

# Lecture 10

## Force distance curves II

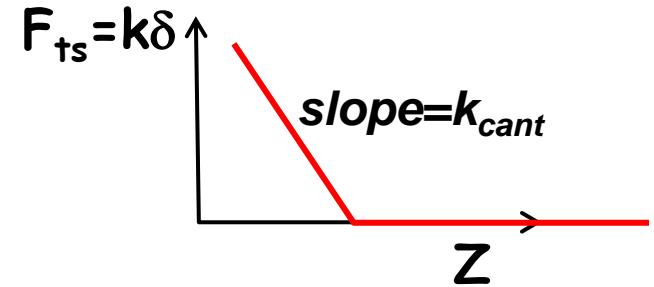
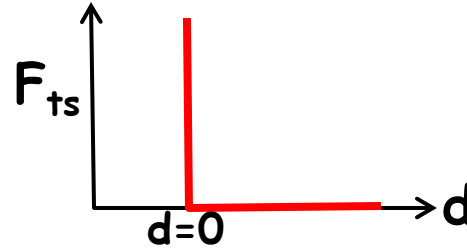
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*Birck Nanotechnology Center*

# F-Z and F-d review

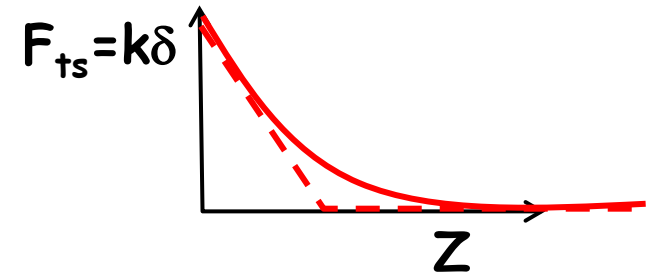
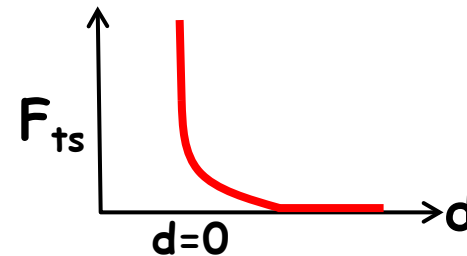
- In theory if one knows F-d then to go to F-Z:
  - For every Z solve for  $k_{\text{cant}}\delta = Fts(d)$  or equivalently solve  $k_{\text{cant}}(d-Z) = Fts(d)$   
which can be done graphically
- In experiment, given F-Z, one goes to F-d by
  - For every F, plot along the x-axis, the quantity  $d = \delta + Z$ , where Z is the Z value at that F and  $\delta = F/k_{\text{cant}}$
- 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

# Some examples of F-Z curves

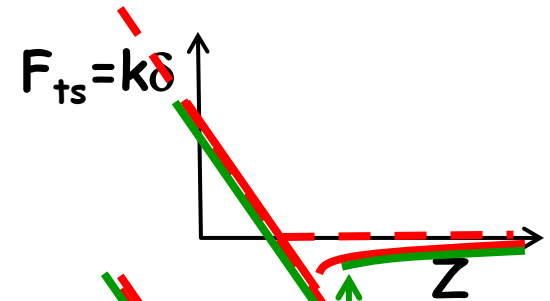
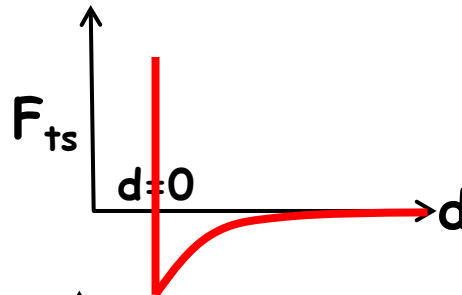
- Infinitely stiff sample, no surface forces



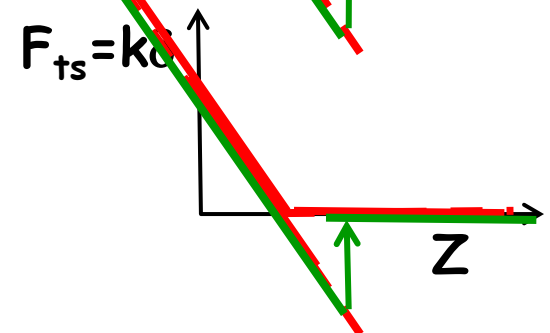
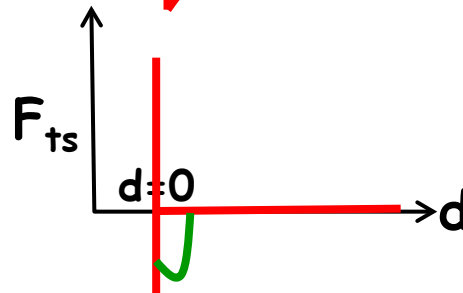
- Infinitely stiff sample with surface repulsive force



- Infinitely stiff sample with attractive VdW force

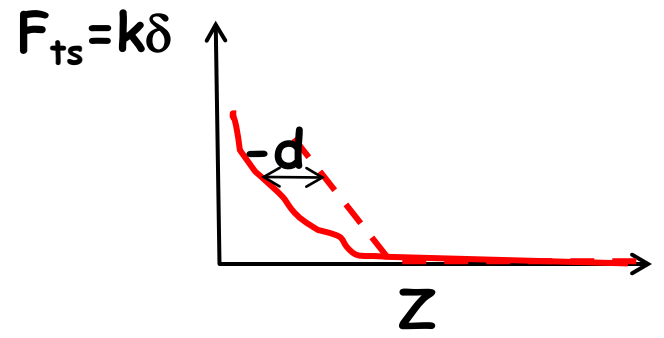
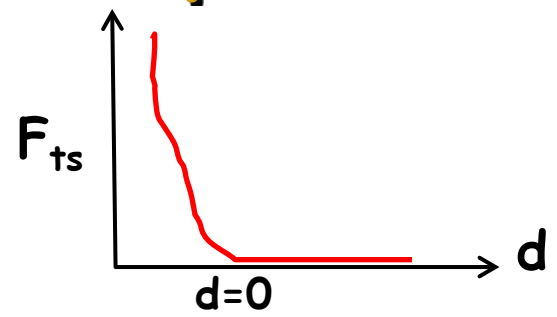


- Infinitely stiff sample with capillary force

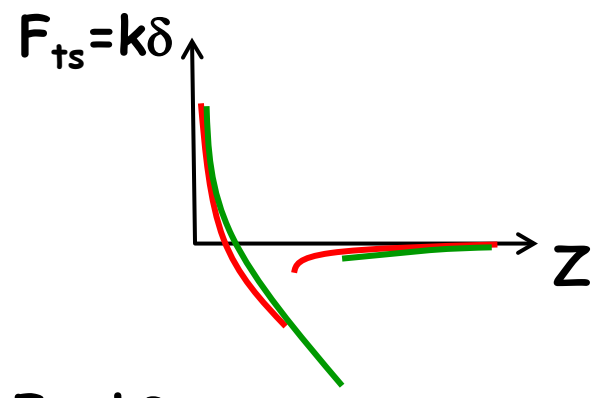
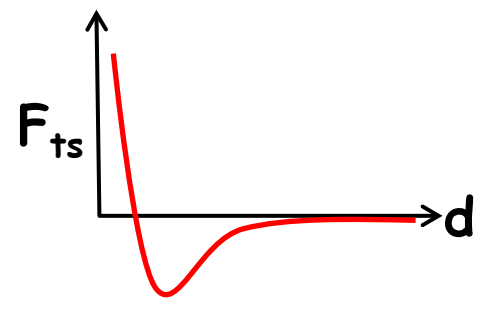


# Some examples of F-Z curves

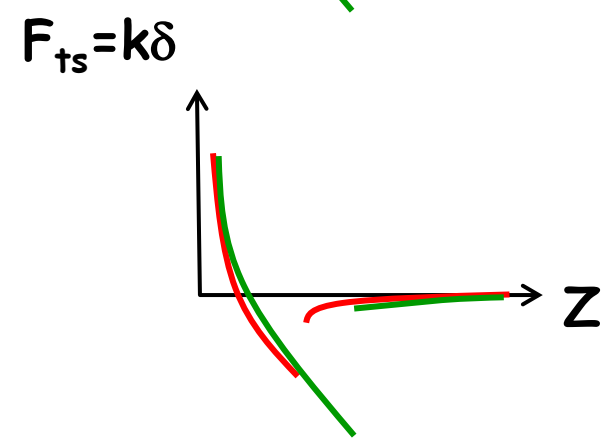
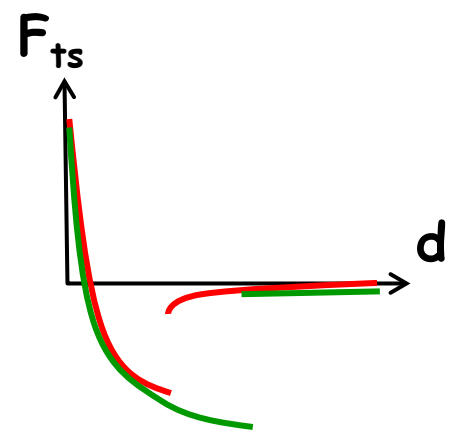
- Soft materials  
no surface forces



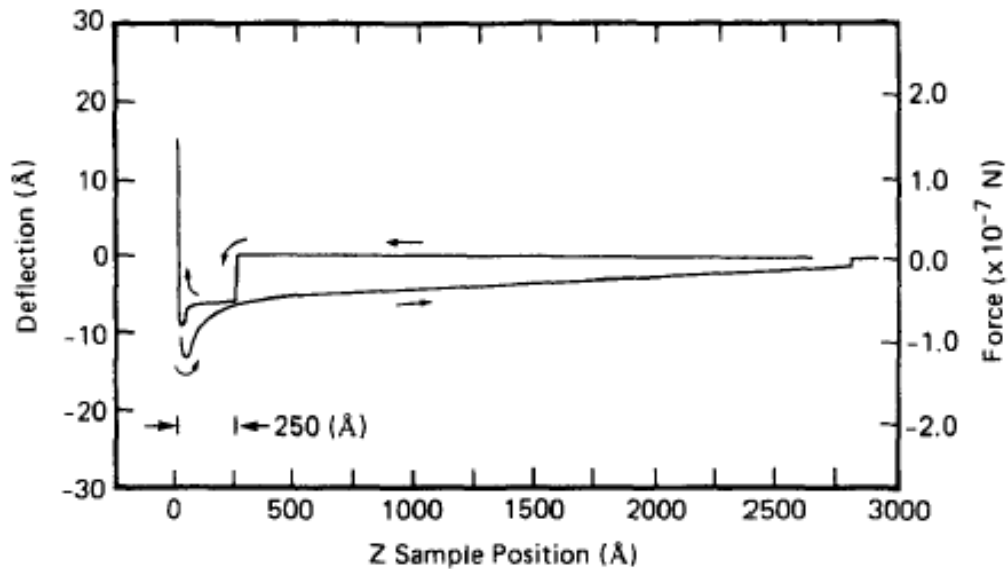
- Soft material  
with attractive  
VdW force



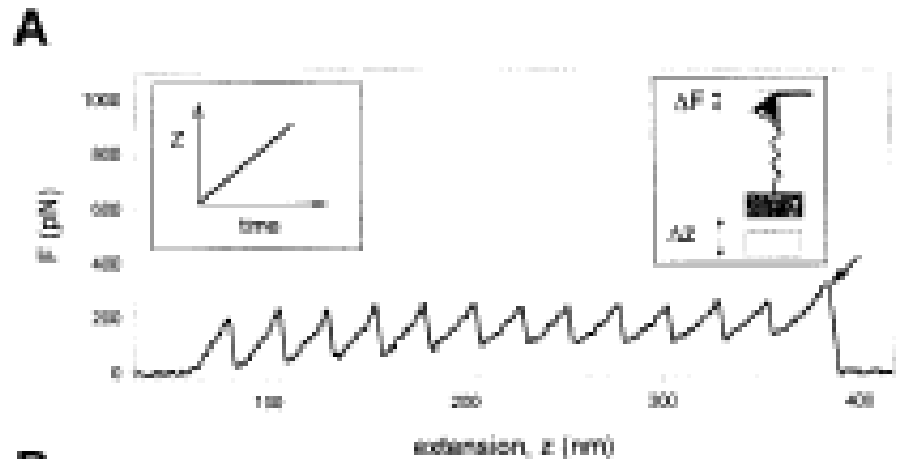
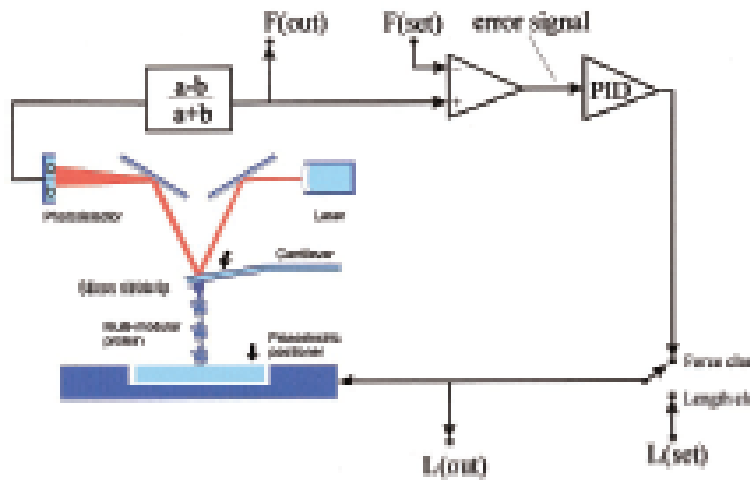
- Soft material with  
hysteretic F-d  
curve



# Other interesting F-Z curves



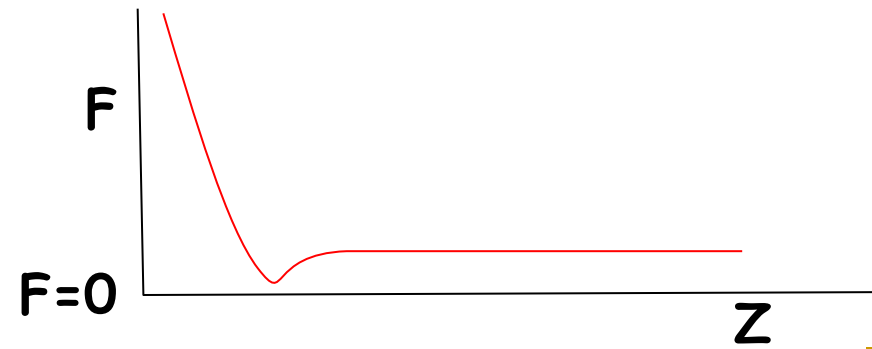
- 25 nm perfluoropolyether polymeric liquid on silicon (from Mate et al (1989))



B

- 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  $\sim 0$  far from sample
- Reflected spot size affects sensitivity

from Butt, Kappl, Cappella, in reader

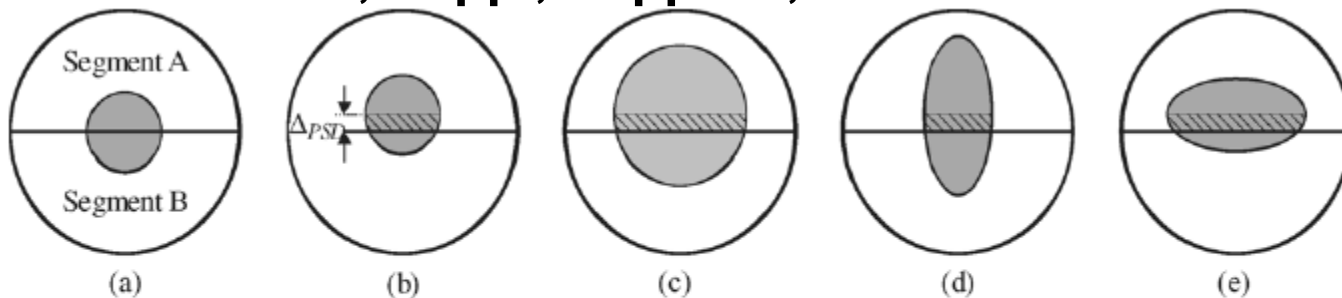
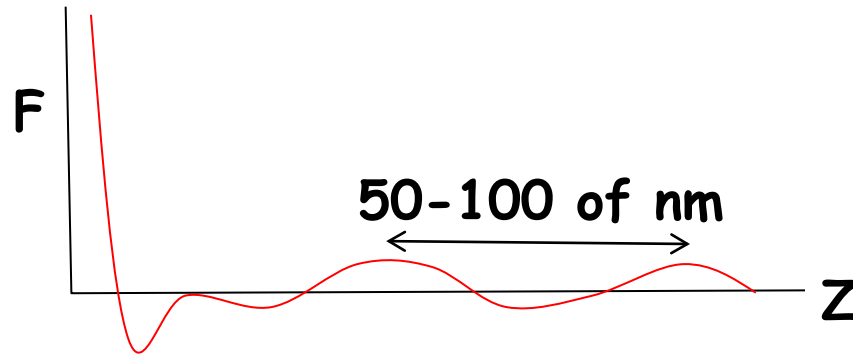


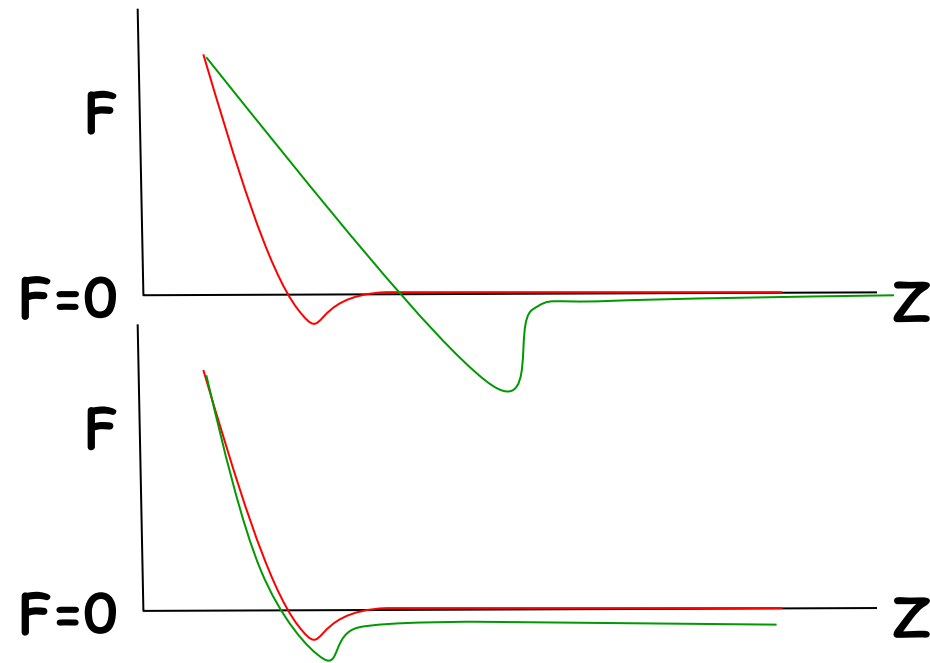
Fig. 10. The effect of laser spot shape on optical lever sensitivity. (a) A centered spot leads to zero deflection signal  $(A - B)/(A + B)$ . (b) A well-shaped rotational symmetric and small spot produces a large relative area change between the  $A$  and  $B$  photodiode segments for a given deflection. 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



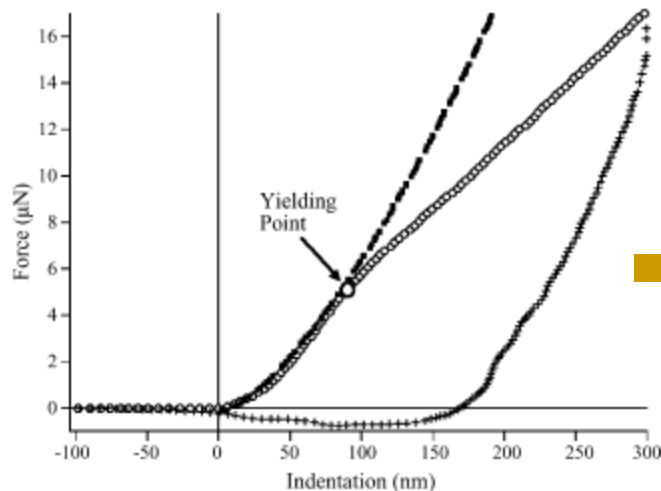
- Laser spot spilling over cantilever edge, reflecting off substrate interfering with signal back from cantilever
- Focus spot better, or use non-coherent laser. IR lasers are less coherent than others.

# Artefacts in F-Z curves



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

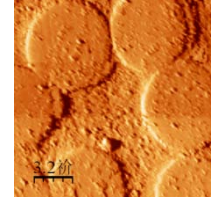
- Hydrodynamic drag - reduce speed



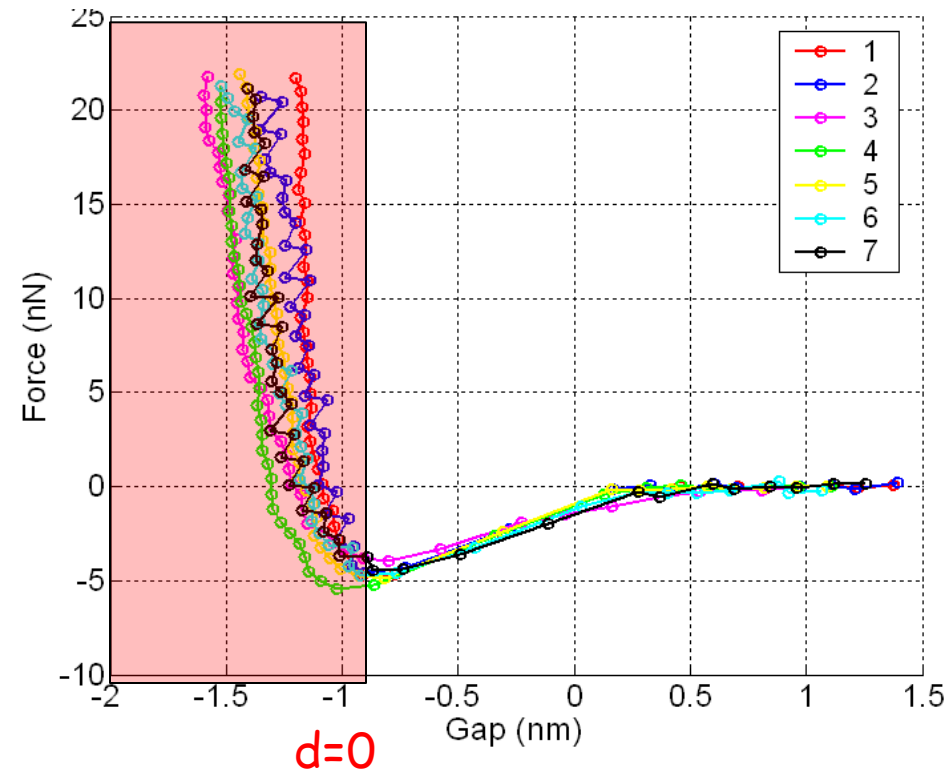
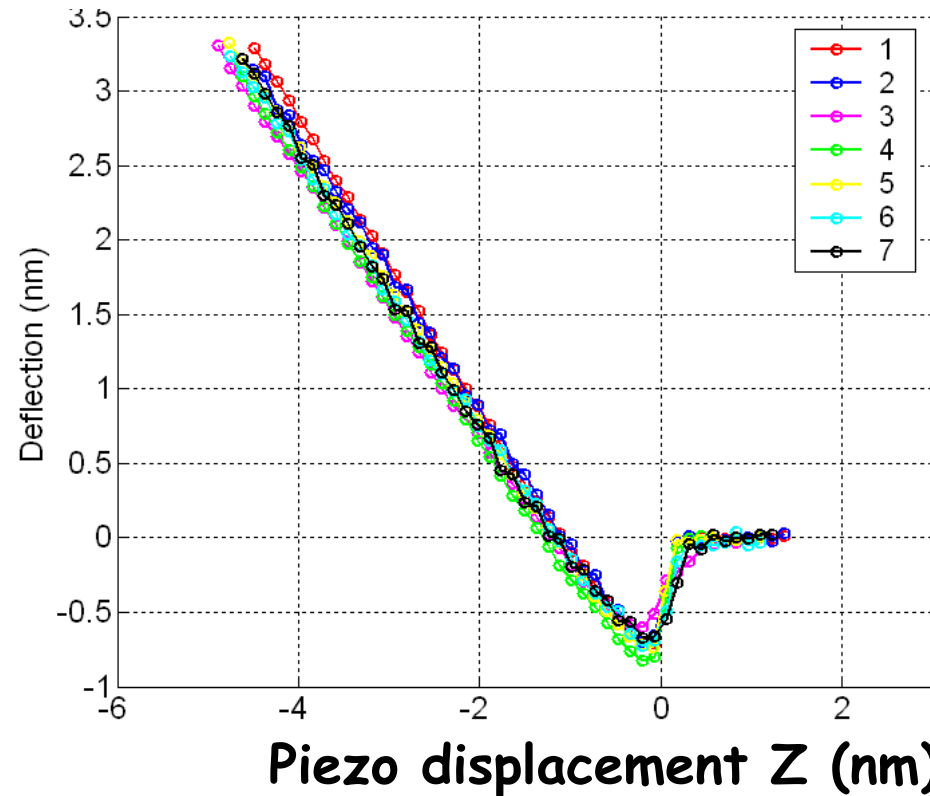
- Large indentation with plastic deformation - reduce force!



# Estimating sample elasticity and adhesion from F-Z curves

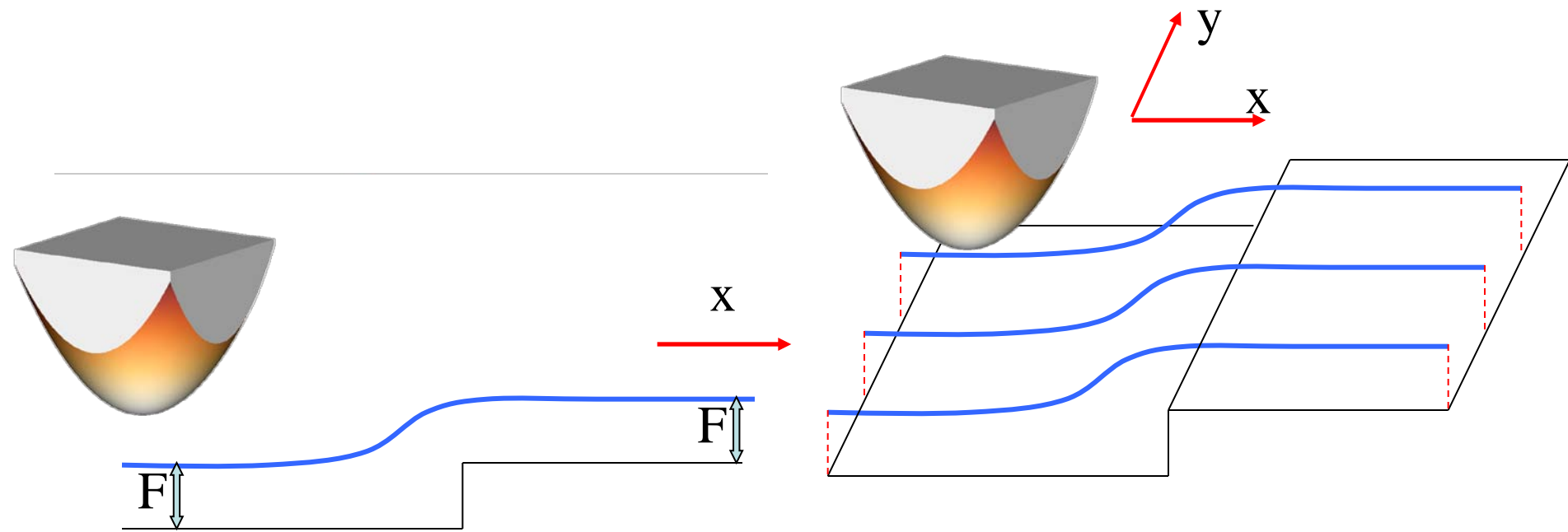


Convert deflection vs. displacement curves to force vs. distance (gap) curves



- 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  $F = -F_{ad} + (3/2)E^*sr\sqrt{R}(-d)^{3/2}$
- Make histogram of measured  $E^*$  and  $F_{ad}$

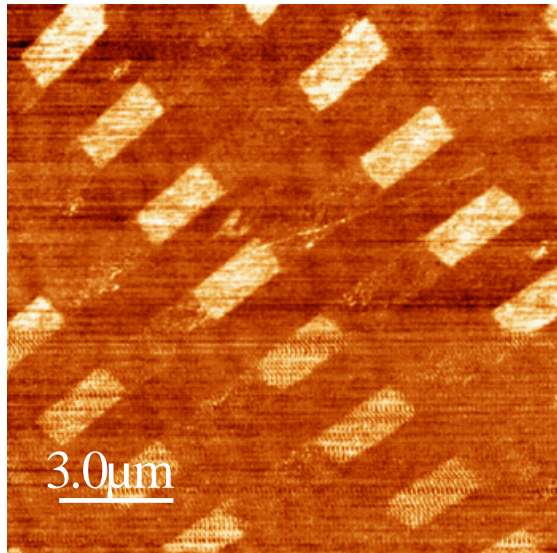
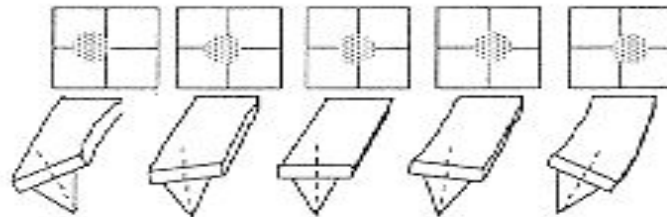
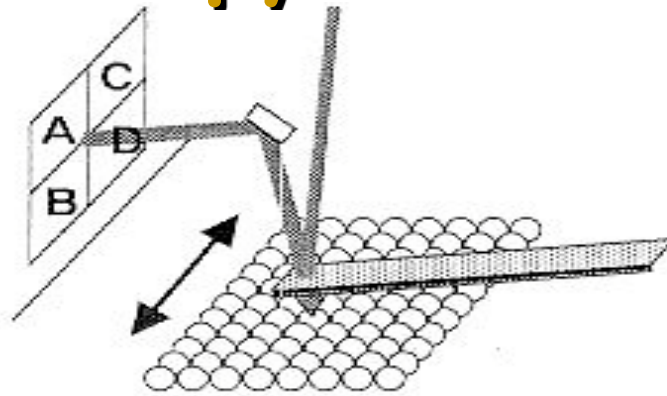
# Contact Mode Imaging



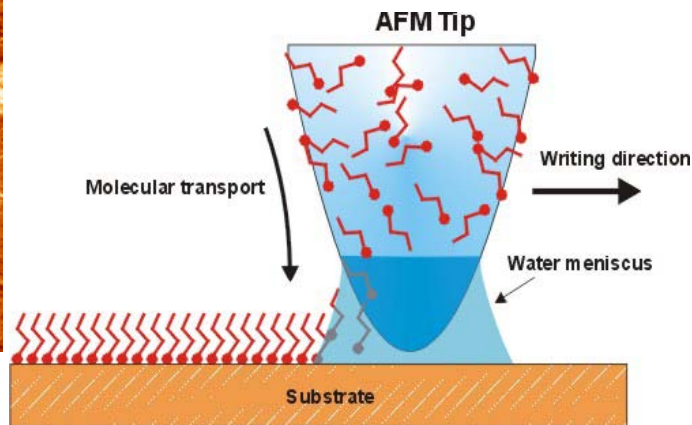
First tip contacts surface with some setpoint normal force which is kept constant during the scan

# Friction Force Microscopy

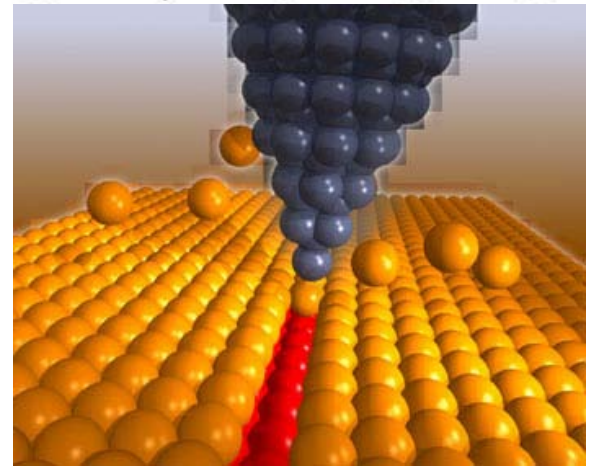
- Torsional deflections due to atomic and molecular friction
- Lateral forces are specific
- Applications to nanotribology, probe based lithography



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



[www.chem.nwu.edu/~mknggrp/](http://www.chem.nwu.edu/~mknggrp/)  
Dip-pen lithography



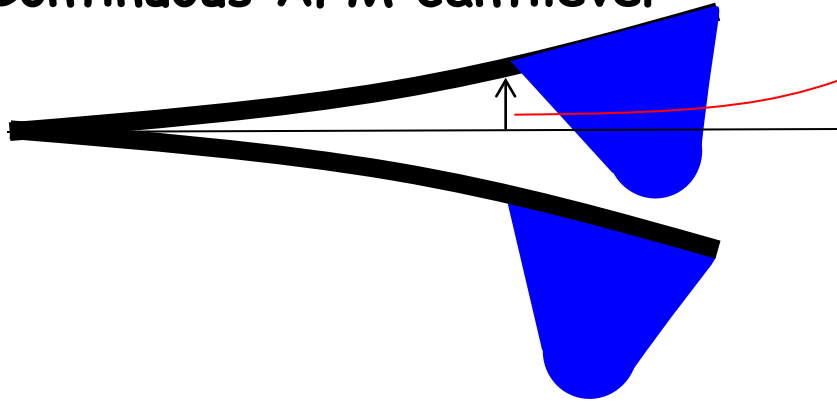
Contact mode oxidation lithography

# 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

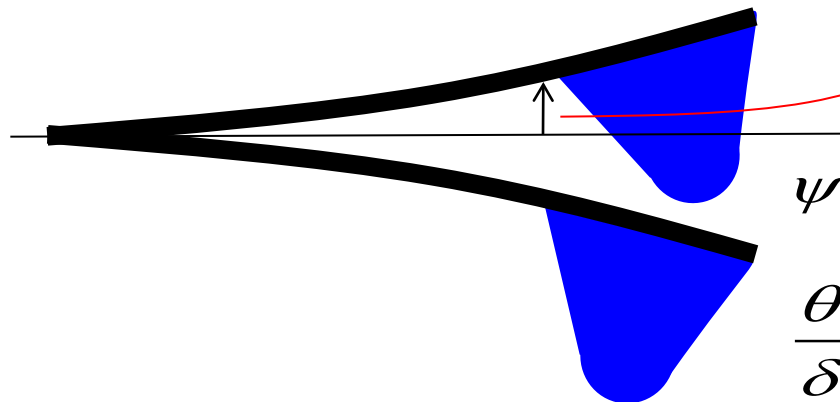


$$w(x,t) = A \sin(\omega t) \psi(x)$$

$$\theta/\delta = ?$$

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

Point mass model



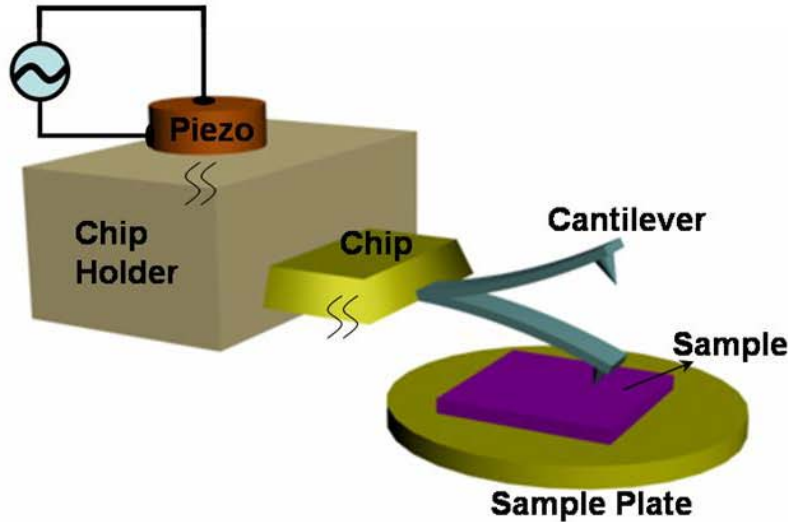
$$w(x,t) = A \sin(\omega t) \psi(x)$$

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

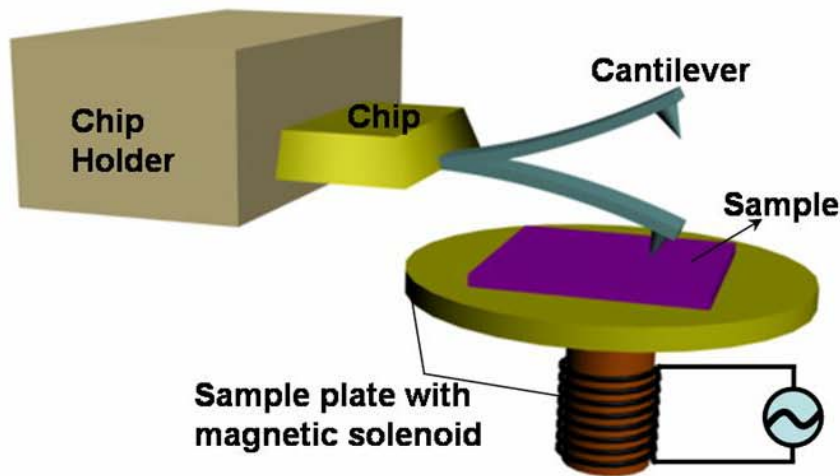
$$\frac{\theta}{\delta} = \frac{2L}{3}$$

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

# 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