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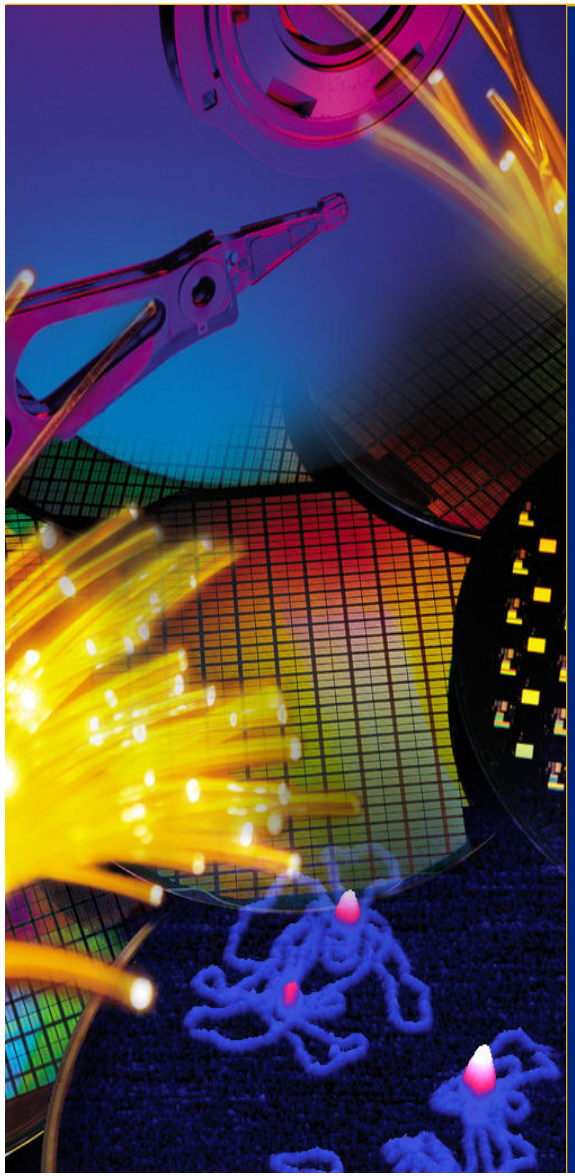
Solutions for a nanoscale world.



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

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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

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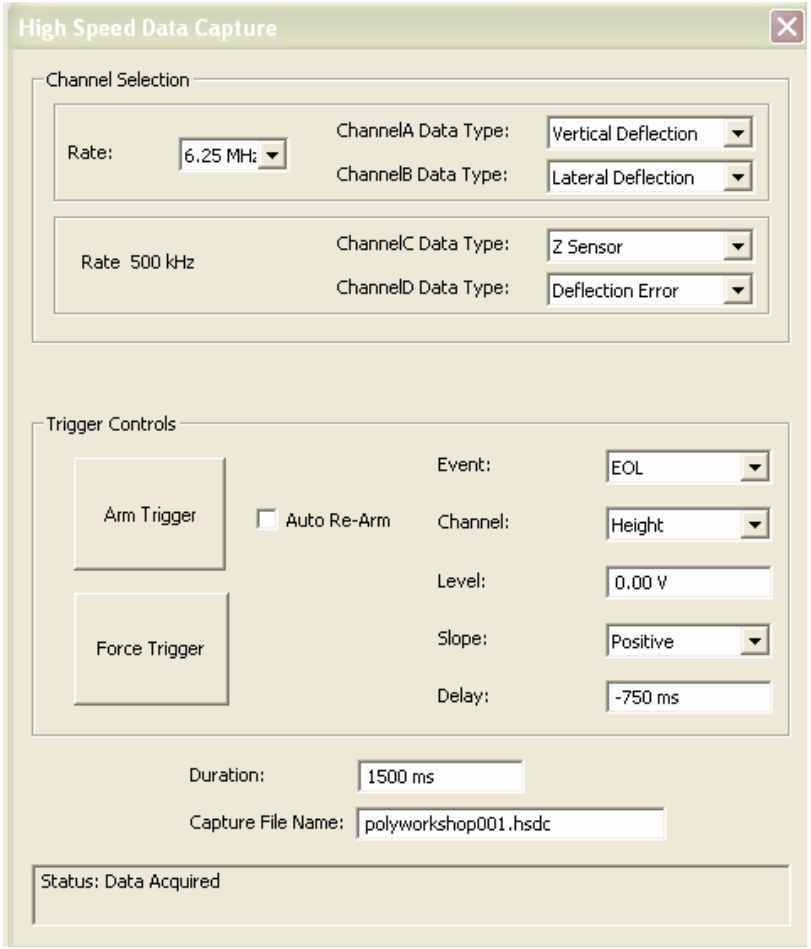
User Interface - High Speed Data Capture

- 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



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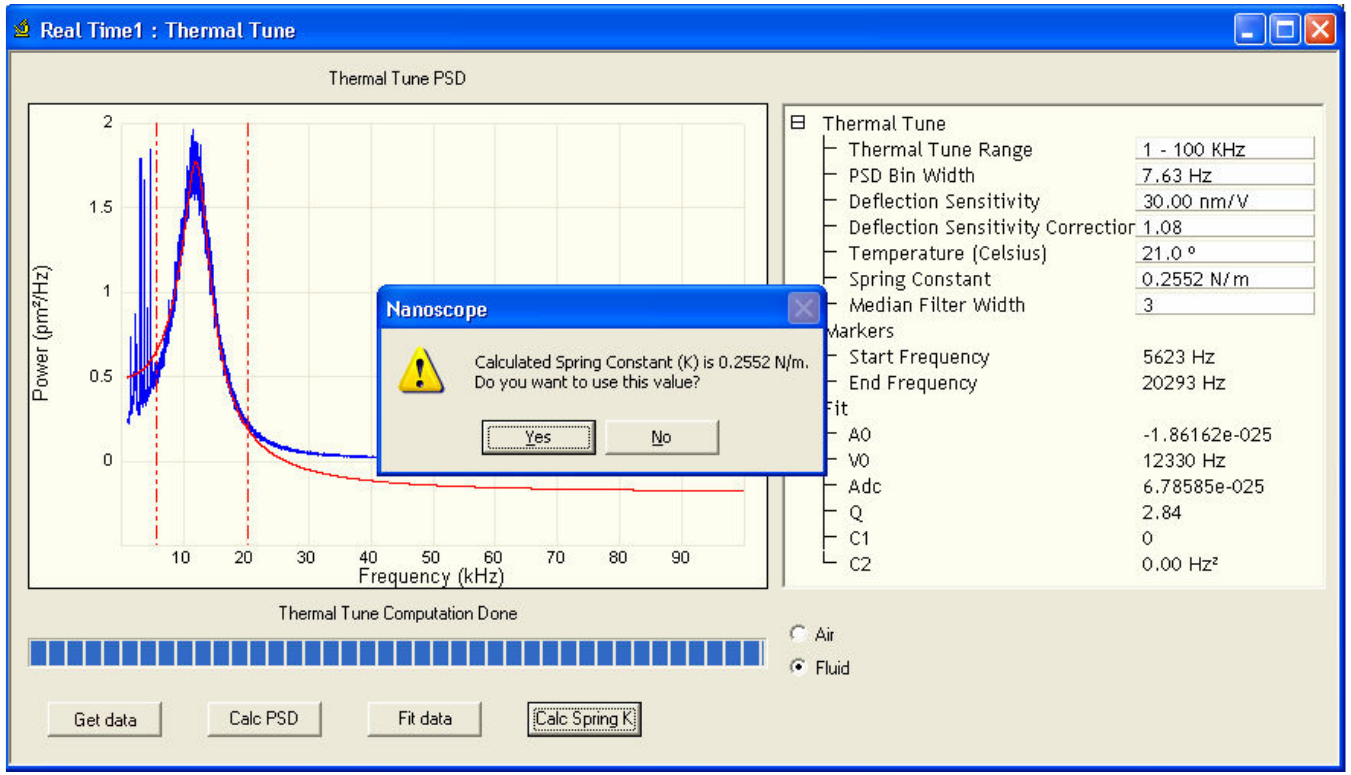
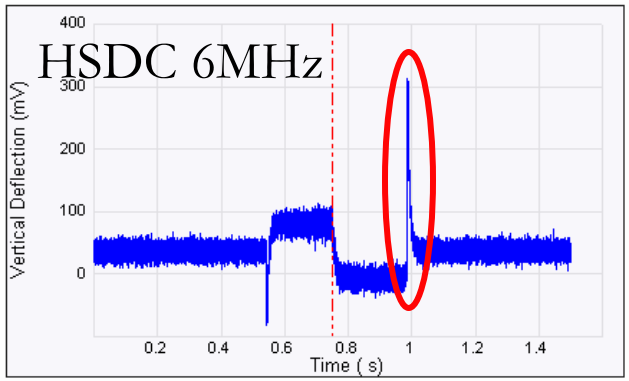
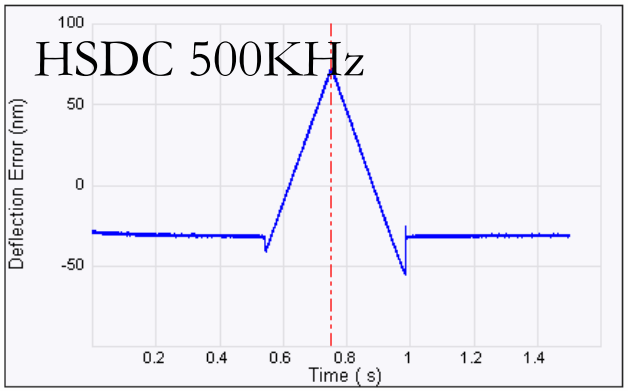
Thermal Tuning In Fluid

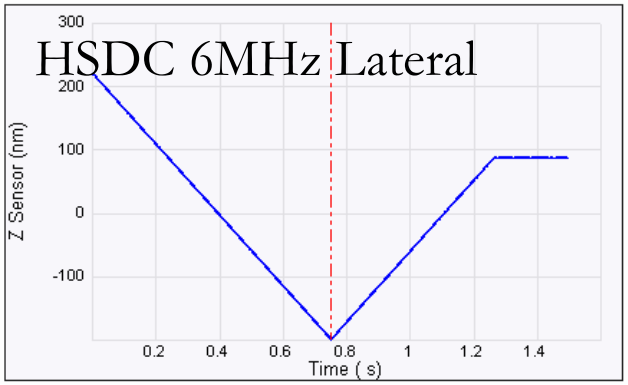
- Identify Resonance Frequencies
- Calculate Spring Constants



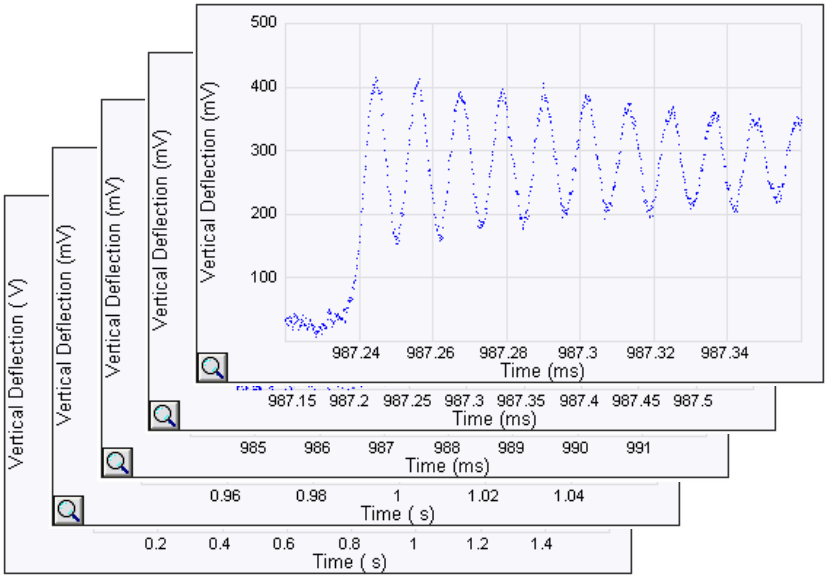
HSDC Of Force Curve Pull-Off







f_o ~90.1kHz



Same data at typical acquisition rate

Each pixel in the final zoomed data represents a sample

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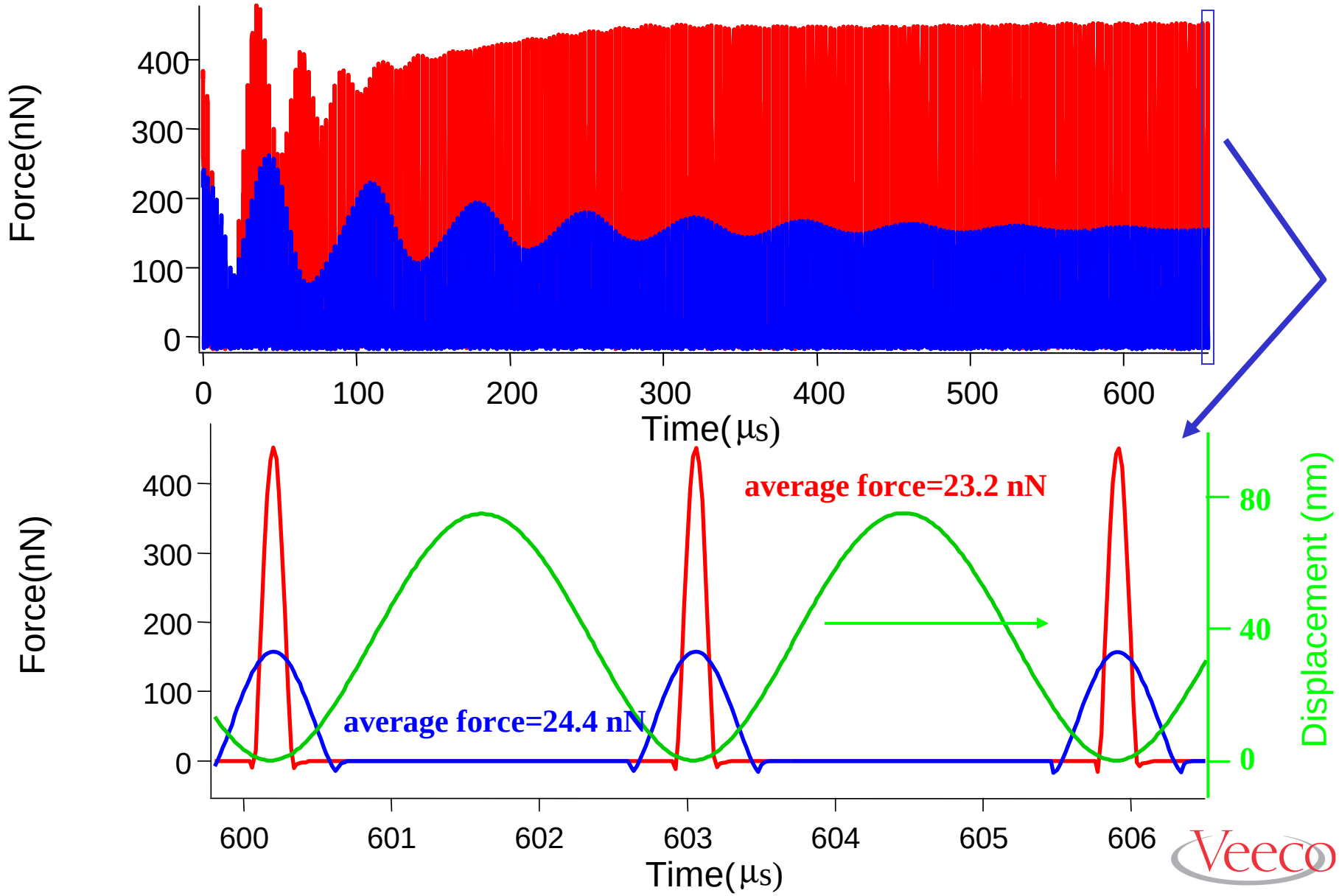
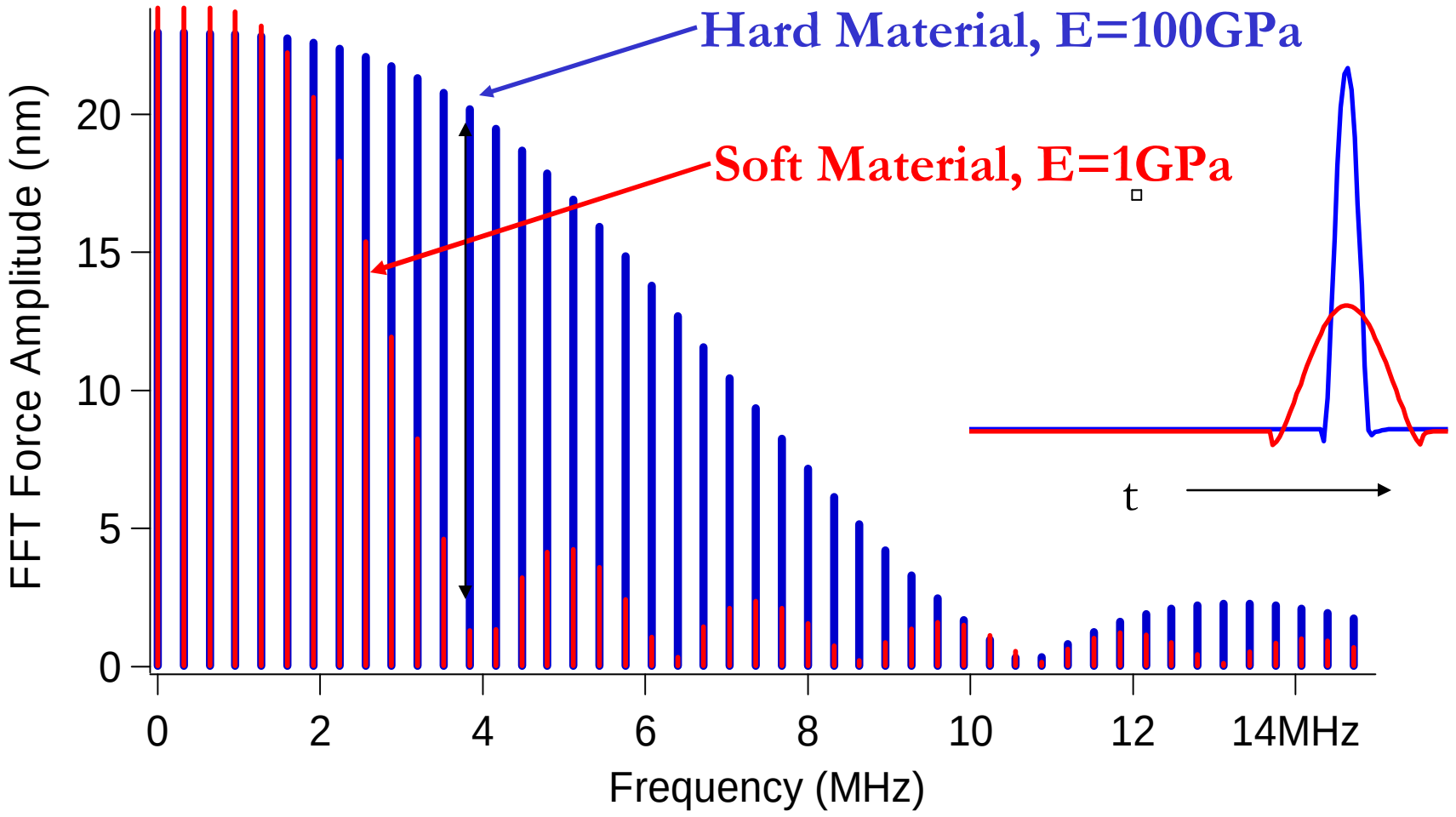
Tapping Harmonics



Tapping Force In Frequency Space



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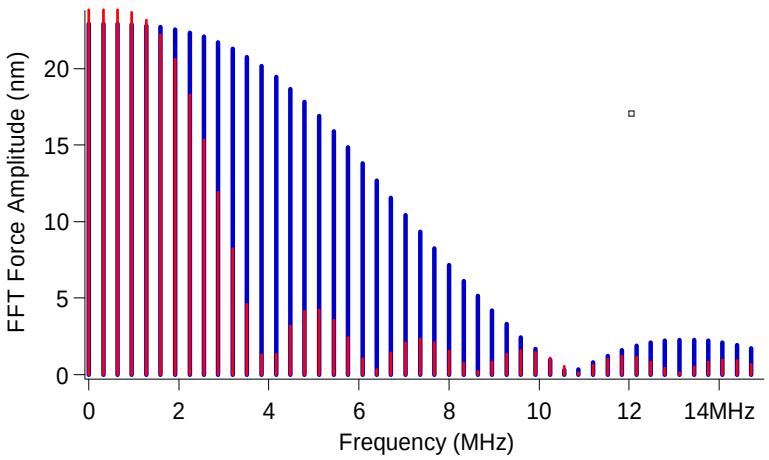
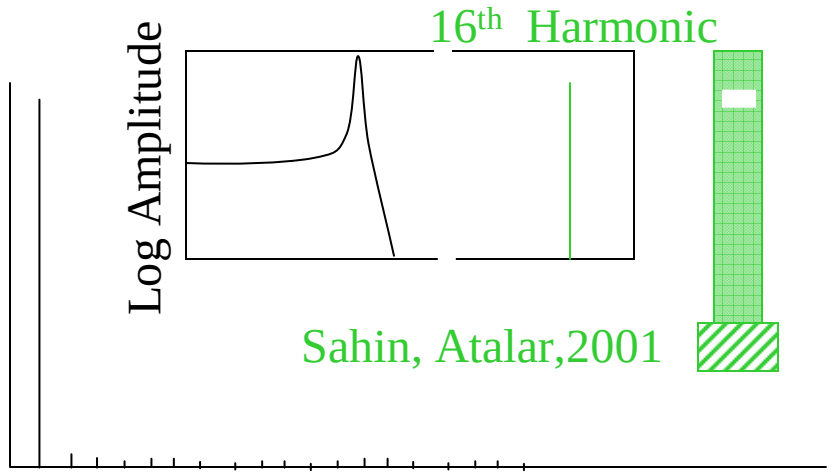
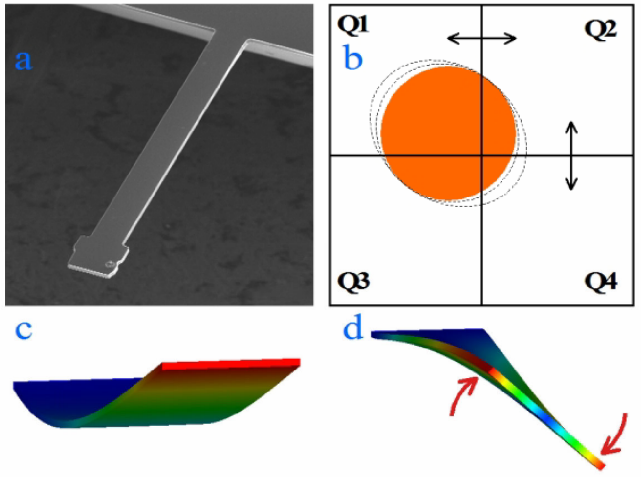
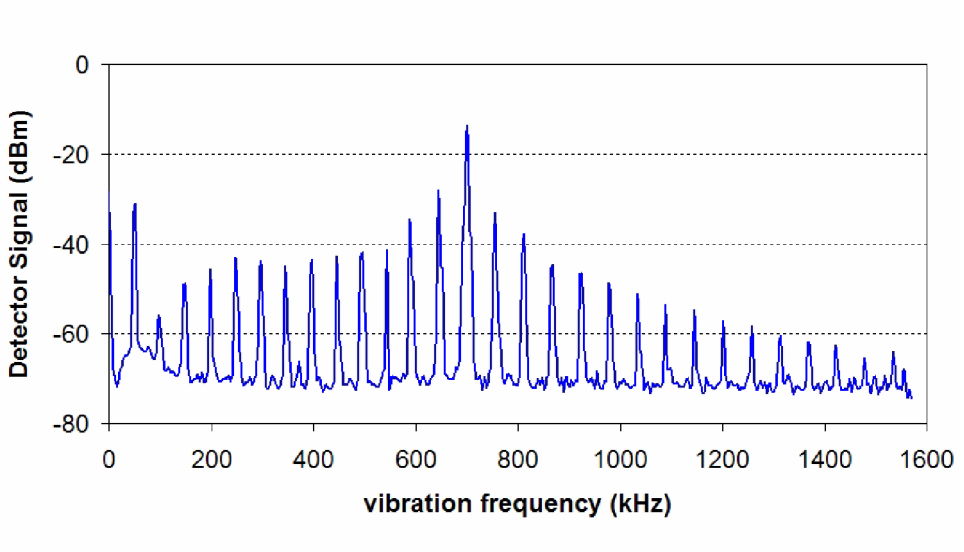
Tapping Harmonic Detection









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

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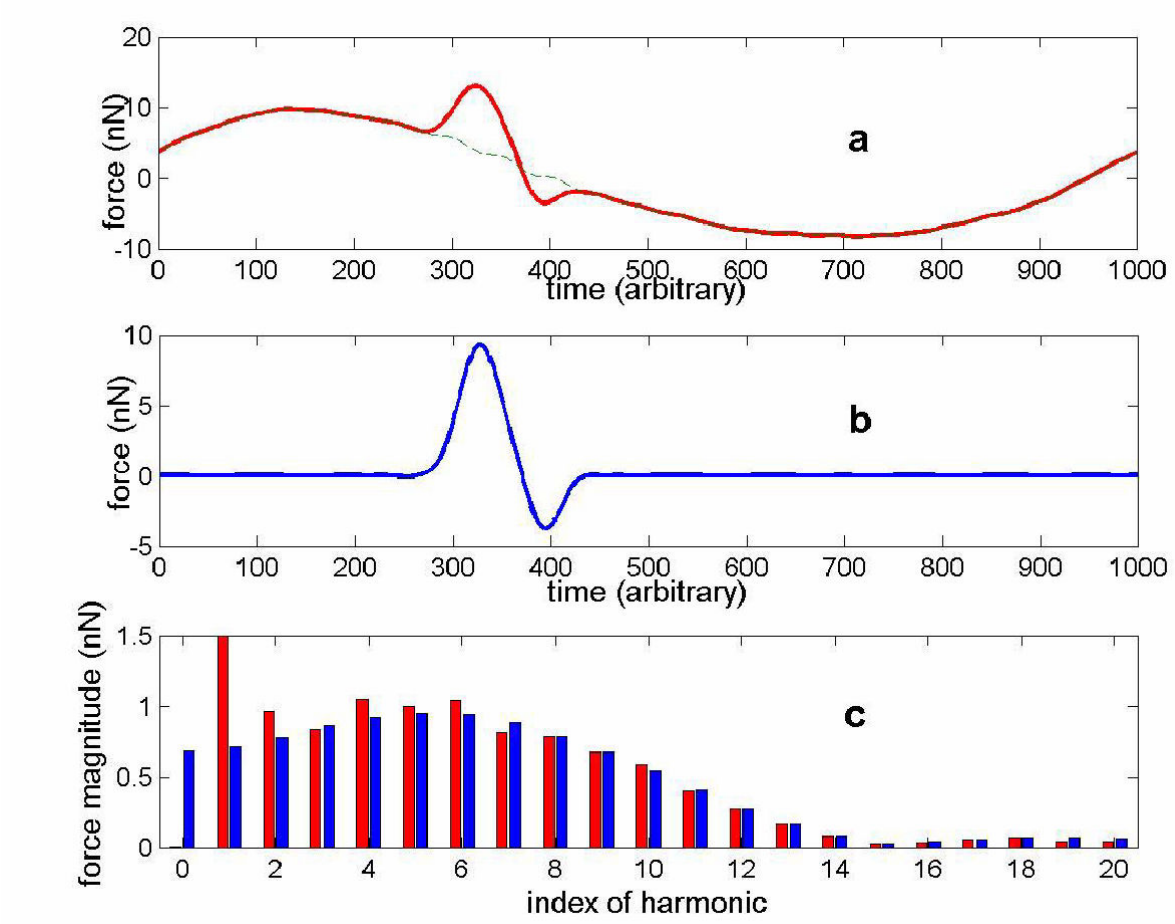
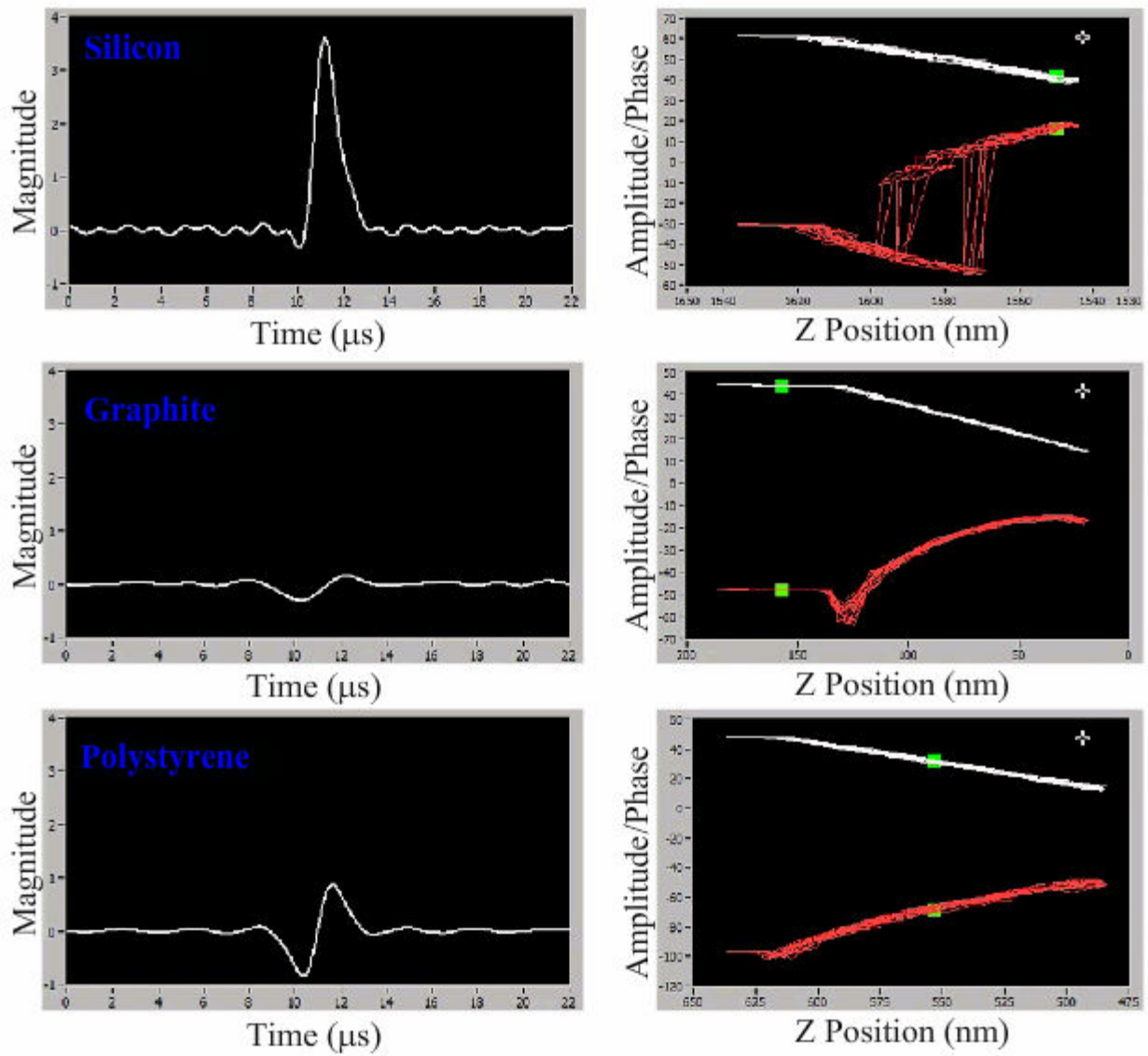
Time Resolved Tapping Force



Real Time Tapping Force



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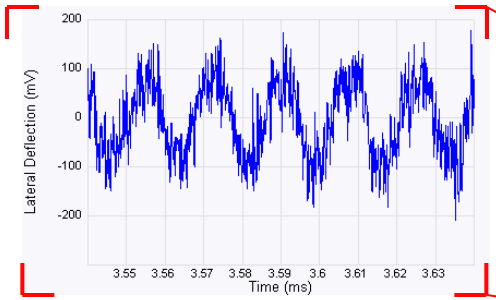
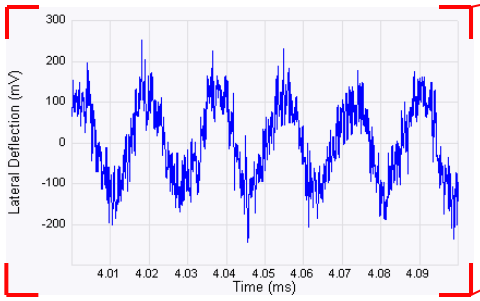
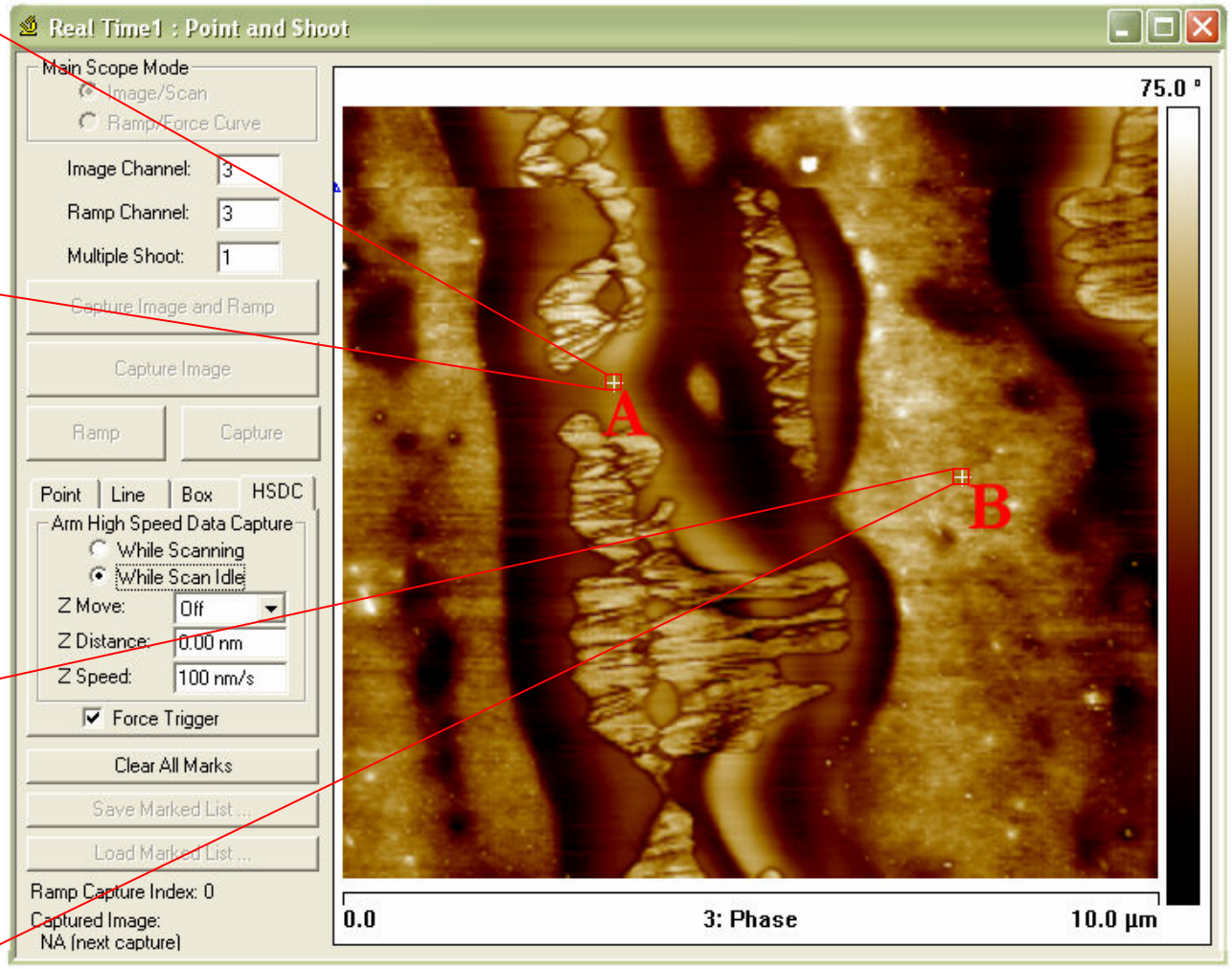
Point And Shoot With High-Speed Data Capture

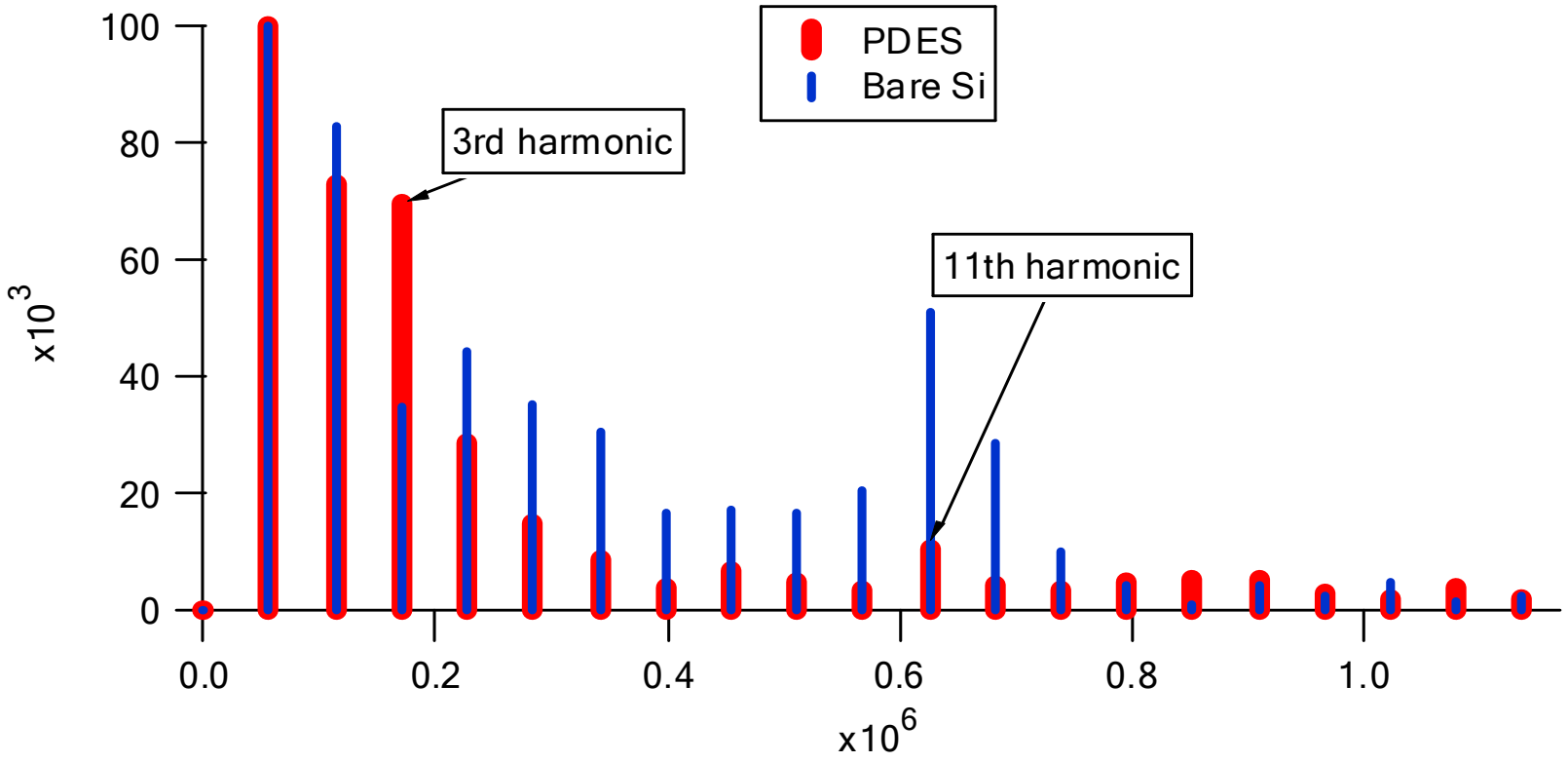


- PDES On Silicon
- A PDES
- B Bare Si





Comparison Of Spectra: PDES vs. Si



When overlaid the differences become clear

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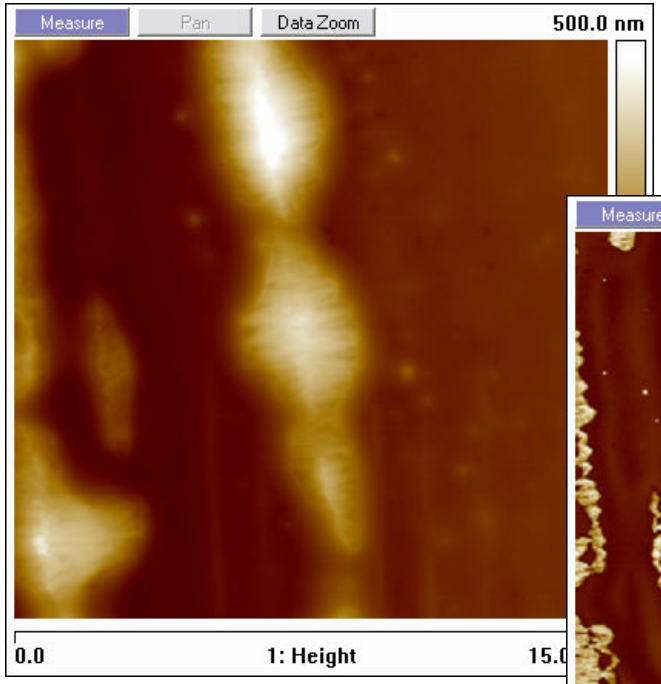
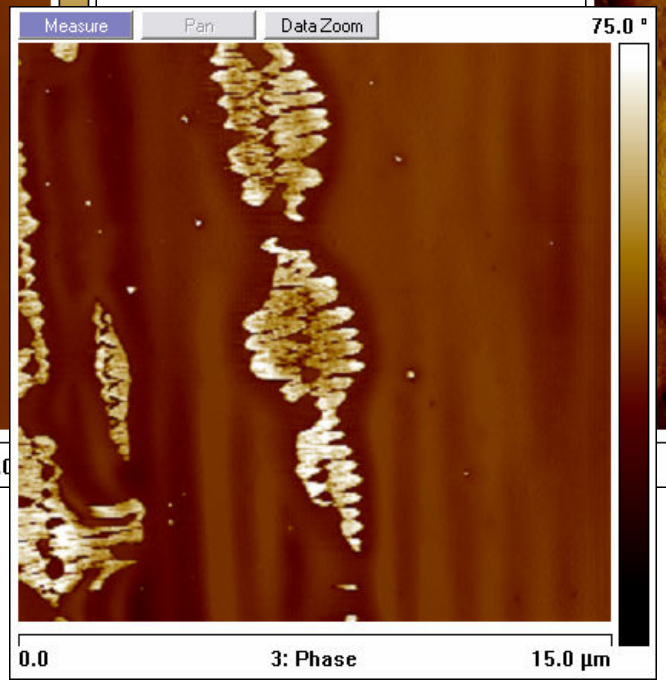
Regular Height, Amplitude And Phase

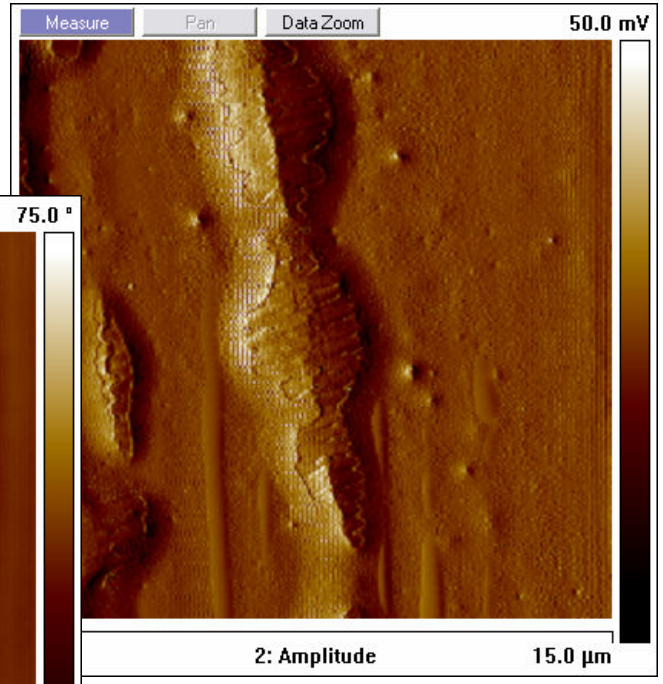
- PDES On Silicon (rubbed)



Height



Phase



Amplitude

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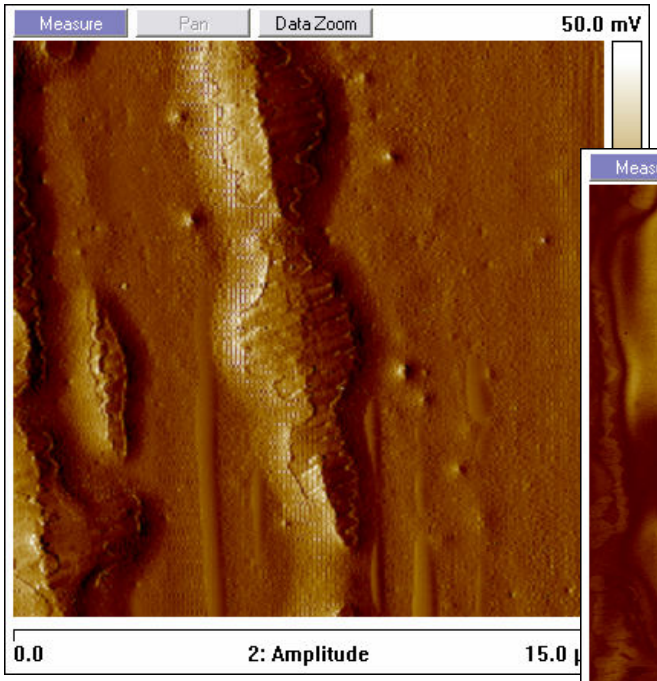
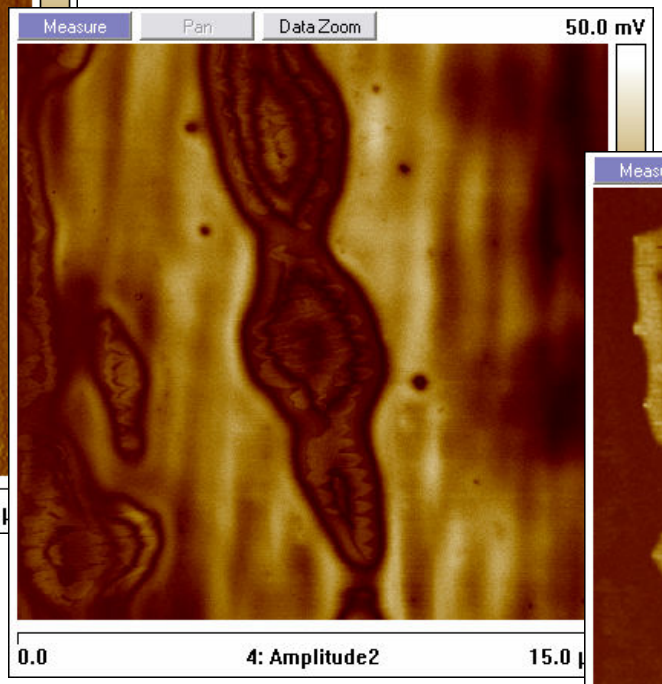
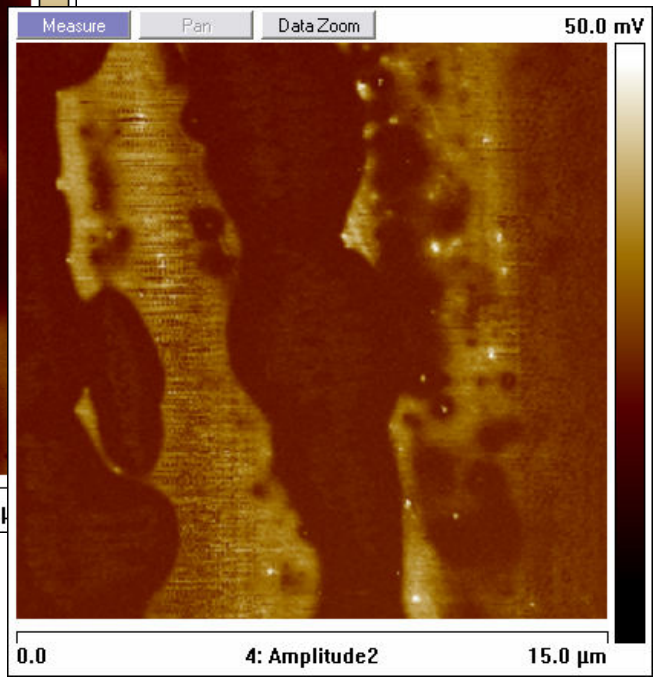
Harmonic Amplitude



Tapping Amplitude



3rd Harmonic



11th Harmonic

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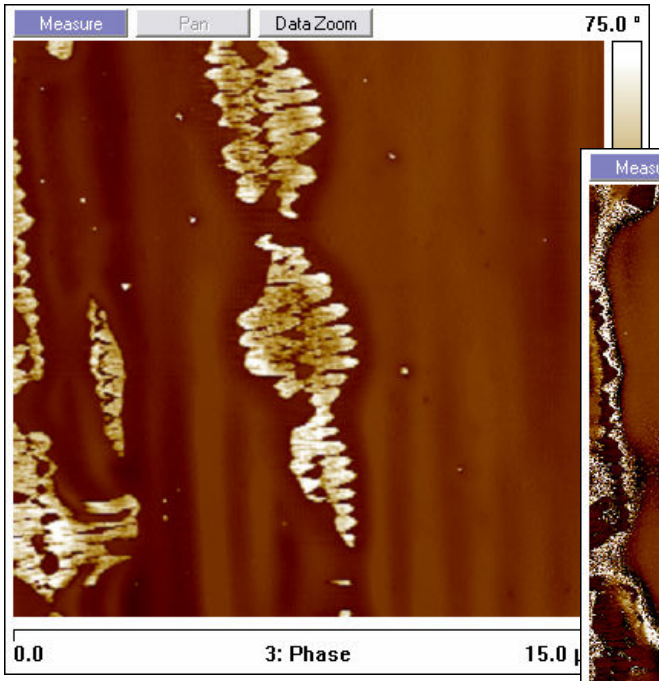
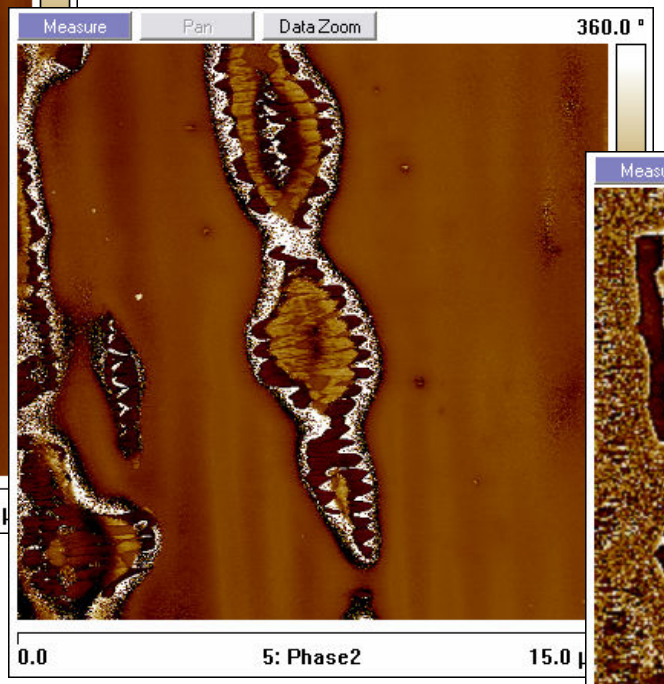
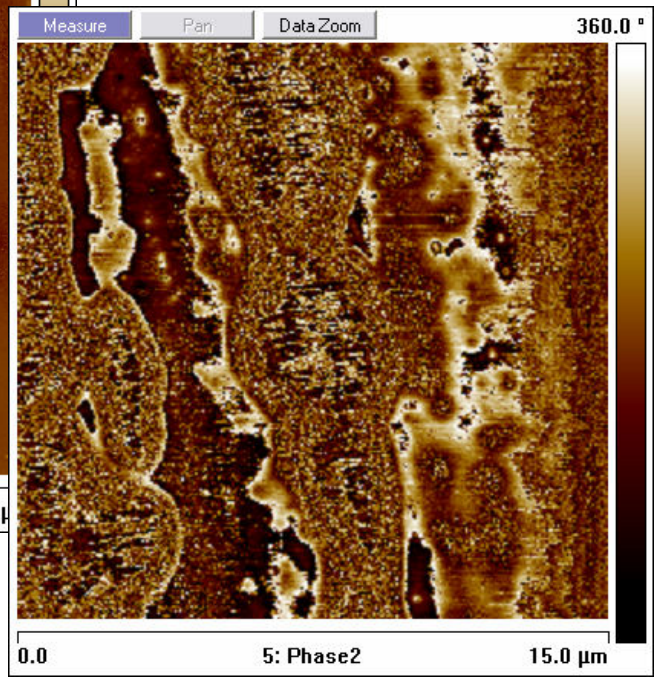
Harmonic Phase



Tapping Phase



3rd Harmonic



11th Harmonic

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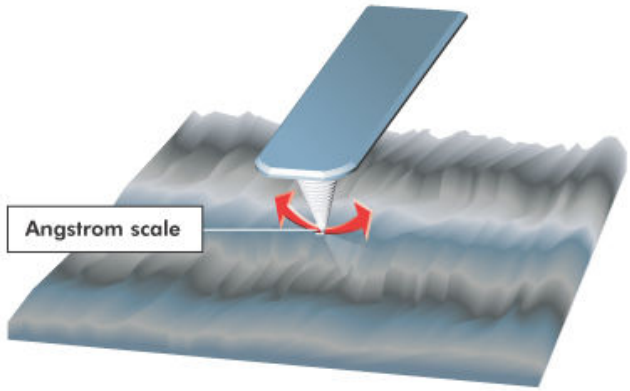
Torsional Resonance

- 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 (Å-scale lateral dither)
    - true non-contract 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



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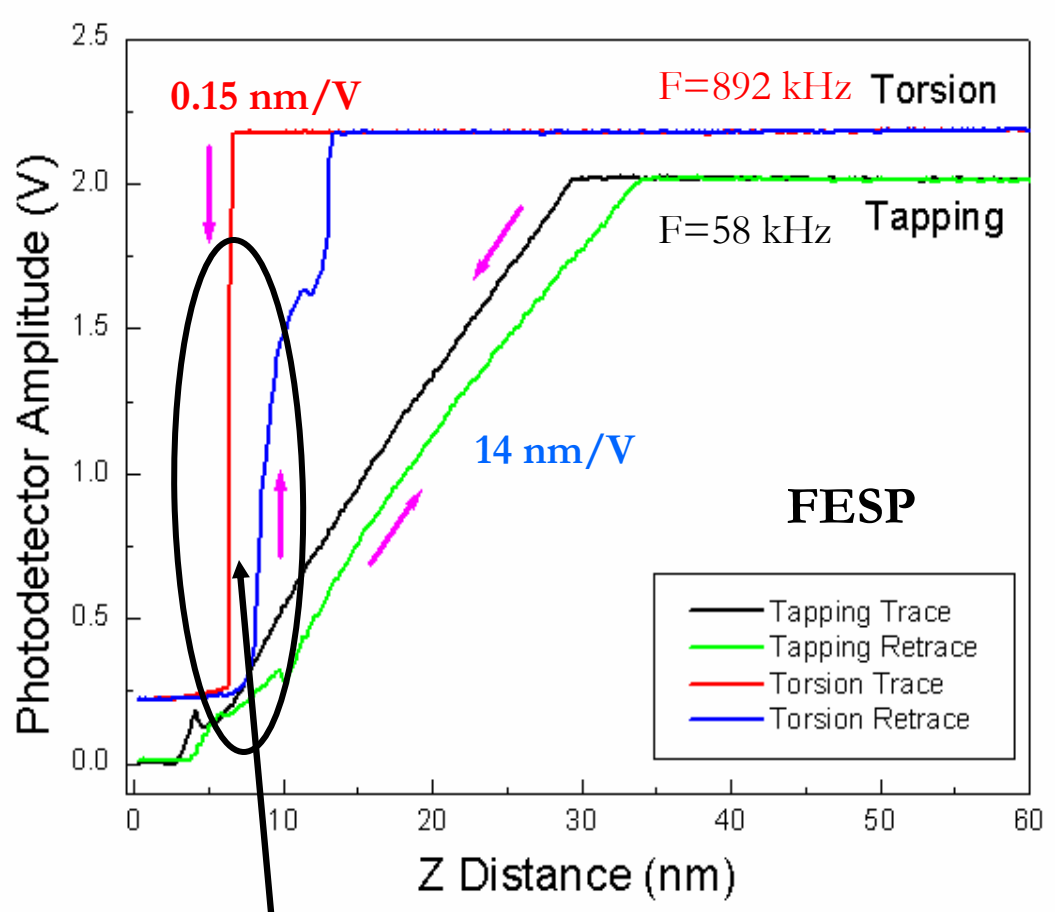
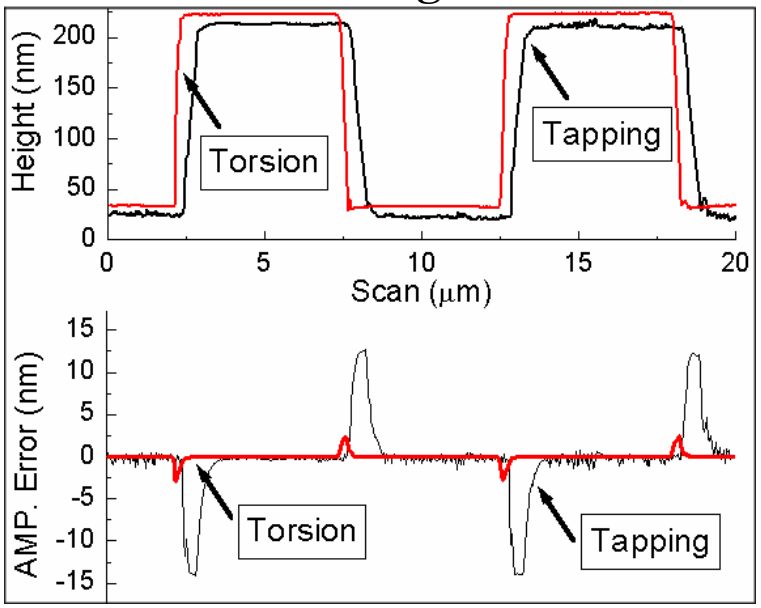
Faster Cantilever Dynamics



High sensitivity to Z displacement

Better Tracking



Small error signal

Scan rate 15 Hz on a grating

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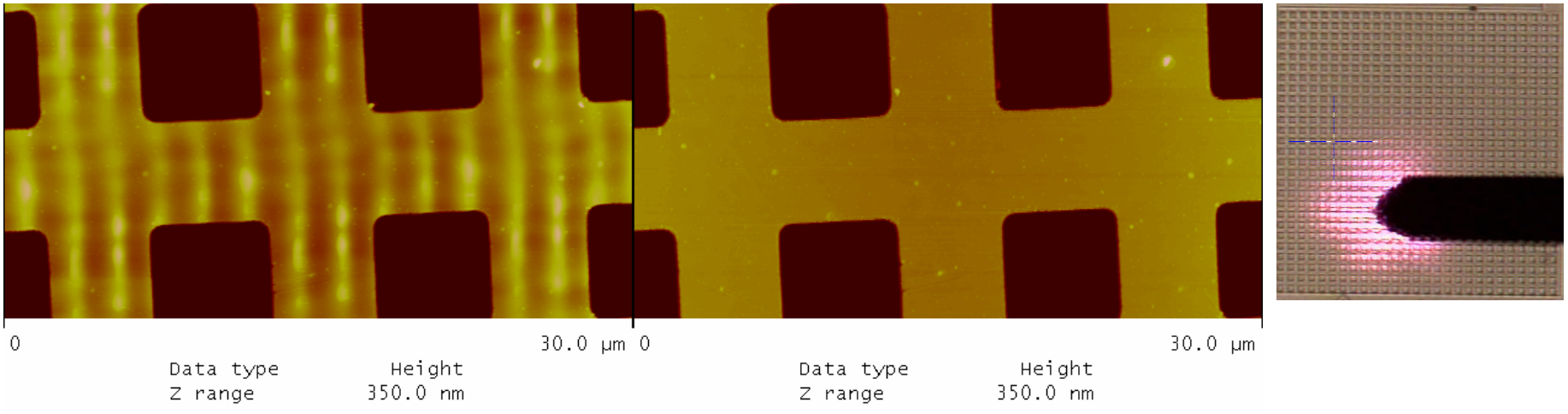
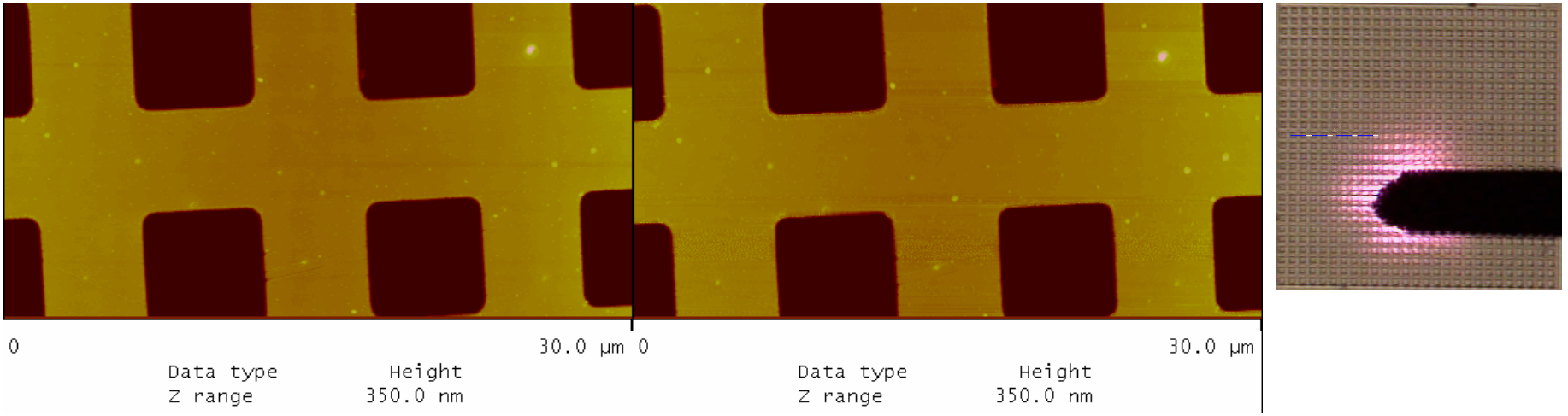
Interference Laser Noise Eliminated In TR





Tapping

Torsion

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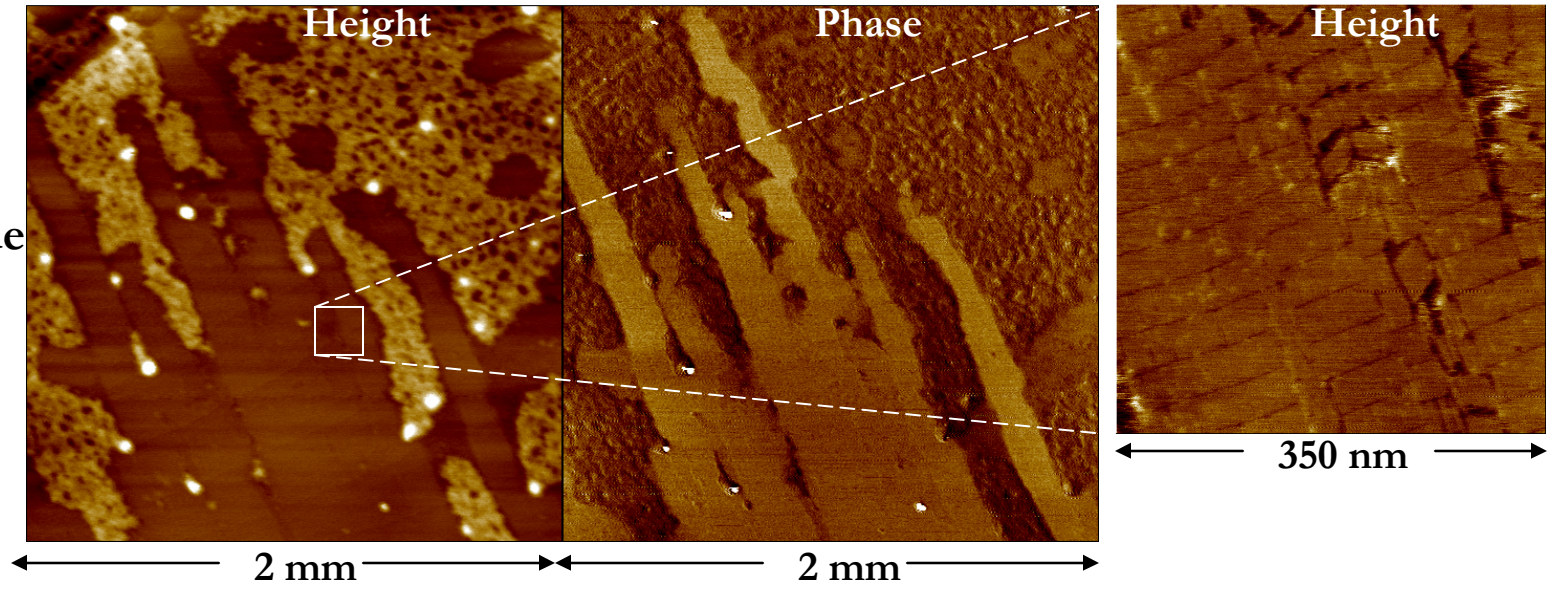
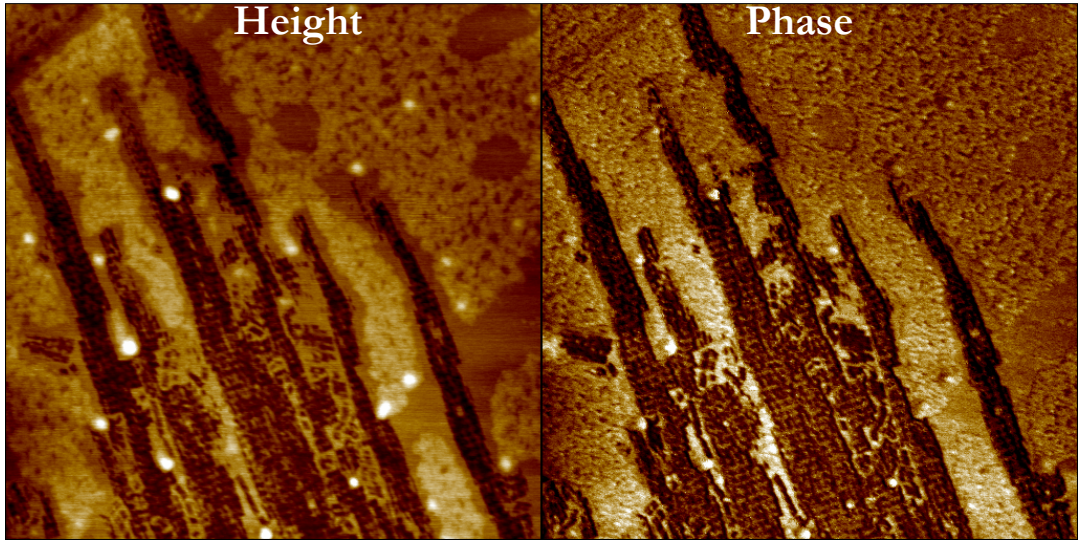
Soft Organic Layers

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

Tapping Mode



Torsion Mode



Lamellar edges are enhanced in TR mode

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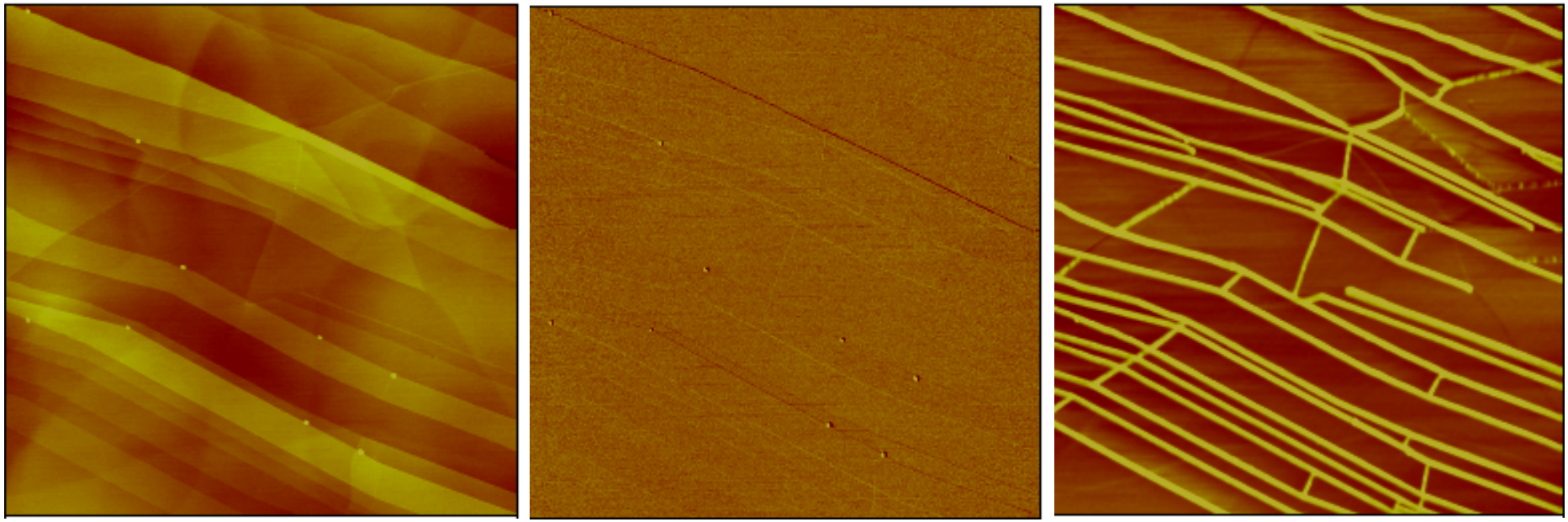
Interleave Scanning With Tapping And TRmode

Tapping height | Tapping phase | TR phase



Height scale 5 nm

Phase scale 10 degree

3 μm scan on HOPG surface @ 1 Hz

TRmode: dynamic measurement increases sensitivity by a factor of Q ~ 1000

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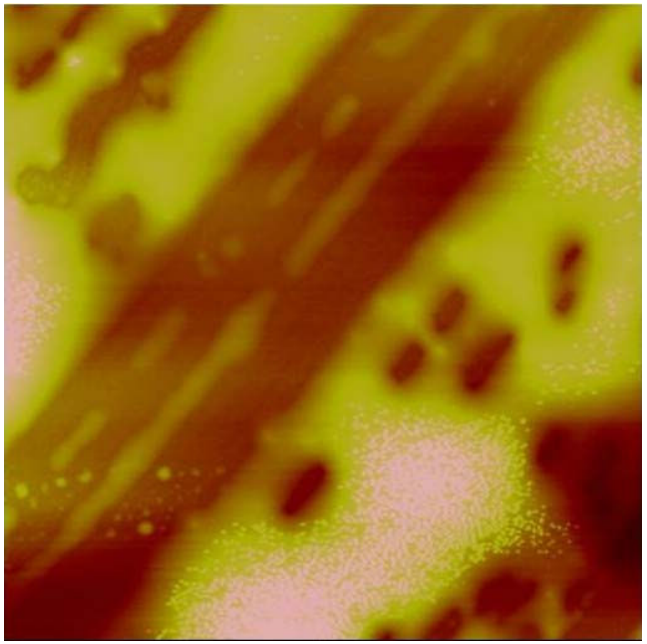
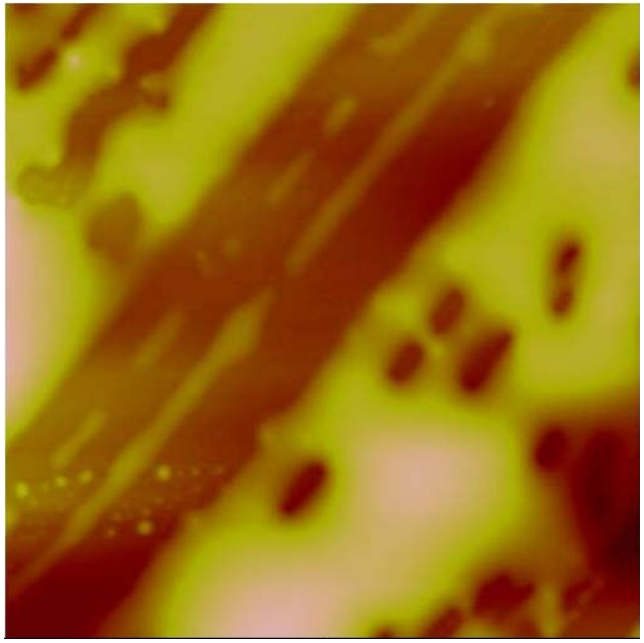
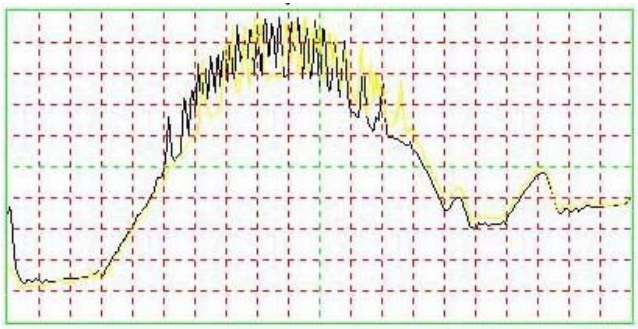
PDES – Sticky Samples



TappingMode



TR Mode



20 µm Scans – Height Data

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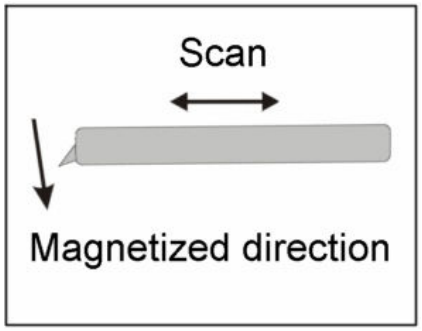
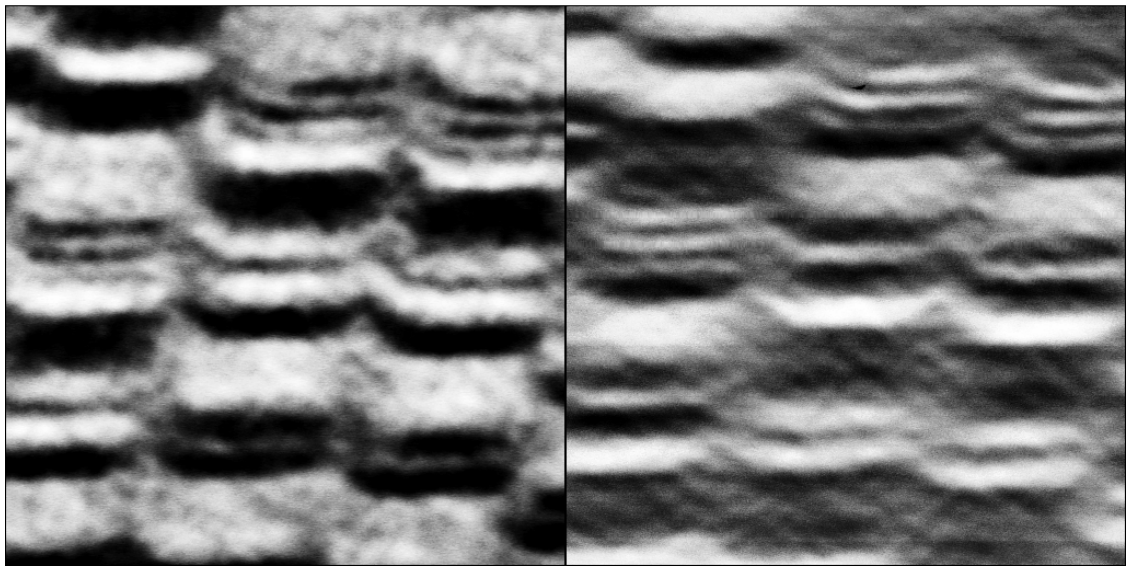
Detecting In-plane Force Gradients In MFM



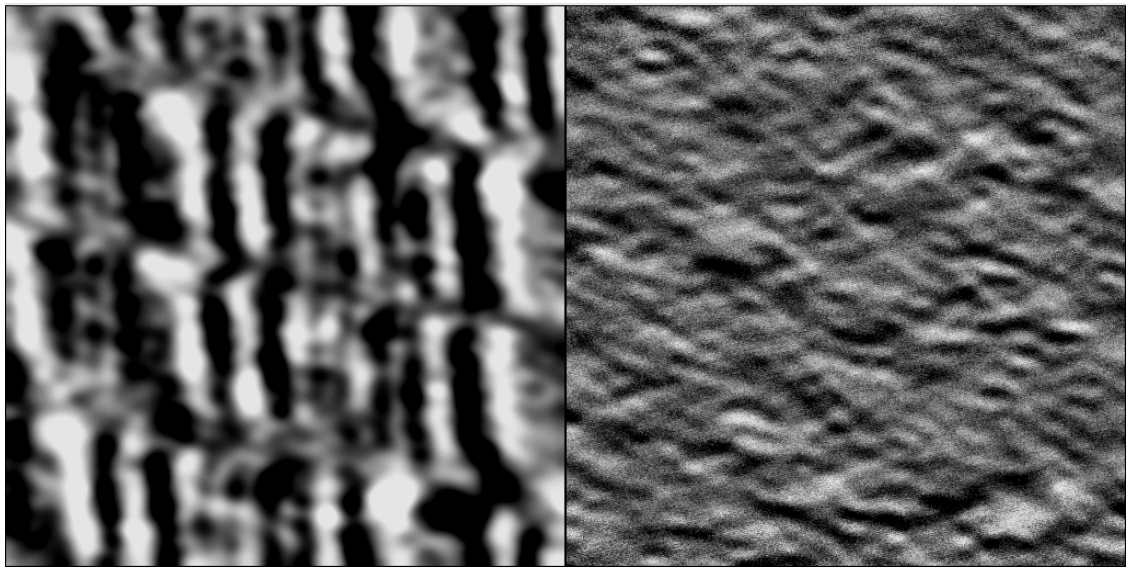


Sample
0-degree

Tapping phase

TR phase

3 μm scan on hard disk



Sample
90-degree

Tapping phase

TR phase

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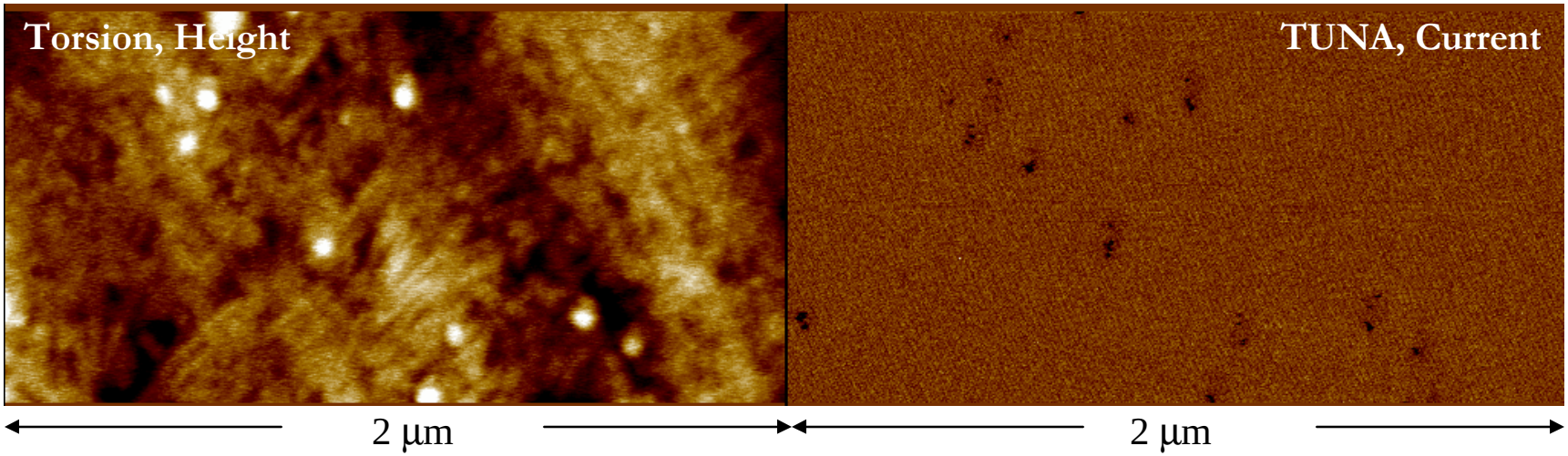
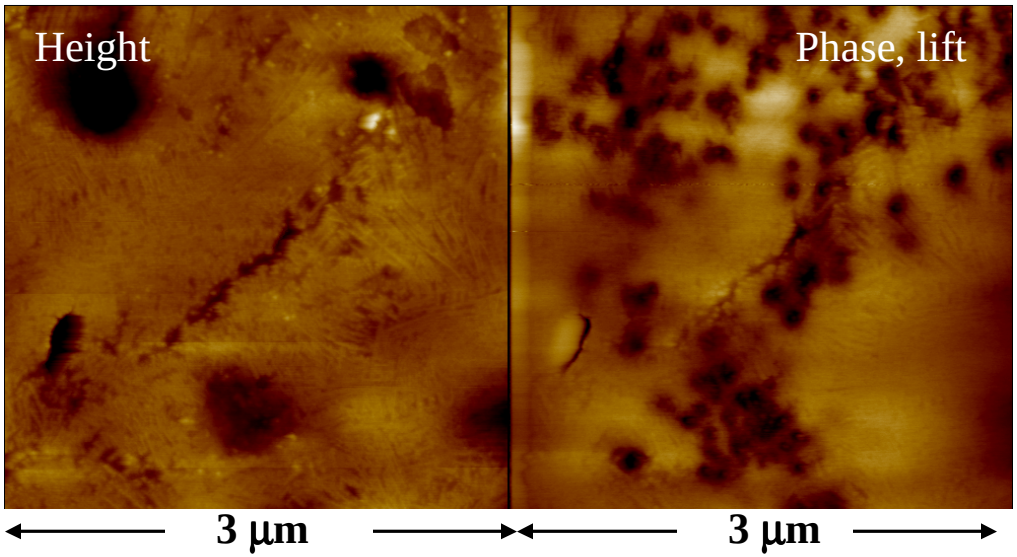
Combining TR Mode with TUNA

Thermoplastic Vulcanizate filled with Carbon Black



Electric Force Mode (Tapping w/Lift)



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

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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.

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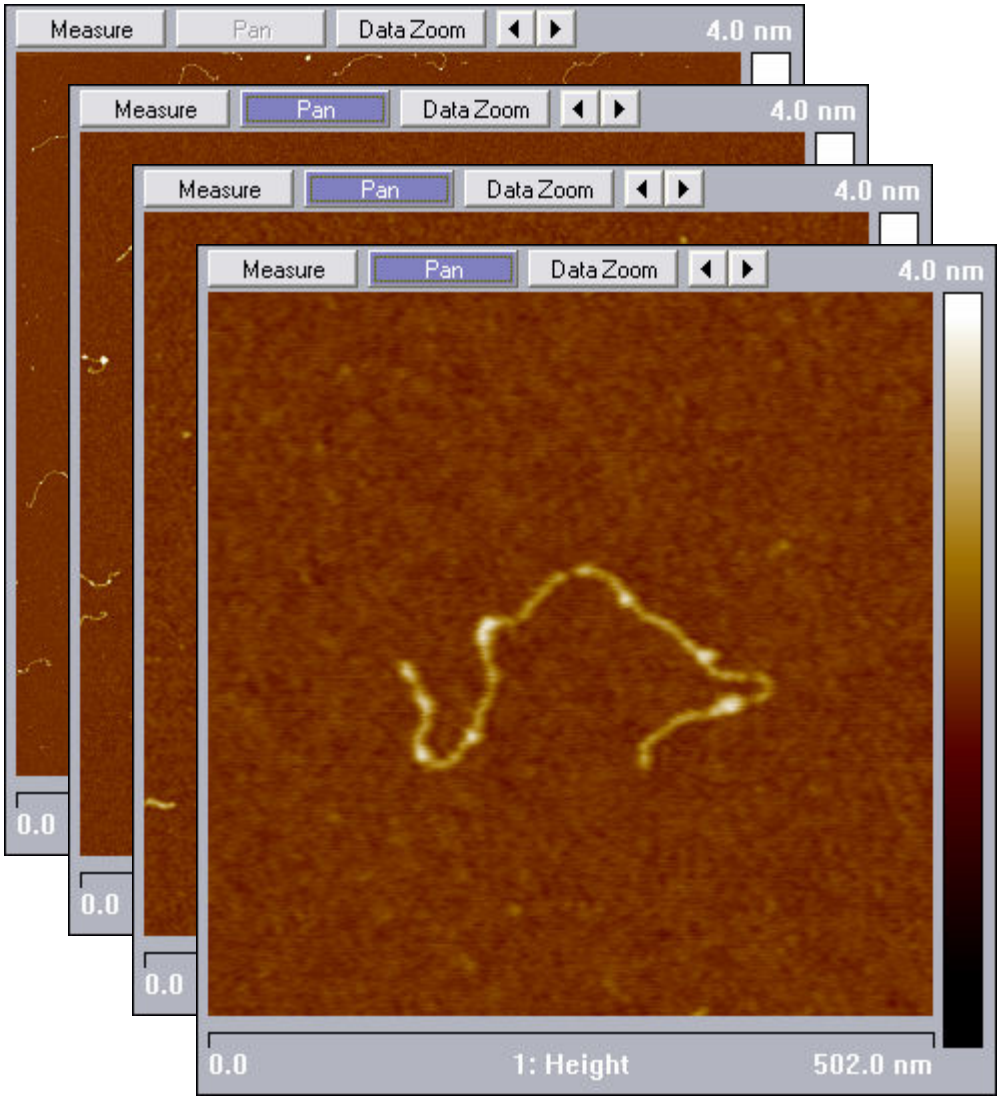
High Pixel Density Images

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



Sample courtesy Jason Reed, UCLA Chemistry

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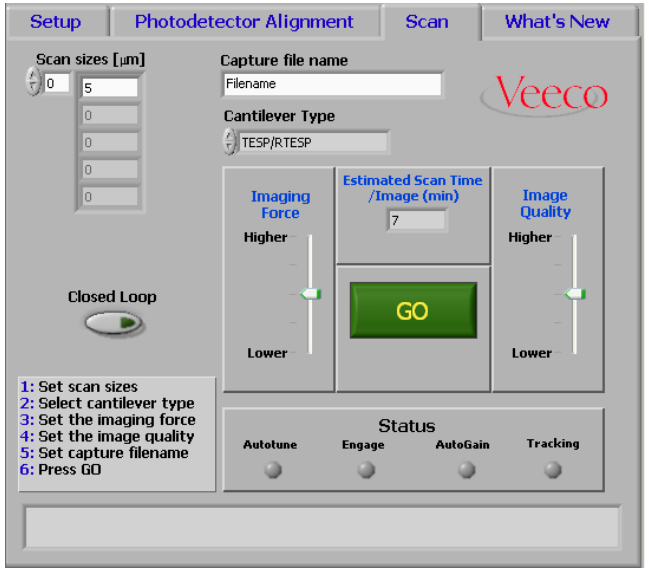
Easy-AFM

- 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

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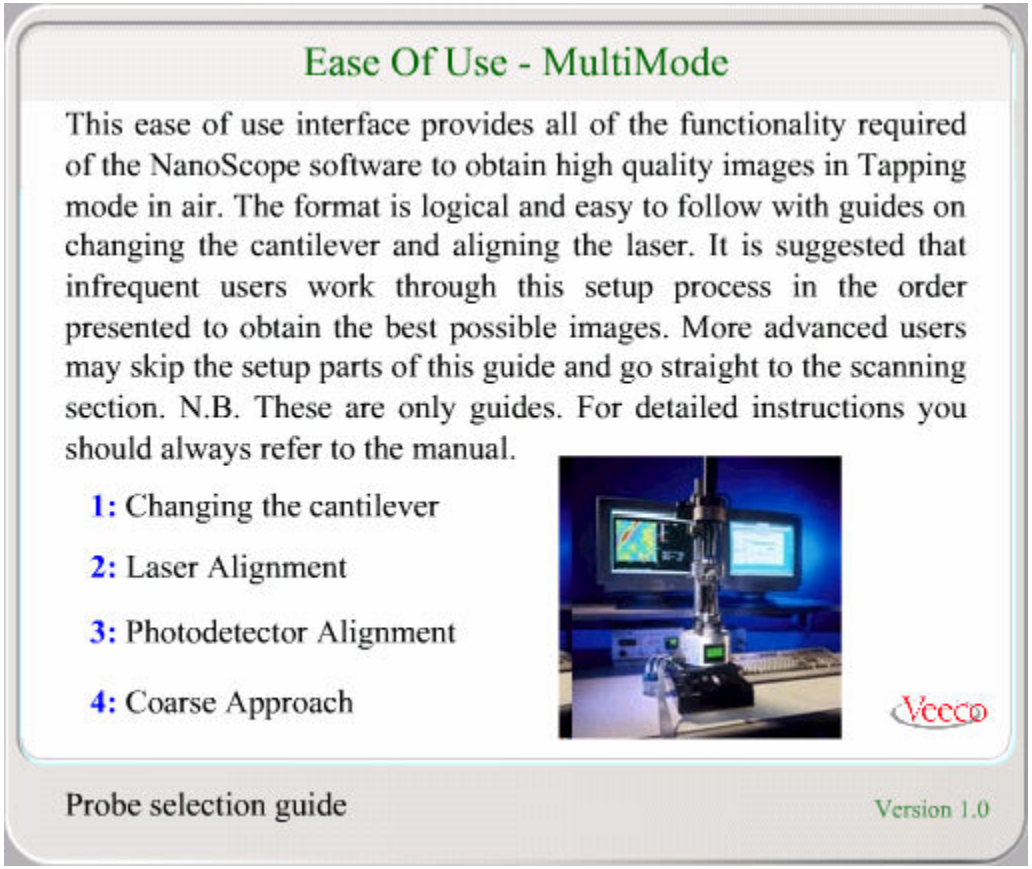
Easy-AFM: Interactive Help

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



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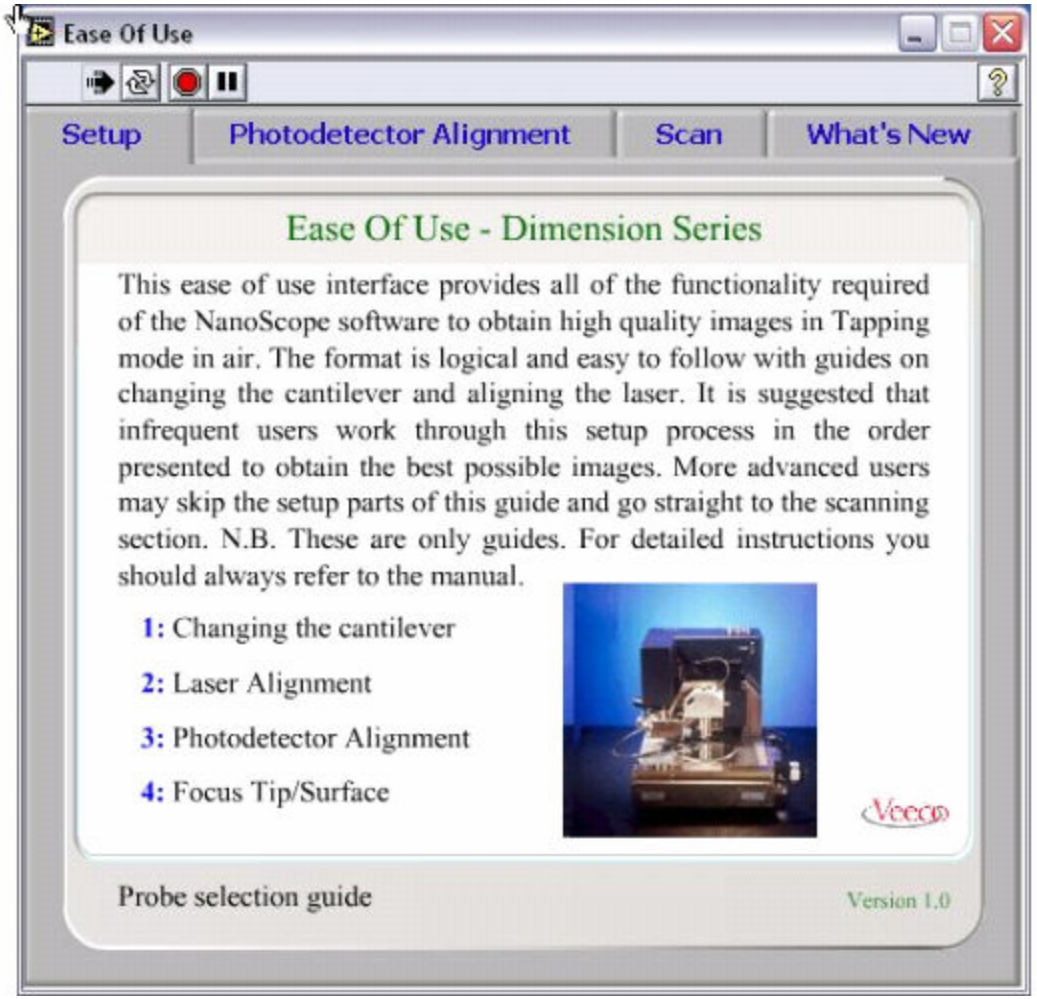
Easy-AFM: Scanning

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



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