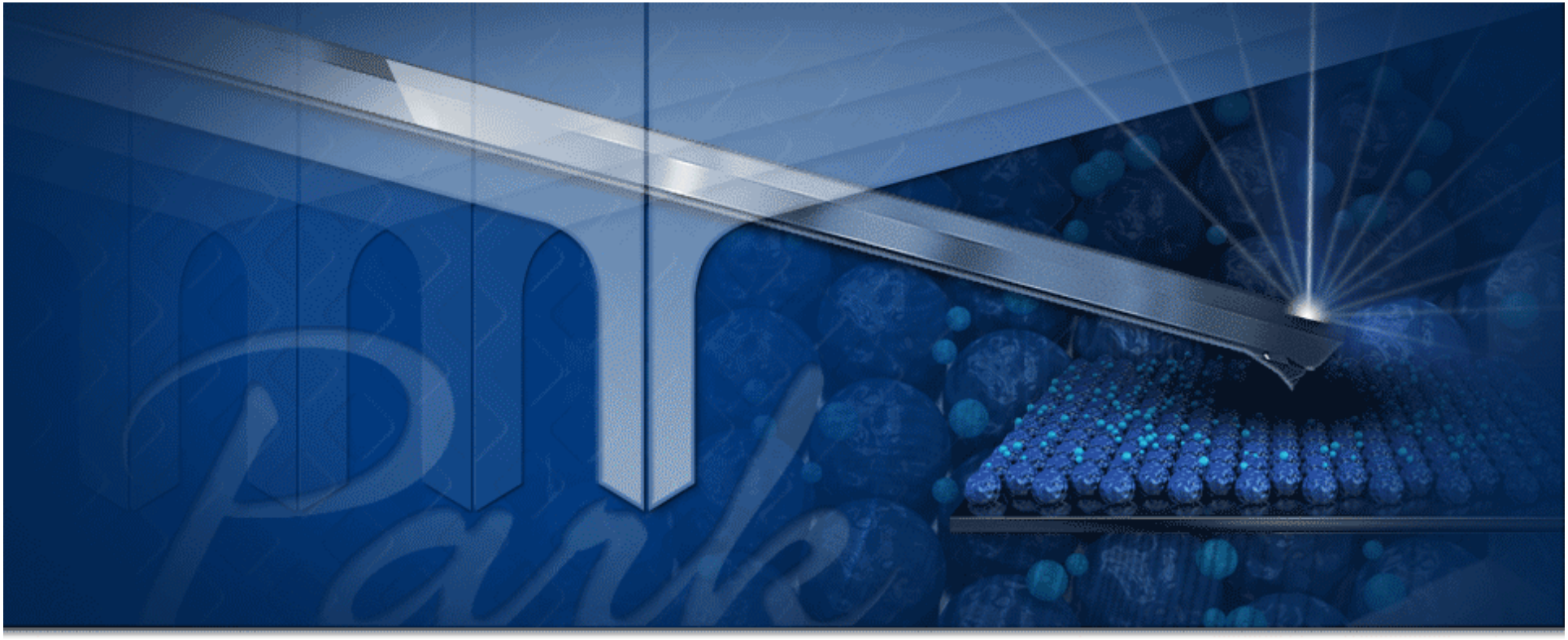


Advanced Inline Slider Metrology with Non-Contact AFM

Sang-il Park

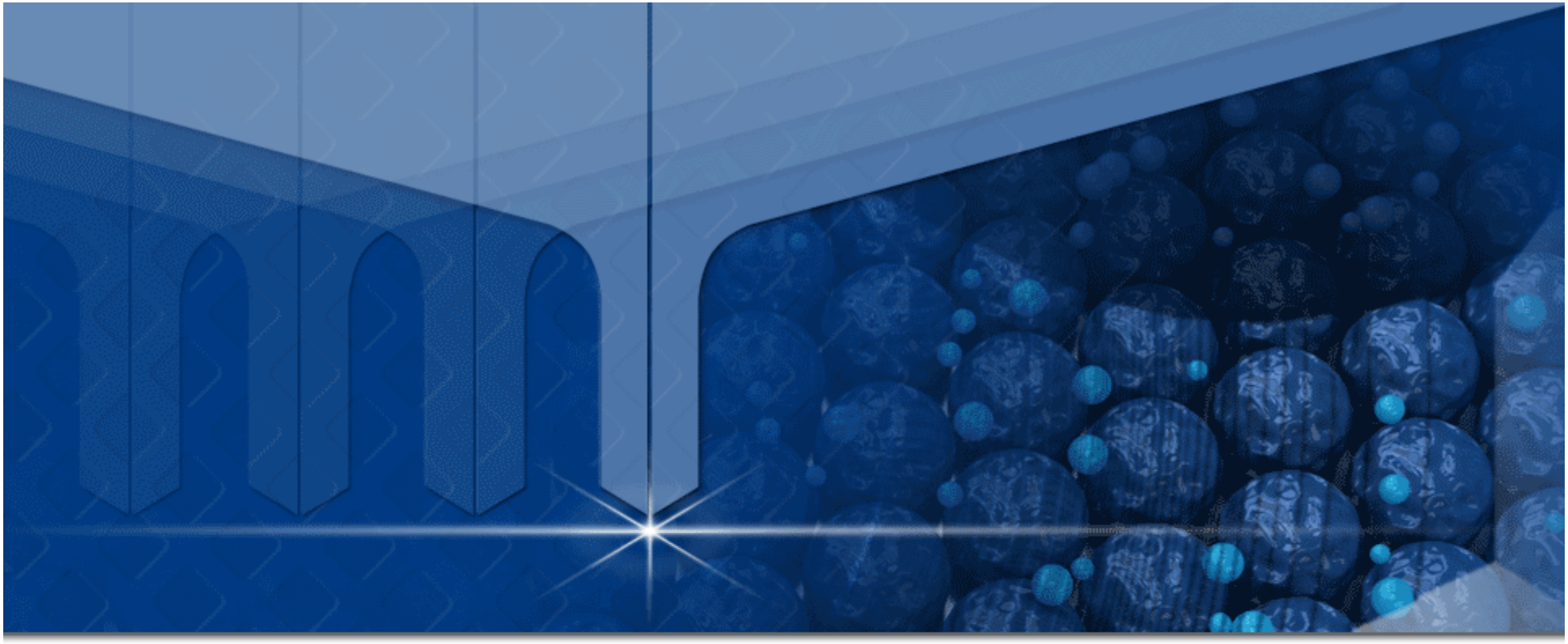
CEO and Chairman

Park SYSTEMS www.parkAFM.com

Nanotechnology Solutions Partner

Outline

- **Introduction**
- **Design Consideration of AFM**
- **Optimized AFM Solutions for Slider Metrology**
  - True Non-Contact vs. Tapping
  - Edge Defect Monitoring
  - IBE Wall Angle Measurements
  - Programmable Data Density



Introduction

Atomic Force Microscope (AFM)

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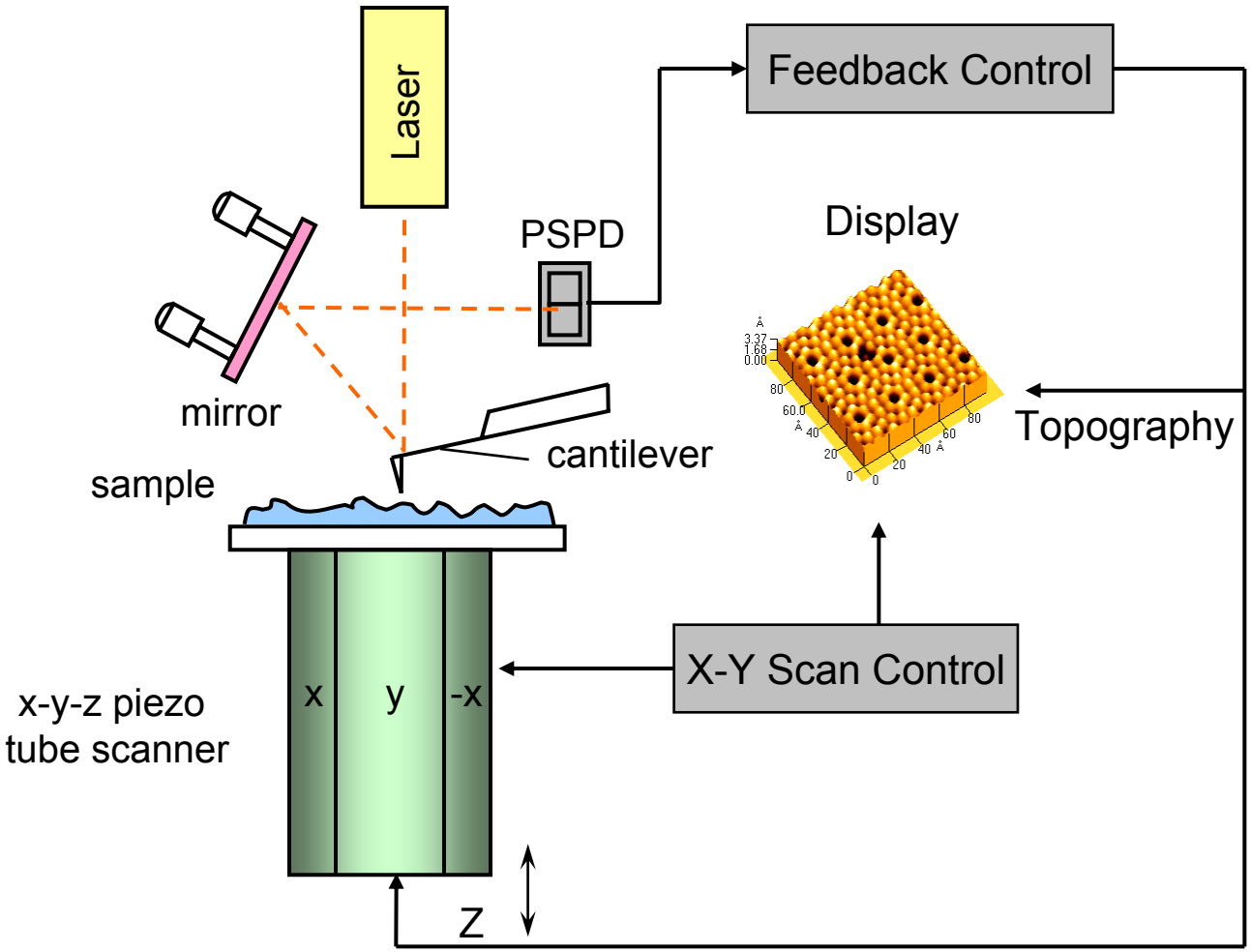

Evolution of Commercial AFM Technology

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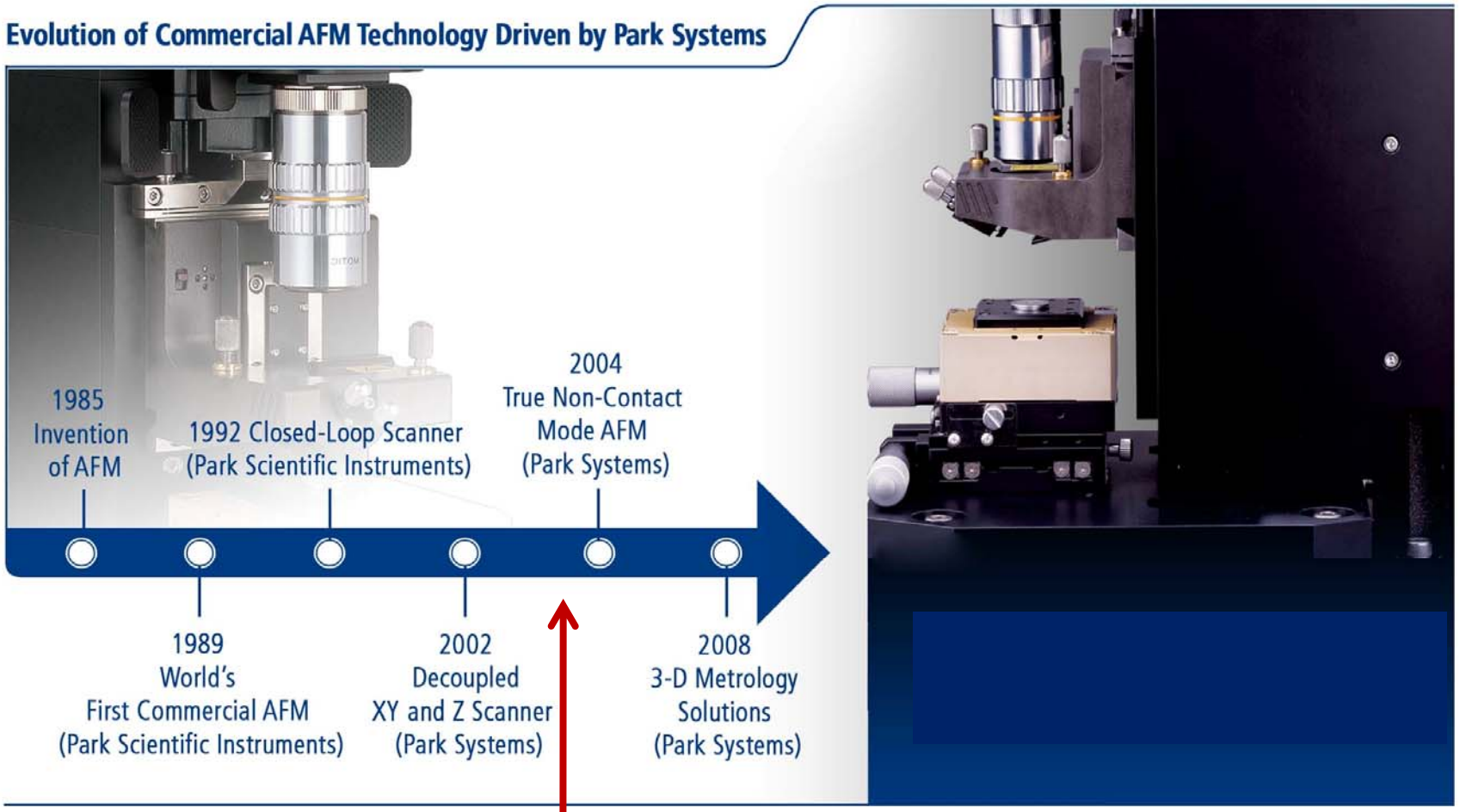
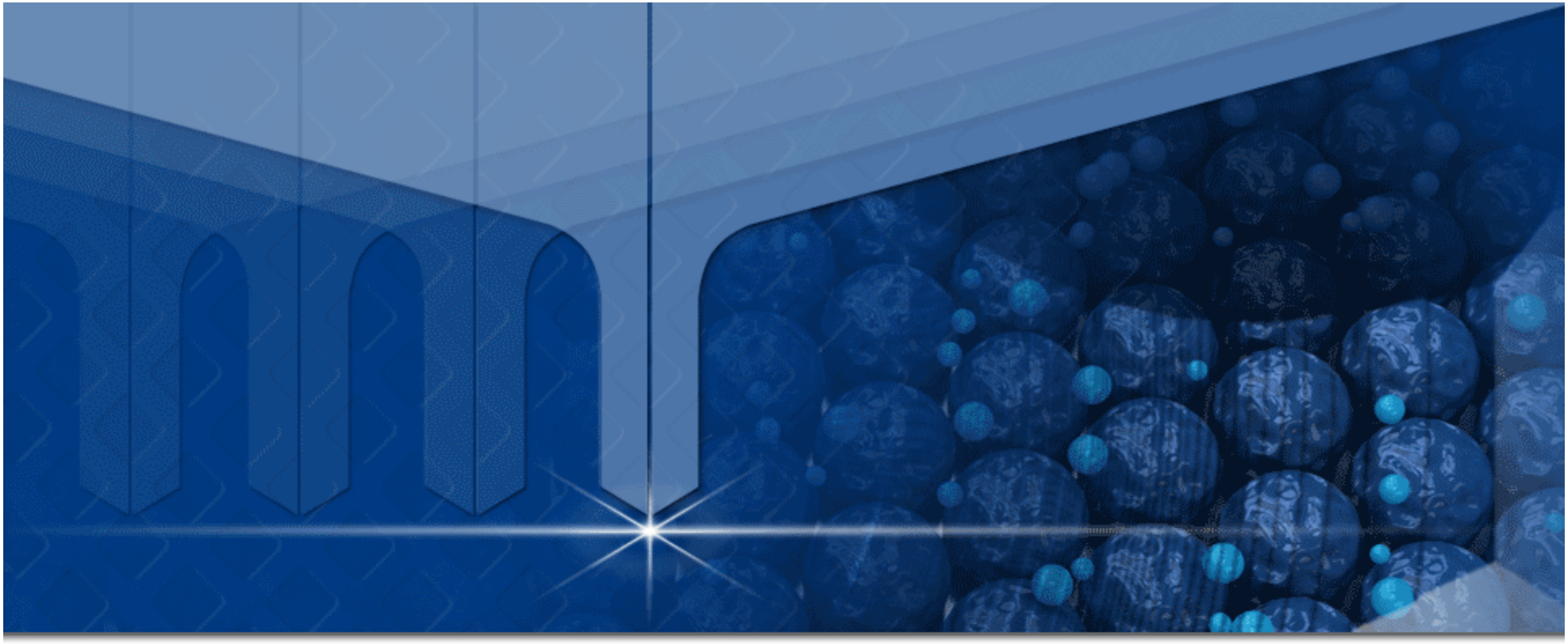
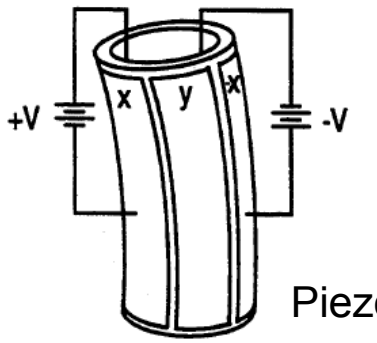


XE-Series AFM release in late 2003

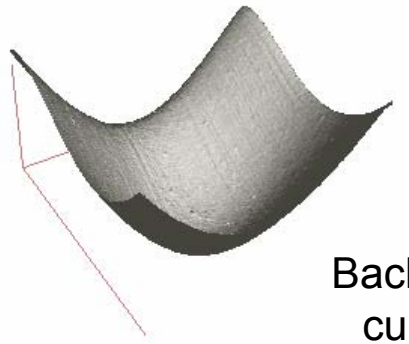


Design Consideration of AFM

Current Limitations of Conventional AFM



Piezo tube



Background curvature

- **Piezo tube is not an orthogonal 3-D actuator (scanner bowing)**
- **Non-Contact Mode not possible due to slow z-servo response**
- **Measurement throughput is prohibitively limiting**

What should we do?

- New AFM platform to eliminate intrinsic hysteresis and non-linearity of piezotube
- New AFM platform to improve Z-servo bandwidth to enable non-contact mode
- New AFM platform to enable smart algorithm to scan sample features of interest

New AFM Platform

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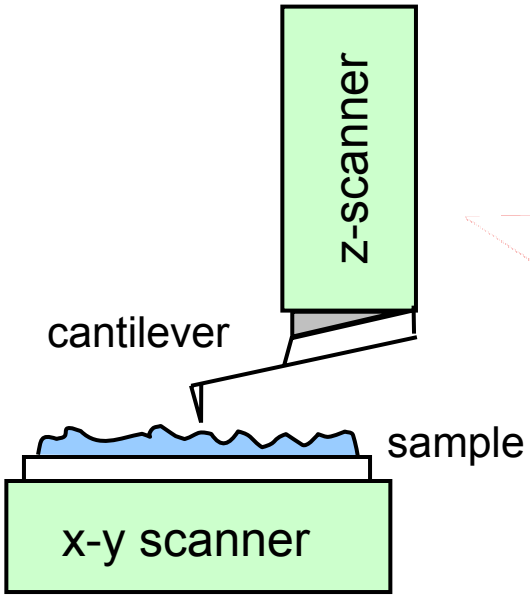
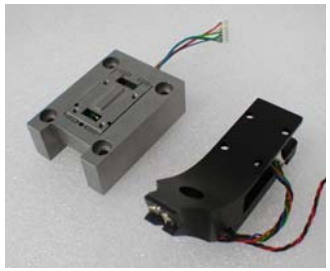
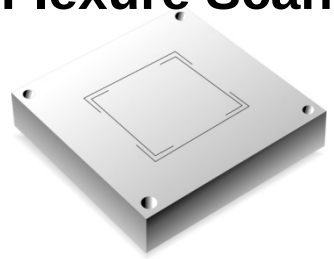


Flexure Guided
High Force Z-Scanner

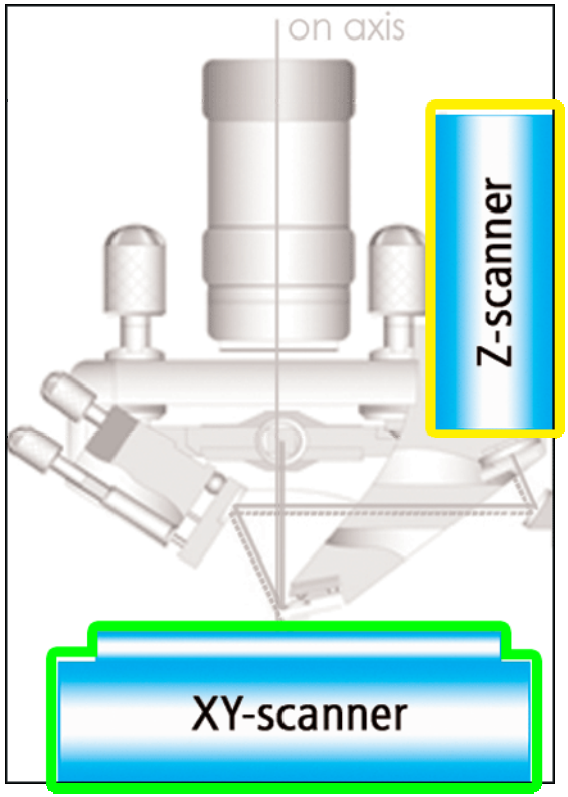


- Separated x-y and z scanner
- Flexure scanners
- Low Z-scanner mass

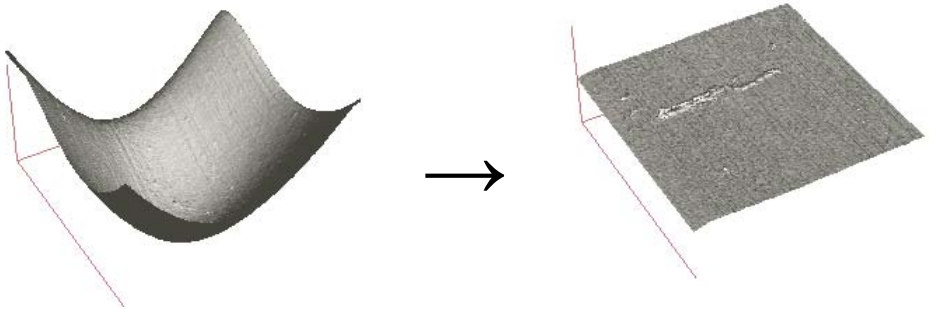
Parallel Kinematic
2D Flexure Scanner



Cross Elimination (XE)

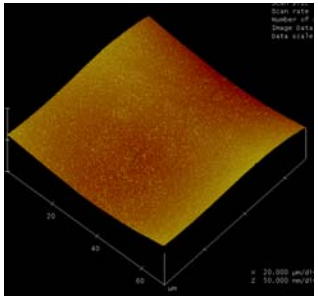


- Independent Z scanner from XY
  - XY scanner scans only sample
  - Z scanner scans only probe
- Background curvature removed



Scanner bowing is practically impossible
to flatten by software

- High order polynomial fitting
- Bowing depends on scan size, speed, and location



Flat XY Scan: Precision Metrology

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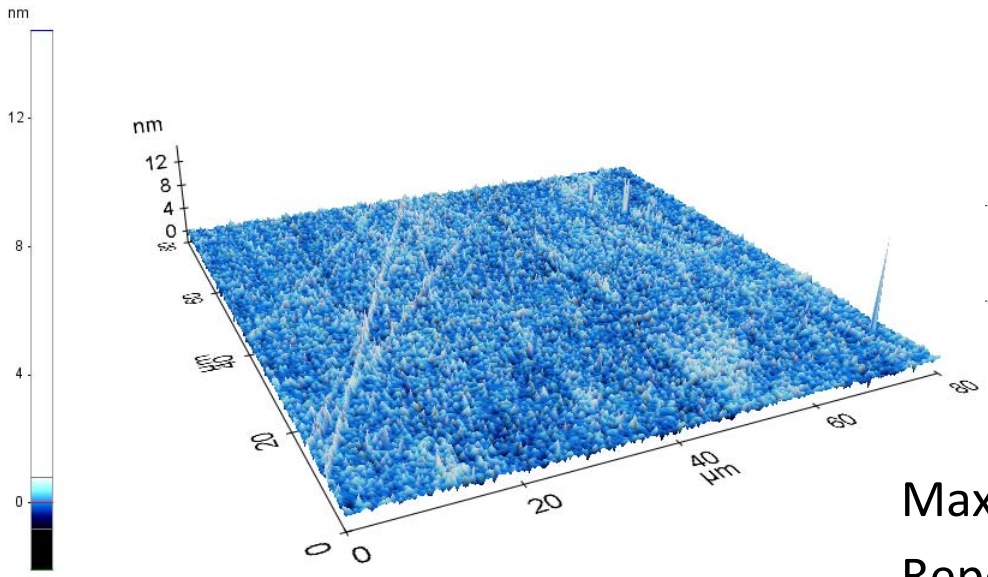
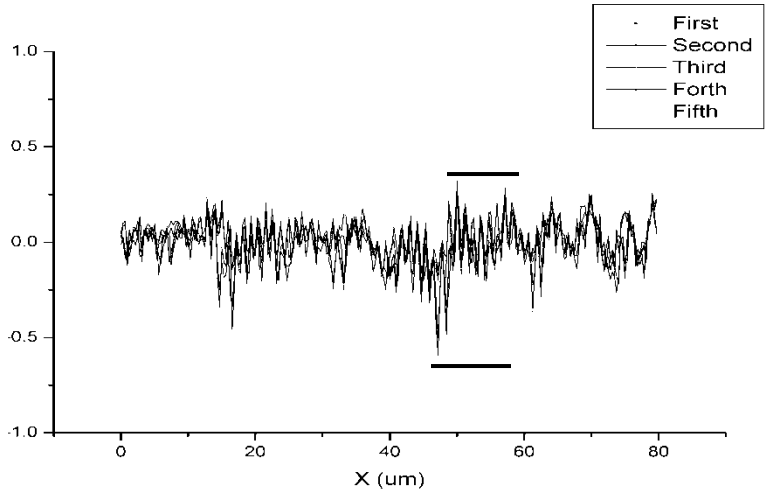
Z Run-out (full scan)





Maximum peak-to-peak = 0.871 nm

Repeatability = 0.481 nm

XY Scan Linearity

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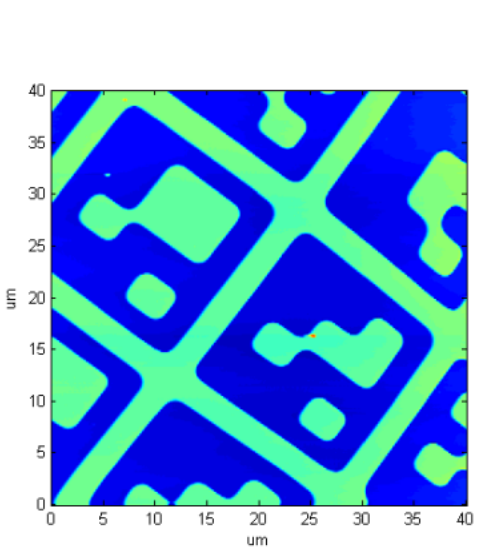
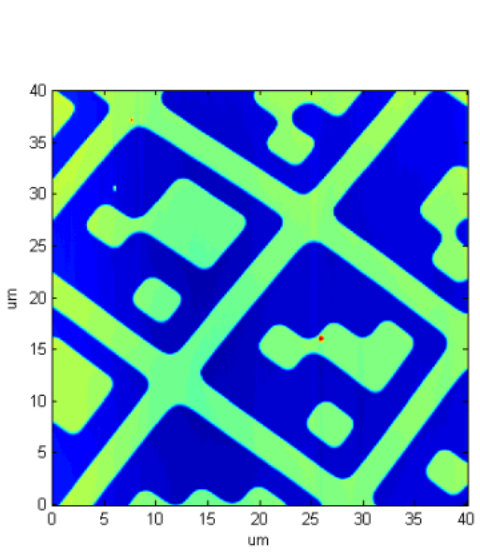
Conventional AFM



0 degree



90 degree

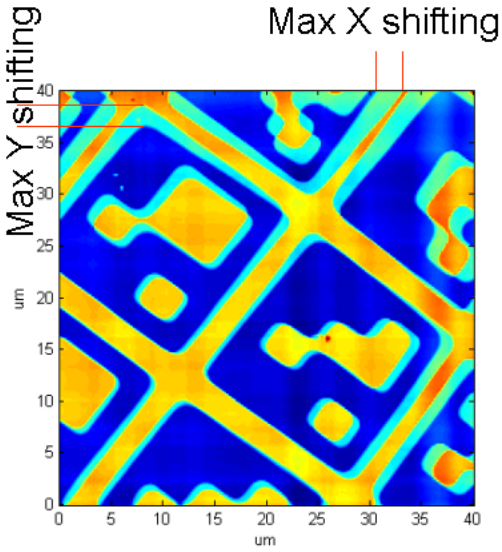
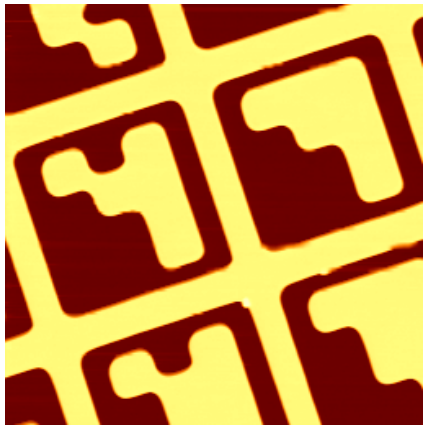
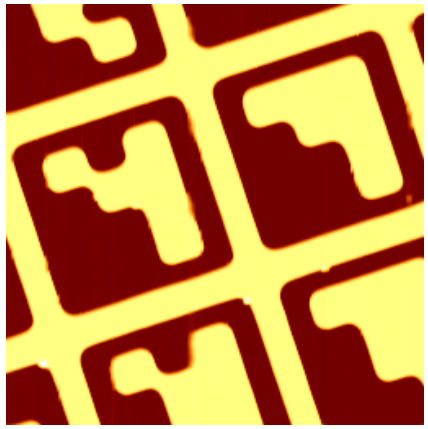
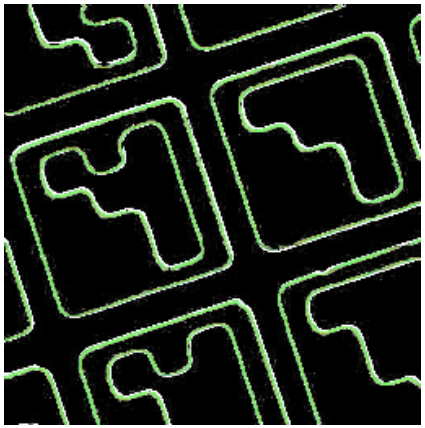


Image matching

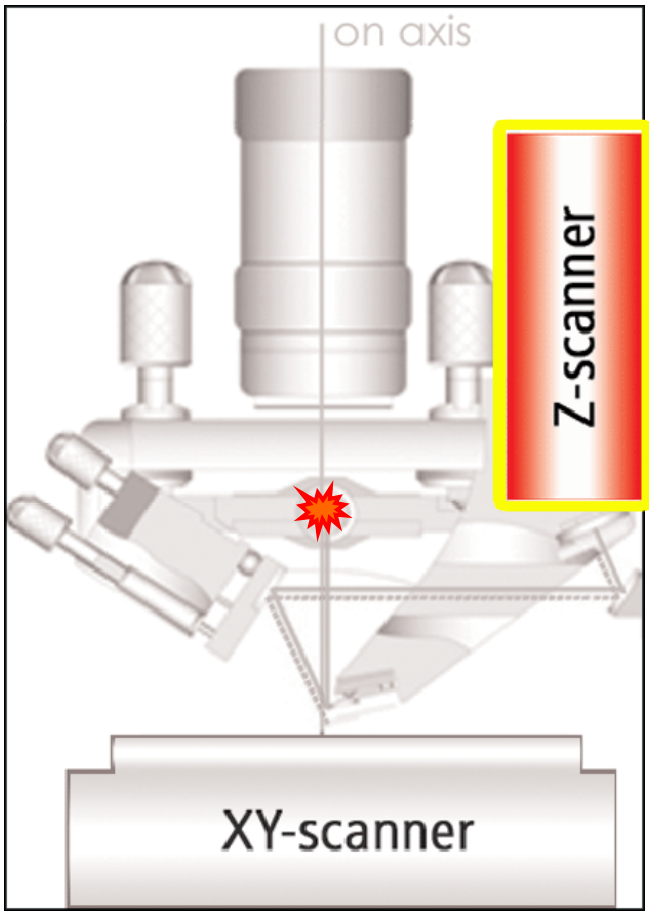
Park AFM







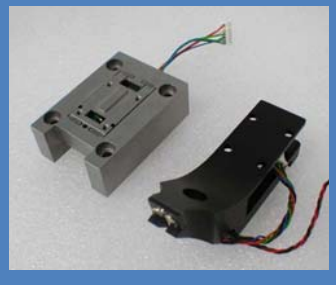
Fast Z-Servo



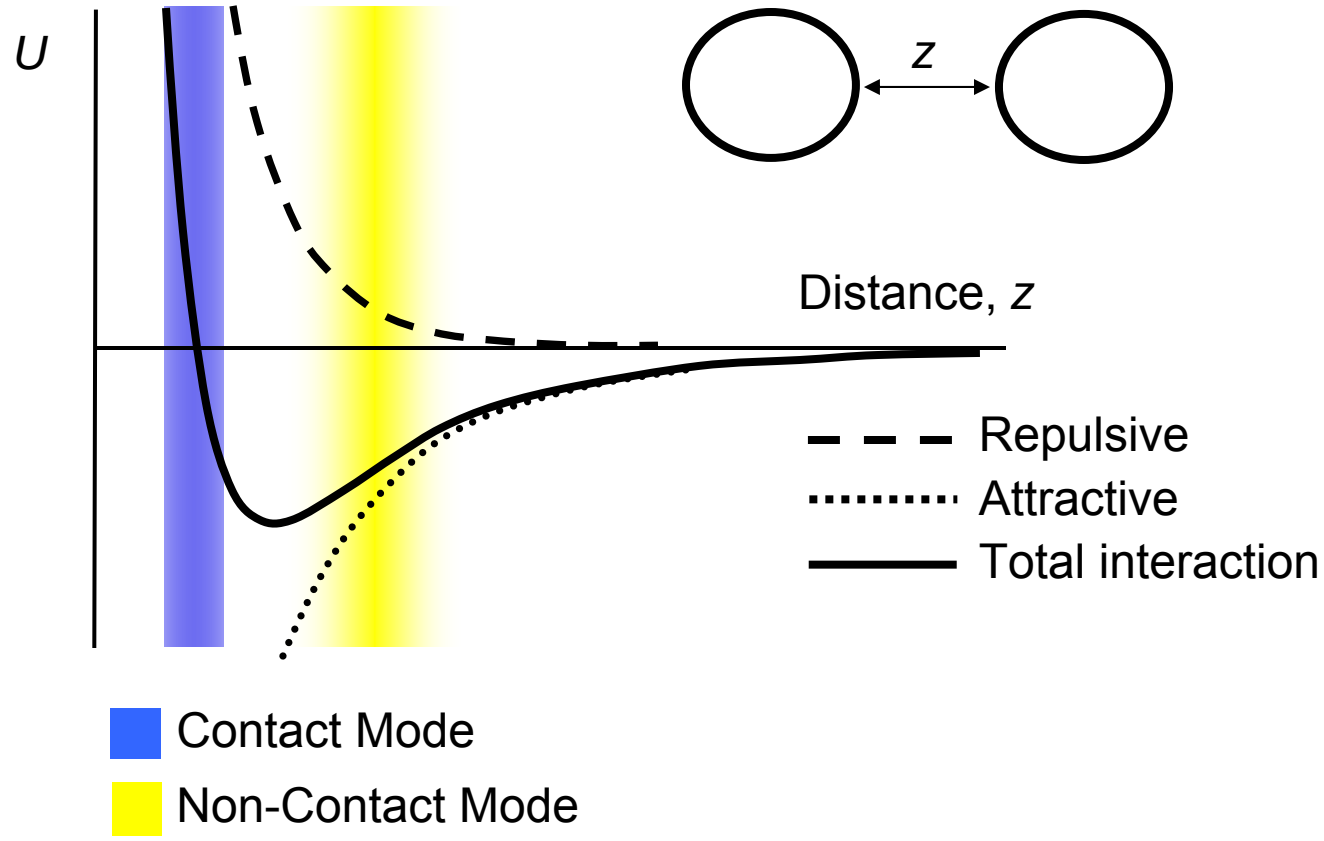
- High force multi-stack piezo
- Large bandwidth of f_0 > 10kHz
- Faster Z-feedback

→ True Non-Contact AFM!

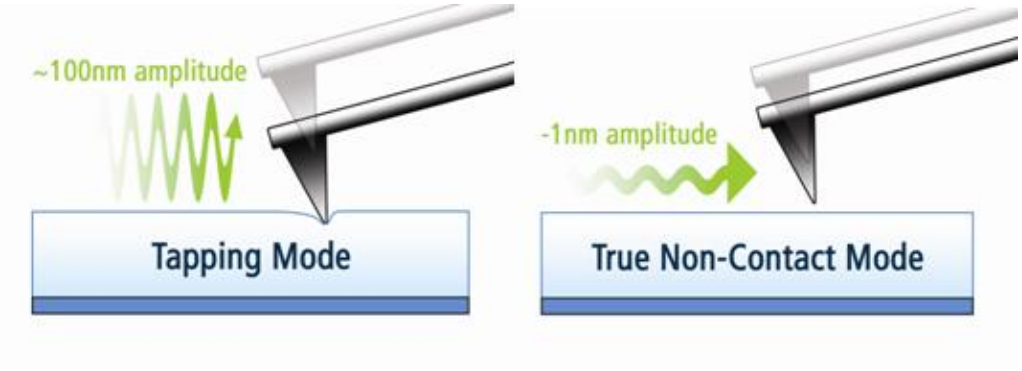
Flexure Guided
High Force Z-Scanner



Inter-Atomic Forces



Faster Z-servo Feedback



- Small amplitude
- Minimized tip-sample interaction
- Less sample damage
- Longer tip life

Tip Wearing Experiment in True Non-Contact

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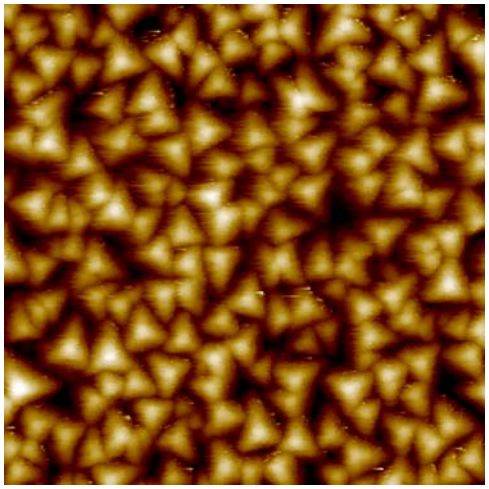
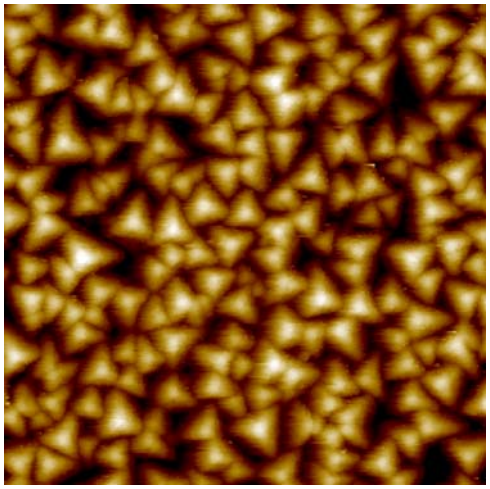
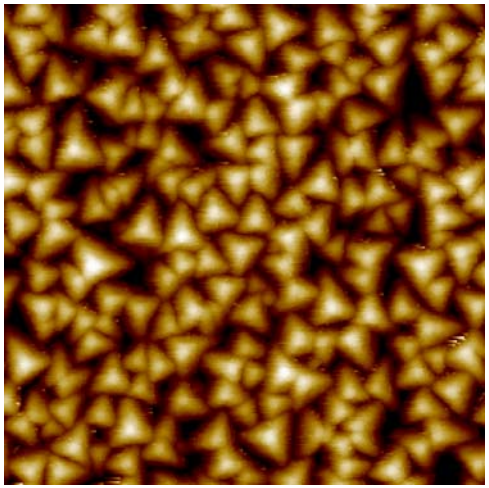
3rd scan



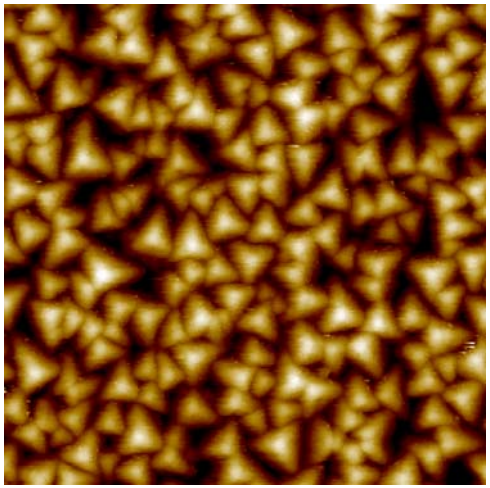
30th scan



70th scan



100th scan



The experiment was repeated with a new tip, while the set point was slightly adjusted for each scan to keep the tip operating in true non-contact mode region.

Even after 100 scans, no tip wearing was observed!

Flat and Linear Baseline & Non-contact Scan Provides:

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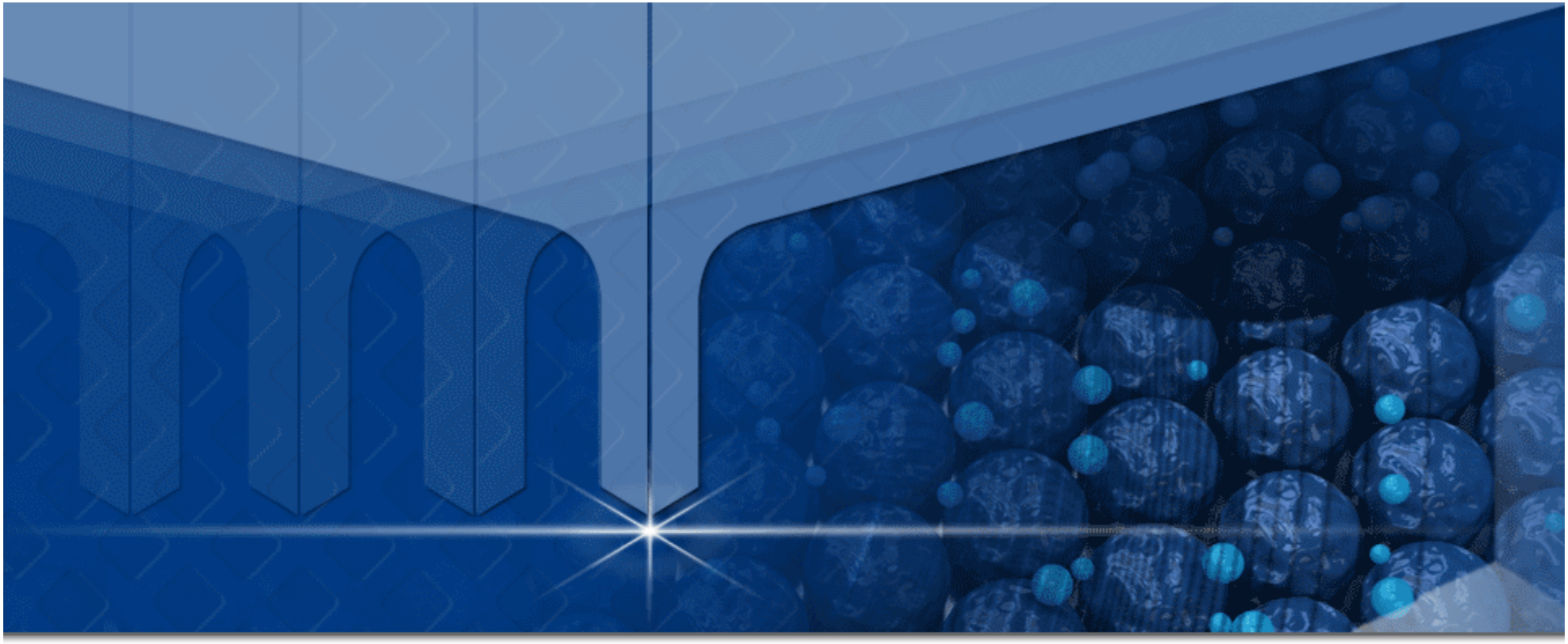
- ✓ **Accurate imaging of shallow sample features**
  - o Low residual bow and removal of tapping artifacts
- ✓ **Better repeatability & reproducibility**
  - o Results less dependent on location and tips
- ✓ **Better system to system matching**
  - o Fewer metrology artifacts in data
- ✓ **Longer tip life**
  - o Less tip wear and tear



Optimized AFM Solutions for Slider Metrology True Non-Contact vs. Tapping

Park SYSTEMS
www.parkAFM.com

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Automated AFM for Slider Manufacturing

Nanotechnology Solutions Partner

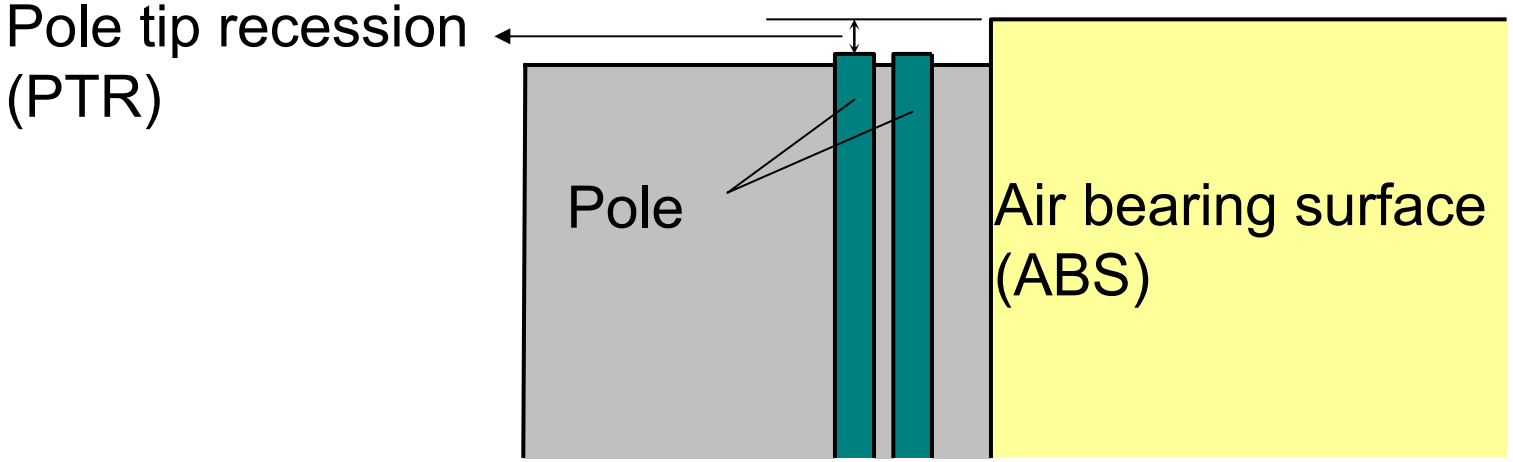
Key Features:

1. **True Non-Contact AFM**
2. Automatic PTR Measurement & Analysis
3. Automatic Tilting Stage
4. Supports Both Rowbars and Sliders
5. Programmable Data Density

Key Options:

1. HGA Sample Fixture
2. Automatic Tip Exchange

Precision Metrology of PTR



- If average PTR is 0.5nm too high, electrical performance yields drop by 10%, and if 0.5nm too low, 5% of hard drives could crash.
- PTR Tolerance for future heads may drop further.
- This requires PTR Gauge Sigma of less than 0.1nm !

Sample Slider Scan

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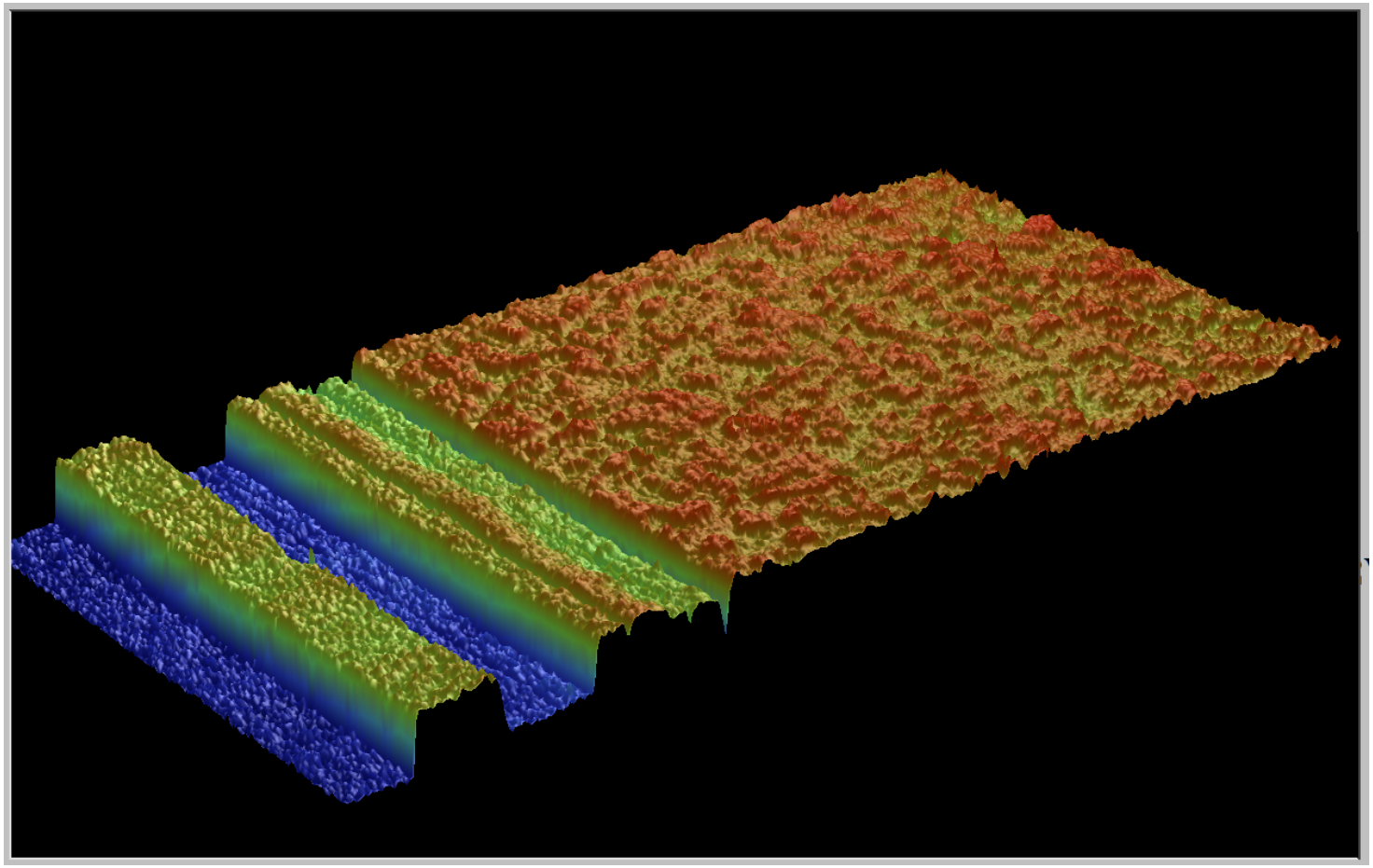

- **High Resolution & High Quality Image**
- **Flat Scan - No need for reference subtraction.**

Advanced Metrology of PTR by New AFM

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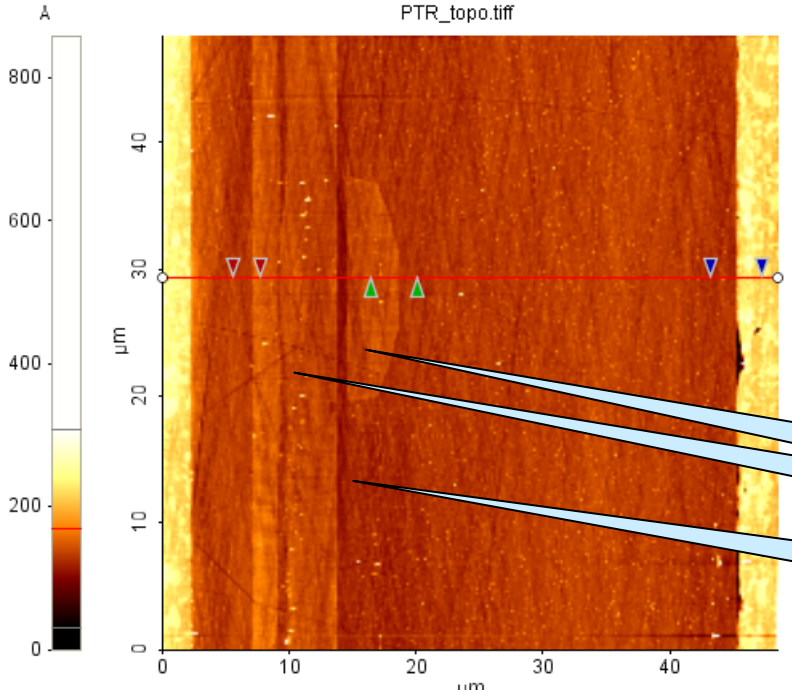
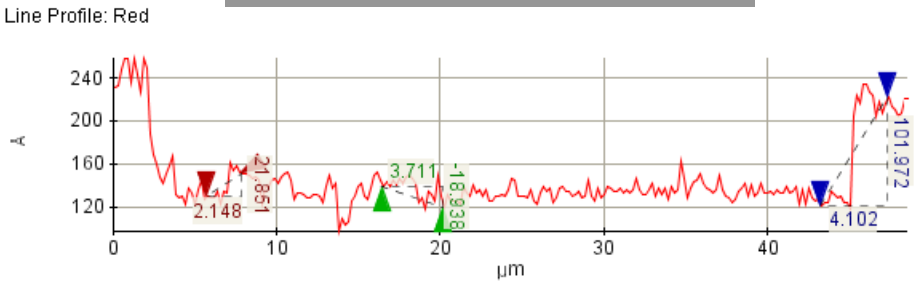
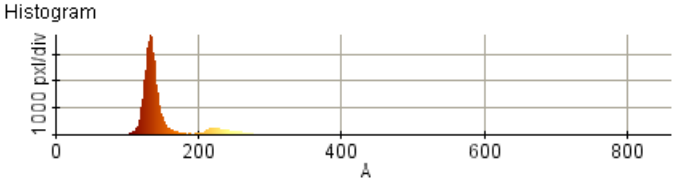


Unprocessed raw data



Pole surfaces

Alumina Overcoat



Pole surfaces are scanned above the overcoat

Statistics

Line	Min(Å)	Max(Å)	Mid(Å)	Mean(Å)	Rpv(Å)	Rq(Å)	Ra(Å)
Red	97.601	259.299	178.450	145.603	161.698	31.761	20.676

PTR Metrology by Piezo Tube based AFM

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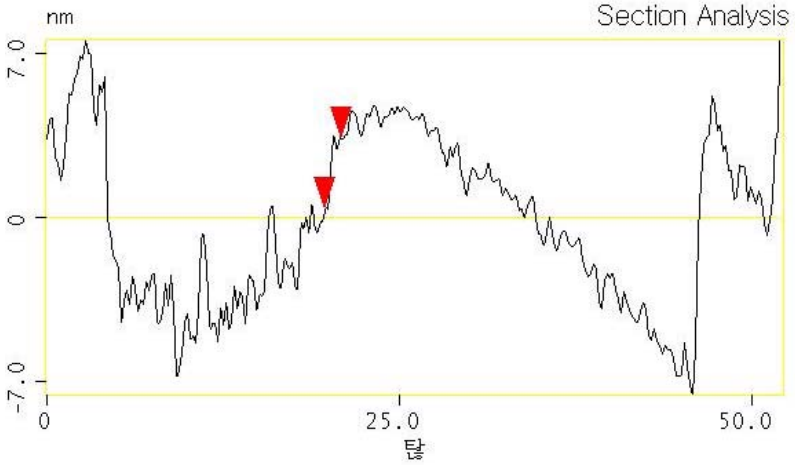
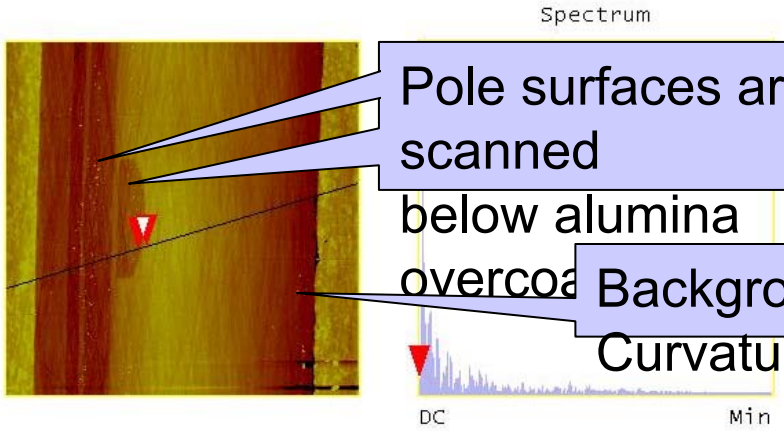


Flattened data

L	1.172 탆
RMS	1.294 nm
lc	DC
Ra(lc)	0.516 nm
Rmax	2.197 nm
Rz	2.197 nm
Rz Cnt	2
Radius	60.435 탆
Sigma	0.895 nm



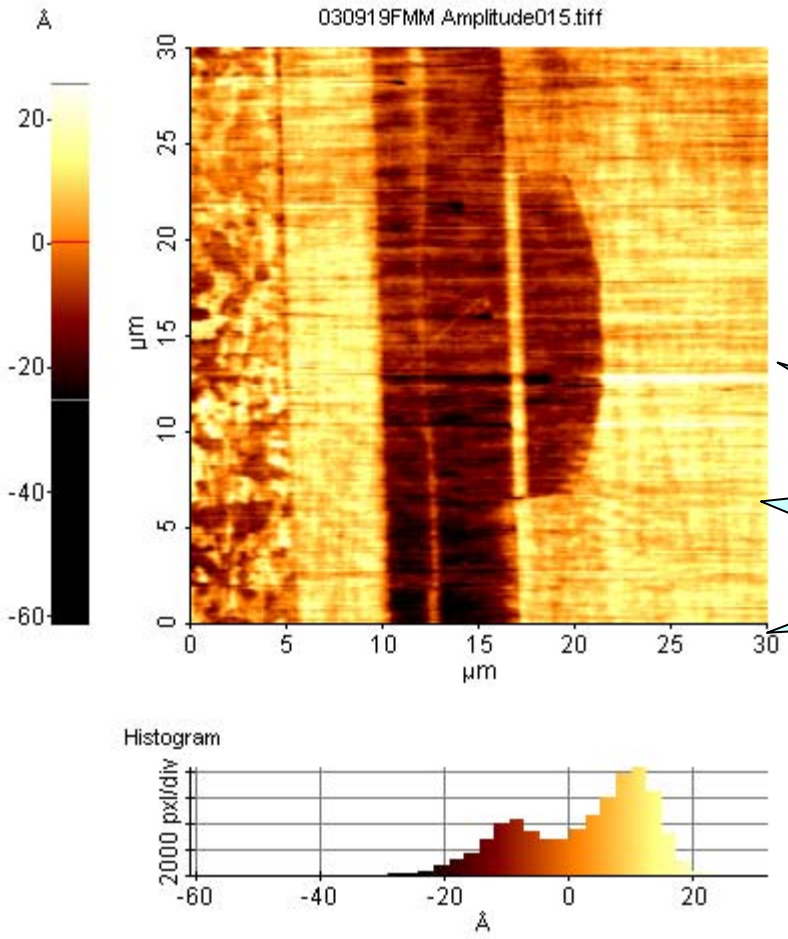
Pole surfaces are scanned below alumina overcoa

Background Curvature!

Surface distance	1.172 탆
Horiz distance(L)	1.172 탆
distance	2.824 nm
	0.138
e distance	
distance	
distance	
Angle	
Angle	
Spectral period	DC
Spectral freq	0 Hz
Spectral RMS amp	0.0003 nm

Cursor: fixed Zoom: 1:1 Cen line: Off Offset: Off

Force Modulation Image of Pole Region



File Name	030919FMM Amplitude015.tiff
Head Mode	FMM
Source	FMM Amplitude
Data Width	256 (pxl)
Data Height	256 (pxl)
X Scan Size	30 (µm)
Y Scan Size	30 (µm)
Scan Rate	0.5 (Hz)
Set Point	5 (nN)

Pole tips are much softer than surroundings

Unprocessed raw data

Tapping force can reach Giga Pascal on sample surface

Will affect the repeatability of PTR measurement

Precision Metrology of PTR

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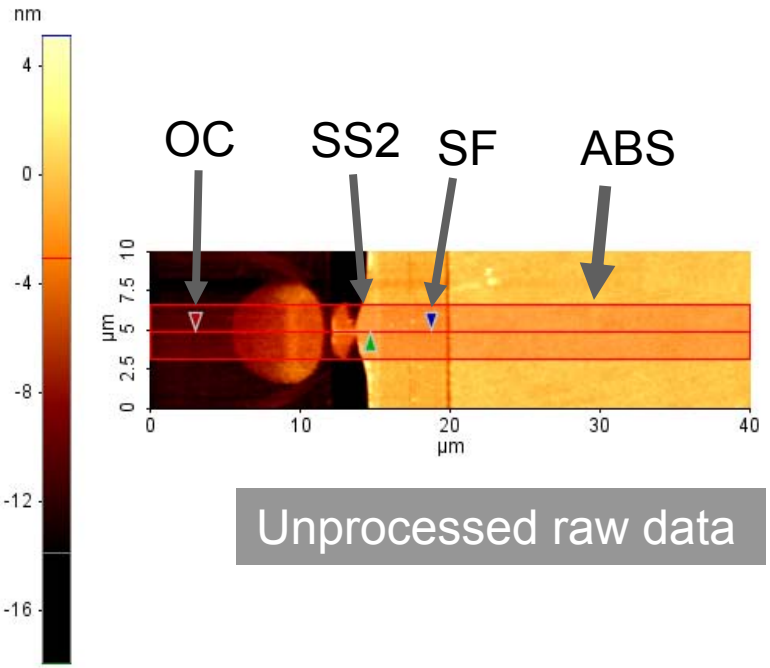
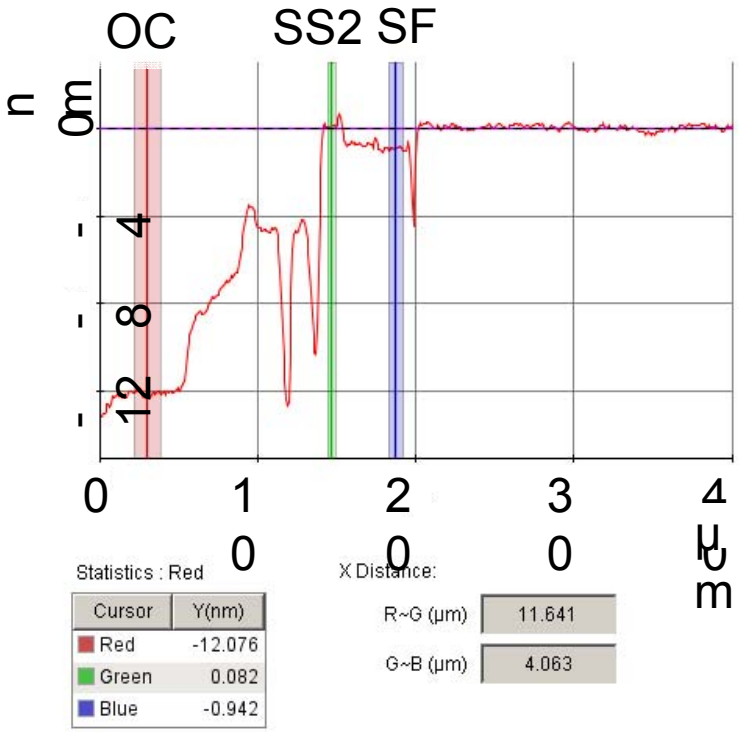


Unprocessed raw data



Statistics : Red

Cursor	Y(nm)
Red	-12.076
Green	0.082
Blue	-0.942

X Distance:

R~G (µm)	11.641
G~B (µm)	4.063

Hardness Measurement with FMM

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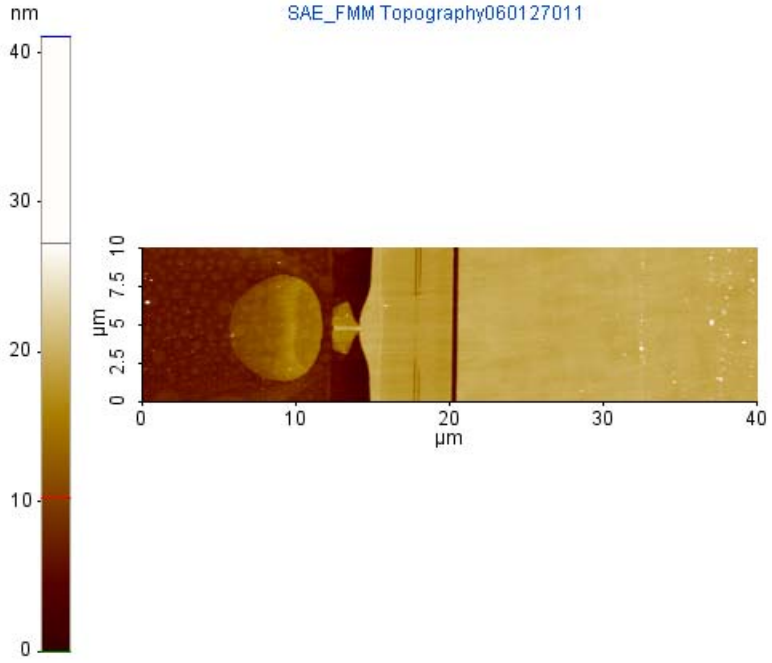
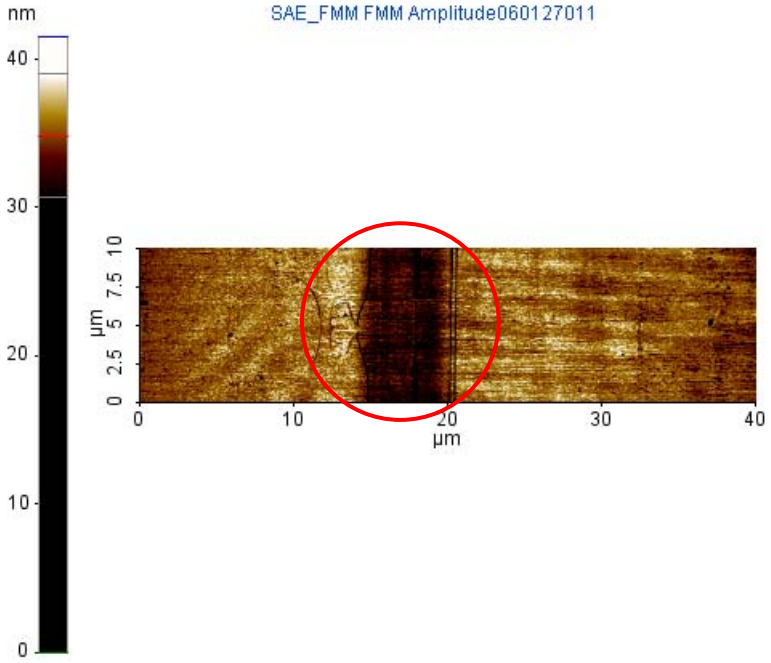
Topography



Hardness



SS2 and SF region is much softer than ABS and OC region!

Non Contact AFM

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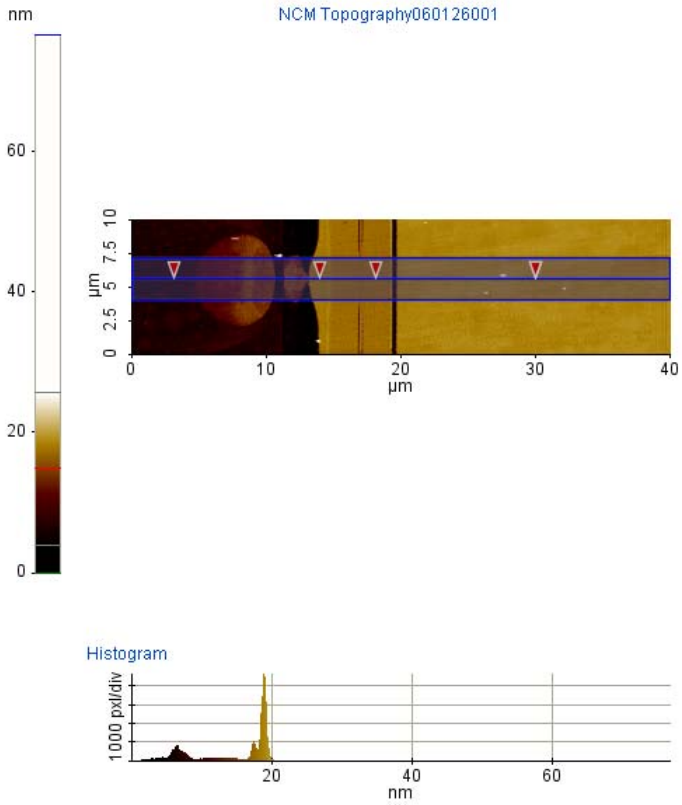
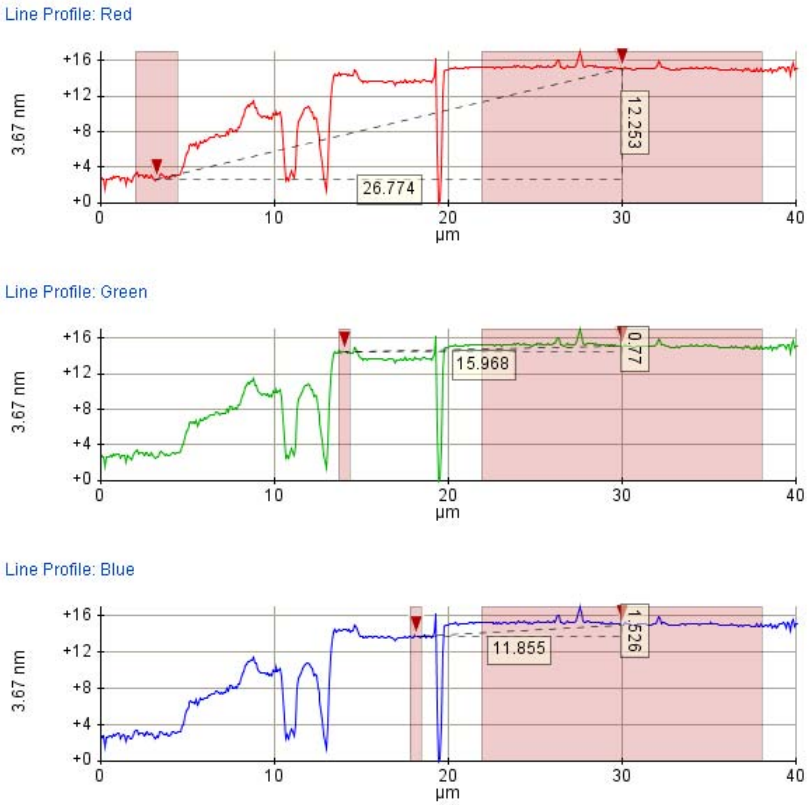
OC	SS2	SF
-12.25	-0.77	-1.53





Tapping Mode, 15%

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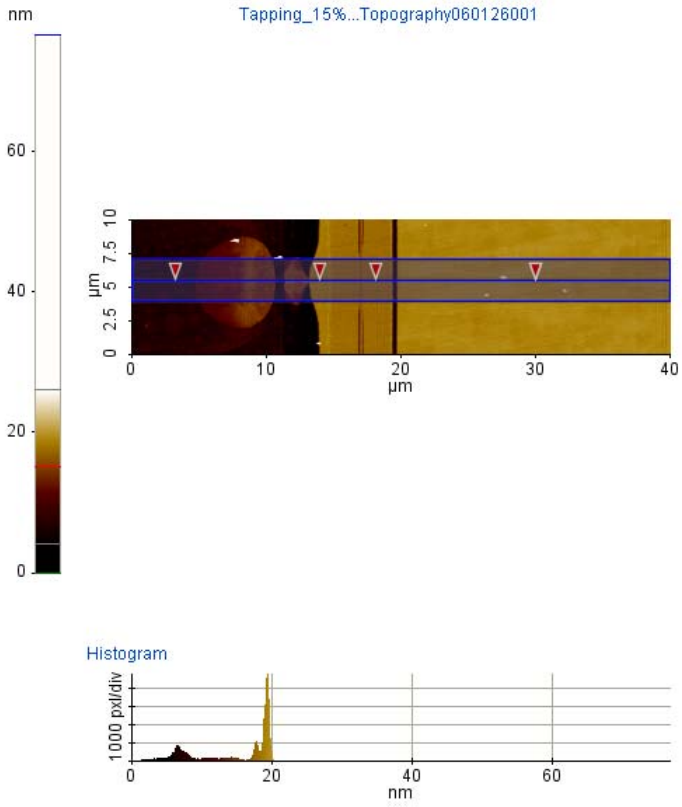
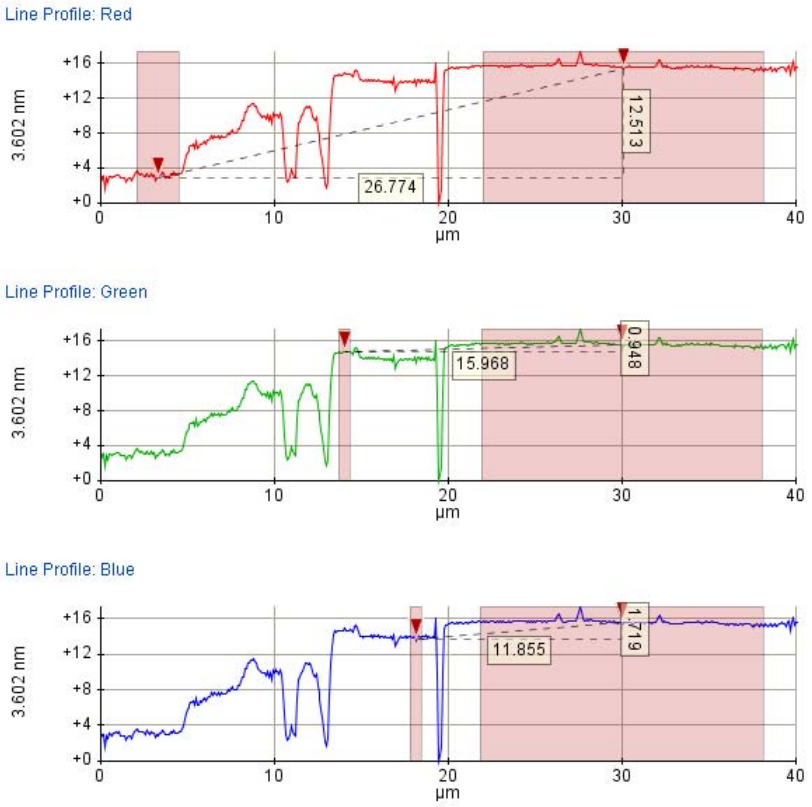
OC	SS2	SF
-12.51	-0.95	-1.72





Tapping Mode, 30%

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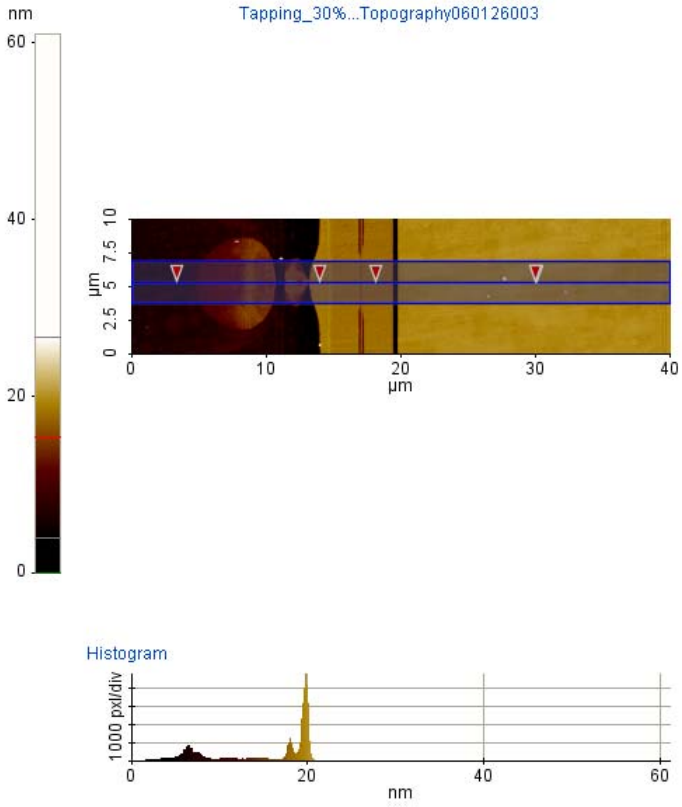
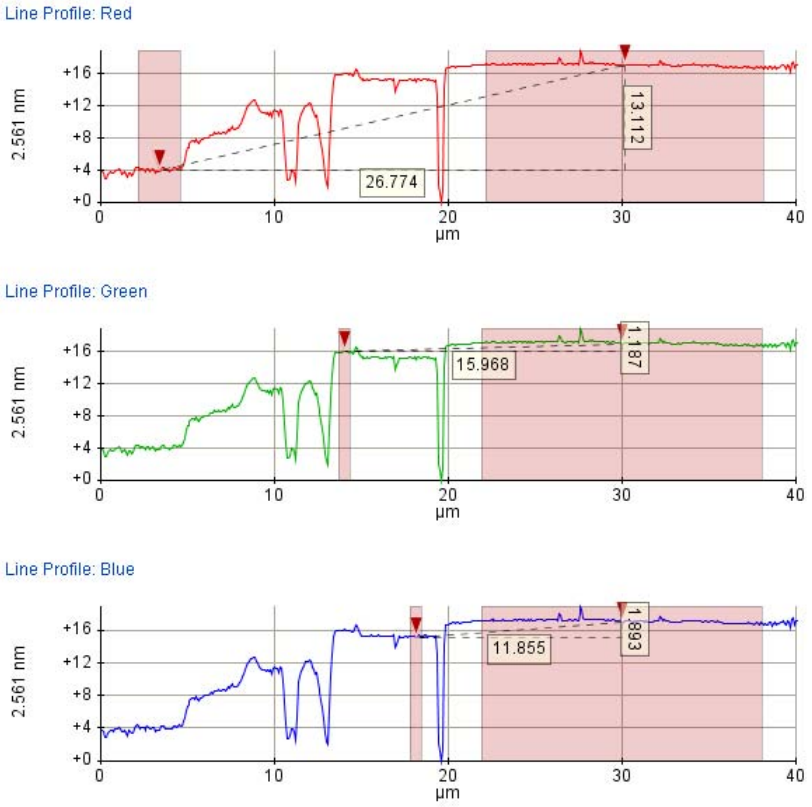
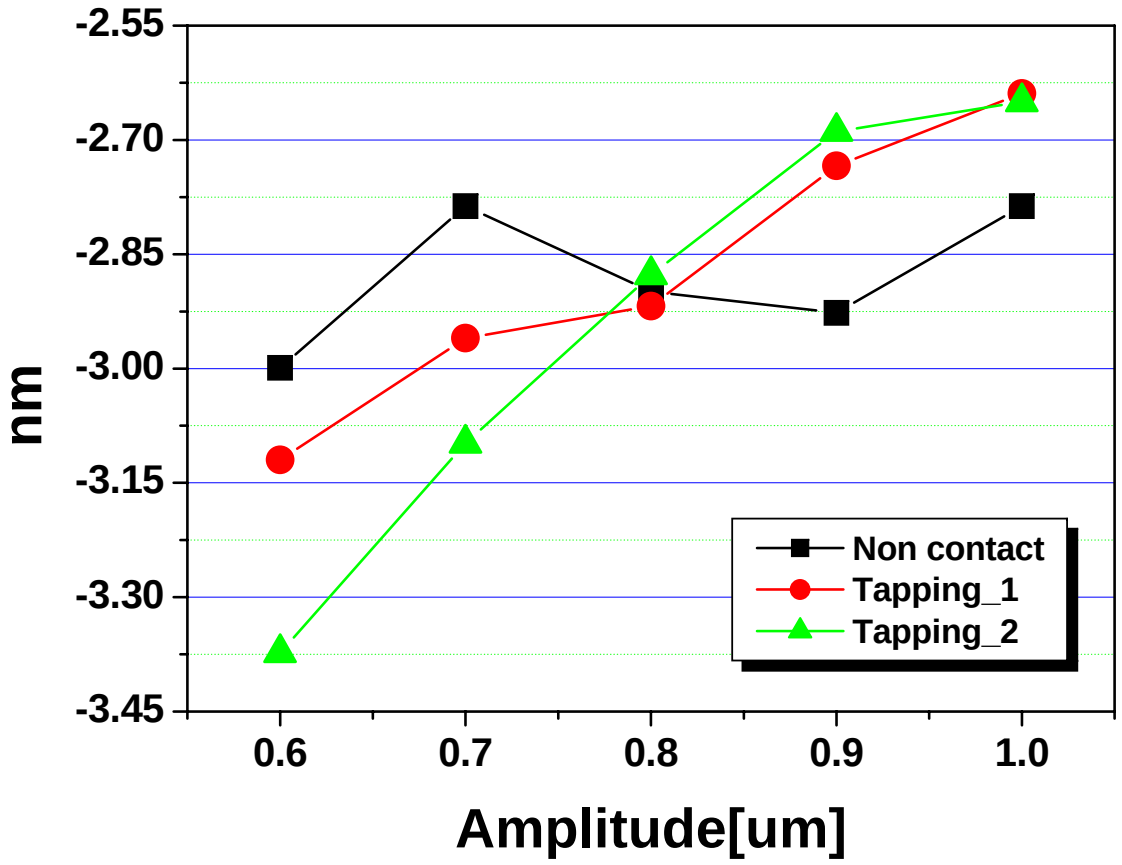
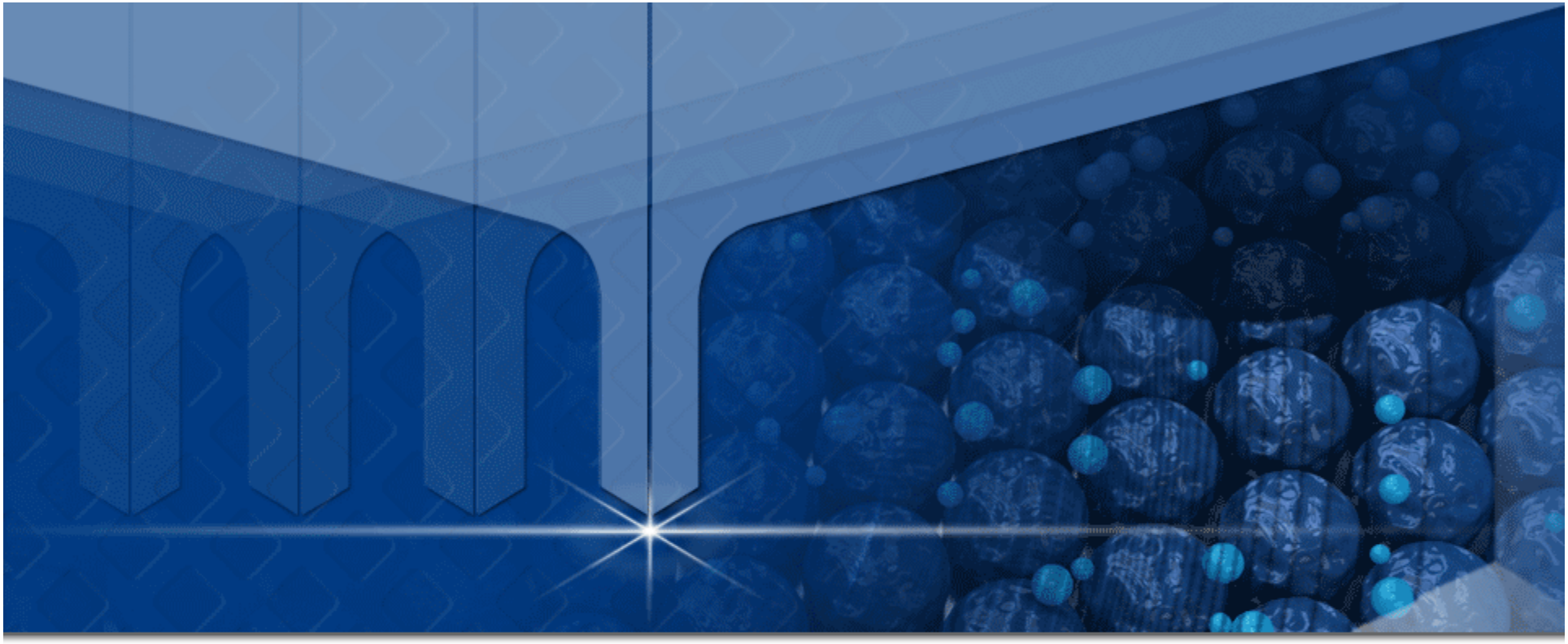
OC	SS2	SF
-13.11	-1.19	-1.89





NCM mode Vs. Tapping mode; PTR Values





Edge Defect Monitoring

Edge Spike Monitoring & IBE Wall Angle Measurement

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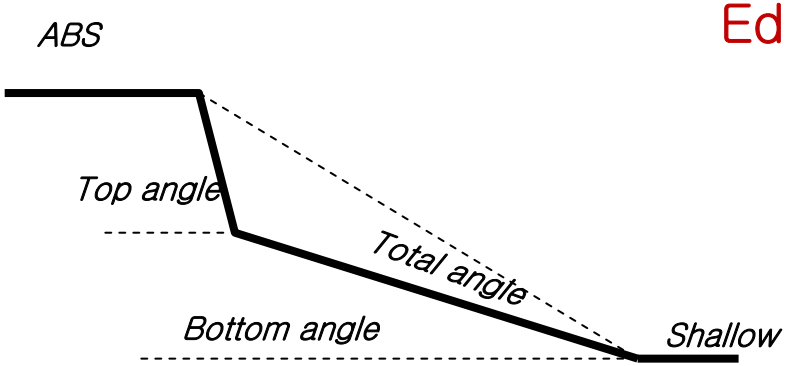
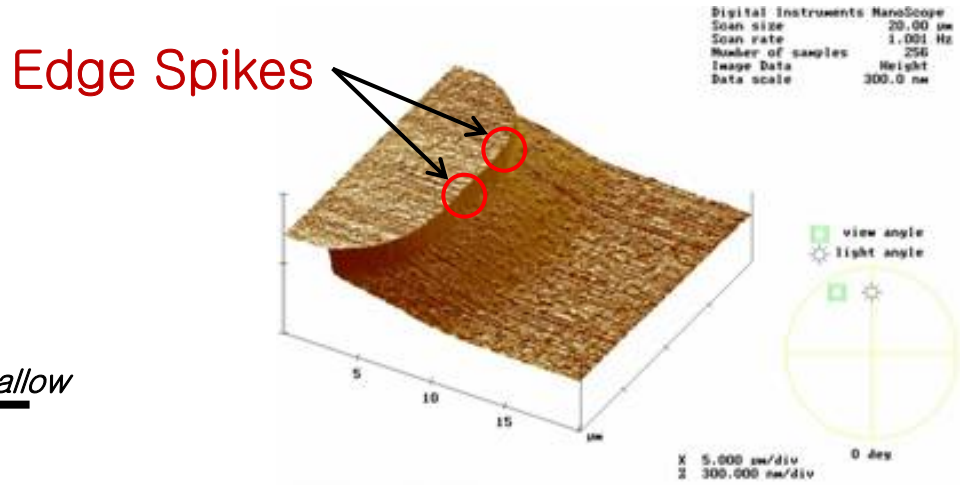
Background 1: Shallow wall angle by IBE process shows bi-linear wall profile which is defined by three independent angles: Top, bottom and total.

Background 2: Spikes along the edge of ABS have be monitored & controlled





Automated AFM Solution for Edge Defects & IBE Wall Angles

Park SYSTEMS www.parkAFM.com

Nanotechnology Solutions Partner

Key Features:

1. Automatic Recipe Run of Defect & Angle Measurements
2. Automatic Analysis of Defects
   - counts, heights, widths, bearing ratios, etc.
3. Automatic Analysis of Angles
   - top, bottom, total angles

Edge Spike Images (New vs. Old)

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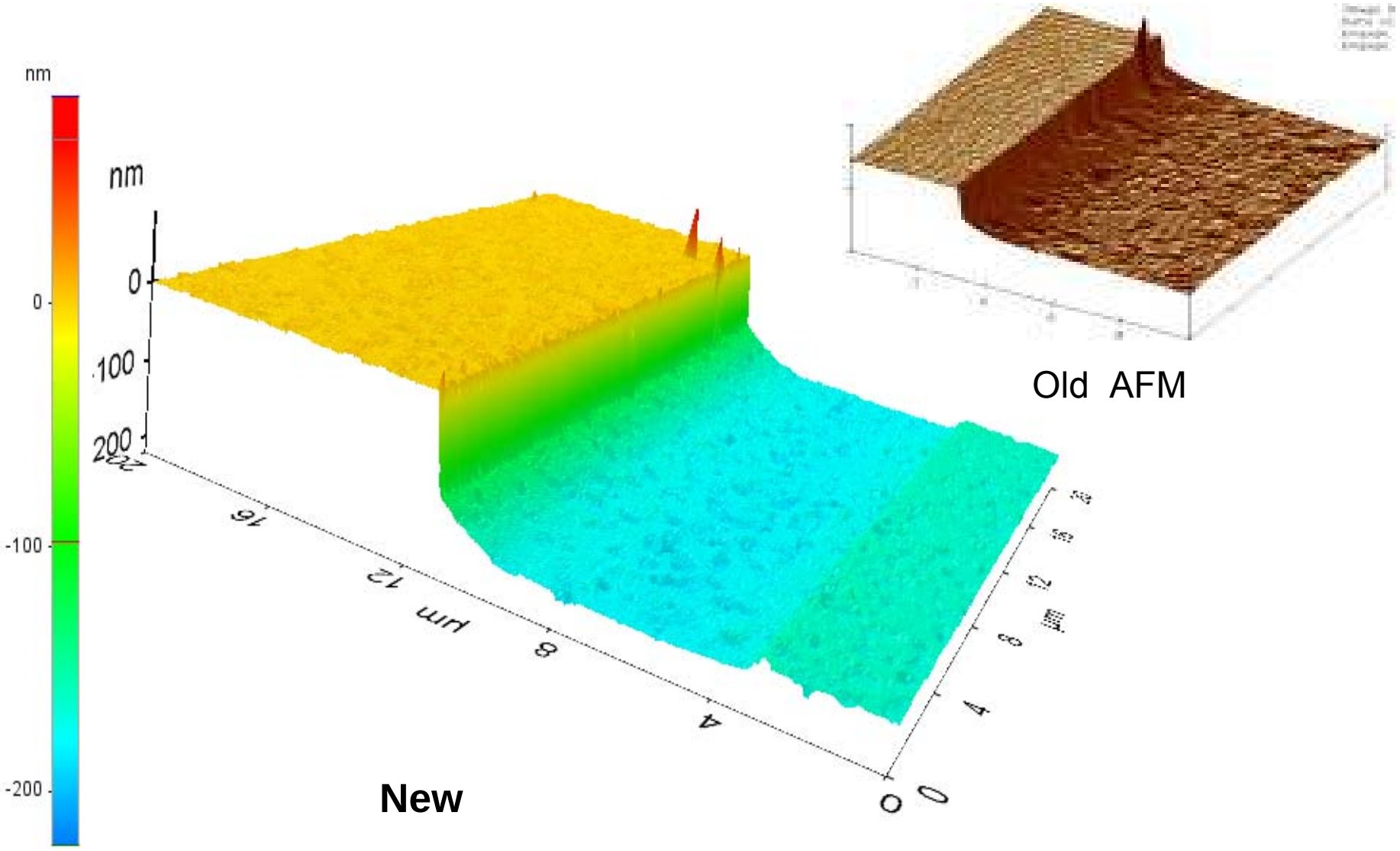

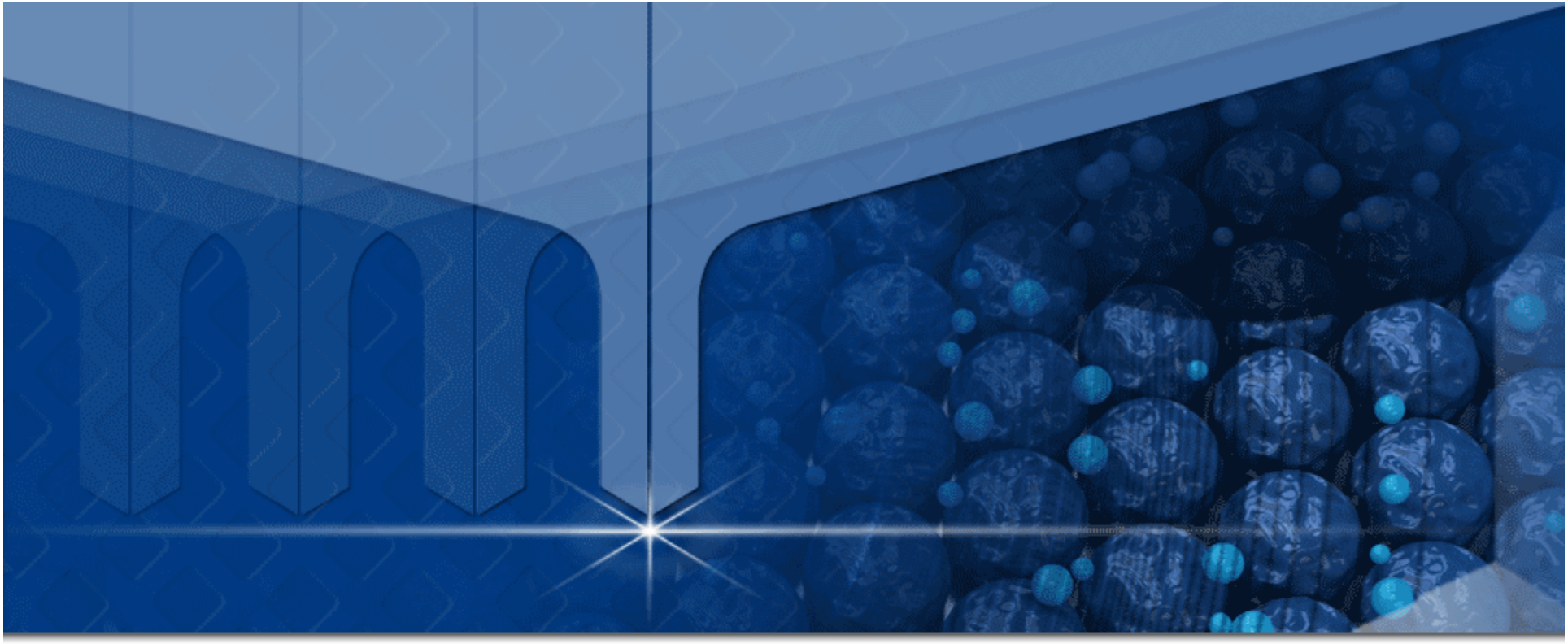

IBE Wall Angle Measurement

AFM Requirements for Angle Measurement

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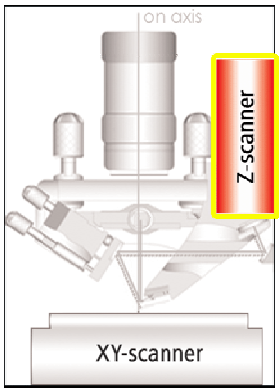
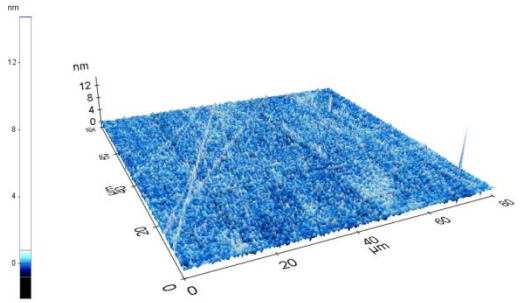
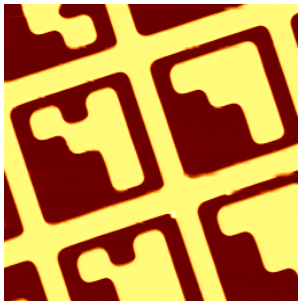
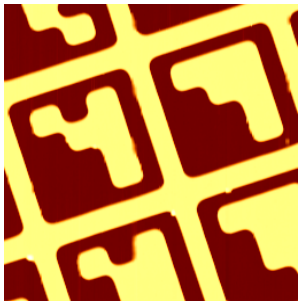
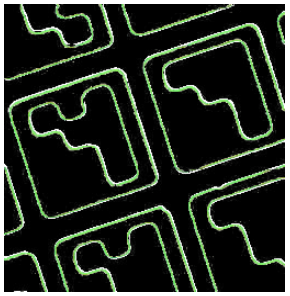
- XY Scan Flatness
- XY Scan Linearity
- Fast Z-Servo











Conventional AFM cannot do critical angle measurements due to

- Background curvature
- XY scan non-linearity
- Slow Z-servo

Critical Angle Metrology with NC-AFM

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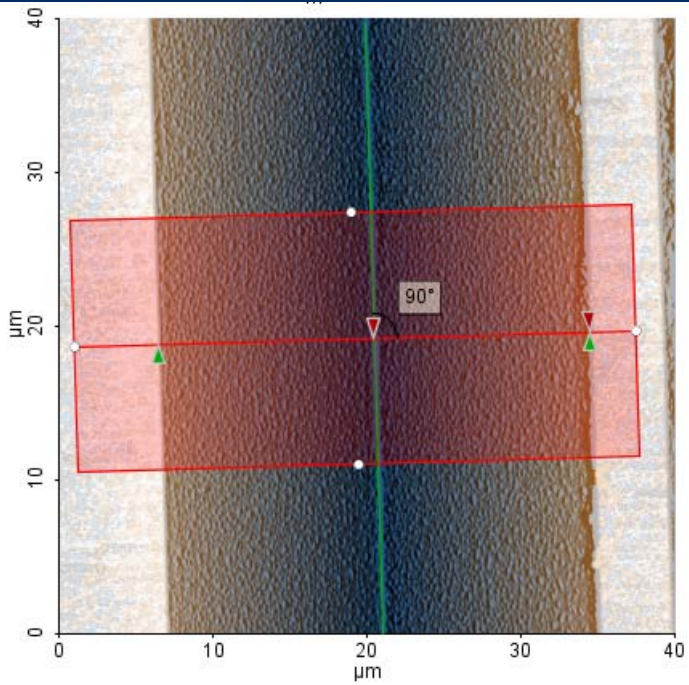
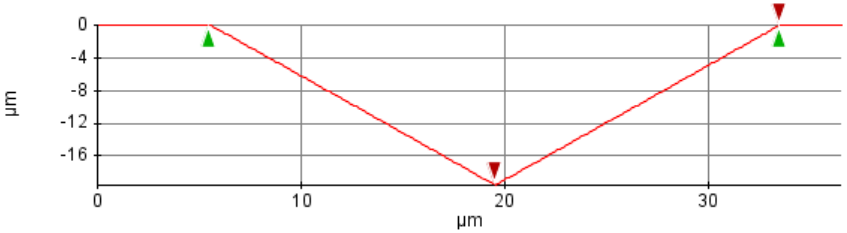
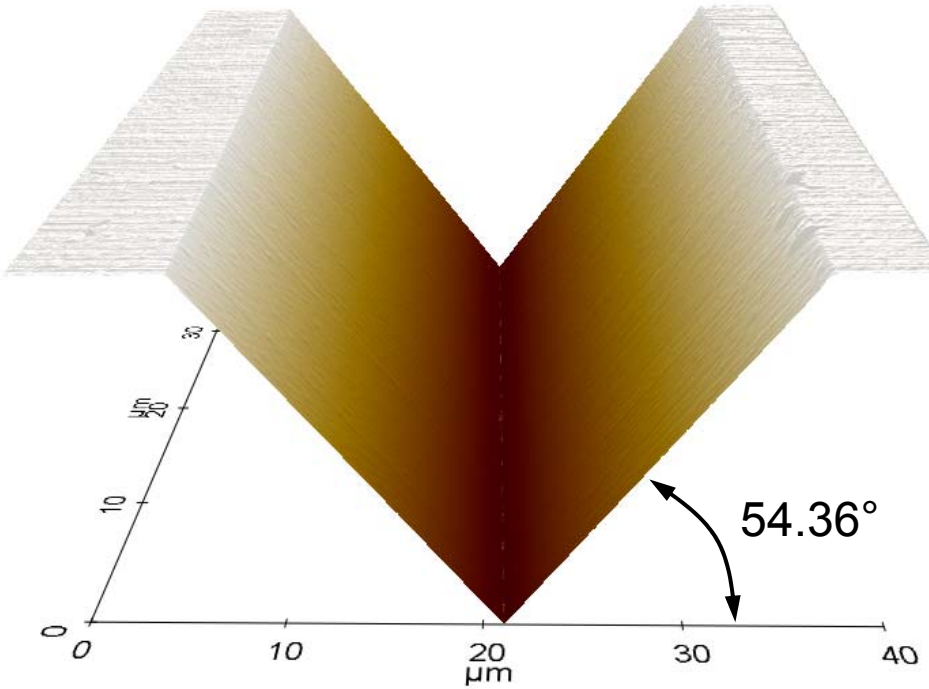


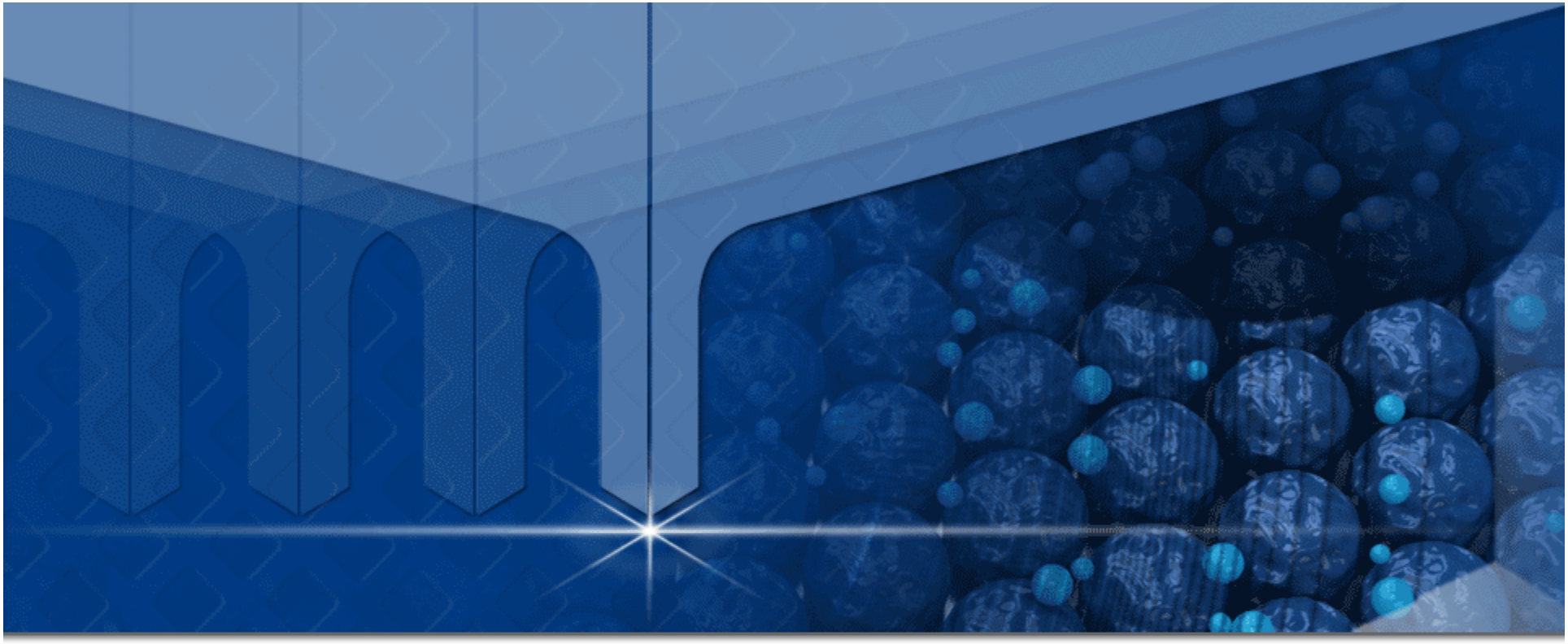


Cursor Statistics : Red

Cursor	ΔX(μm)	ΔY(μm)	Angle(deg)
Red	13.976	19.494	54.361
Green	28.025	-0.043	-0.089



Unprocessed raw data



Programmable Data Density

Park SYSTEMS
www.parkAFM.com

Nanotechnology Solutions Partner

Going Beyond Conventional PTR Measurements

It's not just PTR measurement but much much more!!!

The overall mechanical characterization of sliders now involves

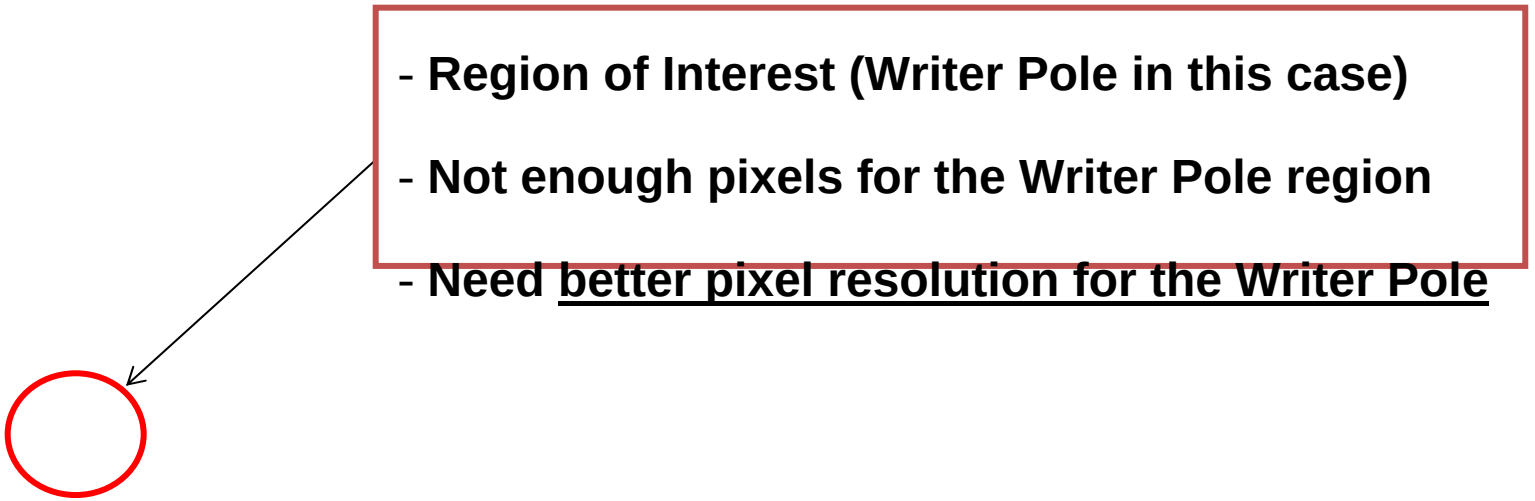
- **A variety of metrology systems and**
- **A variety of resolution requirements**

In order to improve yield and reliability of slider manufacturing, one has to go beyond conventional PTR measurements

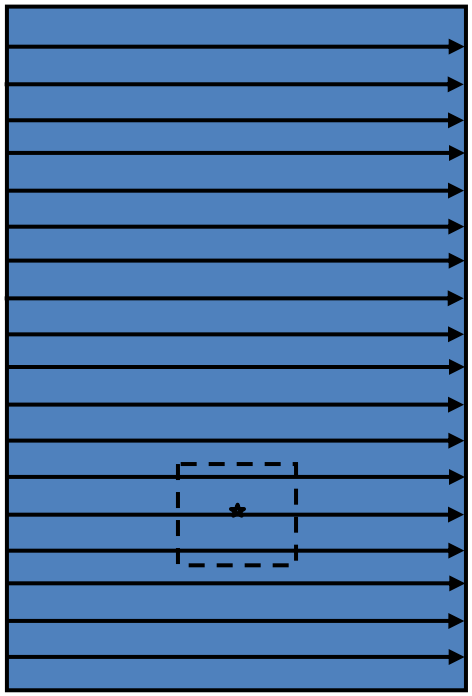
Answer: Programmable Data Density

What is Programmable Data Density?

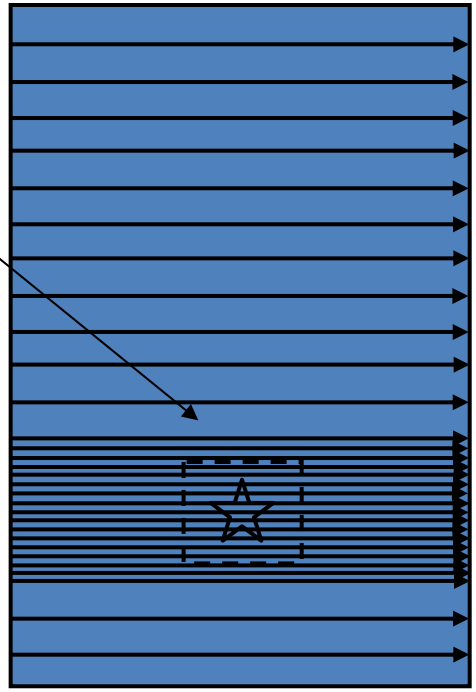
- **Automatically detects the interested region**
- **Takes the image of a higher pixel density for the interested region**



1-D PDD (Programmable Data Density)



More Y-axis pixels per μm



Normal Scan

PDD Scan

2-D PDD (more pixels for both X and Y-axis) is realized!

PDD Key Benefits

- **One Scan (~5 minutes) obtains**
  - Normal PTR image
  - Writer Pole image with high pixel density
  - For conventional AFM, it takes ~30 minutes or longer
- **Multiple PDD zones are possible**

Conclusion

Park SYSTEMS www.parkAFM.com

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- AFM has evolved from a qualitative imaging tool to a quantitative nano-metrology tool for industry
- Automated AFM solution for inline slider metrology was developed
- True Non-Contact mode is a critical requirement for accurate PTR measurements
- Programmable data density is a throughput efficient solution for production scalable AFM metrology