## Lecture 8: Surface Micromachining II

- Announcements:
- HW#2 online and due next Friday at 8 a.m.
- I have been traveling since Wednesday; back next Tuesday
- This is Thursday lecture and is a prepared video
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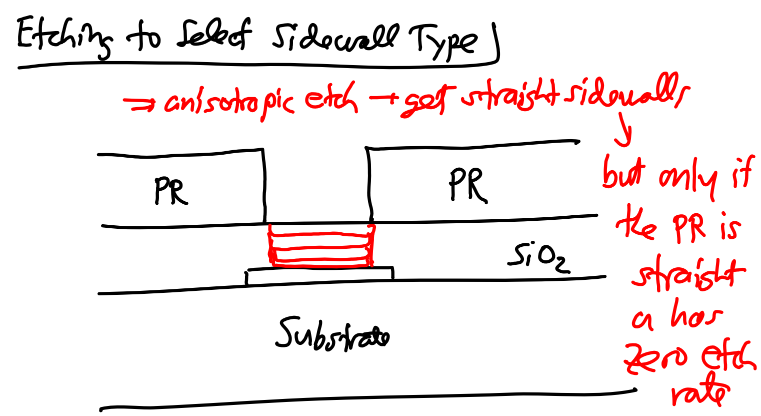
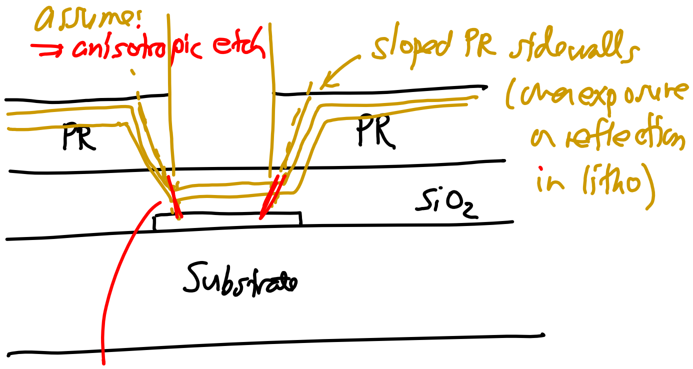
- Today:
- Reading: Senturia Chpt. 3, Jaeger Chpt. 11, Handout: "Surface Micromachining for Microelectromechanical Systems"
- Lecture Topics:
  - Polysilicon surface micromachining
  - Stiction
  - Residual stress
  - Topography issues
  - Nickel metal surface micromachining
  - 3D "pop-up" MEMS
  - Foundry MEMS: the "MUMPS" process
  - The Sandia SUMMIT process
- --------------------------------------
- Last Time:
- Going through Module 5 on Surface Micromachining

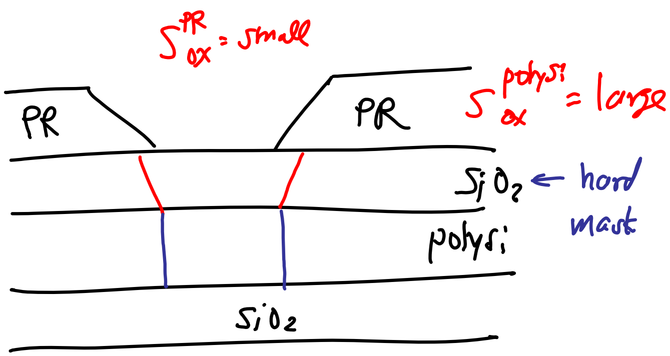
- Straight or Sloped Sidewalls:
- Often want sloped sidewalls in order to reduce the sharpness of corners
  - Easier to deposit over
  - Sharp corners concentrate stresses
  - High stress can weaken structures creating a reliabilty concern
  - High stress can dissipate energy, lowering Q
- When you want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





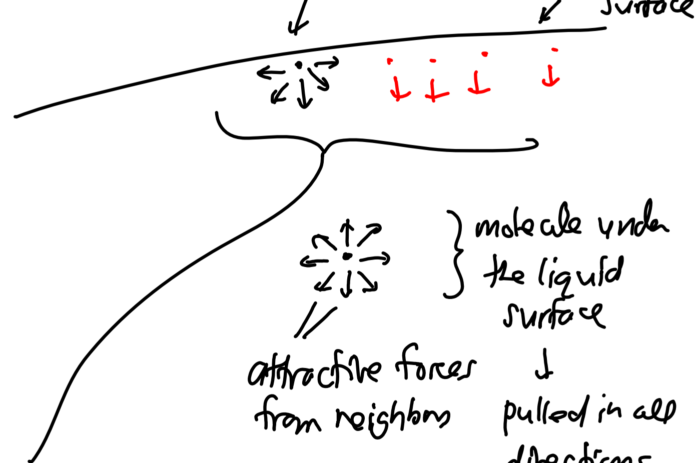

transfer to some degree the slope of the PR into slope in the etched film

What can we do to get straight sidewalls?




## Microstructure Stiction

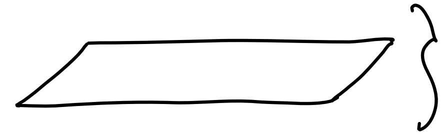
### Surface Tension




Equilibrium (nothing is moving)
↓
forces balanced out by liquid's resistance to compression

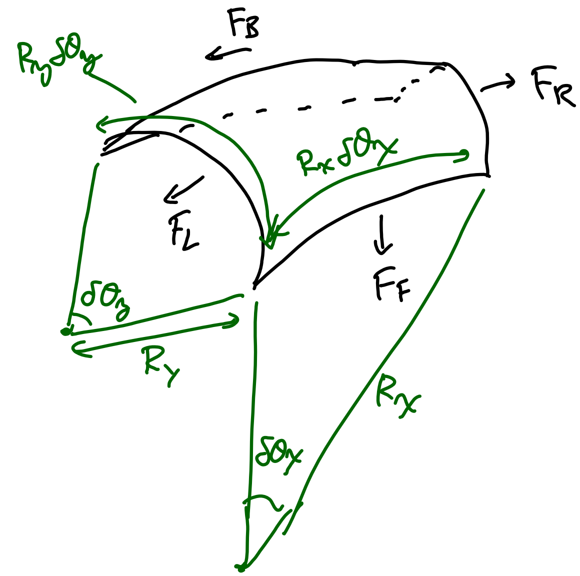
⇒ Result: liquid squeezes to achieve the smallest surface area (smallest energy state)

### Surface Curvature & Pressure



No pressure difference
↓
surface remains flat

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



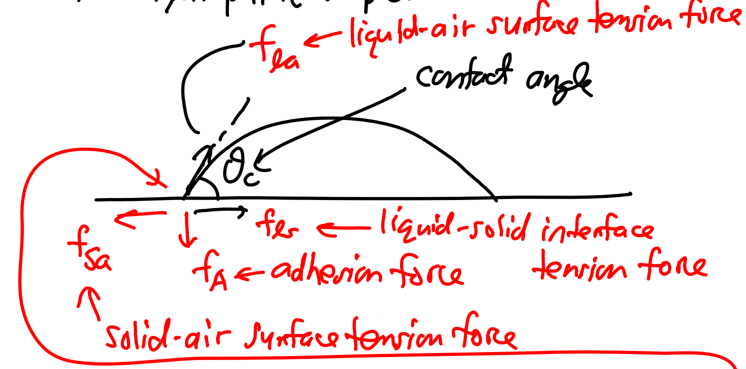

**Young-Laplace Equation**

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

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 property dependent on the interface between different materials

**Example.** Hydrophilic Droplet




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

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

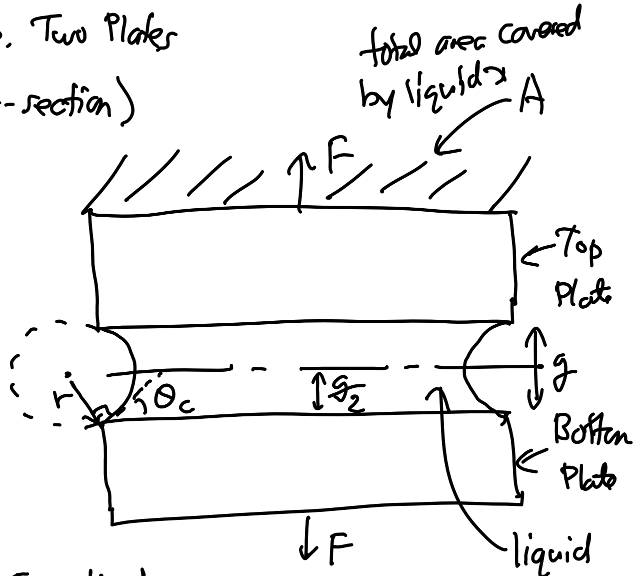
$f_{sa} = f_{ls} + f_{la}\cos\theta_c$ → $\boxed{\gamma_{sa} = \gamma_{ls} + \gamma_{la}\cos\theta_c}$

[for all $\gamma$]

Relationship between surface tensions captured by contact angle.

## Example. Two Plates

(cross-section)




### Laplace Equation

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

$\gamma_{la}$ ← surface tension @ the liquid-air interface

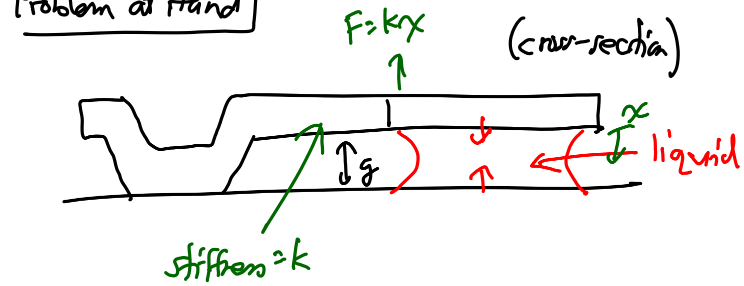
$r$ ← radius of curvature of the liquid [(−) if convex]

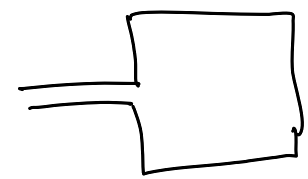
$$\left[ r = \frac{-(g/2)}{\cos\theta_c} \right] \Rightarrow \boxed{F = -\Delta p_{la} A = \frac{2A\gamma_{la}\cos\theta_c}{g}}$$

Force needed to keep the plates apart

⇒ (+) force means (−) laplace pressure

## Problem at Hand




### Remarks

① To prevent stiction:

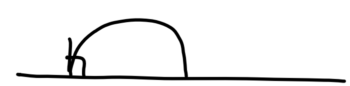
⇒ reduce A (wetted area)

⇒ reduce $\gamma_{la}$ → choose the right liquids (& solids)

⇒ make g large

⇒ increase k → make things thicker

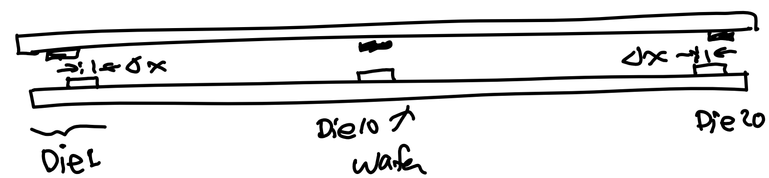
⇒ $\theta_c > 90°$

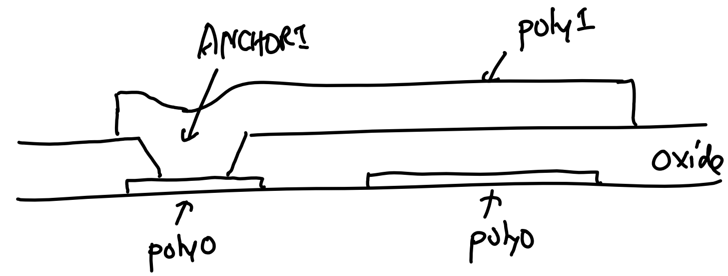
| Liquid | Solid | Contact angle |
|---|---|---|
| water | soda-lime glass | 0° |
| ethanol | lead glass | |
| diethyl ether | fused quartz | |
| carbon tetrachloride | | |
| glycerol | | |
| acetic acid | | |
| water | paraffin wax | 107° |
| | silver | 90° |
| methyl iodide | soda-lime glass | 29° |
| | lead glass | 30° |
| | fused quartz | 33° |
| mercury | soda-lime glass | 140° |

Some liquid-solid contact angles[5]

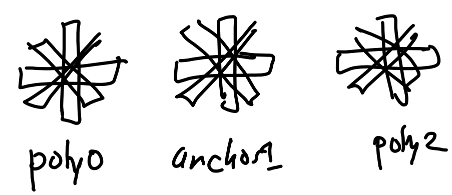
Misalignments

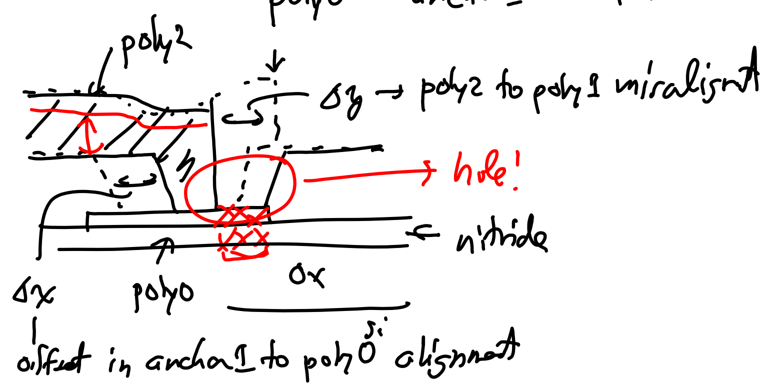


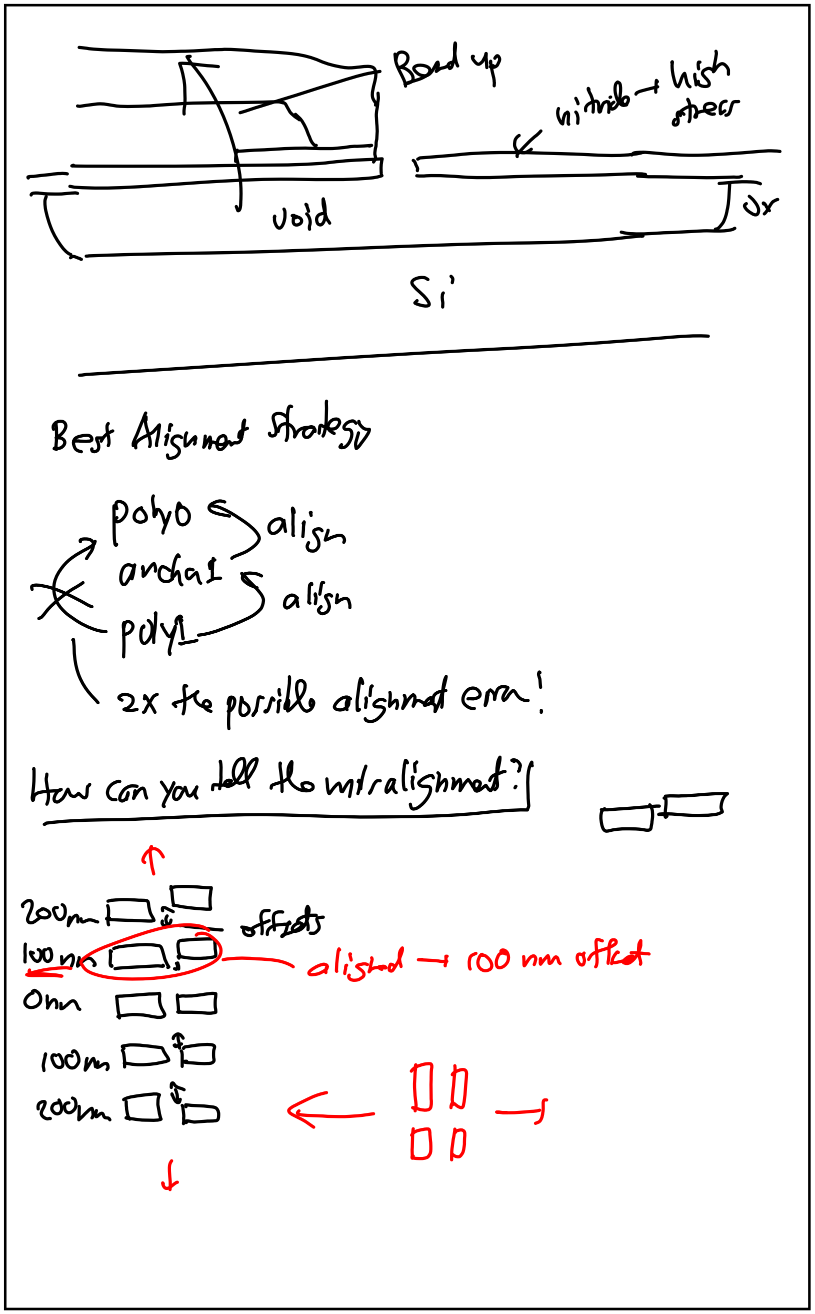

Which layer to Align?




Alignment Keys




Bend up
nitride + high stress
void
ox
Si
Best Alignment Strategy
poly0
anchor
poly1
align
align
2x the possible alignment error!
How can you tell the misalignment?
200nm
100nm
0nm
100nm
200nm
offsets
aligned → 100 nm offset