Data Report for University of Illinois

Prepared by
Song Xu, Ph.D.
Agilent Technologies

For demonstration purposes only!

Topography analysis with atomic force microscope using AAC imaging mode

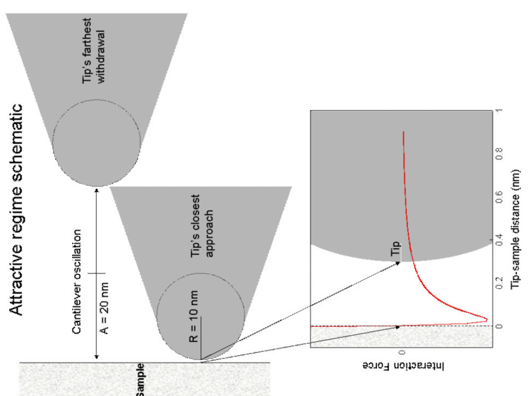
The following samples are imaged using Agilent 5500 AFM with AAC mode:

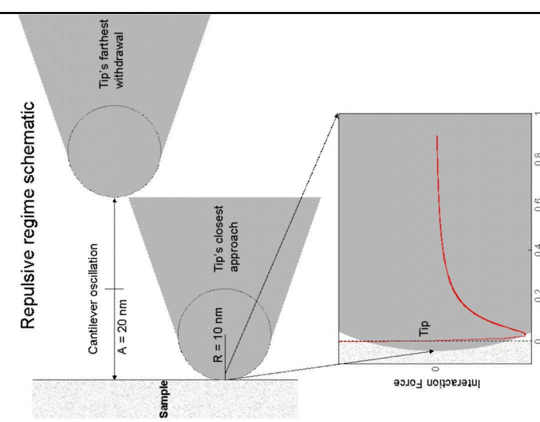
1. BFO-LSMO-STO
2. CCSTO
3. CeO2
4. Nano wires (Ketaki)
5.

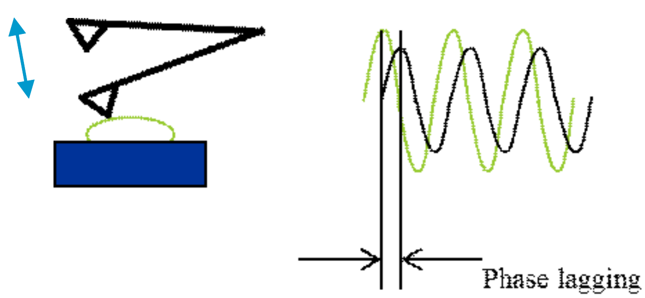
AAC imaging mode:

Using a vibrating cantilever, the AFM tip is driven to oscillat near its resonance frequency (~300KHz) while engaging the sample surface. Depending on the driving power and setpoint, the very end of the sharp tip lightly "tap" the sample surface at varying force to minimize the damage and disturbance of the sample. The scanner feed back on the vibration amplitude of the oscillating to maintain such light force in order to obtain accurate high resolution image of the sample topography information. At the same time, the phase, or timing of the cantilever oscillation reveals the sample's physical stiffness information.

AAC imaging mode is the ideal technique when obtain precise topography information. After imaging processing software as well as mathematical metrology analysis tools allow user to gain rich collection of surface information, such as RMS roughness, surface texture, grain sizing statistics, grain surface coverage etc. A 3D rendering of the topography give us a very detailed lifelike view of the sample under the microscope and allow us to perform detailed measurement from the data.

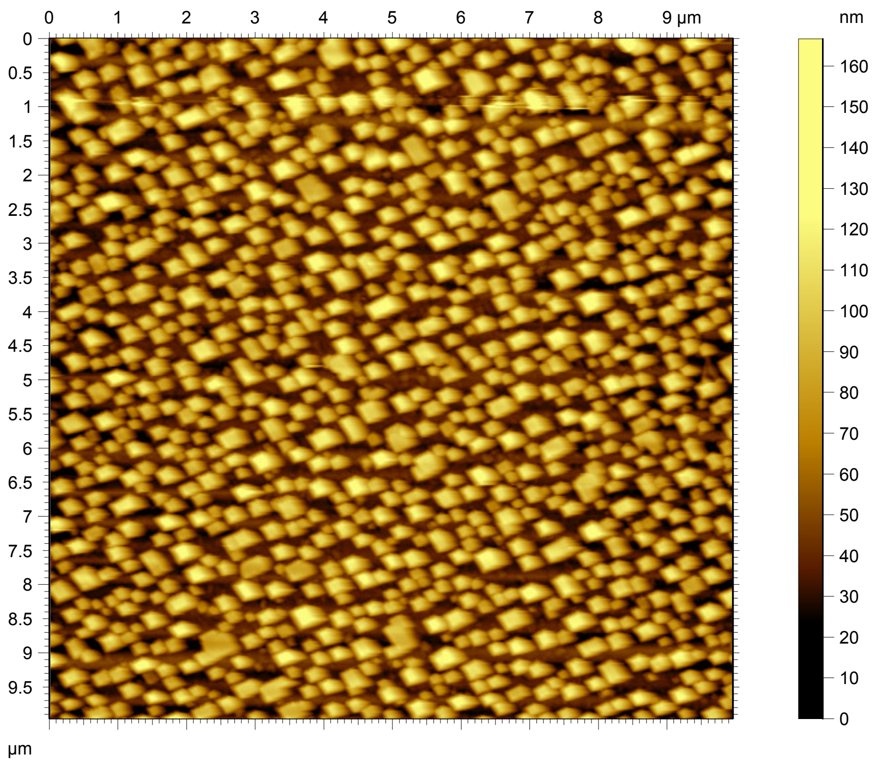


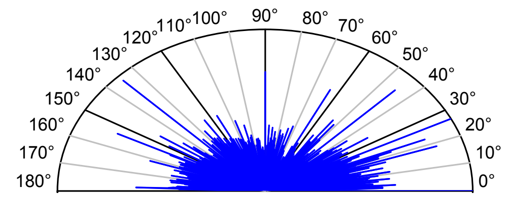




For demonstration purposes only!

BFO-LSMO-STO March 22nd sample 10x10 micron scan roughness and texture analysis





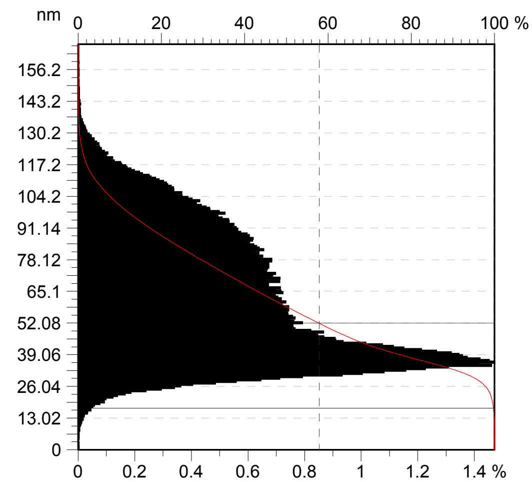
Isotropy: 65.7 %

First Direction: 0.144°

Second Direction: 26.5°

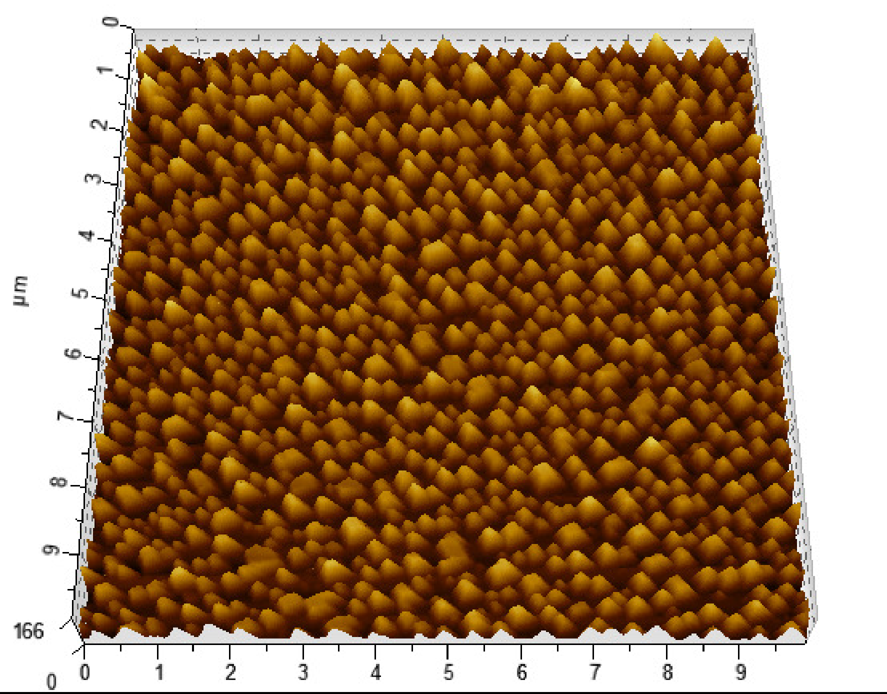
Third Direction: 135°

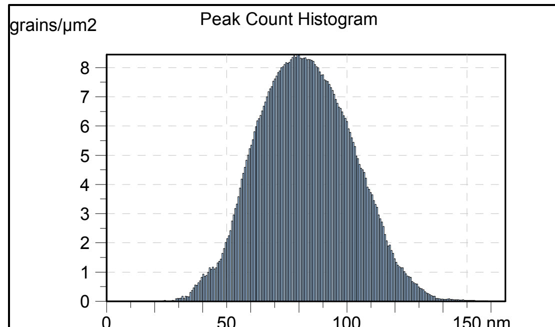
Texture analysis



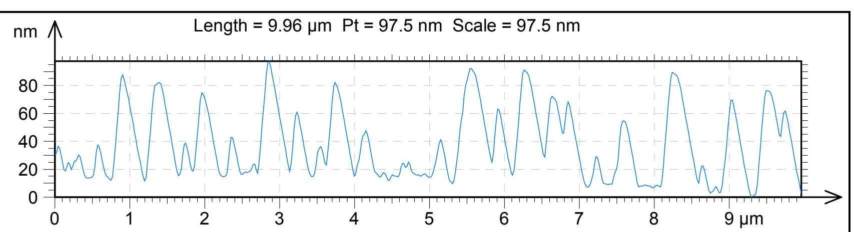
Smr(c2) - Smr(c1) 41.9 %

Histogram analysis (height statistics)





Grain size statistics



Cursor profile across center of image

ISO 25178

Height Parameters

Sq	25.8	nm	*Root mean square height*
Ssk	0.472		*Skewness*
Sku	2.26		*Kurtosis*
Sp	104	nm	*Maximum peak height*
Sv	62.9	nm	*Maximum pit height*
Sz	167	nm	*Maximum height*
Sa	22.0	nm	*Arithmetic mean height*

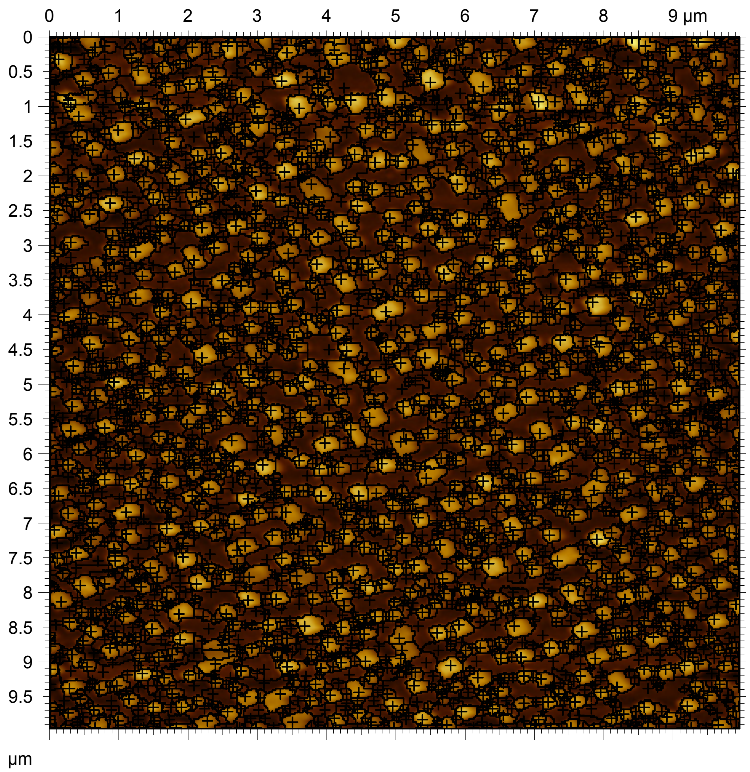
ISO 23178 Roughness measurement

For demonstration purposes only!

Pico Image Expert 6.2.6561

BFO-LSMO-STO March 22nd sample 10x10 micron scan grain analysis and statistics

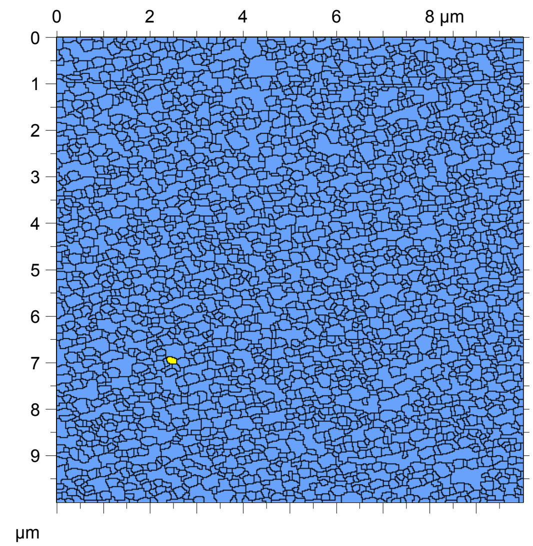
Grain detection and statistics



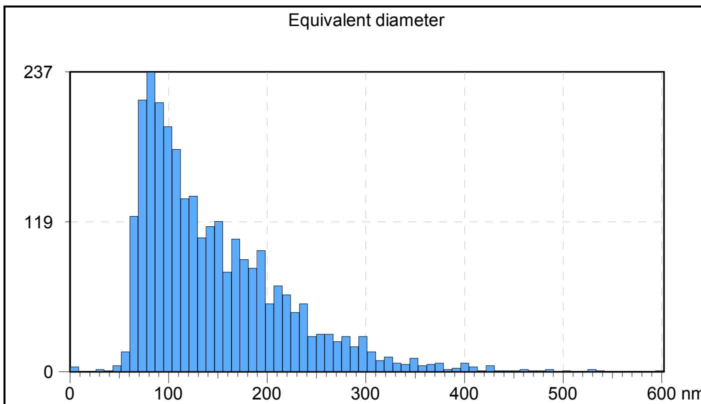
Number of motifs	3115
Mean Height	60.6 nm
Mean of equivalent diameters	0.162 μm
Mean of mean diameters	0.157 μm
Mean aspect ratio	2.59

Analysis of Individual Grains

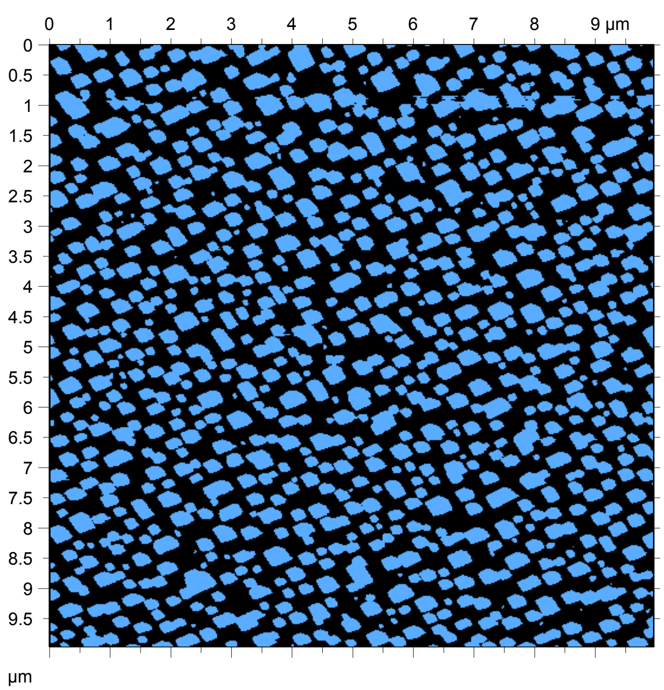
(Click on a grain to read parameter)



Grain #	1966
Area	0.0167 μm²
Perimeter	0.530 μm
Mean diameter	0.144 μm
Form factor	0.746
Aspect ratio	2.00
Compactness	0.744
Orientation	161°



Grain coverage detection



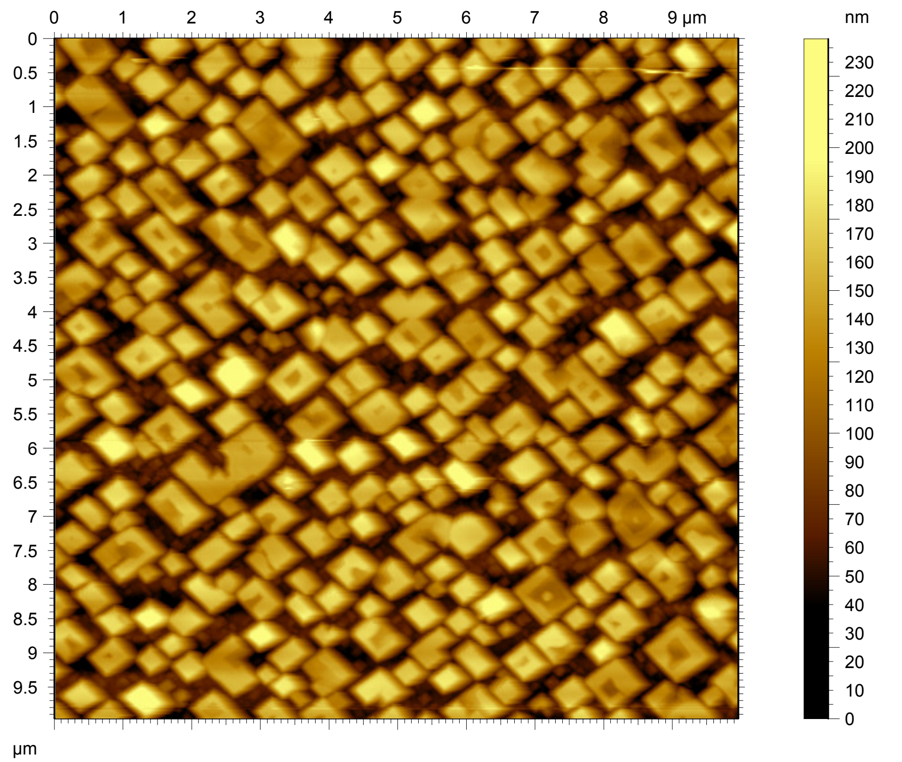
Mean parameters on 2840 grains

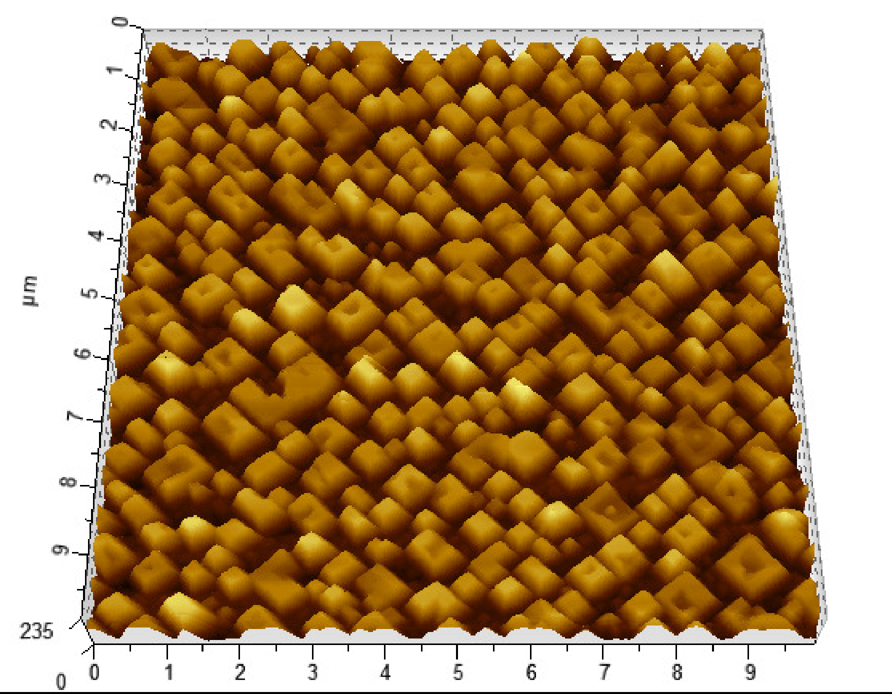
Number of grains: 2840
Total area occupied by the grains: 60.7 μm² (60.7 %)
Density of grains: 28.4 grains / μm2.

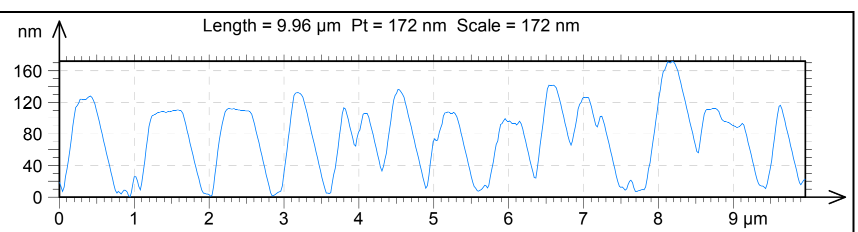
Area	=	0.0214 μm²	+/- 0.0245 μm²
Perimeter	=	631 nm	+/- 362 nm
Form factor	=	0.572	+/- 0.157
Aspect ratio	=	3.20	+/- 2.22
Roundness	=	0.449	+/- 0.161
Compactness	=	0.659	+/- 0.121
Orientation	=	87.3°	+/- 64.4°

For demonstration purposes only!

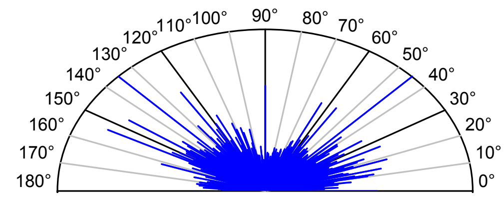
BFO-LSMO-STO March 22nd sample 10x10 micron scan roughness and texture analysis







Cursor profile across center of image



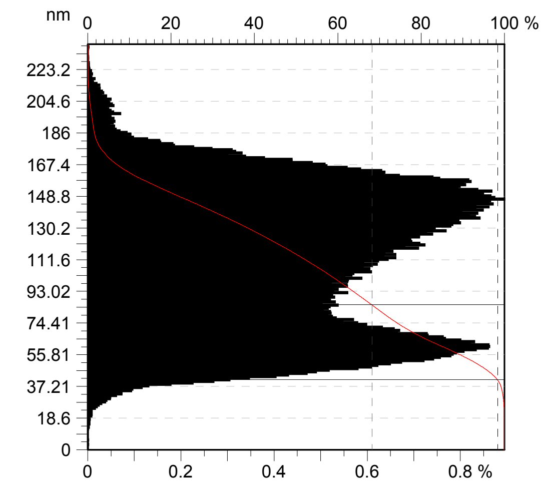
Isotropy: 78.8 %

First Direction: 45.0°

Second Direction: 135°

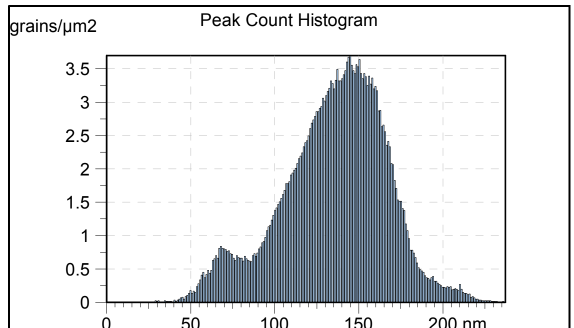
Third Direction: 153°

Texture analysis



Smr(c2) - Smr(c1) 30.2 %

Histogram analysis (height statistics)



Grain size statistics

ISO 25178

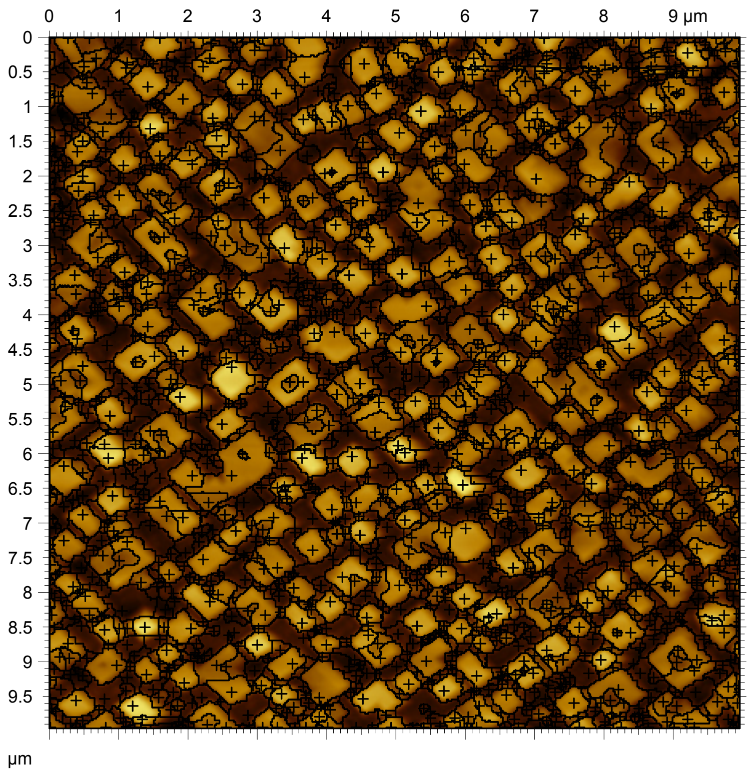
Height Parameters

Sq	41.0	nm	Root mean square height
Ssk	-0.0369		Skewness
Sku	1.94		Kurtosis
Sp	127	nm	Maximum peak height
Sv	111	nm	Maximum pit height
Sz	238	nm	Maximum height
Sa	35.5	nm	Arithmetic mean height

ISO 23178 Roughness measurement

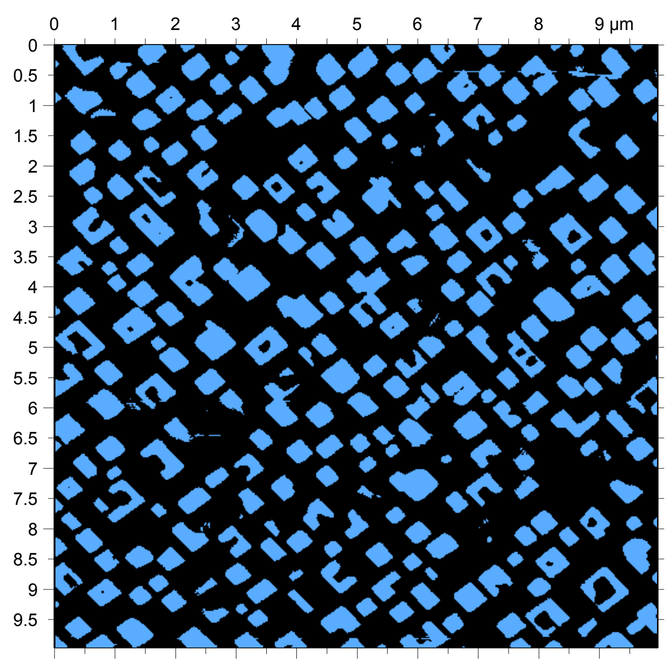
BFO-LSMO-STO March 22nd sample 10x10 micron scan grain analysis and statistics

Grain detection and statistics



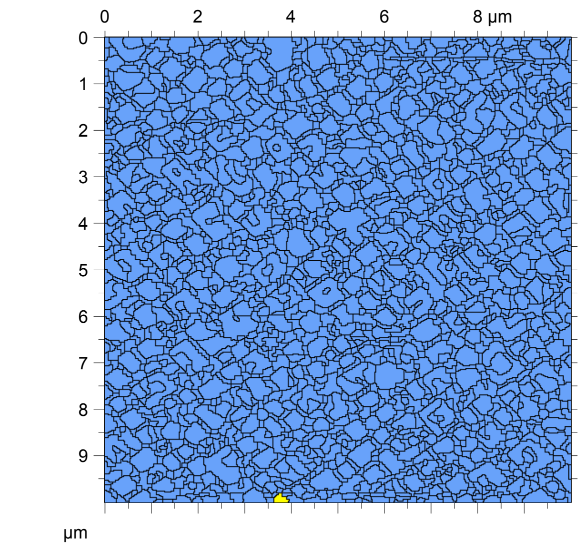
Number of motifs	1655
Mean Height	86.6 nm
Mean of equivalent diameters	0.227 µm
Mean of mean diameters	0.211 µm
Mean aspect ratio	3.09

Grain coverage detection

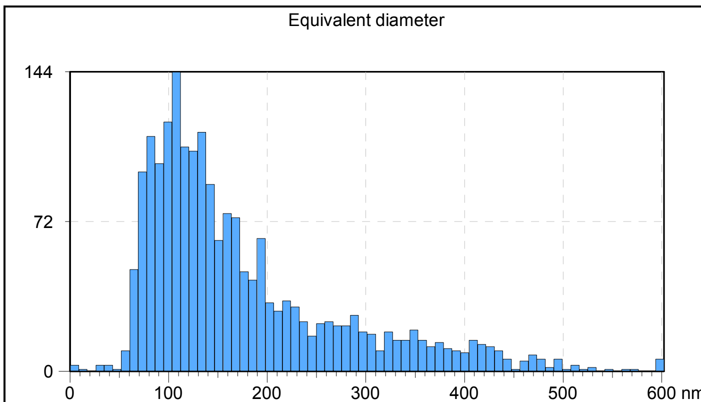


Analysis of Individual Grains

(Click on a grain to read parameter)



Grain #	1966
Area	0.0304 µm²
Perimeter	0.859 µm
Mean diameter	0.194 µm
Form factor	0.518
Aspect ratio	3.20
Compactness	0.629
Orientation	171°



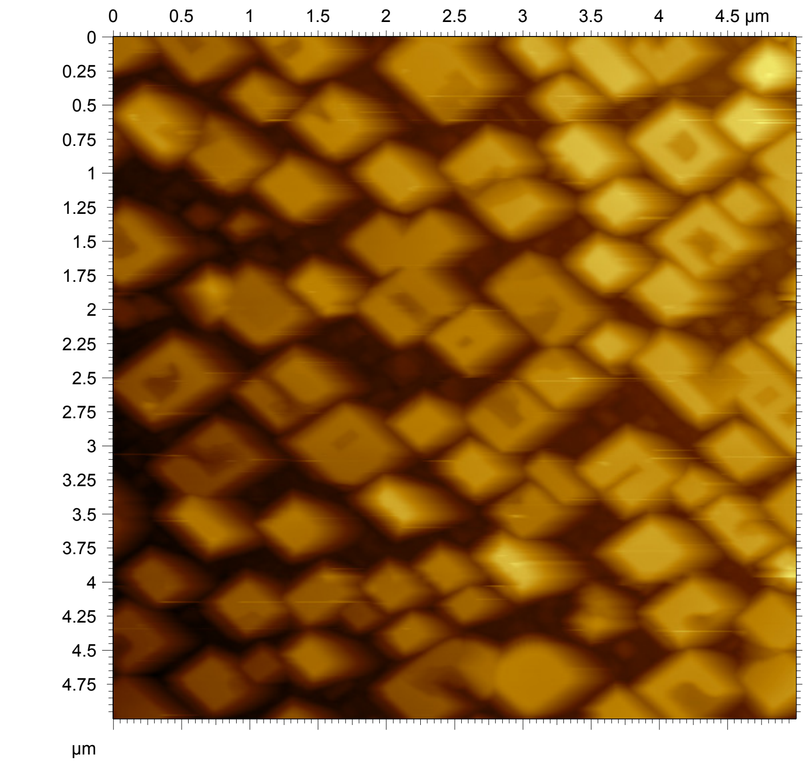
Mean parameters on 2004 grains

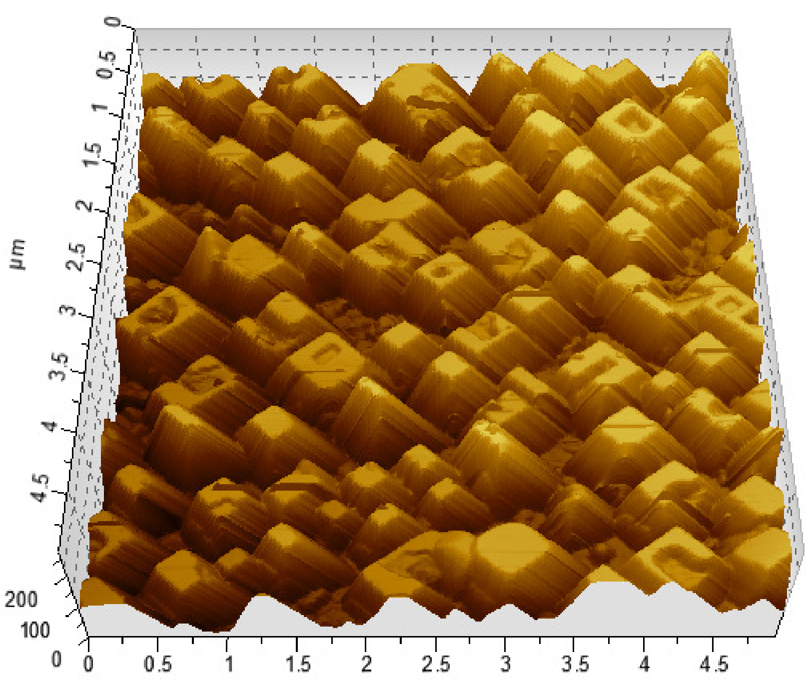
Number of grains: 2004
Total area occupied by the grains: 65.7 µm² (65.7 %)
Density of grains: 20.0 grains / µm2.

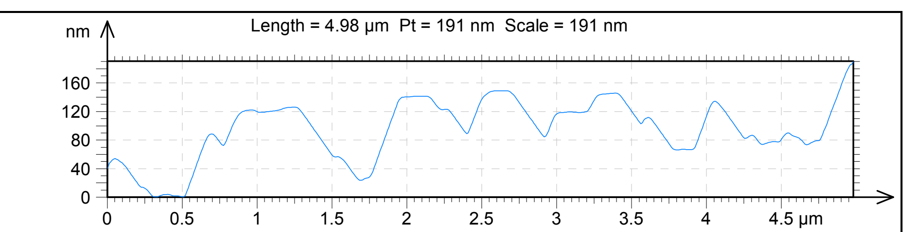
Area	=	0.0328 µm²	+/- 0.042 µm²
Perimeter	=	801 nm	+/- 484 nm
Form factor	=	0.507	+/- 0.150
Aspect ratio	=	3.82	+/- 3.14
Roundness	=	0.427	+/- 0.204
Compactness	=	0.637	+/- 0.145
Orientation	=	87.4°	+/- 55.7°

For demonstration purposes only!

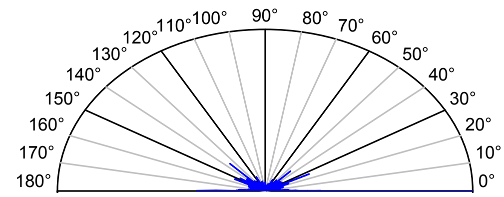
BFO-LSMO-STO March 21st sample 5x5 micron scan roughness and texture analysis







Cursor profile across center of image



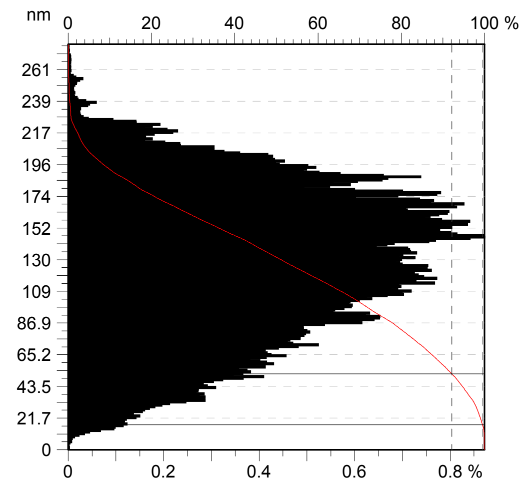
Isotropy: 10.6 %

First Direction: 0.214°

Second Direction: 135°

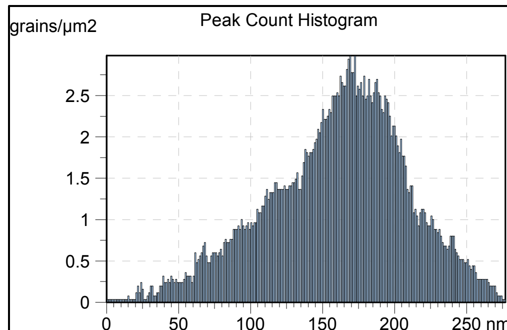
Third Direction: 26.5°

Texture analysis



Smr(c2) - Smr(c1) 7.43 %

Histogram analysis (height statistics)



Grain size statistics

ISO 25178

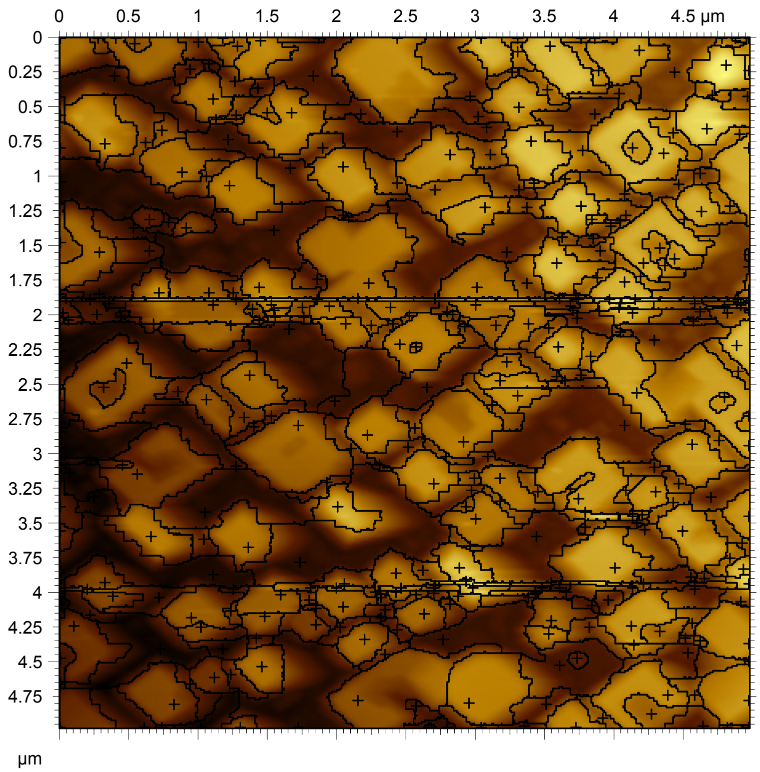
Height Parameters

Sq	49.9	nm	*Root mean square height*
Ssk	-0.174		*Skewness*
Sku	2.29		*Kurtosis*
Sp	149	nm	*Maximum peak height*
Sv	129	nm	*Maximum pit height*
Sz	278	nm	*Maximum height*
Sa	41.5	nm	*Arithmetic mean height*

ISO 23178 Roughness measurement

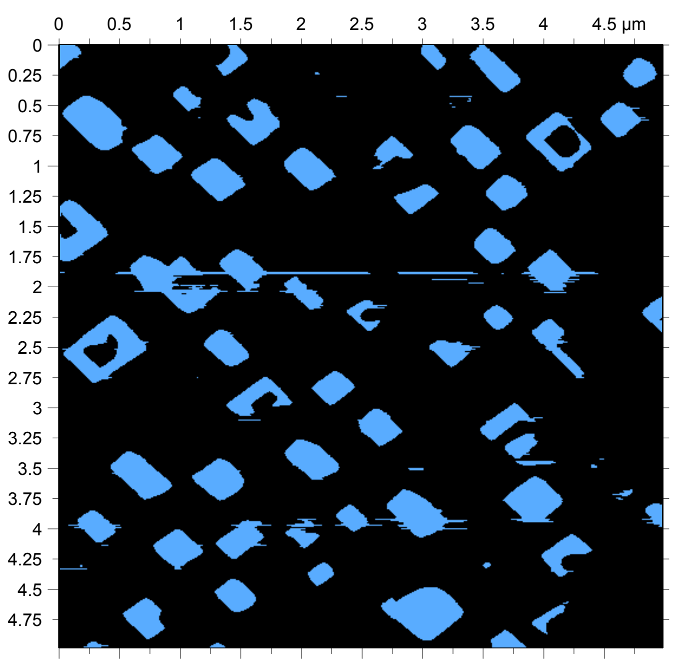
BFO-LSMO-STO March 21st sample 5x5 micron scan grain analysis and statistics

Grain detection and statistics



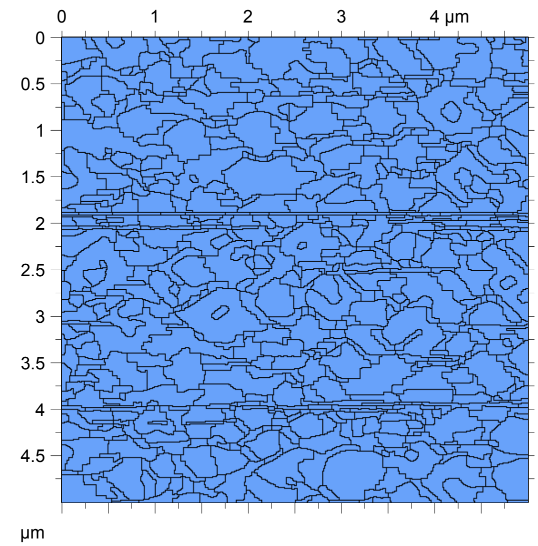
Number of motifs	380
Mean Height	128 nm
Mean of equivalent diameters	0.232 µm
Mean of mean diameters	0.204 µm
Mean aspect ratio	5.32

Grain coverage detection

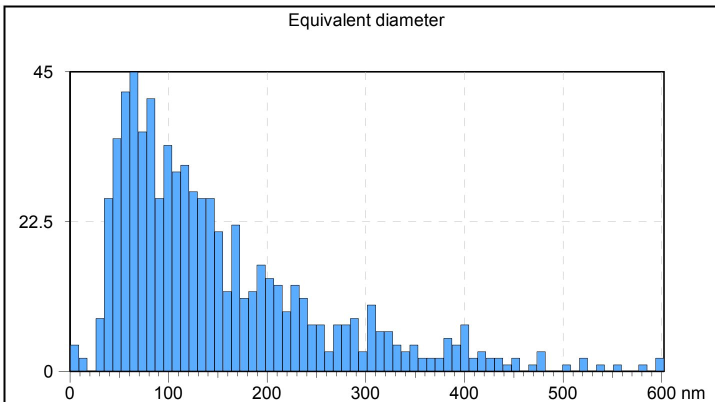


Analysis of Individual Grains

(Click on a grain to read parameter)



Grain #	1966
Area	***** nm²
Perimeter	-8.89 µm
Mean diameter	-8.89 µm
Form factor	*****
Aspect ratio	*****
Compactness	*****
Orientation	*****°



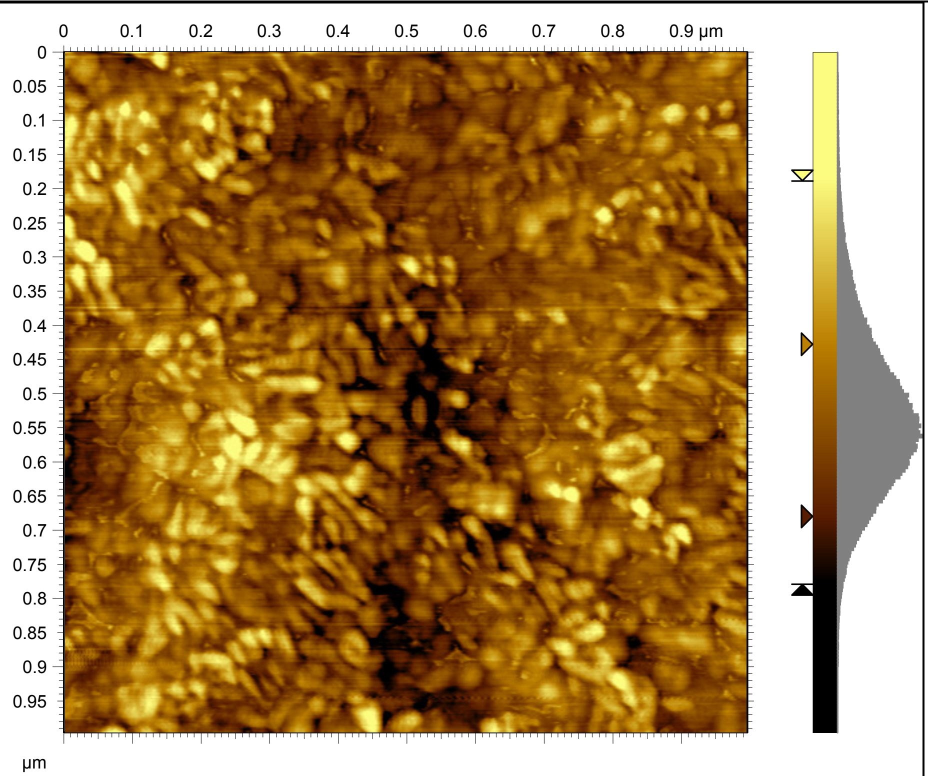
Mean parameters on 714 grains

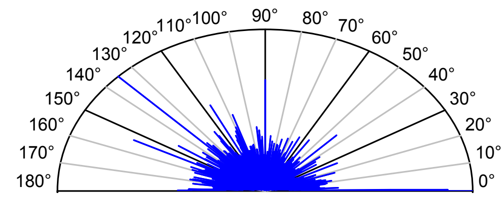
Number of grains: 714
Total area occupied by the grains: 19.3 µm² (77.3 %)
Density of grains: 28.6 grains / µm2.

Area	=	0.0271 µm²	+/- 0.0402 µm²
Perimeter	=	793 nm	+/- 586 nm
Form factor	=	0.410	+/- 0.162
Aspect ratio	=	5.91	+/- 7.89
Roundness	=	0.402	+/- 0.725
Compactness	=	0.578	+/- 0.259
Orientation	=	86.0°	+/- 73.3°

For demonstration purposes only!

CCSTO sample 1x1 micron scan roughness and texture analysis





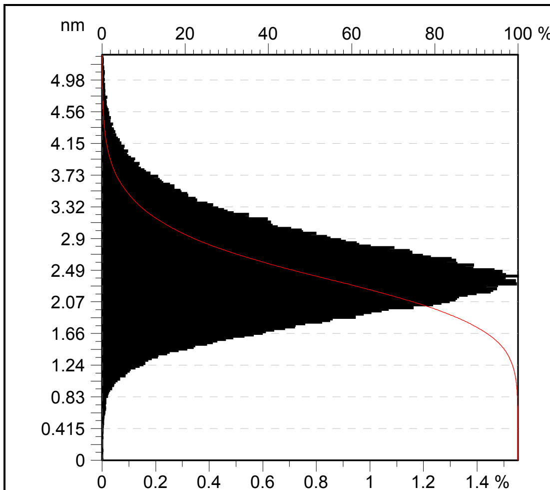
Isotropy: 36.7 %

First Direction: 135°

Second Direction: 0.344°

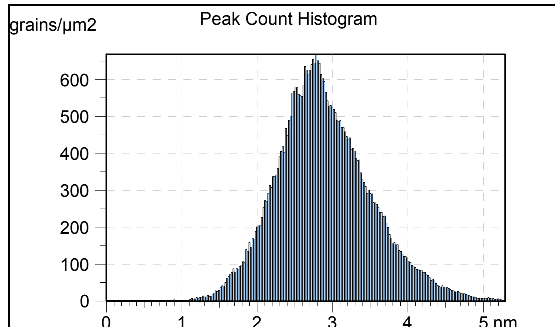
Third Direction: 154°

Texture analysis

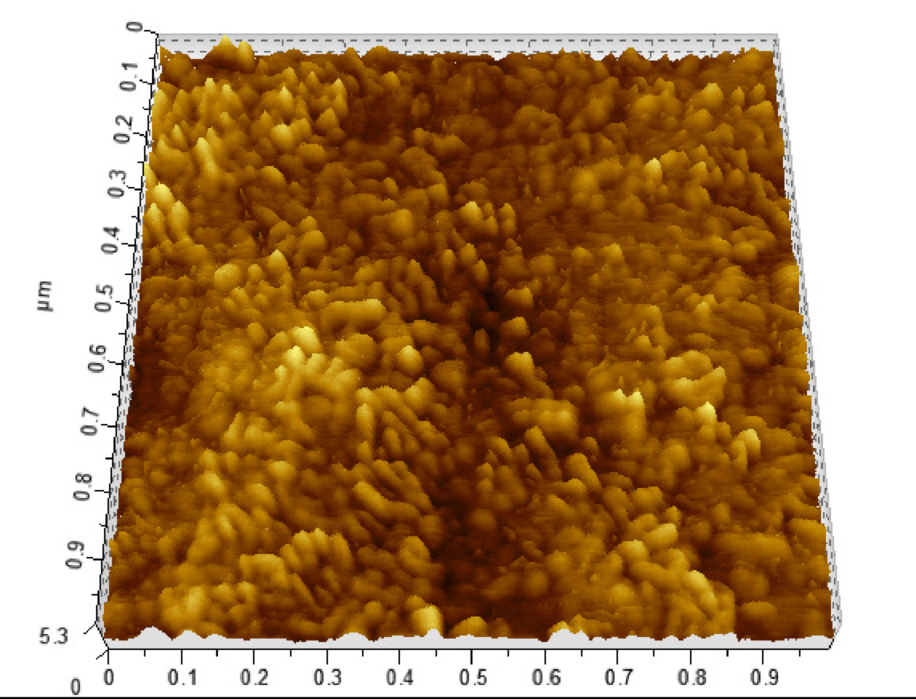


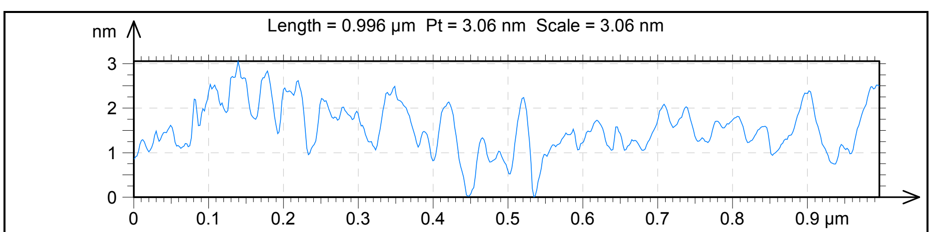
Smr(c2) - Smr(c1) 0.00 %

Histogram analysis (height statistics)



Grain size statistics





Cursor profile across center of image

ISO 25178

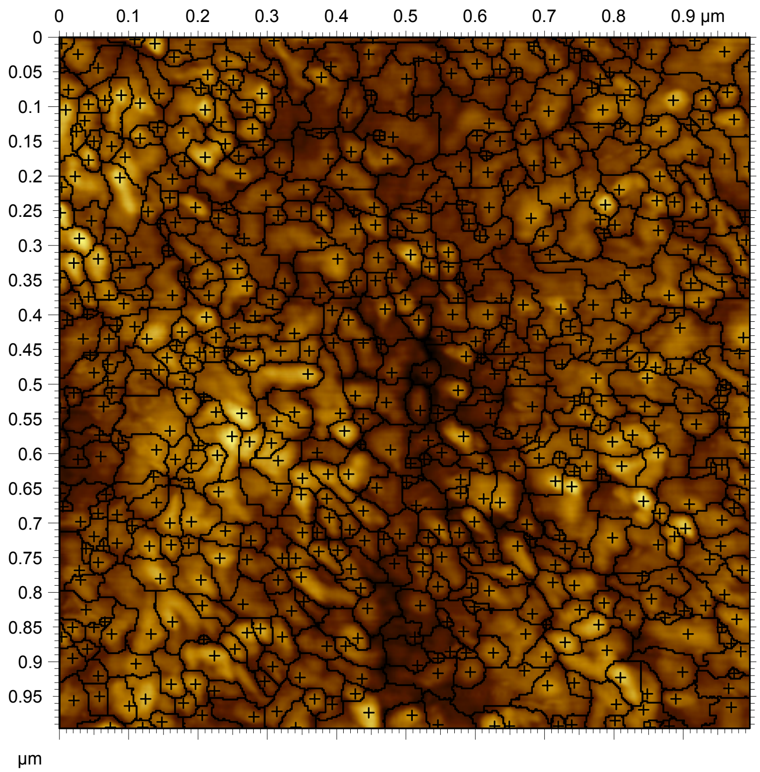
Height Parameters

Sq	0.615	nm	*Root mean square height*
Ssk	0.466		*Skewness*
Sku	3.57		*Kurtosis*
Sp	2.83	nm	*Maximum peak height*
Sv	2.48	nm	*Maximum pit height*
Sz	5.31	nm	*Maximum height*
Sa	0.478	nm	*Arithmetic mean height*

ISO 23178 Roughness measurement

CCSTO sample 1x1 micron scan grain analysis and statistics

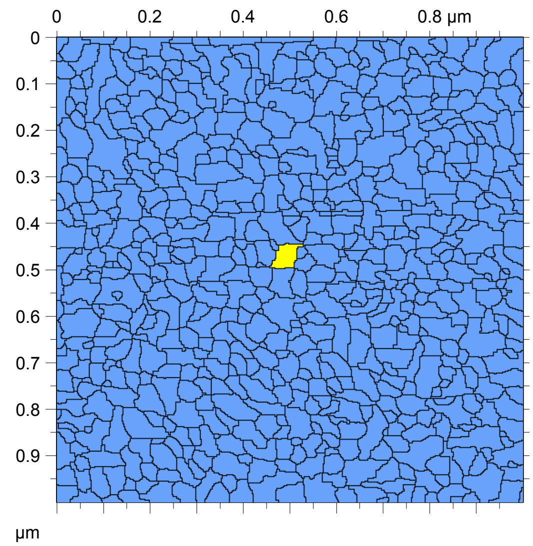
Grain detection and statistics



Number of motifs	581
Mean Height	0.591 nm
Mean of equivalent diameters	0.0414 µm
Mean of mean diameters	0.0396 µm
Mean aspect ratio	2.33

Analysis of Individual Grains

(Click on a grain to read parameter)



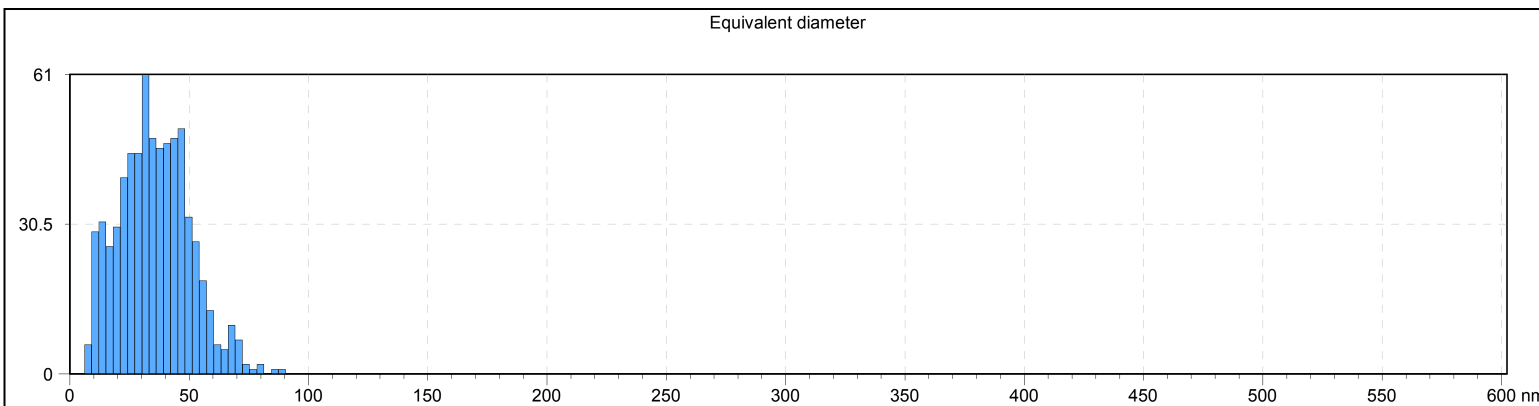
Grain #	305
Area	1949 nm²
Perimeter	0.224 µm
Mean diameter	0.0492 µm
Form factor	0.490
Aspect ratio	1.95
Compactness	0.688
Orientation	48.8°

Motif segmentation analysis uses mathematical modeling to detecte individual grain size, diameter, volume and aspect ratio. Statistics model is used to obtain an overview of the sample's grain structure for easy comparison between differennt samples.

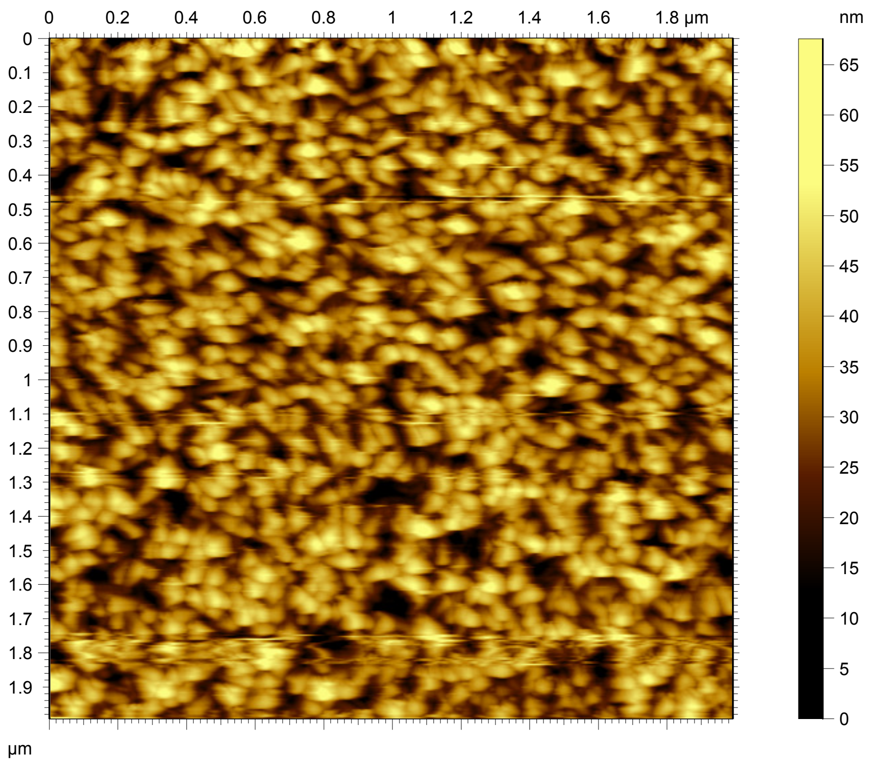
Mean parameters on 678 grains

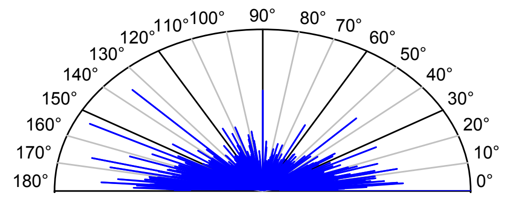
Number of grains: 678
Total area occupied by the grains: 0.789 µm² (78.9 %)
Density of grains: 678 grains / µm2.

Area	=	1163 nm²	+/- 927 nm²
Perimeter	=	154 nm	+/- 73.3 nm
Form factor	=	0.559	+/- 0.127
Aspect ratio	=	2.54	+/- 1.42
Roundness	=	0.496	+/- 0.240
Compactness	=	0.694	+/- 0.117
Orientation	=	101°	+/- 58.6°



CeO2 film on Si sample 2 x 2 micron scan roughness and texture analysis





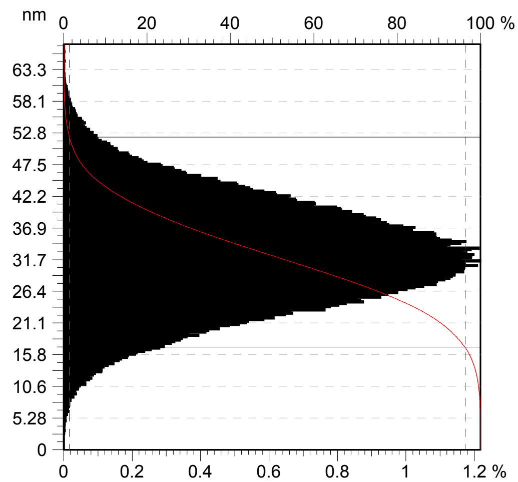
Isotropy: 67.5 %

First Direction: 0.264°

Second Direction: 154°

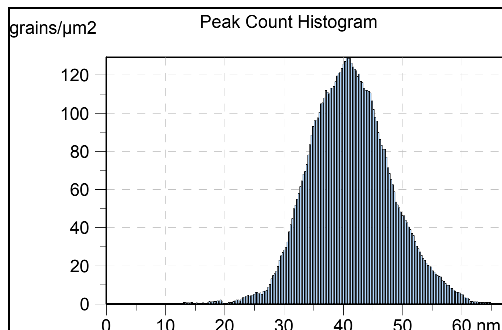
Third Direction: 135°

Texture analysis

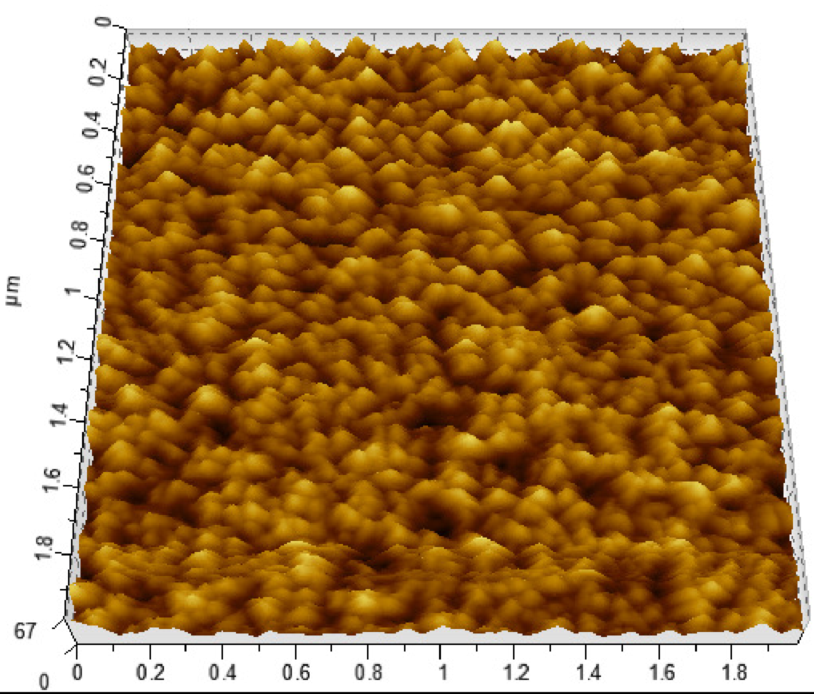


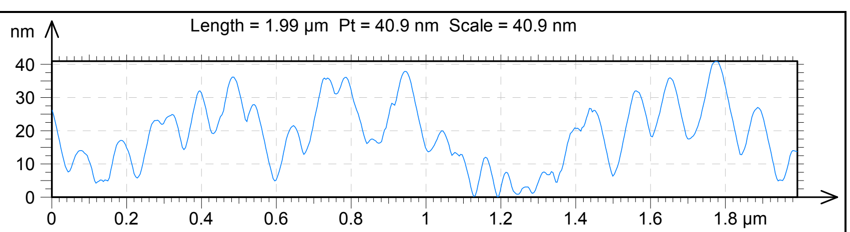
Smr(c2) - Smr(c1) 95.0 %

Histogram analysis (height statistics)



Grain size statistics





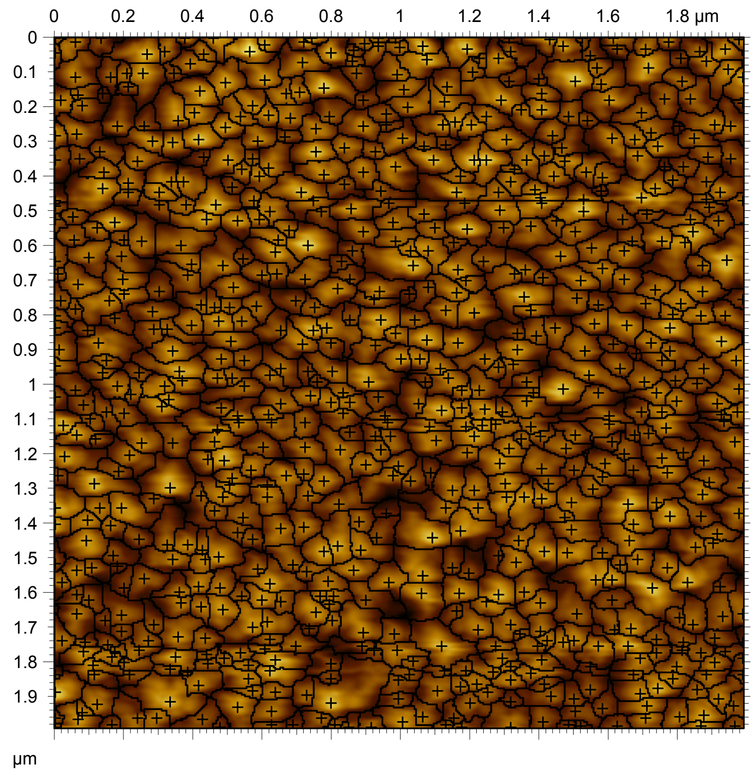
Cursor profile across center of image

ISO 25178			
Height Parameters			
Sq	8.71	nm	Root mean square height
Ssk	0.0637		Skewness
Sku	2.88		Kurtosis
Sp	35.1	nm	Maximum peak height
Sv	32.5	nm	Maximum pit height
Sz	67.6	nm	Maximum height
Sa	6.99	nm	Arithmetic mean height

ISO 23178 Roughness measurement

CeO2 film on Si sample 2 x 2 micron scan grain analysis and statistics

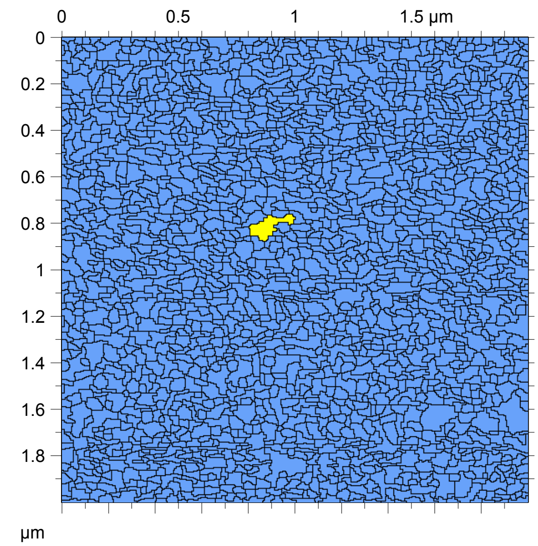
Grain detection and statistics



Number of motifs	749
Mean Height	6.47 nm
Mean of equivalent diameters	0.0745 µm
Mean of mean diameters	0.0721 µm
Mean aspect ratio	2.31

Analysis of Individual Grains

(Click on a grain to read parameter)

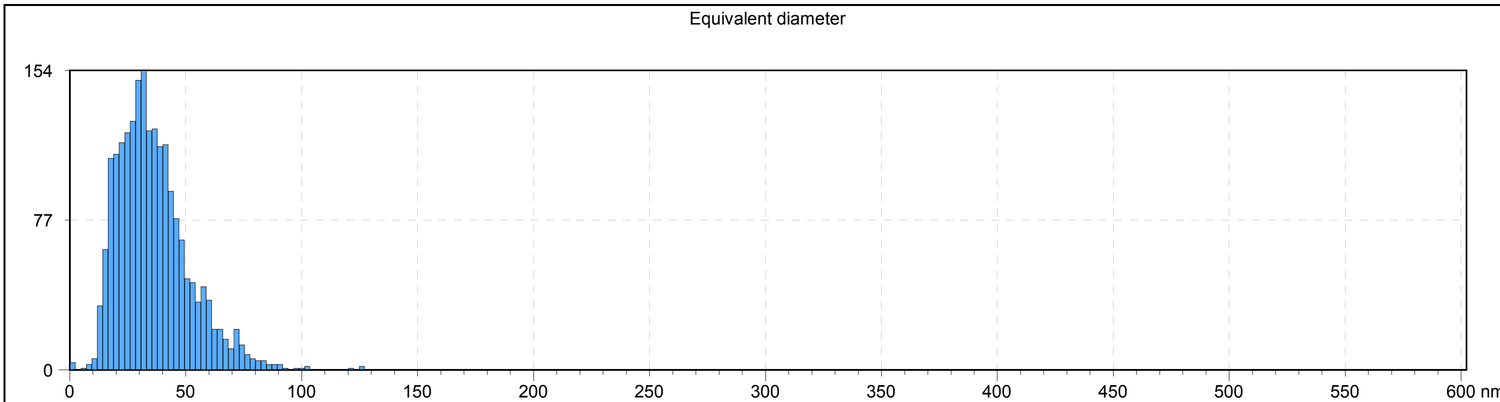


Grain #	843
Area	0.00824 µm²
Perimeter	0.606 µm
Mean diameter	0.0896 µm
Form factor	0.282
Aspect ratio	3.85
Compactness	0.523
Orientation	23.4°

Mean parameters on 2064 grains

Number of grains: 2064
Total area occupied by the grains: 2.51 µm² (62.7 %)
Density of grains: 516 grains / µm2.

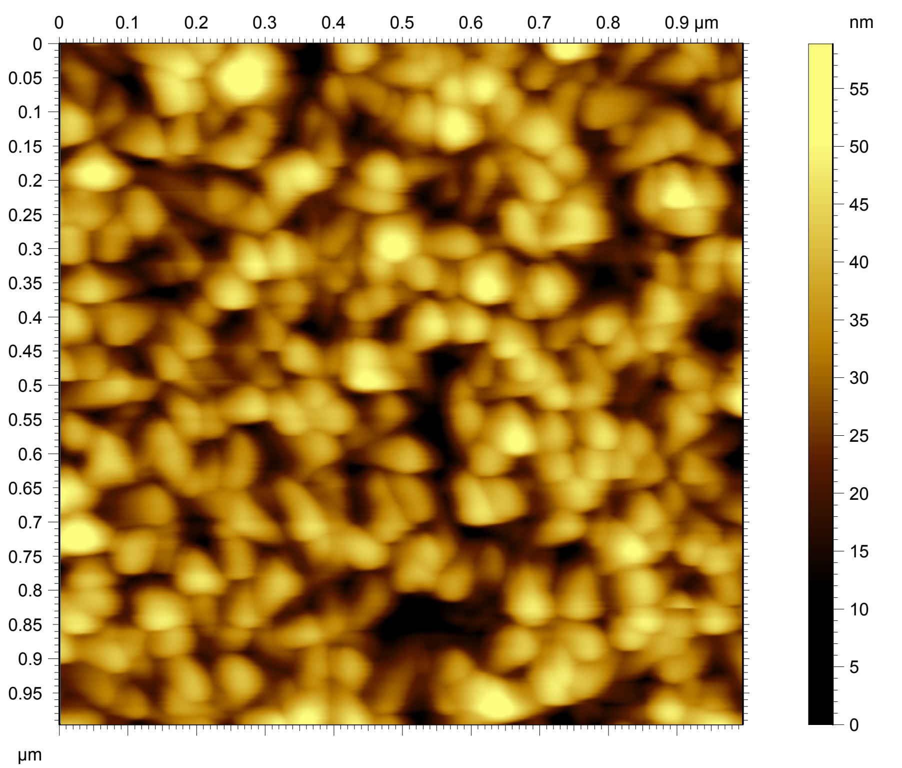
Area	=	1216 nm²	+/- 1140 nm²
Perimeter	=	170 nm	+/- 87.1 nm
Form factor	=	0.495	+/- 0.150
Aspect ratio	=	3.66	+/- 2.76
Roundness	=	0.417	+/- 0.205
Compactness	=	0.632	+/- 0.134
Orientation	=	97.2°	+/- 65.7°

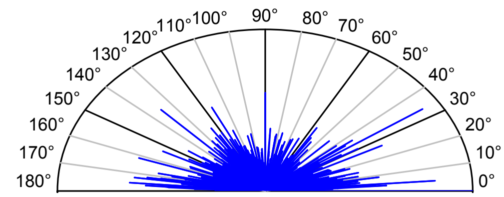


For demonstration purposes only!

Pico Image Expert 6.2.6561

CeO2 sample 1 x 1 micron scan roughness and texture analysis





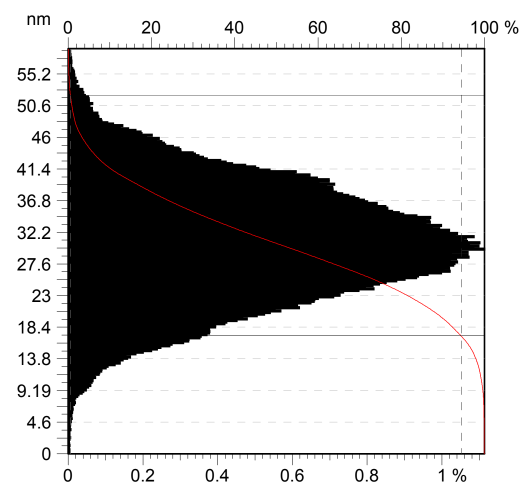
Isotropy: 93.5 %

First Direction: 0.133°

Second Direction: 33.7°

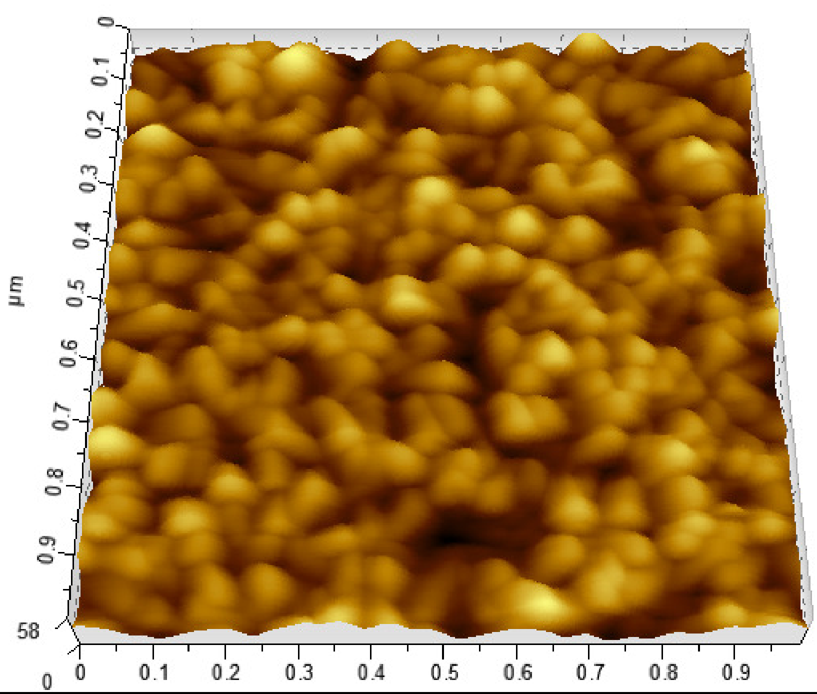
Third Direction: 135°

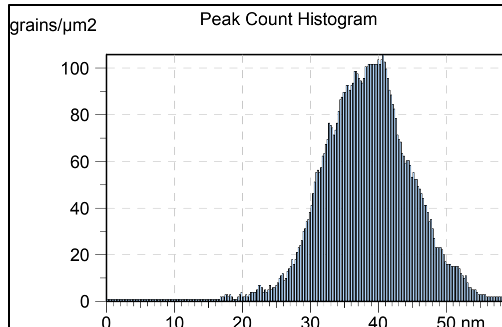
Texture analysis



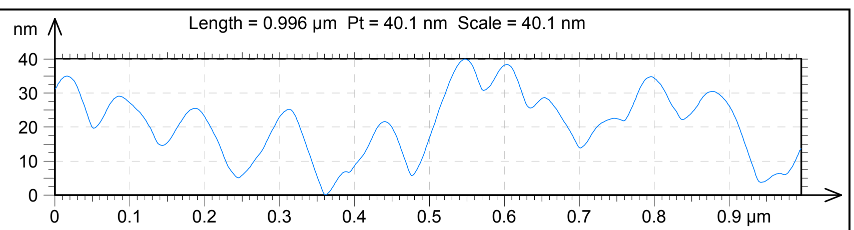
Smr(c2) - Smr(c1) 93.9 %

Histogram analysis (height statistics)





Grain size statistics



Cursor profile across center of image

ISO 25178

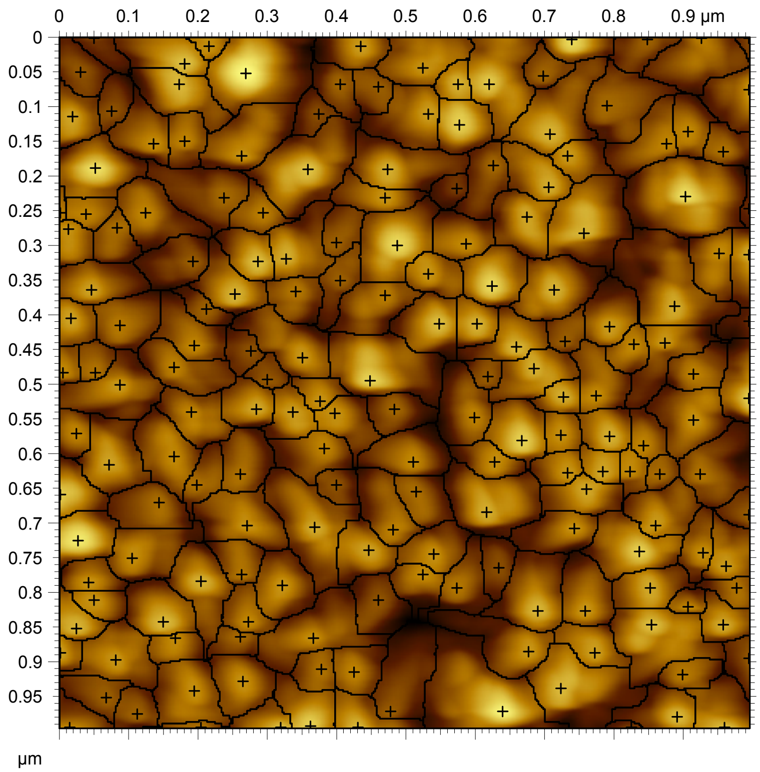
Height Parameters

Sq	8.42	nm	*Root mean square height*
Ssk	0.0102		*Skewness*
Sku	2.81		*Kurtosis*
Sp	28.2	nm	*Maximum peak height*
Sv	30.6	nm	*Maximum pit height*
Sz	58.8	nm	*Maximum height*
Sa	6.77	nm	*Arithmetic mean height*

ISO 23178 Roughtness measurement

CeO2 film on Si sample 1 x 1 micron scan grain analysis and statistics

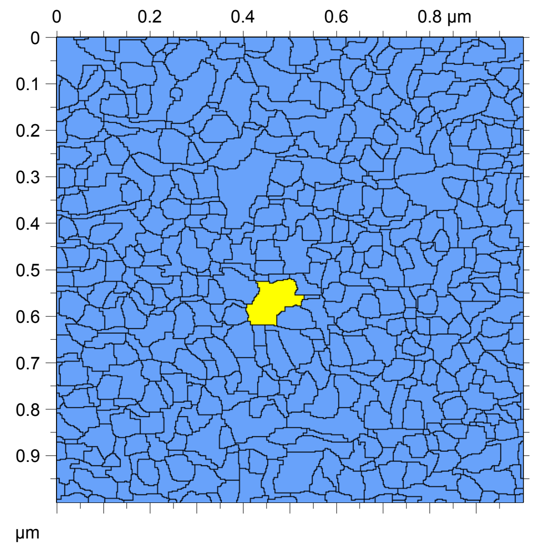
Grain detection and statistics



Number of motifs	182
Mean Height	6.49 nm
Mean of equivalent diameters	0.0779 µm
Mean of mean diameters	0.0756 µm
Mean aspect ratio	2.14

Analysis of Individual Grains

(Click on a grain to read parameter)



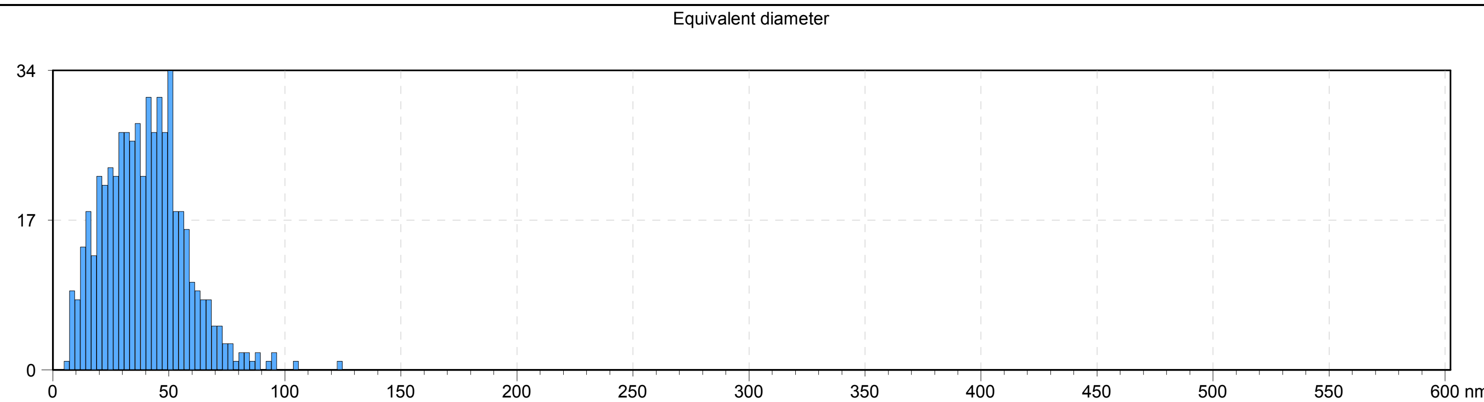
Grain #	288
Area	0.00701 µm²
Perimeter	0.433 µm
Mean diameter	0.0921 µm
Form factor	0.469
Aspect ratio	2.16
Compactness	0.720
Orientation	37.4°

Grain coverage detection

Mean parameters on 547 grains

Number of grains: 547
Total area occupied by the grains: 0.802 µm² (80.2 %)
Density of grains: 547 grains / µm2.

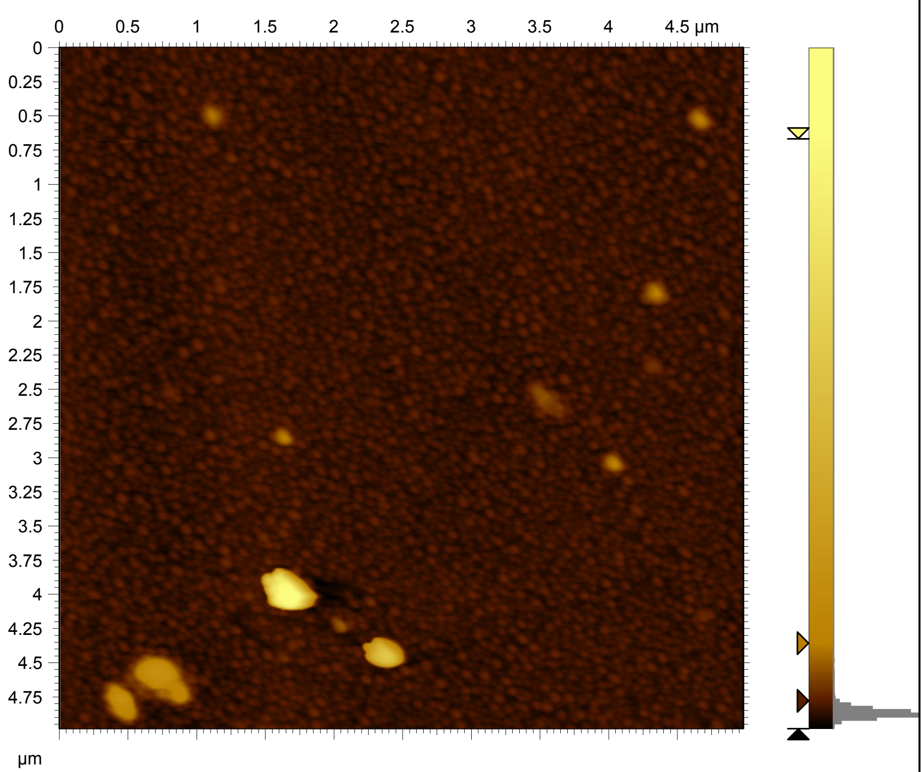
Area	=	1467 nm²	+/- 1286 nm²
Perimeter	=	181 nm	+/- 86.2 nm
Form factor	=	0.500	+/- 0.147
Aspect ratio	=	3.30	+/- 3.11
Roundness	=	0.459	+/- 0.190
Compactness	=	0.663	+/- 0.139
Orientation	=	89.0°	+/- 59.6°

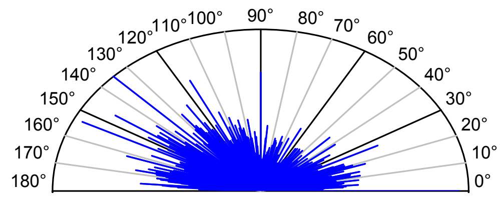


For demonstration purposes only!

Pico Image Expert 6.2.6561

NbSrTiO film sample 5x5 micron scan roughness and texture analysis





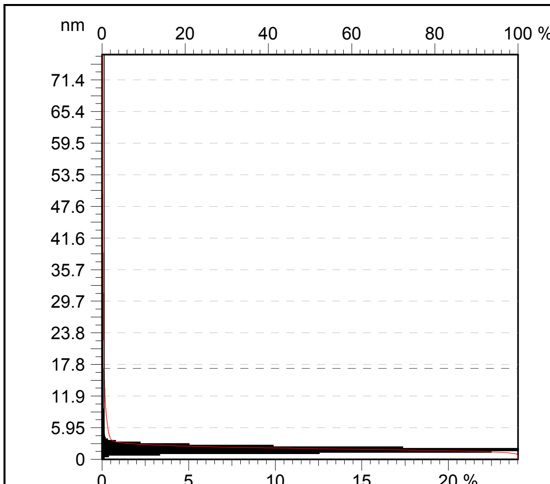
Isotropy: 65.5 %

First Direction: 135°

Second Direction: 154°

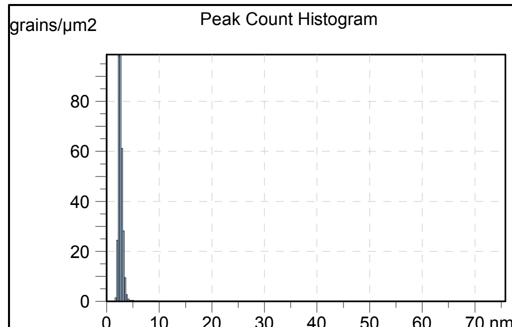
Third Direction: 0.169°

Texture analysis

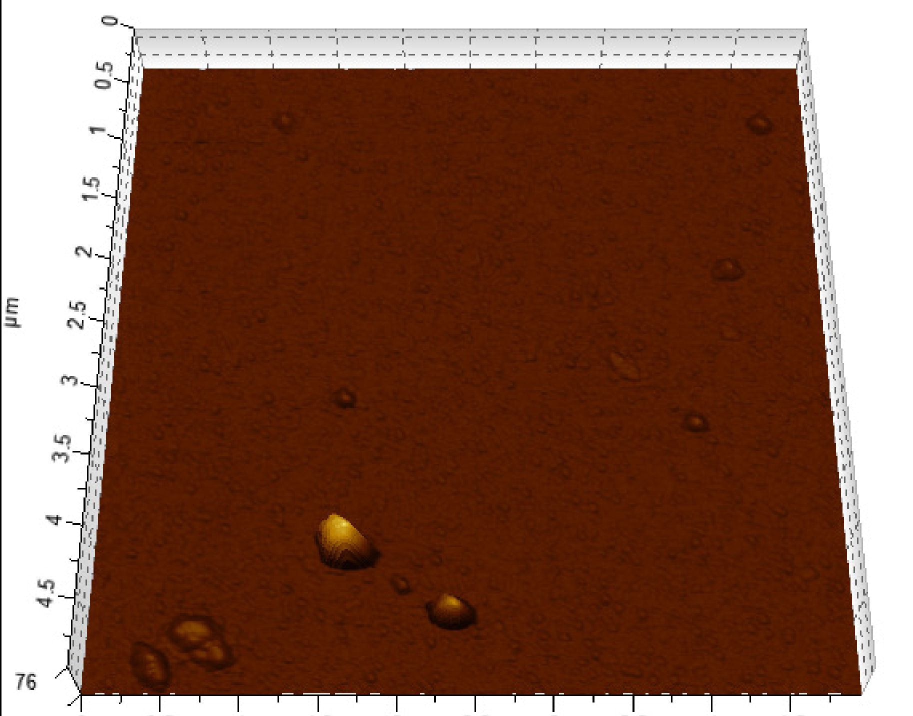


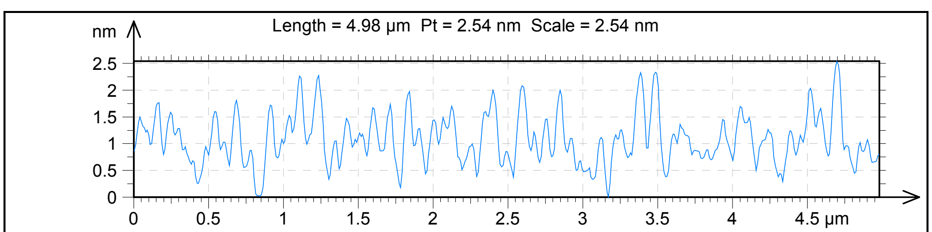
Smr(c2) - Smr(c1) 0.00 %

Histogram analysis (height statistics)



Grain size statistics





Cursor profile across center of image

ISO 25178

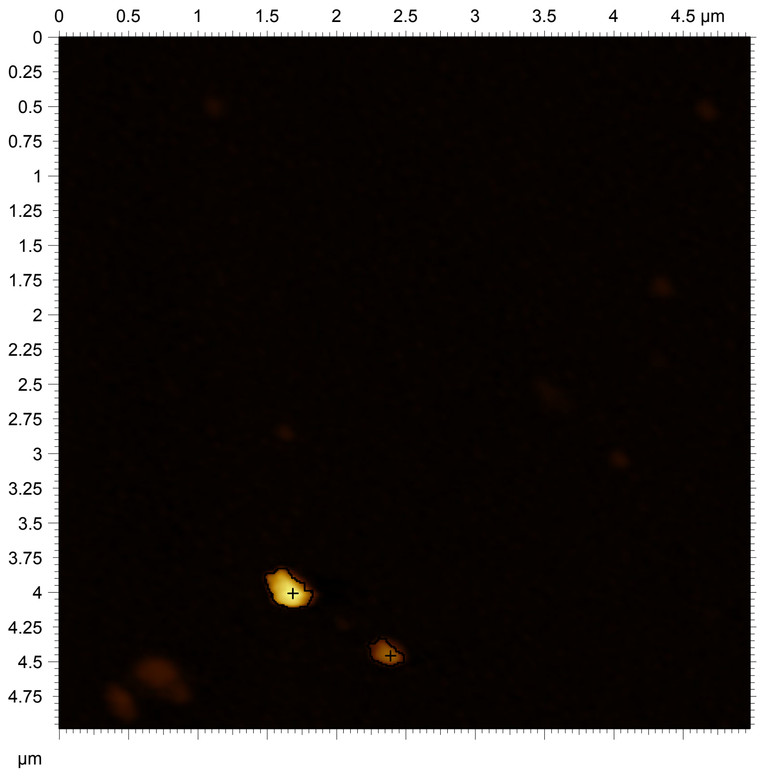
Height Parameters

Sq	3.08	nm	*Root mean square height*
Ssk	15.8		*Skewness*
Sku	290		*Kurtosis*
Sp	73.9	nm	*Maximum peak height*
Sv	2.26	nm	*Maximum pit height*
Sz	76.1	nm	*Maximum height*
Sa	0.716	nm	*Arithmetic mean height*

ISO 23178 Roughness measurement

NbSrTiO film sample 5x5 micron scan grain analysis

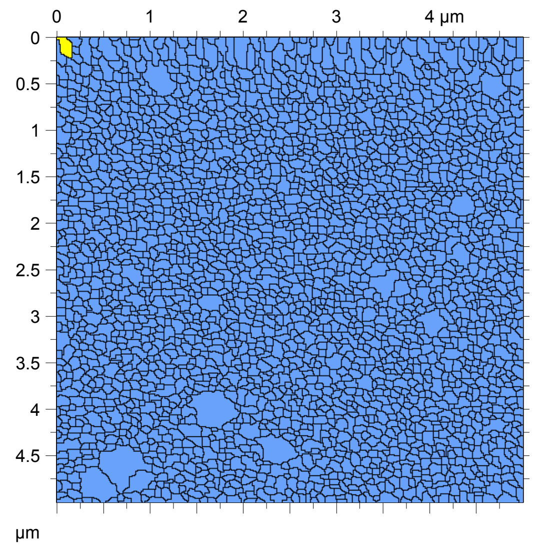
Grain detection and statistics



Number of motifs	3
Mean Height	27.9 nm
Mean of equivalent diameters	2.03 µm
Mean of mean diameters	1.98 µm
Mean aspect ratio	1.89

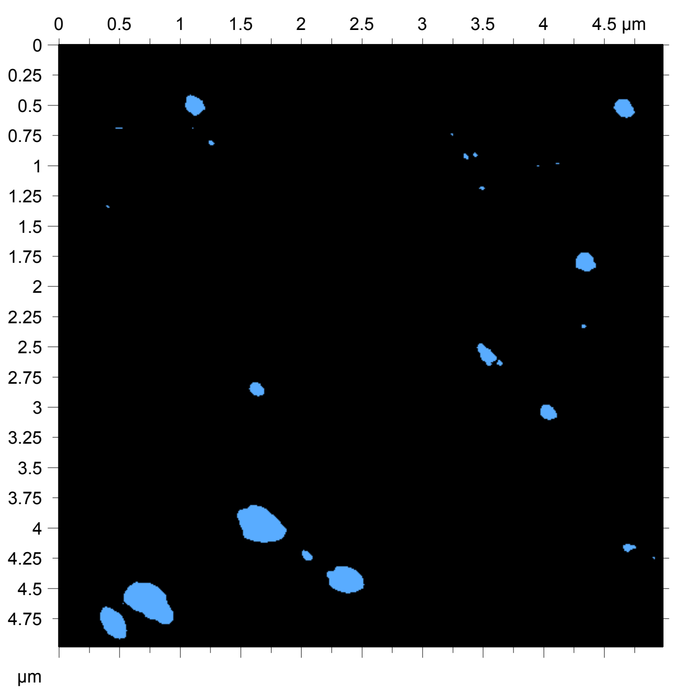
Analysis of Individual Grains

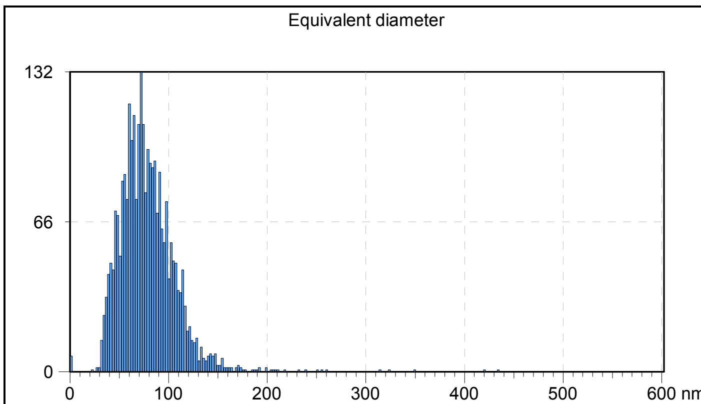
(Click on a grain to read parameter)



Grain #	1
Area	0.0188 µm²
Perimeter	0.636 µm
Mean diameter	0.150 µm
Form factor	0.583
Aspect ratio	2.18
Compactness	0.658
Orientation	112°

Grain coverage detection





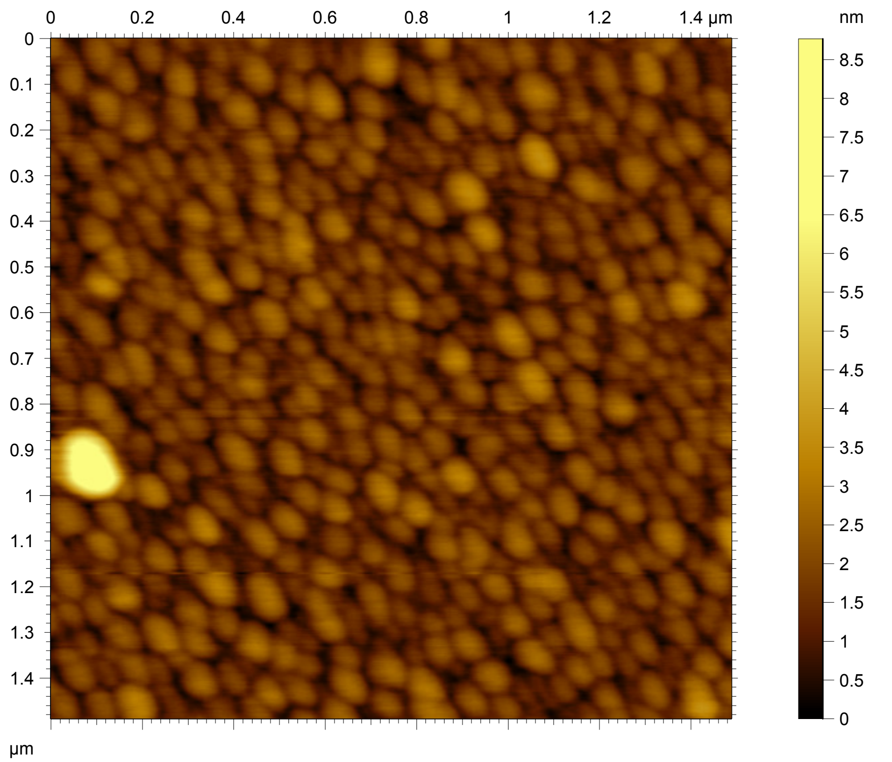
Mean parameters on 2750 grains

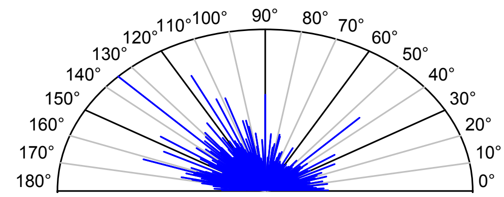
Number of grains: 2750
Total area occupied by the grains: 15.3 µm² (61.2 %)
Density of grains: 110 grains / µm2.

Area	=	5564 nm²	+/- 6249 nm²
Perimeter	=	322 nm	+/- 139 nm
Form factor	=	0.615	+/- 0.126
Aspect ratio	=	2.41	+/- 1.18
Roundness	=	0.485	+/- 0.121
Compactness	=	0.691	+/- 0.0913
Orientation	=	107°	+/- 57.2°

For demonstration purposes only!

NbSrTiO film sample 1.5 x 1.5 micron scan roughness and texture analysis





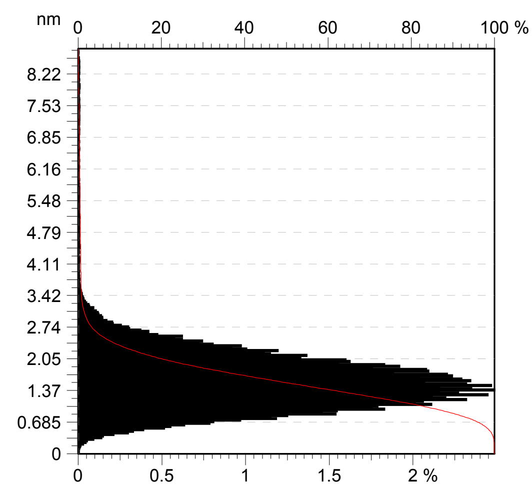
Isotropy: 59.8 %

First Direction: 135°

Second Direction: 116°

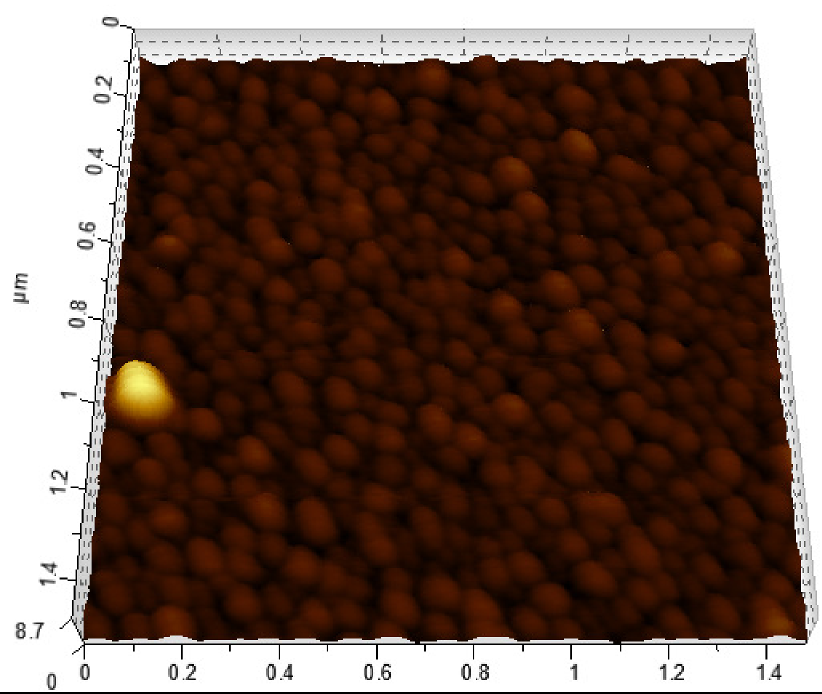
Third Direction: 45.0°

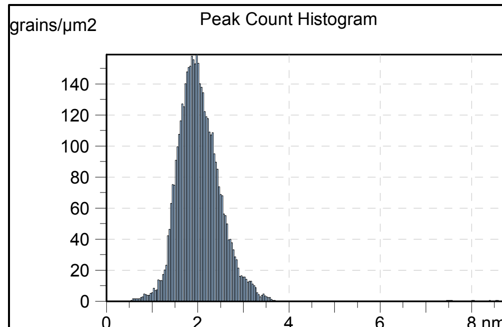
Texture analysis



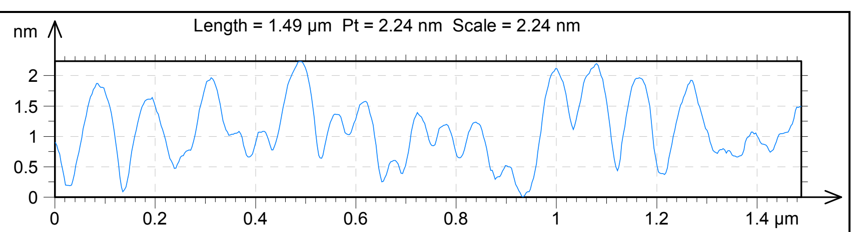
Smr(c2) - Smr(c1) 0.00 %

Histogram analysis (height statistics)





Grain size statistics



Cursor profile across center of image

ISO 25178

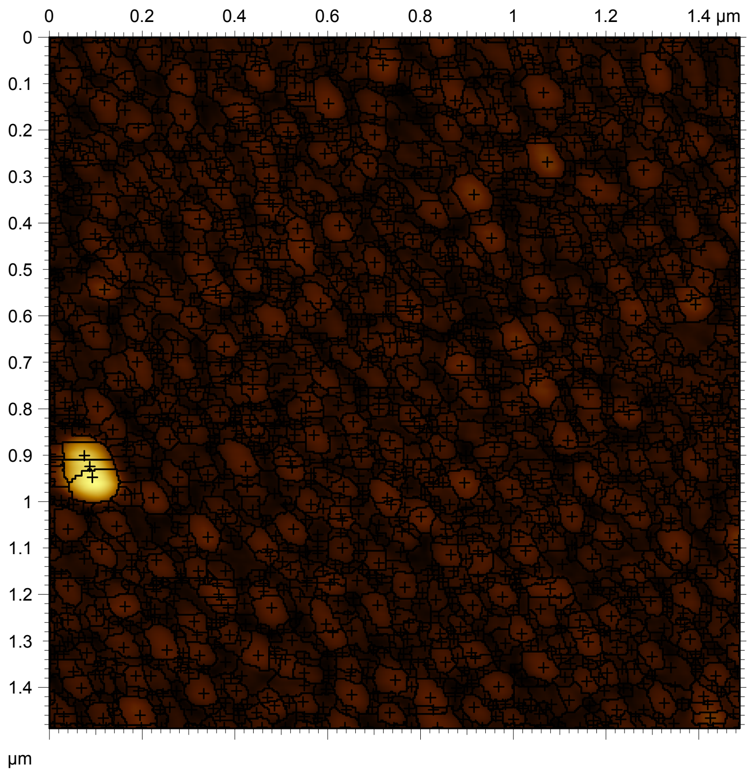
Height Parameters

Sq	0.683	nm	Root mean square height
Ssk	2.77		Skewness
Sku	23.6		Kurtosis
Sp	7.17	nm	Maximum peak height
Sv	1.60	nm	Maximum pit height
Sz	8.77	nm	Maximum height
Sa	0.481	nm	Arithmetic mean height

ISO 23178 Roughness measurement

NbSrTiO film sample 1.5x1.5 micron scan grain analysis

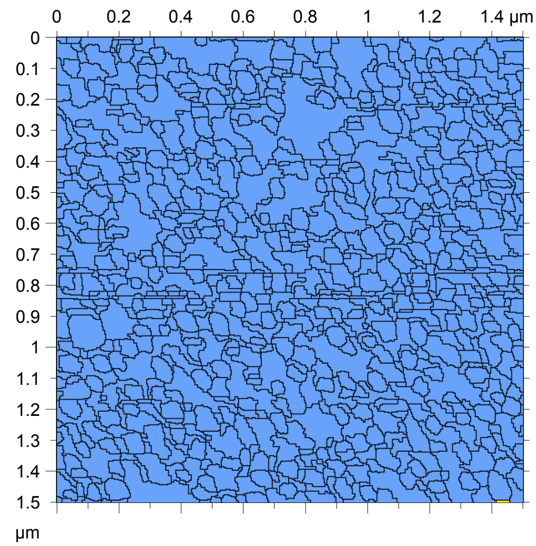
Grain detection and statistics



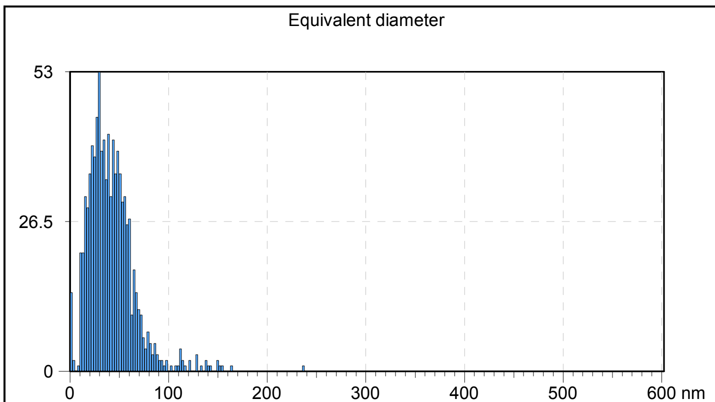
Number of motifs	1698
Mean Height	1.40 nm
Mean of equivalent diameters	0.035 µm
Mean of mean diameters	0.0336 µm
Mean aspect ratio	2.81

Analysis of Individual Grains

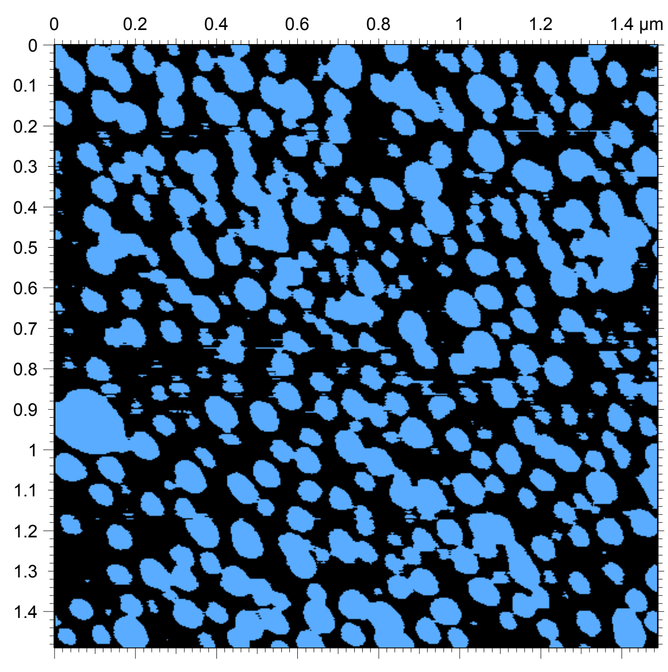
(Click on a grain to read parameter)



Grain #	910
Area	112 nm²
Perimeter	0.0822 µm
Mean diameter	0.0119 µm
Form factor	0.208
Aspect ratio	14.0
Compactness	0.291
Orientation	0.00°



Grain coverage detection



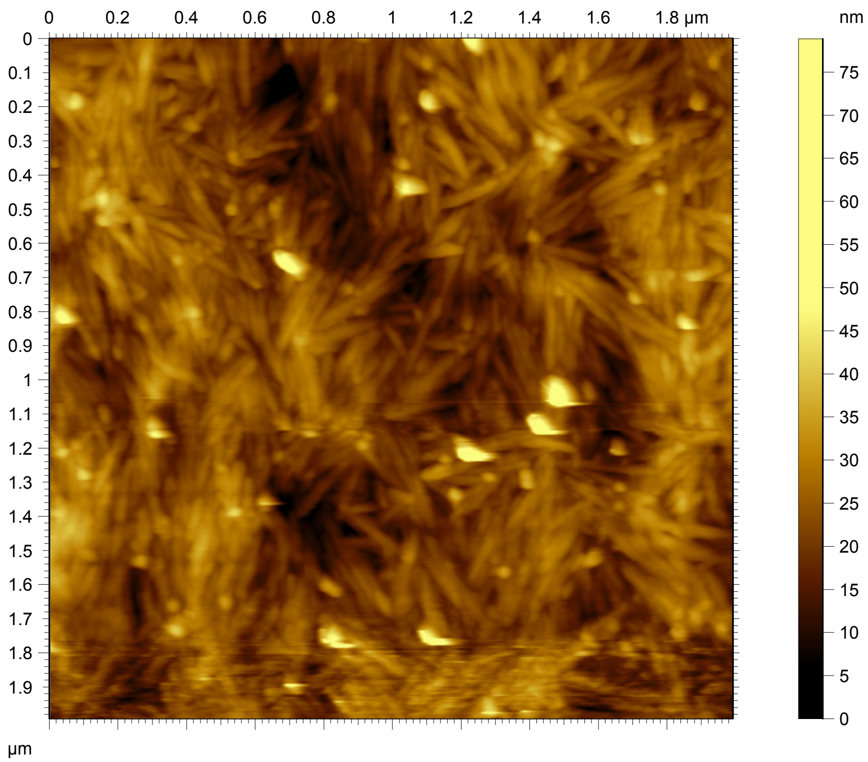
Mean parameters on 910 grains

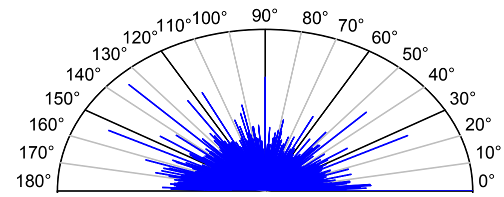
Number of grains: 910
Total area occupied by the grains: 1.67 µm² (74.2 %)
Density of grains: 404 grains / µm2.

Area	=	1835 nm²	+/- 2744 nm²
Perimeter	=	208 nm	+/- 168 nm
Form factor	=	0.473	+/- 0.170
Aspect ratio	=	3.51	+/- 2.84
Roundness	=	0.442	+/- 0.368
Compactness	=	0.644	+/- 0.164
Orientation	=	108°	+/- 58.3°

For demonstration purposes only!

"Tom's sample" 2x2 micron scan roughness and texture analysis





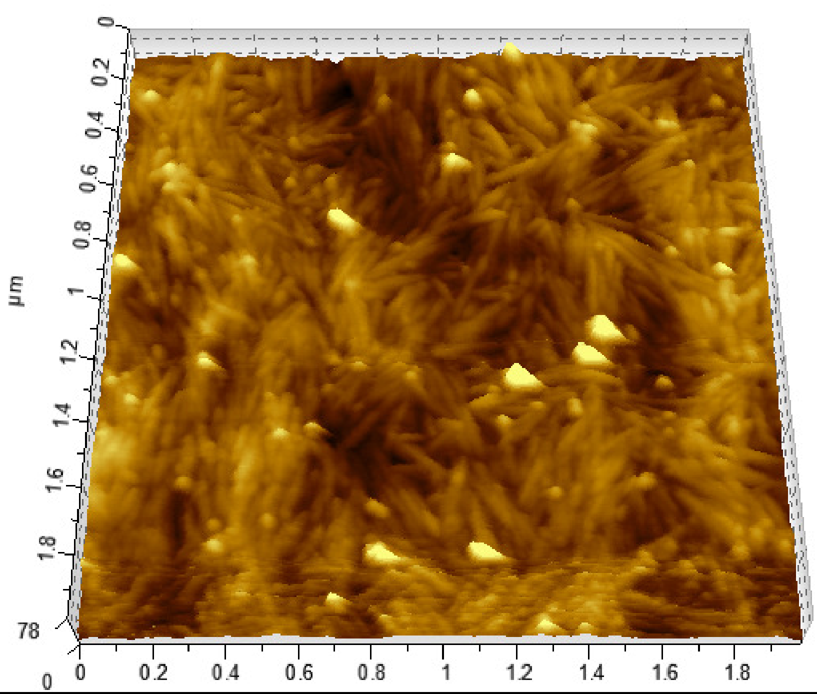
Isotropy: 43.1 %

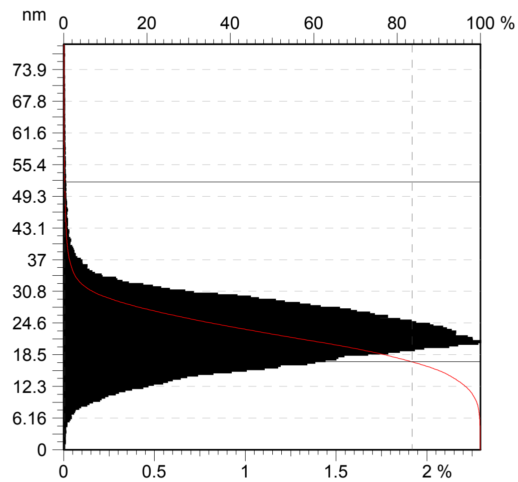
First Direction: 0.215°

Second Direction: 135°

Third Direction: 154°

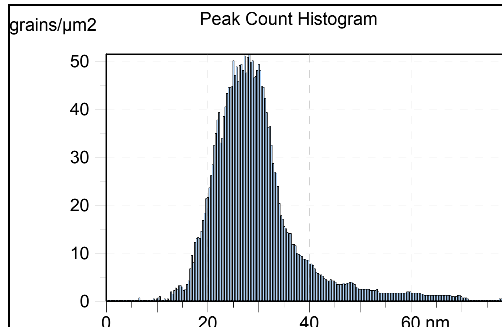
Texture analysis



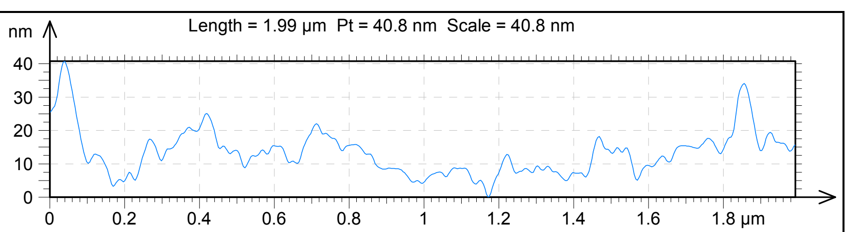


Smr(c2) - Smr(c1) 83.4 %

Histogram analysis (height statistics)



Grain size statistics



Cursor profile across center of image

ISO 25178

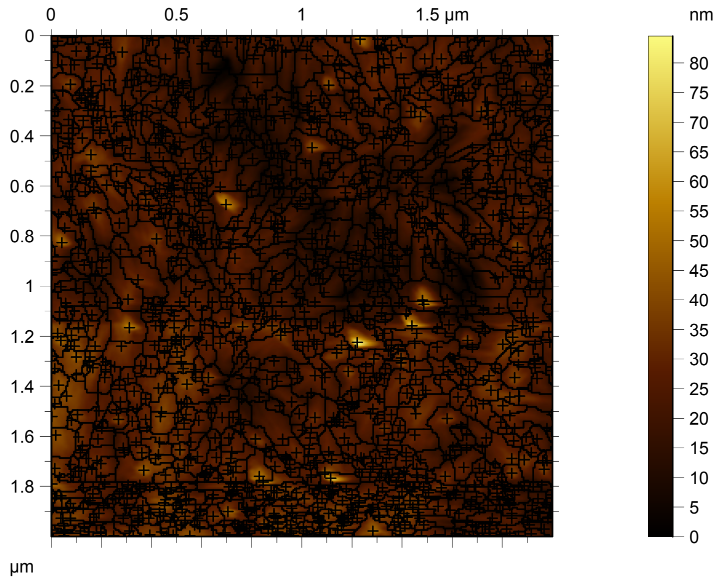
Height Parameters			
Sq	6.00	nm	*Root mean square height*
Ssk	0.670		*Skewness*
Sku	6.56		*Kurtosis*
Sp	56.2	nm	*Maximum peak height*
Sv	22.7	nm	*Maximum pit height*
Sz	78.9	nm	*Maximum height*
Sa	4.58	nm	*Arithmetic mean height*

ISO 23178 Roughness measurement

For demonstration purposes only!

"Tom's sample" 2x2 micron scan grain analysis and statistics

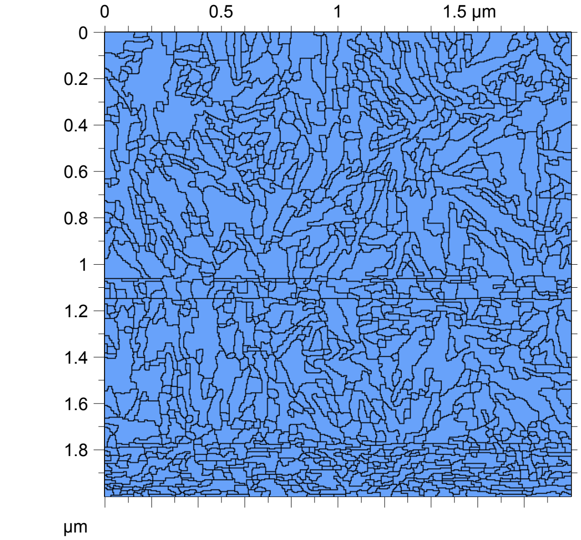
Grain detection and statistics



Number of motifs	1263
Mean Height	1.35 nm
Mean Area	0.00318 µm²

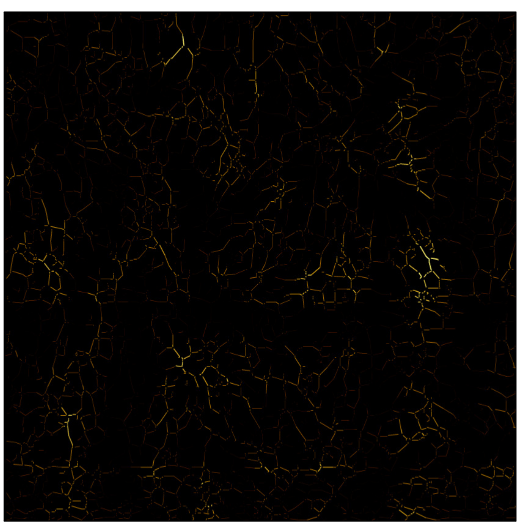
Analysis of Individual Grains

(Click on a grain to read parameter)



Grain #	1966
Area	***** nm²
Perimeter	-8.89 µm
Mean diameter	-8.89 µm
Form factor	*****
Aspect ratio	*****
Compactness	*****
Orientation	*****°

Micro valley vector analysis



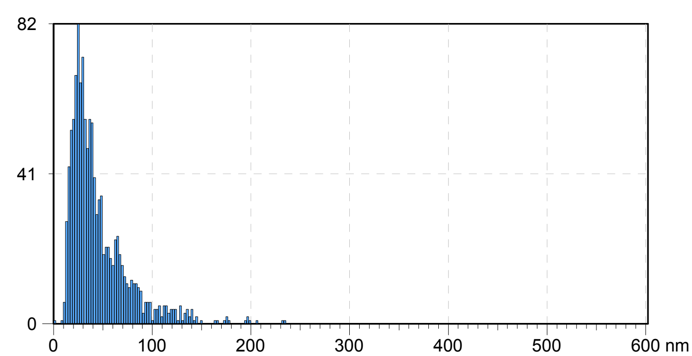
All furrows are displayed.

Maximum depth of furrows : 24.2 nm

Mean depth of furrows : 8.94 nm

Mean density of furrows : 193845 cm/cm2

Equivalent diameter



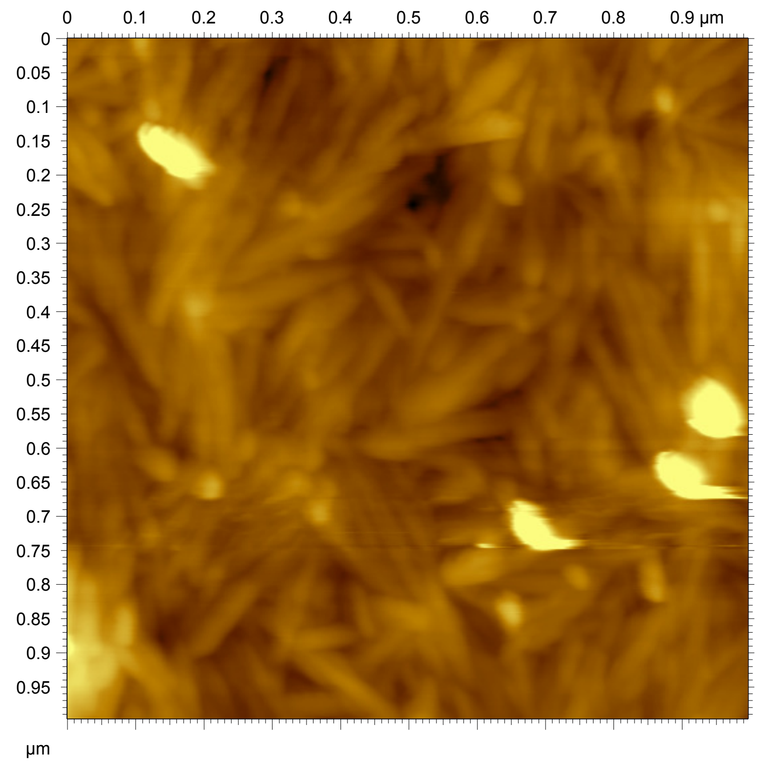
Mean parameters on 1194 grains

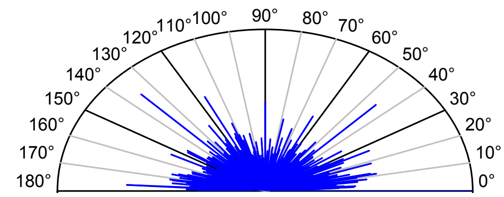
Number of grains: 1194
Total area occupied by the grains: 2.85 µm² (71.2 %)
Density of grains: 299 grains / µm2.

Area	=	2385 nm²	+/- 4033 nm²
Perimeter	=	234 nm	+/- 204 nm
Form factor	=	0.463	+/- 0.165
Aspect ratio	=	4.32	+/- 3.66
Roundness	=	0.381	+/- 0.186
Compactness	=	0.599	+/- 0.151
Orientation	=	87.8°	+/- 59.6°

For demonstration purposes only!

"Tom's sample" 1x1 micron scan roughness and texture analysis





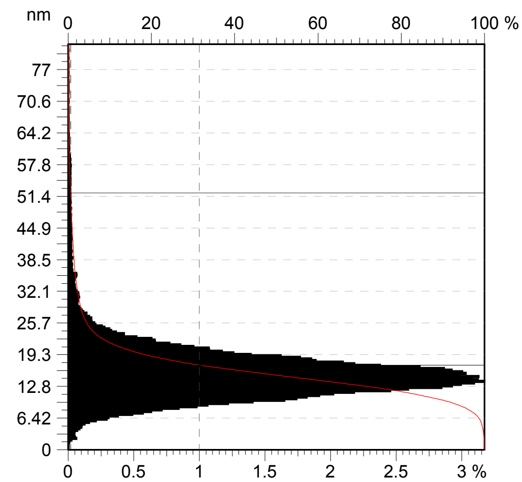
Isotropy: 46.3 %

First Direction: 0.152°

Second Direction: 135°

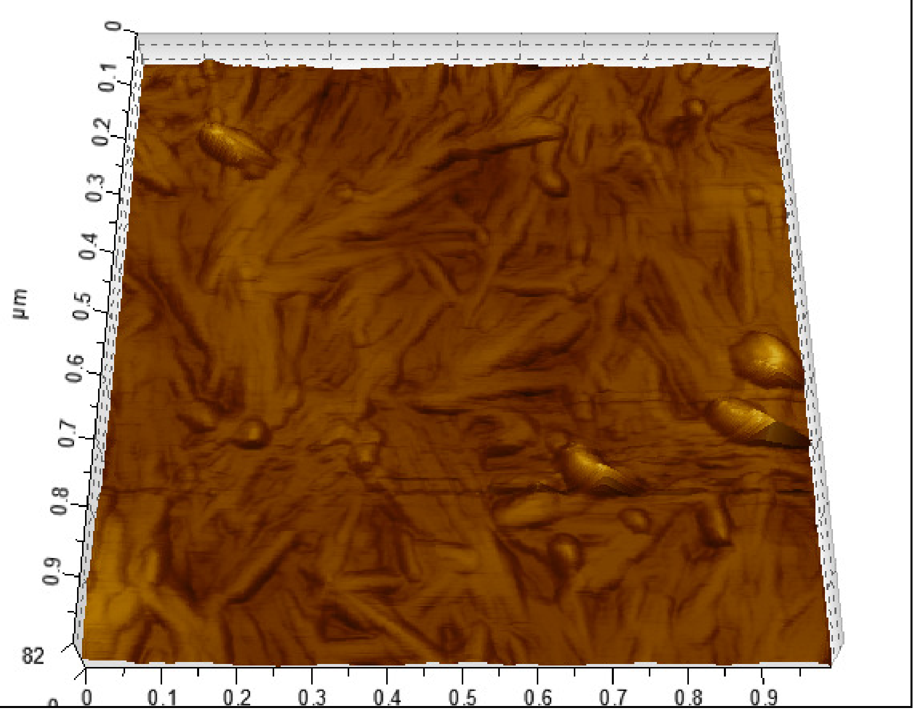
Third Direction: 45.0°

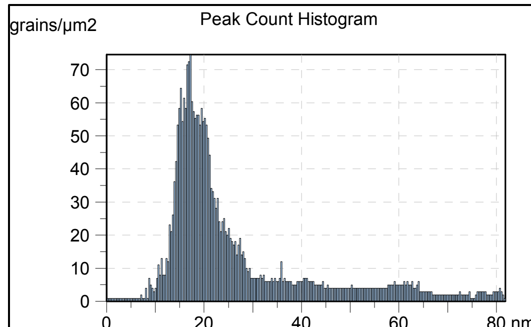
Texture analysis



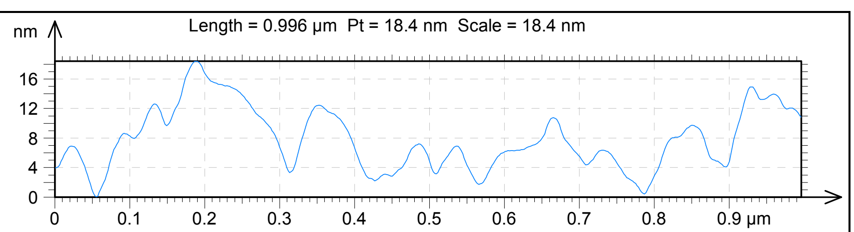
Smr(c2) - Smr(c1) 30.9 %

Histogram analysis (height statistics)





Grain size statistics



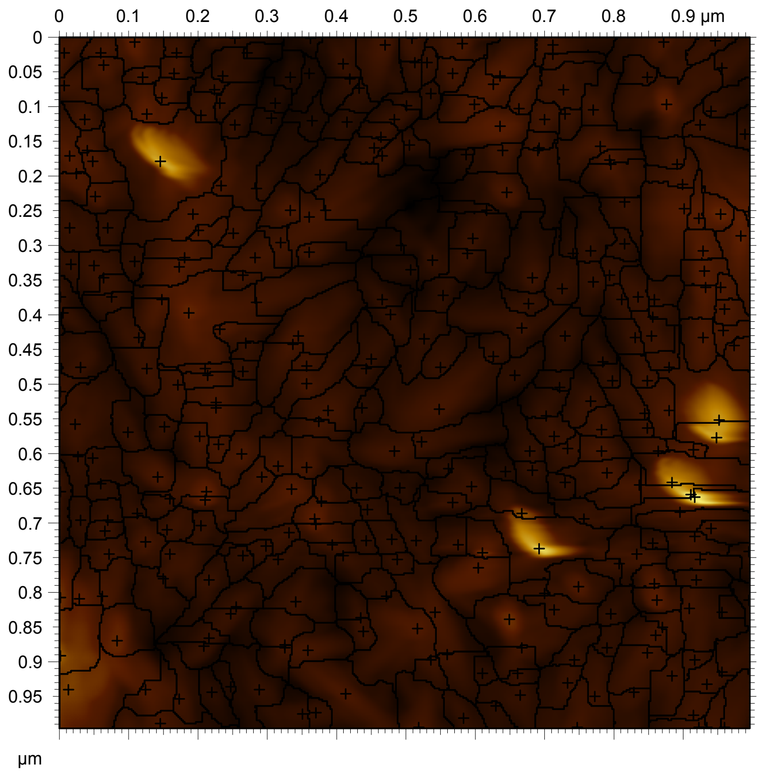
Cursor profile across center of image

ISO 25178			
Height Parameters			
Sq	6.33	nm	*Root mean square height*
Ssk	2.92		*Skewness*
Sku	19.2		*Kurtosis*
Sp	66.3	nm	*Maximum peak height*
Sv	15.9	nm	*Maximum pit height*
Sz	82.2	nm	*Maximum height*
Sa	4.07	nm	*Arithmetic mean height*

ISO 23178 Roughness measurement

t "Tom's sample" 2x2 micron scan grain analysis and statistics

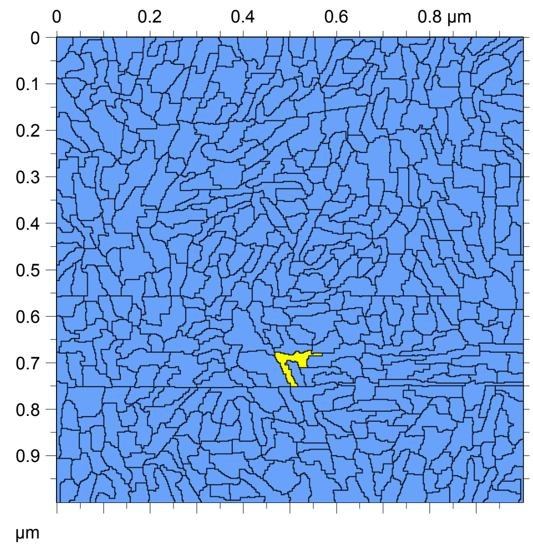
Grain detection and statistics



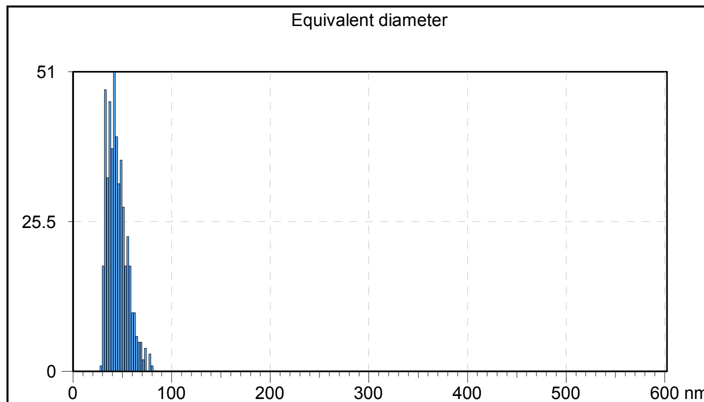
Number of motifs	324
Mean Height	1.15 nm
Mean of equivalent diameters	0.0569 µm
Mean of mean diameters	0.054 µm
Mean aspect ratio	2.64

Analysis of Individual Grains

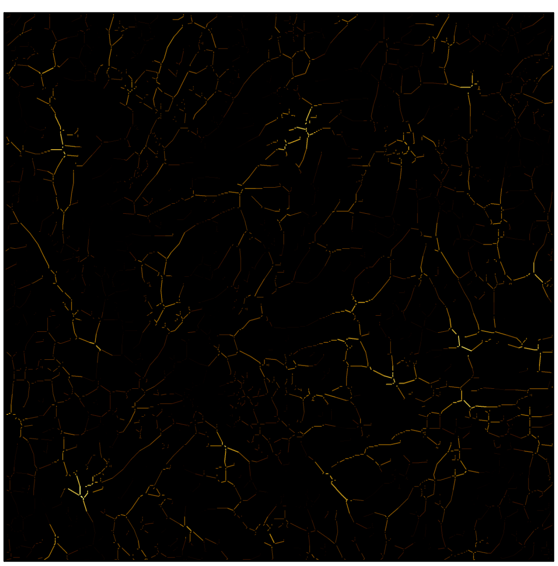
(Click on a grain to read parameter)



Grain #	328
Area	1758 nm²
Perimeter	0.408 µm
Mean diameter	-8.89 µm
Form factor	0.133
Aspect ratio	*****
Compactness	-0.00532
Orientation	31.3°



micro alley vector analysis



All furrows are displayed.

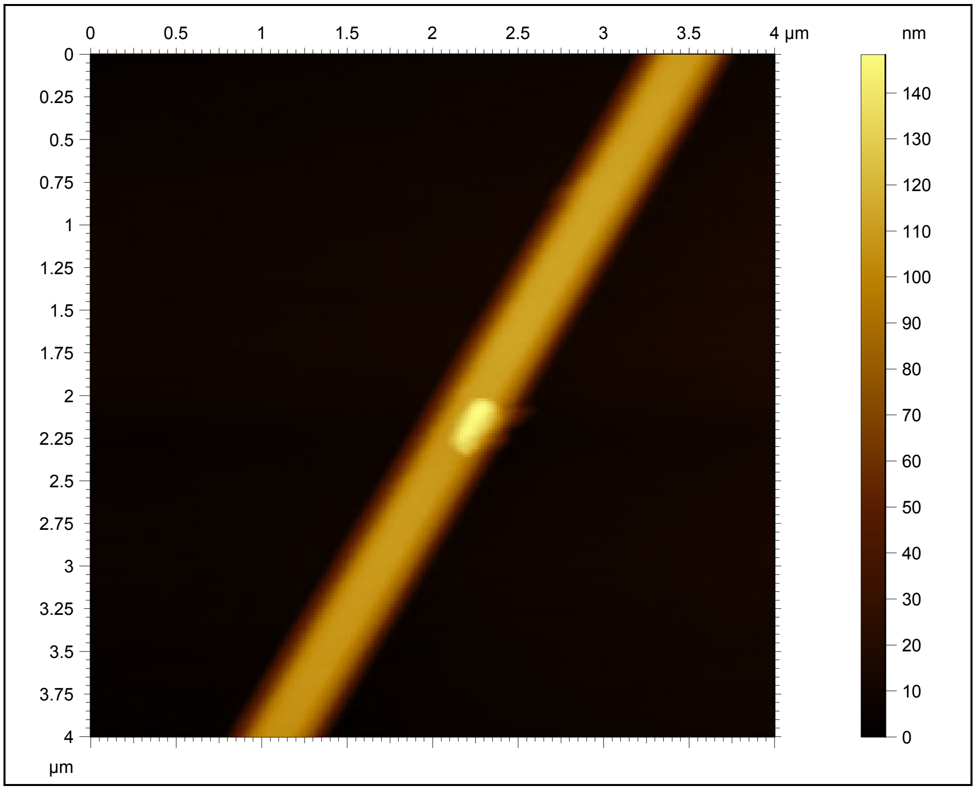
Maximum depth of furrows : 17.5 nm
Mean depth of furrows : 6.70 nm
Mean density of furrows : 287232 cm/cm2

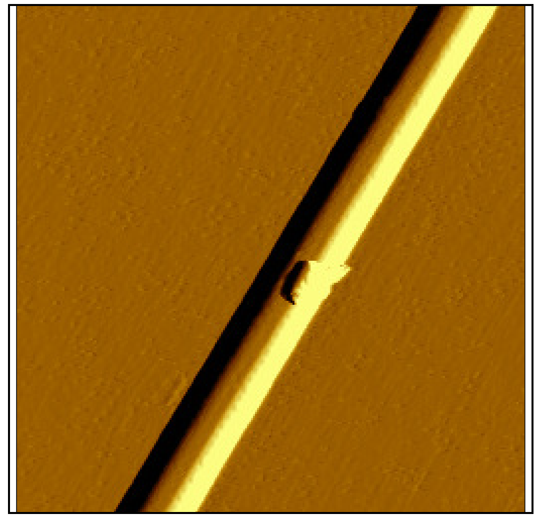
Mean parameters on 476 grains

Number of grains: 476
Total area occupied by the grains: 0.791 µm² (79.1 %)
Density of grains: 476 grains / µm2.

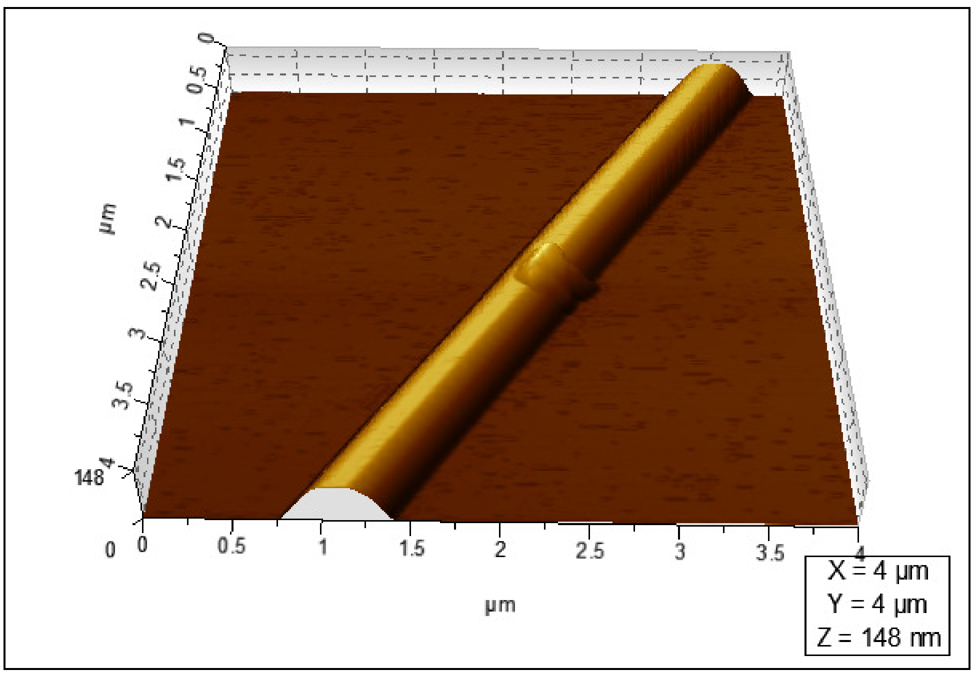
Area	=	1661 nm²	+/- 786 nm²
Perimeter	=	221 nm	+/- 64.9 nm
Form factor	=	0.440	+/- 0.127
Aspect ratio	=	3.47	+/- 3.57
Roundness	=	0.458	+/- 0.546
Compactness	=	0.648	+/- 0.193
Orientation	=	83.4°	+/- 50.2°

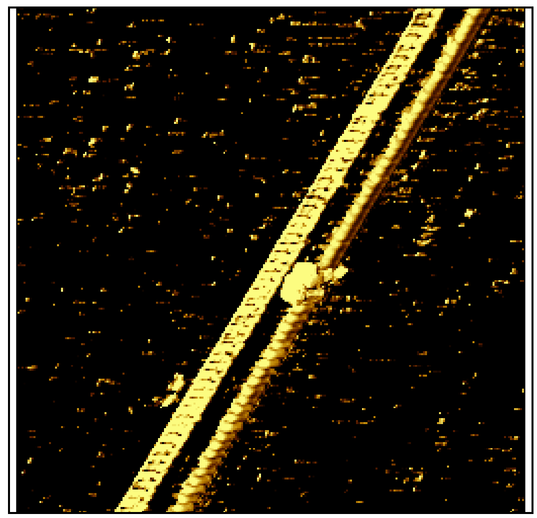
Nano wire sample 4x4 micron topography image



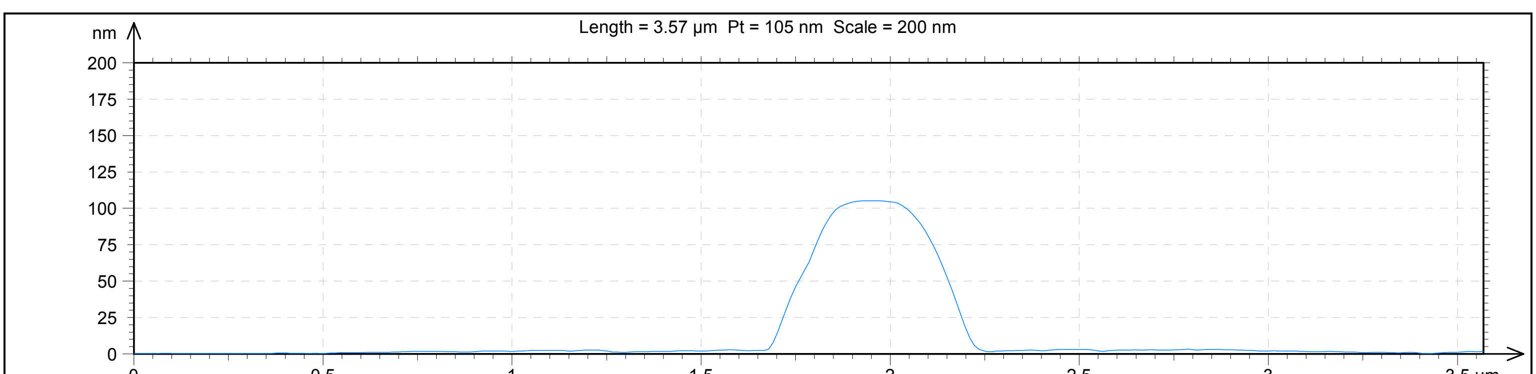


left: topography image 2D
up: amplitude image





left: topography image 3D
up: phase image
below: cursor profile across the image center



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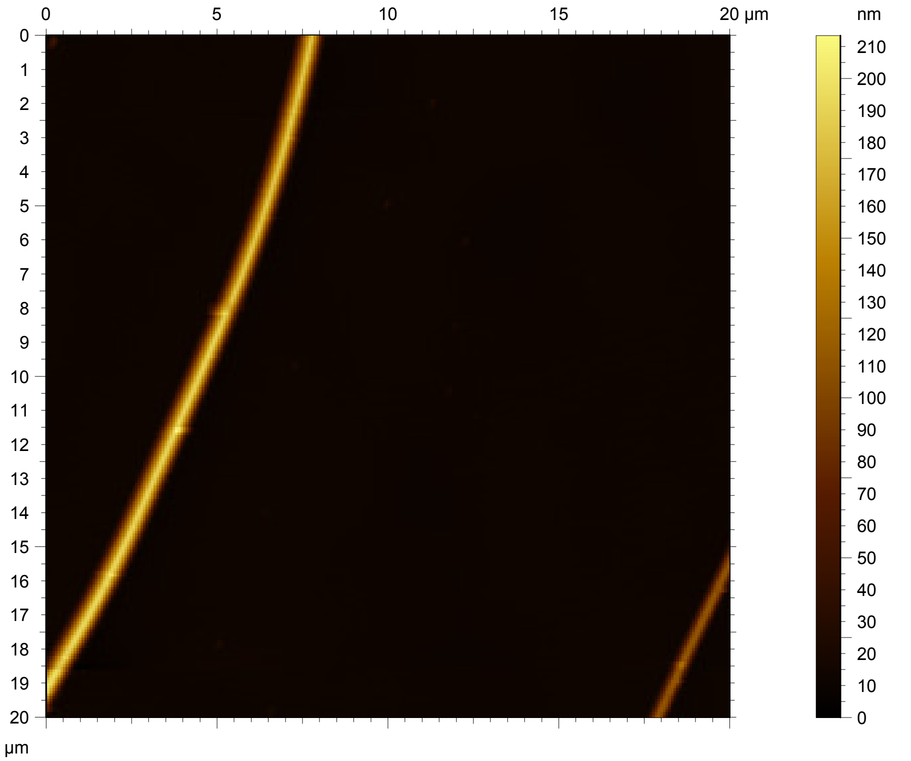
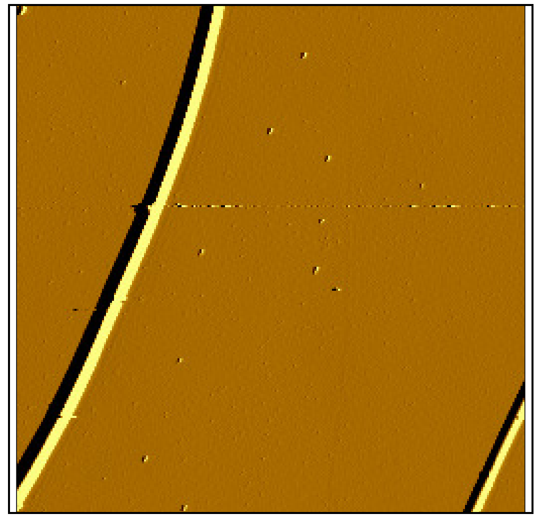
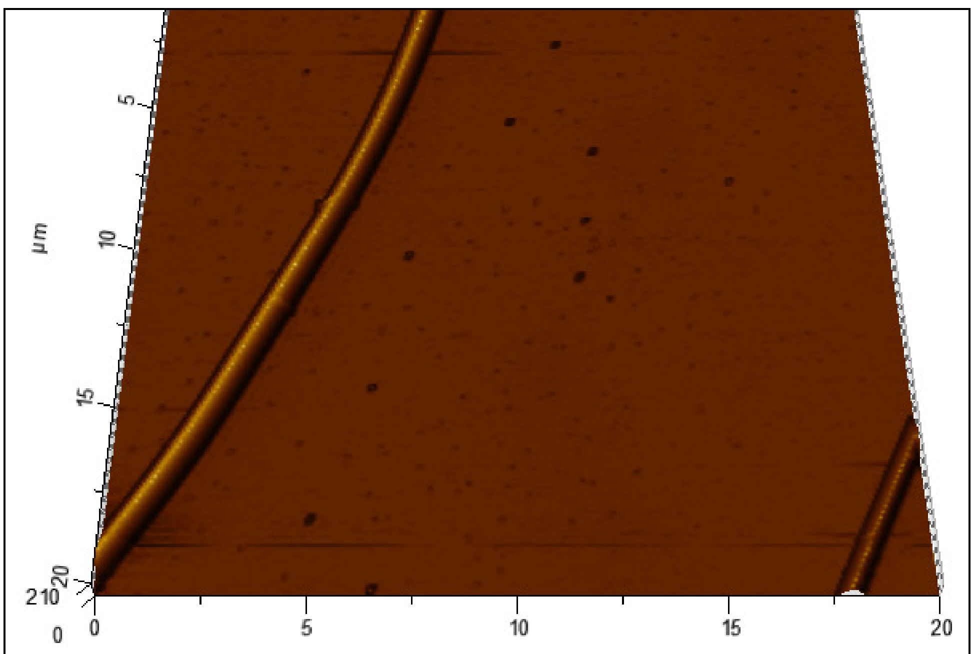
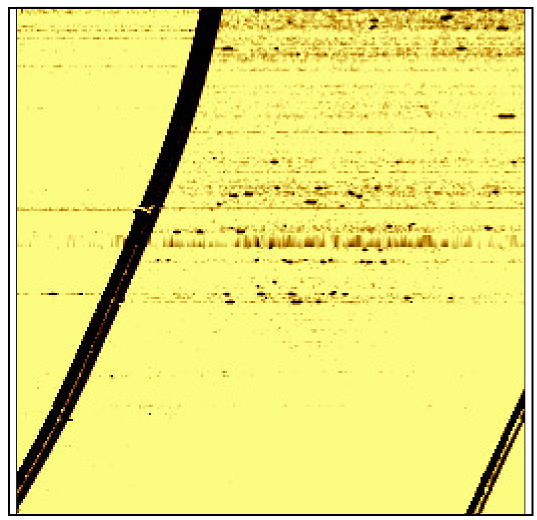
Nano wire sample 20 x 20 micron topography image



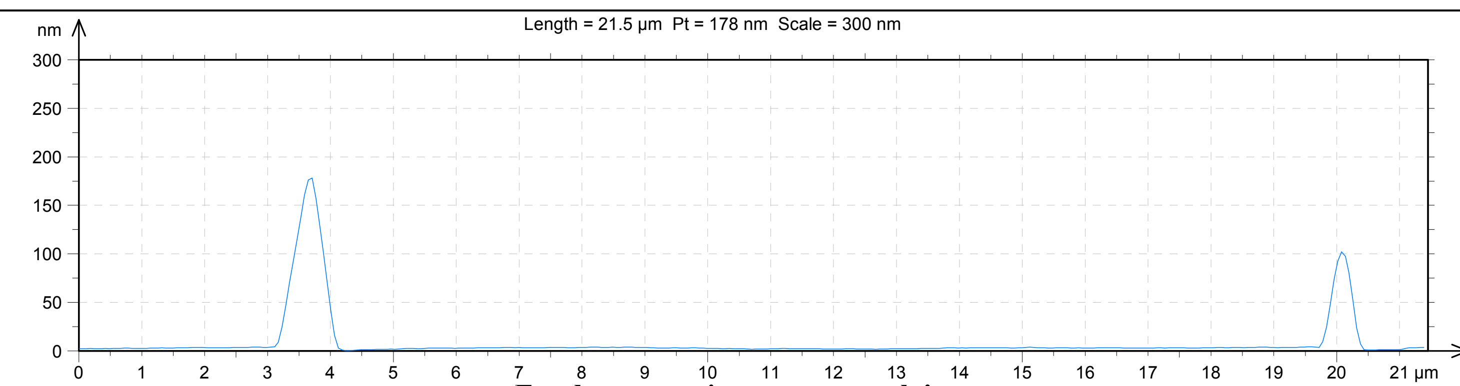


left: topography image 2D
up: amplitude image





left: topography image 3D
up: phase image
below: cursor profile across both nano wires



For demonstration purposes only!

Force indentation with atomic force microscope to measure sample stiffness

The following sample is studies with force indentation to measure the sample stiffness:

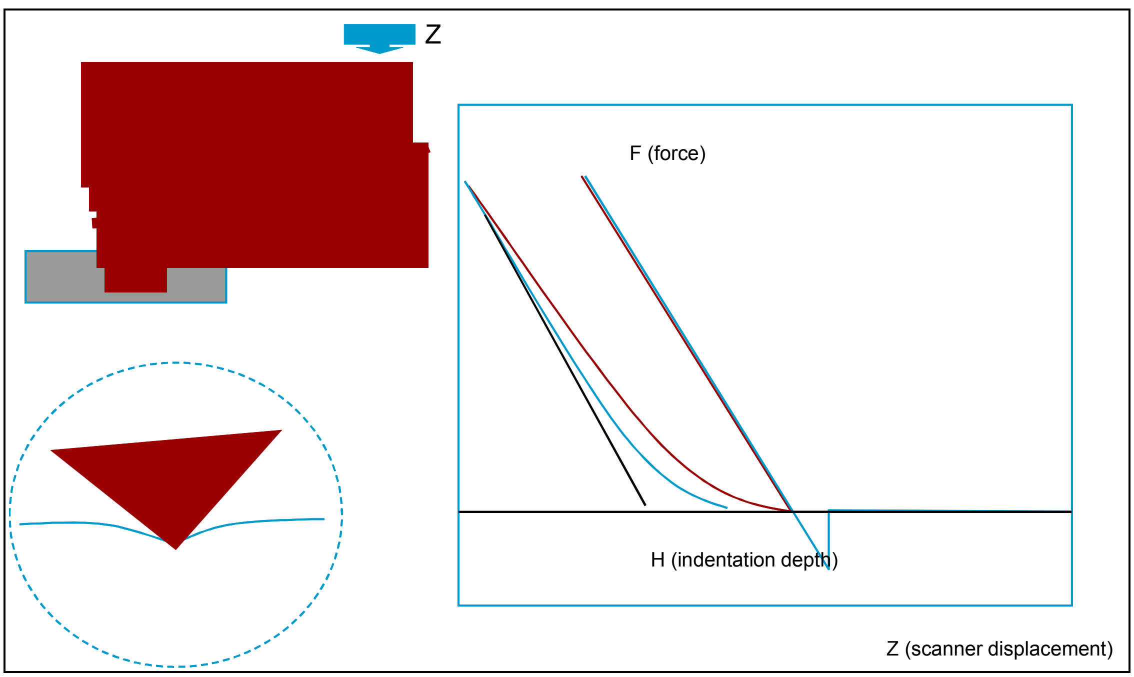
1. nanofibers

AFM force indentation:

Using force indentation mode, a stiff AFM probe is pushed into the sample with higher force to allow the apex of the tip to indent the sample. By analying the vertical load vs the depth of the penatration, the stiffness can be calculated.

A stiff AFM cantilever with not sharpened apex is ideal for accurate measurement of the sample stiffness. In such experiment, a 50 N/m, 350 KHz cantilever suite the dual purpose of indentation and AAC mode imaging. Ideally, a non-sharpened tip is suggested for better estimation of the tip shape, which is important in accurate calculation of the sample stiffness. However, the unsharpened the tip also would compromise the topographic resolution a little.

Mathenatical model used here to calculate the Youngs Modules is programmed into the "plug in" feature of the PicoView software. In order for accurate mearuement of the nanofiber stiffness, an "volume" indentation is carried to measure an matrix of points, Youngs Modules is automatically calculated with the "plug in", and displayed as an low pixel image. Youngs Modules of the nanofiber can be read out of pixel on top of the nanofiber.



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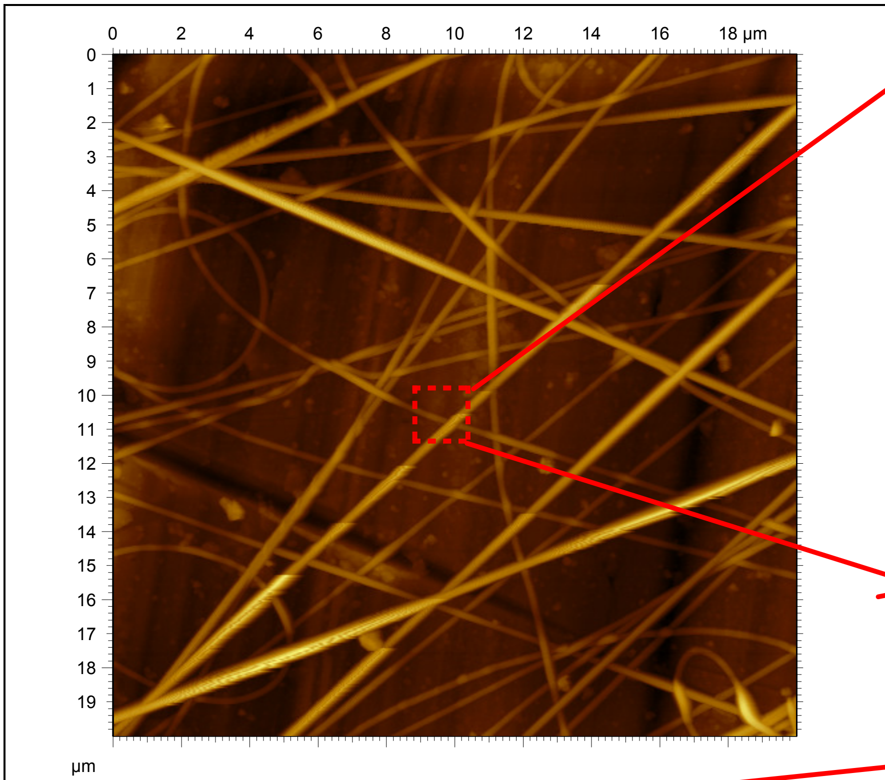
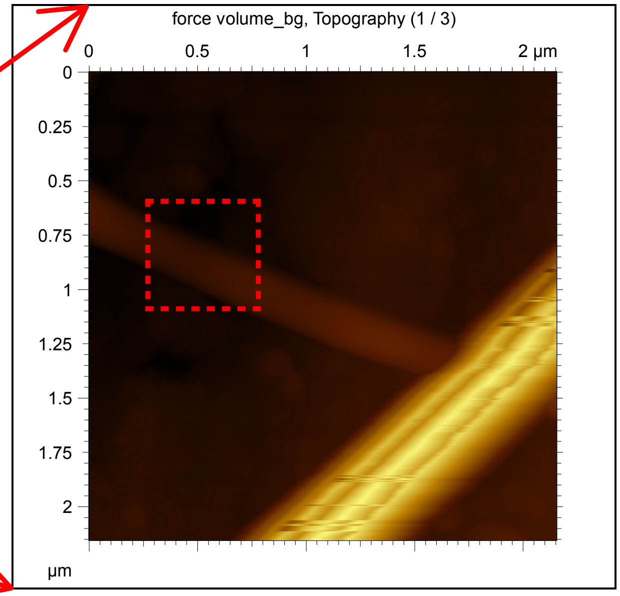
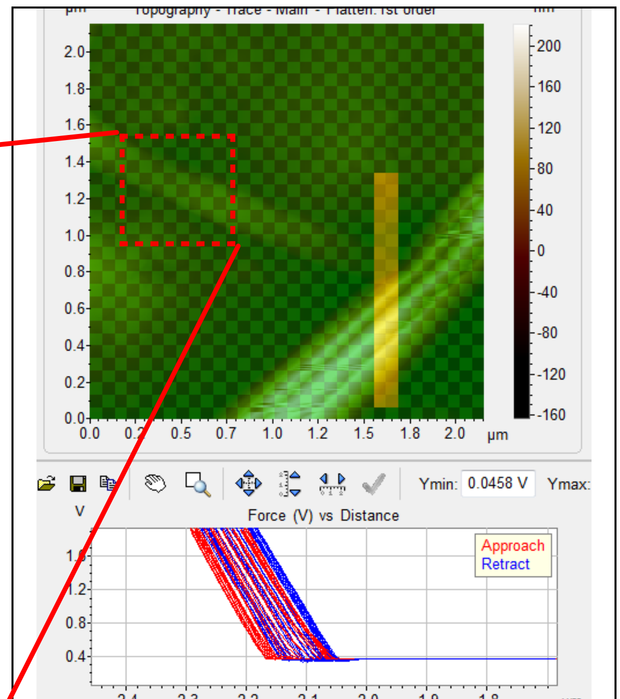
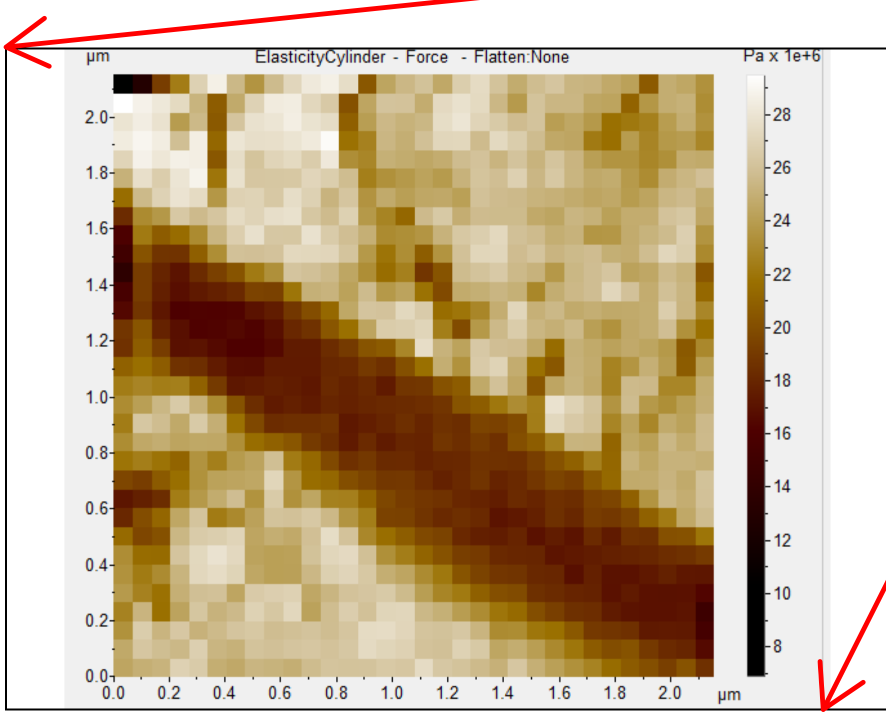
Force indentation analysis of nanofiber on aluminum foil









up & up left: A series of zoomed topography images are performed to focus the measurement area on top of one nanofiber.

left: An 32 x 32 array of indentation is performed and the Youngs Modulus are calculated on each measurement point. An stiffness map is generated. The nanofiber appear to have lower stiffness compare to the substrate aluminum.

Magnetic Forc Microscopy imaging of nanofiber containing magnetic nanoparticles, mixed with free magnetic nanoparticles

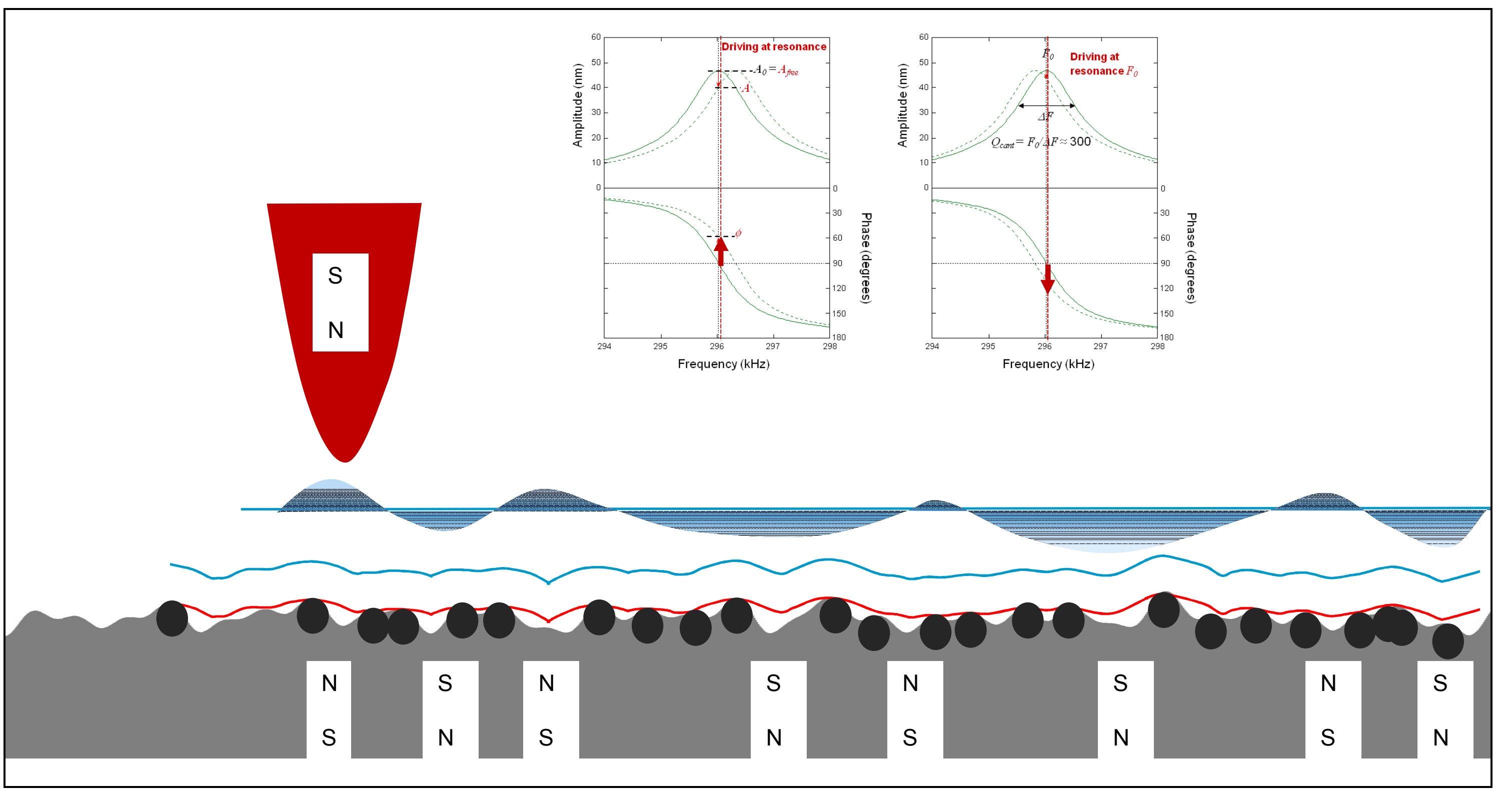
The following sample is studies with magnetic force microscopy (MFM):

1. magnetic nanoparticle contained inside nanofibers, mixed with free magnetic nanoparticles.

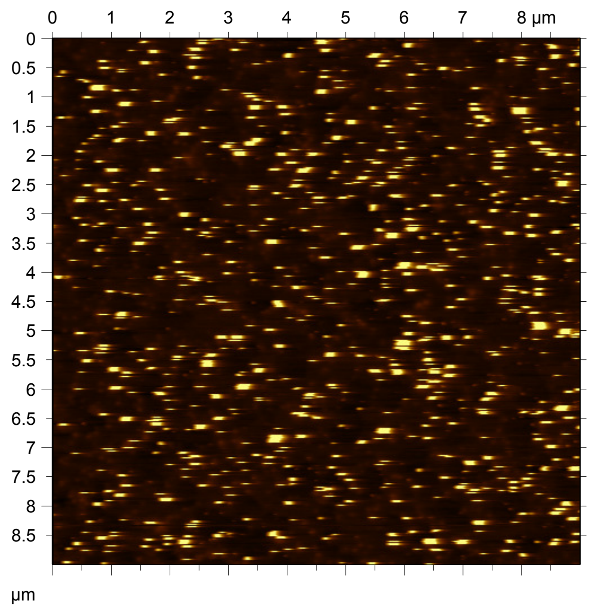
Magnetic Force Microscopy

Using a magnetically coated AFM probe, local magnetic field can be imaged. The AFM probe first scan the sample with regular AAC mode to obtain topography image, on second scan, the AFM probe is lifted 50 away from the surface, and hover over the sample surface without touching the sample, the magnetic field would shift the probe oscillation phase depends on the strength and direction of the field. Mapping out such phase shift would reveal the local magnetic field domains.

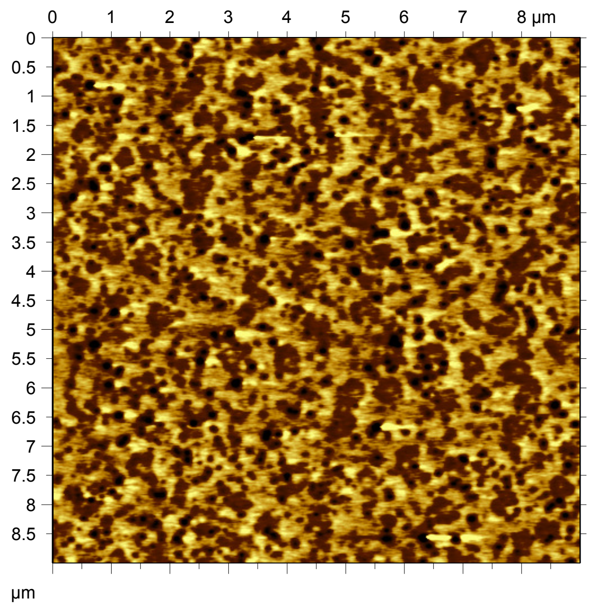
The magnetic nanoparticles and fiber do not generate strong enough magnetic field, therefore, a uniform magnetic field is placed beneath the sample. The existance of the magnetic nanoparticle cause the disturbance of magnetic field, which is imaged with this MFM image mode.



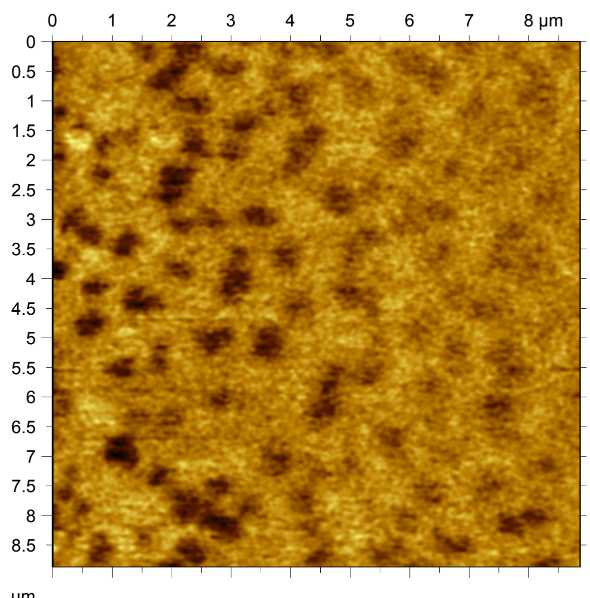
Magnetic Forc Microscopy imaging of nanofiber containing magnetic nanoparticles, mixed with free magnetic nanoparticles



Topography image with AAC mode



MFM image at a separation distance of 50nm



MFM image at a separation distance of 200nm

At bigger separation distance, the fine magnetic texture become uniform, therefore the MFM image shows much less contrasted

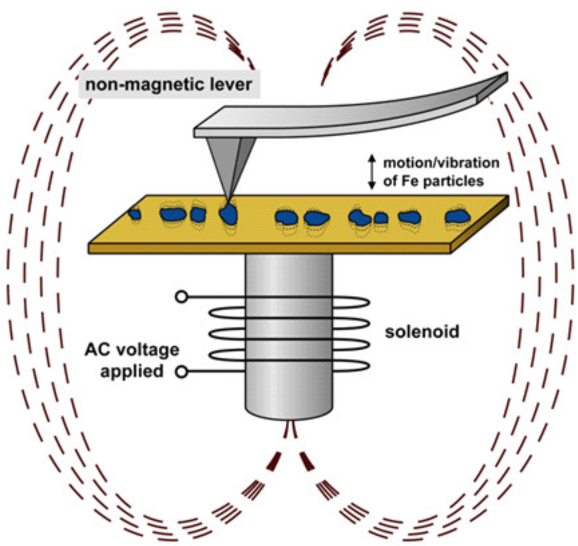
Magnetic Sample Modulation imaging of nanofiber containing magnetic nanoparticles, mixed with free magnetic nanoparticles

The following sample is studies with magnetic sample modulation (MSM):

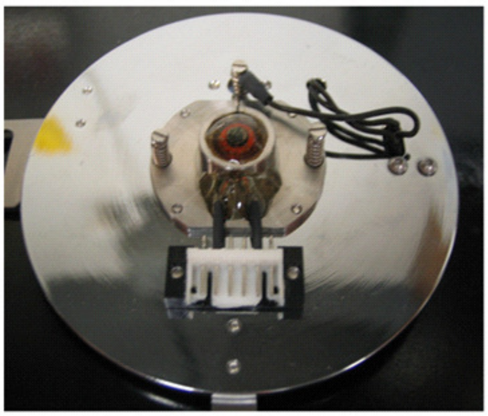
1. magnetic nanoparticle contained inside nanofibers, mixed with free magnetic nanoparticles.

Magnetic Sample Modulation (MSM)

To image magnetic nanoparticles, instead of applying a uniform constant magnetic field, we use an alternating magnetic field to modulate the sample. The particle and fiber would respond to the AC magnetic field, and oscillating within its mechanical confine. We then use a contact mode non-magnetic AFM probe to scan the sample, and the oscillating particle and fiber would push to vibrate the probe. Compare to the MFM, where the tip would scan the sample at an separated distance, therefore compromise spatial resolution, the MSM directly measure and image the magnetic response, instead of the magnetic field variations. MSM gives much higher resolution and reveal much more contrast when working with magnetic nano materials.



MAC sample plate



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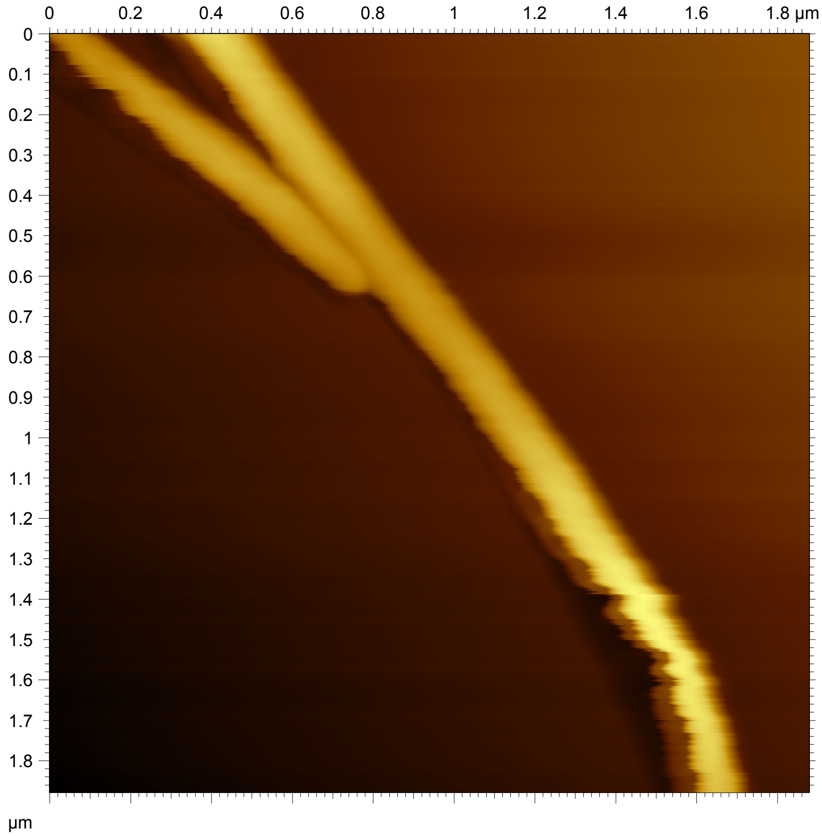
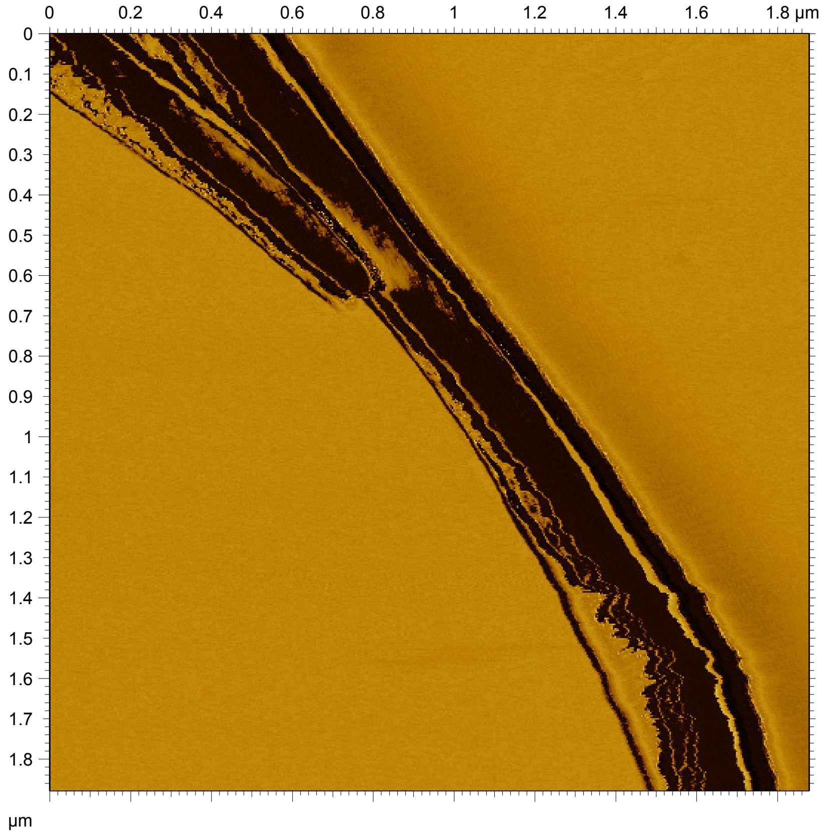
Magnetic Sample Modulation imaging of nanofiber containing magnetic nanoparticles, mixed with free magnetic nanoparticles



Topography image with contact mode



simultaneous MSM image. Since we use a lock-in amplifier to detect the sample oscillation, the MSM signal not only shows the amplitude of the sample particle and fiber modulation, it also gives phase information. Depends on the mechanical environment, the sample particle and fiber would have its own different natural resonance frequency, when driven at different frequency, which would result in difference in phase shift of the vibration. Here the darker color shows us that there is around 180 degree in phase shift in the sample vibration compare to the driving signal.

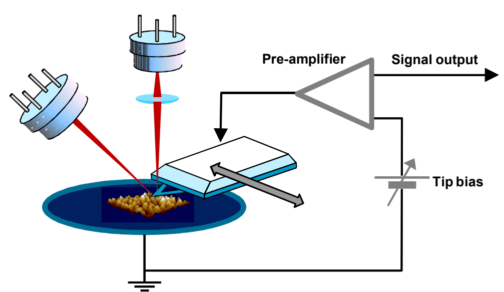
Kelvin Force Microscope imaging to study sample electrical property

The following sample is studies with Kelvin Force Microscopy:

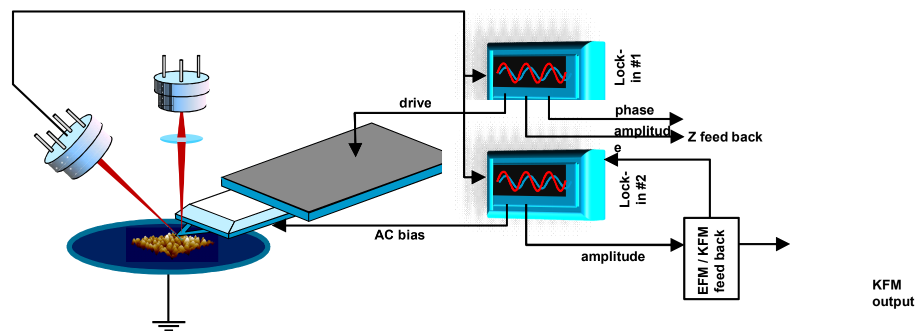
1. conductive nanowires

Kelvin Force Microscope:

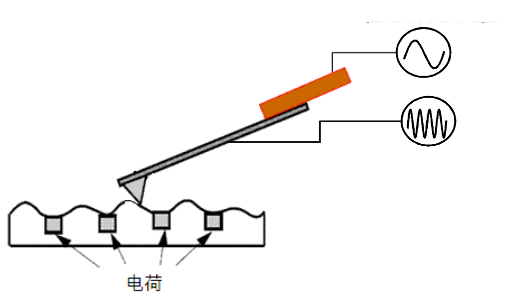
There are many techniques to measure electrical property. When a sample can be easily grounded, one could use contact mode conductive AFM to measure the conductivity. However, when one need to measure the electrical property of isolated nanowires, one need to choose an AC bias tip techniques. Here we present KFM imaging of electrical property of nanowire array.



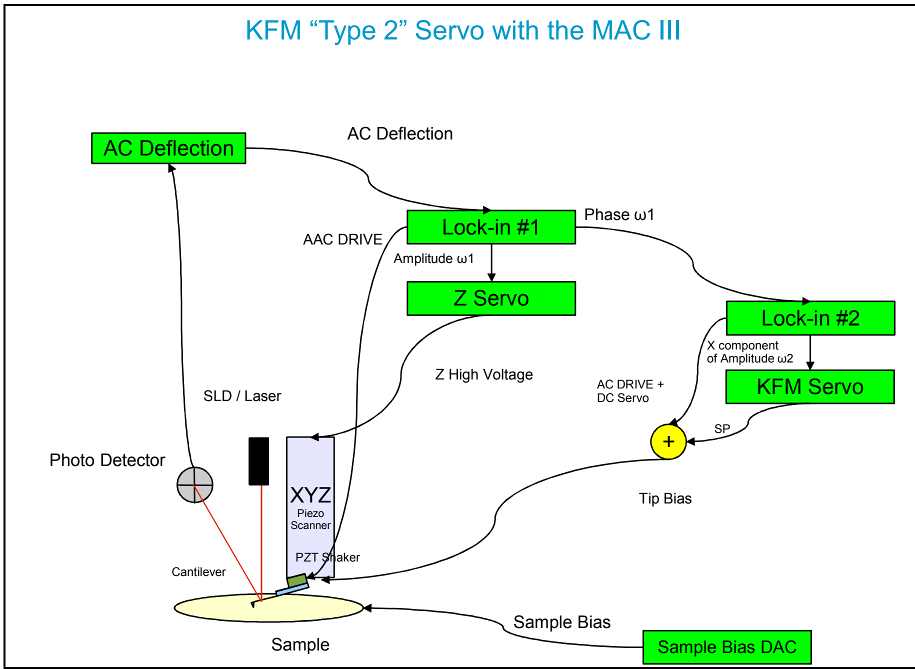
Current Sensing Imaging (CSAFM)



Electrical property imaging(EFM, KFM)



Schematic diagram of signal routing of single pass FM KFM with tripple lock-in atomic force microscope



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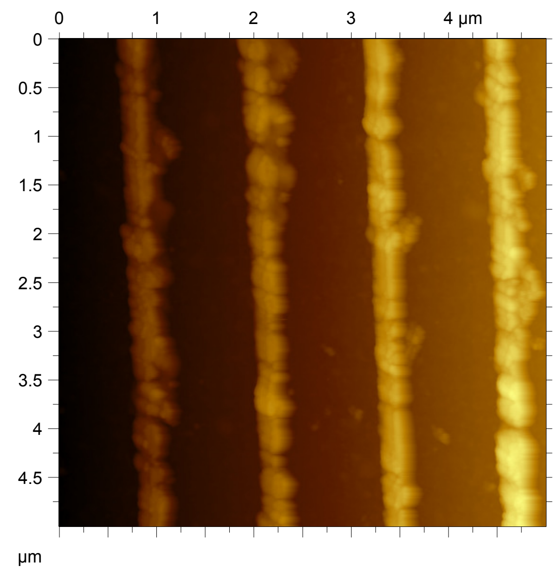
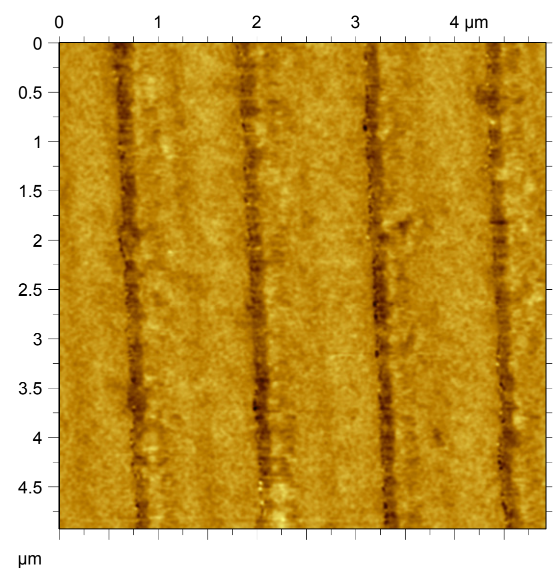
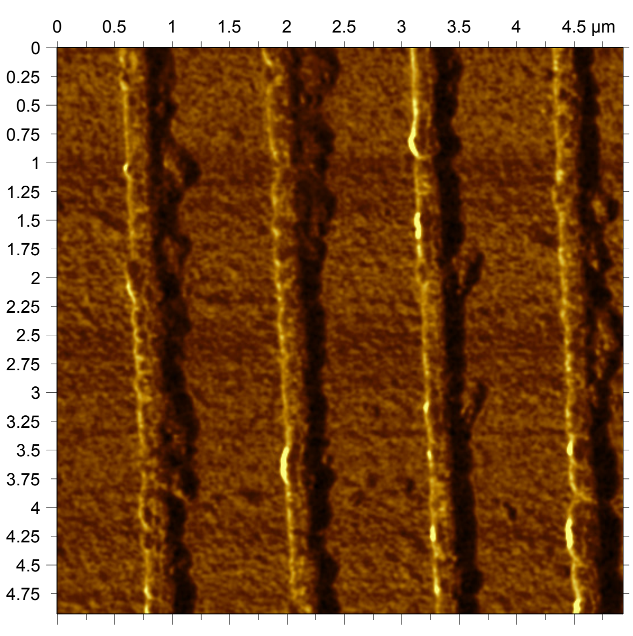
Kelvin Force Microscope imaging to study sample electrical property



Topography image with AAC mode



KFM surface potential image
sample potential difference contrast is the result of different material's contact potential



KFM capacitance gradient image
Material conductivity would result in different capacitance between the nanowire and the conductive AFM tip. Higher conductivity results in higher capacitance.

For demonstration purposes only!