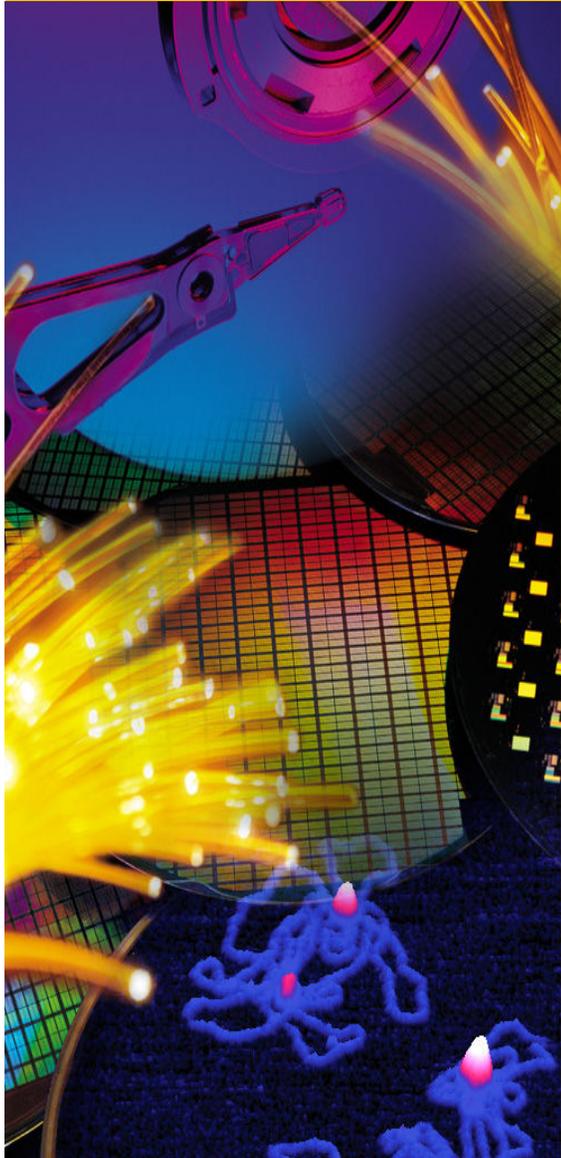




Solutions for a nanoscale world.



# Advanced Imaging Modes For AFM

Peter Harris  
Veeco Instruments  
Santa Barbara

# Introduction

- NanoScope V Controller
  - Thermal Tuning
  - High Speed Data Capture
  - 3-Axis Closed-Loop Support
  - 3 Independent Lock-Ins
  - Harmonic Imaging
  - Torsional Resonance
  - High Pixel-Density Images
  - Easy-AFM



# High Speed Data Capture

- Capture 64 Mbytes Of Data
- 2 Channels At 50 MHz (AC coupled)
  - ~330 ms per channel
- 2 Channels At 6.3 MHz and 2 Channels At 500 kHz (DC Coupled)
  - ~2.5 seconds per channel
- Works In Image, Ramp And Sweep Modes
- Not Required To Be Engaged
  - thermal tunes up to 2 MHz
- Trigger on EOL, EOF, Edge or Manual
  - data collection can start before or after trigger event
- Point & Shoot Allows Capture At Specific Image Points

# User Interface - High Speed Data Capture

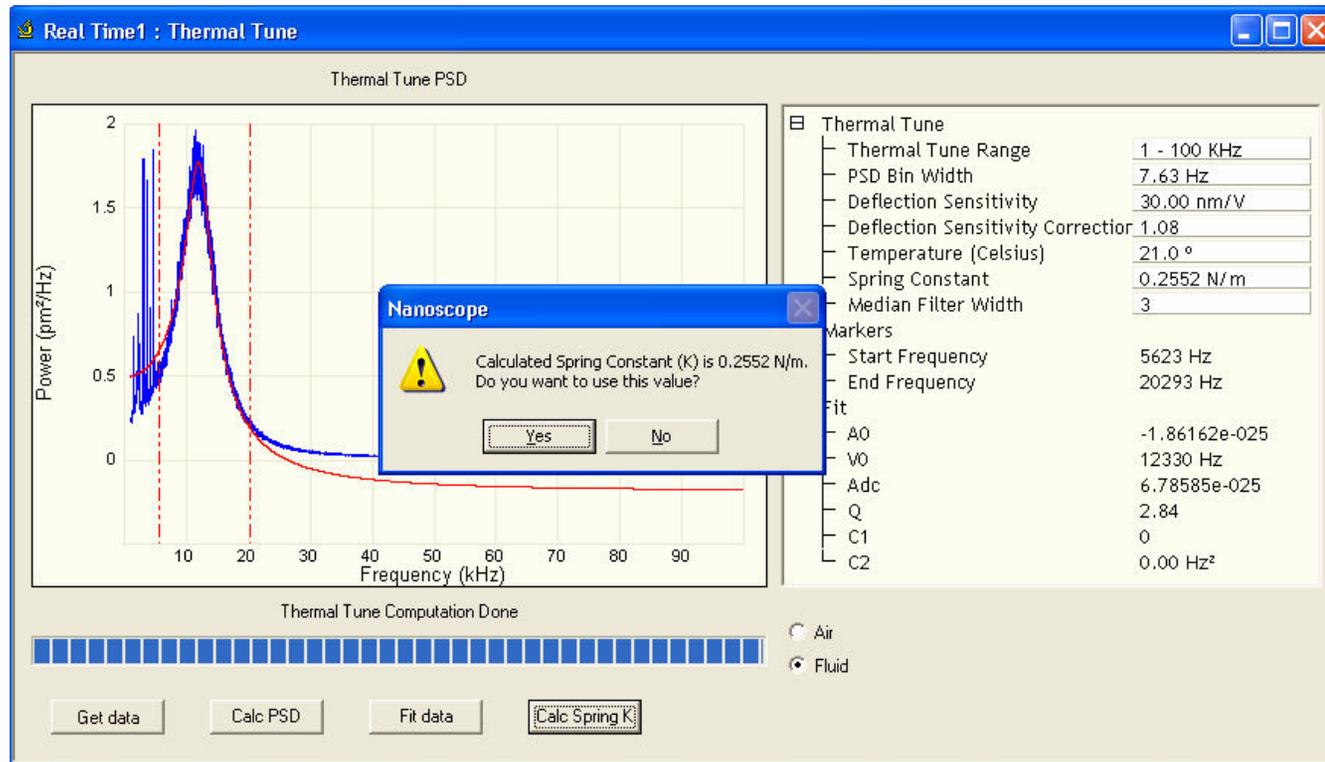
- Collect Data At Timescales Previously In-Accessible To AFM
- Simple User Interface
- Minimal Input Required
  - set data rate
  - assign channel data types
  - choose a trigger option
  - set the measurement duration

The screenshot shows a software window titled "High Speed Data Capture" with a close button in the top right corner. The window is divided into several sections:

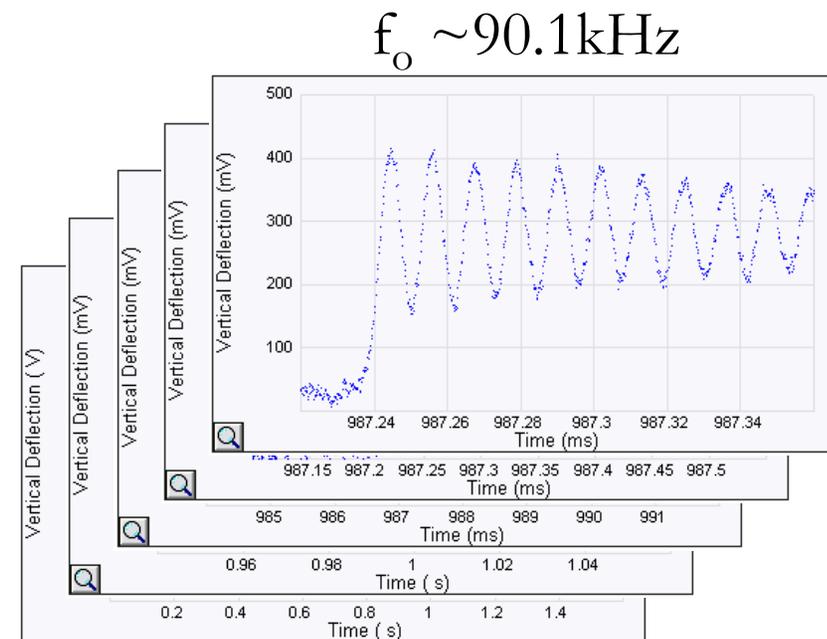
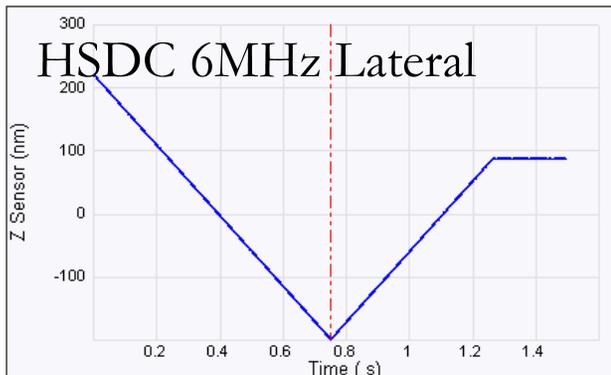
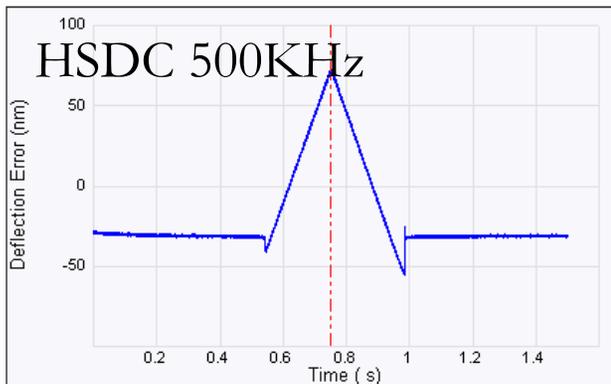
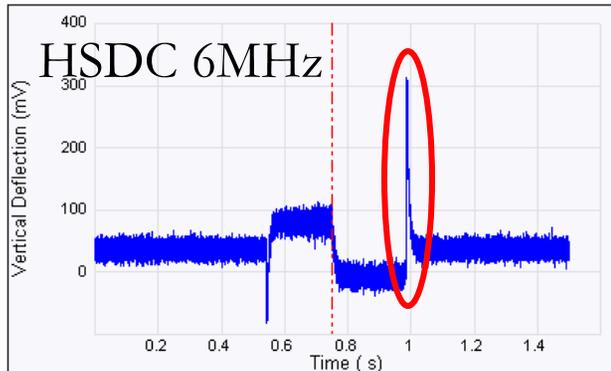
- Channel Selection:** This section contains two rows of controls. The first row has a "Rate:" dropdown set to "6.25 MHz", "ChannelA Data Type:" set to "Vertical Deflection", and "ChannelB Data Type:" set to "Lateral Deflection". The second row has a "Rate" dropdown set to "500 kHz", "ChannelC Data Type:" set to "Z Sensor", and "ChannelD Data Type:" set to "Deflection Error".
- Trigger Controls:** This section includes two buttons on the left: "Arm Trigger" and "Force Trigger". To their right is an "Auto Re-Arm" checkbox which is currently unchecked. Further right are several dropdown and text input fields: "Event:" set to "EOL", "Channel:" set to "Height", "Level:" set to "0.00 V", "Slope:" set to "Positive", and "Delay:" set to "-750 ms".
- Duration:** A text input field set to "1500 ms".
- Capture File Name:** A text input field containing "polyworkshop001.hsd".
- Status:** A text box at the bottom showing "Status: Data Acquired".

# Thermal Tuning In Fluid

- Identify Resonance Frequencies
- Calculate Spring Constants

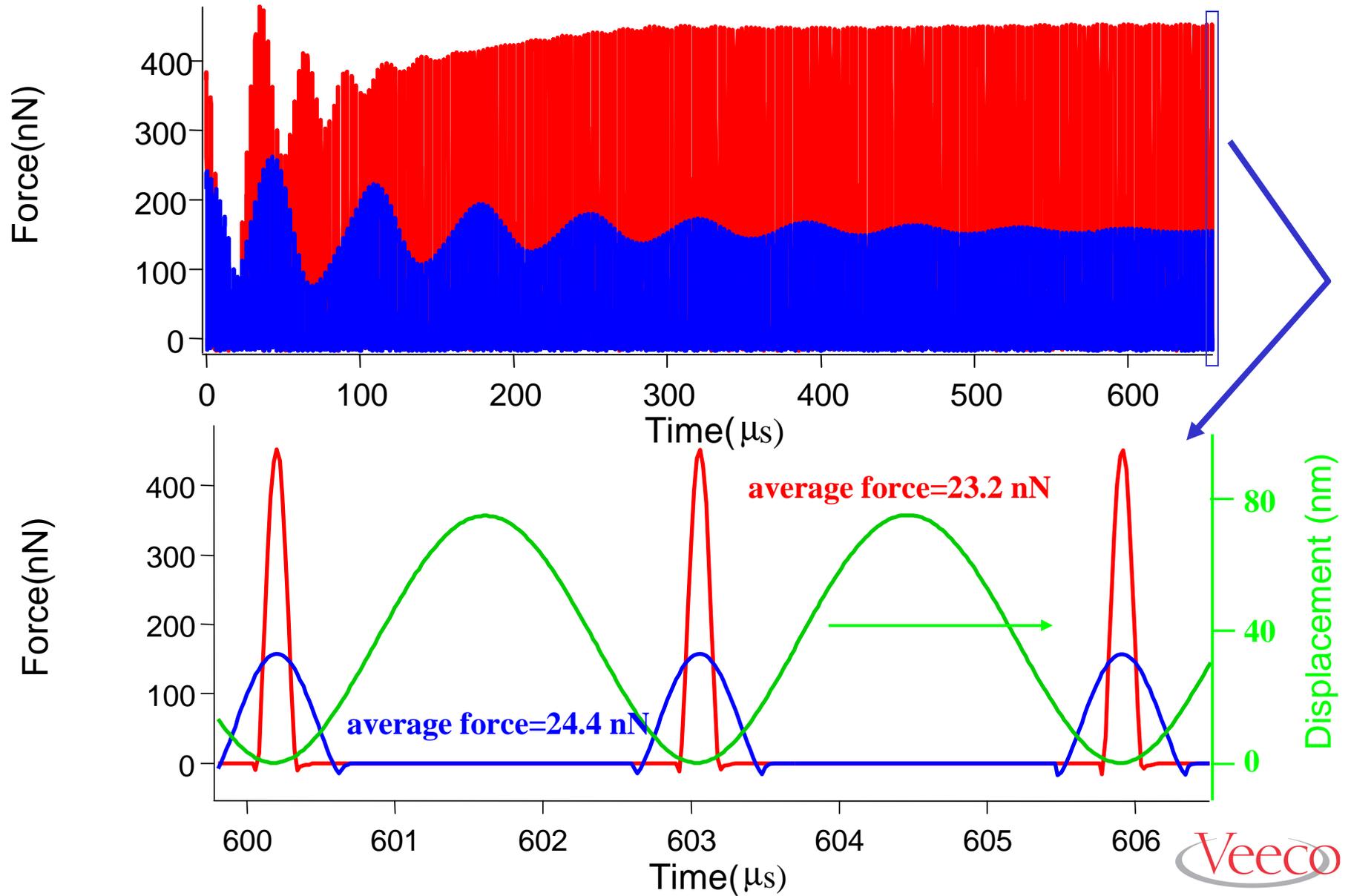


# HSDC Of Force Curve Pull-Off

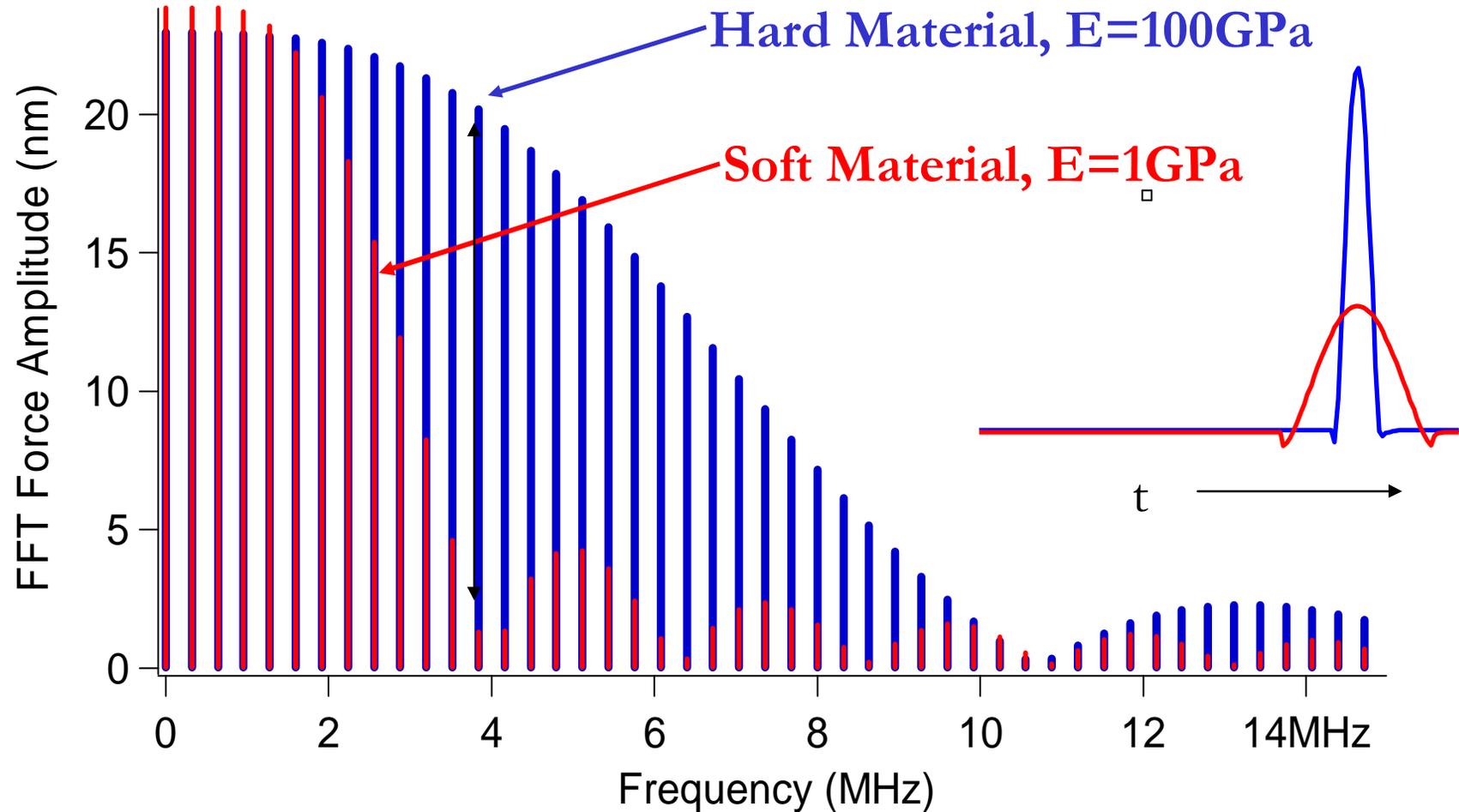


Each pixel in the final zoomed data represents a sample at typical acquisition rate

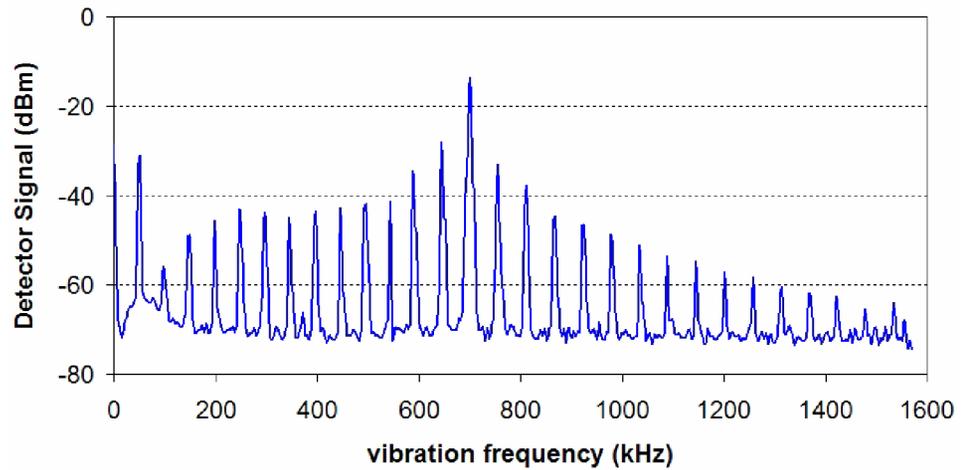
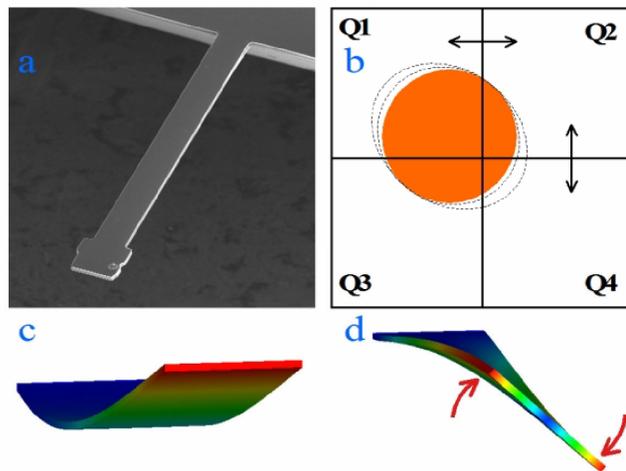
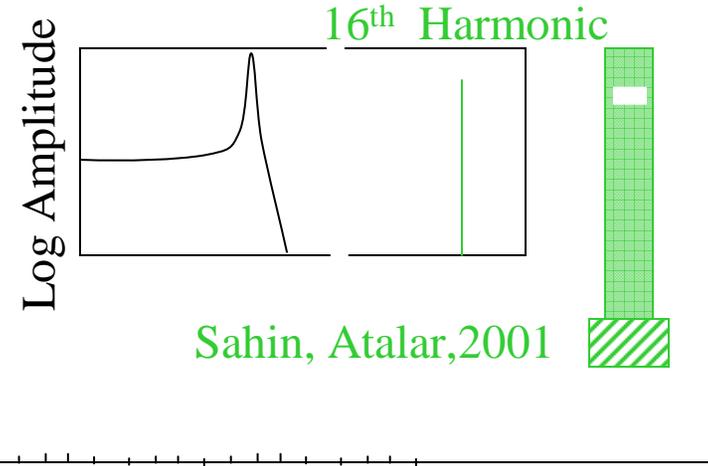
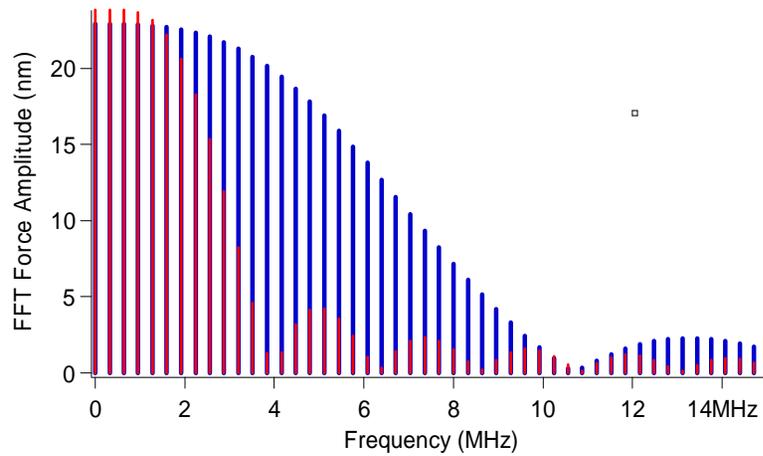
# Tapping Harmonics



# Tapping Force In Frequency Space



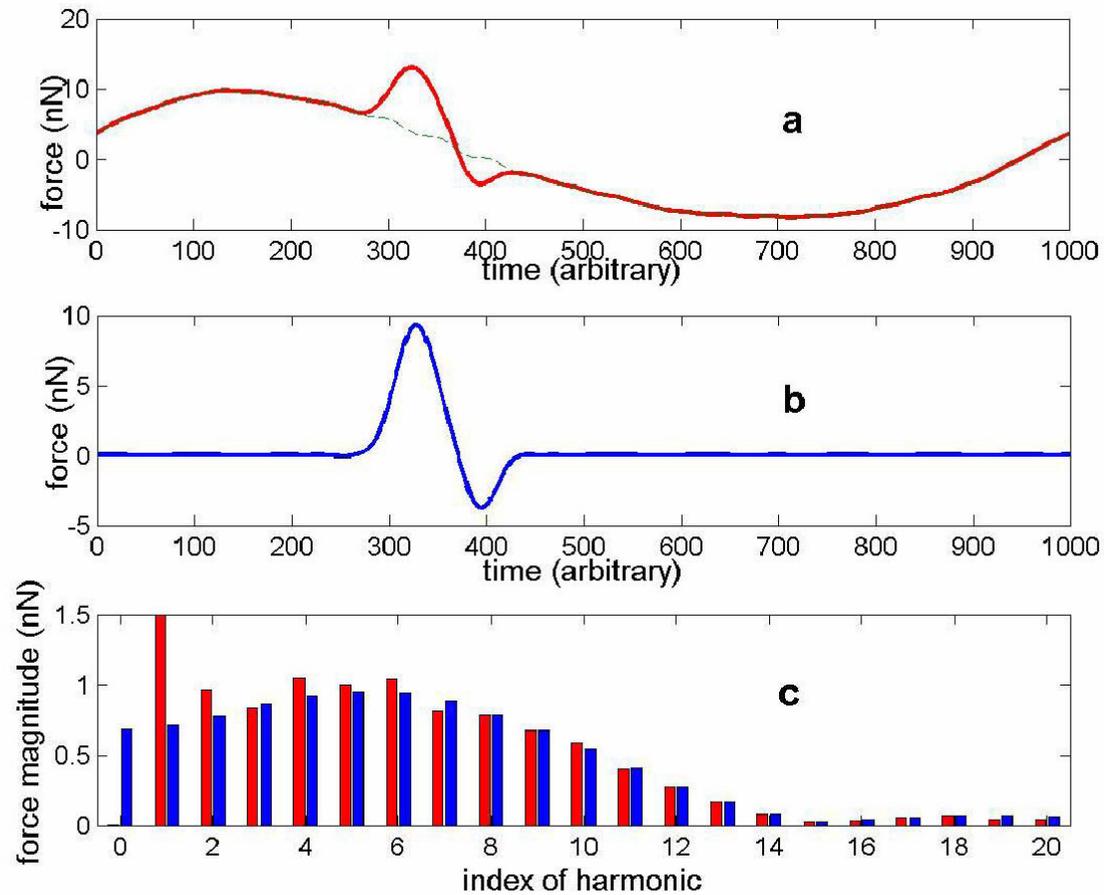
# Tapping Harmonic Detection



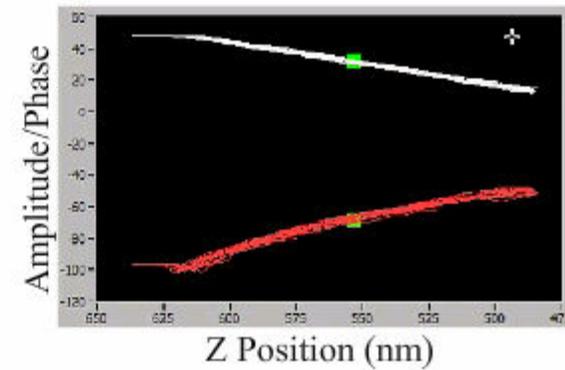
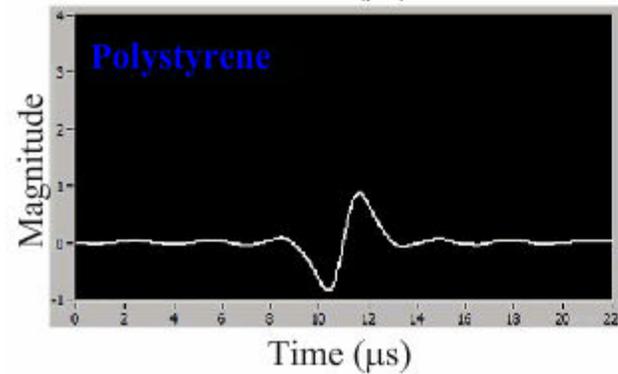
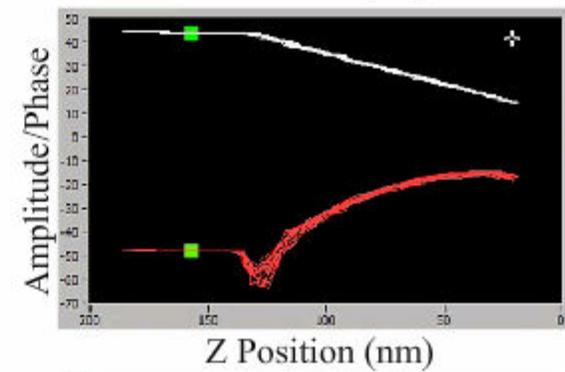
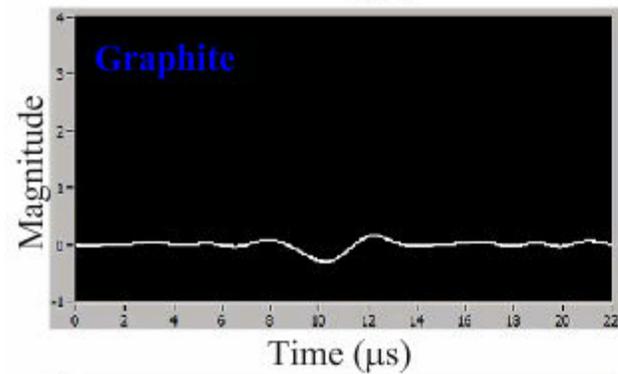
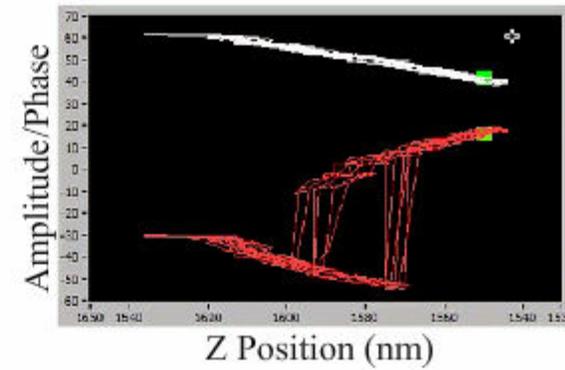
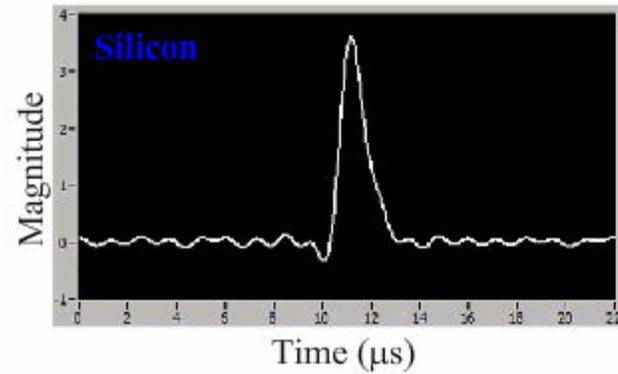
Sahin PhD Thesis  
 Sahin, Quate, Solgaard, Sergei, Su, submitted to Nature



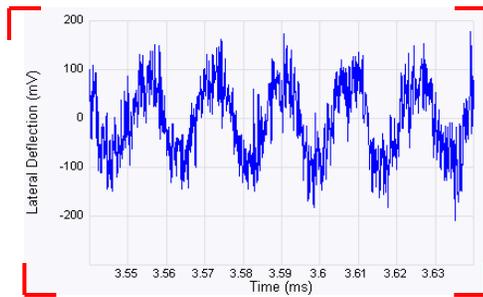
# Time Resolved Tapping Force



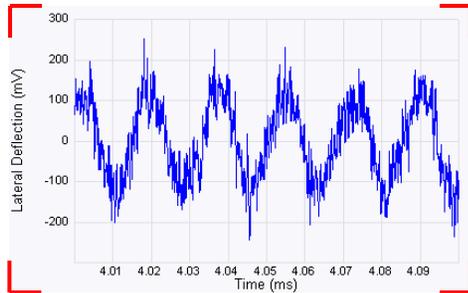
# Real Time Tapping Force



# Point And Shoot With High-Speed Data Capture



- PDES On Silicon
- **A** PDES
- **B** Bare Si



**Real Time1 : Point and Shoot**

Main Scope Mode  
 Image/Scan  
 Ramp/Force Curve

Image Channel: 3  
 Ramp Channel: 3  
 Multiple Shoot: 1

Capture Image and Ramp  
 Capture Image  
 Ramp Capture  
 Capture

Point | Line | Box | HSDC  
 Arm High Speed Data Capture  
 While Scanning  
 While Scan Idle  
 Z Move: Off  
 Z Distance: 0.00 nm  
 Z Speed: 100 nm/s  
 Force Trigger

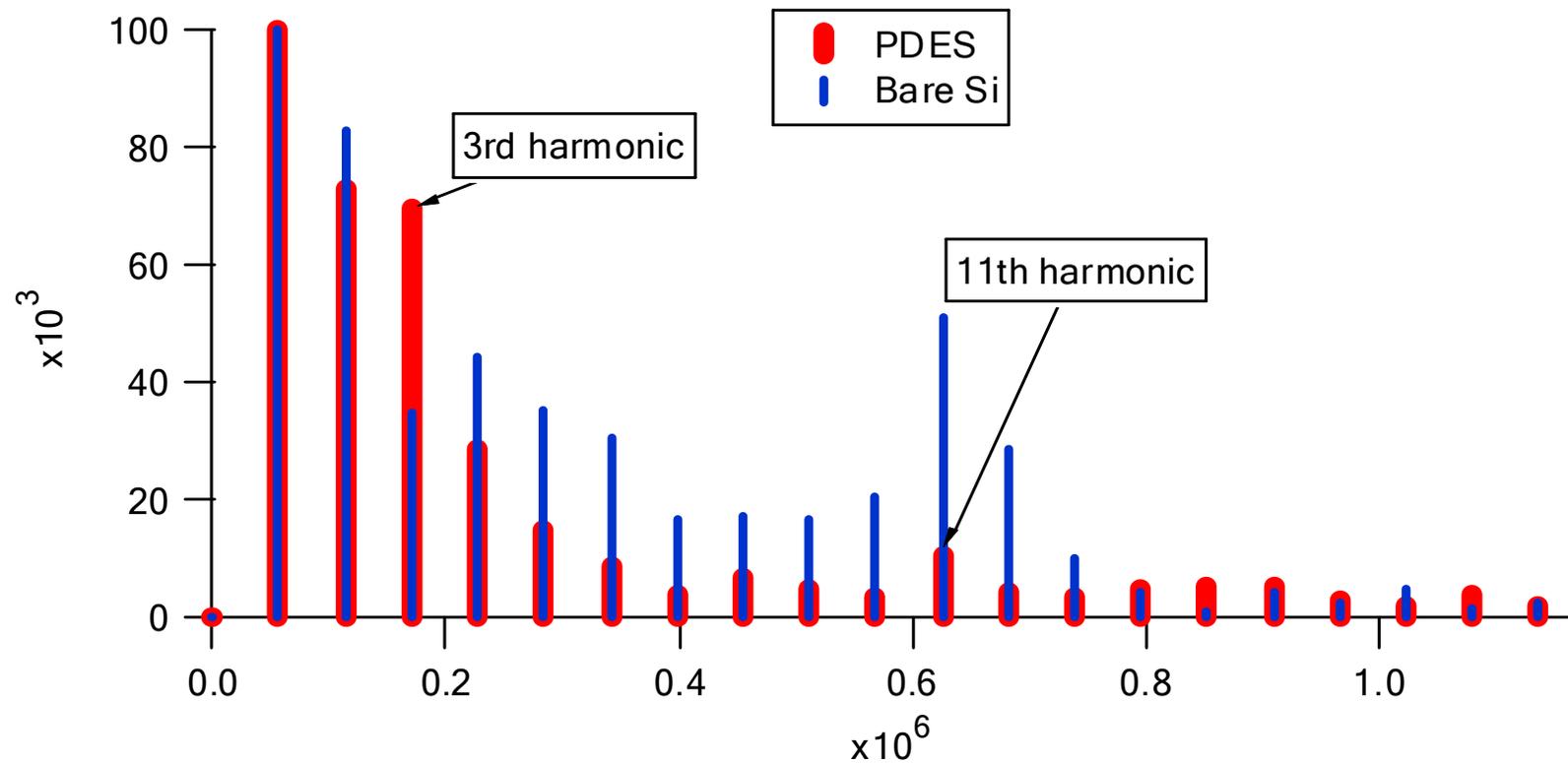
Clear All Marks  
 Save Marked List ...  
 Load Marked List ...

Ramp Capture Index: 0  
 Captured Image: NA (next capture)

75.0 °

0.0 3: Phase 10.0 μm

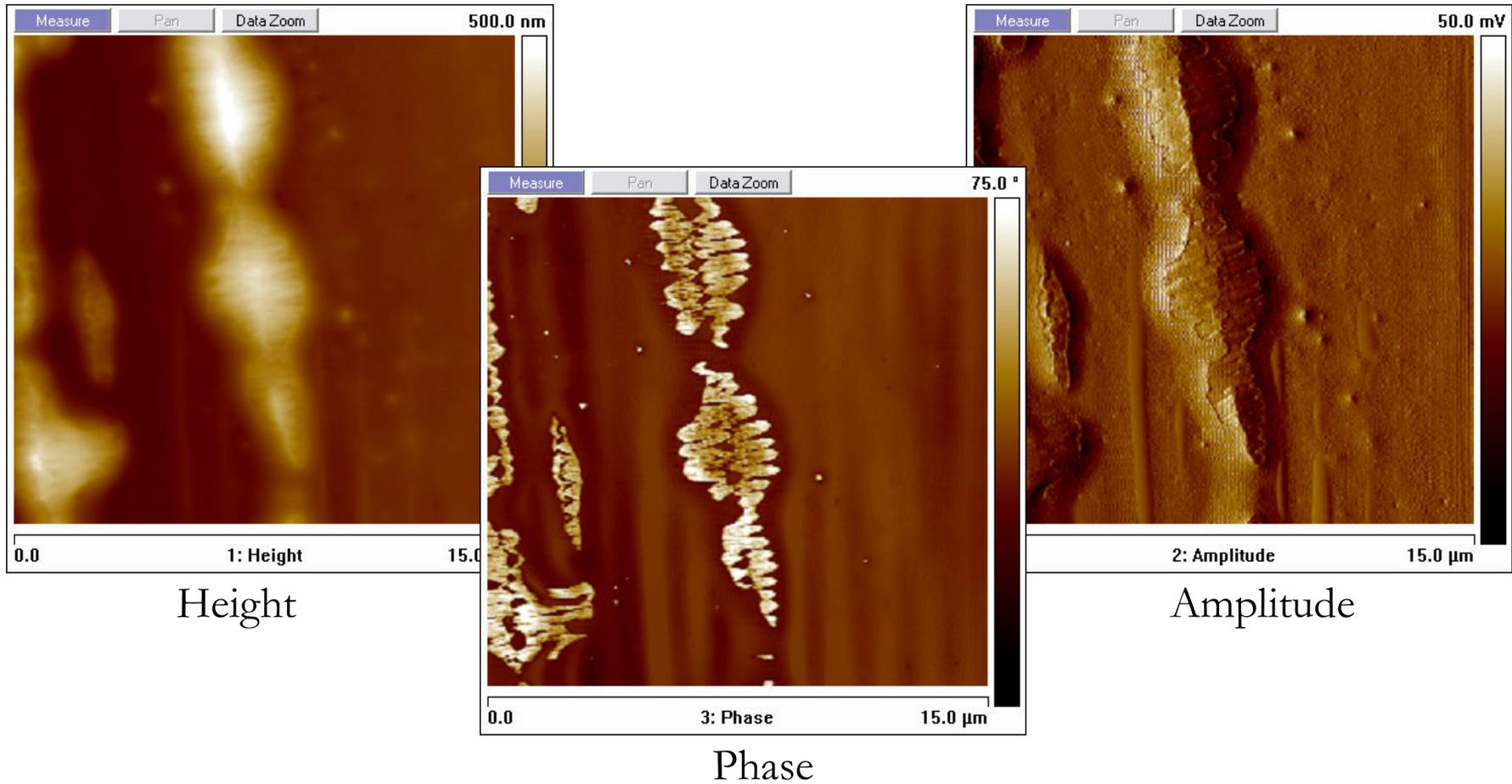
# Comparison Of Spectra: PDES vs. Si



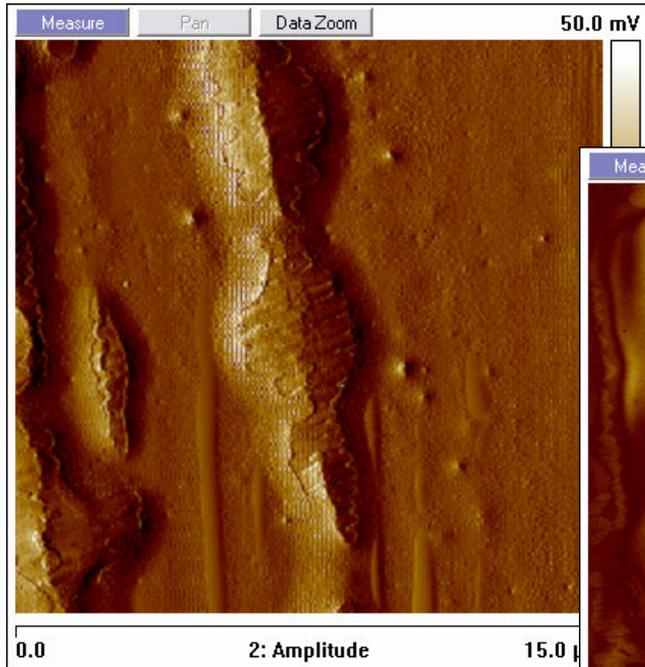
When overlaid the differences become clear

# Regular Height, Amplitude And Phase

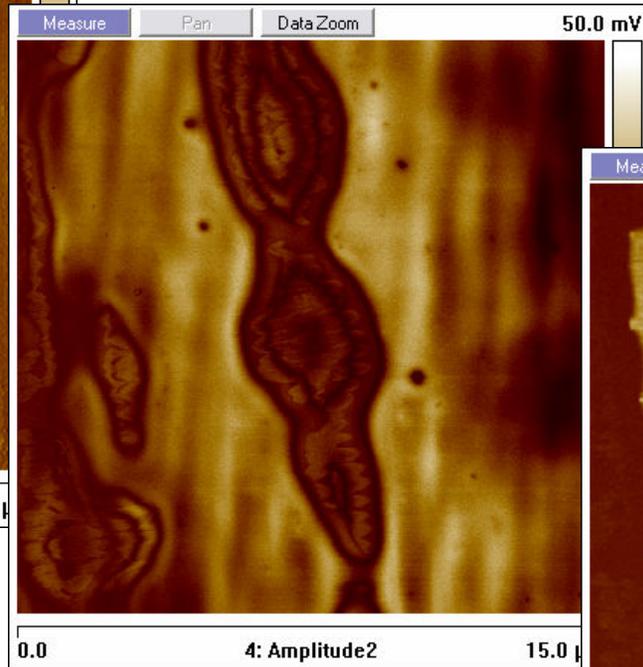
- PDES On Silicon (rubbed)



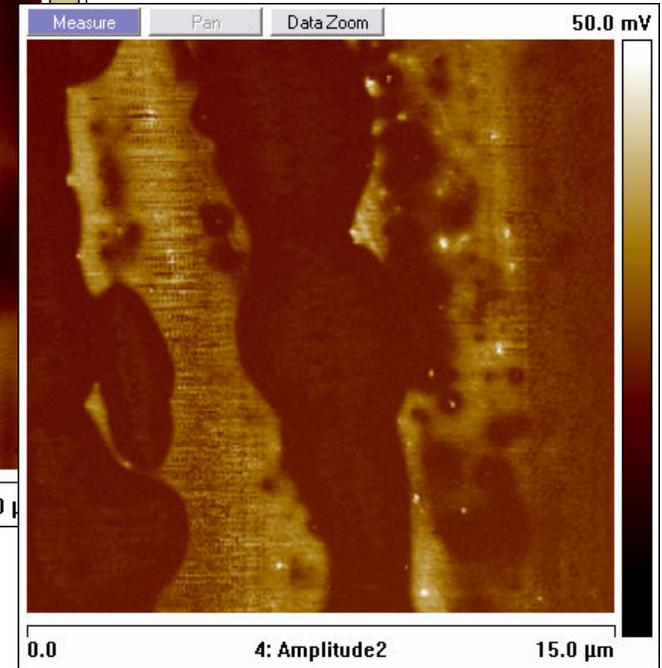
# Harmonic Amplitude



Tapping Amplitude

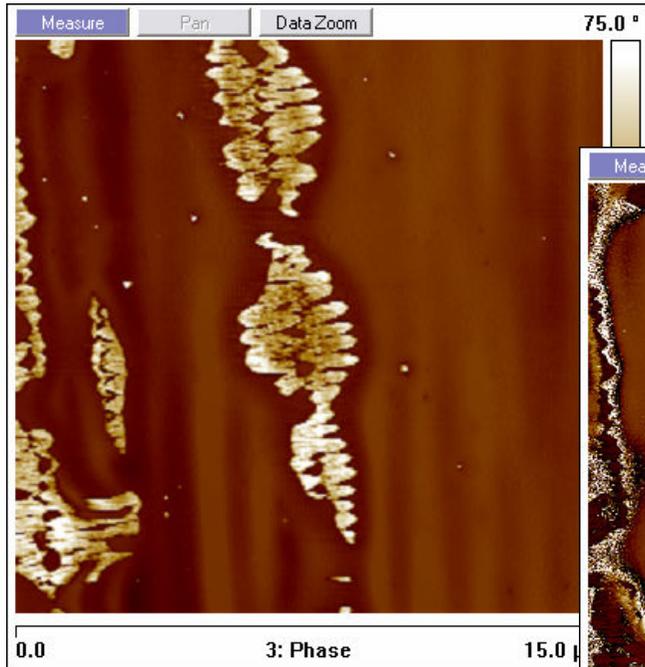


3<sup>rd</sup> Harmonic

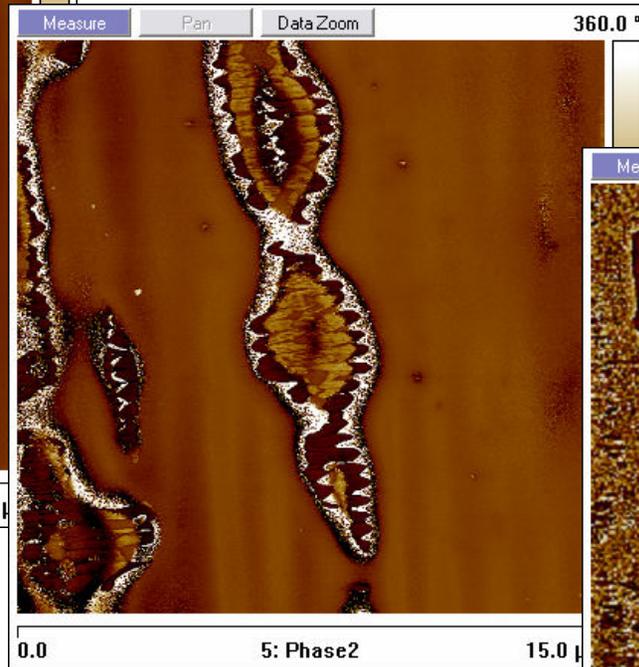


11<sup>th</sup> Harmonic

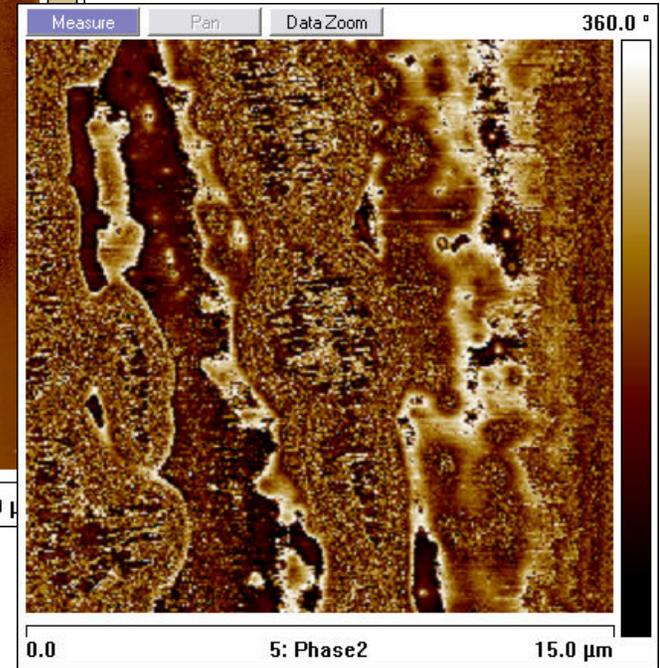
# Harmonic Phase



Tapping Phase



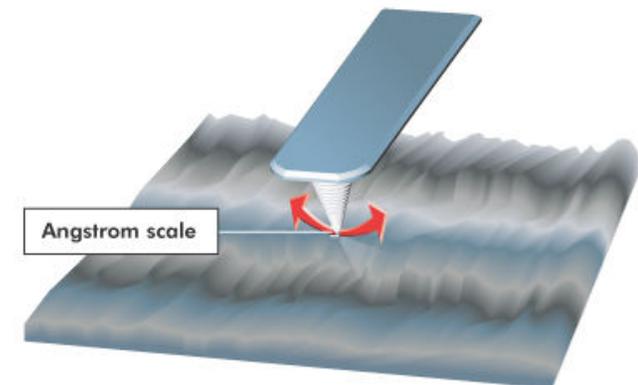
3<sup>rd</sup> Harmonic



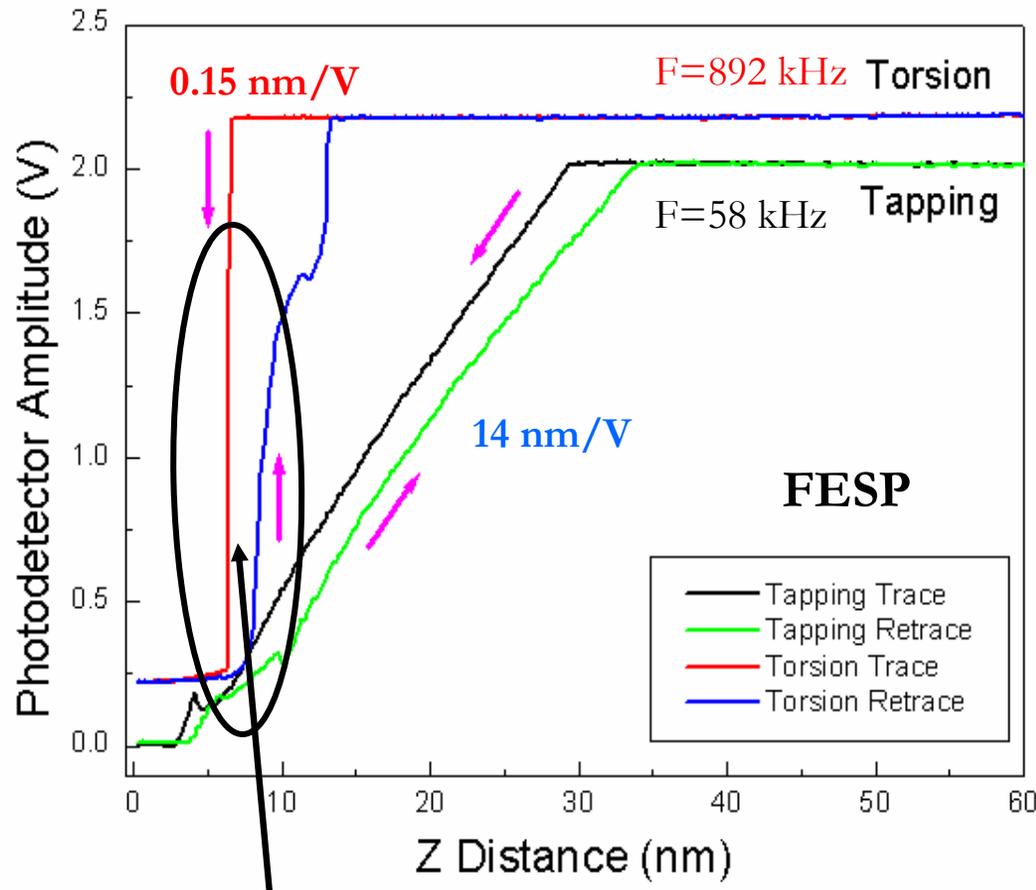
11<sup>th</sup> Harmonic

# Torsional Resonance

- 2 Modes Of Operation
  - Tapping TR
    - feedback in tapping mode (vertical amplitude)
    - monitor torsional amplitude and phase in interleave mode
  - Torsional Resonance
    - feedback on torsional amplitude or phase ( $\text{\AA}$ -scale lateral dither)
    - true non-contact technique
    - measures lateral forces and lateral force gradients
    - maps in-plane anisotropy of most materials
    - delivers fast-scan tip dynamics
    - increases phase imaging sensitivity
    - reduces laser interference noise

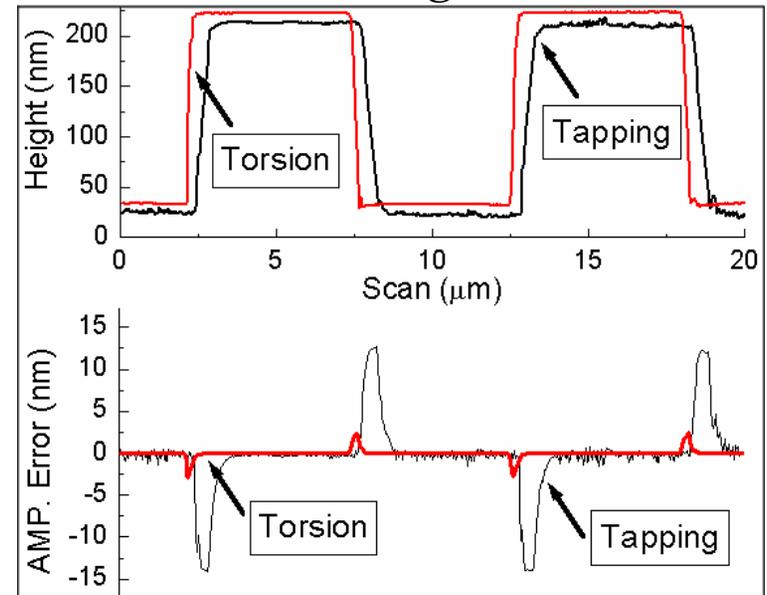


# Faster Cantilever Dynamics



High sensitivity to Z displacement

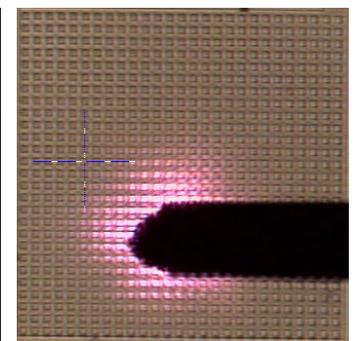
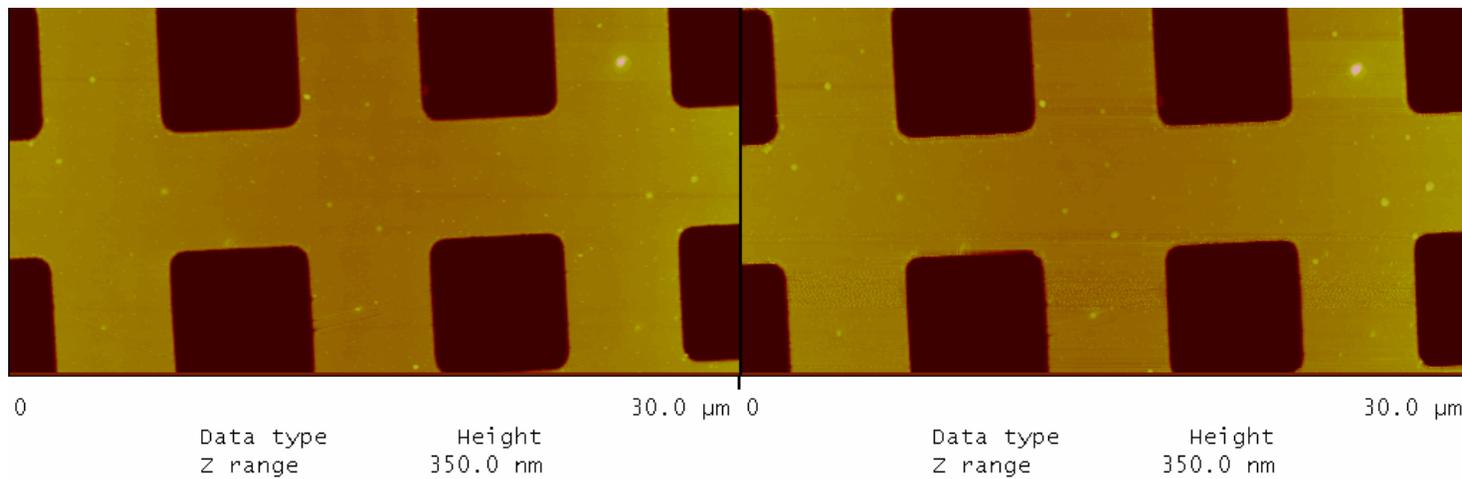
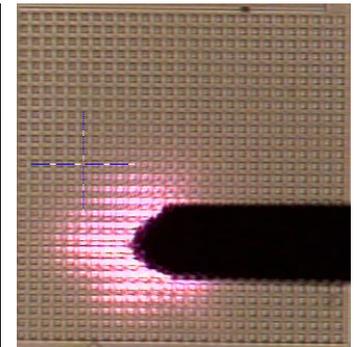
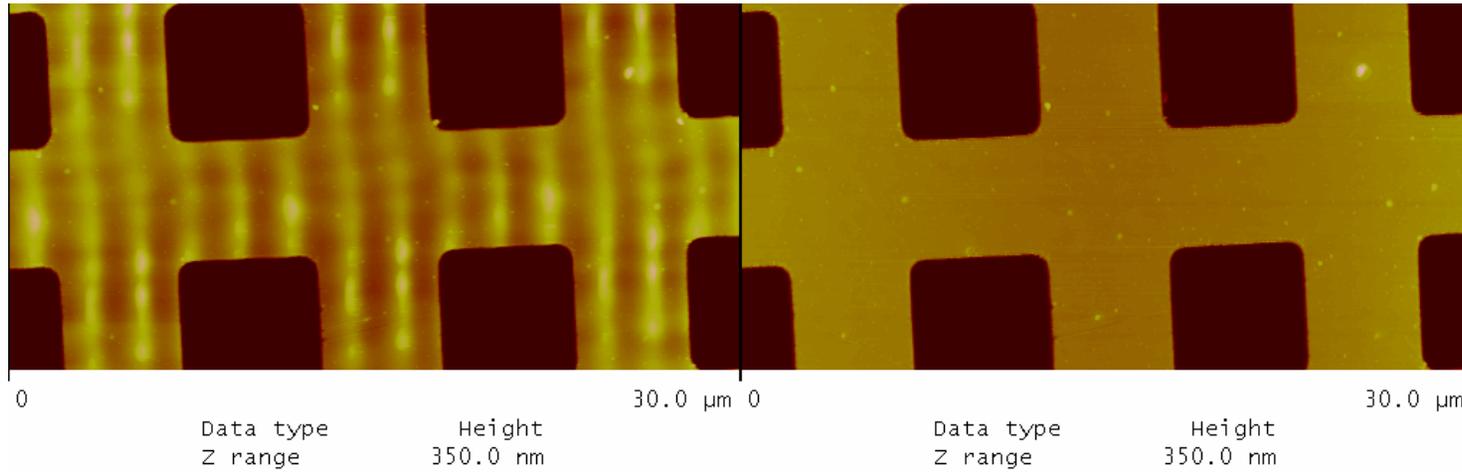
## Better Tracking



Small error signal

Scan rate 15 Hz on a grating

# Interference Laser Noise Eliminated In TR



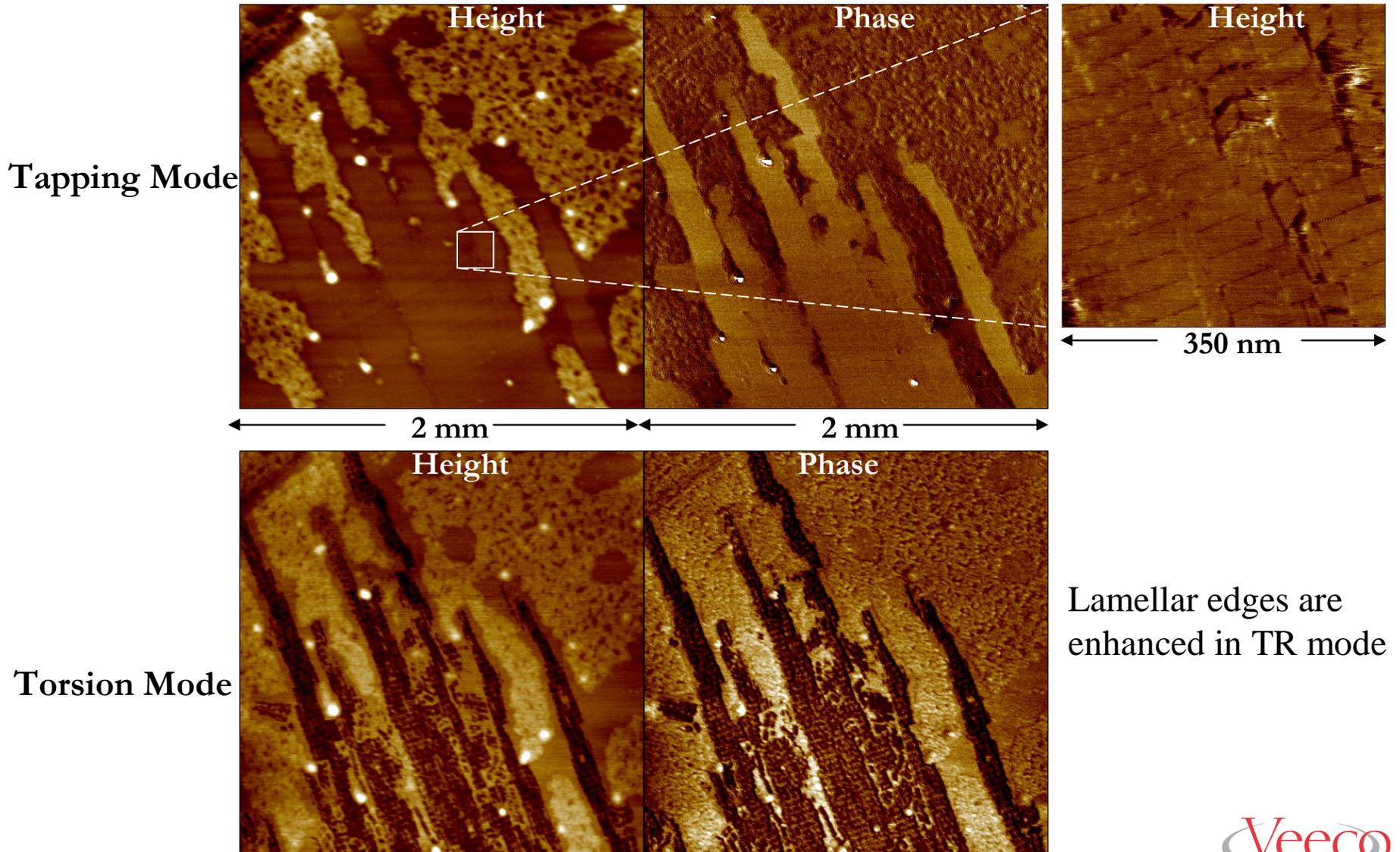
Tapping

Torsion



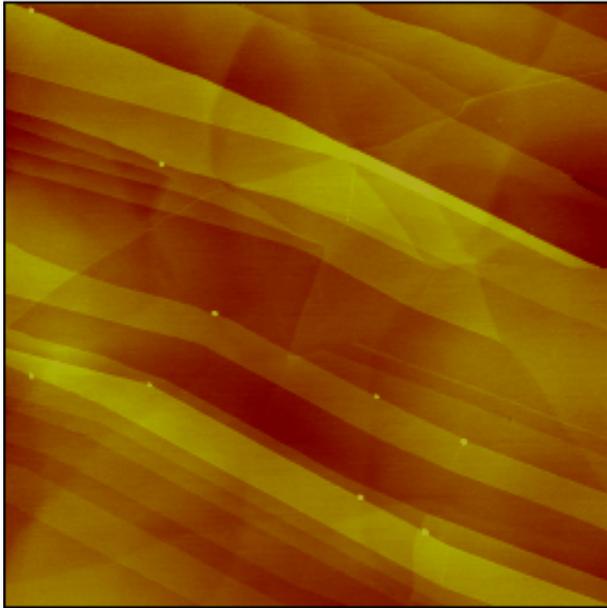
# Soft Organic Layers

## Lamellar Domains of $C_{242}H_{486}$ alkane on graphite



# Interleave Scanning With Tapping And TRmode

Tapping height



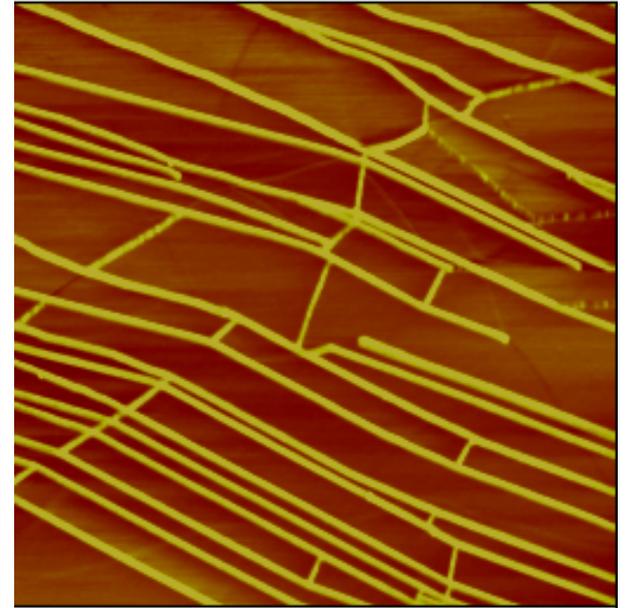
Height scale 5 nm

Tapping phase



Phase scale 10 degree

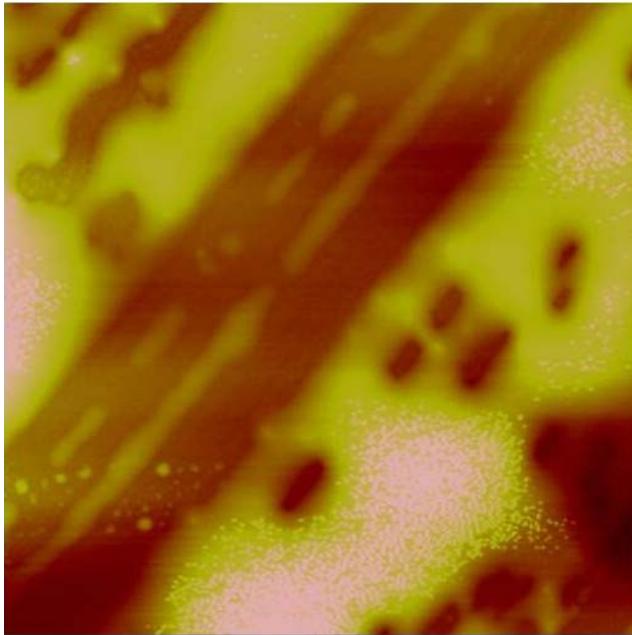
TR phase



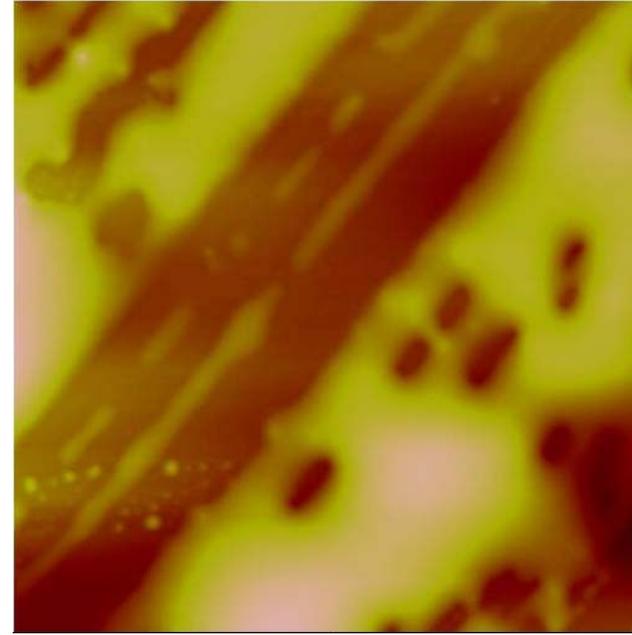
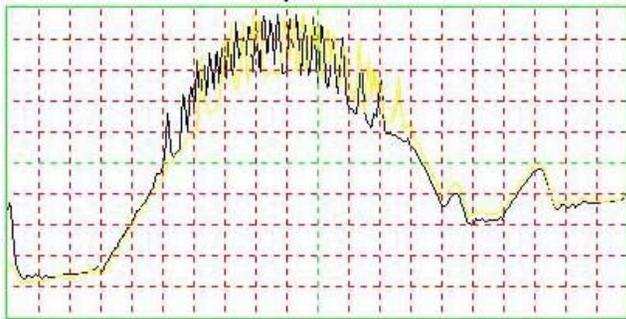
3  $\mu\text{m}$  scan on HOPG surface @ 1 Hz

TRmode: dynamic measurement increases  
sensitivity by a factor of  $Q \sim 1000$

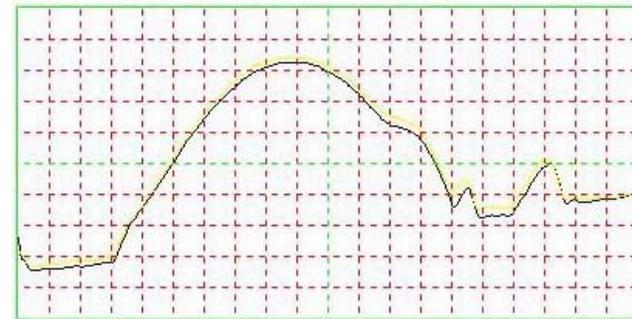
# PDES – Sticky Samples



**Tapping Mode**

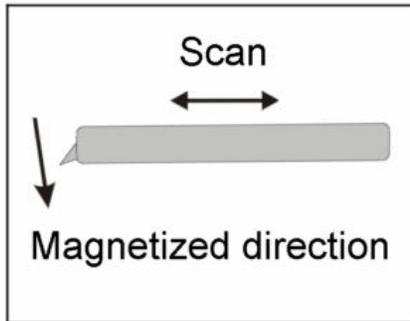


**TR Mode**

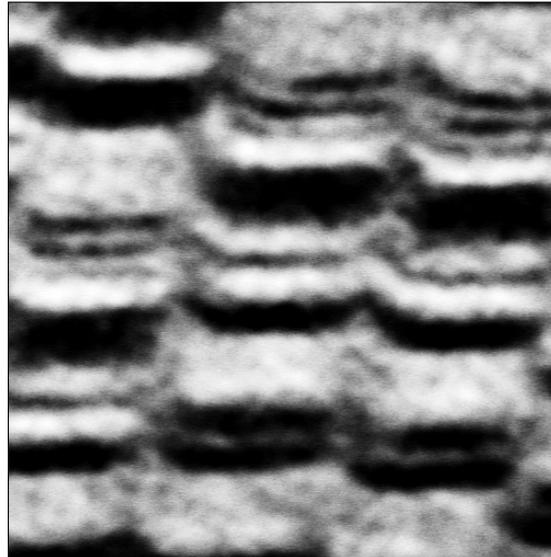


**20  $\mu\text{m}$  Scans – Height Data**

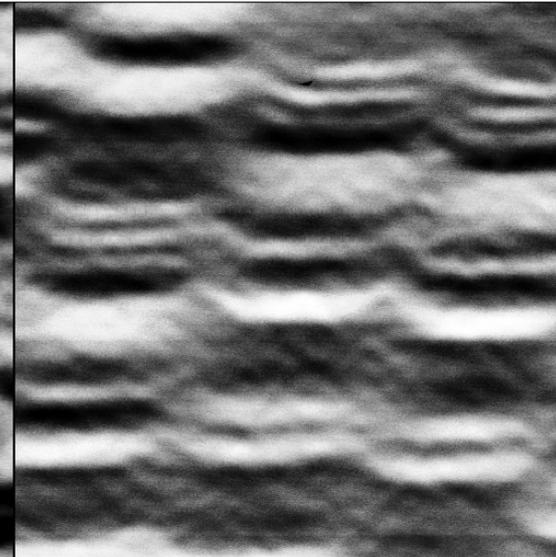
# Detecting In-plane Force Gradients In MFM



Tapping phase



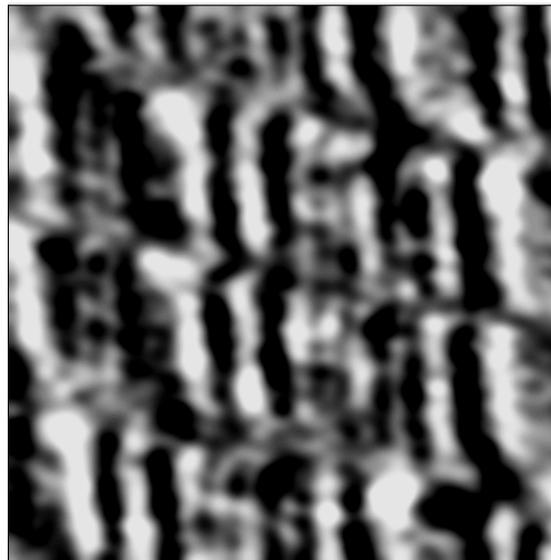
Sample  
0-degree



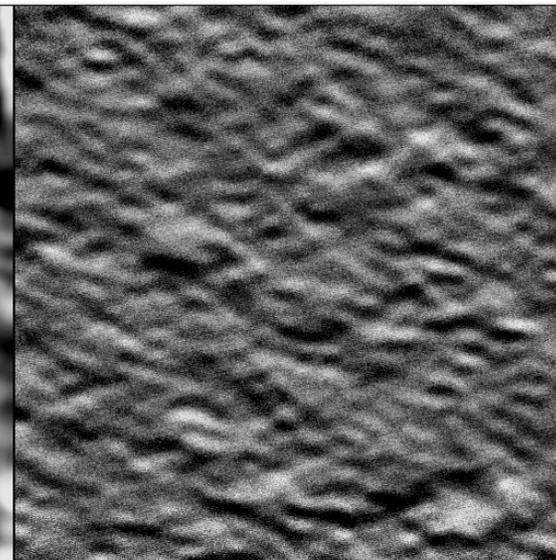
TR phase

3  $\mu\text{m}$  scan on  
hard disk

Tapping phase



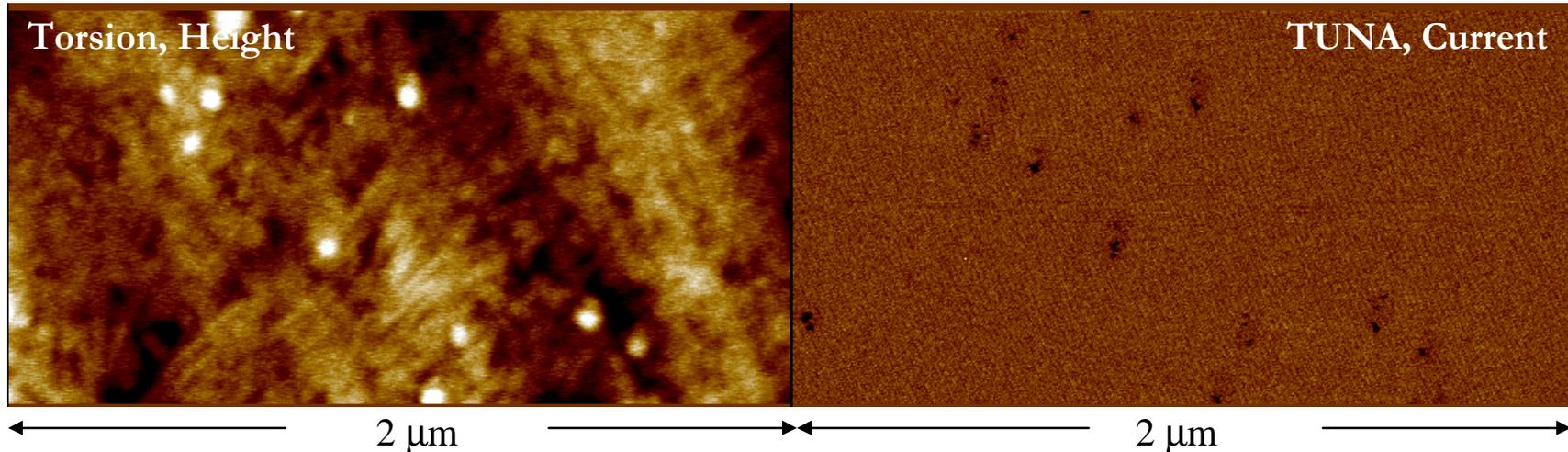
Sample  
90-degree



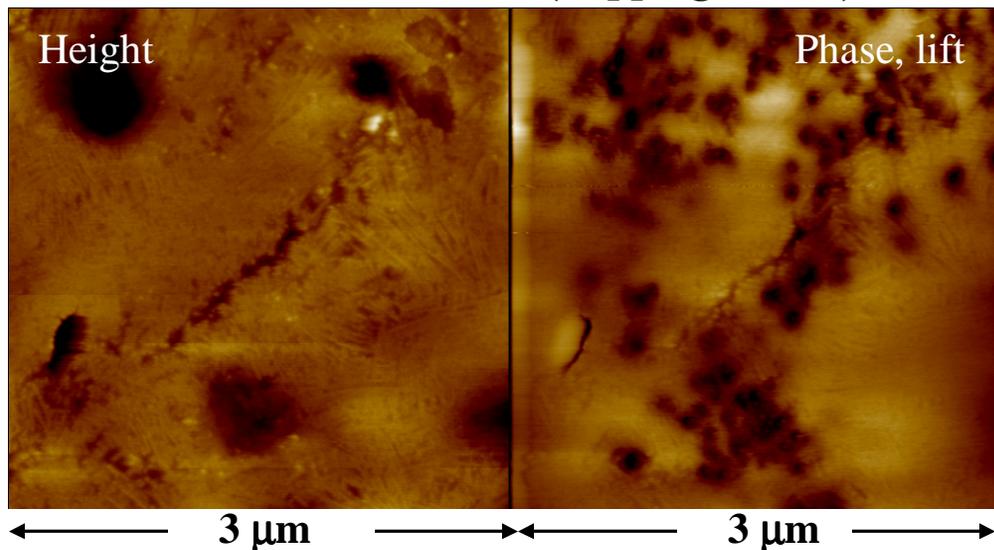
TR phase

# Combining TR Mode with TUNA

Thermoplastic Vulcanizate filled with Carbon Black



Electric Force Mode (Tapping w/Lift)



- TR+TUNA allows probing local I/V characteristics on soft conducting materials

# Summary Of TRmode

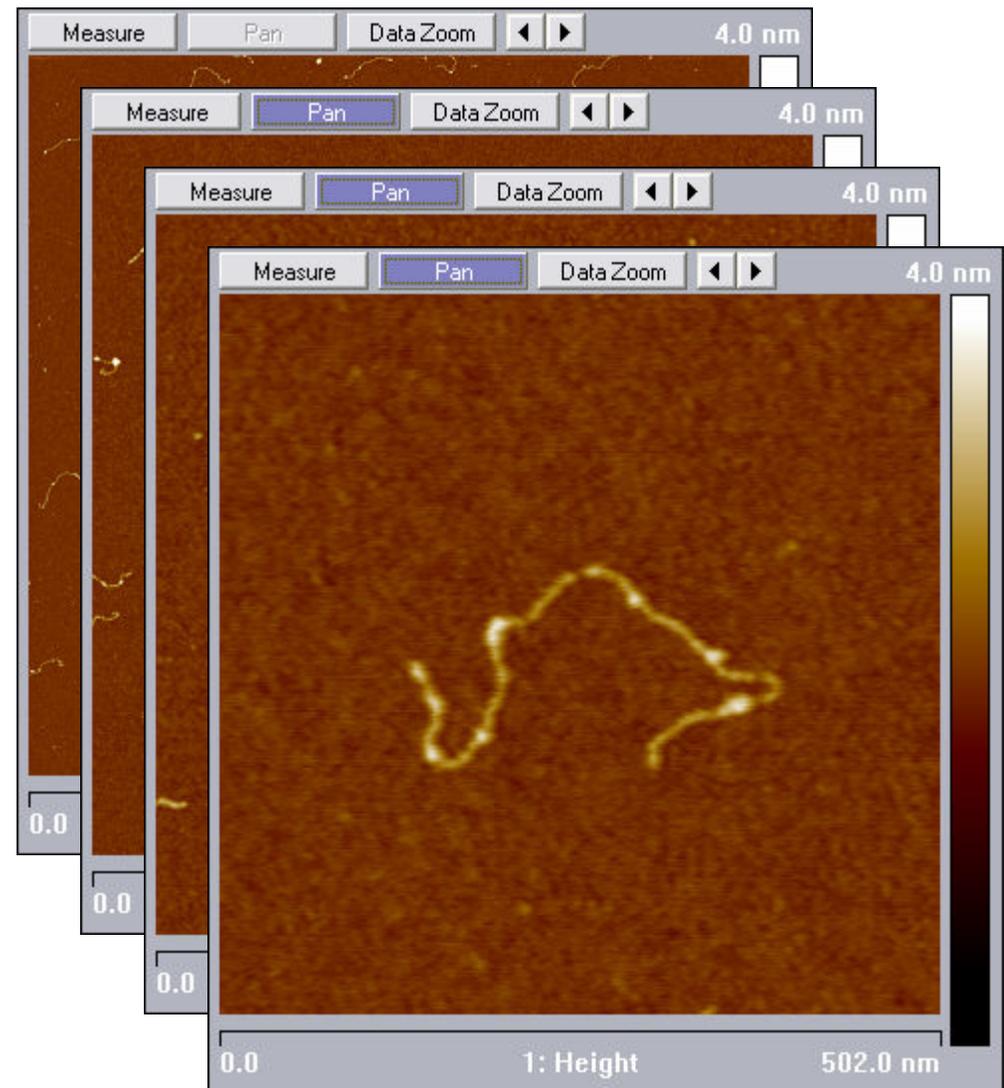
- Maintaining constant lateral tip/surface interaction with a feedback loop
- Improved sensitivity over tapping and LFM
- Detecting in-plane force gradients in MFM lift-mode
- Mapping in-plane anisotropic material properties
- Interleaves with tapping for complimentary lateral and vertical characterization
- Holding tip in proximate contact with surface
- Measuring electric properties on soft samples

# High Pixel Density Images

- High Pixel Density
  - up to 5120 x 5120 with square pixels
  - up to 16384 x 1600 for non square pixels
  - 3 simultaneous data channels
- Improve Time-To-Results
  - reduce the need to capture several images at lower pixel densities
  - eliminate the need for offset adjustments to correlate information from multiple images at lower pixel densities
  - allow observation of large structures and small features in the same image.

# High Pixel Density Images

- DNA In Air
- 5120 x 5120 Pixels
- 3 Data Channels
- Zoom During Scanning

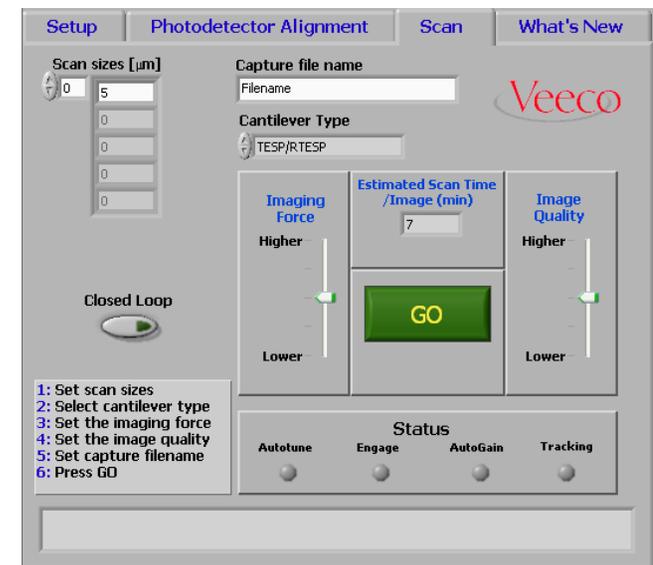


Sample courtesy Jason Reed, UCLA Chemistry



# Easy-AFM

- Intuitive, Easy-To-Follow Graphical User Interface
- Targeted At New Or Infrequent Users
  - not intended to replace user training
- Ideal For Multi-User Environments
- Reduces Initial Set-Up Time
  - probe, laser, and detector alignments
  - engaging the system
- Minimal User Input Required
- Automatically Adjusts Scan Parameters
- Currently Supports Tapping Mode In Air



User Interface

# Easy-AFM: Interactive Help

- System dependant
- Can be skipped
- Helps with both setup and scanning

## Ease Of Use - MultiMode

This ease of use interface provides all of the functionality required of the NanoScope software to obtain high quality images in Tapping mode in air. The format is logical and easy to follow with guides on changing the cantilever and aligning the laser. It is suggested that infrequent users work through this setup process in the order presented to obtain the best possible images. More advanced users may skip the setup parts of this guide and go straight to the scanning section. N.B. These are only guides. For detailed instructions you should always refer to the manual.

- 1: Changing the cantilever
- 2: Laser Alignment
- 3: Photodetector Alignment
- 4: Coarse Approach



Veeco

Probe selection guide

Version 1.0

# Easy-AFM: Scanning

- Minimal User Input
  - Scan sizes
  - open/closed-loop
  - type of cantilever
  - imaging force
  - pixel resolution
  - filename

