Lecture 20
VEDA: Scanning controls

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Why use VEDA scanning simulations?

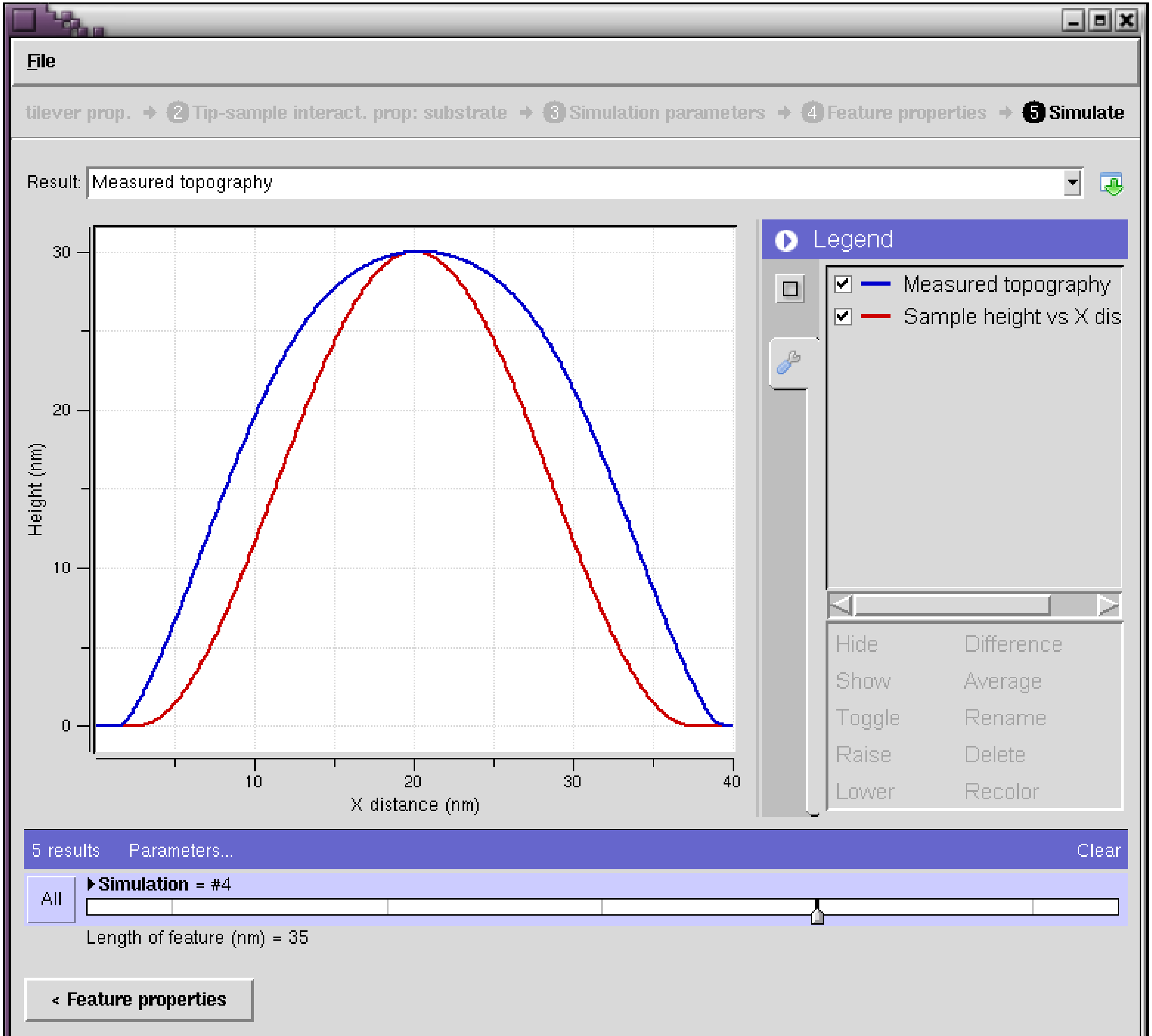
- Understand the effects of various parameters such as feedback gains and setpoint so that you can quickly and easily optimize your images when scanning.
- Understand common imaging artifacts so that you can recognize them in your images

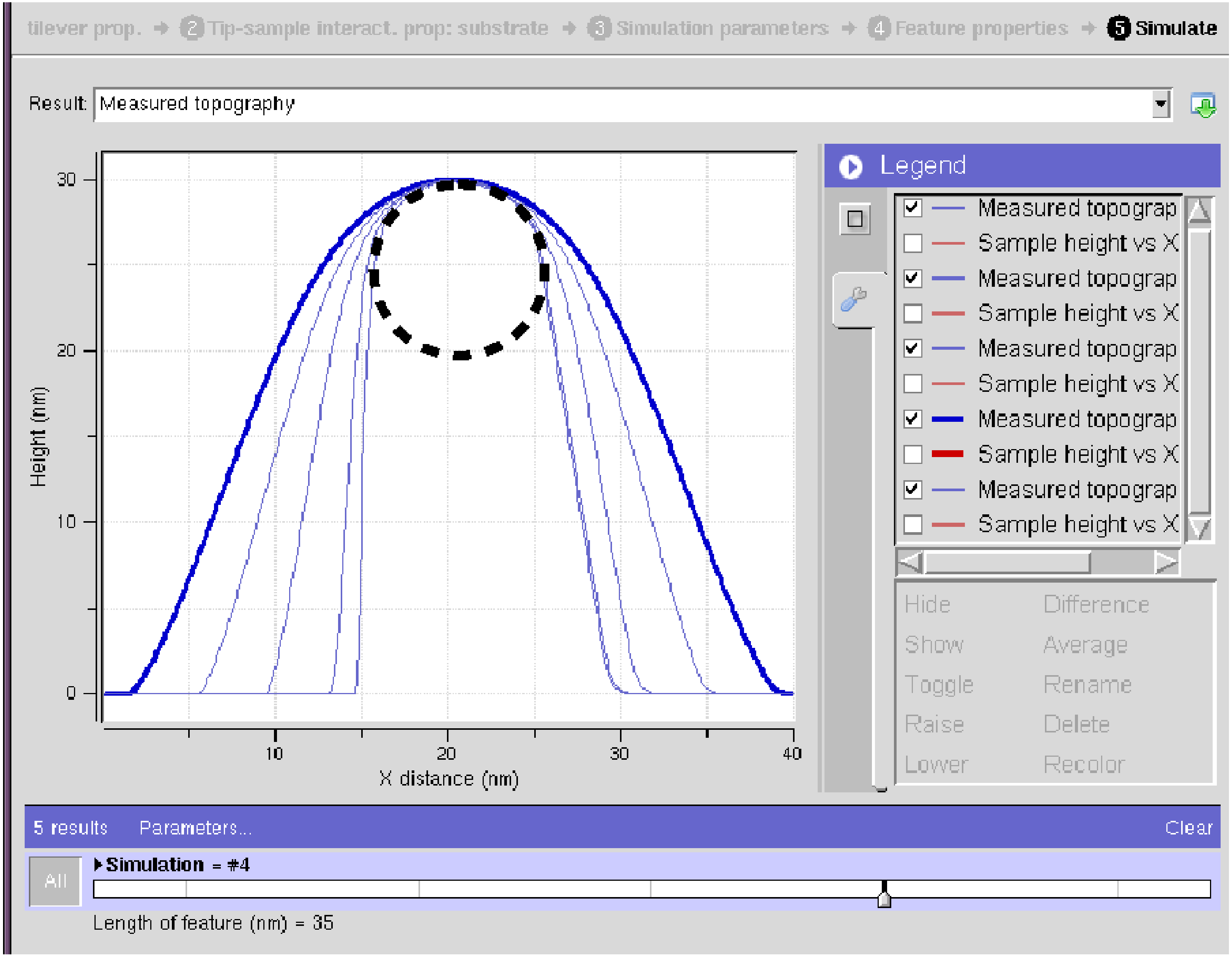
Outline

- Contact mode scanning tool
  - Basic operation and features
  - Demonstration: Tip-sample convolution
  - Scanning parameters: controller gains, setpoint, speed
- Amplitude modulated scanning
  - Demonstration of basic operation and features
  - Phase contrast
  - Jumps between attractive and repulsive mode

Tip-sample geometry convolution

- Question: what happens to your image as the feature size gets much smaller than your tip radius?
- Demonstration:
- Start with a 5 nm tip radius, substrate length of 40 nm, sinusoidal feature of length 35 nm, and include geometric convolution
- Reduce the feature width down to 1 nm over a few runs and see what happens.


File
tilever prop.
2 Tip-sample interact. prop: substrate
3 Simulation parameters
4 Feature properties
5 Simulate
Result: Measured topography
Legend
Measured topography
Sample height vs X dis
Hide
Difference
Show
Average
Toggle
Rename
Raise
Delete
Lower
Recolor
Height (nm)
X distance (nm)
30
20
10
0
10
20
30
40
5 results
Parameters...
Clear
All
Simulation = #4
Length of feature (nm) = 35
< Feature properties



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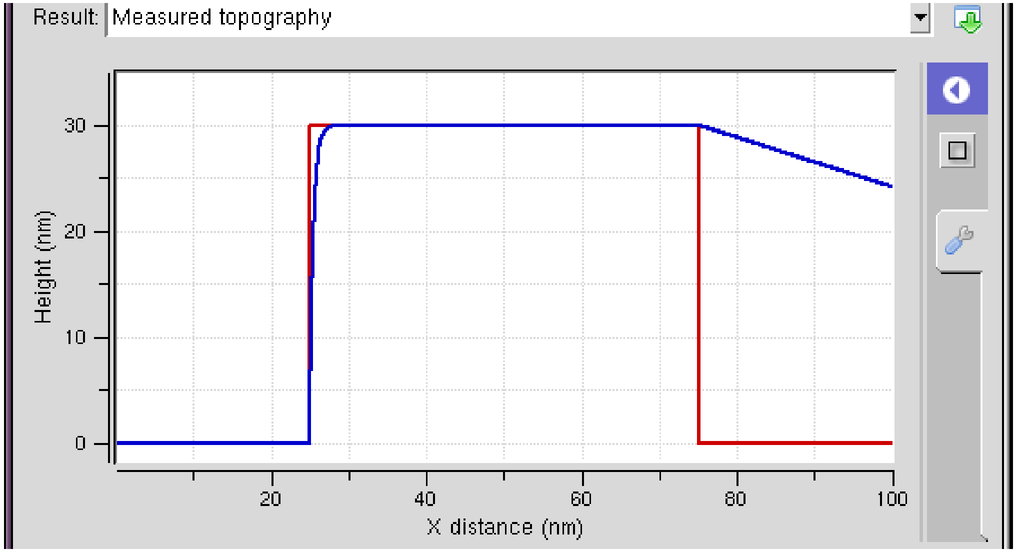
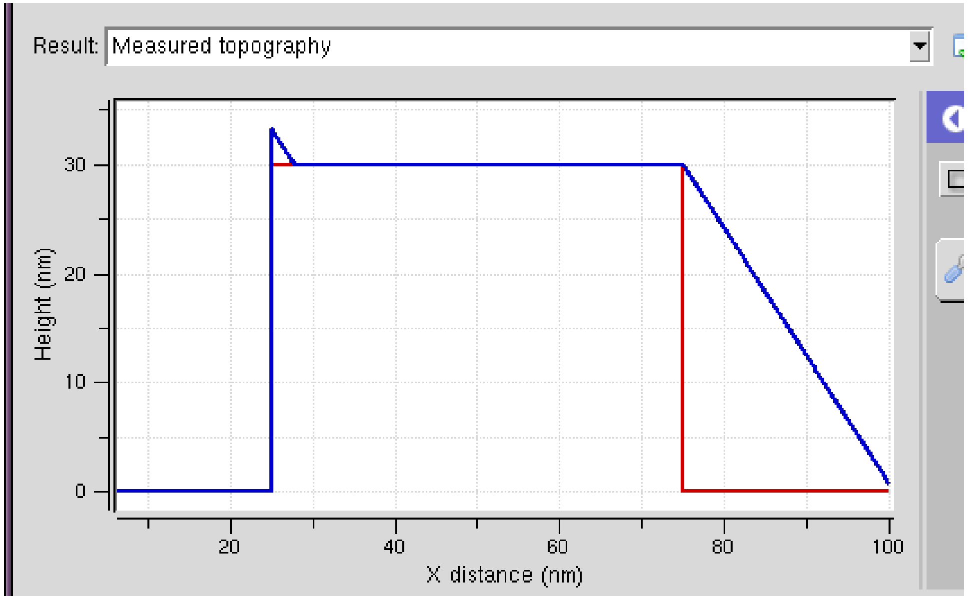
Effects of controller gains: “easy” topography

- Sinusoidal features are “easy”, because topography is continuous, smooth.
- Good imaging is possible with pure integral gain and zero proportional gain
- Increasing gain gets better image, but if you go too high, controller becomes unstable.
- Demonstration: defaults except 100 lines/s, increasing integral gain

Setpoint and forces

- Defaults except: Hertz, step, setpoint 0.1 nm
- Steps are more difficult – discontinuous. rise time & parachuting
- How to reduce parachuting?
- Increasing integral gain: 0.04 -> 0.5. tradeoff: closer to instability, overshoot at leading edge
- Increase setpoint: 0.1 -> 1 nm. tradeoff higher mean forces
- Slow down scan, 10 lines/s -> 3
- Proportional gain: reduces overshoot/slow rise time





Problem

Start with all the defaults except:
tab 3: substrate length 40 nm,
tab 4: feature = cylinder, dia = 20 nm, height = 20 nm

- Can you optimize the imaging parameters?
- Change control P & I gains, setpoint, and scan speed.
- Try to keep measurement error at X=11 and X=31 under 0.2 nm, and keep peak interaction force under 2.5 nN.
- Obviously if scan speed is very very slow, this will be easy to meet, so see how fast you can scan and still meet the requirements.

Outline

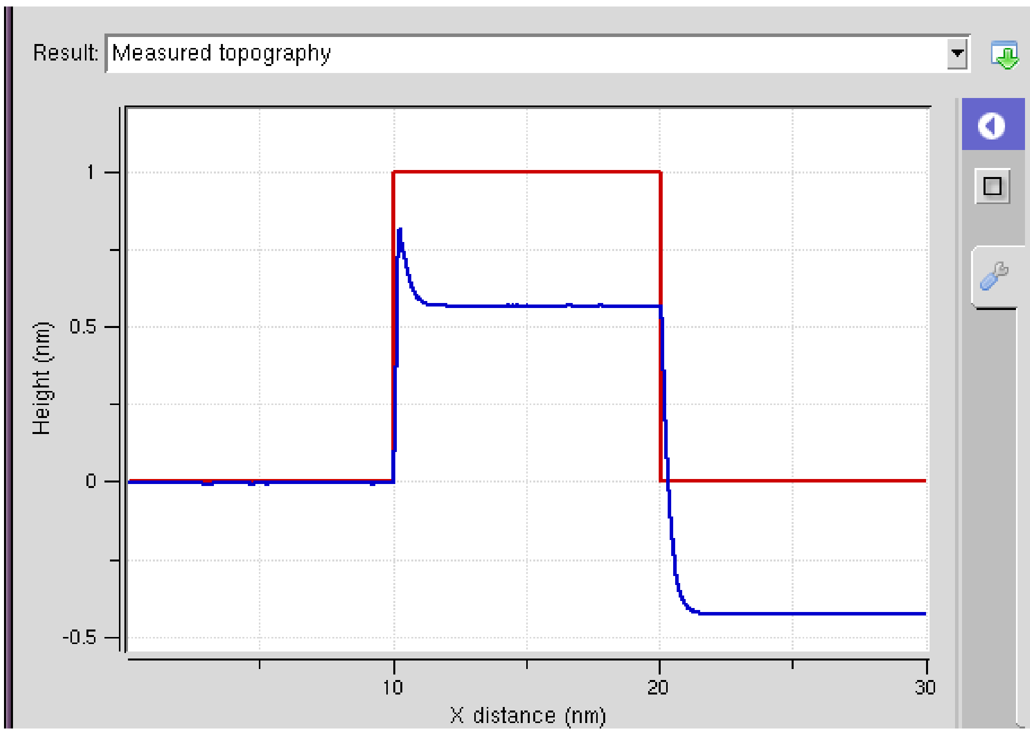
- Contact mode scanning tool
  - Basic operation and features
  - Setpoint and forces
  - Tip-sample convolution
  - Effect of controller gains
- Amplitude modulated scanning
  - Demonstration of basic operation and features
  - Phase contrast
  - Jumps between attractive and repulsive mode

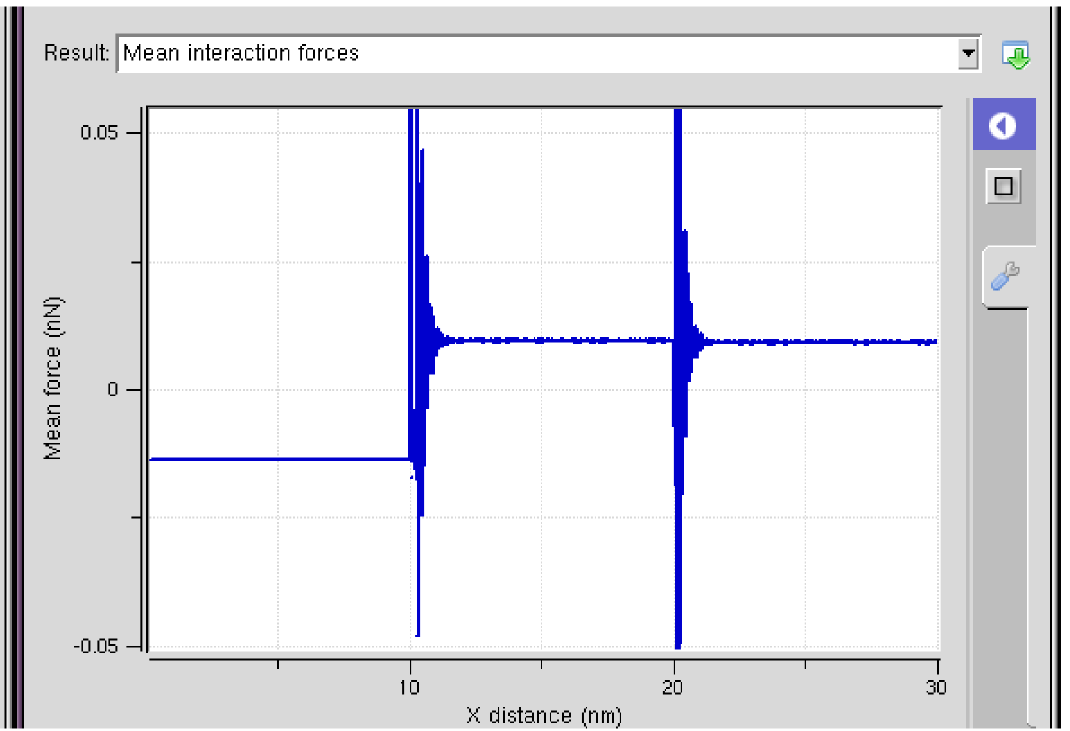
AM scanning

- Advantages: tip-sample forces much reduced over contact mode (especially lateral forces)
- New ability: multiple vibration properties such as amplitude, phase, allow creating many different types of imaging modes, obtaining information about sample composition
- Complexity: must consider attractive vs. repulsive regimes, data interpretation may be quite difficult.

Demonstration: attractive vs. repulsive

- amplitude setpoint has same properties as deflection setpoint in contact mode: tradeoffs between controller response and mean force:
- additionally affects imaging regime
- AMS ex 3, setpoint 0.6, sample H = 3.0e-20





Phase contrast

- In the simplest possible behavior, tip motion is a sine wave, which can be described by three numbers: frequency, amplitude, and phase.
- In AM-scanning, frequency is fixed, amplitude is controlled by Z feedback, but phase is not controlled.
- Variations in phase can give us information on the sample

Problem

While imaging a two component-blend polymer sample with a tapping mode cantilever in air, how does the phase contrast image depend on the viscoelastic properties of the two blends?

Load AMS example 2

Make setpoint=0.6, Kp=0.1

Choose DMT with viscoelastic interaction model (H=10-19 J, Fad=2 nN)

1) Make $E_{feature}$=5 GPa $E_{substrate}$=1 GPa, but $visc_{feature}$=$visc_{substrate}$ =0 Pa-s– Do you see phase contrast?
2) Make $E_{feature}$=5 GPa $E_{substrate}$=1 GPa, but $visc_{feature}$=100 Pa-s $visc_{substrate}$ =1 Pa-s– Do you see phase contrast?
3) Make $E_{feature}$=5 GPa $E_{substrate}$=1 GPa, but $visc_{feature}$=1 Pa-s $visc_{substrate}$ =100 Pa-s– Do you see phase contrast?
4) Explain your results

Problem

- You are scanning a MW CNT (diameter 10nm, E eff=20 GPa on a Silicon surface)
- Start by loading Example 1 in AMS tool
- tab 1: start with 33 line/s (decrease simulation time)
- tab 2: Assume effective Hamaker const on Si $=10^{-19}$
- tab 3: modify substrate len = 15
- tab 4: set feature len = dia = 10. E = 20, H = 10^{-20} J,

assume similar adhesion forces

- Tune feedback control parameters for optimal imaging (i.e.low measurement error, low forces, fast scan speed)
- Parameters you might change:
  - unconstrained amplitude, setpoint ratio, P & I gains, scanning speed.
- If you finish early, explore effect of lock-in amplifier parameters

Final Thoughts

- VEDA development is user driven. If you have comments, suggestions, bug reports, or feature requests, send them in: drkiraco@purdue.edu