Lecture 10
Force distance curves II

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F-Z and F-d review

- In theory if one knows F-d then to go to F-Z:
  - For every Z solve for $k_{cant}\delta$ = Fts(d) or equivalently solve $k_{cant}(d-Z)$ = Fts(d)
    which can be done graphically
- In experiment, given F-Z, one goes to F-d by
  - For every F, plot along the x-axis, the quantity $d=\delta+Z$, where Z is the Z value at that F and $\delta=F/k_{cant}$
- Note that F-d maps one on one to F-Z curves but given a F-Z curve, more than one F-d's can exist that yield the same F-Z

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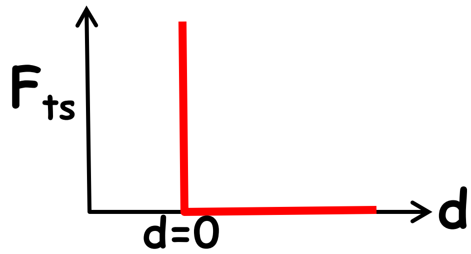
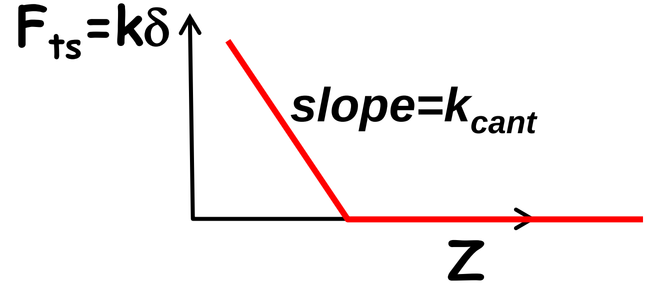
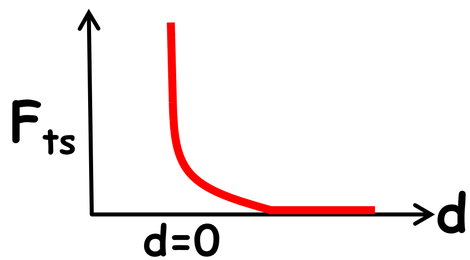
Some examples of F-Z curves

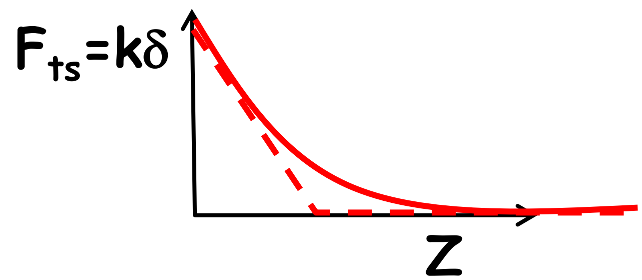
- Infinitely stiff sample, no surface forces



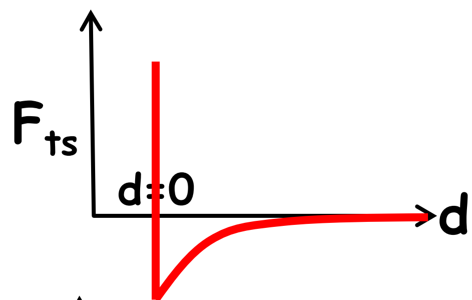


- Infinitely stiff sample with surface repulsive force

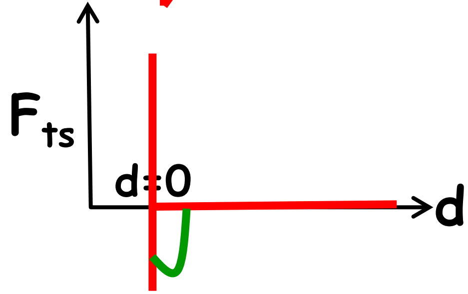


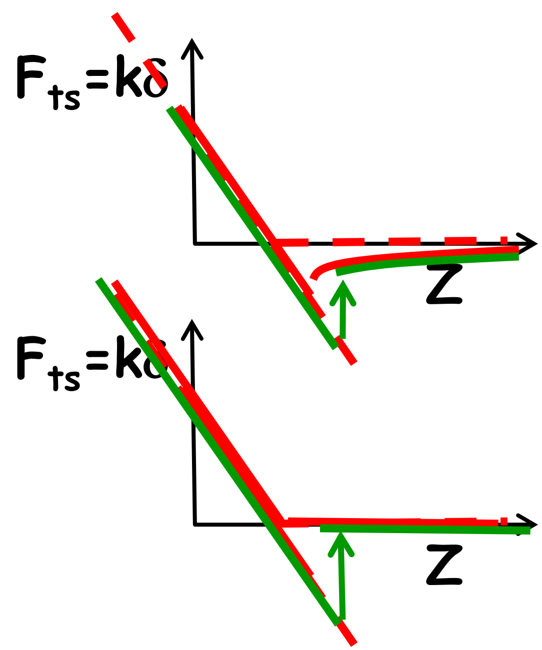


- Infinitely stiff sample with attractive VdW force



- Infinitely stiff sample with capillary force





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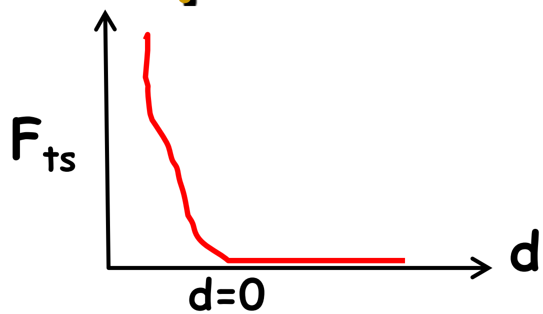
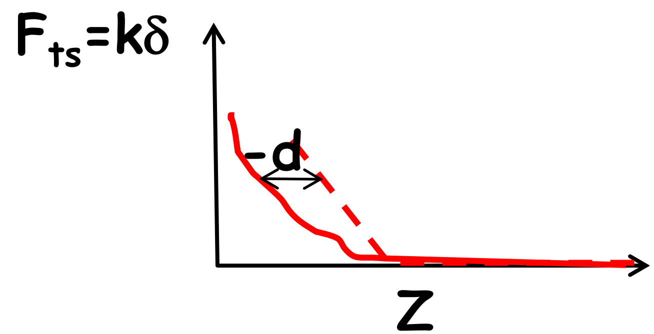
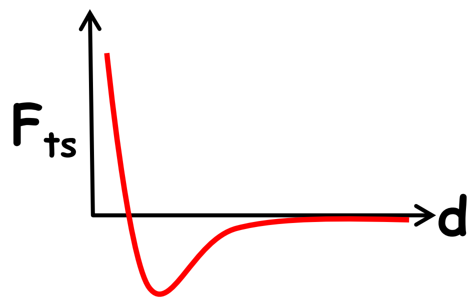
Some examples of F-Z curves

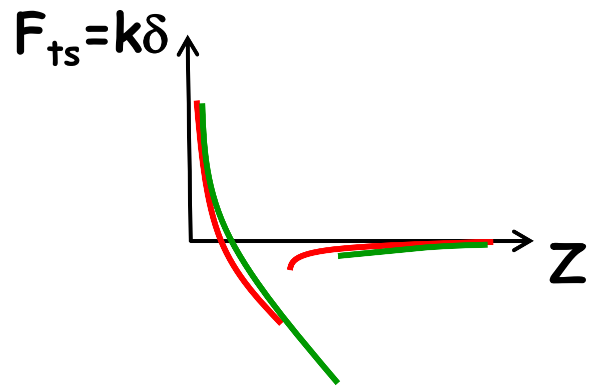
- Soft materials
  no surface forces



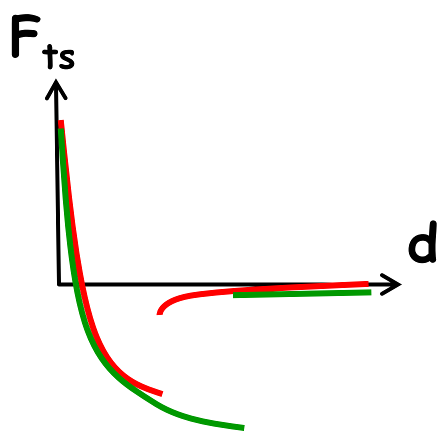


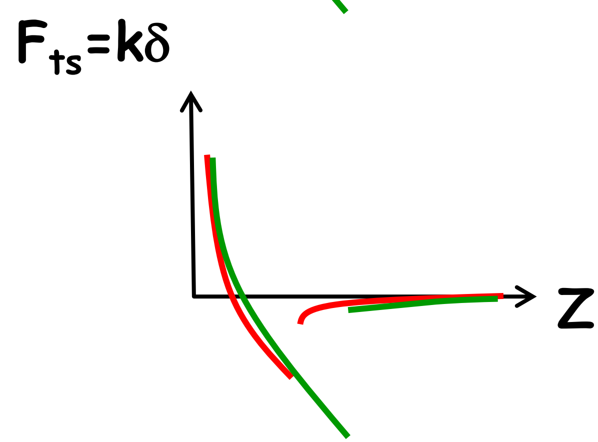
- Soft material
  with attractive
  VdW force





- Soft material with
  hysteretic F-d
  curve





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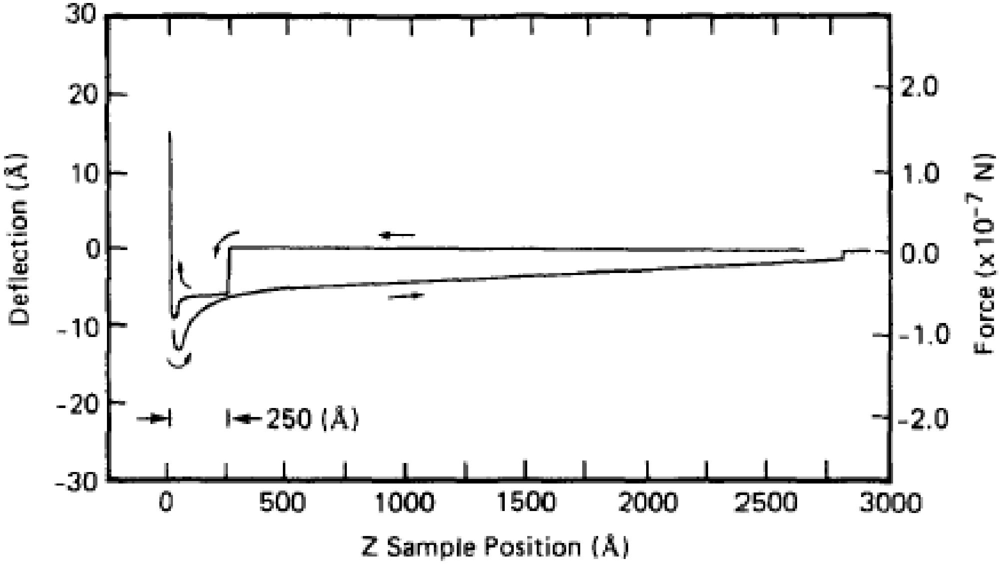
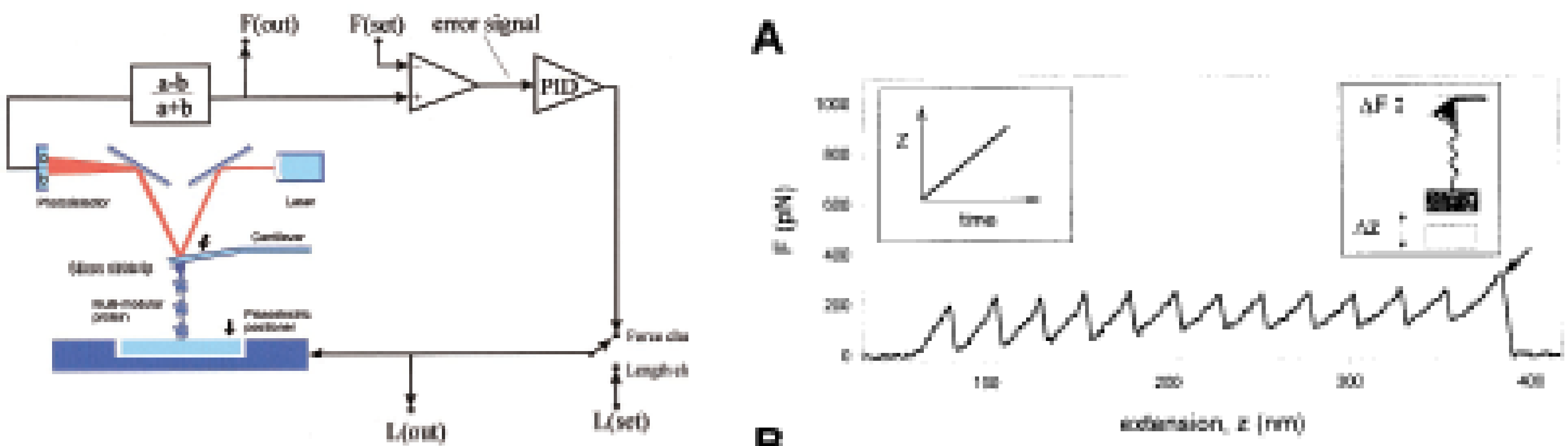
Other interesting F-Z curves

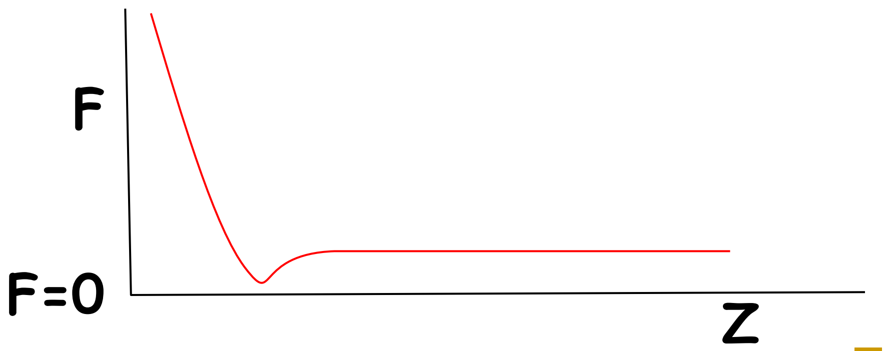


- 25 nm perfluoropolyether polymeric liquid on silicon (from Mate et al (1989))



- Force-extension curves on titin (Fernandez et. al PNAS (2001))

Effects of positioning reflected laser spot in photodiode on F-Z curves



- Laser spot not centered in photodiode - recenter so that photodiode output is ~0 far from sample
- Reflected spot size affects sensitivity

from Butt, Kappl, Cappella, in reader

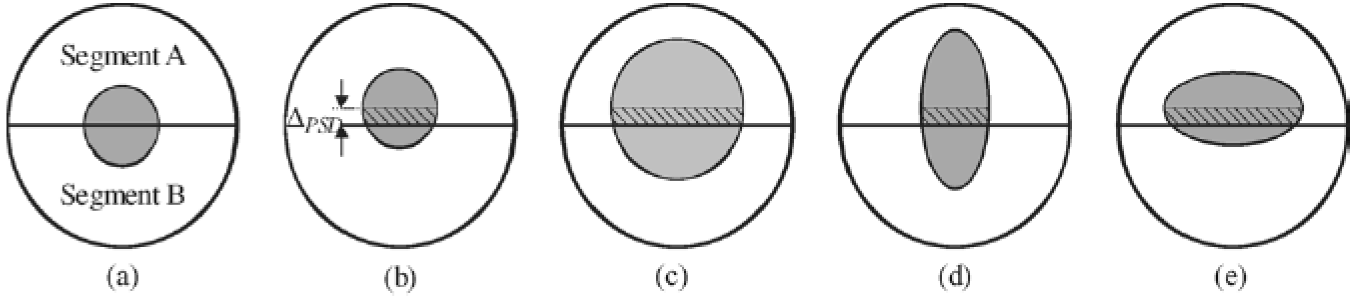
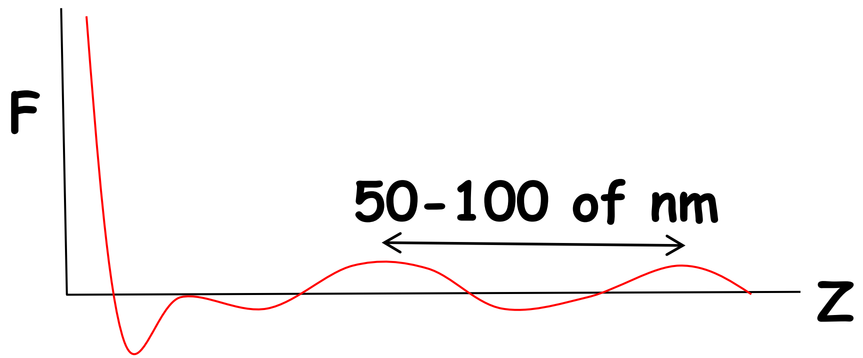


Fig. 10. The effect of laser spot shape on optical lever sensitivity. (a) A centered spot leads to zero deflection signal $(A - B)/(A + B)$. (b) A well-shaped rotational symmetric and small spot produces a large relative area change between the A and B photodiode segments for a given deflection. This corresponds to a high sensitivity. For large deflections, however, the linear regime is small. If the spot is large (c) or distorted (d) the same deflection can produce a smaller change in relative area, hence a lower sensitivity. Also an increased sensitivity for distorted spots is possible (e).

Apparent periodic signal in non-contact range



- Laser spot spilling over cantilever edge, reflecting off substrate interfering with signal back from cantilever
- Focus spot better, or use non-coherent laser. IR lasers are less coherent than others.

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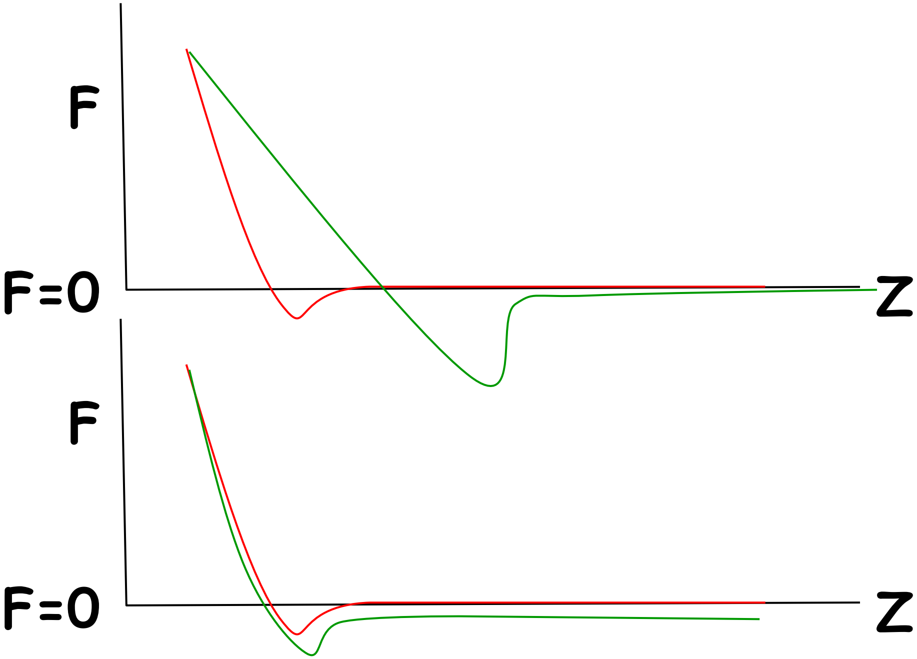
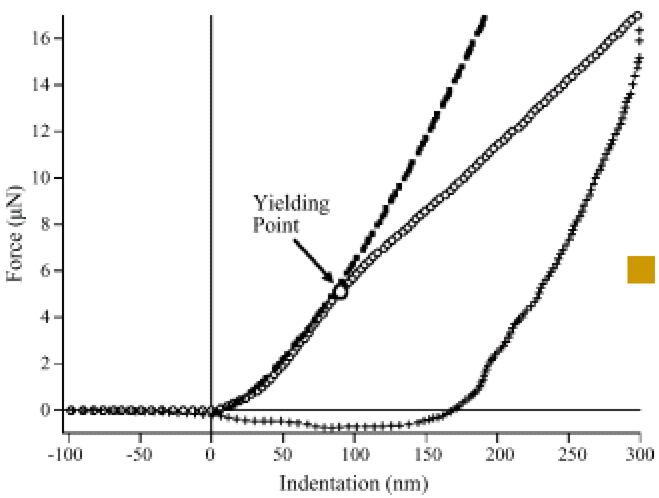
Artefacts in F-Z curves



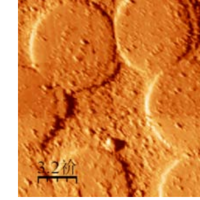
- Z piezo hysteresis – warm up piezo first, use closed loop piezos

- Hydrodynamic drag- reduce speed

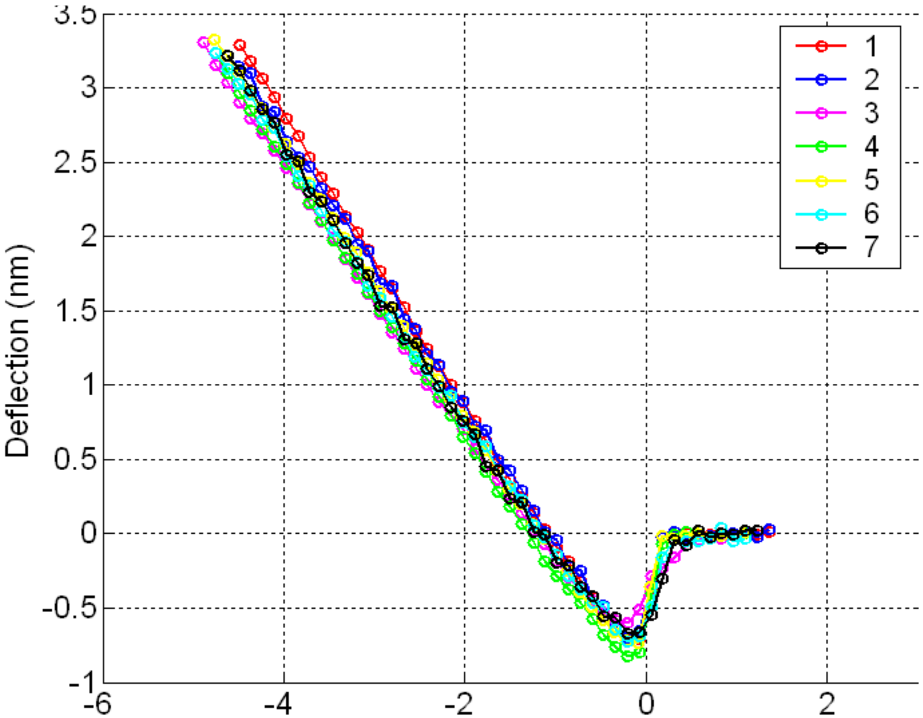


- Large indentation with plastic deformation – reduce force!

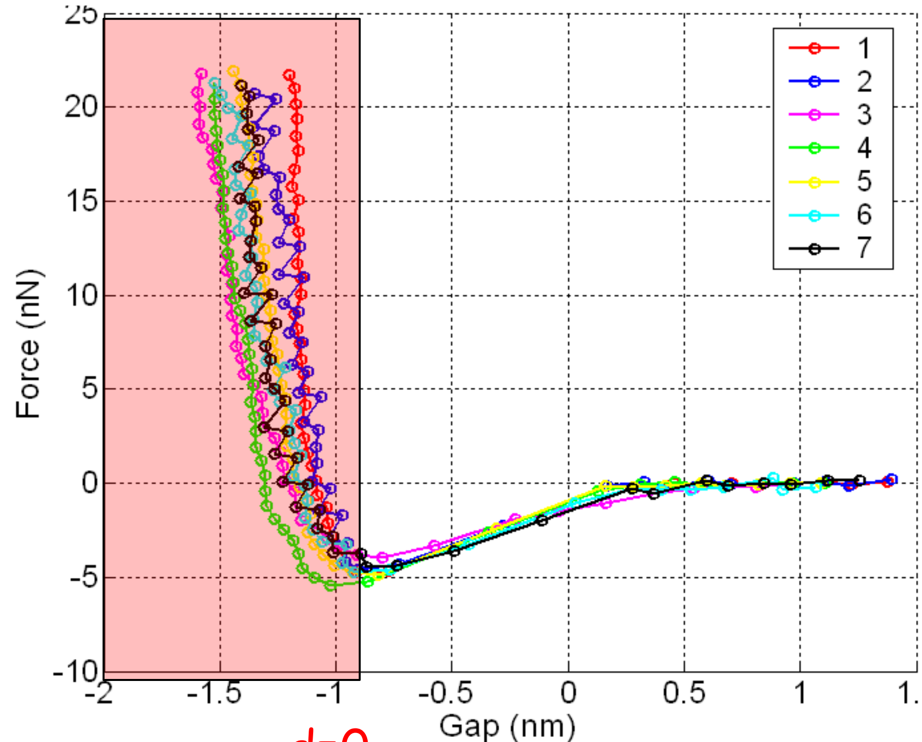
Estimating sample elasticity and adhesion from F-Z curves



Convert deflection vs. displacement curves to force vs. distance (gap) curves



Piezo displacement Z (nm)



d=0

- For each curve identify d=0 where F-d reaches a minimum
- From F-d choose which model you want to use DMT, Hertz, Sneddon,Oliver-Pharr etc
- Fit curve in shaded region to DMT model F=-Fad+(3/2)E*srt(R) (-d)^3/2
- Make histogram of measured E* and Fad

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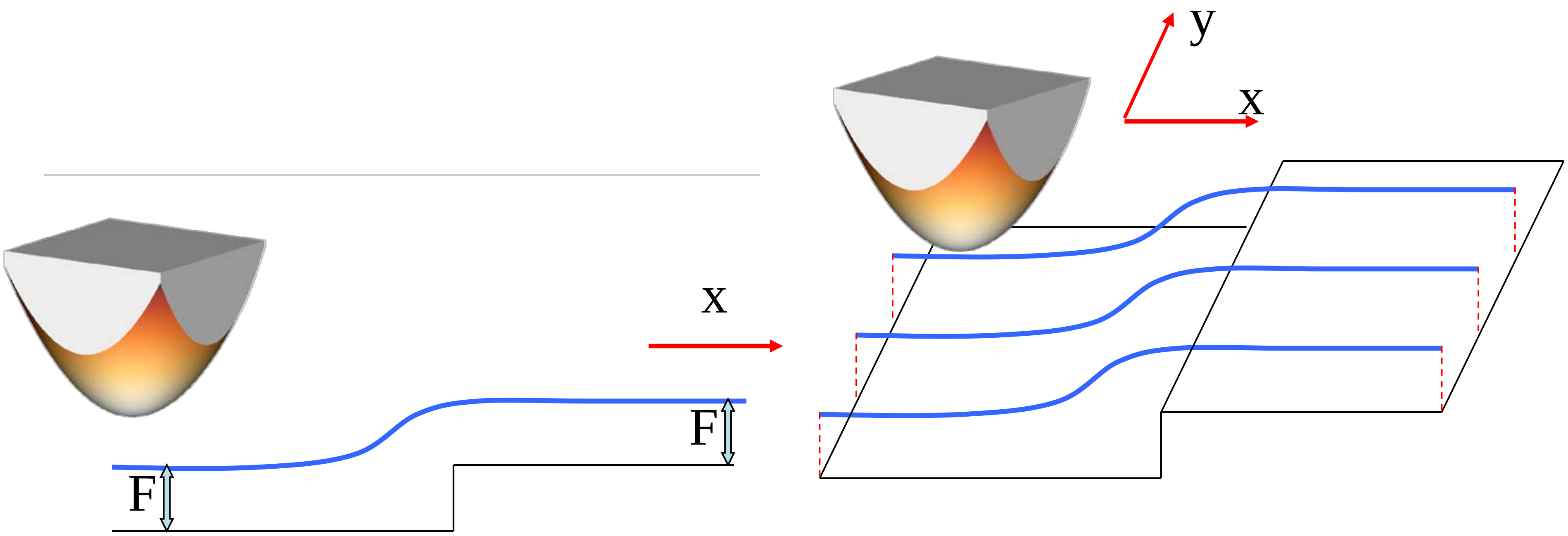
Contact Mode Imaging



First tip contacts surface with some setpoint normal force which is kept constant during the scan

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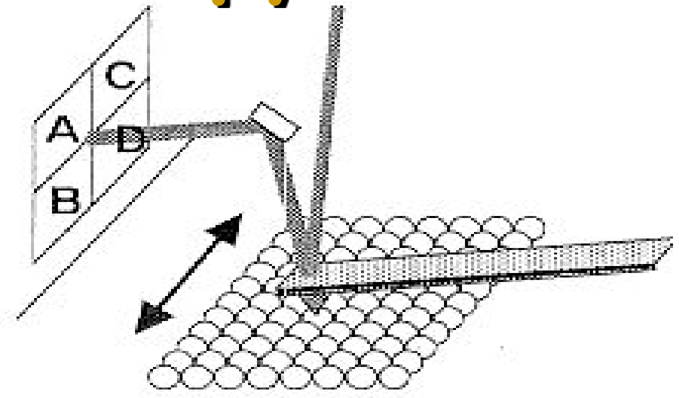
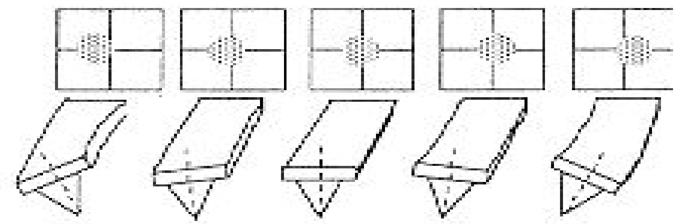
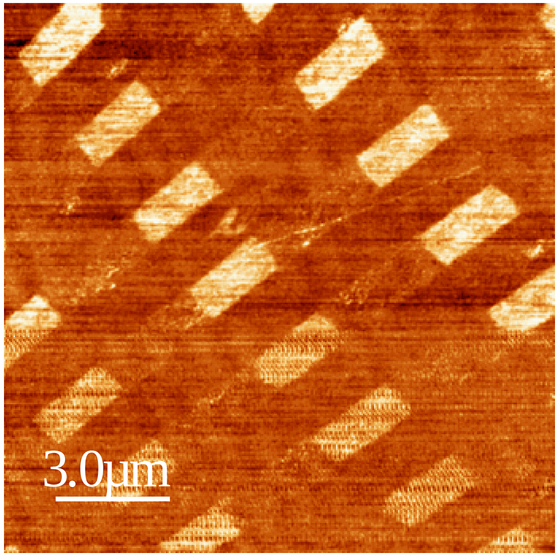
Friction Force Microscopy

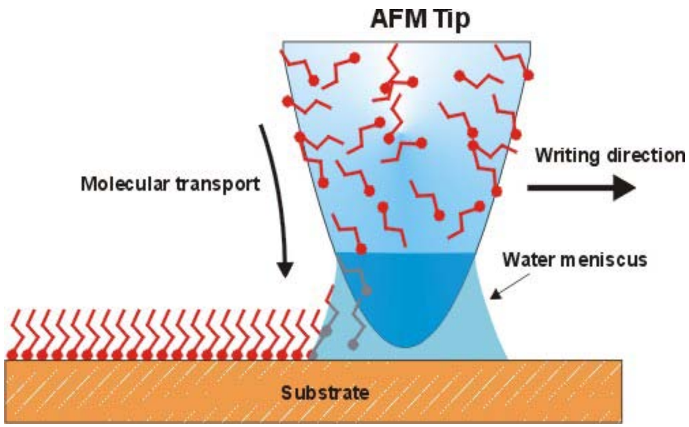
- Torsional deflections due to atomic and molecular friction
- Lateral forces are specific
- Applications to nanotribology, probe based lithography



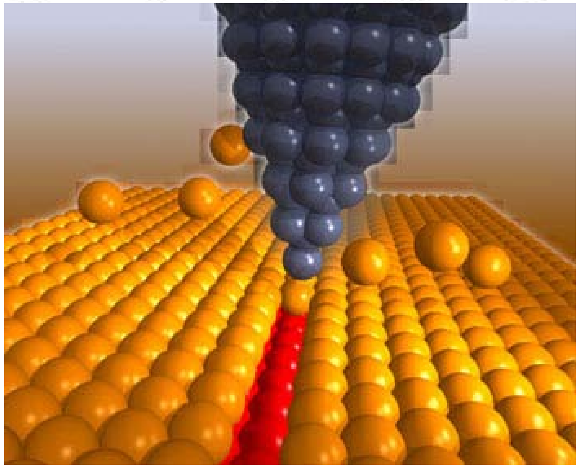




Friction force image of a self assembled monolayer (Riefenberger Group)



www.chem.nwu.edu/~mkngrp/
Dip-pen lithography



Contact mode oxidation lithography

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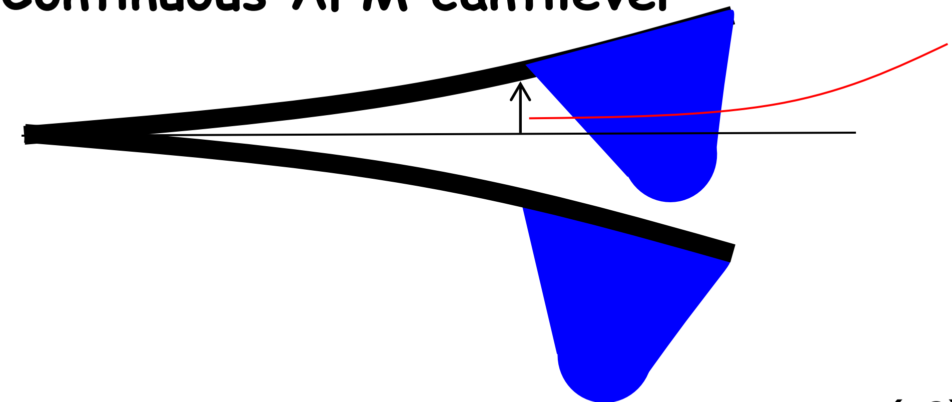
Brief intro to dynamic AFM

- Cantilever driven near resonance
- The cantilever's resonant frequency, phase and amplitude are affected by short-scale force gradients
- In Amplitude Modulated AFM (AM-AFM) or tapping mode, driving frequency is fixed while cantilever approaches the sample
- In Frequency Modulated AFM (FM-AFM) the phase and amplitude are held constant while approaching the sample

The point mass model

Continuous AFM cantilever

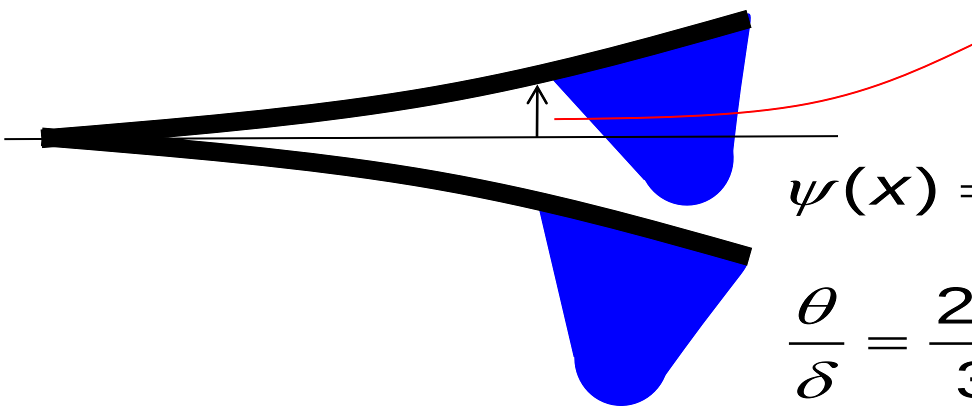


w(x,t) = A sin(ωt) ψ(x)

θ/δ=?

$$\psi(x) = \cos(\beta\frac{x}{L}) - \cosh(\beta\frac{x}{L}) - \frac{\cos(\beta)+\cosh(\beta)}{\sin(\beta)+\sinh(\beta)}\left[\sin(\beta\frac{x}{L}) - \sinh(\beta\frac{x}{L})\right]$$

Point mass model



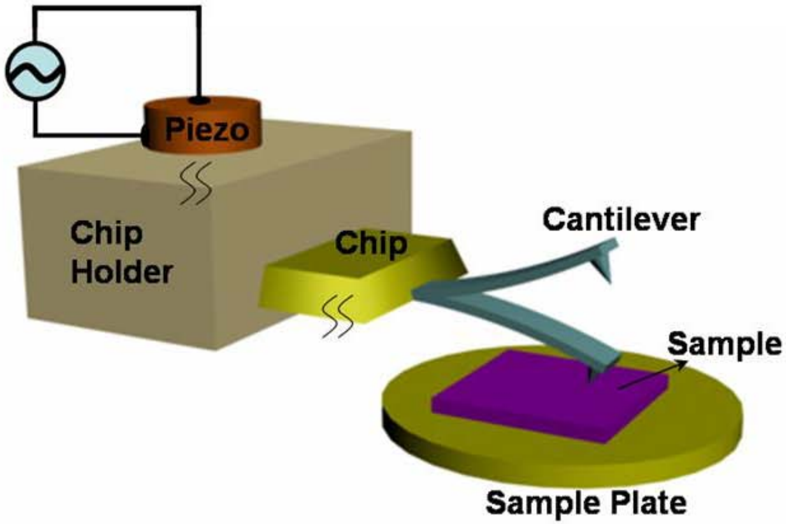
w(x,t) = A sin(ωt) ψ(x)

$$\psi(x) = -\frac{L^3}{6EI}\left(\frac{x}{L}\right)^3 x^3 + \frac{1}{2}\frac{L^3}{EI}\left(\frac{x}{L}\right)^2$$

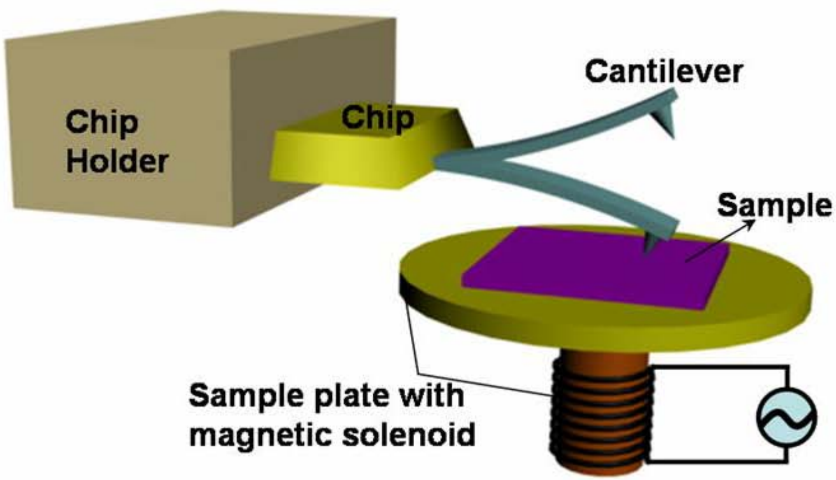
$$\frac{\theta}{\delta} = \frac{2L}{3}$$

- Tip is massive, cantilever inertia negligible
- Replace cantilever by a spring of spring constant= static bending stiffness of lever
- Cantilever oscillates such that θ/δ=2L/3

Forced vibrations



a. Acoustic excitation



b. Magnetic excitation

- Mechanical (acoustic or piezo excitation)
- Magnetic excitation
- Magnetostrictive excitation
- Photothermal excitation
- Lorentz force excitation
- Ultrasound excitation
- Direct piezoelectric excitation