Atomic Force Microscopy:

A Guide to Understanding and Using
the AFM

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Atomic Force Microscopy

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Note to Reader

The purpose of this paper is to provide the new user of the Atomic Force Microscope (AFM) with a more concise version of the manual in order to start utilizing the AFM. I will go into a little bit of the theory of why it works but this is mainly something to get you started. It is always necessary to continue your knowledge of this machine and try to explore using different aspects of the software.

Introduction

The Atomic Force Microscope is an instrument that can analyze and characterize samples at the microscope level. This means we can look at surface characteristics with very accurate resolution ranging from 100 µm to less than 1µm.

The AFM operates by allowing an extremely fine sharp tip to either come in contact or in very close proximity to the sample that is being imaged. This tip is usually a couple of microns long and often less than 100Å in diameter. The tip is located at the free end of a cantilever that is 100 to 200µm long. The sample is then scanned beneath the tip. Different Forces either attract or repeal the tip. These deflections are recorded and processed using imaging software; the resulting image is a topographical representation of the sample that was just imaged. If you want to know about the sample rather than just a view of its surface, there are different imaging modes that are used for different types of analysis. Either different hardware or scanning techniques are required to obtain the data necessary for the analysis. The AFM can measure a number of characteristic properties of the sample that other forms of microscopy cannot reproduce.

Brief History and Comparison

In 1986, the Atomic Force Microscope was invented by Gerd Binning to overcome a limitation of the AFM’s predecessor, the Scanning Tunneling Microscope. The STM could only image materials that could conduct a tunneling current. The AFM opened the door to imaging other materials, such as polymers and biological samples that do not conduct a current. In some cases, the resolution of STM is better than AFM because of the exponential dependence of the tunneling current on distance. The force-distance dependence in AFM is much more complex when characteristics such as tip shape and contact force are considered. The AFM wins in terms of versatility easily. In comparison, with other forms of microscopy the AFM is better or comparable.

- AFM versus SEM:

  Compared with Scanning Electron Microscope, AFM provides extraordinary topographic contrast direct height measurements and unobstructed views of surface features (no coating is necessary).

- AFM versus TEM:

  Compared with Transmission Electron Microscopes, three-dimensional AFM images are obtained without expensive sample preparation and yield far more complete information than the two-dimensional profiles available from cross-sectioned samples.

- 4. AFM versus Optical Microscope:

  Compared with Optical Interferometric Microscope (optical profiles), the AFM provides unambiguous measurement of step heights, independent of reflectivity differences between materials.

Interactive Forces

The main difference between these types of microscopy and the AFM is, as the name suggests, interactive forces between the sample and the tip. The force most commonly associated with atomic force microscopy is an interatomic force called the van der Waals force. The relation between this force and distance is shown in Fig. 1.

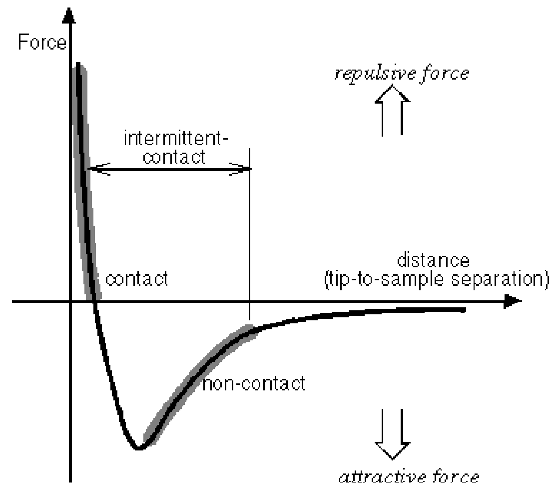


Figure 1: van de Waals force vs. distance

In the contact region, the cantilever is held less than a few angstroms (10^{-10}m) from the sample surface, and the interatomic force between the cantilever and the sample is repulsive. In the non-contact region, the cantilever is held on the order of tens to hundreds of angstroms from the sample surface, and the interatomic force between the cantilever and sample is attractive. Different scanning modes operate in different regions of this curve: Non–contact in the attractive region, contact mode in the repulsive and intermittent or tapping mode fluctuates between the two.

It is easier to understand this curve if you think of the point of the tip like a group of atoms interacting with the surface which essentially another group of atoms.

At the right side of the curve, the atoms are separated by a large distance. As the atoms are gradually brought together, they first weakly attract each other. This attraction increases until the atoms are so close together that their electron clouds begin to repel each other electrostatically. This electrostatic repulsion progressively weakens the attractive force as the distance continues to decrease. Following the graph, the force goes to zero when the distance reaches a couple of angstroms. Anything closer than this, the total van der Waals force becomes positive (repulsive). This distance will not change, therefore any more attempt to force the sample and tip closer will result in deformation or damage to the sample or the tip.

There are two other forces that arise during the scan: a capillary force that is caused by a build-up of water, which is normally present without an inert environment, on the tip; the force caused by the cantilever itself, which is like a force caused by a compressed spring.

Characterization at the microscopic level

Even though, the process of the scanning is straightforward and can be done at times with your total attention, not all images are accurate representations of the actual topography of the sample. There are parameters that can be changed in each scan and other forces outside the interatomic forces that can alter the image or the sample. For example, Fig. 2 is a 5-micron scan of Copper that has been treated with Tetrahydrofuran. The two lines of raised peaks are not actual features on the sample but points during the scan when the sample was inadvertently disturbed. A discussion of what is a good image versus a bad one is located at the end of this paper.

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Figure 2: 5 micron Cu scan containing two lines of noise

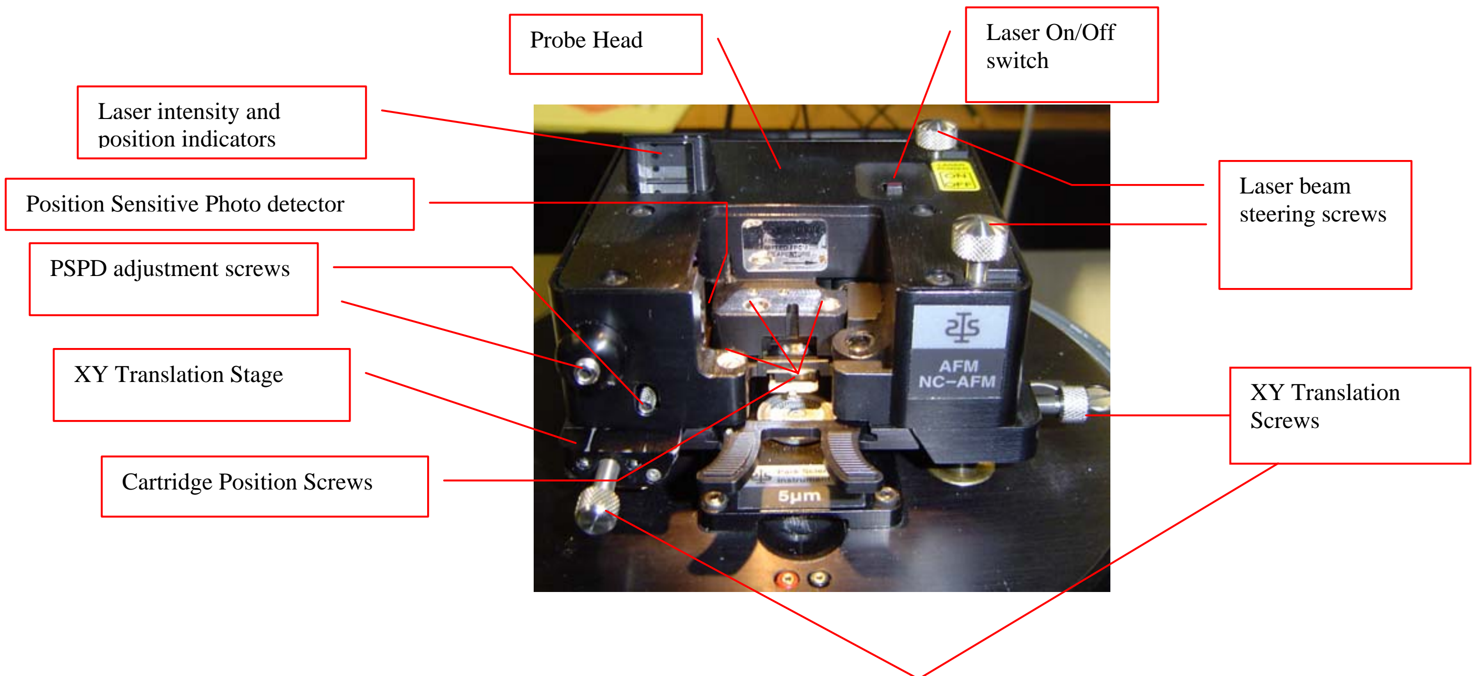
ProScan Image Processing software provided with the AFM is used to process and analyze the image, which can make it easier to recognize an image that is a misrepresentation. Processing allows for modification of the image in order to remove artifacts without modifying the surface features. In Analysis, quantitative measurements can be taken of individual cross sections or surface regions. Surface statistics such as distance measurements, peak-to-valley measurements and surface roughness are a few commonly acquired measurements.

Getting Started Step-by-Step

Now we will begin a discussion of the process of how to take an image. We will start by giving an overview of the components of the AFM, the options on the probe head move mode screen and options on the image screen.

AFM components

Probe Head



Probe Head: Interchangeable head slips into place on the XY translation; different heads have certain scan mode capabilities, houses laser and photodiode

XY Translation Stage: Holds probe head, movable in XY direction by XY translation screws and in Z direction by controls in software

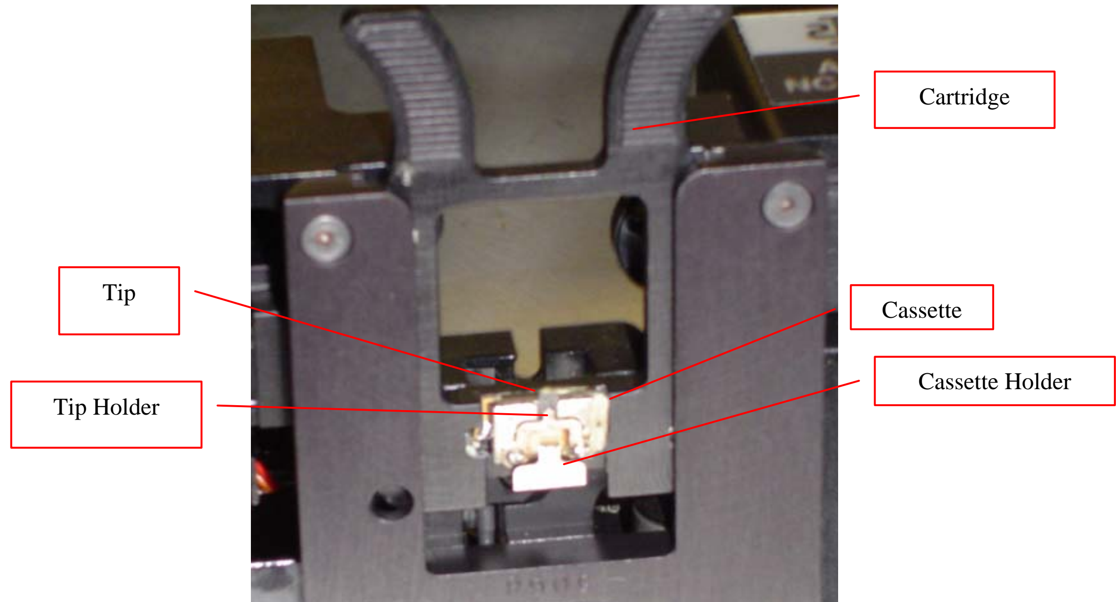
Position Sensitive Photo detector (PSPD): Detects laser deflections, which is then converted into a topographical map

PSPD adjustment screws: controls position of PSPD; screw on left controls up and down adjustment; screw on right controls left right adjustment

Laser Beam Steering Screws: controls position of laser on back of cantilever

Laser Intensity and Position Indicators: Lights represent laser position and intensity on photo detector

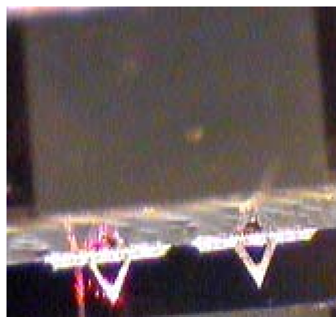
Cartridge



Cartridge: removable part of probe head that holds the cassette which in turn holds the tip.

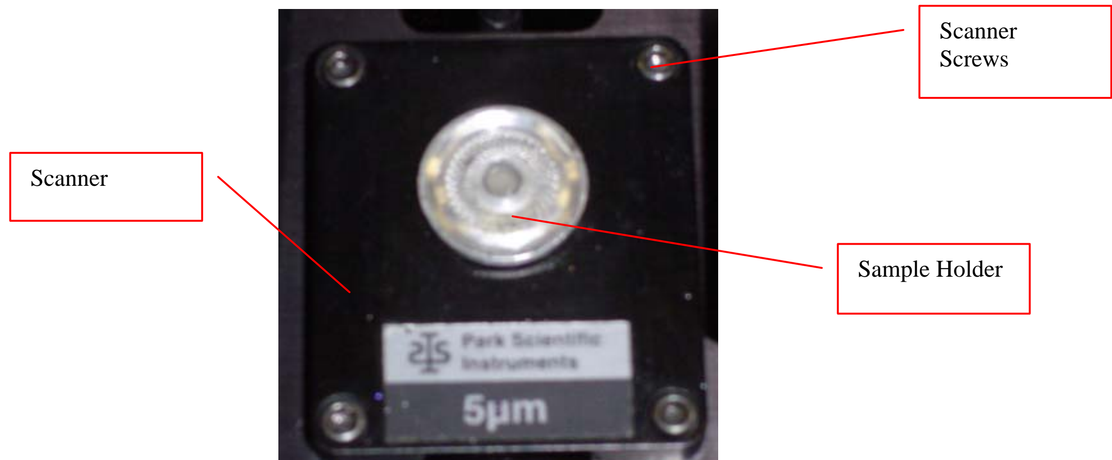
Cassette: removable from cartridge and is held in position be holder and three balls which fit into slots in cassette

Tip: actually cantilever chip, which contains the probe tips



View from optical microscope of cantilevers

Scanner



Scanner: component that moves sample under tip during scan. Voltage applied to piezoelectric scanner tube housed inside moves sample precise increments back and forth. Size at bottom indicates maximum size scan possible. ***Extremely fragile handle with care***

Scanner screws: unscrewing these four screws allows for removal and installation

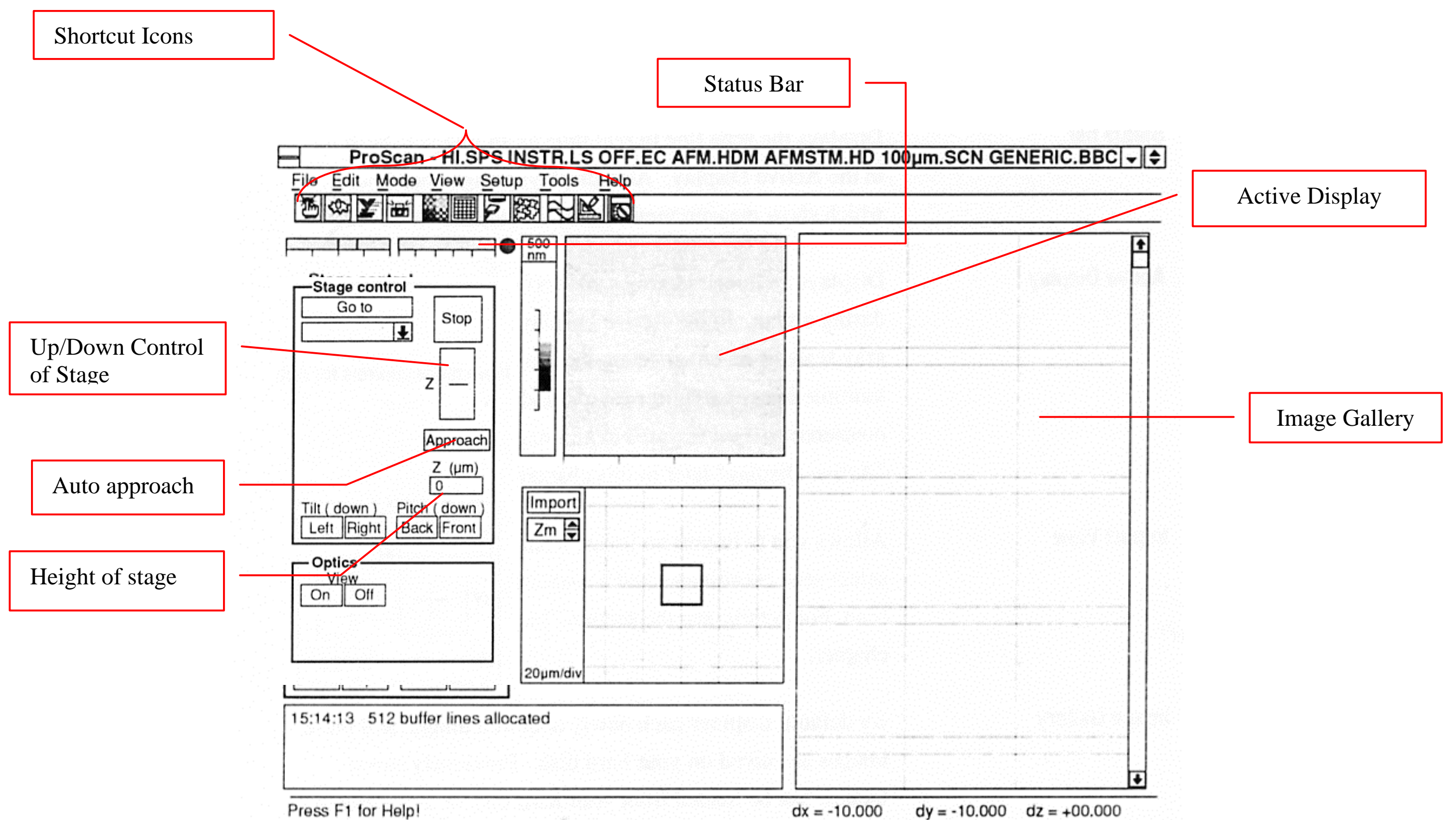
Sample Holder: holds sample and piezoelectric scanner tube directly underneath

Proscan Data Acquisition and Image Processing Software

Once again, this is just an overview of the essentials that are needed for basic AFM operation. After basic knowledge and familiarity with the instrument has been gained then a more in depth understanding and knowledge of different capabilities can be acquired by reading the manuals.

Proscan Data Acquisition controls the AFM and collects the data then converts it to an image. It operates primarily in two modes: Move Mode and Image Mode. Each screen has certain controls for the imaging processes but contain some of the same displays.

Data Acquisition Screen in Move Mode



When opening the Proscan Data Acquisition software, the opening screen is the move mode screen. The stage can be controlled

Oscilloscope

ProScan - HI.SPS INSTR.LS OFF.EC AFM.HDM STM.HD 100µm.SCN GENERIC.BBC

File Edit Mode View Setup Tools Help

2 µm

AC 2 µm

500 nm

H F Topography A

Slope

Repeat

X ↔ Y

Image

Size (µ) X offset (µ) Y offset (µ)

Scan rate Set point Servo gain

Z servo

Smpl bias

Import

Zm

20µm/div

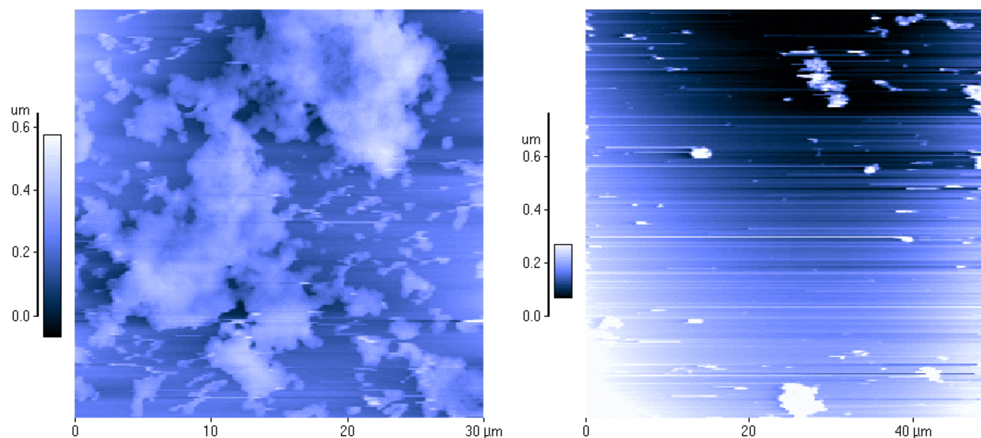
15:14:13 512 buffer lines allocated

Image Analysis

Now we will discuss the difference between a good image vs. a bad one. When I say good image I do not only mean image quality but being able to recognize features which are really present and some which are artifacts of the scan.

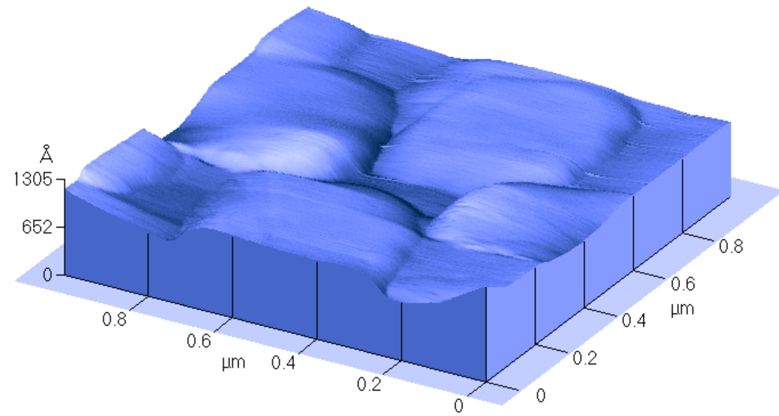
Bad Images

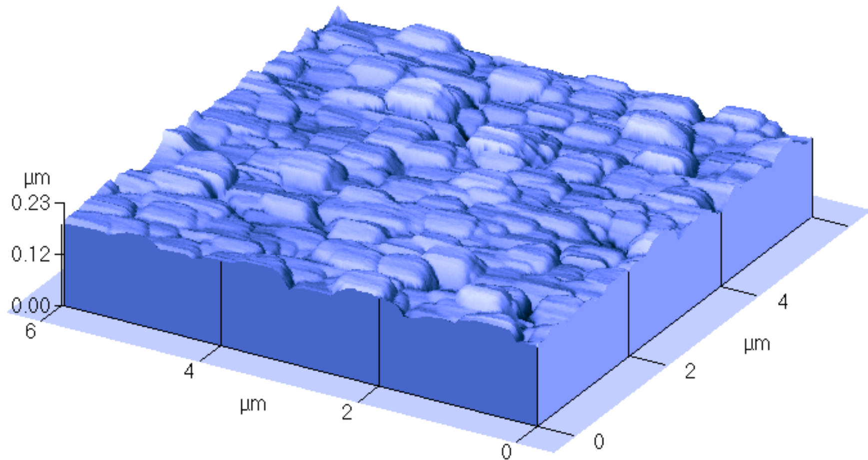
Bad images likes those which have poor resolution or which contain unreadable features are not preferrable but can still tell us something about our sample. For instance, say the group is producing sample which contain some sort of chemical on the surface. If the images show lots of particles on the surface or irregular formations, then it can be assumed that the process being used to manufacture these samples is not viable. These images are two examples of manufacturing problems detected by the AFM. The image on the left shows coagulations of what is supposed to be a thin film on the surface. The right hand image shows how dirt on the sample ruins the scan as well, in this case it is not known wither the dirt came from the manufacturing process or the imaging process.

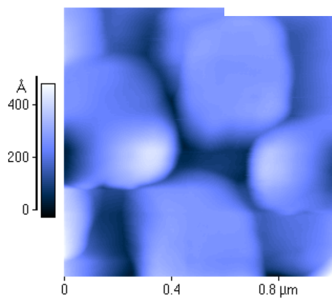


With bad images, a lot of parameters can affect the quality of suitable sample images. These changes will result in bad images that would have been fine if not for these changes in parameters. One such example is deformation or dullness of tip. The AFM assumes that the tip

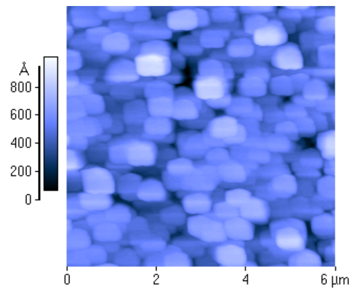
used for every scan is sharp and intact. These next two images are scan of Tungsten taken with a tip that was either worn down by use or may have been broken during the change of samples.





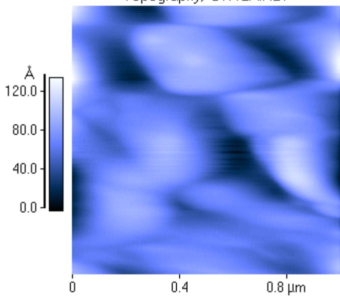


Topography, SW1LR.HDF

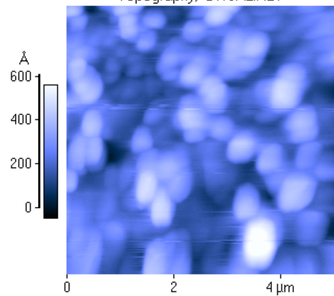


Topography, SW6RL.HDF

To the left are the 2-deminsional images of the same sample. At first glance there is no sign that these scans are bad images. It was only seen through the 3-D representation and questioning the truth of the



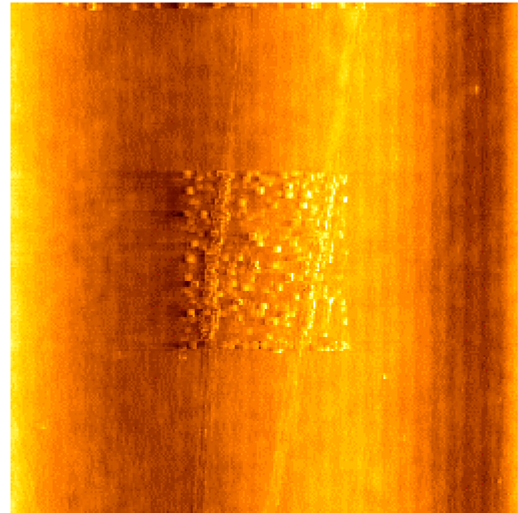
Topography, SS1LR.HDF

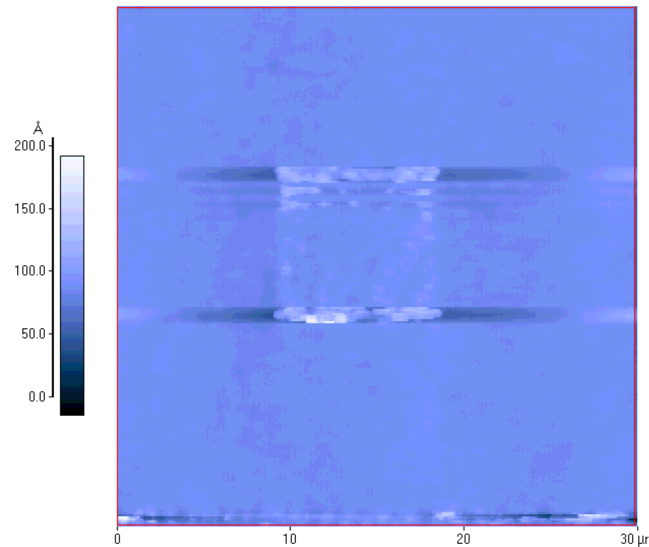


Topography, SS5LR.HDF

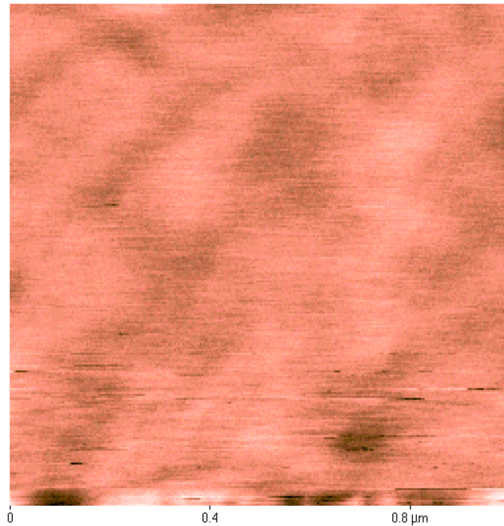
scan. A new operator will probably not be able to pinpoint these bad images. Unfamiliarity with how different materials look does not allow it, but with experience it should be possible.

Other parameters that could be changed that affect the scan are the options in the Pro Scan Data Acquisition Image Mode Screen. The options like Set Point and Scan Speed can not only affect the image but can harm the sample. The gain however only will affect the image. Changing the set point effects the force that is the tip senses between it and the sample. If the Set Pont is too low then the scan will not scan because the force is not strong enough between the sample and the tip to cause deflections of the cantilever. If the Set Point is too high then the tip can actually deform the sample or itself. Unless it's a really hard material the sample will deform. The images to the right shows the deformation of the sample by a high Set Point.





There are other outside factors that cause bad images that at times cannot be controlled. Ambient noise both acoustic and electric can affect the scan .   Noise can be pinpointed as reason for bad images when the rest of the scan is fine but there are random placed peaks or lines of peaks on one scan but not he other.



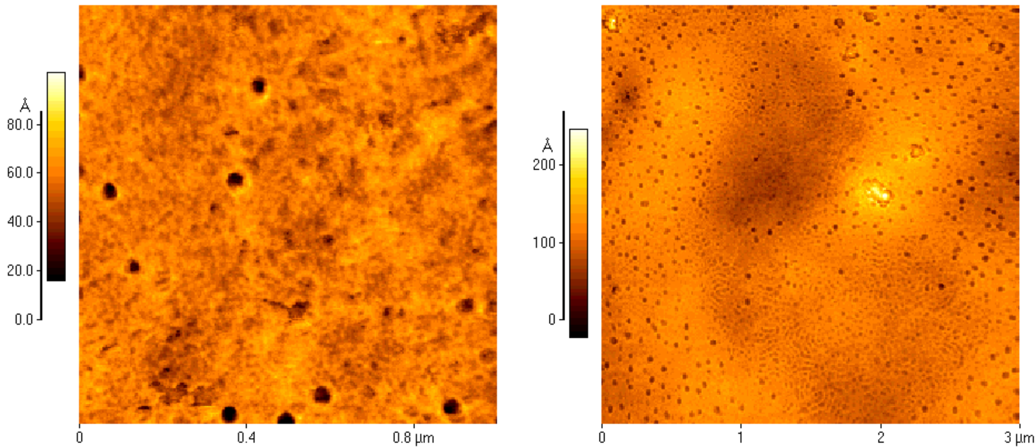
The image above shows how the entire image how noise can affect the end of a graph. This could have been caused by a constant noise that lasted a couple of seconds.

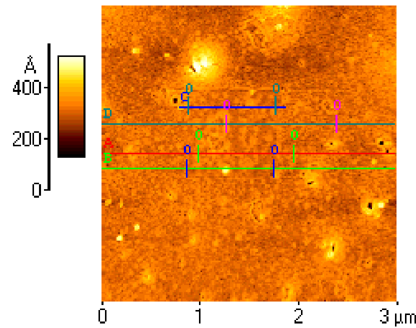
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

The image above shows lines of noise that are very unlike the rest of the scan. These were caused by sharp noises rather than a long standing noise.

Good Images

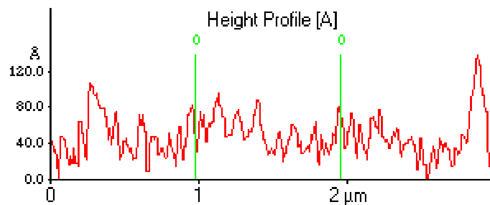
Good images are those that display clear definition and sharp characteristics that can be analyzed. The images may show what you are expecting but it may not this does not govern if it is a good image or not. The following images are show definite features which could then be analyzed.

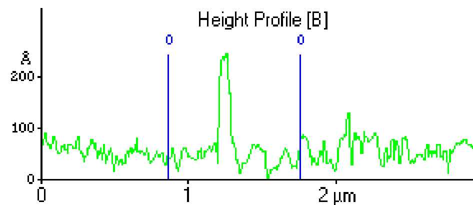


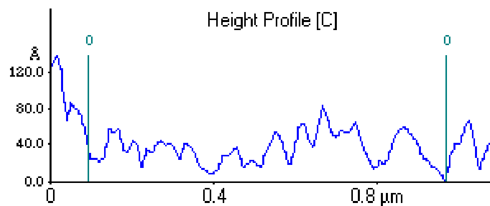


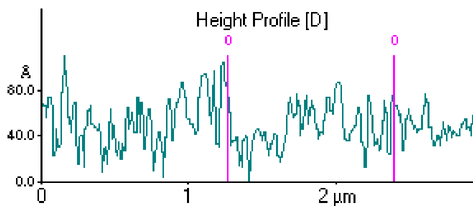
Line Profile Measurements

Topography, 0206S004.hdf



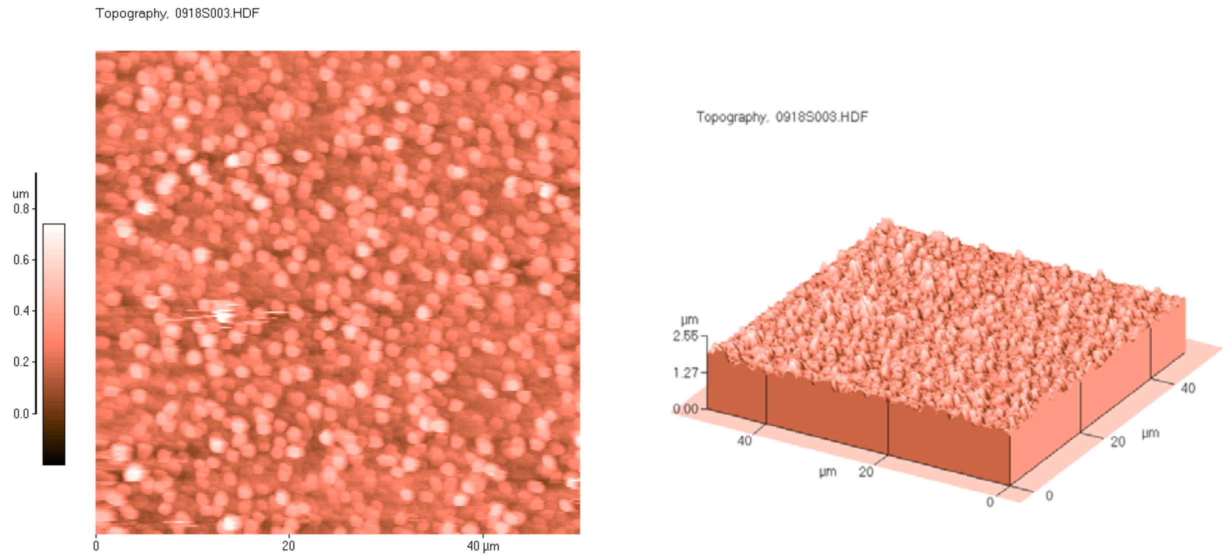




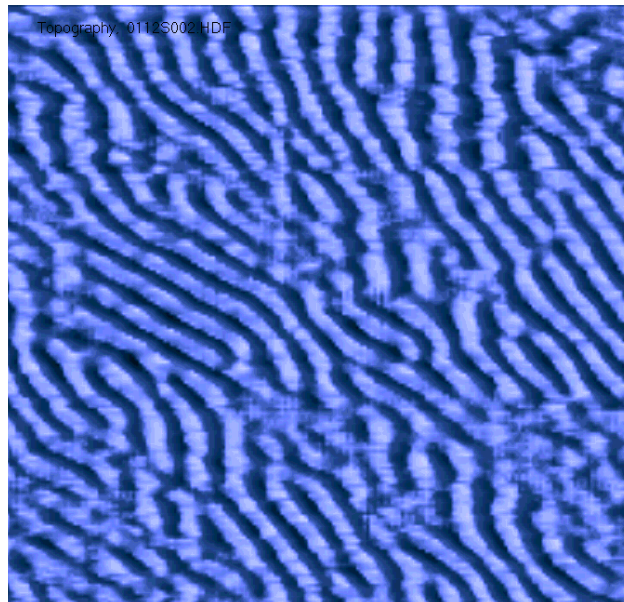


Line	Height	Distance	Rms	Ave	Mean Ht	2-line measurements
[A]	0: 31.7 Å	0: 0.988 um	23.4 Å	18.1 Å	320 Å	
[B]	0: 46.0 Å	0: 0.894 um	33.3 Å	20.1 Å	320 Å	
[C]	0: 19.8 Å	0: 0.894 um	23.3 Å	17.1 Å	320 Å	

The following scans represent images that displayed what we wanted them to show.

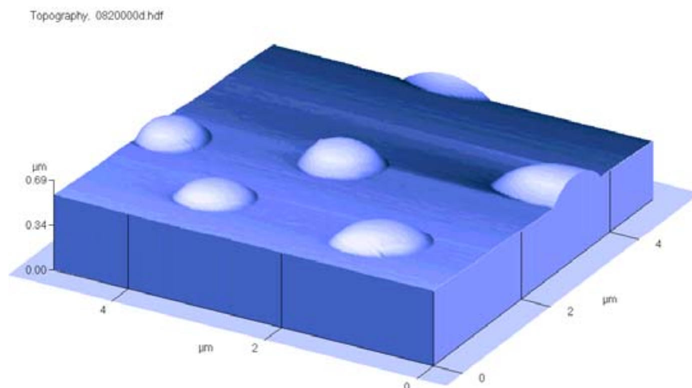


The two images above are of Teravicta RF Switches.

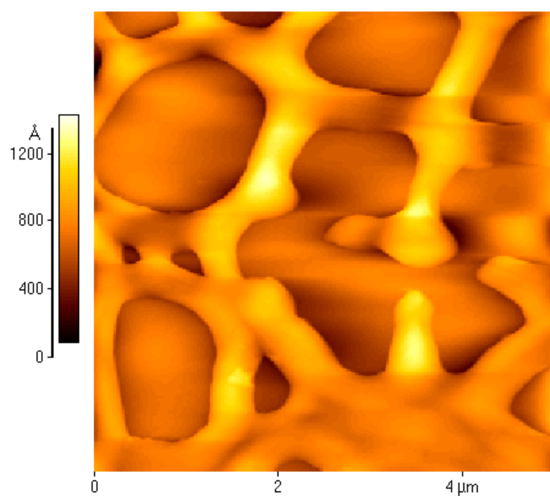


The images above is of a Diblock Copolymer sample.

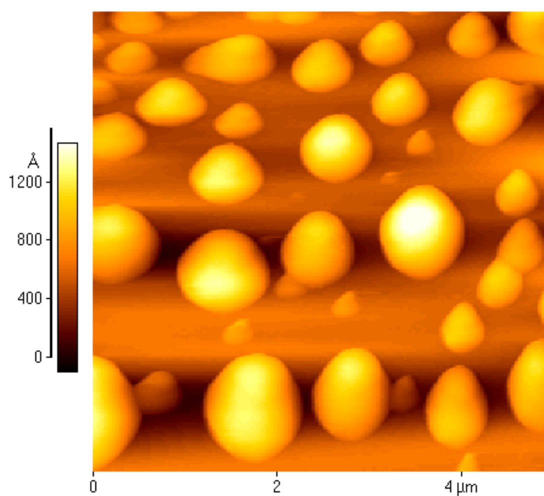
The following images show features that were not expected and help the research group decide in which direction to continue.



Multi Image Presentation



Topography, 1118S000.HDF



Topography, 1117S00C.HDF

Images of Diblock Copolymers.