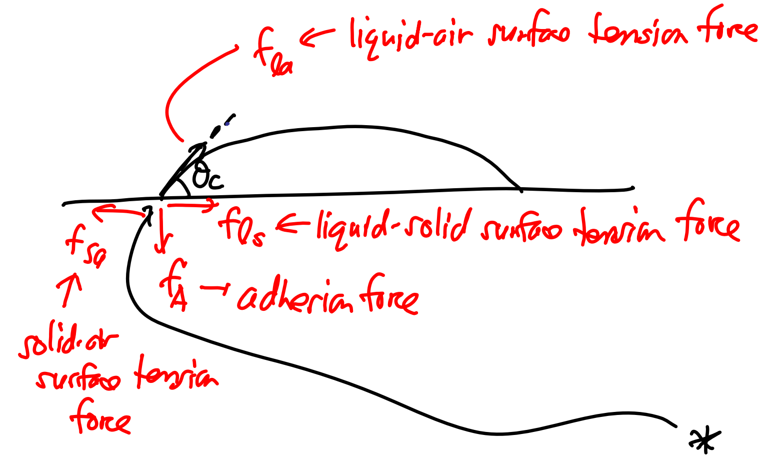
Young-Laplace Equation (governs the shape of the liquid)

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

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

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

Example. Hydrophillic Droplet



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

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

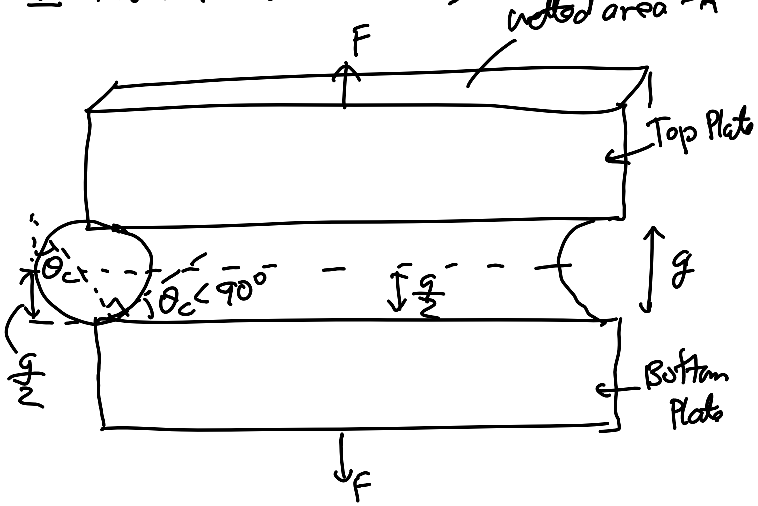
$f_{sa} = f_{ls} + f_{la}\cos\theta_c$ → $\boxed{\gamma_{sa} = \gamma_{ls} + \gamma_{la}\cos\theta_c}$

↑ fcn of γ

↑ Relationship between surface tension largely captured by θ_c

Adhesion Force

Ex. Two Plates (cross-section)



Laplace Eqn:

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

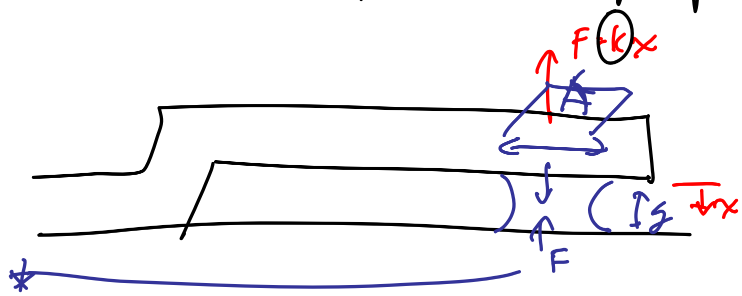
γ_{la} ← surface tension @ the liquid-air interface

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

Δp_{la} ↑ Pressure Difference @ the 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.



Remarks.

To prevent stiction:

1. surface area (wetted), A↓
2. γ_{la}↓ → liquid choice
3. g↑ → make sacrificial layer thicker

(4) make k↑ (stiffness of the structure)

(5) $\theta_c > 90°$ → remove the adhesion force!

↑ controlled by choice of structural material

&

or by the right coating

Some Contact Angles

Liquid	Solid	Contact angle
water	soda-lime glass lead glass fused quartz	0°
ethanol		
diethyl ether		
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]