Lecture 8: Surface Micromachining II

- Announcements:
- I am on travel today (Thursday); this is a prepared video lecture
- HW#1 due Tuesday, 2/14 at 10 a.m.
- Handout online: paper titled "Surface Micromachining for Microelectromechanical Systems"
- Handout online: paper titled "Etch Rates for Micromachining—Part II"
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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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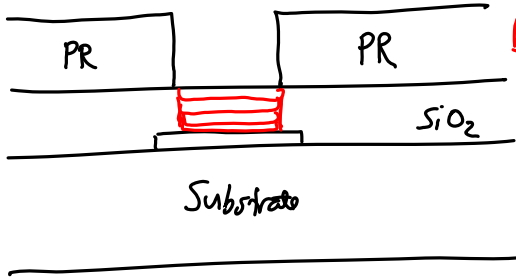
- Last Time:
- Going through Module 5 on Surface Micromachining

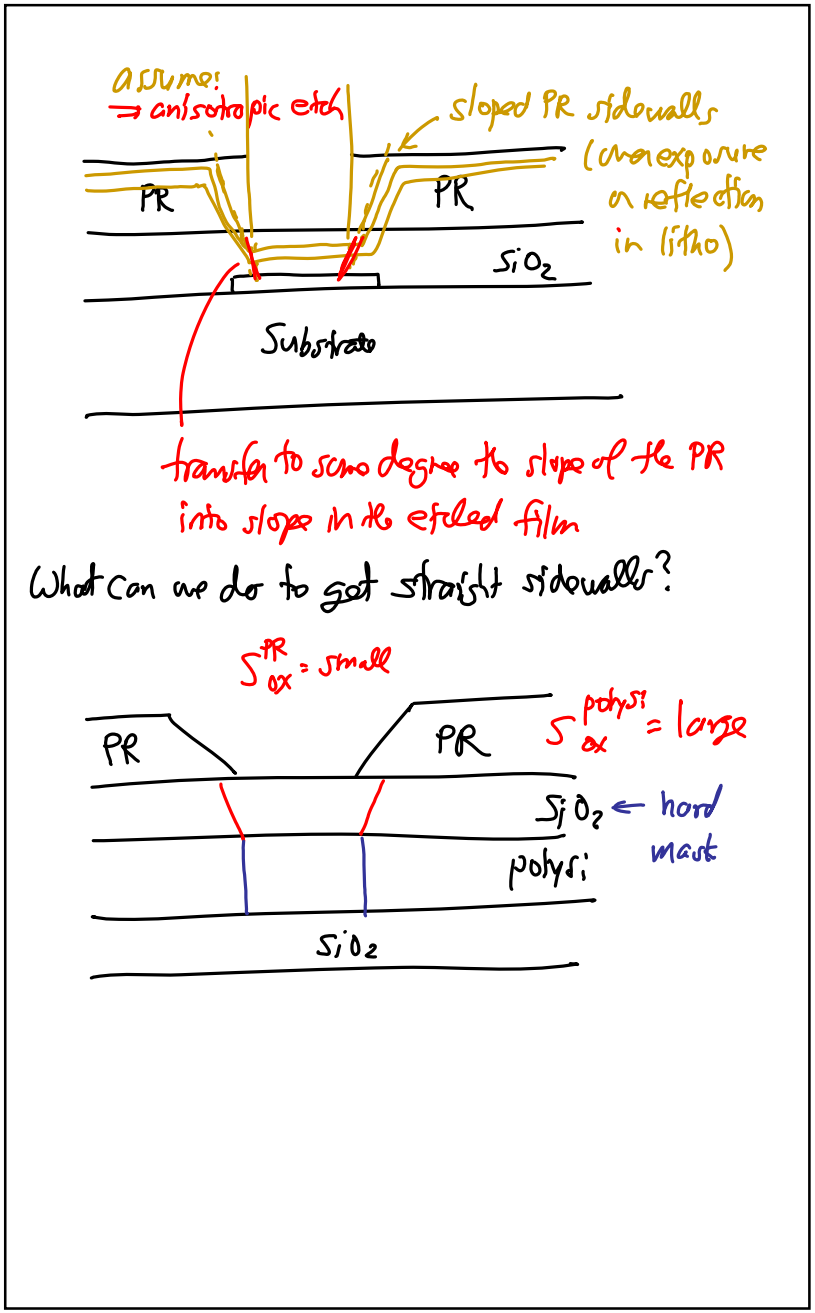
- Straight or Sloped Sidewalls:
- Often want sloped sidewalls in order to reduce the sharpness of corners
  - Easier to deposit over
  - Sharp corners concentrate stresses
  - High stress can weaken structures creating a reliabilty concern
  - High stress can dissipate energy, lowering Q
- When you want 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

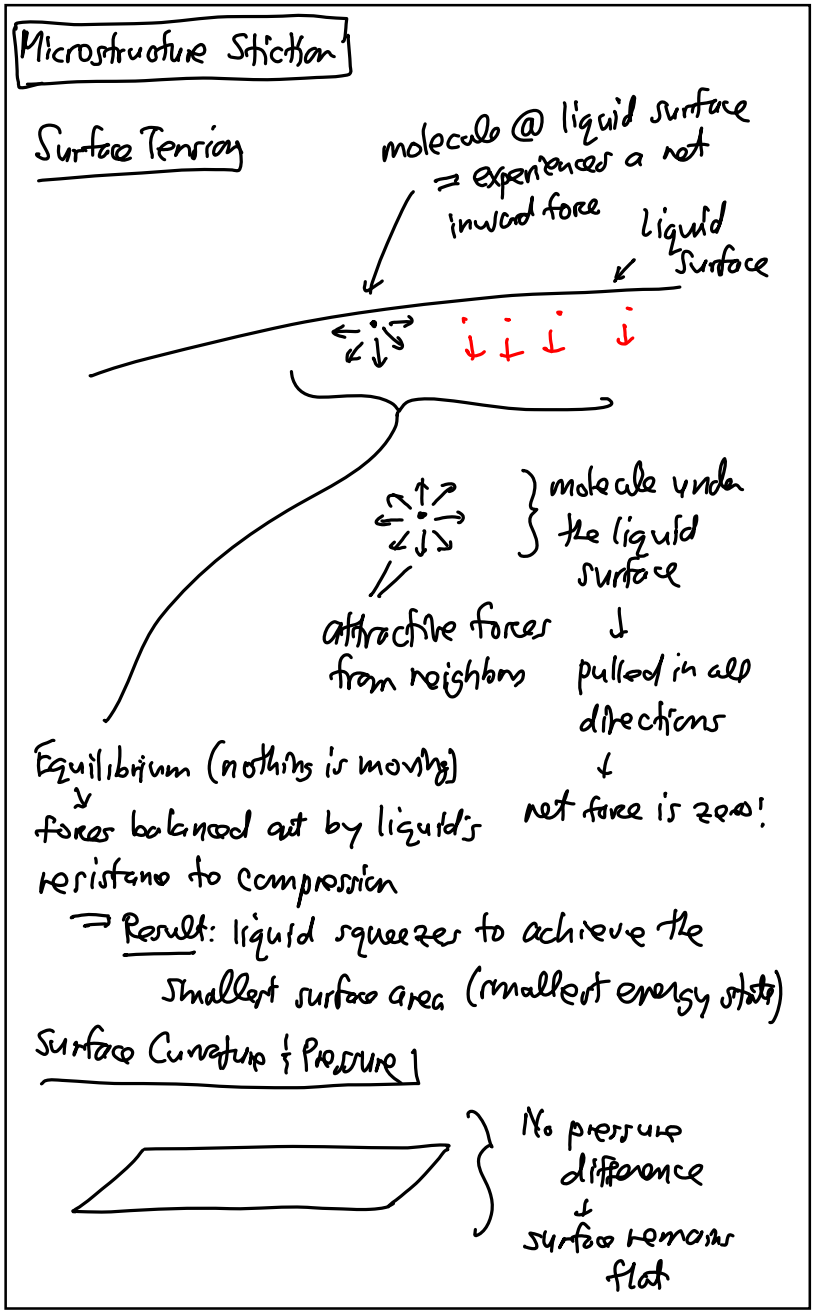
Etching to Select Sidewall Type

⇒ anisotropic etch → get straight sidewalls

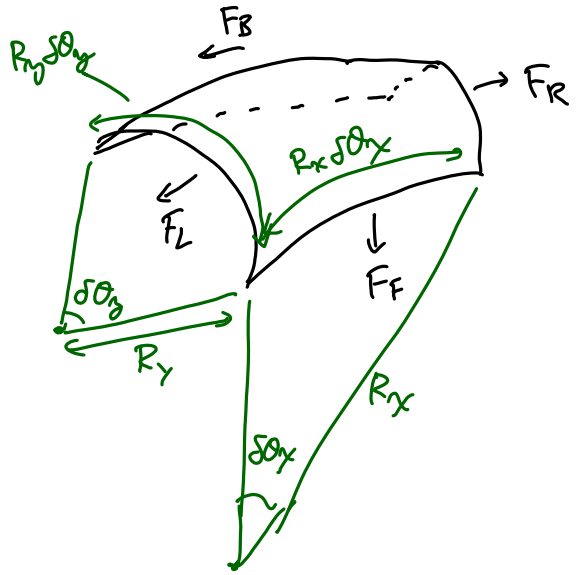
but only if the PR is straight or has zero etch rate







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



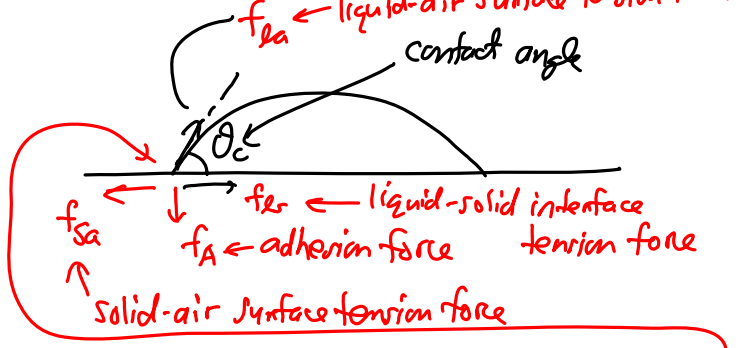
Young-Laplace Equation

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

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 properly dependent on the interface between different materials

Example. Hydrophilic Droplet



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

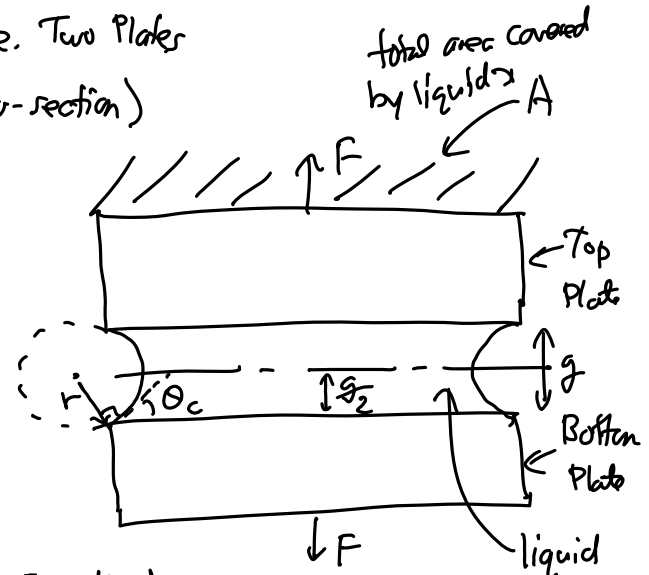
$$f_A = f_{la}\sin\theta_c$$

$$f_{sa} = f_{ls} + f_{la}\cos\theta_c \quad \text{[fcn of } \theta\text{]} \qquad \boxed{\gamma_{sa} = \gamma_{ls} + \gamma_{la}\cos\theta_c}$$

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

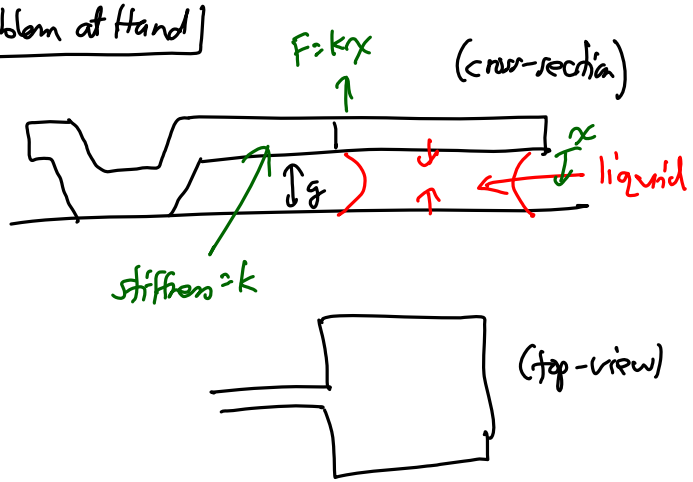
r ← radius of curvature of the liquid [<0 if convex]

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

Force needed to keep the plates apart

⇒ (+) force means (−) Laplace pressure

Problem at Hand



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

⇒ $\theta_c > 90°$

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]