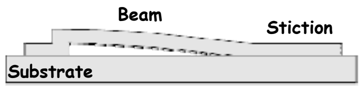
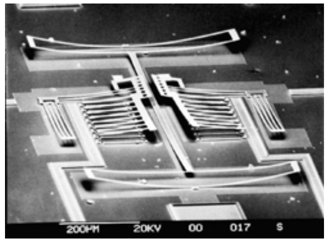
Issues in Surface Micromachining

- Stiction: sticking of released devices to the substrate or to other on-chip structures
  - Difficult to tell if a structure is stuck to substrate by just looking through a microscope
- Residual Stress in Thin Films
  - Causes bending or warping of microstructures
  - Limits the sizes (and sometimes geometries) of structures
- Topography
  - Stringers can limit the number of structural levels

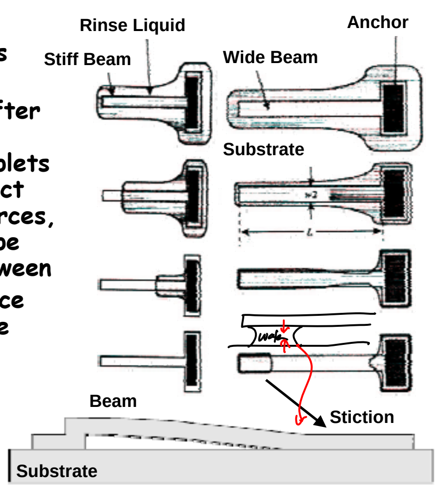




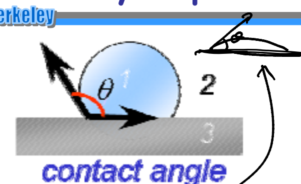
Microstructure Stiction

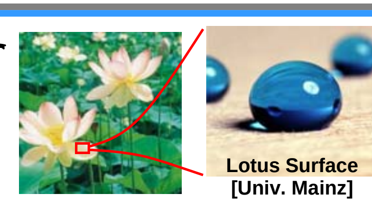
Microstructure Stiction

- Stiction: the unintended sticking of MEMS surfaces
- Release stiction:
  - Occurs during drying after a wet release etch
  - Capillary forces of droplets pull surfaces into contact
  - Very strong sticking forces, e.g., like two microscope slides w/ a droplet between
- In-use stiction: when device surfaces adhere during use due to:
  - Capillary condensation
  - Electrostatic forces
  - Hydrogen bonding
  - Van der Waals forces

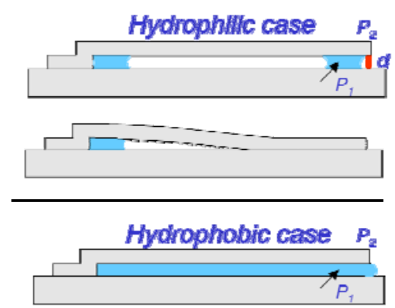


Hydrophilic Versus Hydrophobic





- Hydrophilic:
  - A surface that invites wetting by water
  - Get stiction
  - Occurs when the contact angle $\theta_{water} < 90^o$
- Hydrophobic:
  - A surface that repels wetting by water
  - Avoids stiction
  - Occurs when the contact angle $\theta_{water} > 90^o$



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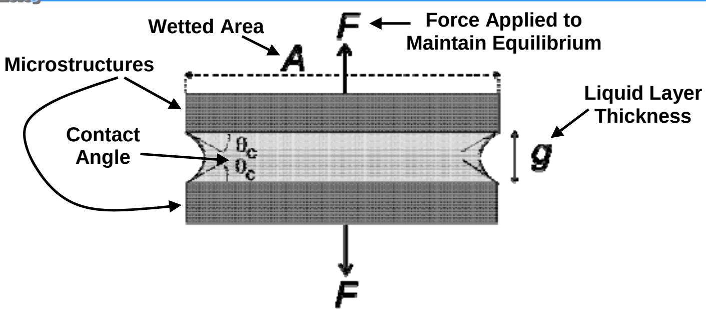
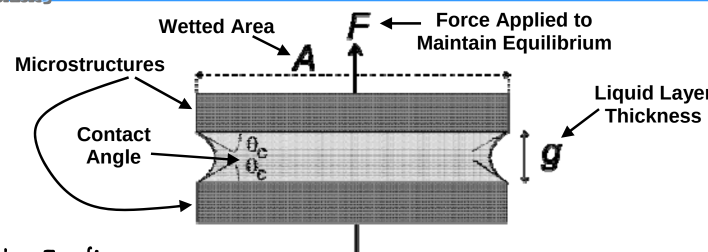


- Thin liquid layer between two solid plates ⇨ adhesive
- If the contact angle between liquid and solid $\theta_c < 90°$:
  - Pressure inside the liquid is lower than outside
  - Net attractive force between the plates
- The pressure difference (i.e., force) is given by the Laplace equation

Microstructure Stiction Modeling



Laplace Equation:

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

γ_{la} ← Surface Tension @ the Liq.-Air Interface

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

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

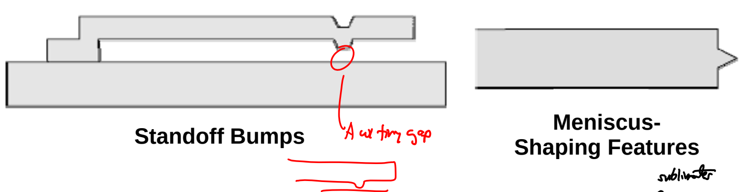
$\left[r = -\frac{(g/2)}{\cos\theta_c}\right] \Rightarrow$

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

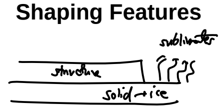
← Force needed to keep the plates apart
⇒ (+) force means a (−) Laplace pressure

Avoiding Stiction

- Reduce droplet area via mechanical design approaches



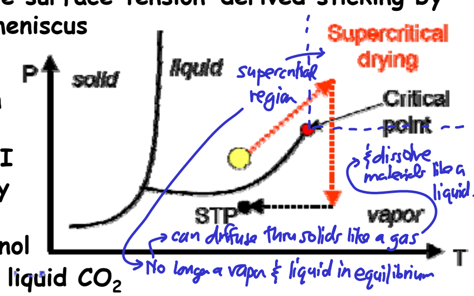
- Avoid liquid-vapor meniscus formation
  - Use solvents that sublimate
  - Use vapor-phase sacrificial layer etch



- Modify surfaces to change the meniscus shape from concave (small contact angle) to convex (large contact angle)
  - Use teflon-like films
  - Use hydrophobic self-assembled monolayers (SAMs)

Supercritical CO_2 Drying

- A method for stictionless drying of released microstructures by immersing them in CO_2 at its supercritical point
- Basic Strategy: Eliminate surface tension-derived sticking by avoiding a liquid-vapor meniscus
- Procedure:
  - Etch oxide in solution of HF
  - Rinse thoroughly in DI water, but do not dry
  - Transfer the wafer from water to methanol
  - Displace methanol w/ liquid CO_2
  - Apply heat & pressure to take the CO_2 past its critical pt.
  - Vent to lower pressure and allow the supercritical CO_2 to revert to gas → liquid-to-gas Xsition in supercritical region means no capillary forces to cause stiction



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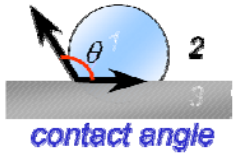

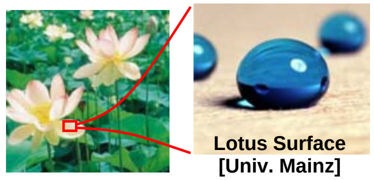

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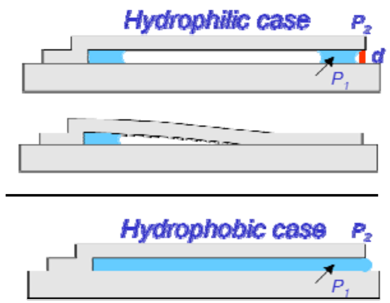
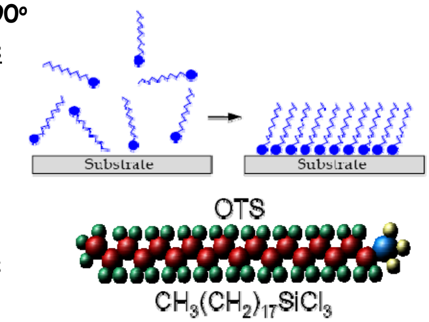


Tailoring Contact Angle Via SAM's

- Can reduce stiction by tailoring surfaces so that they induce a water contact angle > 90°

Self-Assembled Monolayers (SAM's):

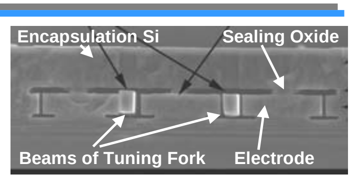
- Monolayers of "stringy" molecules covalently bonded to the surface that then raise the contact angle
- Beneficial characteristics:
  - Conformal, ultrathin
  - Low surface energy
  - Covalent bonding makes them wear resistant
  - Thermally stable (to a point)



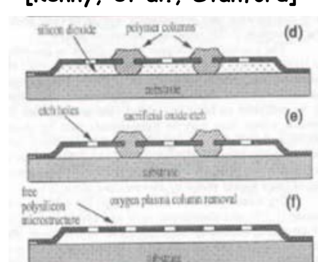
	θ_{water}
ODT SAM	112 ± 0.7°
SiO_2	<10°

Dry Release

- Another way to avoid stiction is to use a dry sacrificial layer etch
- For an oxide sacrificial layer
  - use HF vapor phase etching
  - Additional advantage: gas can more easily get into tiny gaps
  - Issue: not always completely dry → moisture can still condense → stiction → soln: add alcohol
- For a polymer sacrificial layer
  - Use an O_2 plasma etch (isotropic, so it can undercut well)
  - Issues:
    - Cannot be used when structural material requires high temperature for deposition
    - If all the polymer is not removed, polymer under the suspended structure can still promote stiction



Released via vapor phase HF [Kenny, et al., Stanford]



[Kobayashi]