Lecture 6: Surface Micromachining I

- Announcements:
- We will go 2 hours today
- HW#2 online and due next Friday
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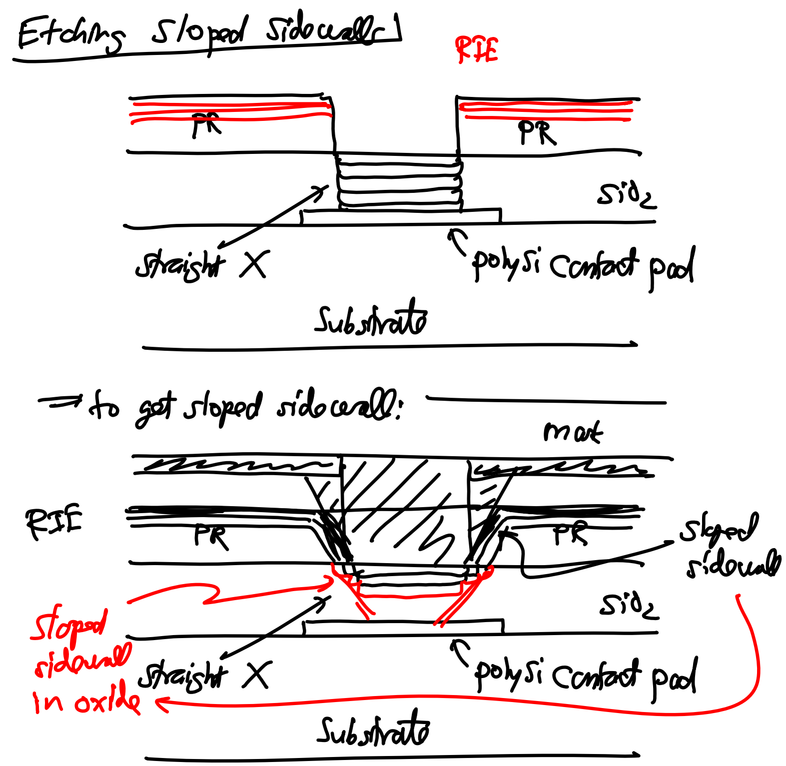
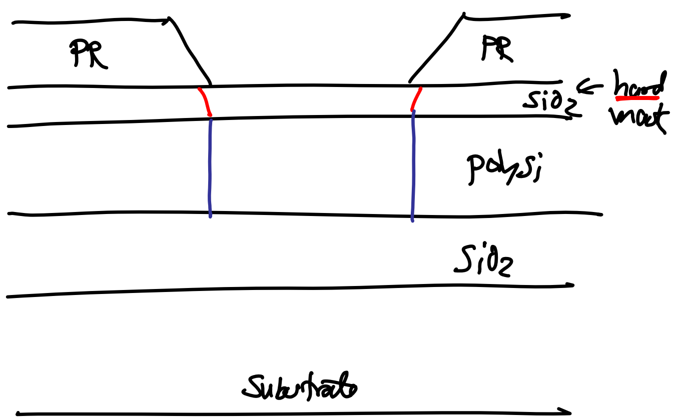
- Today:
- Reading: Senturia Chpt. 3, Jaeger Chpt. 11, Handout: "Surface Micromachining for Microelectromechanical Systems"
- Lecture Topics:
  - Polysilicon surface micromachining
  - Stiction
  - Residual stress
  - Topography issues
  - Nickel metal surface micromachining
  - 3D "pop-up" MEMS
  - Foundry MEMS: the "MUMPS" process
  - The Sandia SUMMIT process
- ------------------------------------
- Last Time: going through a detailed surface micromachining process

- 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



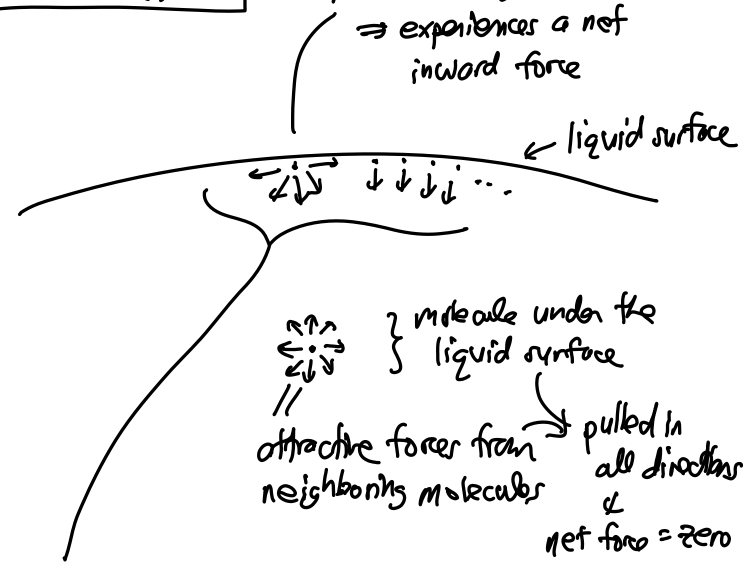
What if we want straight sidewalls when the PR sidewalls are not straight?

RIE w/ S^{poly}_{ox} = large



Microstructure Stiction

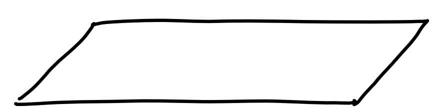
Surface Tension



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

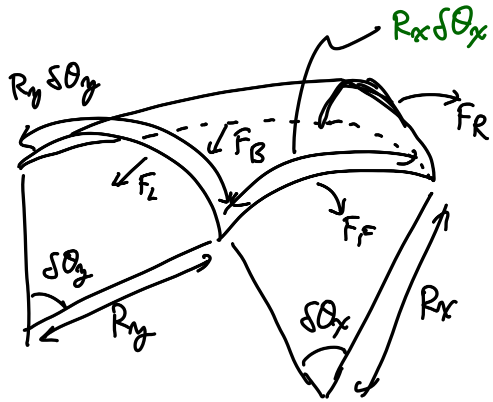
⇒ Result: liquid squeezes to achieve the smallest surface area (smallest energy state)

Surface Curvature & Pressure



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

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

where $\Delta p \triangleq$ pressure difference

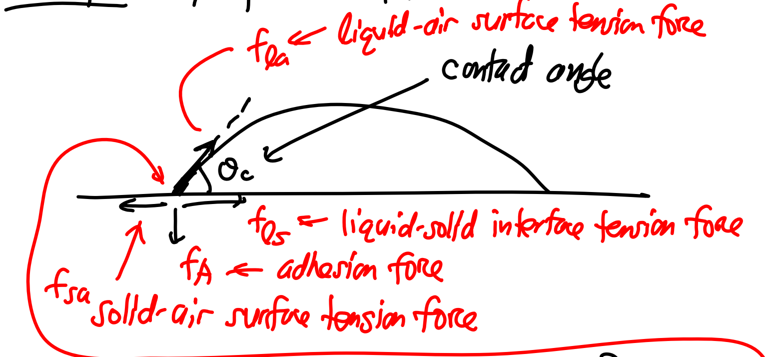
$\gamma \triangleq$ surface tension (force/length)

R_x & $R_y \triangleq$ radii of curvature

Contact Angle → governed by a balance of surface tensions

↳ really a property dependent on the interface between different materials

Example: Hydrophilic Droplet



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

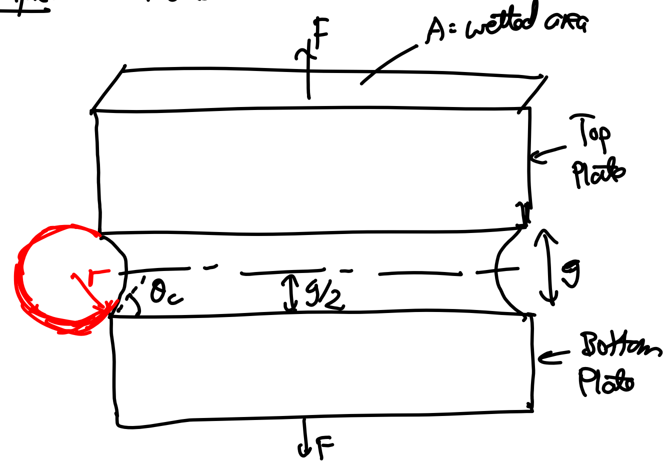
$f_A = f_{la}\sin\theta_c$

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

[fn γ]

Relationship between surface tensions can be captured by contact angle.

Example. Two Plates



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]

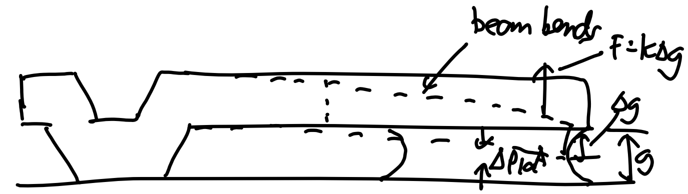
ΔP_{la}: Pressure Difference of the Liquid-Air Interface

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

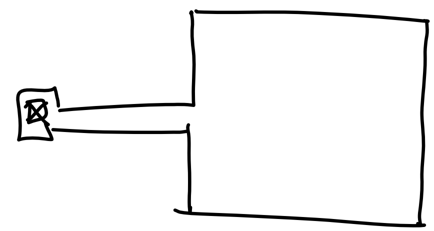
F: Force needed to keep the plates apart.

⇒ (+) force means (-) Laplace pressure.

The Actual Problem



$$F = k\Delta g = \Delta P_{la} A = \frac{2A\gamma_{la}\cos\theta_c}{g - \Delta g}$$



Remarks

To prevent stiction:

1. reduce A (wetted area)
2. reduce γ_{la} ← choose the right liquid & solid
3. make g large
4. increase k → make the structure thicker
5. $\theta_c > 90°$

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]