Lecture 10
Force distance curves II

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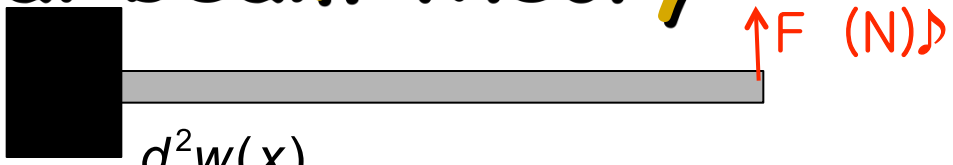
Classical beam theory

- Example2



$$EI\frac{d^4w(x)}{dx^4}=0\Rightarrow\frac{d^3w(x)}{dx^3}=c_1\Rightarrow\frac{d^2w(x)}{dx^2}=c_1x+c_2$$

$$\Rightarrow\frac{dw(x)}{dx}=\theta(x)=\frac{1}{2}c_1x^2+c_2x+c_3$$

$$w(x)=\frac{1}{6}c_1x^3+\frac{1}{2}c_2x^2+c_3x+c_4$$

Boundary conditions

$$w(0)=\theta(0)=0\quad EI\frac{d^2w(L)}{dw^2}=0\;EI\frac{d^3w(L)}{dw^3}=-F$$

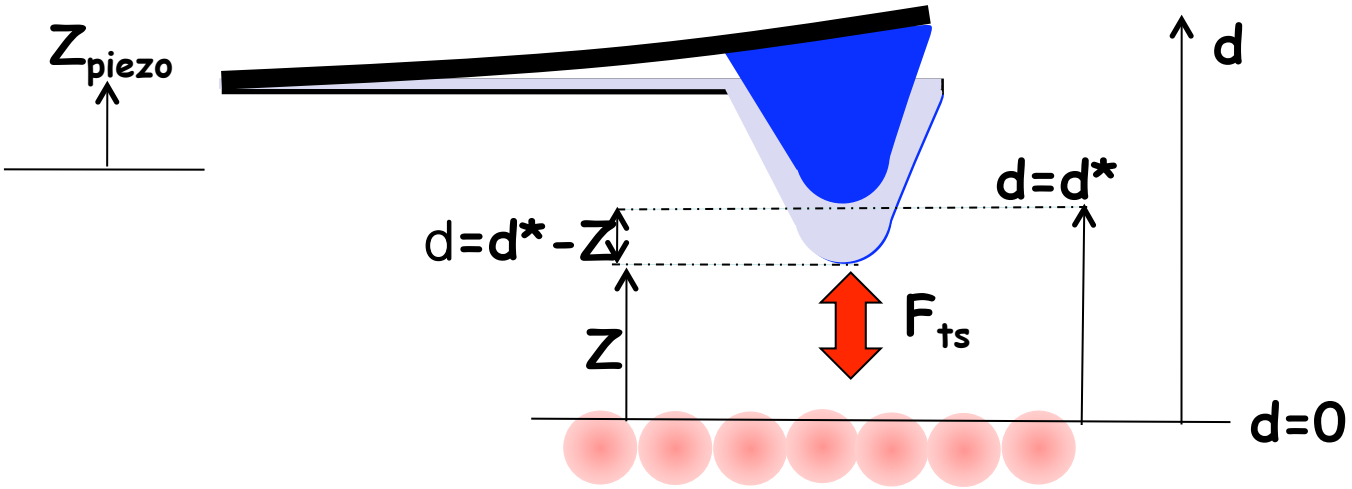
(*no point moment applied at* $x=L$)

$$\Rightarrow c_3=c_4=0,\ c_1=-\frac{F}{EI},c_2=\frac{FL}{EI}$$

$$w(L)=\delta=\frac{1}{3}\frac{FL^3}{EI},\quad\theta(L)=\theta=\frac{1}{2}\frac{FL^2}{EI}\Rightarrow\frac{\theta}{\delta}=\frac{2}{3}L$$

$F=k\delta$, *where* $k=\dfrac{3EI}{L^3}$ *is the static bending stiffness of thecantilever*

Equilibrium positions during approach and retraction



- How do d* and d change as Z is reduced during approach and then retracted?

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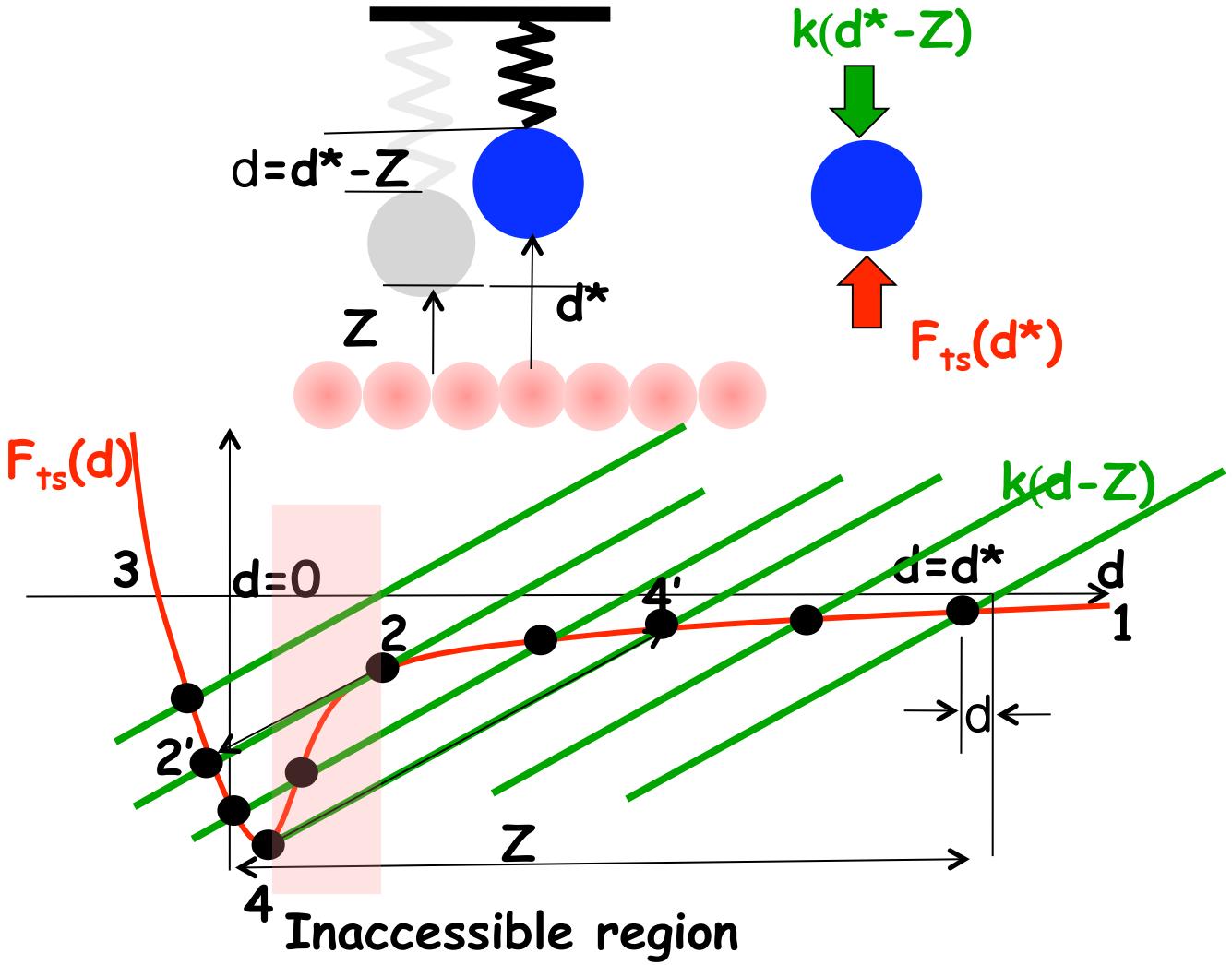
Equilibrium positions during approach and retraction



- With soft cantilevers (small k) it is not possible to measure entire 'd' range

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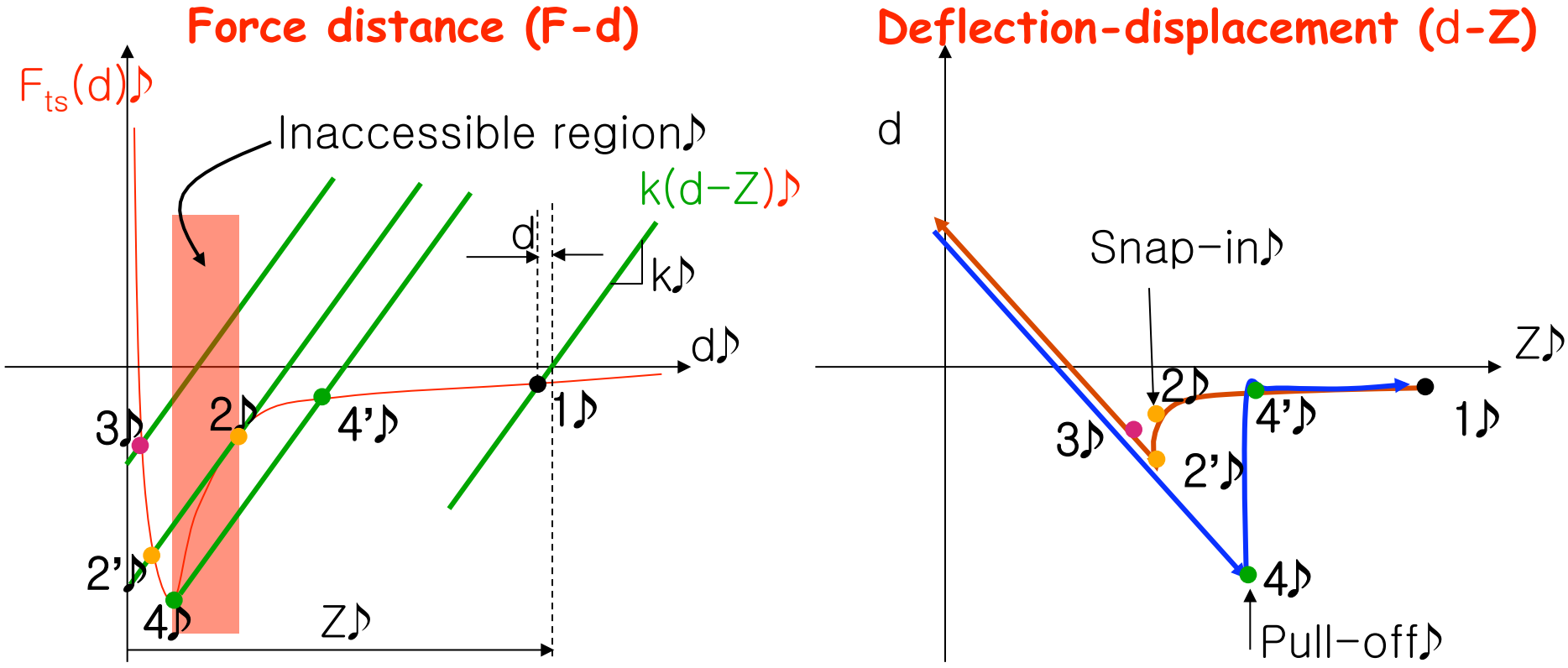
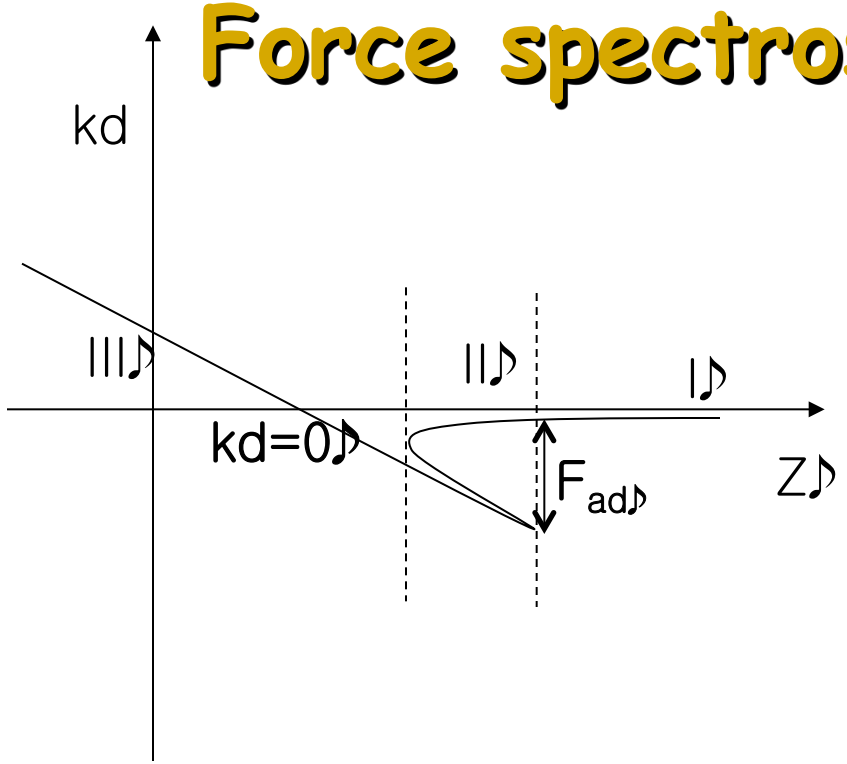
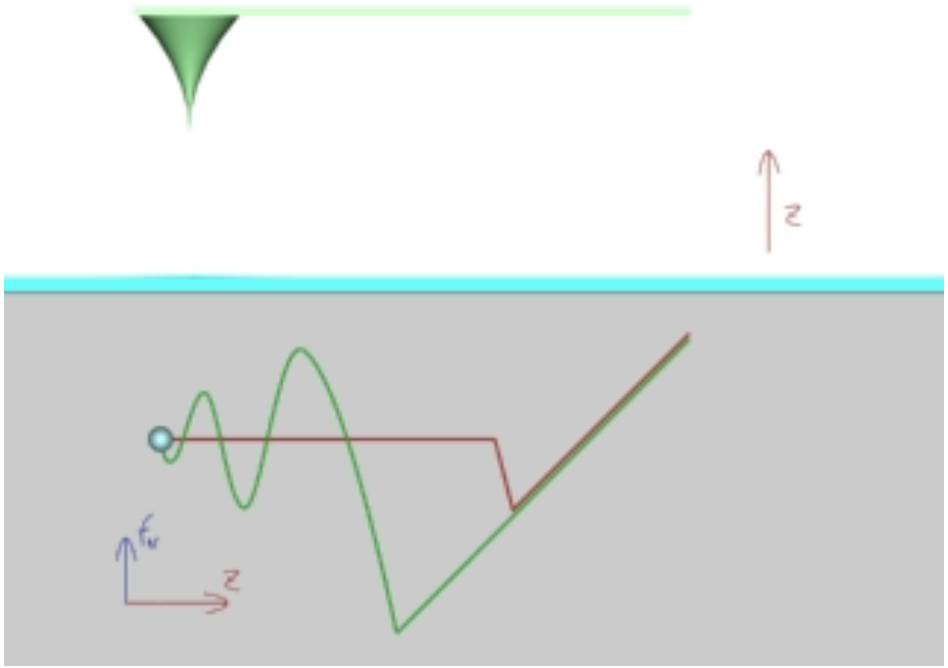
Force distance & force-displacement



- Note that hysteresis occurs in the d-Z curve between approach and retraction even though $F_{ts}(d)$ in conservative

Force spectroscopy - summary



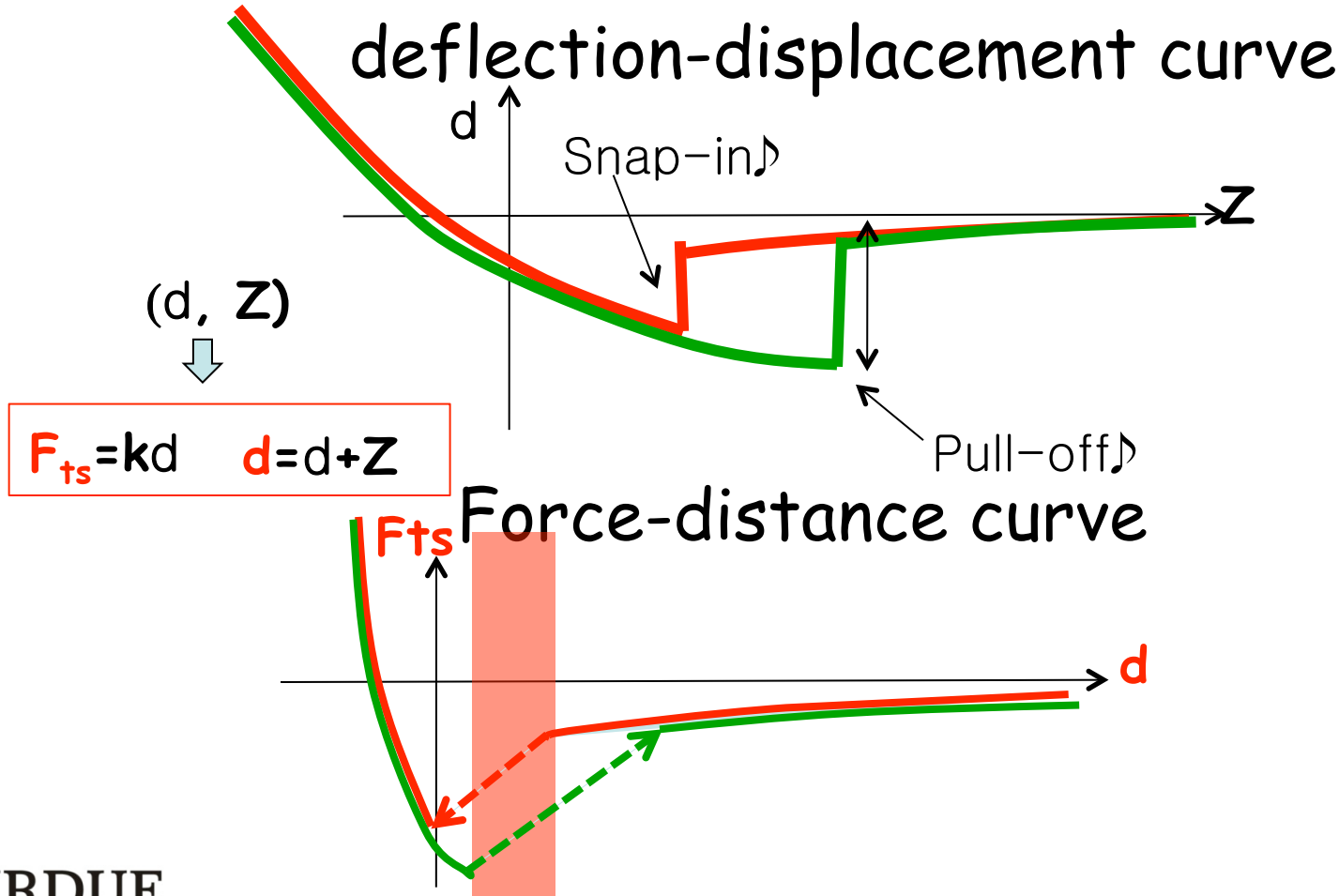


- Three distinct regions
- Pull-off force ~ F_{Ad} which can be converted to W_{132} (work of adhesion between two infinitely wide planes)
- Slope in III is good measure of repulsive forces (local elasticity)
- If k is known then from the static-force distance curve, F(d) can be calculated for all d except for inaccesible range near snap -in

Animation courtesy J. Gomez-Herrero, UAM, Spain

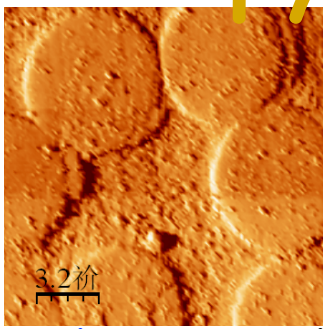
Force-displacement & force distance

- In a typical d-Z experiment in AFM, the cantilever approaches/retracts from the sample while recording the cantilever deflection.
- However in force spectroscopy we are interested in converting this to a force-distance curve i.e. F_{ts} vs. d. How to convert?

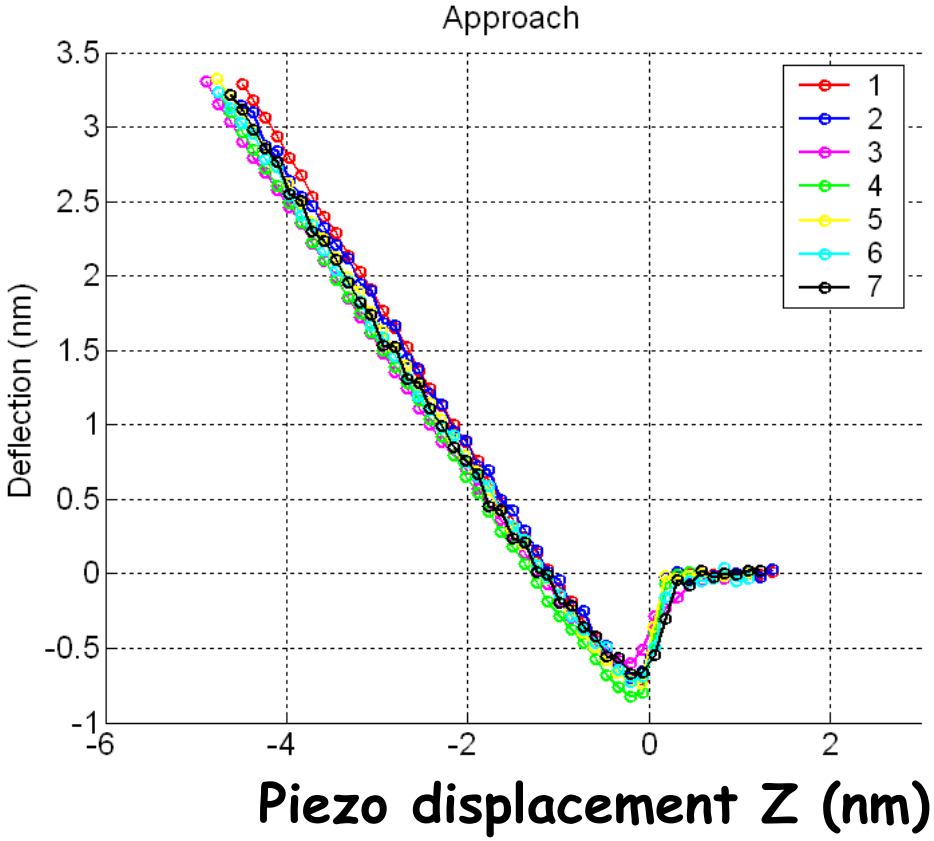


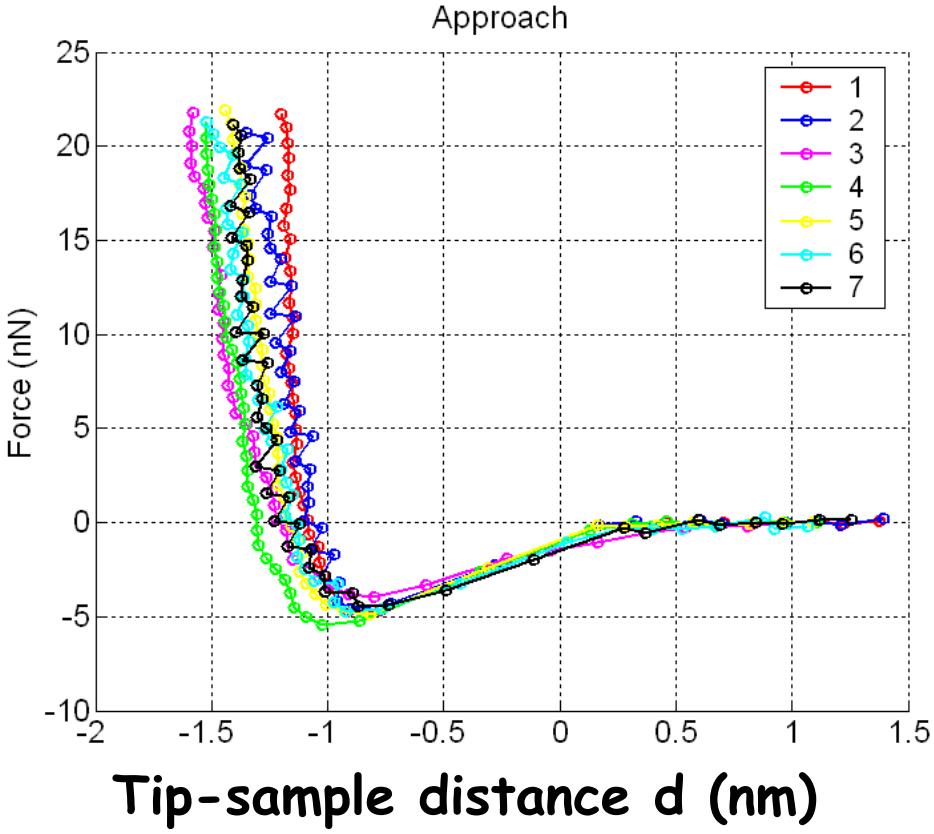
- Important: d is only known to within an arbitrary constant!

Force spectroscopy – an example



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





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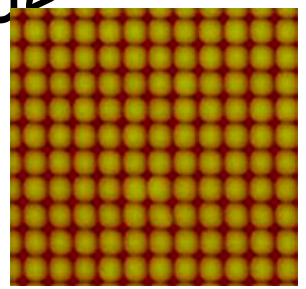
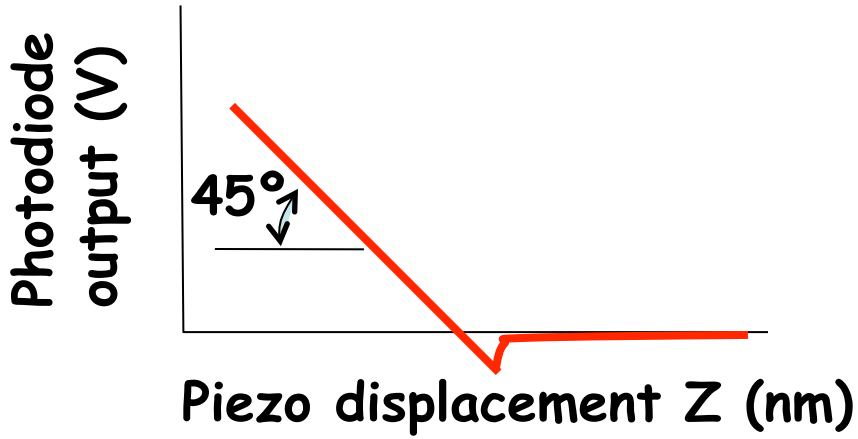
Often d axis is recentered to zero where force is a minimum

Three important calibrations

- Z-piezo calibration: By scanning a sample of known height (callibration grating) in contact mode



- Cantilever deflection calibration: d-Z curve on a hard sample



- Cantilever stiffness calibration (to be discussed later in class)

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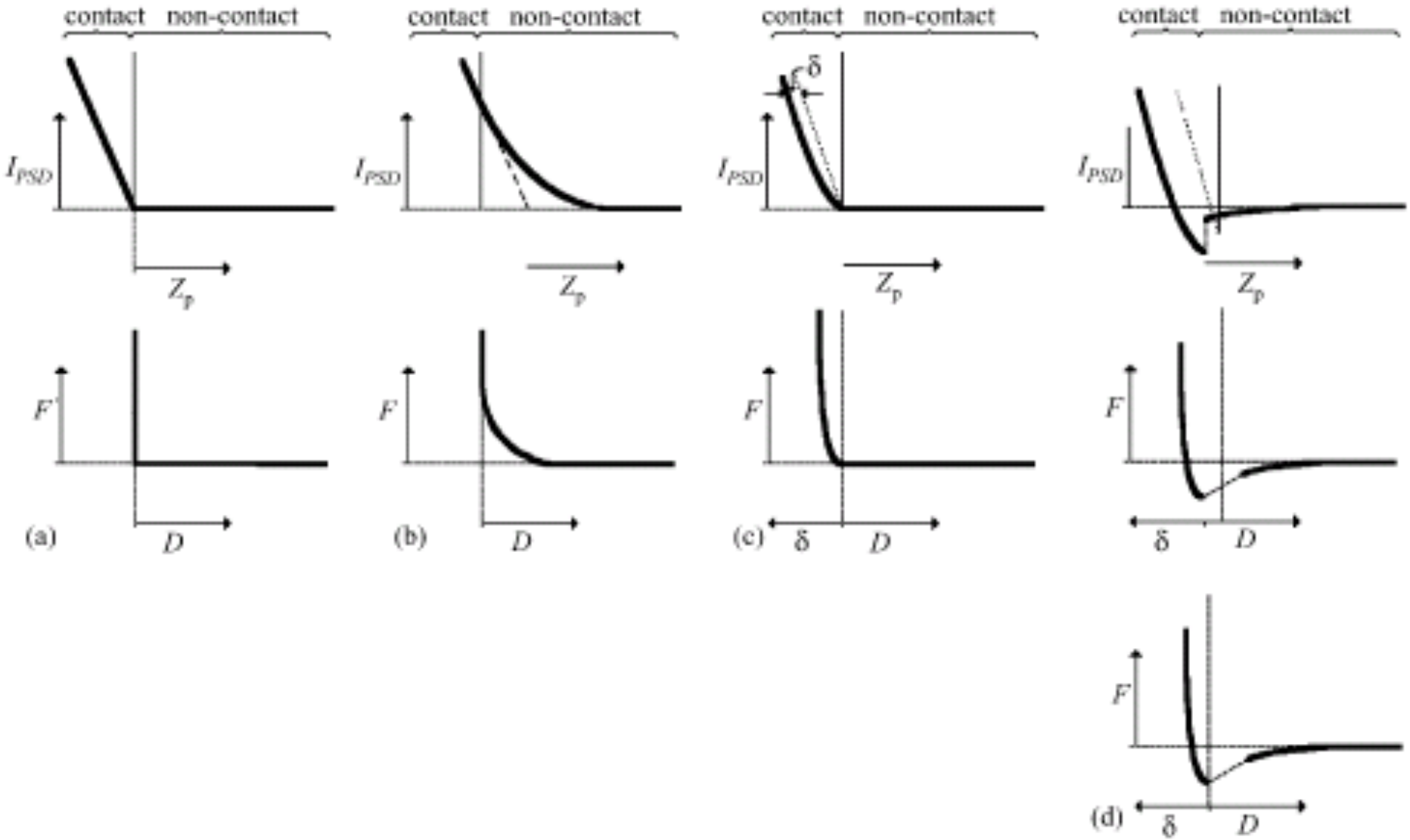
Some other interactions



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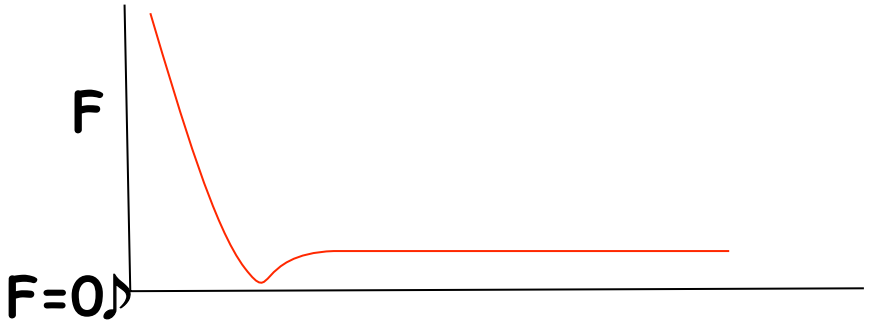
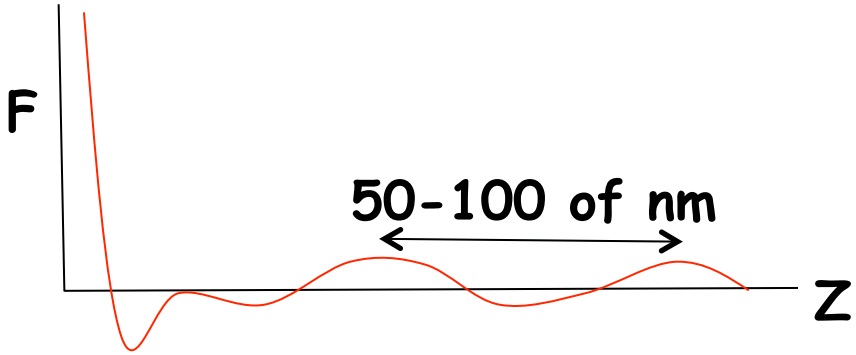
Artefacts in F-Z curves

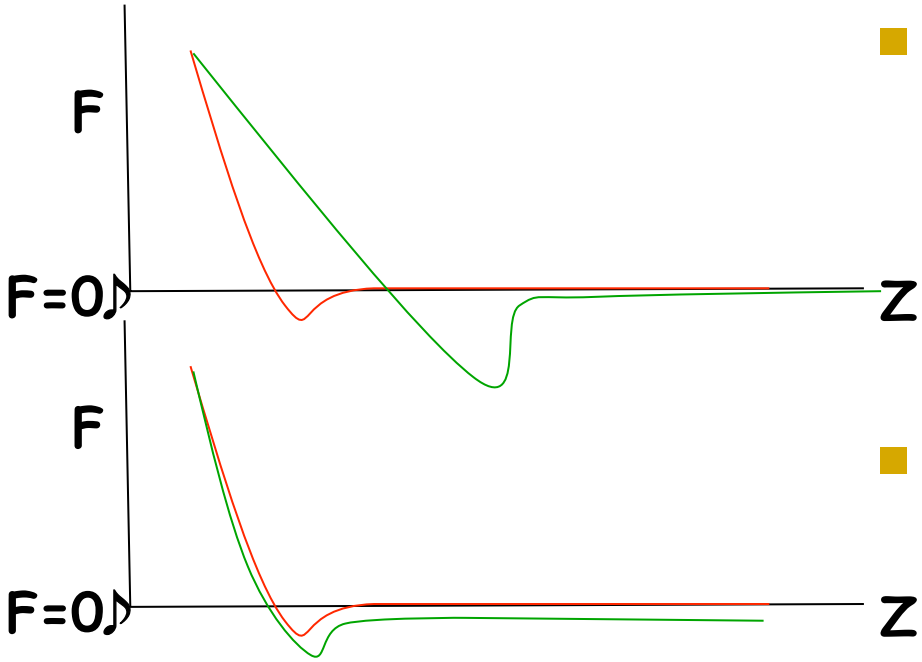


- Laser spot not centered in photodiode – recenter so that photodiode output is ~0 far from sample

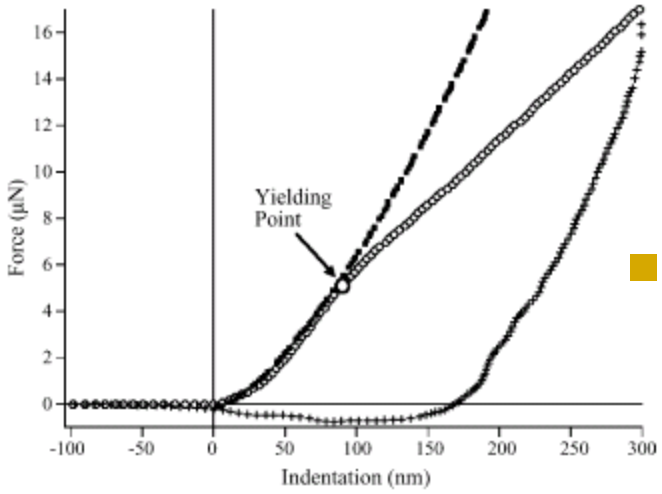


- Laser spot spilling over cantilever edge, reflecting o ff substrate interfering wi th signal back from ca ntilever – Focus spot be tter, or use non-coherent la ser

Artefacts in F-Z curves



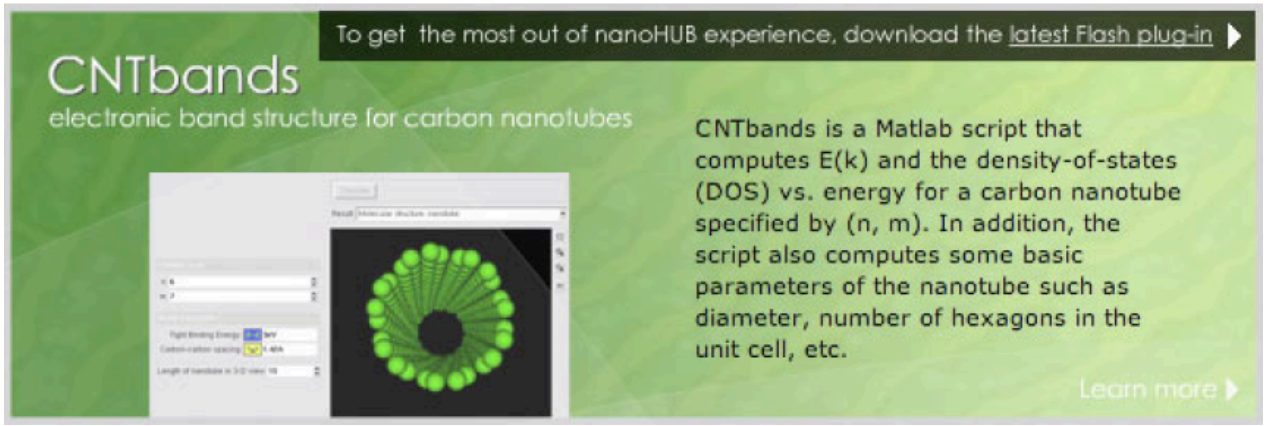
- Z piezo hysteresis – warm up piezo first, use closed loop piezos
- Hydrodynamic drag- reduce speed

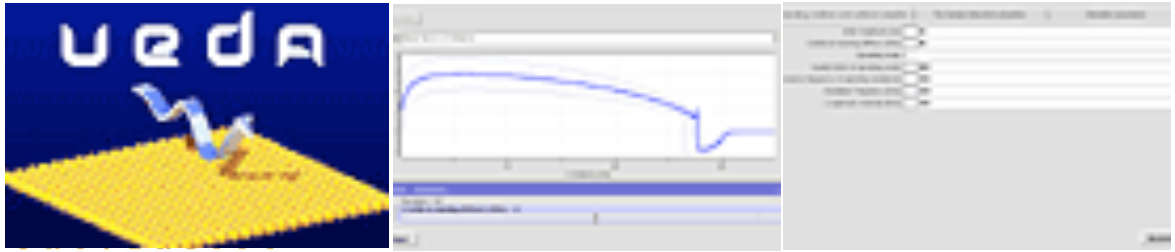


- Large indentation with plastic deformation – reduce force!

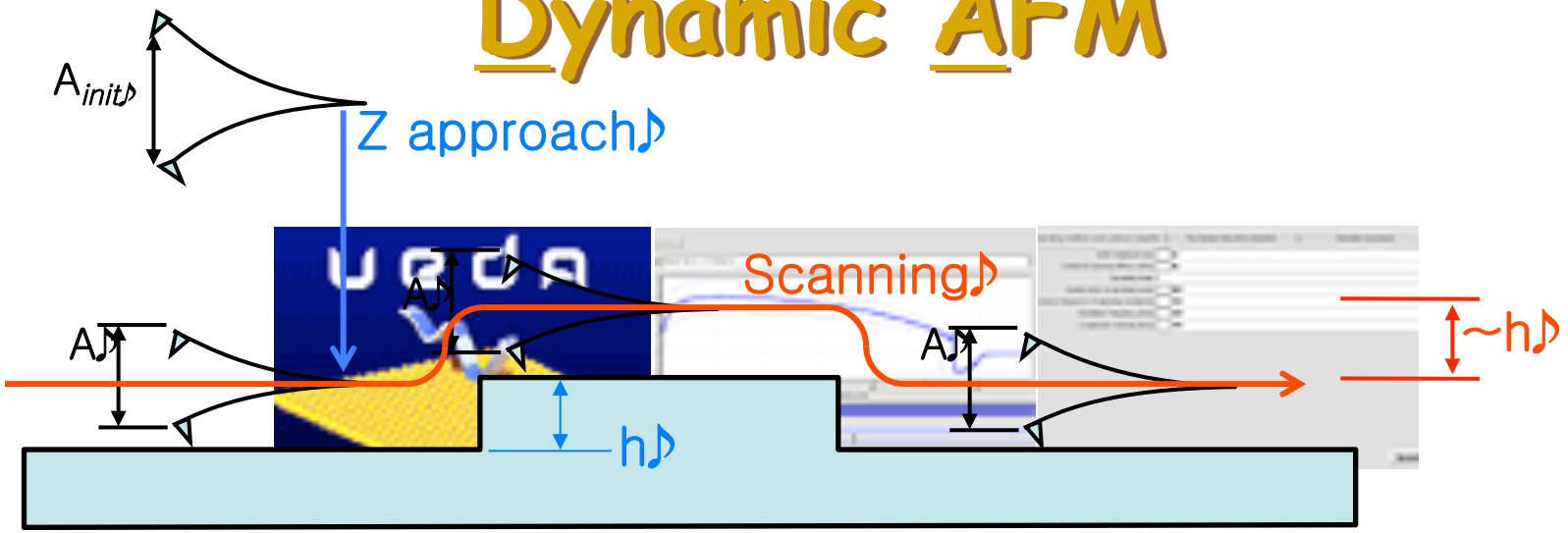
Network for Computational Nanotechnology (NCN)

- www.nanohub.org
- Jobs run on the national Teragrid and supercl usters
- Nanoelectronics, nanoelectromechanical syst ems, biology/nanomedicine
- Thousands of users





VEDA- Virtual Environment for Dynamic AFM



- Many tools released on www.nanohub.org[1]: F-Z, Dynamic Approach Curves, FM-approach, Amplitude Modulated Scanning
- Extension to liquids (natural, bimodal, higher harmonics etc)
- Accurate numerical simulations , convenient input parameters
- Freely accesible, web-based
- Simulations run off national teragrid and Purdue clusters
- Extensions to EFM, MFM, user specified forces on the horizon

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Next class

- VEDA tutorial (rm 236 ME building) taught by Daniel Kiracofe and John Melcher