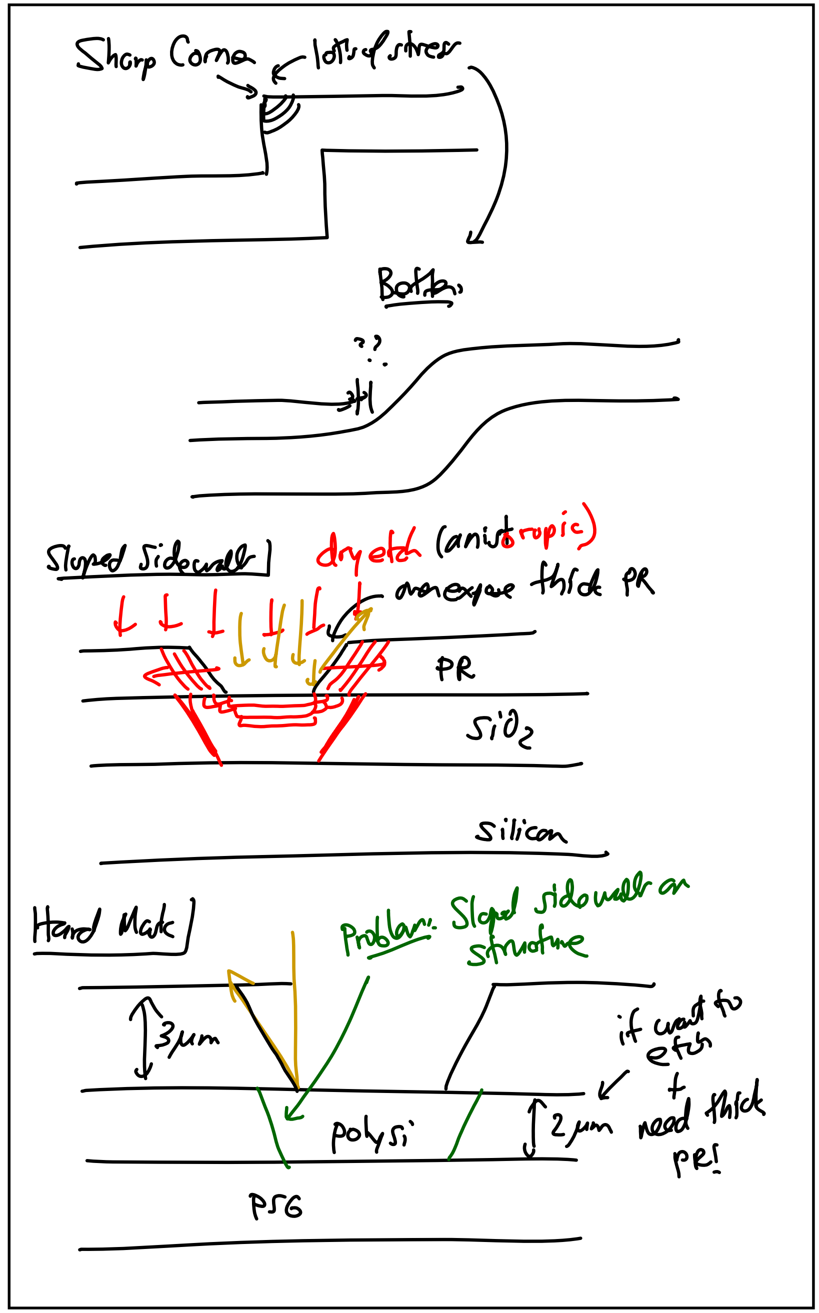
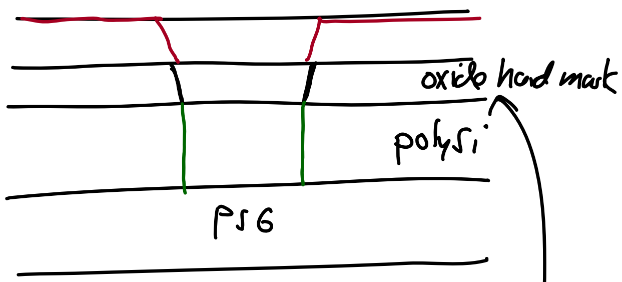
Lecture 9: Surface Micromachining II

- Announcements:
- HW #2: Due next Tuesday
- HW#3 will be online very soon
- ------------------------------------
- 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 … continue with this today
- Often want sloped sidewalls in order to reduce the sharpness of corners
  - 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



Need straight sidewalls:
↳ Solution: use oxide hard mask



material that etches slower than PR in the polySi etcher

→ This allows:

① thin PR → easier to define
→ can get better resolution lithographically
→ PR sidewalls straighter

② Oxide mask has straighter sidewalls than PR

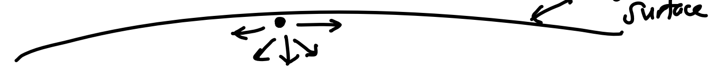
③ $S_{PR}^{polySi} = 30:1$

$S_{ox}^{polySi} = 50:1$

④ polySi sidewalls → straight!

Surface Tension

molecule @ surface experiences a net inward force

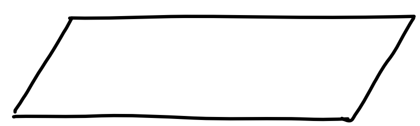


molecule under the liquid surface → pulled in all directions equally by attractive forces from neighbors

Eventually balanced by liquid's resistance to compression!

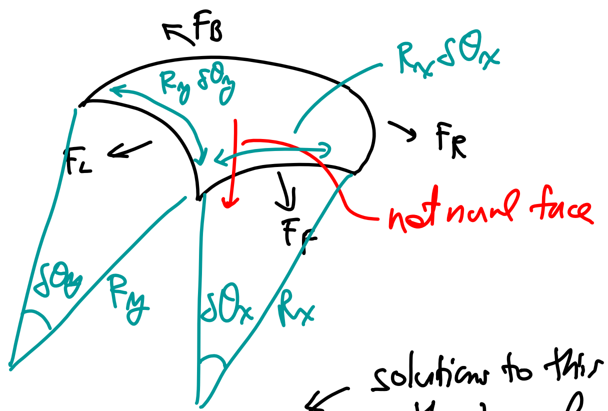
→ Result: Liquid squeezes itself to the smallest possible surface area!

Surface Curvature & Pressure



⇒ if no pressure difference → surface remains flat

⇒ but when pressure from the top is different from bottom → have a pressure difference
↳ surface curves to generate a net normal force to maintain balance



Young-Laplace Equation ← solutions to this determine the shape of water droplets!

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

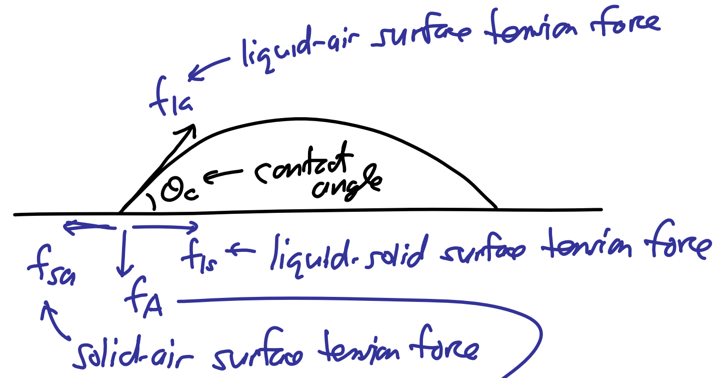
where $\Delta p \triangleq$ pressure difference

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

R_x & $R_y \triangleq$ radii of curvature

Contact Angle → dictated by balance of surface tensions

surface tension: property of a liquid's interface w/ another medium



Equilibrium:

⇒ both horizontal & vertical forces must cancel exactly @ contact point

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

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

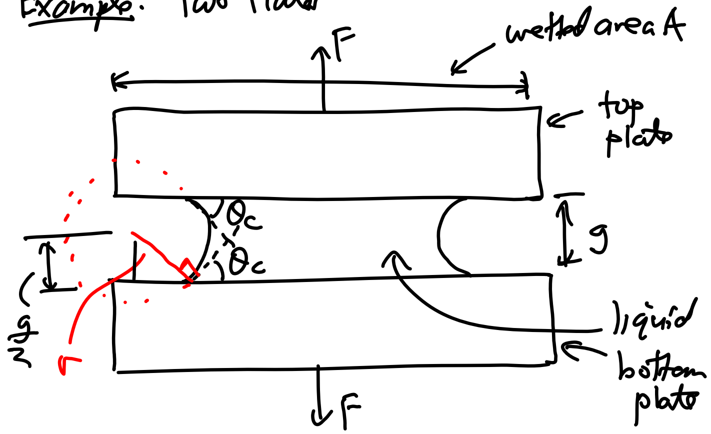
[f ∝ γ]

Relationship between surface tensions can be described by the contact angle!

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]

Example. Two Plates



Laplace Equation)

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

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

r ← Radius of Curvature of the Meniscus ((-) if concave)

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.

⇒ This depends on:

1. A
2. g → gap!
3. θ_c → contact angle!
4. γ_{la}