Lecture 8: Surface Micromachining II

- **Announcements**:
- HW#2 due Thursday, 2/21 at 9 a.m.
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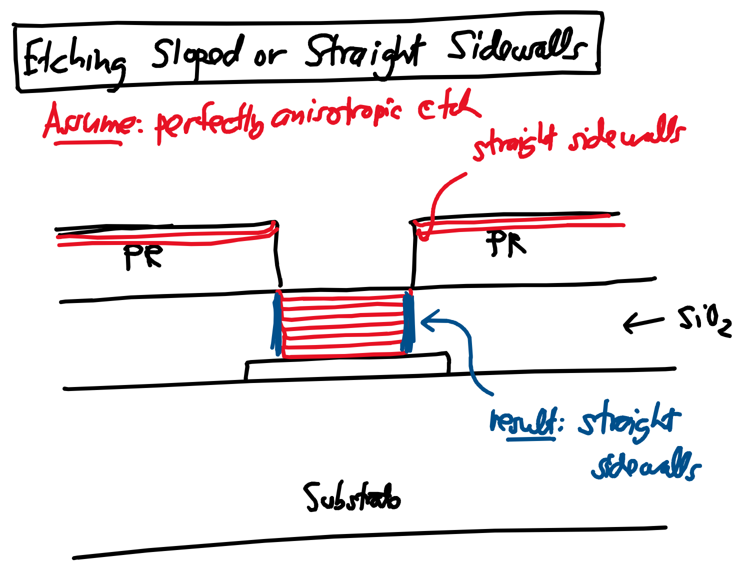
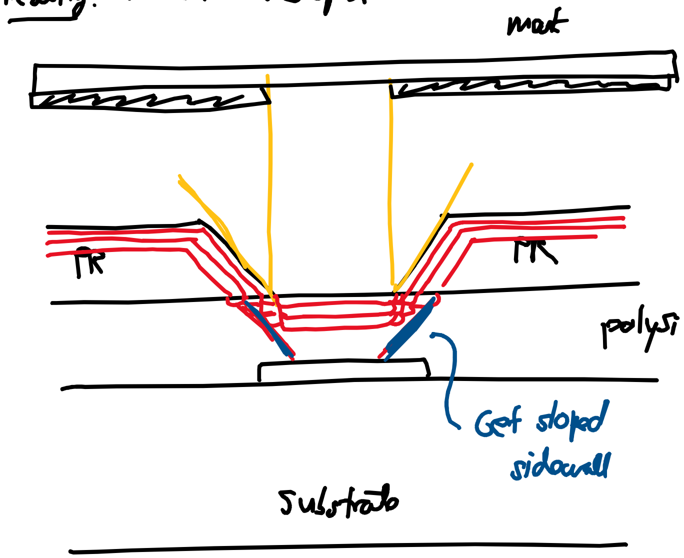
- **Today**:
- Reading: Senturia Chpt. 3, Jaeger Chpt. 11, Handouts: "Surface Micromachining for Microelectromechanical Systems", "Etch Rates for Micromachining—Part II"
- Lecture Topics:
  - Polysilicon surface micromachining
  - Stiction
  - Residual stress
  - Topography issues
  - Nickel metal surface 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 reliabilty 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



Reality: PR will be sloped

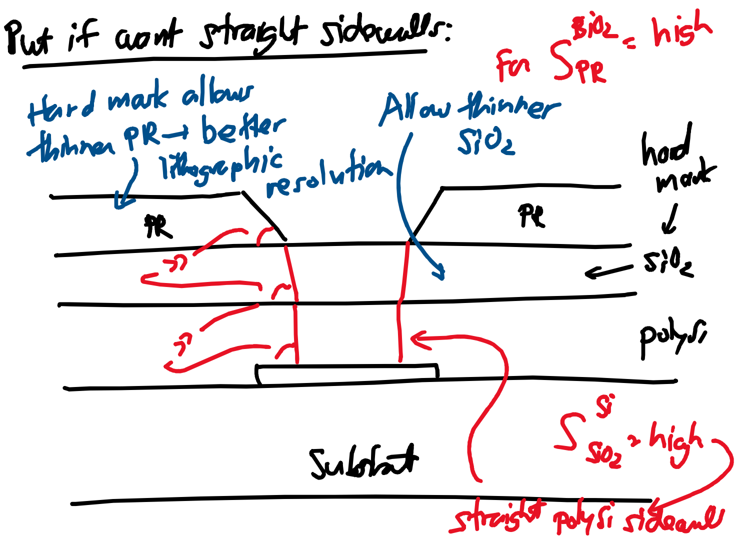
Anisotropic Etch (still)



Remarks:

① If want sloped sidewalls → over-expose the PR

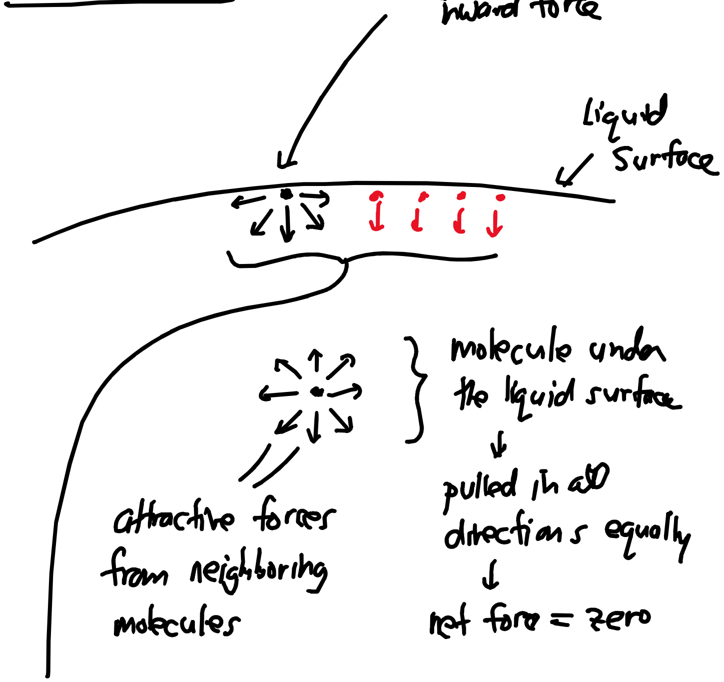
But if want straight sidewalls:



Microstructure Stiction

Surface Tension

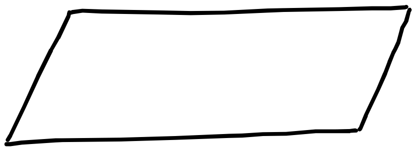
molecule @ liquid surface ⇒ experiences a net inward force



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

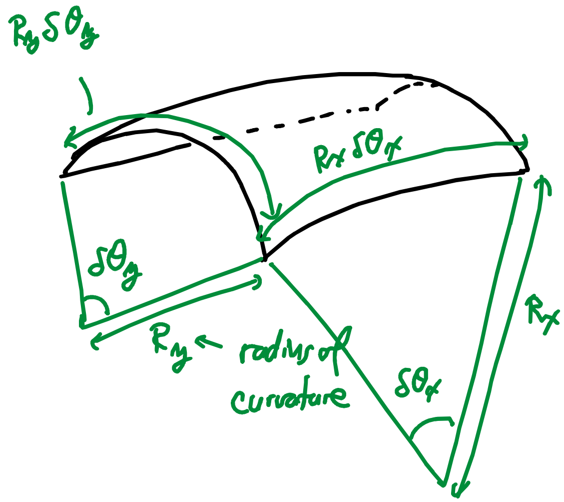
⇒ Result: liquid squeezes to achieve the smallest surface area → smallest energy state

Surface Curvature & Pressure



No Pressure Difference → surface remains flat

⇒ upon introduction of a differential pressure
↳ surface curves to generate a net normal force to maintain 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 $\Delta p \stackrel{\Delta}{=}$ pressure difference

$\gamma \stackrel{\Delta}{=}$ surface tension (force/length)

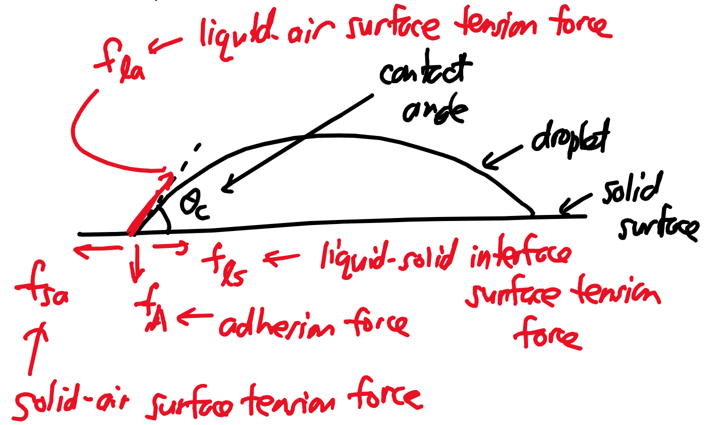
R_x & R_y $\stackrel{\Delta}{=}$ radii of curvature

Contact Angle

→ governed by a balance of surface tensions

⇒ dependent on the interface between different materials

Example. ~~Hydrophilic~~ Droplet on Hydrophillic Surface



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

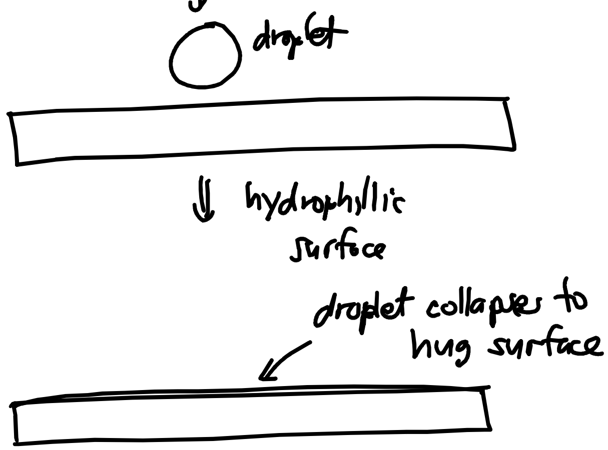
$f_A = f_{la} \sin\theta_c$

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

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

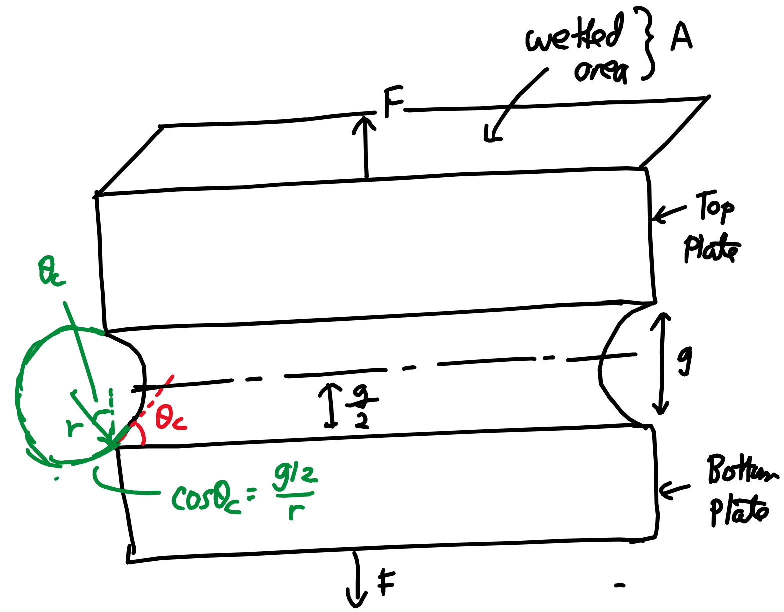
↑ relationship between surface tensions captured by contact angle

If hydrophillic surface → water loves it



Example. Two Plates

(cross-section)



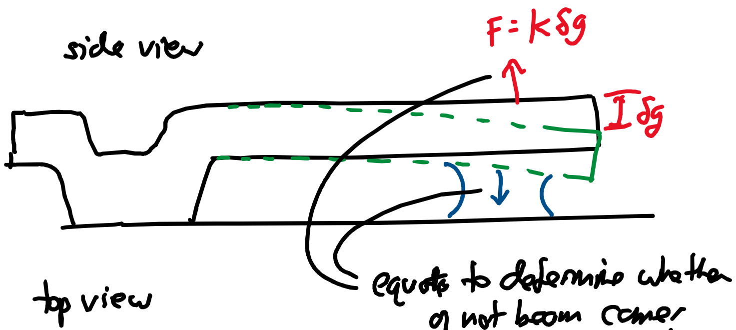
Laplace Equation

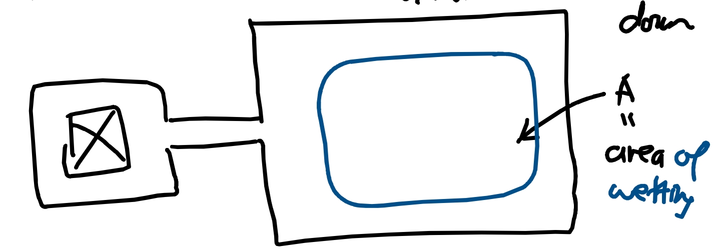
$$\Delta p_{la} = \frac{\gamma_{la}}{r}$$

- γ_{la} ← surface tension @ liquid-air interface
- r ← radius of curvature of the liquid [(-) 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 plates apart.
(+) force means (-) Laplace pressure





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
↑ stiffeners

⇒ $\theta_c > 90°$

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]