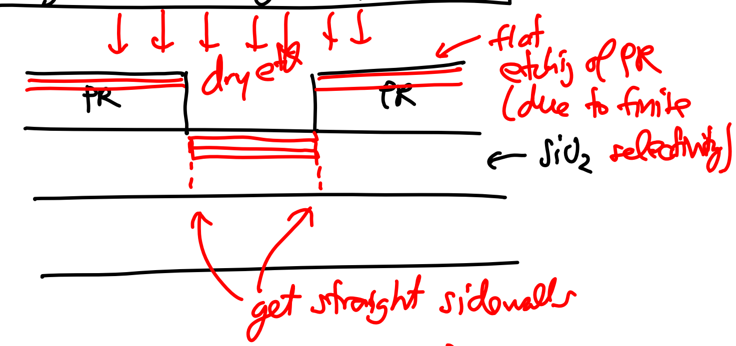
- **Announcements**:
- This is our make-up lecture from last Thursday's strike
- HW#2 is due tomorrow night at 7 p.m.
- ---------------------------------
- **Today**:
- Finish surface micromachining process from Module 5
- Reading: Senturia Chpt. 3, Jaeger Chpt. 11, Handout: "Surface Micromachining for 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
- ----------------------------------
- Go through initial stiction slides from Module 5

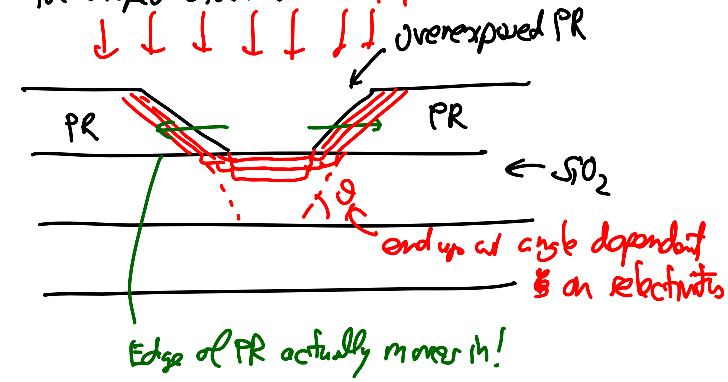
over

- Continue surface micromachining from last time
- Remarks:

Etching to Achieve Angled Sidewalls



⇒ for sloped sidewalls: dry etch



- 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 more 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

Microstructure Stiction

Surface Tension

molecule @ liquid surface → experiences a net inward force

Liquid Surface

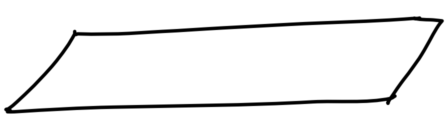
molecule under the liquid surface → pulled in all directions → effectively zero net force on it

attractive forces from neighbors

Eventually, all balanced by liquid's resistance to compression!

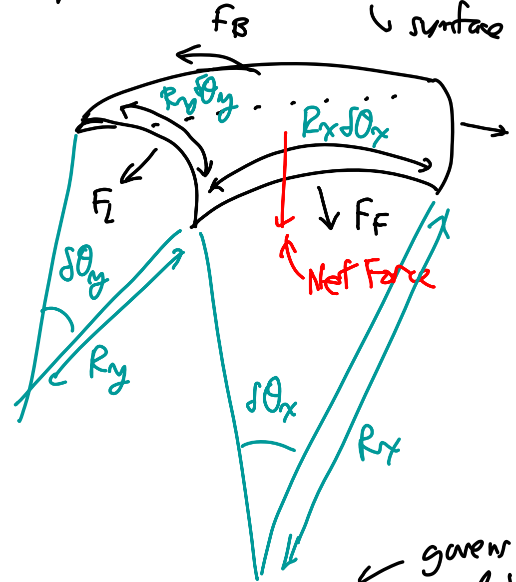
→ Result: liquid squeezes to achieve the smallest surface area (smallest energy state)

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 balance



Young-Laplace Equation

← governs the shape of the liquid

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

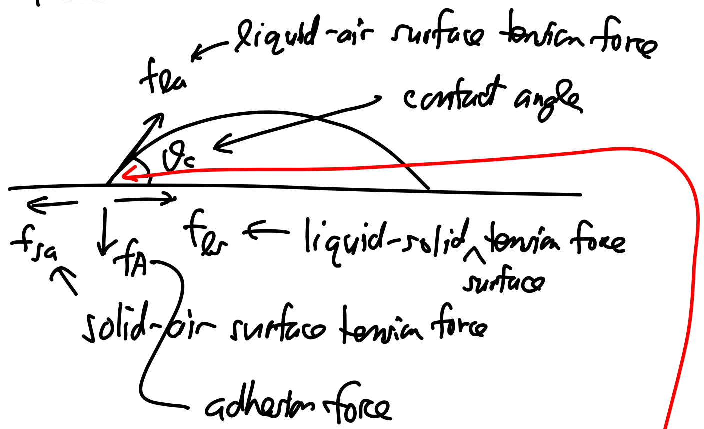
where: $\Delta p \triangleq$ pressure difference
$\gamma \triangleq$ surface tension (force/length)
R_x & $R_y \triangleq$ radii of curvature

Contact Angle

→ dictated by balance of surface tensions

really a property dependent upon the interface between different materials

Hydrophillic Droplet Example



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

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

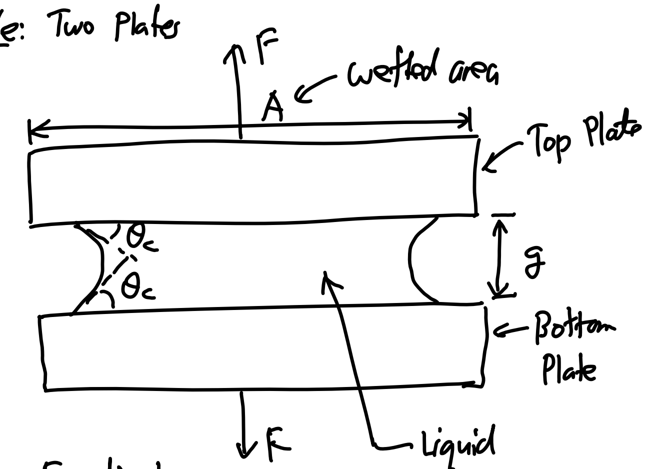
$$f_{sa} = f_{ls} + f_{la}\cos\theta_c \longrightarrow \boxed{\gamma_{sa} = \gamma_{ls} + \gamma_{la}\cos\theta_c}$$

$[f \propto \gamma]$

Relationship between surface tensions can be captured by the contact angle.

i.e., θ_c contains all the surface tensions → any expression containing θ_c depends on all interface elements

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

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

Force needed to keep the plates apart.

⟹ (+) force means (-) Laplace pressure

Note: This depends on θ_c, so depends on all materials/gases associated w/ the interface!