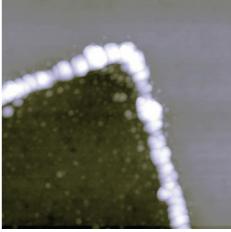
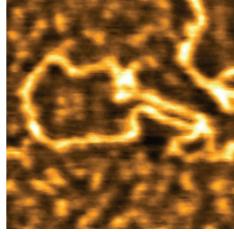
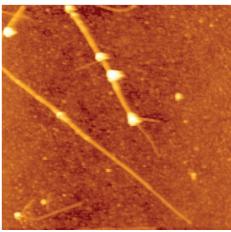
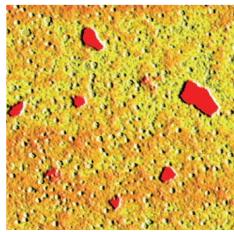
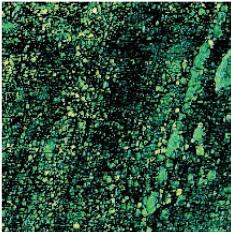
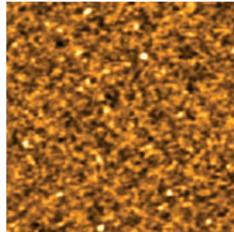
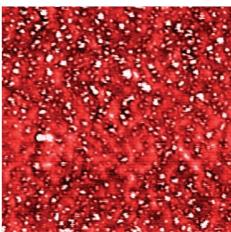
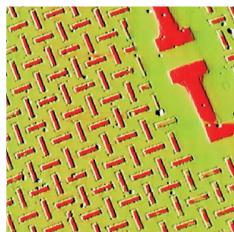
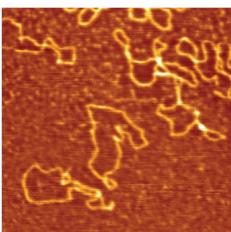
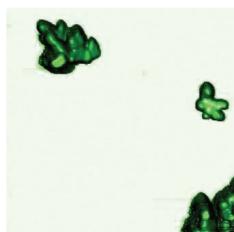


PACIFIC NANOTECHNOLOGY
advancing nanotechnology

Nano-DST™ AFM User Manual



Innovative

Easy To Use

Productive

PACIFIC NANOTECHNOLOGY PRODUCT WARRANTY

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- 4) Products not operated within the acceptable parameters noted per Pacific Nanotechnology installation instructions.
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SAFETY STATEMENTS

LASER OPERATION: AFM SCANNING HEAD LASER

WARNING: NEVER LOOK DIRECTLY INTO THE LASER BEAM



In order to avoid the possibility of the user inadvertently looking into the laser, always use the software or hardware to switch the laser off before raising the head to eye level.

The diode laser in the Nano-DST™ scanning head is certified as a Class 3R laser with a wavelength of 670nm and the maximum power is 3mW. It complies with US 21 CFR 1040.10 and 1040 except for deviations pursuant to Laser Notice No. 50, dated June 24, 2007.

In addition to the above, please follow laser safety control measures in American National Standards Institute Z136.1-1986.

WARNING: OPERATING THE SYSTEM IN A HIGH HUMIDITY ENVIRONMENT MAY CAUSE FAILURES.

HIGH VOLTAGE

Wherever high voltage is present on the system, extreme care should always be taken to avoid direct contact while the instrument hardware is powered on. Always power off the equipment before attempting to remove any panels or PC boards and before touching any connectors by hand or with electrically conductive tools.

WARNING OF MISUSE

If the unit is used in other ways than directed by Pacific Nanotechnology, Inc., the warranty will be void.

UNIT CARRYING INSTRUCTIONS

The unit weight is greater than 18Kg (39.68 lb). At least two persons are needed to lift, carry, or move it.

PACIFIC NANOTECHNOLOGY, INC. 2004
 3350 SCOTT BLVD., BUILDING #29 • SANTA CLARA, CALIFORNIA 95054
 PHONE: (408) 982-9492 • FAX: (408) 982-9151

DECLARATION OF CONFORMITY

We,
Pacific Nanotechnology,
3350 Scott Boulevard, Suite # 29
Santa Clara, CA 95054, USA

hereby declare that under our sole responsibility the products:

Atomic Force Microscope
Models: DST AFM, Nano-Im 6 X 6, Nano-Im 8 X 8, Nano-Im 12 X 12 and Nano-R3

Are in conformity with the provisions of the following EU Directives,
including all amendments, and national legislation implementing these directives:

73/23/EEC
89/336/EEC
93/68/EEC

by Applying the following standards:

EN61010-1: 2001
EN60825-1: 1994+A1+A2
EN61326-1: 1997+A1:1998+A2:2001+A3: 2003
EN55011, Class A, EN61000-4-2, EN61000-4-3, EN61000-4-4
EN61000-4-5, EN61000-4-6, EN61000-4-11

Santa Clara, CA
January 1, 2008

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Preface

INTRODUCTION

The Nano-DST™ AFM is an easy-to-use, high-performance atomic force microscope (AFM). While the Nano-DST™ can be operated with little or no understanding of the components of an AFM, Pacific Nanotechnology recommends that those who are new to AFMs first take the time to read the AFM Tutorial on page xiv. Some understanding of the components and theory of an AFM system will greatly facilitate your ability to get optimal results from the Nano-DST™ AFM.

AFM HISTORY

When we think of microscopes, we typically think of optical or electron microscopes. Such microscopes create a magnified image of an object by focusing electromagnetic radiation, such as photons or electrons, on its surface. Optical and electron microscopes can easily generate two-dimensional magnified images of an object's surface, with a magnification as large as 1000x for an optical microscope, and as large as 100,000x for an electron microscope. Although these are powerful tools, the images obtained are typically in the plane horizontal to the surface of the object. Such microscopes do not readily supply the vertical dimensions of an object's surface – the height and depth of the surface features.

The atomic force microscope (AFM), developed in the mid 1980's, uses a sharp probe to magnify surface features. With an AFM, it is possible to image an object's surface topography with extremely high magnifications, up to 1,000,000x. Furthermore, the magnification of an AFM is made in three dimensions: the horizontal X-Y plane and the vertical Z dimension. As acknowledged by Bennig and Roher¹, the inventors of the tunneling microscope, such a powerful technique has its origins in the stylus profiler.

STYLUS PROFILERS

Magnification of the vertical surface features of an object [those features leaving the horizontal plane and extending in the vertical direction] have historically been measured by a stylus profilers. Figure A illustrates an example of an early profiler. This profiler, invented by Schmalz² in 1929, utilized an optical lever arm to monitor the motion of a sharp probe mounted at the end of a cantilever. A magnified profile of the surface was generated by recording the motion of the stylus on photographic paper. This type of "microscope" generated profile "images" with a magnification of larger than 1000x.

A common problem with stylus profilers was the possible bending of the probe due to collisions with surface features. Such "probe bending" was a result of horizontal forces on the probe that developed when it encountered large features on the surface. This problem was first addressed by Becker³ in 1950 and later by Lee⁴. Both Becker and Lee suggested oscillating the probe from a null position

1. G. Bennig and H. Rohrer, Scanning Tunneling Microscopy-From Birth to Adolescence, Rev. of Mod. Phys, Vol 59, No. 3, 1987, P 615

2. Über Glatte und Ebenheit als physikalisches und physiologisches Problem, Gustav Shmalz, Zeitschrift des Vereines deutscher Ingenieure, Oct 12, 1929, pp. 1461-1467

3. U.S. Patent 2,7288,222

4. UK Patent 2,009,409

above the surface to make contact with the surface. Becker remarked that the detail of images measured using this vibrating profile method would depend on the sharpness of the probe.

In 1971, Russell Young⁵ demonstrated a non-contact type of stylus profiler. In his profiler, called the Topographiner, Young made use of the fact that, for electrically conductive samples, the electron field emission current between a sharp metal probe and a surface is very dependent on the probe-sample distance.

In the Topographiner, the probe was mounted directly on a piezoelectric ceramic that was used to move the probe in a vertical direction above the surface. An electronic feedback circuit monitoring the electron emission was then used to drive the piezoceramic and thus keep the probe-sample spacing fixed. Then, with piezoelectric ceramics, the probe was used to scan the surface in the horizontal [X-Y] dimensions. By monitoring the X-Y and Z position of the probe, a 3-D image of the surface was constructed. The resolution of Young's instrument was controlled by the instrument's vibrations.

SCANNING TUNNELING MICROSCOPES AND ATOMIC FORCE MICROSCOPES

In 1981, researchers at IBM were able to utilize the methods first demonstrated by Young to create a scanning tunneling microscope⁶ [STM]. Bennig and Rohrer demonstrated that by controlling the vibrations of an instrument very similar to Young's Topographiner, it was possible to monitor the electron tunneling current between a sharp probe and a sample. Since electron tunneling is much more sensitive than field emissions, the probe could be used to scan very close to the surface. The results were astounding: Bennig and Rohrer were able to see individual silicon atoms on a surface. Although the STM was considered a fundamental advancement for scientific research, it had limited applications because it only worked on electrically conductive samples.

A major advancement in profilers occurred in 1986 when Bennig and Quate⁷ demonstrated the AFM. Using an ultra-small probe tip at the end of a cantilever, the AFM could achieve extremely high resolutions. Initially, the motion of the cantilever was monitored with an STM tip. It was soon realized that a light-lever, similar to the technique first used by Schmalz, could be used for measuring the motion of the cantilever. Bennig and Quate proposed that the AFM could be improved by vibrating the cantilever above the surface.

The first practical demonstration of the vibrating cantilever technique in an AFM was made in 1987 by

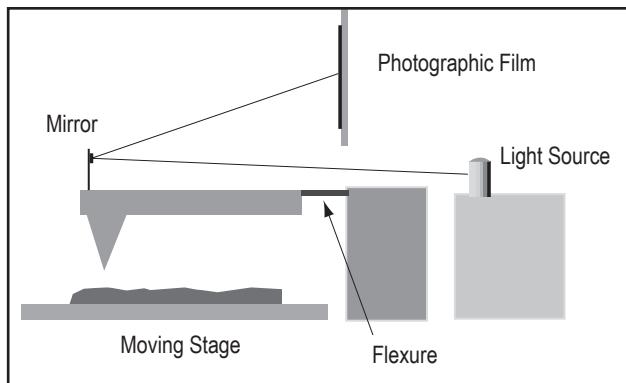


Figure A: Example of a surface profiler made in 1929.

-
- 5. R. Young, J. Ward, F. Scire, The Topografiner: An Instrument for Measuring Surface Microtopography, Rev. Sci. Inst., Vol 43, No 7, p 999
 - 6. G. Bennig, H. Rohrer, Ch. Gerber, E. Weibel, Surface Studies by Scanning Tunneling Microscopy, Vol. 49, No 1, 1982, p 57
 - 7. G. Bennig, C.F. Quate, Ch. Geber, Atomic Force Microscope, Phys. Rev. Letters, Vol. 56, No 9, p 930
 - 8. Y. Martin, C.C. Williams, H.K. Wickramasinghe, Atomic Force Microscope-Force Mapping and Profiling on a sub 100-Å scale. J. Appl. Phys. Vol 61, No 9, 1987, p 4723

Wickramsinghe⁸, using an optical interferometer to measure the amplitude of a cantilever's vibration. Oscillation amplitudes of between 0.3 nm and 100 nm were achieved with this optical technique. Because the probe came into close contact with the surface upon each oscillation, Wickramsinghe was able to sense the surface materials; the differences between photo-resist and silicon were readily observed.

NANOSCIENCE & NANOTECHNOLOGY OVERVIEW

Approximately 15 years ago scientists and engineers began discussing a technological revolution that would be as dramatic and far-reaching to society as the industrial revolution: the nanotechnology revolution. At first, the primary promoters of the nanotechnology revolution were considered eccentric. However, their ideas and visions are now becoming accepted by the mainstream intellectual, scientific, and engineering communities. Recently, governments and major corporations around the world have committed several billion dollars per year for the advancement of nanotechnology and nanoscience research and development.

ATOMS AND MOLECULES

The systematic study, manipulation, and modification of atoms and molecules having nanometer-sized dimensions began several hundred years ago. Society has benefited greatly because chemists are able to use chemical reactions to combine several types of atoms to create new types of molecules. With the advent of quantum physics, physicists, chemists, and biologists can routinely study the spectra of atoms and molecules. Several decades ago, biochemists began to discover the usefulness of particular types of molecules such as proteins, enzymes, and DNA.

Until recently, however, working with and controlling atoms and molecules was limited to large quantities of these nanometer-sized objects. Realistically, chemists would modify hundreds of trillions of molecules in a typical chemical reaction. When chemists synthesize new molecules, they make them in large quantities by using macroscopic methods such as heat to initiate chemical reactions. Biologists can identify and create new types of genetic material, but only for a large number of molecules.

SO WHAT'S NEW?

All the revolutions in science and technology are facilitated by many driving forces occurring simultaneously. The nanotechnology revolution, too, is being driven by a number of developments, ideas, and technical advancements, the primary ones being instruments that measure and manipulate atoms and molecules:

- The invention of the Scanning Tunneling Microscope (STM) permitted us to see single atoms on a surface for the first time. Before this, it was possible to view and create images of lattices of many molecules using techniques based on electromagnetic radiation. For example, x-ray techniques make it possible to recreate the positions of atoms in a complex matrix or lattice.
- Tunneling electronic microscopes (TEM) make it possible to directly image atoms in a lattice. However, these techniques cannot see single atoms, as they rely on the scattering of electromagnetic radiation from a collection of atoms.

Another important innovation is the laser "tweezer." By using the momentum of photons, it is possible to

isolate collections of several hundred molecules or atoms in a single location. Prior to this invention, the possibility of isolating a few molecules or even a few hundred molecules was not considered possible.

The drive to make smaller computer chips & higher density information storage:

Moore's law, popularized in the late 20th century, dictates that there is a relationship between time and the size of electronic devices such as transistors. This relationship has been very effective in predicting advances in the world of microelectronics for almost thirty years. However, physicists are predicting that Moore's law will begin breaking down when the size of electronic devices becomes less than 100 nanometers. There is a great effort, therefore, to discover new methodologies for creating electronic devices of this size and smaller.

The storage of information is considered an essential advancement of modern civilization:

At first, recording information and ideas on written paper was a great achievement; books and newspapers allowed the flow of knowledge and information throughout the world. Today, information is stored digitally and transmitted electronically. Digital bits with dimensions of less than a micron are stored on magnetic disks and compact discs. There is an ever-increasing need to store and transmit information on smaller spaces and transmit information with faster methodologies.

Emerging belief that it is possible to mimic the mechanisms of biology:

Researchers in the life sciences have discovered over the past few decades that there are many fundamental mechanisms that facilitate the recreation and support of all life forms. At a distance, these mechanisms can be characterized as machines or engines. They absorb energy and, in a very efficient way, cause events to occur. For example, a virus will permeate a cell and then integrate with the genetic material of the cell.

Presently, we can observe these activities on a macroscopic scale. In many cases, we do not understand how they work or why they work. But there is a belief that we can understand, emulate, and even use these fundamental activities or machines that occur in biological systems.

Creation of mechanical devices having nanometer tolerances and motions (MEMS):

To a great extent, the industrial revolution occurred because it became possible to shape mechanical objects and thus create new types of machines. Before the industrial revolution, it was possible to routinely make objects that had dimensions on the order of a few hundredths of an inch. An artist could paint pictures; a potter could make dishes and pots. With the industrial revolution, it became possible to routinely make machines with tolerances of a few thousandths of an inch (25 to 100 microns), which gave way to the invention of the steam engines, railroads, cars, and airplanes.

With MEMS technology, it is now possible to use machining technologies to create machines smaller than the width of a human hair. This ability is presently used in the sensors that activate airbags in cars, set the frequency of computers, and allow digital projection.

NANOSCIENCE

Applying the scientific method to further understand the behavior of atoms and molecules at the nanometer scale will push forward the frontiers of human knowledge. Currently, our vision of the nano-world is based only on evidence we collect from the macroscopic world we live in. Presently, biologists, chemists, physicists, and engineers have only a mental picture of what is occurring on the nanometer

scale. In fact, only very recently have they actually seen or directly observed nano-events.

As an analogy, suppose you were presented with a gift in a box wrapped with paper. In an effort to guess what is in the package, you could shake it or maybe drop it. Based on how the package behaves under this “interrogation,” you may get an idea of what is in it [i.e., is it heavy?, does it make a noise?]. With the nano-revolution, scientists will be able to open the package-and really see what is inside.

With new ideas and methods, scientists are beginning to further understand how a single atom or molecule behaves. Even more interesting is the direct understanding of how collections of two or three or even a dozen atoms or molecules behave.

NANOTECHNOLOGY

The fundamental knowledge gained through nanoscience and developments in nanotechnology will certainly accelerate over the next several decades. With the control of materials at the nanometer dimension, engineers are already able to create new types of products and services. For example, the smallest transistors we make in a factory today are about 130 nanometers wide. With future nanotechnology advancements, engineers will be able to make chips that have transistors 2-3 nanometers wide. Today, cosmetic manufacturers use liposomes with diameters of a few tens of nanometers to reduce the dehydration of skin.

We expect that the nanotechnology revolution will result in the creation of new types of products and services that will greatly benefit our lives.

What is possible? When the ideas and concepts discussed as part of the nanotechnology revolution are fully implemented, what is possible? At this point, many of the possibilities being discussed seem like science fiction.

We can only imagine what is possible. Imagine:

- All of recorded history will fit in a package small enough to carry in our pockets. This includes all written documents, music, and movies.
- Our world will be safer because the computers and sensing systems that fit in a package the size of a pill will be able to warn us of dangers.
- Life will be extended because we can create systems and modules that replicate the functions and systems in our bodies.
- New types of “quantum computers” will make calculations billions of times faster than today’s digital computers.
- We can create new types of molecules with the mechanical assembly of chemical systems instead of today’s assembly by thermodynamic chemical reactions.

WHAT IS THE AFM'S CONTRIBUTION TO NANOTECHNOLOGY?

Measurement: An atomic force microscope (AFM) creates a highly magnified, three-dimensional image of a surface. The image is generated by monitoring the motion of an atomically sharp probe as it is scanned across a surface. With an AFM, scientists and engineers can directly view and measure surface features having dimensions on the order of a few nanometers, including single atoms and molecules.

An AFM makes it possible to measure more than the physical dimensions of a surface, as there is a "physical" interaction of the probe with the surface. For example, by lightly pushing against the surface with the probe, it is possible to measure surface hardness. Also, the degree of ease with which the probe glides across the surface is a measure of the surface "friction."

Modification: An AFM can be used to write on a surface, just as a pen is used to write on paper. This new type of "lithography" is a completely new method for making surface modifications at the nanometer scale. It is already possible to modify surfaces by physically scratching the surface, directly depositing molecules on the surface, and using electric fields to modify surfaces. Presently, this use of the AFM is in a very exploratory stage, but it is showing tremendous promise. One of the important technological issues that must be solved is the writing speed of AFM lithography systems.

Manipulation: An AFM probe can be used to directly move objects across a surface. The objects may be pushed, rolled around, or even picked up by the probe. With such methods, it is possible to create nanometer-sized objects. One of the important aspects of using an AFM for direct manipulation is the user interface for generating the motions of the probe. Some interfaces measure the locations of particles, such as microspheres on a surface, and then automatically move the spheres to a pre-established location. In another type of interface, called the nanomanipulator, the motion of the probe follows the motion of the user's hand. When you move your hand up and down, the probe moves up and down. This kind of interface also allows the user to "feel" and "touch" a surface.

AFM Tutorial

INTRODUCTION

This section serves as an introduction to at. With a basic understanding of the technologies employed in an AFM and how they are implemented in the design and operation of the instrument, you can obtain optimal results from your Nano-DST™ AFM.

CONCEPTS & TECHNOLOGIES

DIMENSIONS AND MAGNIFICATION

An AFM is optimized for measuring surface features that are extremely small, therefore it is important to be familiar with the dimensions of the features being measured. An AFM is capable of imaging features as small as a carbon atom (~0.25 nanometers in diameter) and as large as the cross section of a human hair (~80 microns in diameter).

The common unit of dimension used for making measurements in an AFM is the nanometer [nm], one billionth of a meter:

$$1 \text{ meter} = 1,000,000,000 \text{ nanometers}$$

$$1 \text{ micron } (\mu\text{m}) = 1,000 \text{ nanometers}$$

Another common unit of measure is the Angstrom (\AA), a tenth of a nanometer:

$$1 \text{ nanometer} = 10 \text{ Angstroms}$$

Magnification in an AFM is the ratio of the actual size of a feature to the size of the feature when viewed on a computer screen. Thus, when the entire screen is used to view the cross section of a human hair on a 500 mm (20-inch) computer monitor, the magnification can be expressed as:

$$\text{Magnification} = 500 \text{ mm} / .08 \text{ mm} = 6,250x$$

In the case of extremely high resolution imaging, the entire field of view of the image may be 100 nm. In this case, the magnification on a 500 mm computer screen is:

$$\text{Magnification} = 500 \text{ mm} / (100 \text{ nm} * 1 \text{ mm} / 1,000,000 \text{ nm}) = 5,000,000x$$

PIEZOELECTRIC CERAMIC TRANSDUCER

Precise mechanical motion in an AFM is created from electrical energy using an electromechanical transducer. The electrical motor used in a washing machine is a common example of an electromechanical transducer. The electromechanical transducer most commonly used in an AFM is the piezoelectric ceramic.

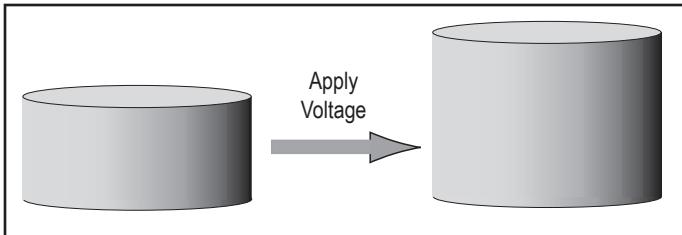


Figure B: When a voltage is applied to the top and bottom surface of the piezoelectric disc, the disc expands.

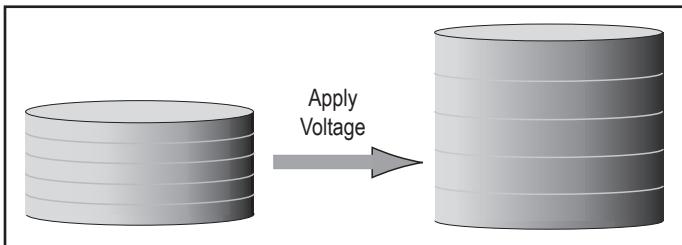


Figure C: When a voltage is applied to the top and bottom surface of a stack of piezoelectric discs, the entire stack expands.

A piezoelectric material undergoes a change in geometry when it is placed in an electric field. The amount and direction of motion depends on the type of piezoelectric material, the shape of the material, and the field strength. Figure B shows the motion of a piezoelectric disk when exposed to an electric potential.

A typical piezoelectric material will expand by about 1 nm per applied volt. Therefore, larger motions can be attained by making piezoelectric transducers with hundreds of layers of piezoelectric materials, as illustrated in Figure C.

The amount of expansion of the whole stack depends on the applied voltage, the piezo material, and the number of disks. By using one thousand layers of piezoelectric material, it is possible to get motions as large as 1000 nm per volt, or 0.1 mm of motion with 100 volts.

FORCE SENSORS

The construction of an AFM requires a force sensor to measure the forces between a small probe and the surface being imaged. A common type of force sensor utilizes the relationship between the motion of a cantilever and the applied force. The relationship is given by Hooke's law:

$$F = -K * D$$

Where:

- K is a constant which depends on the material and dimensions of the cantilever
- D is the motion of the cantilever

For a cantilever made of silicon that has dimensions of:

$$L = 100 \mu\text{m}, W = 20 \mu\text{m}, T = 1 \mu\text{m}$$

The force constant, K, is approximately 1 newton/meter. Therefore, a force of 1 nanonewton is required to move the cantilever 1 nm.

The motion of the cantilever can be measured with the “light lever” method, as illustrated in Figure D. A laser beam is reflected off the back side of the cantilever and onto a photo-detector. Deflection of the cantilever causes the laser beam to move across the surface of the photo-detector.

The motion of the cantilever is then directly proportional to the output of the photo-detector. Motions as small as 1 nm are routinely measured by AFMs using this method.

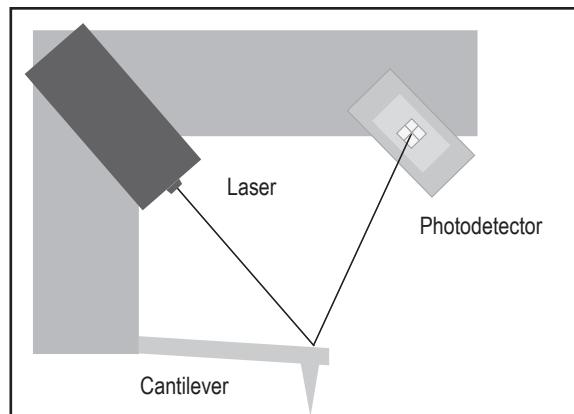


Figure D: The light lever method for sensing the motion of the cantilever.

FEEDBACK CONTROL

Feedback control is commonly used for keeping the motion of one object in a fixed relationship to another object. A simple example of feedback control occurs when you walk down a sidewalk. As you walk, you constantly control your motion by viewing the edge of the sidewalk. If you begin to walk off the sidewalk, you correct your motion so that you stay on the sidewalk. Feedback control is used for many everyday applications, including the automatic controls in airplanes and the thermostat controls in buildings. In an AFM, feedback control is used to keep the probe in a “fixed” relationship with the surface while a scan is measured.

AFM THEORY & INSTRUMENTATION

The theory and operation of an AFM is similar to that of a stylus profiler. The primary difference is that probe forces on the surface are much smaller in the AFM. Because of this, smaller probes can be used, and a much higher resolution can be achieved.

In an AFM, a constant force is maintained between the probe and sample while the probe is raster scanned across the surface. By monitoring the Z motion of the probe as it is scanned, a three dimensional image of the surface is constructed.

The constant force is maintained by measuring the force on the cantilever with the light lever sensor and by using a feedback control electronic circuit to control the position of the Z piezoelectric ceramic. The motion of the probe over the surface is generated by piezoelectric ceramics that move the probe and force a sensor across the surface in the X and Y directions. See Figure E.

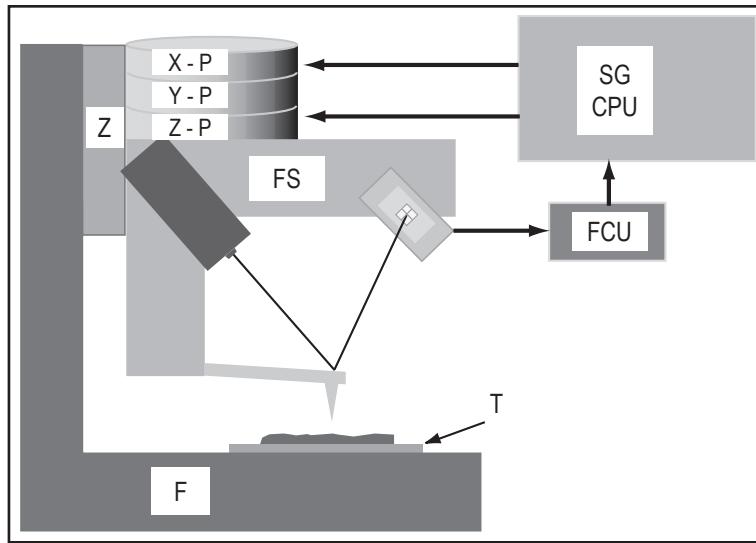


Figure E: Main components and subsystems of an AFM system.

Z - Coarse Z Motion Translator: Moves the AFM head towards the surface so that the force sensor can measure the force between the probe and sample. The motion of the translator is usually about 10 mm.

T - Coarse X-Y Translation Stage: Positions the section of the sample to be imaged directly under the probe.

X-P & Y-P - X and Y Piezoelectric Transducers: Move the probe over the surface in a raster motion when an image is measured.

FS - Force Sensor: Measures the force between the probe and the sample by monitoring the deflection of the cantilever.

Z-P - Z Piezoelectric Ceramic: Moves the force sensor and probe in the vertical direction in response to the measured deflection of the cantilever as the probe is scanned across the surface.

FCU - Feedback Control Unit: Takes in the signal from the light lever force sensor and controls the voltage that drives the Z piezoelectric ceramic. This voltage refers to the voltage required to maintain a constant deflection of the cantilever while scanning.

SG - X-Y Signal Generator: Controls the raster motion of the probe in the X-Y plane when an image is measured.

CPU - Computer: Used for setting the scanning parameters (such as scan size, scan speed, and feedback control response) and for visualizing images captured with the microscope.

F - Frame: A solid frame supports the entire AFM instrument. The frame must be very rigid in order to prevent vibrations between the tip and the surface.

NOTE: Not shown in Figure E is an optical microscope, which is essential for locating features on the sample surface and for monitoring the probe approach process.

TAKING IMAGES

Taking an image of a sample with an AFM involves the following basic steps:

1. Install a probe in the microscope, and align the light lever sensing system.
2. Position the region of interest on the sample directly under the AFM probe, using the X-Y translation stage and the optical microscope.
3. Engage the Z translation stage to bring the probe to the surface.
4. Start the scanning of the probe over the surface, and monitor the resulting AFM image on the computer screen.
5. Save the image on a computer disk.

RESOLUTION

Traditional microscopes have only one measure of resolution: the resolution in the plane of an image. An AFM has two measures of resolution: in the X-Y plane of the measurement surface (in-plane resolution) and in the direction perpendicular to the surface (vertical resolution).

In-Plane Resolution: The in-plane resolution depends on the geometry of the probe used for scanning. In general, the sharper the probe, the higher the resolution. The theoretical line scans in Figure F illustrate the difference between using a sharp probe and a dull probe to measure two spherical features on a sample surface. The sharper probe will result in a higher resolution image.

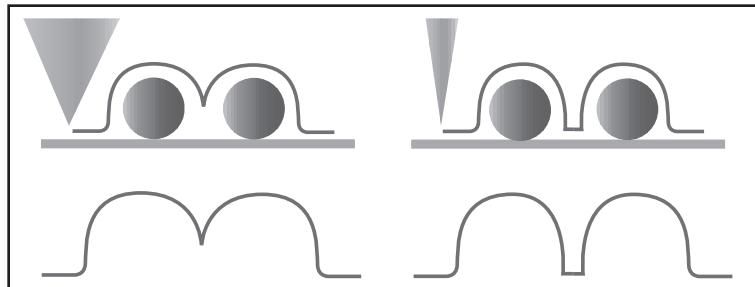


Figure F: Using a dull probe vs. a sharp probe to measure spherical features.

Vertical Resolution: The vertical resolution in an AFM is established by relative vibrations of the probe above the surface. Sources of vibrations include acoustic noise, floor vibrations, and thermal vibrations. Getting the maximum vertical resolution requires minimizing these vibrations.

PROBE SURFACE INTERACTIONS

The strongest forces between the probe and surface are the mechanical forces that occur when the atoms on the probe physically interact with the atoms on a surface. However, other forces between the probe and surface can have an impact on an AFM image. These include surface contamination, electrostatic forces, and surface material properties.

Surface contamination: In ambient air, all surfaces are covered with a very thin layer (< 50 nm) of contamination. This contamination, which can be comprised of water and hydrocarbons, depends on the microscope's operating environment.

When the probe comes into contact with the surface contamination, capillary forces can pull the probe towards the surface.

Electrostatic forces: Insulating surfaces can store charges on their surface, which can interact with charges on the probe or cantilever. Such forces can be so strong that they "bend" the cantilever when scanning a surface.

Surface material properties: Heterogeneous surfaces can have regions of varying hardness and friction. As the probe is scanned across a surface, the probe-surface interaction can change when moving from one region to another. Such changes in forces can give a "contrast" that is useful for differentiating between materials on a heterogeneous surface.

AFM IMAGING MODES

TOPOGRAPHY MODES

As the probe at the end of the cantilever is scanned over the sample surface, a constant force between the probe and the sample is maintained. There are two methods for measuring the force on the cantilever as the probe encounters changes in the sample topography. In deflection, or "contact," mode, the deflection of the cantilever is measured directly. In vibrating mode, the cantilever is vibrated, and changes in the vibration properties are measured.

Deflection Mode:

Using the feedback control in the AFM, it is possible to scan a sample with a fixed cantilever deflection. Because the deflection of the cantilever is directly proportional to the force on the surface, a constant force is applied to the surface during a scan. While this scanning mode is often called "contact" mode, because the forces of the probe on the surface are often less than a nanonewton, the probe is minimally touching the surface.

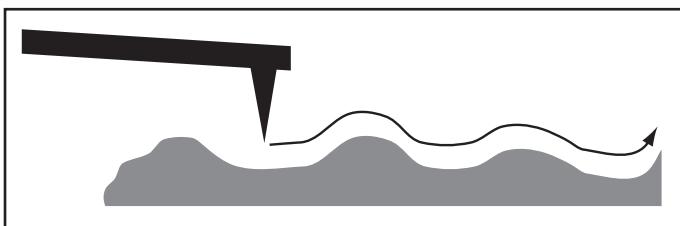


Figure G: In Contact Mode, the probe directly follows the topography of the surface as it is scanned while a constant force is maintained.

Vibrating Mode: The cantilever in an AFM can be vibrated using a piezoelectric ceramic. When the vibrating cantilever comes close to the sample surface, the amplitude and phase of the vibrating cantilever change. The feedback unit keeps either the vibration amplitude or phase constant. Changes in the vibration amplitude or phase are easily measured, and the changes can be related to the force on the surface. This technique has many names, including “non-contact” and “intermittent contact” mode. It is important that the tip not “tap” the surface, as this may break the probe or damage the sample.

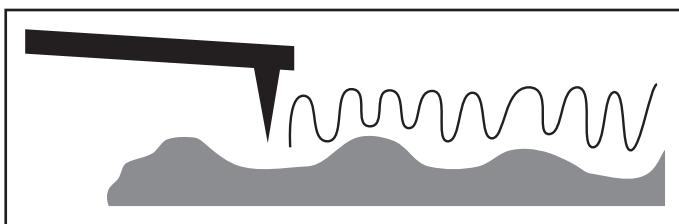


Figure H: In Vibrating Mode, changes in probe's vibrations are monitored to establish the interactive force of the probe with the surface.

MATERIAL SENSING MODES

The interaction of the probe with the surface depends on the chemical and physical properties of the surface. It is therefore possible to measure these interactions and thus “sense” the materials at a sample surface.

Vibrating Material Sensing Mode: The AFM cantilever may be vibrated to measure the force between the probe and sample during a scan. The magnitude of amplitude damping and phase change of the cantilever depends on the surface chemical composition and the physical properties of the surface. Thus, on a non-homogeneous sample, contrast can be observed between regions of varying mechanical or chemical composition. Typically, in vibrating material sensing mode, if the amplitude is fixed by the feedback unit, then the contrast of the material is observed by measuring phase changes. This technique has many names, including phase mode, phase detection, and force modulated microscopy.

Torsion Modes: In contact mode AFM, it is possible to monitor the torsion motions of the cantilever as it is scanned across the surface. The amount of torsion of the cantilever is affected by changes in topography as well as changes in surface chemical properties. If a surface is perfectly flat but has an interface between two different materials, it is often possible to image the change in material properties. This technique is similar to lateral force microscopy (LFM).

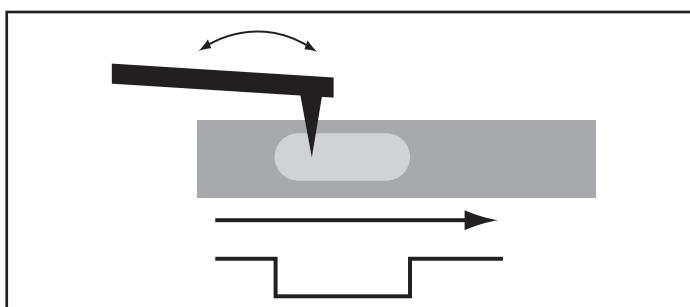
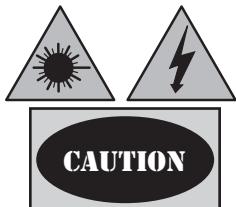


Figure I: In Torsion Mode, changes in the torsion of the cantilever are an indication of changes in the surface chemical composition

Chapter 1 • Instrument Overview



WARNING: Before operating the Nano-DST™ AFM, make sure you are familiar with the safety information on page iv.

CAUTION: To prevent damage to your instrument, probe, and sample, observe all caution statements in the tutorial chapters (Chapters 2, 3, and 4).

NANO-DST™ AFM INSTRUMENT SYSTEM



Figure 1.1: Nano-DST™ Instrument System and Block Diagram

Nano-DST™ Stage: Includes the AFM scanners, stage Signal Access Counsel (SAC) and probes, stepper motors, sample puck, video optical microscope, and the AFM scanner's real-time calibration sensors.

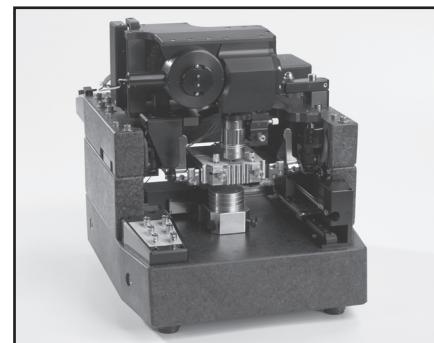


Figure 1.2: Nano-DST™ Stage

Master Computer: The PC-type computer is the virtual interface to the Nano-DST™ AFM stage. Pacific Nanotechnology software programs, resident on the computer's hard disk, are used for measurement, visualization, and analysis of AFM images.

DST Controller: Contains all of the electronics required for operating the Nano-DST™ stage. It is connected to the Master Computer by a standard Ethernet cable, and to the Nano-DST™ stage by four cables. A control CPU is used to drive two independent XYZ boards. Each XYZ board has all of the electronic functions required to run an AFM including a PID control loop, phase/amplitude detection circuit, and XY high voltage circuits. The XYZ boards then drive the metrology and rapid scanners. The Control CPU has a multi-threaded operating system such as LINUX so that each of the scanners can be driven independently.



Figure 1.3: DST Controller

Video Monitor: Displays the optical microscope image of the probe-sample area.

Track ball: Provides an optional way to activate many of the motorized features of the Nano-DST™ stage, including the X-Y stage positioning and the video microscope zoom and focus.

HARDWARE COMPONENTS

NANO-DST™ STAGE

The AFM scanner head rests on three motorized posts, which are used to perform a coarse Z approach of the probe tip to the sample surface. The sample puck rests on a motorized X-Y stage for positioning the sample under the probe. The puck can be easily removed for mounting a sample.

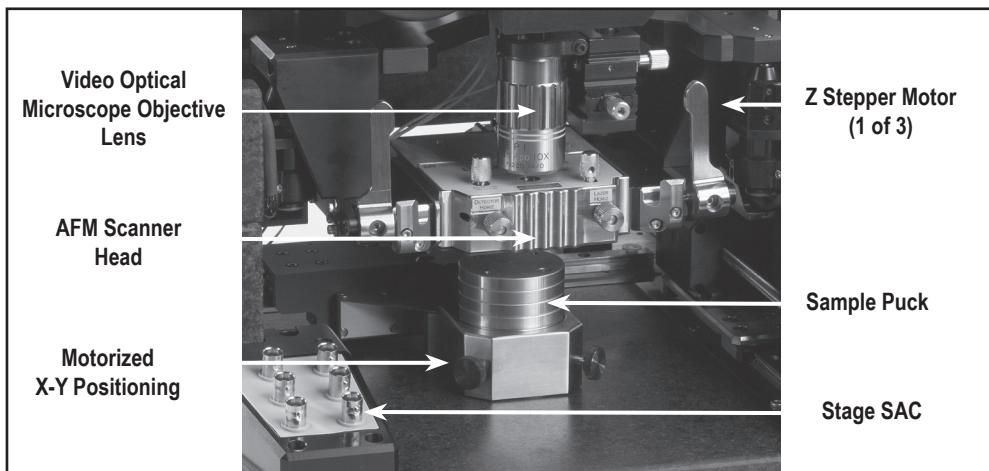


Figure 1.4: Stage Components

DUAL SCANNERS

There are two types of scanners on a DST system: Metrology scanner and Rapid scanner, both utilize a light lever force sensor design.

In the light lever, a red laser is focused on the back of the cantilever and is then projected onto a quad photo diode (photo detector). Two pairs of manual adjustment knobs on the scanner head are used to align the sensing system. One pair controls the position of the laser light on the backside of the cantilever; the other pair moves the photo detector in relation to the light path. A Z-axis piezo moves the probe vertically in response to force variations sensed by the probe. X and Y piezos move the probe over the sample in a raster pattern, which defines the scan region.

The Dual Scanners contain the components that: 1] Measure the force between the probe and the sample, and 2] Control the precise positioning of the probe in X, Y, and Z.

Metrology Scanner

A piezoelectric driven flexure metrological scanner is used for the metrological applications. Its XY scan range is typically 90 microns but can be as large as 360 microns. A range of 8 microns is available with the Z piezoelectric element. Calibration sensors in the X, Y and Z axes facilitate accurate metrological measurements and positioning of the AFM probe. The flexure scanner advantage over traditional piezoelectric tube scanners is that they have a minimal amount of bow in the Z axis. Additionally the flexure scanner has a minimal amount of coupling between the X, Y, and Z axis.

Rapid Scanner

The rapid scanner has an XY range of 4 microns and a Z dynamic range of about 0.5 microns. Because the scanner has a limited dynamic range, it has a very high resolution in the XY axis and also a very low vertical noise floor. Additionally, the rapid scanner has a very high resonant frequency and can be scanned in the XY axis at rates as high 512 Hz. The Z feedback for the AFM can be derived from either the metrology or the rapid scanner.

The sample to be imaged with the Rapid Scanner is mounted on top of the Rapid Scanner as indicated by the arrow (Figure 1.7).

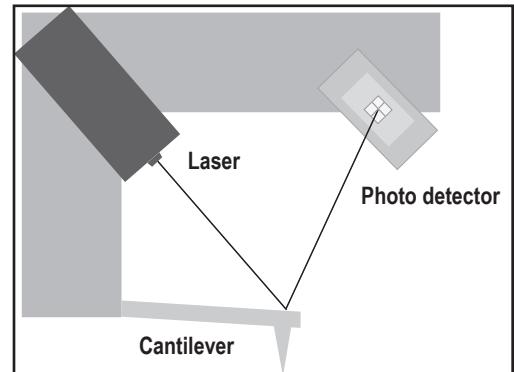


Figure 1.5: Light Lever Sensing System



Figure 1.6: Metrology Scanner

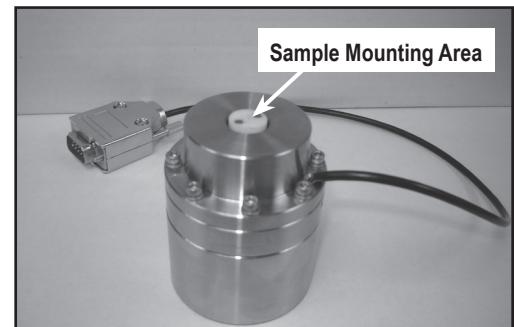


Figure 1.7: Rapid Scanner

LIGHT LEVER AFM PROBES

CAUTION

CAUTION: Use care when handling AFM probes, as they can break very easily. Always handle with tweezers, and never touch the cantilever.

The Light Lever Nano-DST AFM is shipped with probes required for the two basic imaging modes: contact and close contact (vibrating cantilever). The probes come in marked boxes, 10 probes to a box.



Figure 1.8: AFM Probes

The probe tip projects from the end of a cantilever which is mounted to a chip [Figure 1.9]. The metal plate that holds the cantilever chip is mounted in the AFM scanner; it is magnetically secured to the bottom of the scanner.

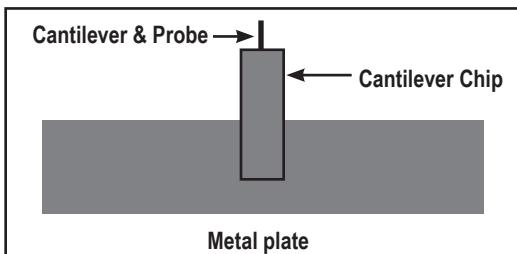


Figure 1.9: PNI AFM Light Lever Probe (Top View -- Not to Scale)

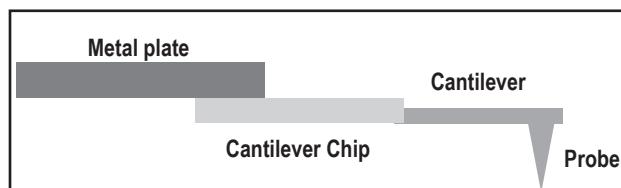


Figure 1.10: PNI AFM Probe (Side View -- Not to Scale)

The two types of probes appear identical to the naked eye, but under the instrument's optical microscope, you can see that contact cantilevers are significantly longer than close-contact cantilevers.

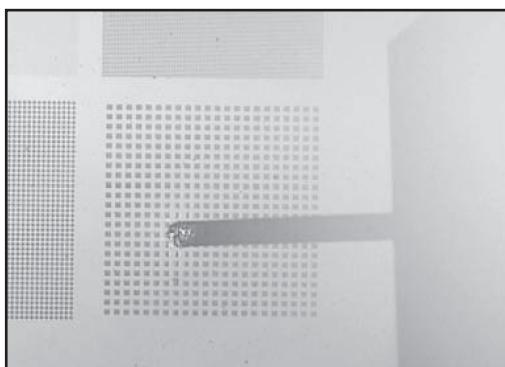


Figure 1.11: Contact Cantilever

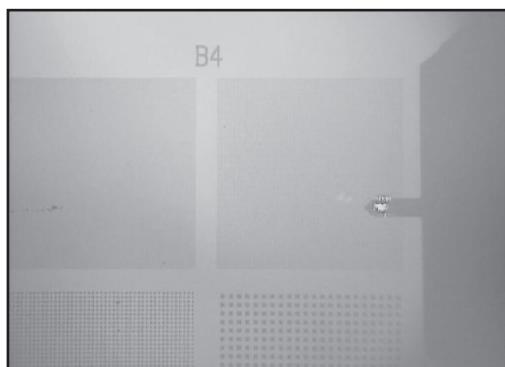


Figure 1.12: Close-Contact Cantilever

SAMPLE PUCK

The sample to be imaged is mounted on the sample puck. The puck is composed of removable layers so the height of the puck can be adjusted to accommodate different sample thicknesses (see Sample Mounting Section in Chapter 5). The pin on the bottom of the puck fits into a groove on the X-Y stage so it can be safely and easily guided into position under the probe.



Figure 1.13: Sample Puck

STAGE SIGNAL ACCESS CONSOLE (SAC)

The stage SAC is designed to give convenient access to some controller signals that might be useful up at the stage for some experiments. The Stage SAC is required to use the secondary Rapid Scanner. The Stage SAC, as shown in Figure 1.14 has a 9-pin female D-Sub connector and 6 isolated BNC connectors.

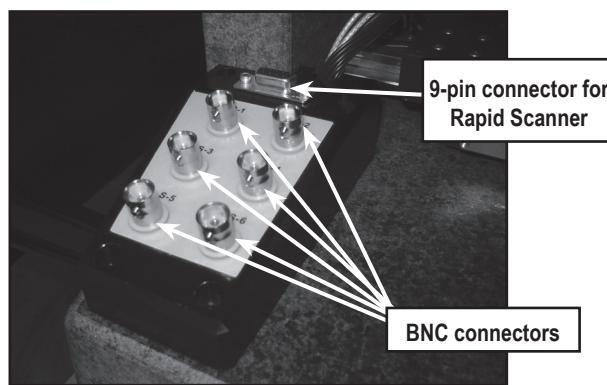


Figure 1.14: Stage SAC

PNI REFERENCE

The Nano-DST™ system is supplied with a PNI AFM reference, which is helpful for establishing the baseline performance of your instrument's AFM scanners as well as the optical microscope. The reference also serves as a useful test sample when learning how to use your instrument (the tutorials in this manual are based on this sample).

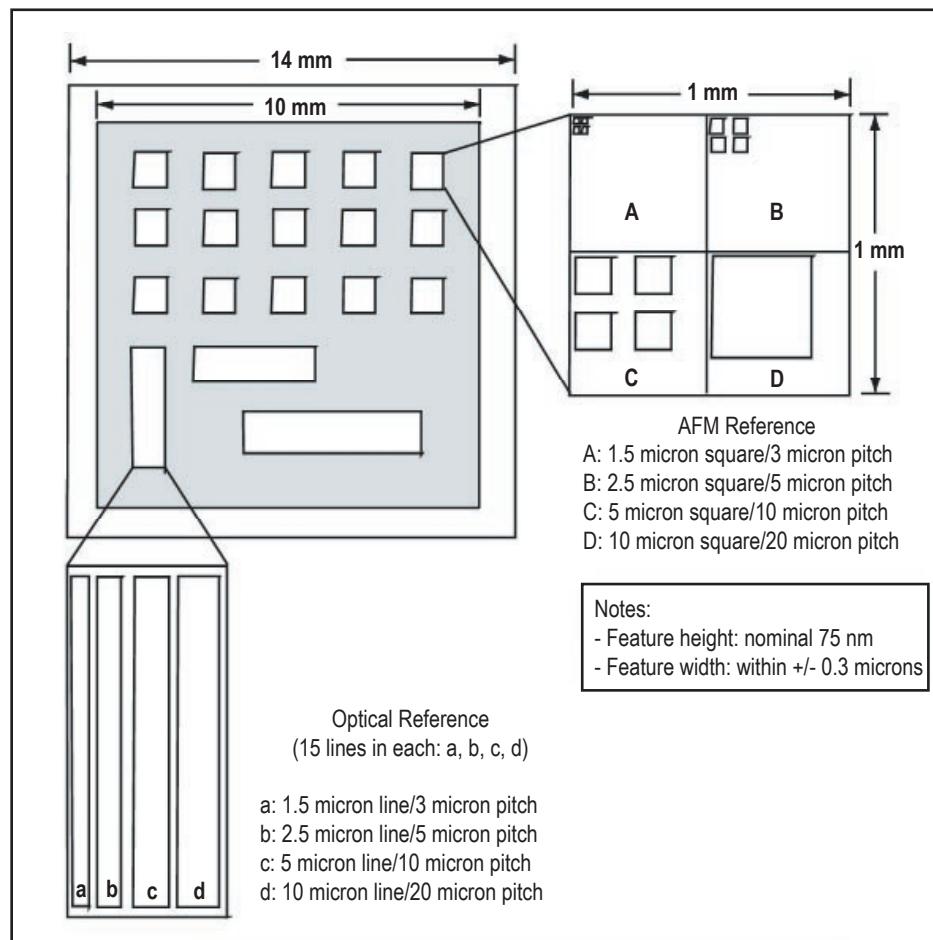


Figure 1.15: PNI Reference

The patterns in the reference are made with a silicon nitride film deposited on a silicon metal plate. This combination gives optimal color contrast when viewed with an optical microscope.

The pattern for AFM measurements is composed of four blocks of square features. The features in each block have uniform size and pitch, with each block containing features of a different size, as illustrated in Figure 1.13. This pattern is repeated at 15 locations on the reference. The optical microscope reference pattern is composed of a series of four sets of parallel lines. A second pattern is oriented perpendicular to the first.

SOFTWARE MODULES

The SPM Cockpit™ software modules serve three functions:

- acquire AFM data
- process and analyze the acquired data
- display AFM images (contained in the analysis modules)

The interfaces for the image acquisition and analysis modules feature tool bars that provide convenient access to the most commonly used software functions for the given mode of operation. However, regardless of the module (acquisition or analysis) or mode [EZMode™ or X'Pert™] you are in, all of the SPM Cockpit™ software functions are always accessible via the menu items. Note that the PNI Analysis software is included with all Nano-DST™ AFM systems, and NanoRule+™, a more full-featured analysis software package, is available as an option.

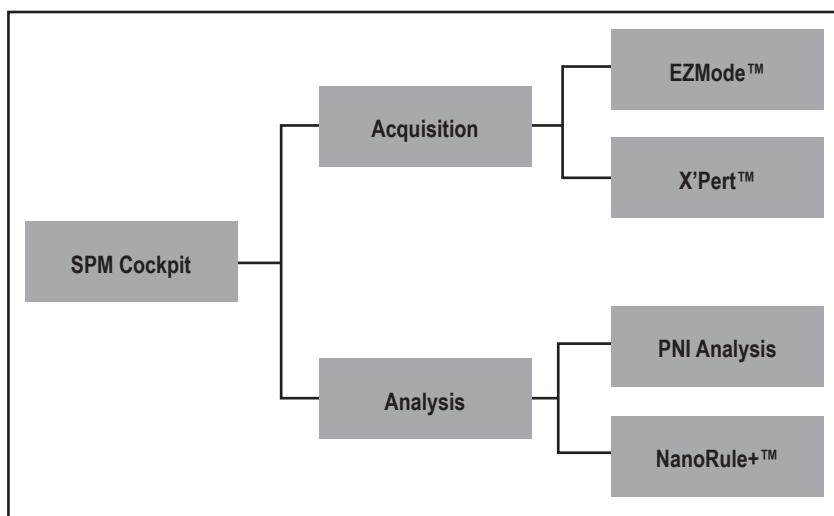


Figure 1.16: SPM Cockpit™ Software Modules

ACQUISITION

When you launch the SPM Cockpit™ software, the acquisition module opens by default. You will be in either EZMode™ or X'Pert™ Mode, depending on the mode used in the last session. Use the Mode menu to switch between the two.

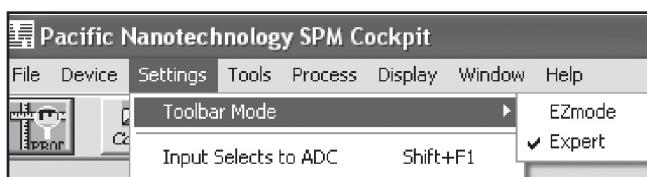


Figure 1.17: Mode Menu is used to select either EZ or Expert Mode

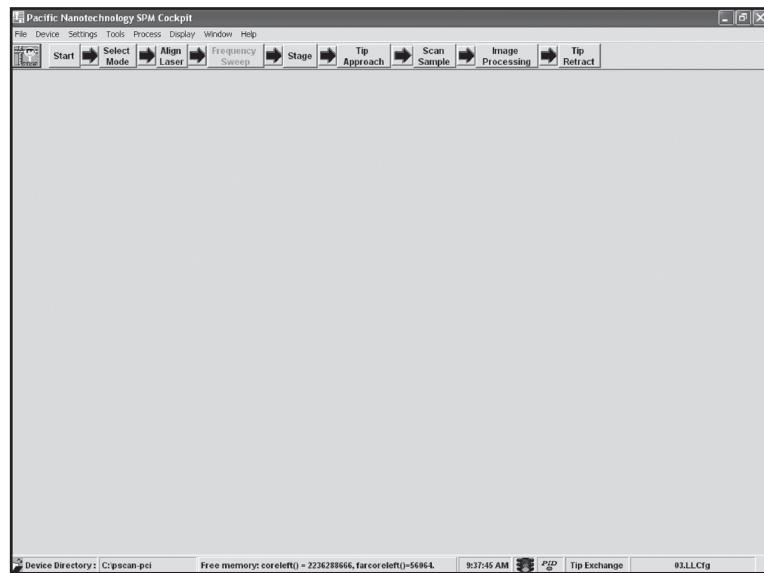


Figure 1.18: Acquisition Module Main Screen -- EZMode™

EZMode™ is intended for new and occasional AFM users. A set of short-cut buttons forms an easy-to-follow flow chart that takes you through the basic steps for taking an AFM image. Each button opens a dialog offering the choices necessary for accomplishing that step.



Figure 1.19: EZMode™ Short Cut Buttons

X'Pert™ Mode is oriented toward advanced AFM users who want to take advantage of a wider range of choices and features for acquiring an image. The X'Pert™ Mode short-cut buttons access the functions for accomplishing the same required steps in EZMode™, as well as additional functions, but the buttons are not necessarily organized into sequential steps.



Figure 1.20: X'pert™ Mode Short Cut Buttons

ANALYSIS

From the acquisition module, you can switch to the analysis module by clicking:



A series of short-cut buttons is displayed for easy access to the most commonly used image processing and analysis tools.

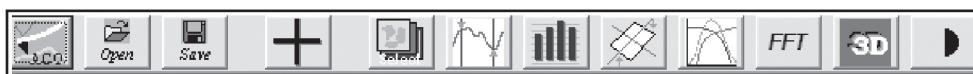


Figure 1.21: Analysis Module Short Cut Buttons

To return to the acquisition module, click:



BASIC IMAGING PROCEDURE

Acquiring an image with the Light Lever Nano-DST™ AFM requires the following basic steps:

1. Launch the SPM Cockpit™ software.
2. Open a configuration file [contact, close-contact, rapid scan].
3. Linearize the XYZ position sensors.
4. Install or change probe if necessary.
5. Load a sample [sometimes it is preferable to load the sample after Step 7].
6. Align laser and detector.
7. Tune probe if necessary.
8. Locate features for imaging.
9. Bring the probe into contact with the sample.
10. Scan the sample.
11. Perform image processing and analysis routines.
12. Retract the probe from the sample.

Chapter 2

Tutorial: Contact EZMode™ Light Lever

BEFORE YOU BEGIN

This tutorial details the steps for taking a contact AFM image of the PNI AFM reference using EZMode™.

WARNING: Before operating the Nano-DST™ AFM, make sure you are familiar with the safety information on page iv.

POWERING UP THE SYSTEM

1. Turn on the Master Computer.
2. Launch the SPM Cockpit software.
3. Turn on the Nano-DST Controller.
4. Turn on the video monitor.

START

1. Select Settings | Toolbar Mode | EZMode™.

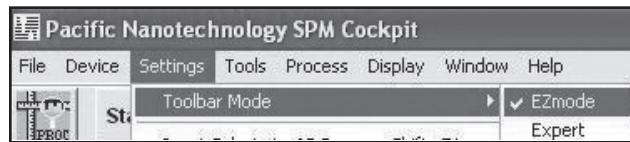


Figure 2.1: SPM Cockpit™

2. Click the Start button on the EZMode™ Toolbar.



Figure 2.2: EZMode™ Toolbar

3. Click Retract Tip, and click OK when complete.

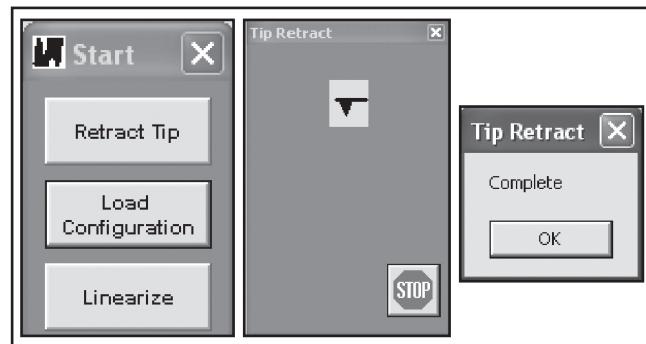


Figure 2.3: Retracting the Tip

4. Click Load Configuration, select the PNI-supplied contact mode configuration file, and click Open. This file should be located in the ConfigFiles folder in the SPM Cockpit™ directory. It has the format nfxxxxContact.PNI_Config, where xxxx is the serial number of your Light Lever Nano-DST™ system.

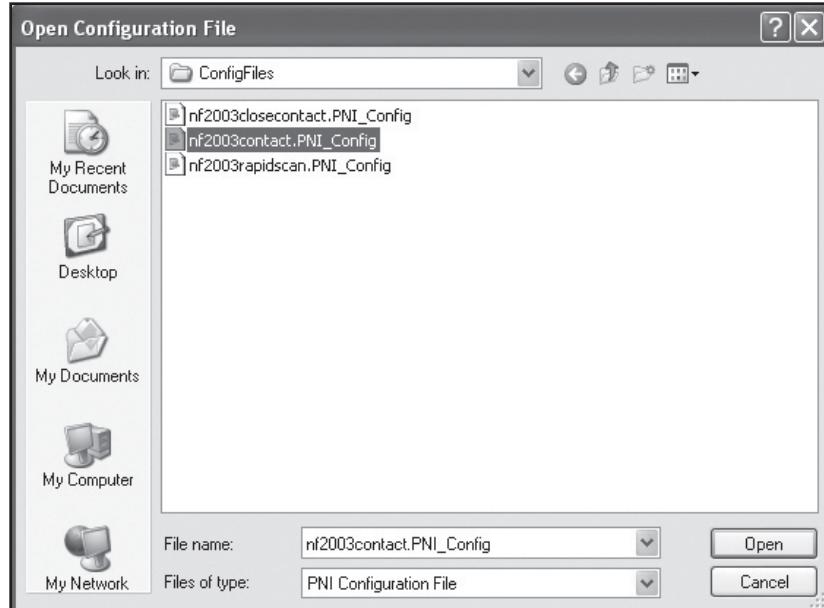


Figure 2.4: Loading a Configuration File

5. Click Linearize, check both boxes, and click OK.

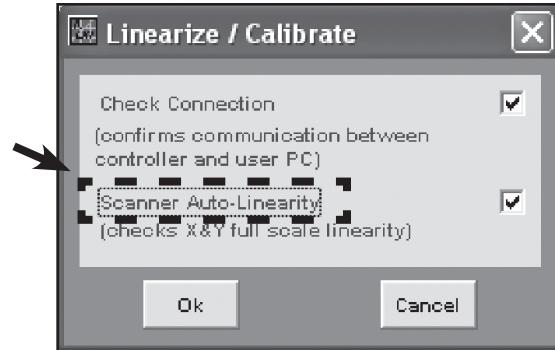


Figure 2.5: Check Connection and Scanner Auto-Linearity

6. Click OK when the communication between the Master Computer and the Controller is confirmed. If there is no connection, you need to exit the SPM Cockpit software and restart both the Master Computer and the Controller.



Figure 2.6: Connection Confirmed

- Click Start to proceed with the linearization procedure. This determines the optimum linear range of the x-y feedback sensors.

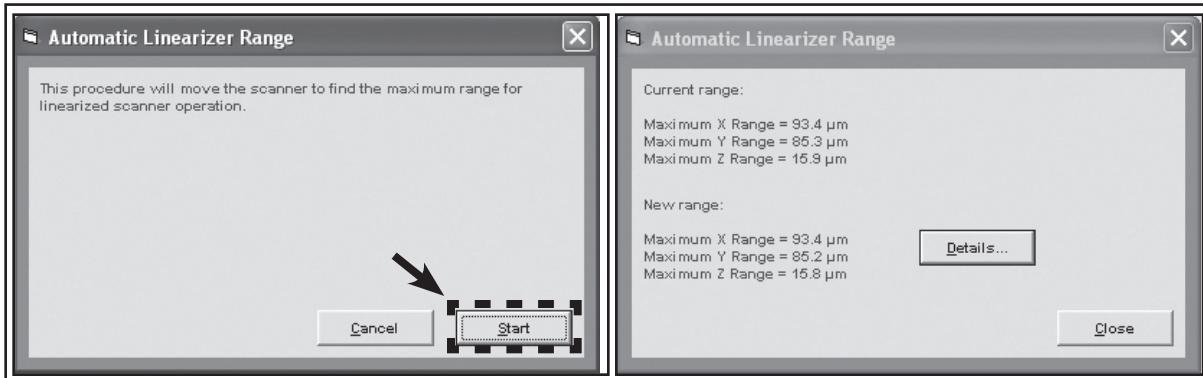


Figure 2.7: Automatic Linearizer Range

- Click Accept when the linearization process is complete, and then click Check New Range if desired. X-Y sensor readings are recorded while the scanner is moved. Straight diagonal lines in both graphs indicate a good result.
- Click Select Mode on the Toolbar, select Contact in the dialog box, and click OK.

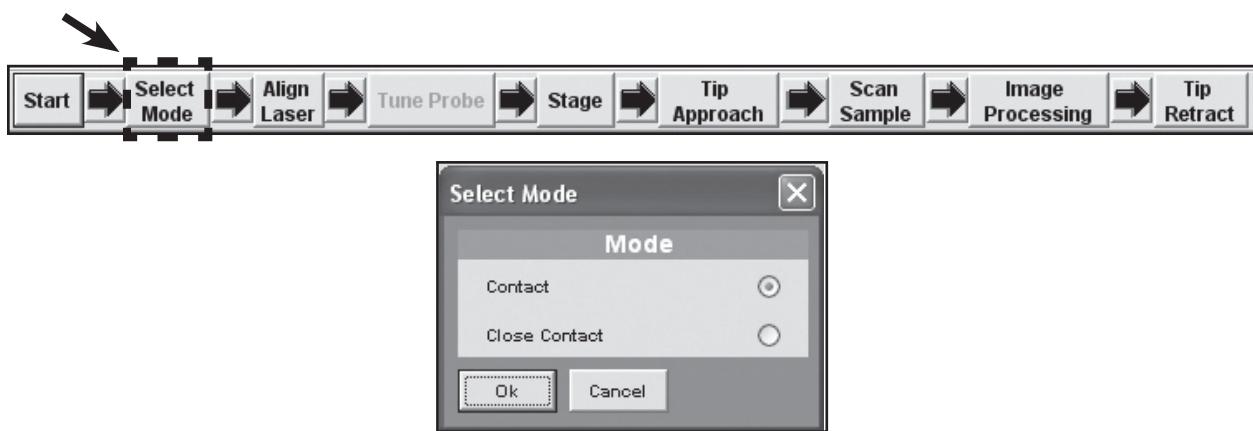


Figure 2.8: Select Mode

CHANGE PROBE

To operate in contact mode, you need to use a contact probe. Probes should be stored in the supplied boxes marked "Contact", as the difference between various types of probes is not easily visible to the naked eye.

- Click Stage from the EZMode™ Toolbar, and click Change Tip in the AFM Stage Controls dialog box, then click Start in the Tip Exchange Wizard.



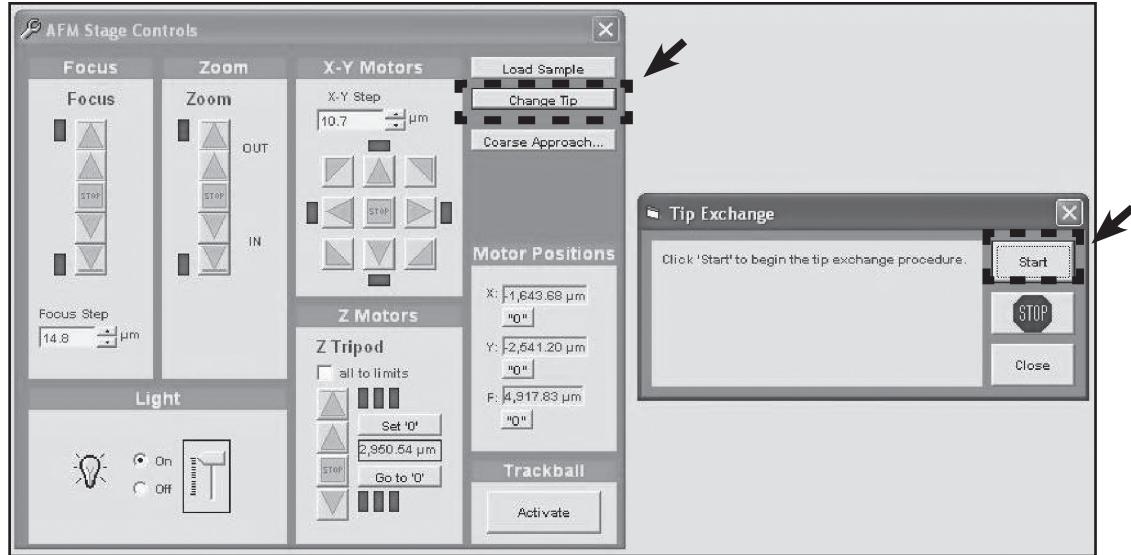


Figure 2.9: Change Tip will put the scanner head into the appropriate position to replace the tip. The Start button in the dialog box will raise the probe tip away from the sample.

- When motor movement is complete, remove the sample puck.

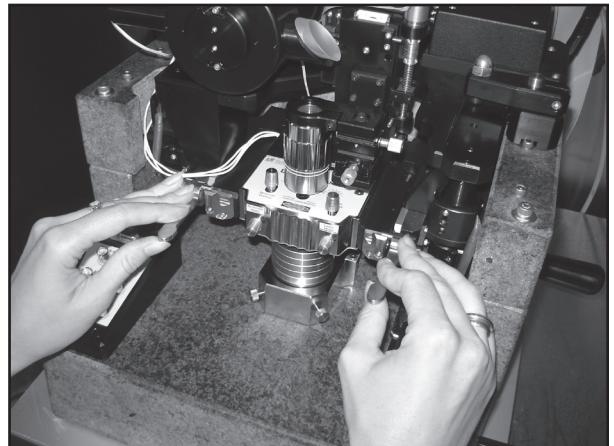


Figure 2.10: Turn the knobs to disengage the scanner head



Figure 2.11: Slide the scanner head toward you

- Grasp the handles on the front of the scanner head (Figure 2.11), and gently slide the scanner head all the way forward.

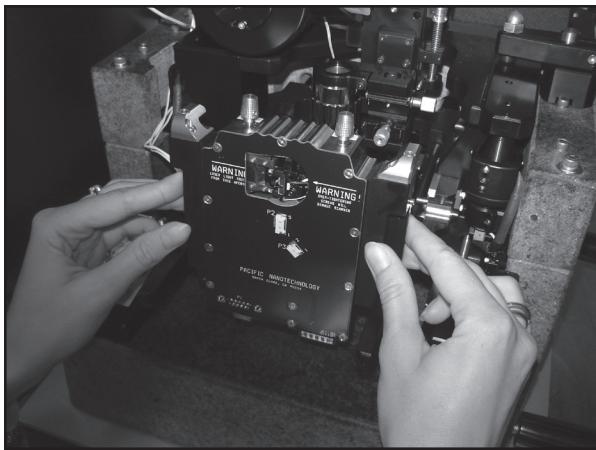


Figure 2.12: Rotate the Scanner Head



CAUTION: Handle AFM probes with care. The cantilever can break off easily if it touches anything or snaps down too forcefully on its magnetic mounting surface on either the scanner or in the probe box.

Probe handling: When loading or removing a probe, pivot the metal plate on the edge opposite the cantilever. This protects the cantilever from striking the magnetic mounting surface and also prevents the plate from snapping down too forcefully, which may damage the probe.

5. Carefully rotate the scanner head up about 90 degrees, as shown in Figure 2.12.

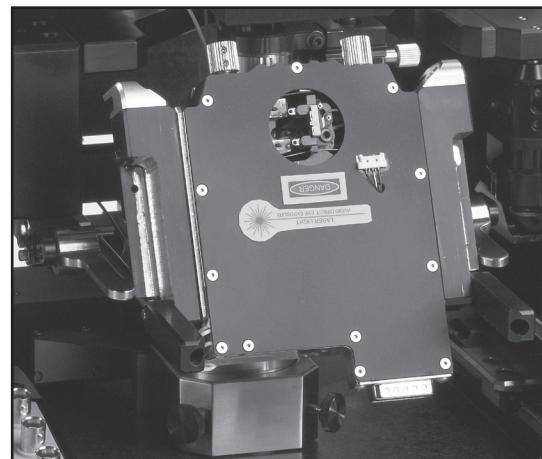


Figure 2.13: Probe Exchange Position

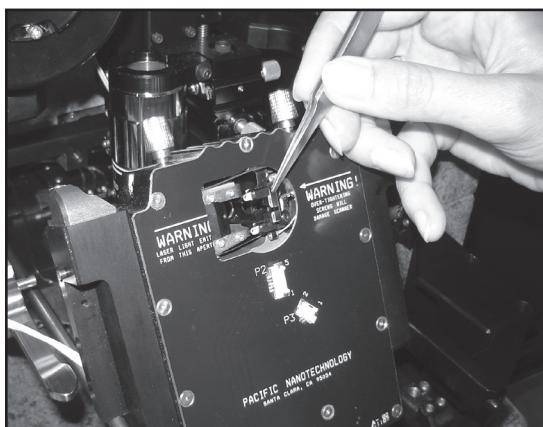


Figure 2.14: Removing the Probe

6. To remove a probe from the scanner:
 - Use tweezers to grasp the metal plate as indicated in Figure 2.14.
 - Carefully rotate the tweezers so the cantilever side of the metal plate lifts up off the magnetic mount first.
 - Set the probe down onto the magnetic strip in the probe box so that the side of the metal plate opposite the cantilever makes contact first.
 - Carefully rotate the tweezers so the cantilever side of the metal plate contacts the magnetic surface as gently as possible.

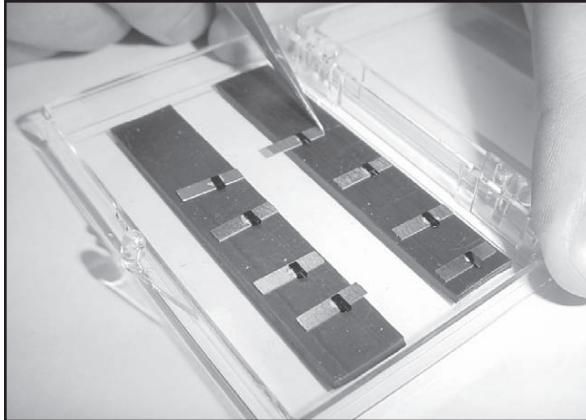


Figure 2.15: Nudge the Probe into Position

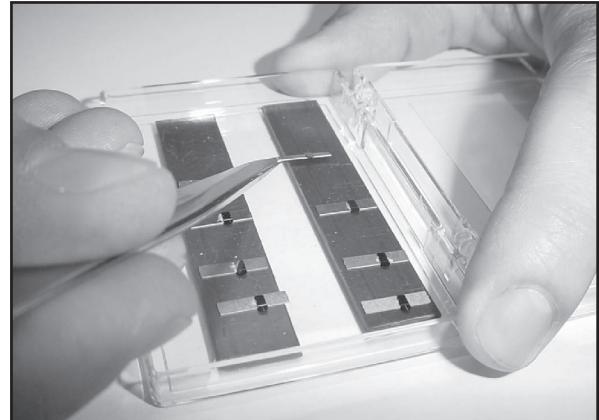


Figure 2.16: Lift the Probe, Cantilever side first

7. To install a new probe in the scanner:

- Use tweezers to nudge the probe so that the metal plate extends over the edge of the magnetic strip in the probe box as shown in Figure 2.15.
- Grasp the metal plate, and carefully rotate the tweezers so the cantilever edge of the metal plate lifts up off the magnetic strip first as shown in Figure 2.16.
- Place the probe onto the magnetic mount in the scan head so that the side of the metal plate opposite the cantilever fits into the L-shaped pocket.
- Use tweezers to push the metal plate flush against the “L” as shown in Figure 2.17.
- Hold the scanner head by the handles and rotate it back to the level position.
- Gently slide the scanner back toward the stage until you feel some resistance.
- Turn the probe exchange knobs up 1/4 turn to lock the scanner head into place.

Once the scanner is locked in position, the Restore button can be clicked. It will restore the Focus and Z motors to their previous positions.

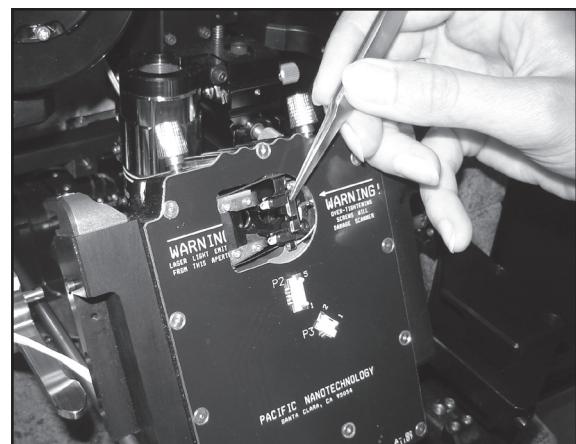


Figure 2.17: Mounted Probe

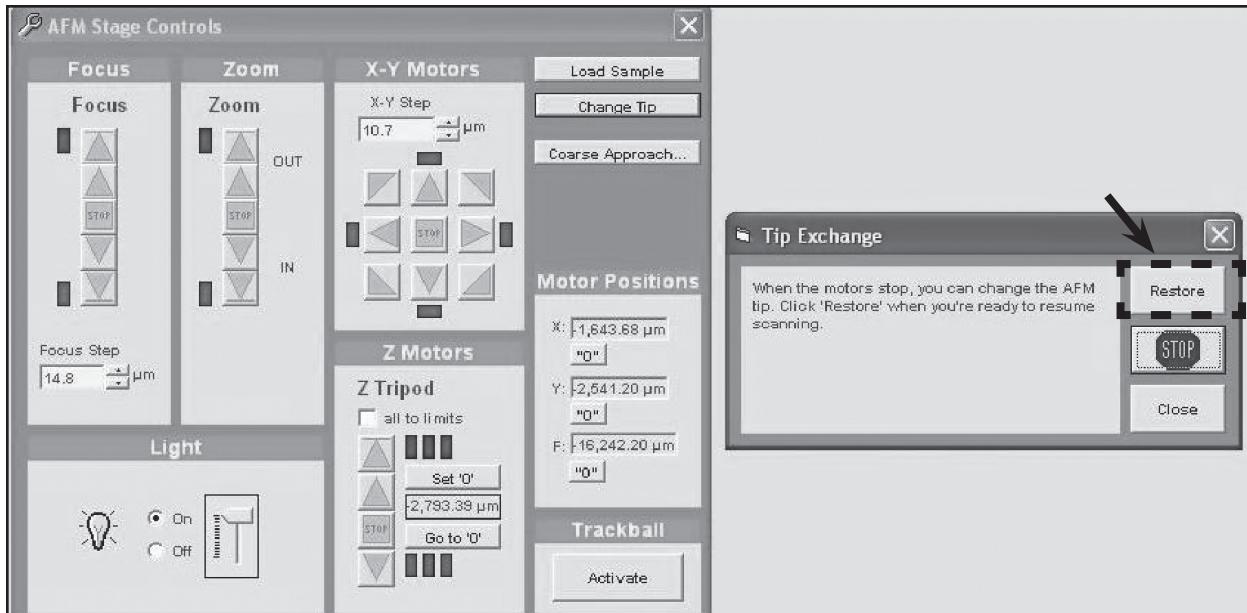


Figure 2.18: Tip Exchange Wizard (accessed from AFM Stage Controls window)

LOAD SAMPLE

Sometimes the presence of a sample can make laser alignment more difficult. Therefore you may want to load the sample after laser alignment and tuning in some instances.



CAUTION: To prevent damage to your scanner, probe, and sample, be sure you have retracted the tip and raised the Z scanner (as described in the following steps) before moving the puck.

To load a sample:

1. Click Stage from the EZMode™ Toolbar.
2. Use the focus controls to bring the probe cantilever into focus on the video monitor.
3. Click the Up button (Figure 2.19) to raise the Z motors until there is at least a few millimeters of clearance between the probe and the sample surface [or puck if no sample is loaded].

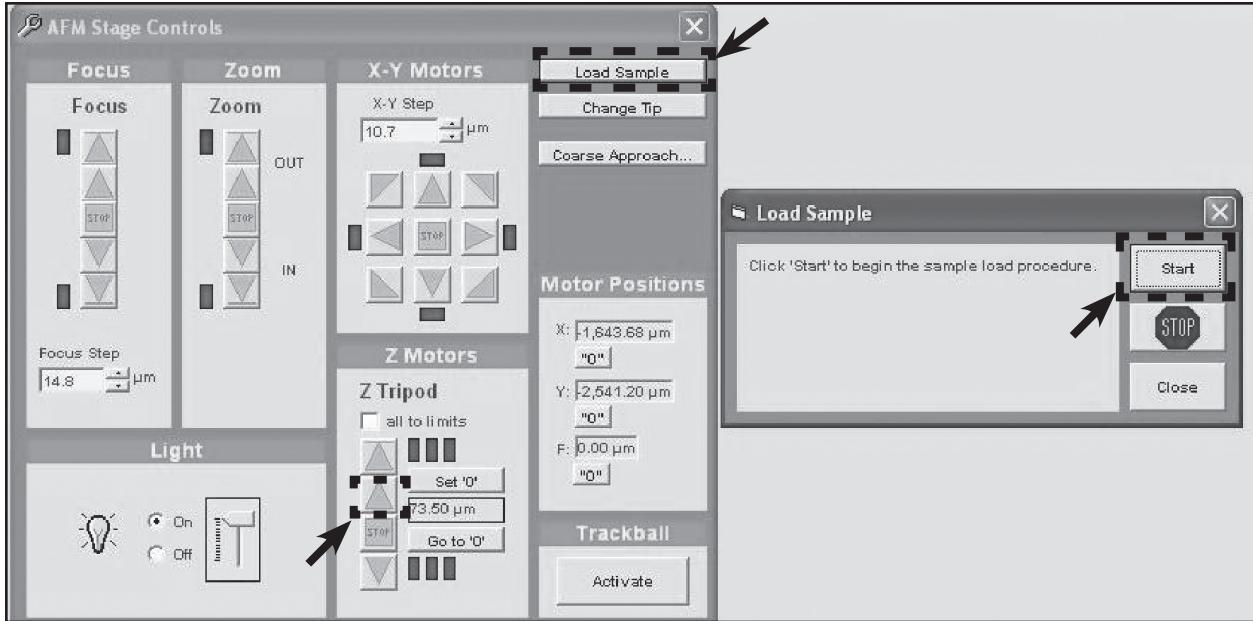


Figure 2.19: Raise the Probe Tip away from the Sample, Click Load Sample button and Start.

4. Click the Load Sample button and then the Start button [see Figure 2.19]. The motorized X-Y stage will move the puck fully forward.

CAUTION

CAUTION: Whenever you engage the motorized X-Y stage, be sure the probe is a safe distance above the sample puck.

5. Being careful not to touch the probe, lift the sample puck out of the pin hole [see Figure 2.20].

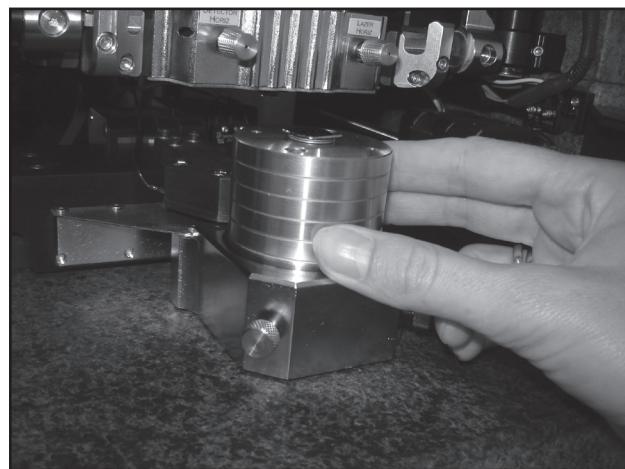


Figure 2.20: Remove Puck

6. Use tweezers to mount the PNI AFM reference on the center of the puck. The sample is held in place magnetically (Figure 2.21). If the PNI reference is already installed on the sample puck, skip to step #7.



Figure 2.21: Mounting the Sample



Figure 2.22: Fit the Sample Puck into the pin hole on the base puck

9. Click the Restore button on the Load Sample window. The motorized X-Y stage will return the puck to its original position. (Figure 2.23)

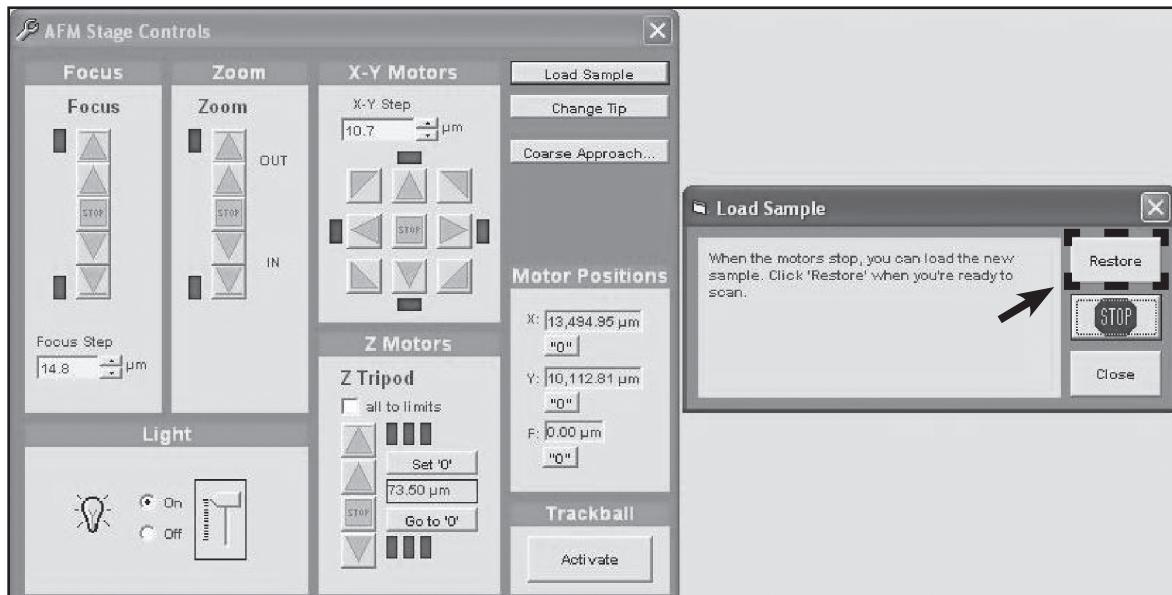


Figure 2.23: Return Sample Puck to initial X-Y position

ALIGN LASER AND DETECTOR

The probe cantilever should already be in focus on the video monitor (per step 2 of the Load Sample section). If you cannot find the probe on the monitor:

- The probe may not have been installed properly. Repeat the probe installation procedure to make sure the probe is seated squarely in the “L” mount.
- The focus lens field of view may need to be adjusted in X-Y, using the adjustment screws. This is usually necessary when switching between a contact and close-contact probe, due to the difference in cantilever length.
- You may need to reposition the focus lens up or down.

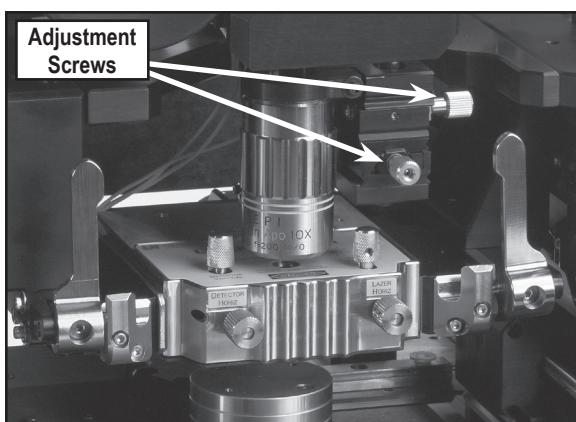


Figure 2.24: Field of View Knobs

You can confirm that you have installed a contact cantilever by noting the difference in length between contact and close-contact cantilevers, as shown in Chapter 1.

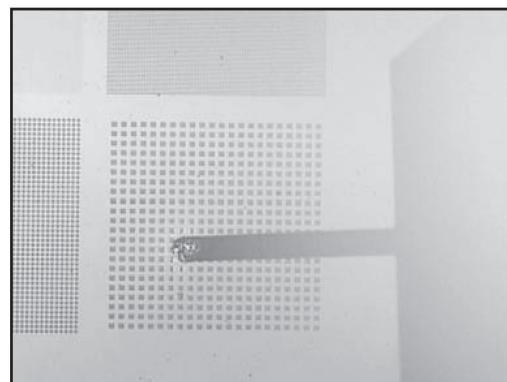


Figure 2.25: Contact Probe as seen in Optical View

ALIGN LASER

To align the laser, open the Red Dot Alignment window by clicking Align Laser on the EZMode™ Toolbar.



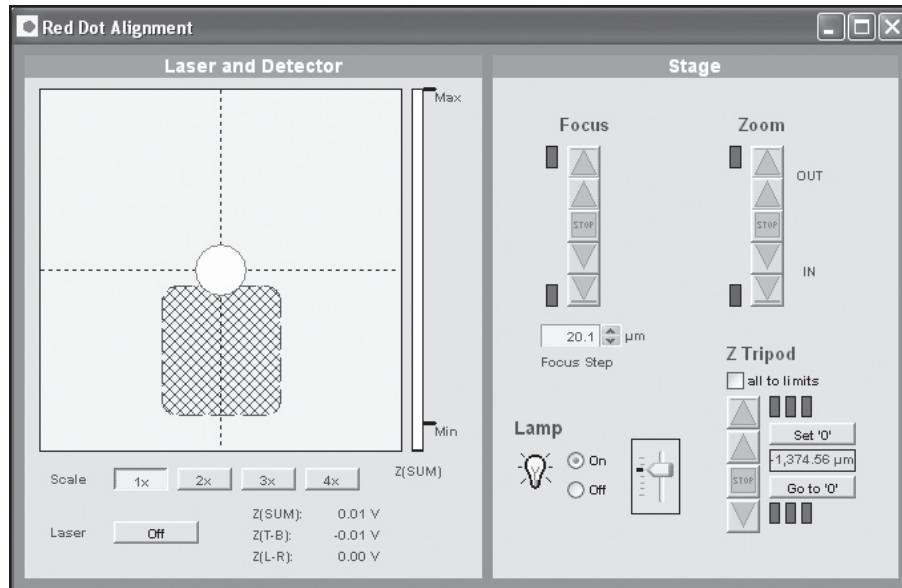


Figure 2.26: Red Dot Window Controls

The red dot alignment procedure has 3 goals:

1. Position the laser spot on the back of the cantilever
2. Position the photo detector in the center of the reflected laser beam
3. Achieve a maximum measured signal strength, Z(SUM)

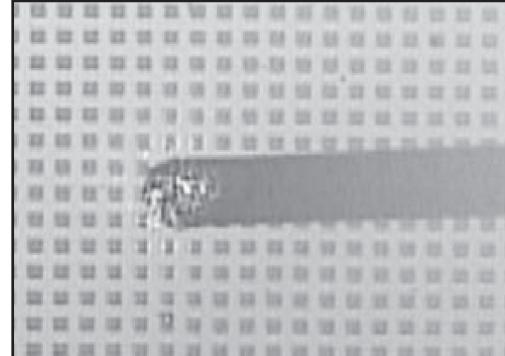


Figure 2.27: Centering the Laser Spot on the Cantilever

Watch the video monitor as you adjust the laser alignment knobs on the scanner head to bring the laser spot onto the back of the cantilever. The laser spot should be centered on the cantilever, **not too close to the end**, as shown in Figure 2.27.

ALIGN DETECTOR

Watch the red dot (in the Red Dot Alignment window shown in Figure 2.28) as you turn the detector alignment knobs to bring the red dot into the top of the crosshatched box. The red dot should be positioned just below the upper border of the box and be centered on the vertical axis.

Please Note: When you are adjusting the detector alignment knobs, if the red dot moves toward the center but the Z(SUM) value is going down, you are moving in the wrong direction. Therefore, rotate the knob in the opposite direction and verify that Z(SUM) increases.

Make sure the Z(SUM) value (signal intensity) is above the minimum. If it is not, you need to re-seat or replace the probe.

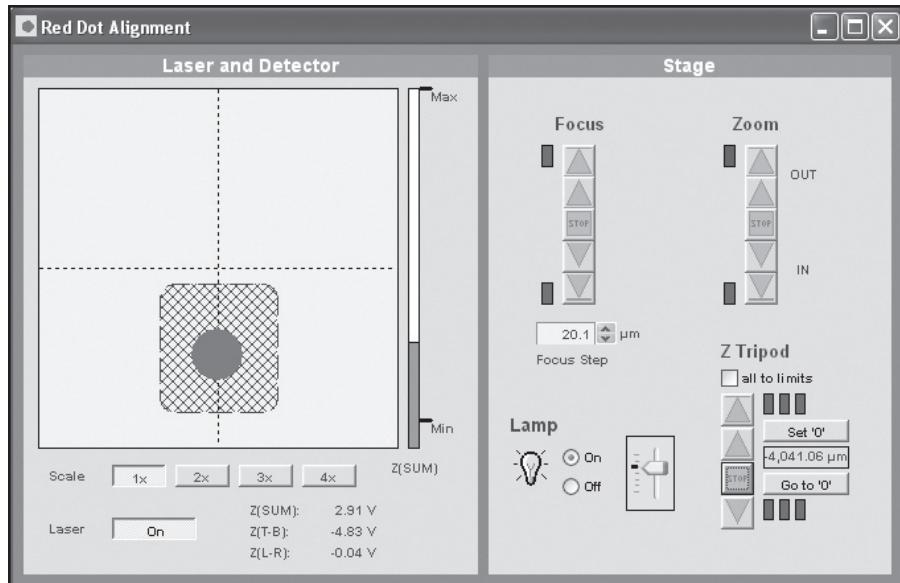


Figure 2.28: Aligning the Detector

APPROACHING THE SAMPLE

Positioning the probe to scan a sample is accomplished in three steps: Coarse Approach, Locating the Field of Interest, and Final Tip Approach.

COURSE APPROACH

Coarse approach is used to bring the probe into close proximity to the sample surface.

1. Click Coarse Approach on Stage Control Window (see Figure 2.29).

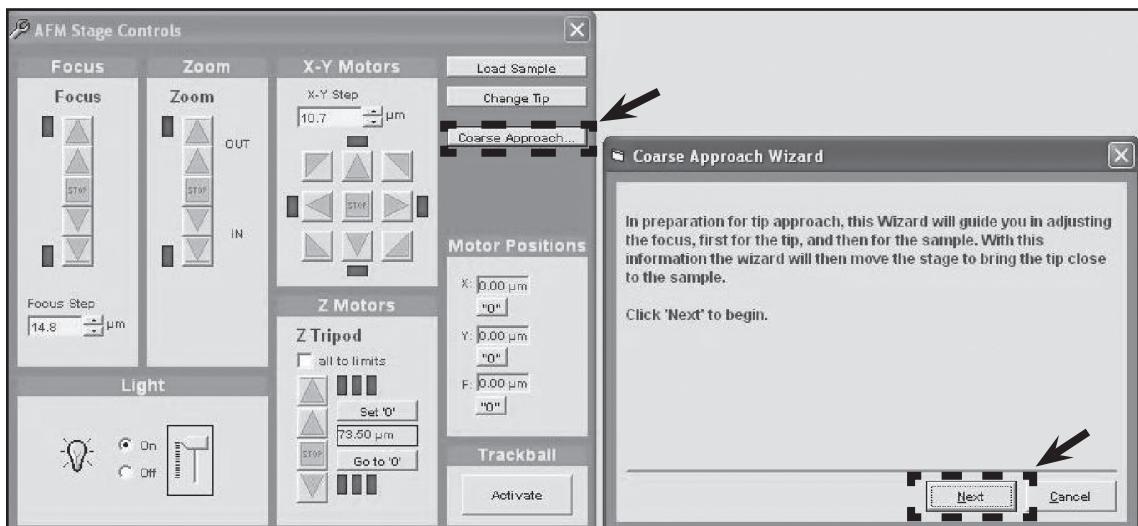


Figure 2.29: Course Approach Start Dialog Box

2. Click Next on the Course Approach Wizard and follow the instructions as shown below. First focus on the probe, then focus on the sample. Click Next after each step.

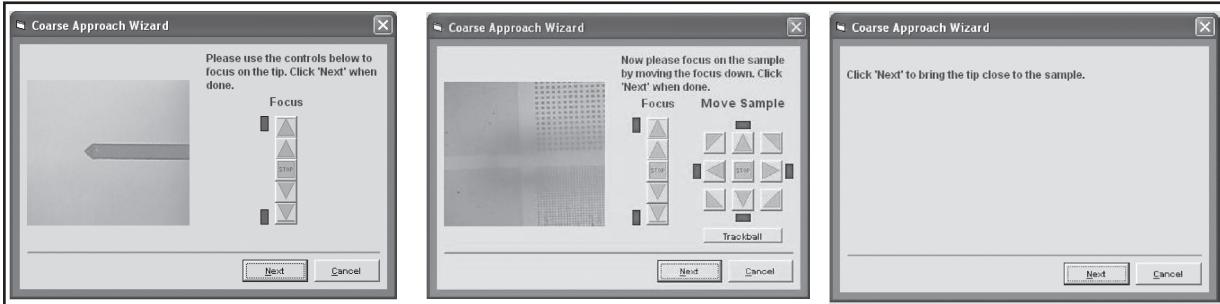


Figure 2.30: Coarse Approach Wizard Screens

LOCATING FEATURES OF INTEREST

After Coarse Approach is complete, features of interest can be located by using the X-Y step controls. Both coarse and fine movement are possible. If necessary, you can orient the Sample by simply rotating the Puck by hand.

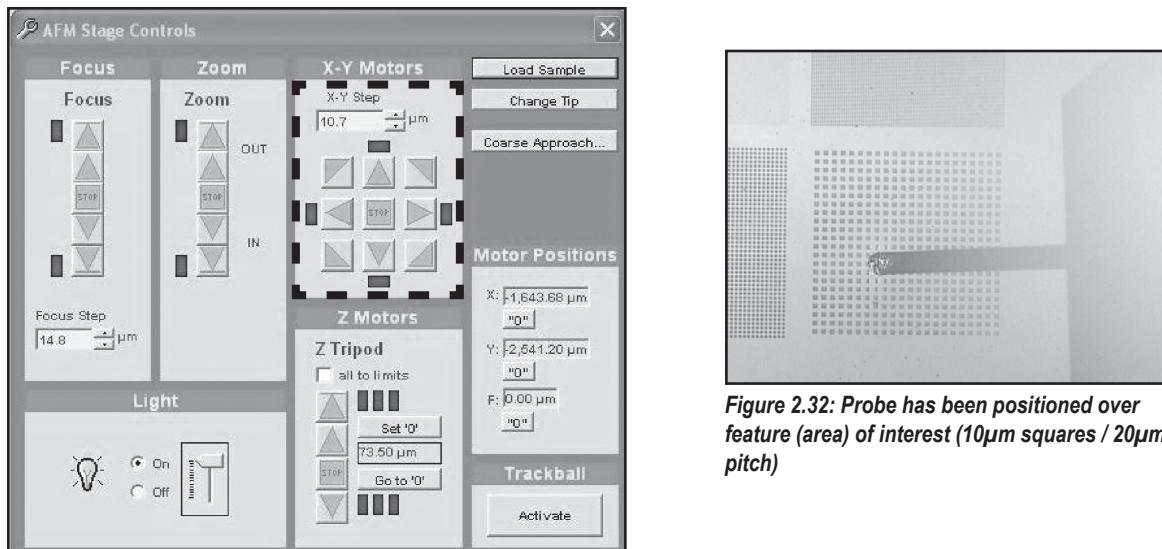


Figure 2.31: X-Y Stage Controls

FINAL TIP APPROACH

You are now ready to perform the final approach to the Sample. Make sure the cantilever is in focus, then click the Tip Approach button on the Toolbar.



CAUTION: Once the Tip Approach is complete, and the tip is in contact with the sample surface, do not exit the SPM Cockpit™ software or turn off the Controller without first retracting the tip. Doing so may cause damage to the tip, scanner, and sample.

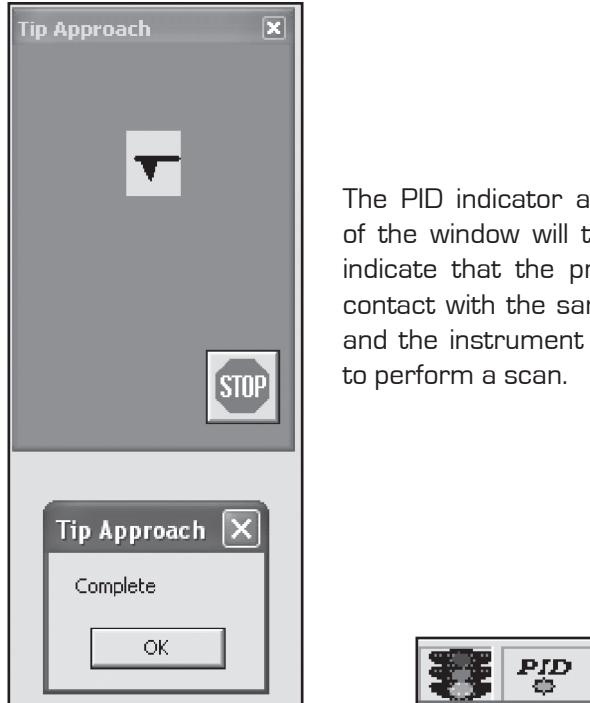


Figure 2.33: Tip Approach confirmation and PID indicator

SCAN SAMPLE

1. Click the Scan Sample button on the Toolbar

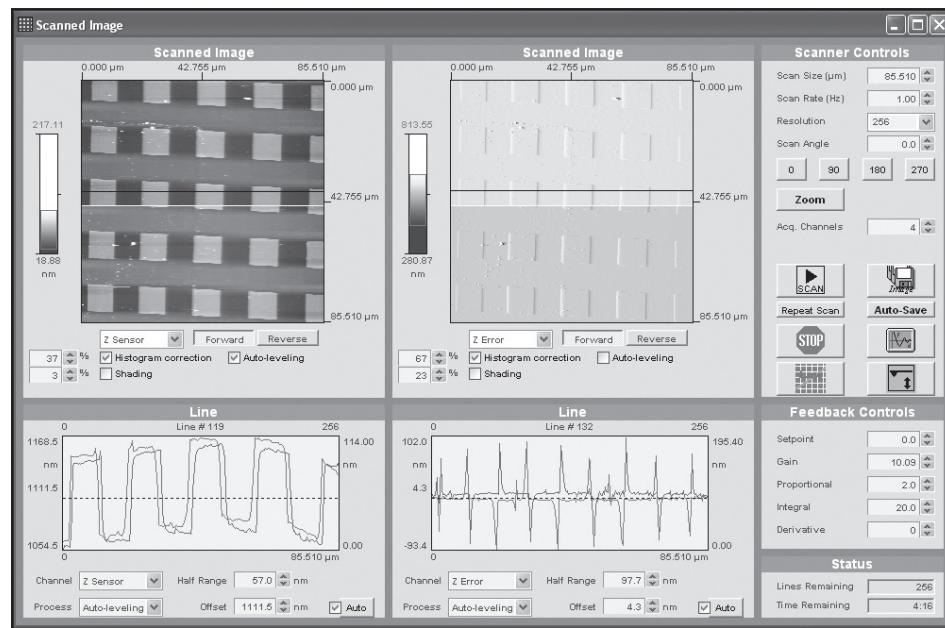


Figure 2.34: Scanned Image Window

2. Set the scanner controls as follows:

- Scan Size: Leave as is – the default size, which is entered by the system when the calibration routine is performed, is the maximum scan area for your scanner.
- Scan Rate: 1 Hz
- Resolution: 256
- Scan Angle: 0
- Acq. Channels: 4
- Topography Gain: 1x

3. Set the feedback controls as follows:

- Setpoint: 0
- Gain: 10t
- Proportional: 2
- Integral: 20
- Derivative: 0

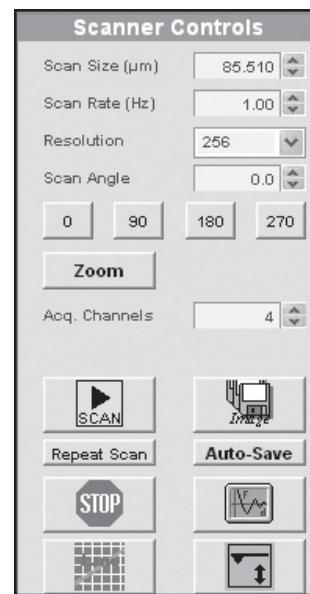


Figure 2.35: Scanner Controls

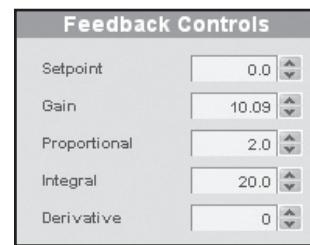


Figure 2.36: Feedback Controls

4. Select the Z(SEN) and Z(ERR) channels from the drop-down menus beneath the two image displays, and for each display, select Forward (or Reverse), Histogram Correction, and Auto-Leveling.
5. Select the Z(SEN) and Z(ERR) channels from the drop-down menus of the two corresponding line scan displays.

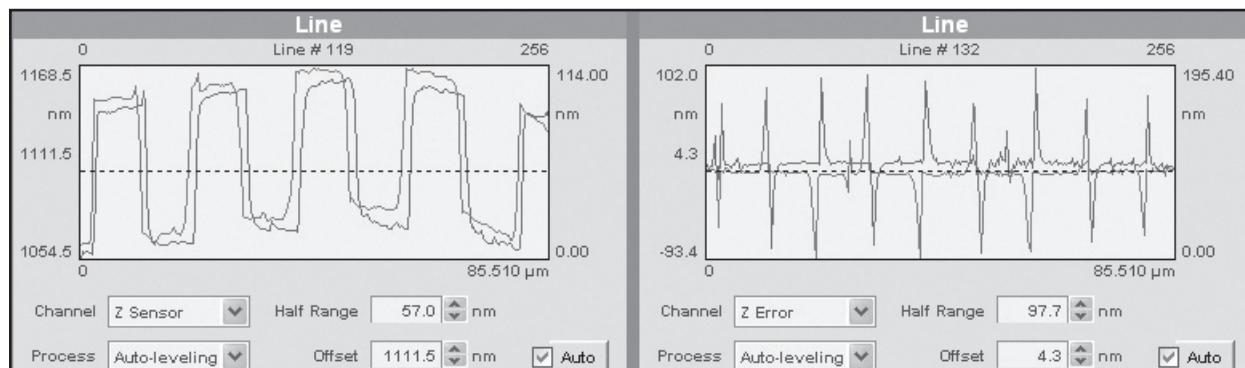


Figure 2.37: Line Profile Settings

6. Click the Scan button to start a scan.

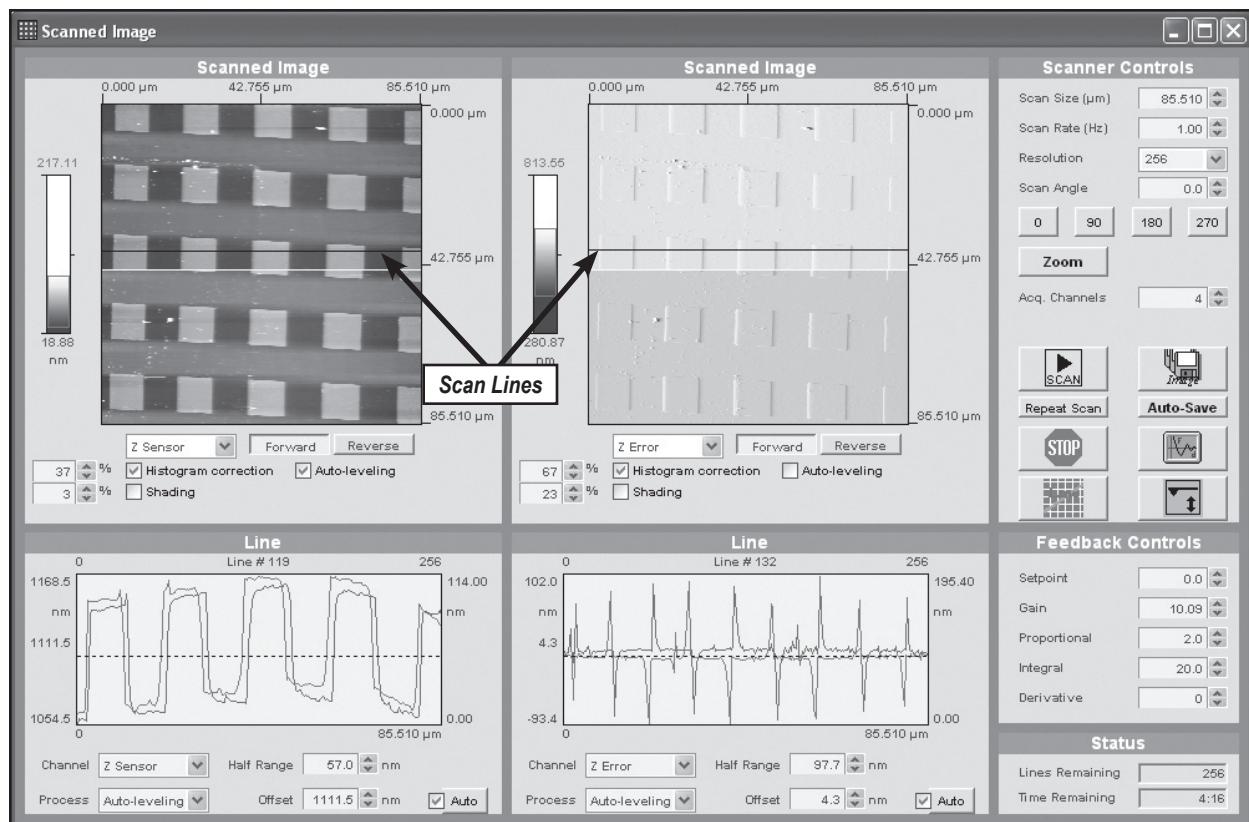


Figure 2.38: Scan in progress

- The images of the selected channels will appear line-by-line in the displays. If no data is generated, the detector may be out of alignment. In this case, click Tip Retract from the Toolbar, re-align the red dot (Page 20), and try another scan.
 - To adjust the Z scale of the images, left-click and drag in the bar to the left of each display to select a Z height range.
 - To view a single line scan, hold down the SHIFT key and left click in either image display to define a horizontal line across the image. Make sure the line includes the square features. The line scan profile for the Z(SEN) channel should resemble the shape and size of the 10µm features. (See line profile in lower left of Figure 2.38.)
- To perform additional scans, click Scan again, or click the Repeat Scan button to take continuous scans of the same region.
 - To zoom to a new scan region:
 - Left-click and drag in the image display to define a scan area.
 - Click OK to confirm the new scan region (Figure 2.40).



Figure 2.39: Selection of Z Height Range

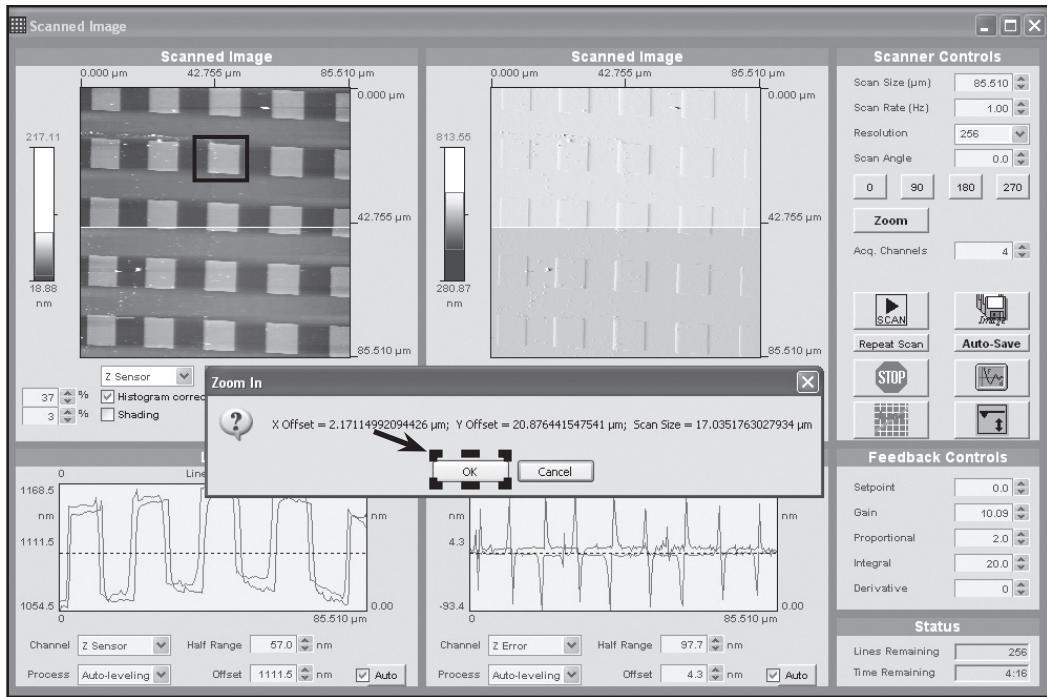


Figure 2.40: Zooming in on features dialog box

- c] Click the Scan button to take a new scan of the area or feature you have selected (Figure 2.41).

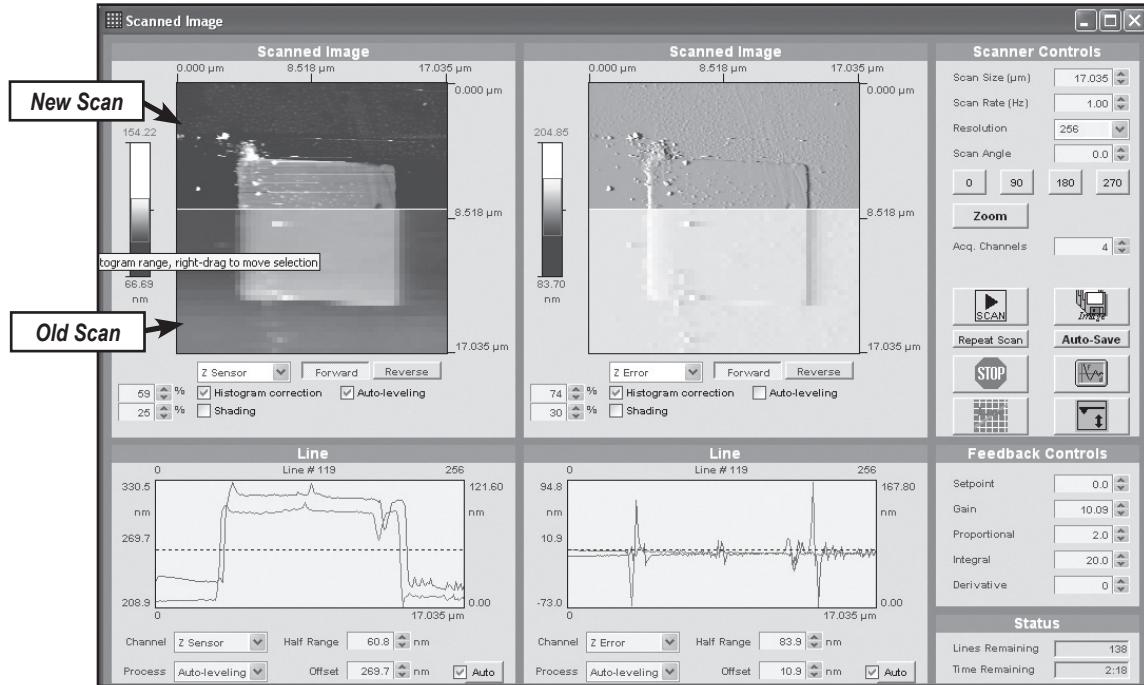


Figure 2.41: Acquiring smaller scan size

9. To scan at an angle, enter the desired scan angle (from 0 to 360°) in the Scan Angle box. Click the Scan button to start a new scan. To scan a larger area at an angle, enter both the desired size and angle (Figure 2.42).

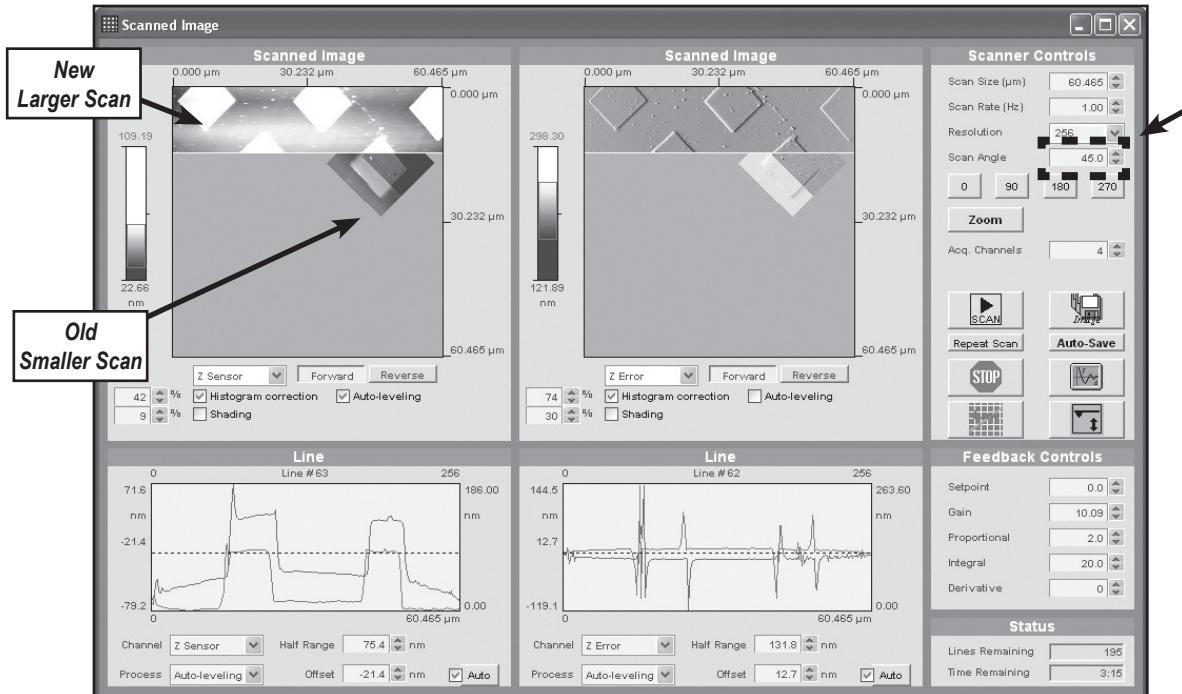


Figure 2.42: Scanning at an angle

The scan size will change depending on the angle selected, and the previously taken scan will rotate by the designated angle. As scanning progresses, the newly acquired image will appear over the previous scan and eventually replace it, Figure 2.43.

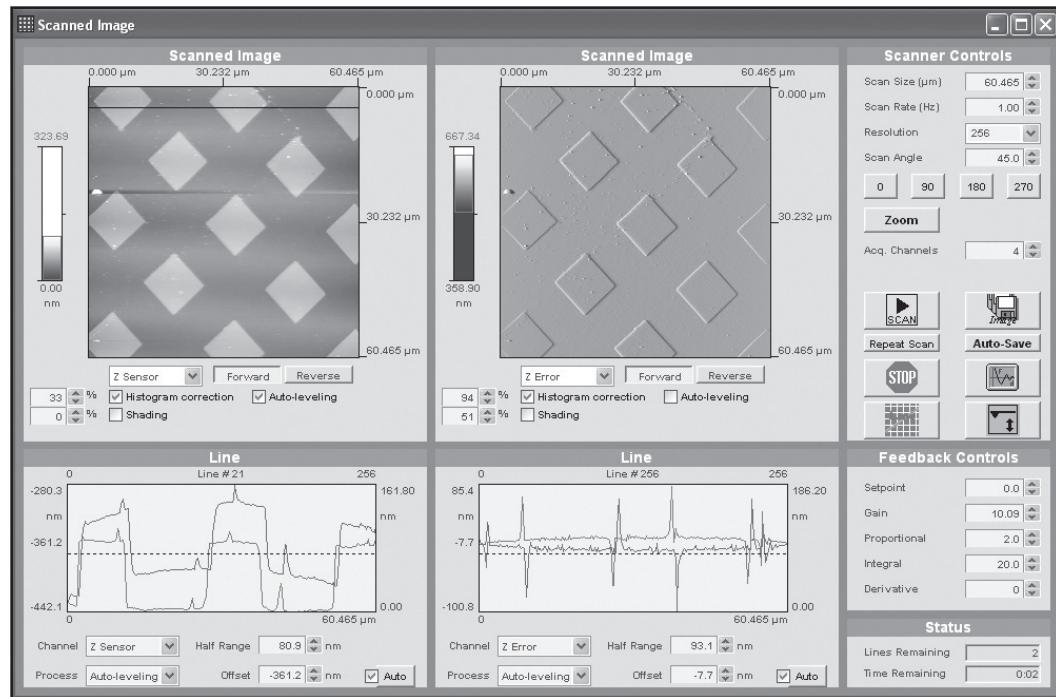


Figure 2.43: Completed frame scanned at 45°

IMAGE PROCESSING

1. Click Image Processing on the EZMode™ Toolbar.



2. Click Select Source to open an image for processing.

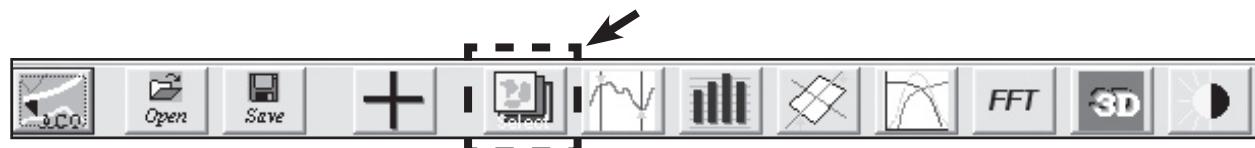
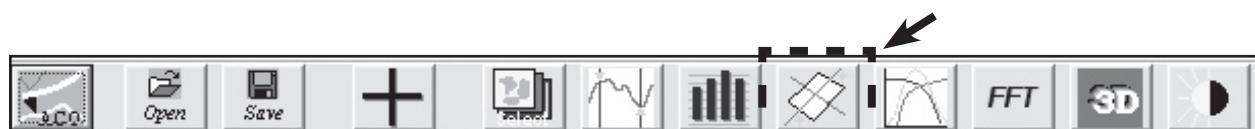


Figure 2.44: Image Processing Module

3. Select the desired acquisition channel and direction for the image to be processed. The raw image data will not resemble the image in the scan image window, because real-time image processing was applied as it was being acquired.
4. Click the Plane Correction button as shown in Figure 2.45 to apply Plane Correction.



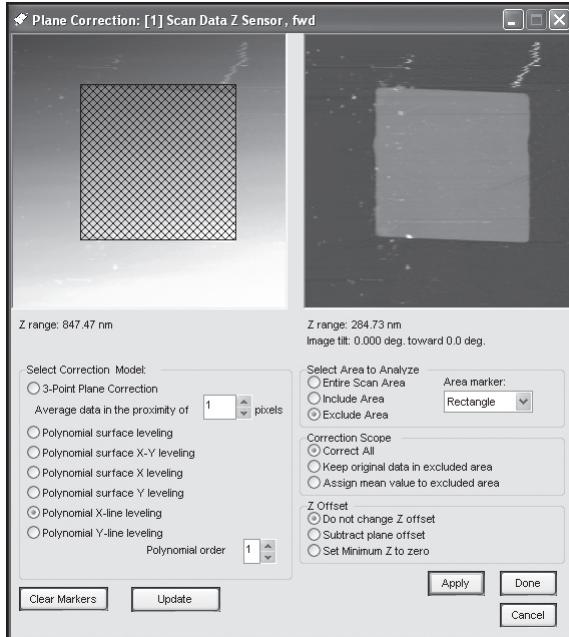


Figure 2.45: Plane Correction Dialog Window

- a] Under Select Correction Model, select:
 - Polynomial X-line leveling
 - Polynomial order: 1
 - b] Under Select Area to Analyze, select:
 - Exclude Area
 - Area Marker: Rectangle
 - c] To exclude the features on the PNI AFM reference, use the mouse to left click and drag in the image display so that every feature (both whole and partial) is completely covered.
 - d] Click Apply and the leveled image appears in the right-hand display.
5. To do line profile measurements, select the button shown.



- a] Under Profile Mode, select Horizontal.
- b] Under Display Mode, click Fit Vertical and Horizontal Scale.
- c] Left-click in the image display to select a data line.
- d] Left-click in the line display to make two measurement markers. In the example below, measurements are on either side of an edge of a feature on the PNI AFM reference. The measurement results displayed to the right indicate a Z-height of approximately 77 nm.

NOTE: These measurements should not be used to calibrate your instrument!

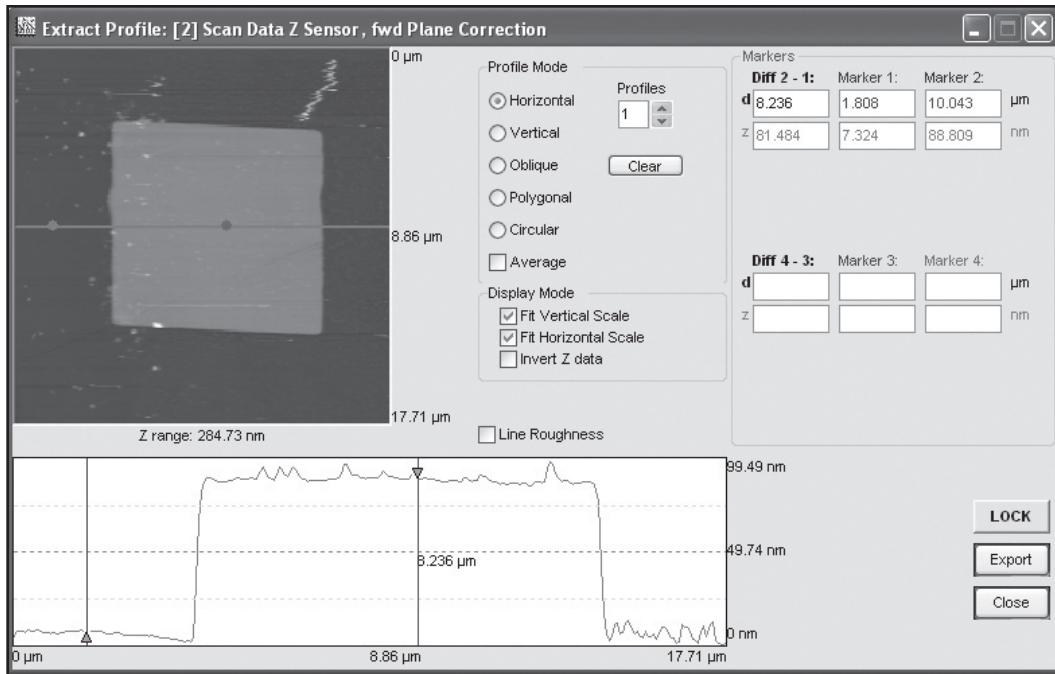


Figure 2.49: Line Profile Tool

6. Select the Histogram tool, and use the slider bars to mark the middle of the two ranges where the Z data points are clustered.

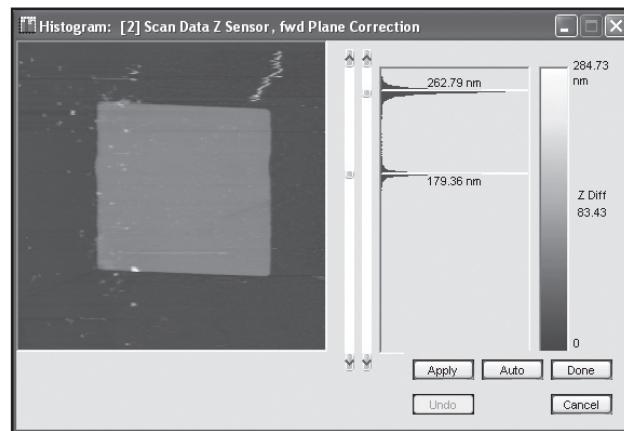
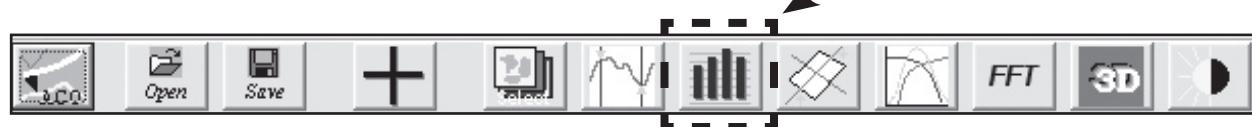


Figure 2.50: Histogram Tool

The Z Diff measurement on the vertical bar confirms the approximately 77 nm height of the PNI AFM reference features.

7. To save any of your processed images, select File / Save Image(s).
8. To view 3-D images of the topography, select the 3D button.

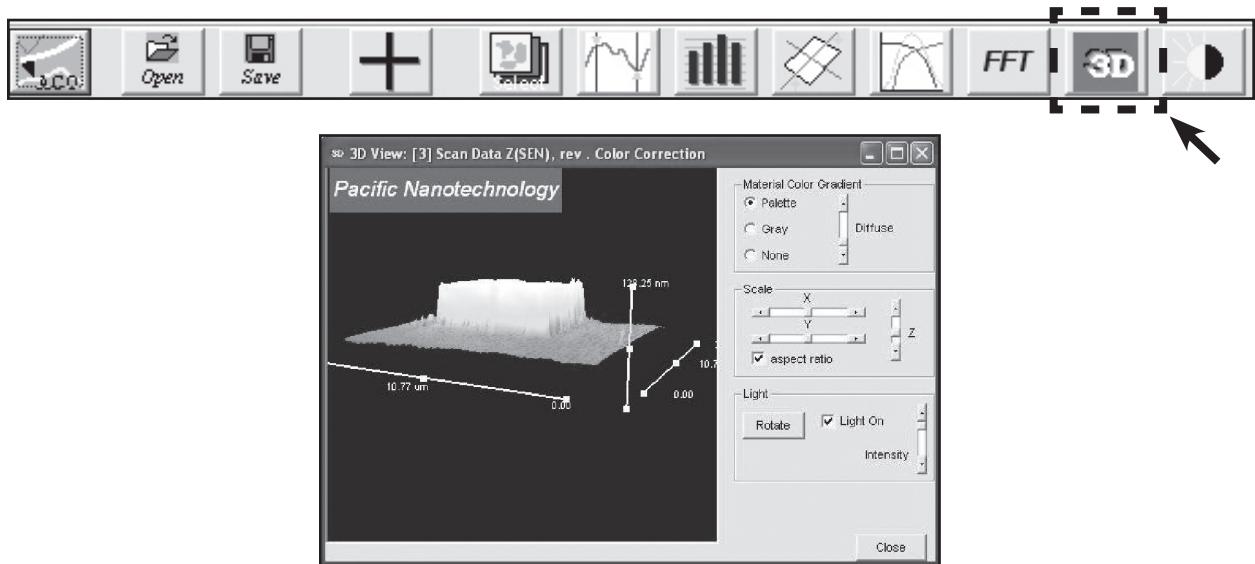


Figure 2.51: 3D View

9. Click the  button to return to the acquisition module.
10. Click Tip Retract on the EZMode™ Toolbar. It is now safe to exit the SPM Cockpit™ software and turn off the Controller.



CAUTION: To prevent damage to your scanner, probe, and sample, be sure to retract the tip before exiting SPM Cockpit™ software or turning off the Controller.

Chapter 3

Tutorial: Close Contact EZMode™ Light Lever

BEFORE YOU BEGIN

This tutorial details the steps for taking a close contact AFM image of the PNI AFM reference using EZMode™.

WARNING: Before operating the Nano-DST™ AFM, make sure you are familiar with the safety information on page iv.

POWERING UP THE SYSTEM

1. Turn on the Master Computer.
2. Launch the SPM Cockpit software.
3. Turn on the Controller.
4. Turn on the video monitor.

START

- 1 Select Settings | Toolbar Mode | EZMode™.

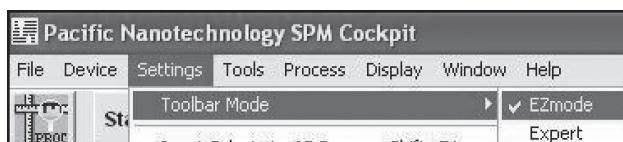


Figure 3.1: SPM Cockpit™

2. Click the Start button on the EZMode™ toolbar.



Figure 3.2: EZMode™ Toolbar

3. Click Retract Tip, and click OK when complete.

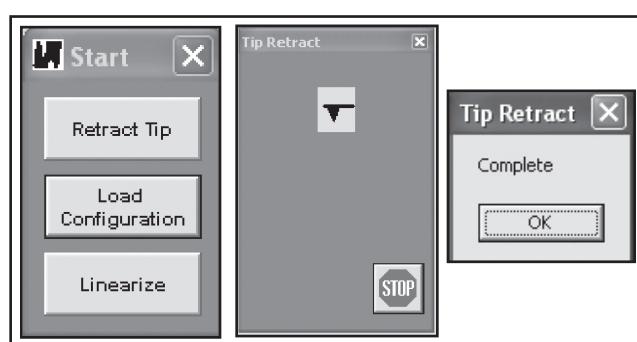


Figure 3.3: Retracting the Tip

- Click Load Configuration, select the PNI-supplied close contact mode configuration file, and click Open. This file is located in the ConfigFiles folder in the SPM Cockpit™ directory. It has the format nfxxxxCloseContact.PNI_Config, where xxxx is the serial number of your Light Lever scanner.

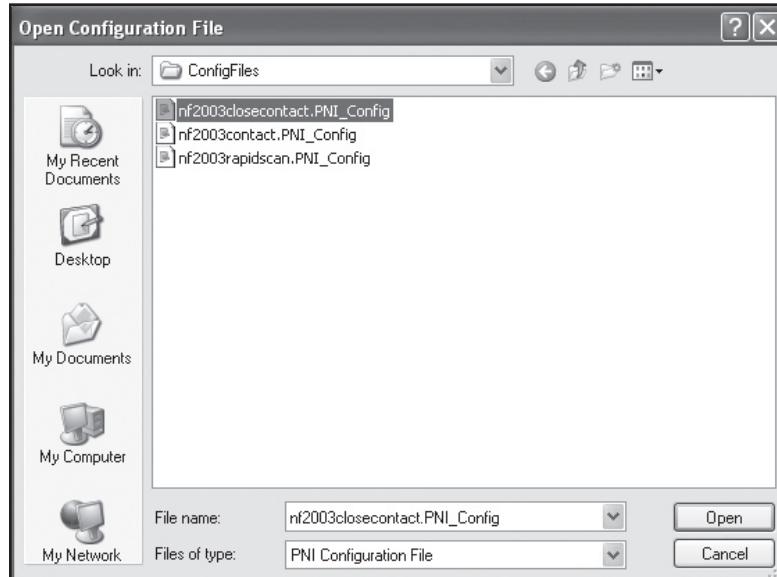


Figure 3.4: Loading a Configuration File

- Click Linearize, check both boxes, and click OK.

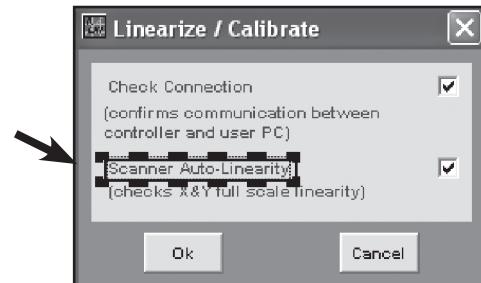


Figure 3.5: Check Connection and Scanner Auto-Linearity

- Click OK when the communication between the Master Computer and the Controller is confirmed. If there is no connection, you need to exit the SPM Cockpit software and restart both the Master Computer and the Controller.



Figure 3.6: Connection Confirmed

- Click Start to proceed with the linearization procedure. This determines the optimum linear range of the x-y feedback sensors.

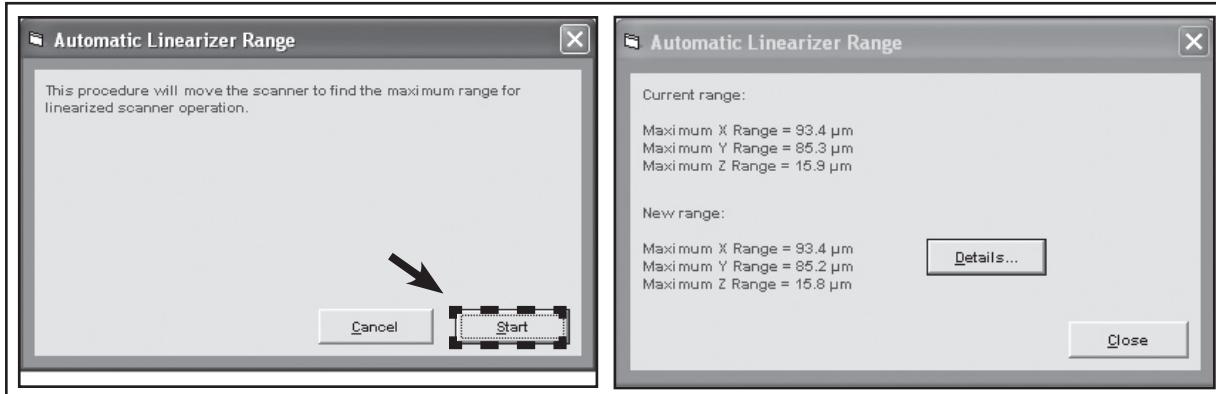


Figure 3.7: Automatic Linearizer Range determination

- Click Accept when the linearization process is complete, and then click Check New Range if desired. X-Y sensor readings are recorded while the scanner is moved. Straight diagonal lines in both graphs indicate a good result.
- Click Select Mode on the Toolbar, select Close Contact in the dialog box, and click OK.

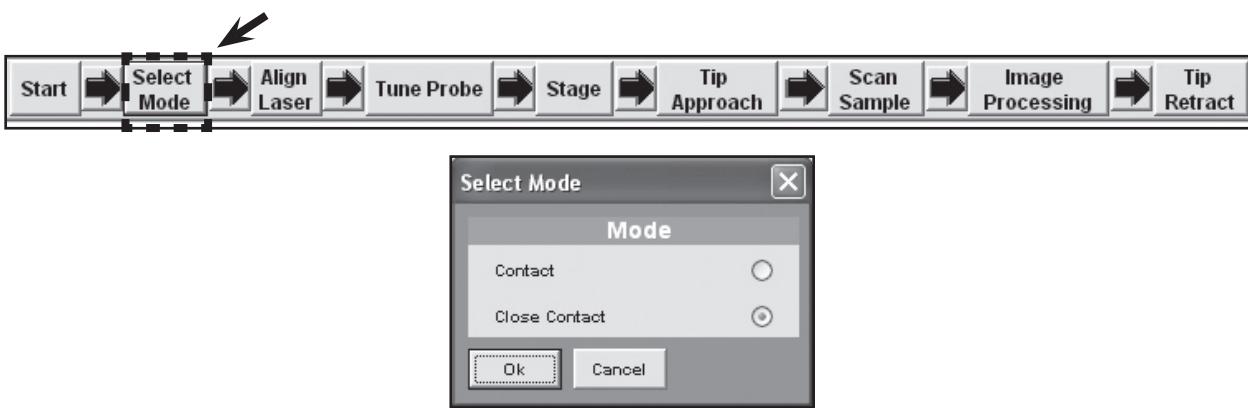


Figure 3.8: Select Mode

CHANGE PROBE

To operate in contact mode, you need to use a close contact probe. Probes should be stored in the supplied boxes marked "Close-contact," as the difference between various types of probes is not easily visible to the naked eye.

- Click Stage from the EZMode toolbar, click Change Tip in the AFM Stage Controls window, then click Start in the Tip Exchange Wizard.



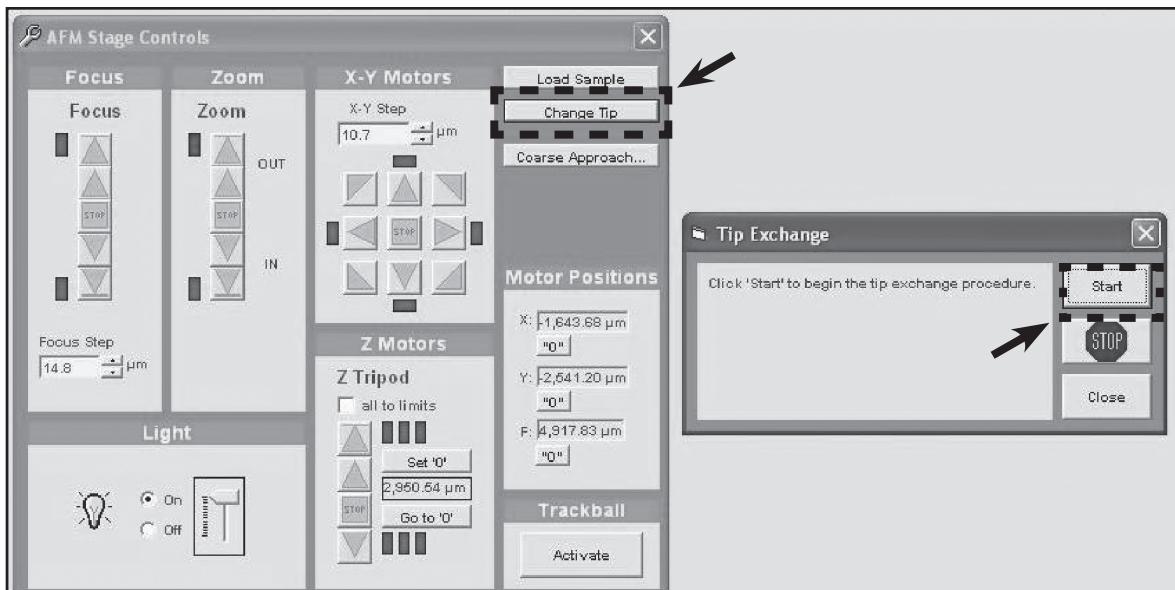


Figure 3.9: Change Tip puts the scanner head into the appropriate position to replace the tip. The Start button in the dialog box will raise the probe tip away from the sample.

2. When motor movement is complete, remove the sample puck.
3. Rotate the probe exchange knobs on the side of the scanner head backwards (away from you) 1/4 turn (Figure 3.10). The scanner head is now able to slide forward about an inch.

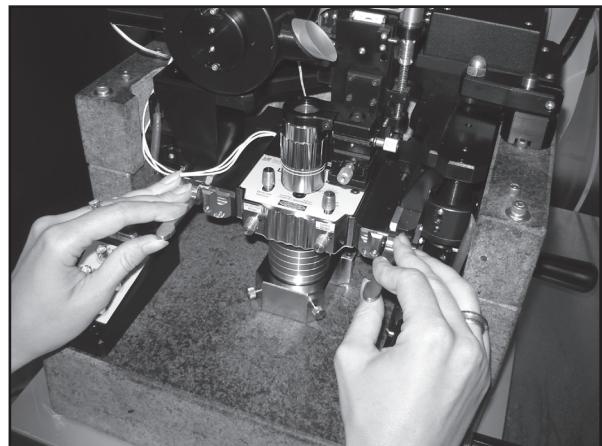


Figure 3.10: Turn the knobs to release the scanner head



Figure 3.11: Slide the scanner head toward you

4. Grasp the handles on the front of the scanner head (Figure 3.11), and gently slide the scanner head all the way forward.

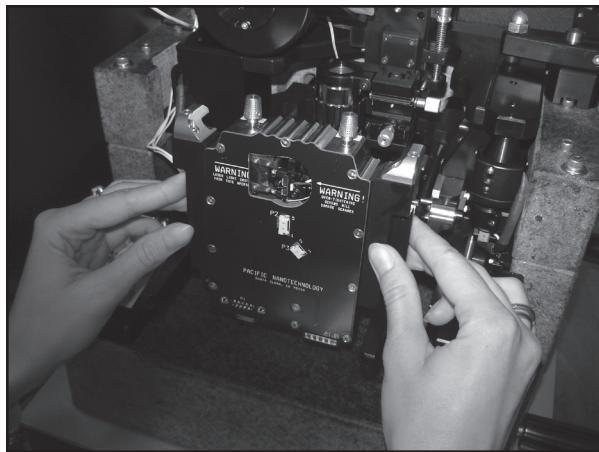


Figure 3.12: Rotate the Scanner Head



CAUTION: Handle AFM probes with care. The cantilever can break off easily if it touches anything or snaps down too forcefully on its magnetic mounting surface on either the scanner or in the probe box.

Probe handling: When loading or removing a probe, pivot the metal plate on the edge opposite the cantilever, as shown below. This protects the cantilever from striking the magnetic mounting surface, and also prevents the plate from snapping down too forcefully, which may damage the probe.

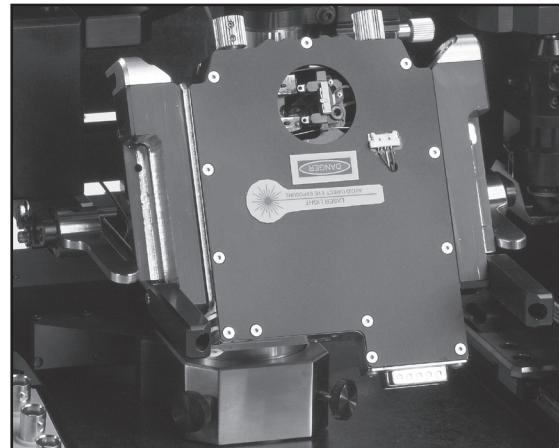


Figure 3.13: Probe Exchange Position

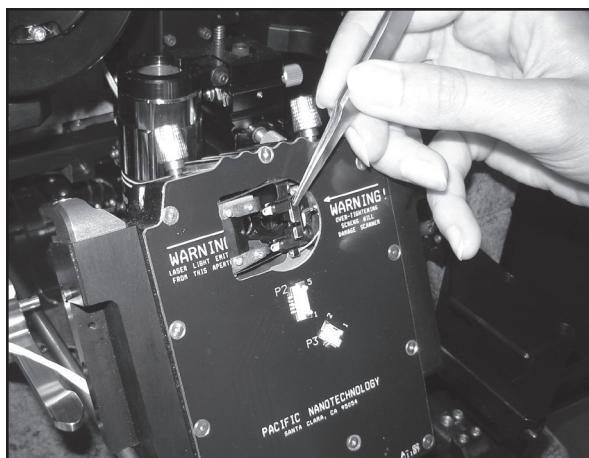


Figure 3.14: Removing the Probe

5. Carefully rotate the scanner head up about 90 degrees, as shown in Figure 3.12.

6. To remove a probe from the scanner:

- Use tweezers to grasp the metal plate as shown in Figure 3.14.
- Carefully rotate the tweezers so the cantilever side of the plate lifts up off the magnetic mount first.
- Set the probe down onto the magnetic strip in the probe box so that the side of the plate opposite the cantilever makes contact first.
- Carefully rotate the tweezers so the cantilever side of the plate contacts the magnetic surface as gently as possible.

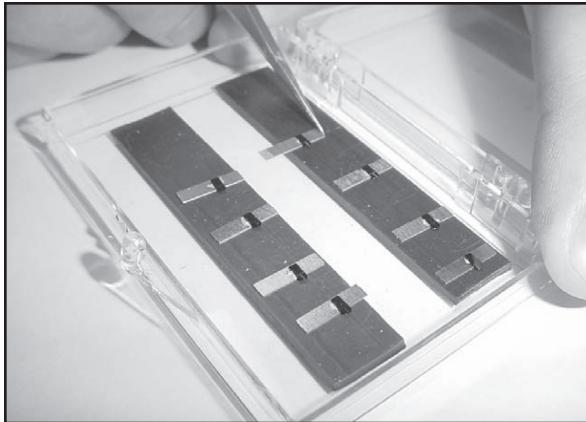


Figure 3.15: Nudge the Probe into Position

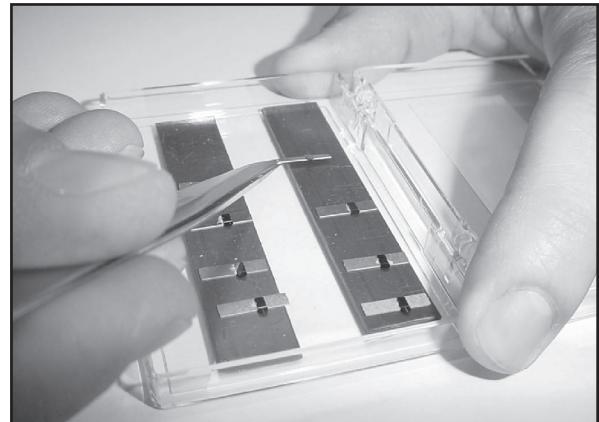


Figure 3.16: Lift the Probe, Cantilever side first

7. To install a new probe in the scanner:

- Use tweezers to nudge the probe so that the metal plate extends over the edge of the magnetic strip in the probe box as shown in Figure 3.15.
- Grasp the metal plate, and carefully rotate the tweezers so the cantilever edge of the metal plate lifts up off the magnetic strip first as shown in Figure 3.16.
- Place the probe onto the magnetic mount in the scan head so the sides of the metal plate opposite the cantilever fits into the L-shaped pocket.
- Use tweezers to push the metal plate flush against the “L” as shown in Figure 3.17.
- Hold the scanner head by the handles and rotate it back to the level position.
- Gently slide the scanner back toward the stage until you feel some resistance.
- Turn the probe exchange knobs up 1/4 turn to lock the scanner head into place.

Once the scanner is locked in position, the Restore button can be clicked. It will restore the Focus and Z motors to their previous positions.

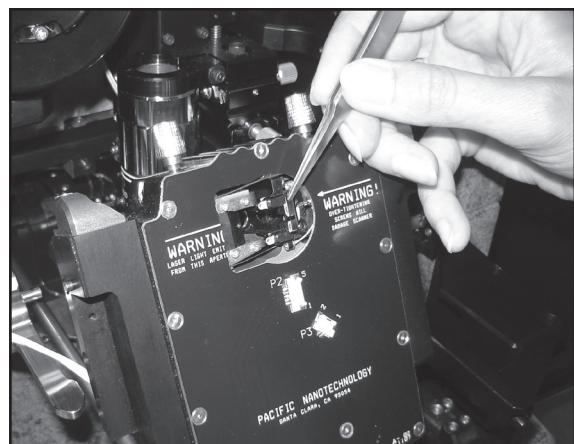


Figure 3.17: Mounted Probe

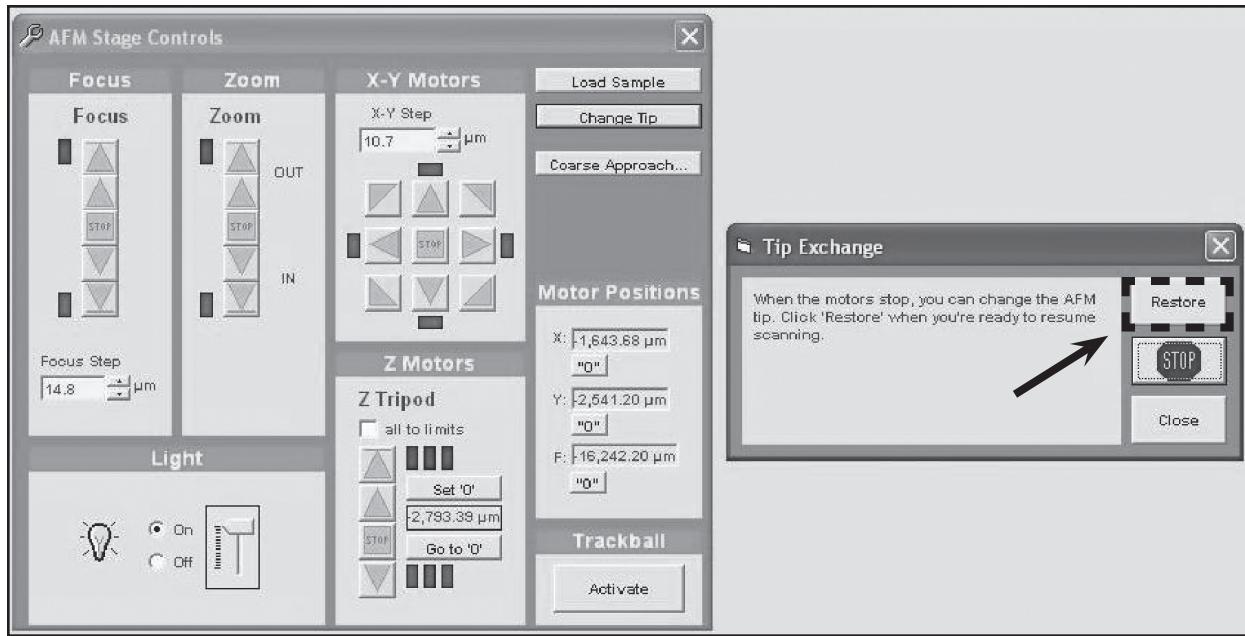
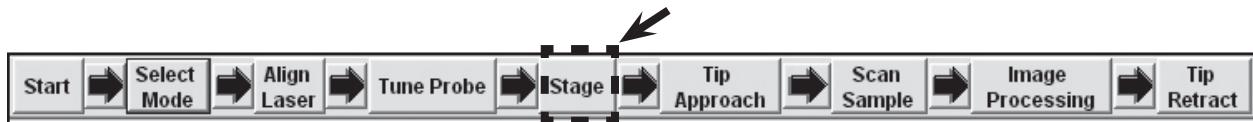


Figure 3.18: Tip Exchange Wizard (accessed from AFM Stage Control Window).

LOAD SAMPLE

Sometimes the presence of a sample can make laser alignment more difficult. Therefore, in some instances, you may want to load the sample after laser alignment and tuning.



CAUTION: To prevent damage to your scanner, probe, and sample, be sure you have retracted the tip and raised the Z scanner (as described in the following steps) before moving the puck.

To load a sample:

1. Click Stage from the EZMode™ toolbar.
2. Use the focus controls to bring the sample surface into focus on the video monitor.
3. Click the Up button (Figure 3.19) to raise the Z motors until there are at least a few millimeters of clearance between the probe and the sample surface (or puck if no sample is loaded).

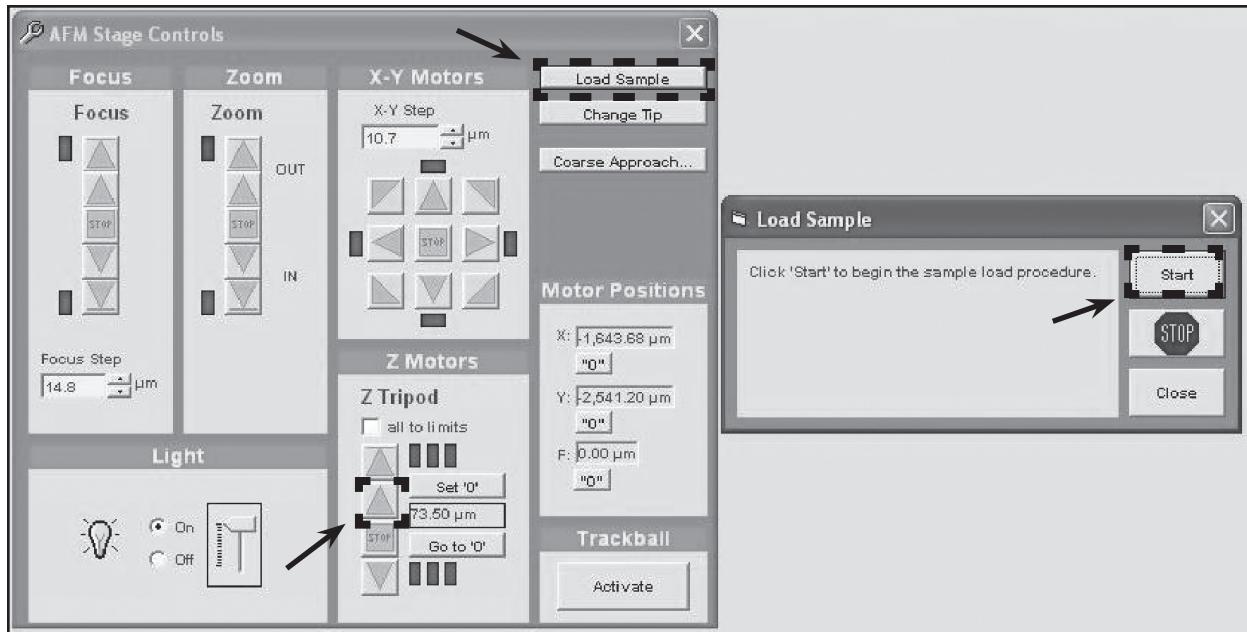


Figure 3.19: To raise the probe tip away from the sample, click Load Sample button and Start.

4. Click the Load Sample button and then the Start button (see Figure 3.19). The motorized X-Y stage will move the puck fully forward.



CAUTION: Whenever you engage the motorized X-Y stage, be sure the probe is a safe distance above the sample/puck.

5. Being careful not to touch the probe, lift the sample puck out of the groove. (Figure 3.20)

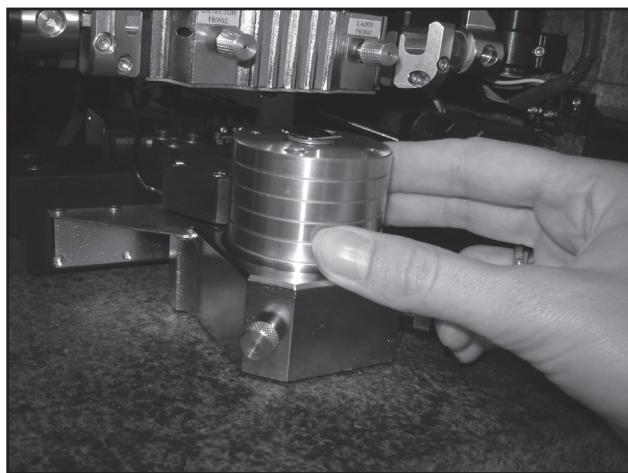


Figure 3.20: Remove Puck

6. Use tweezers to mount the PNI AFM reference on the center of the puck (Figure 3.21). The sample is held in place magnetically. If the PNI reference is already installed on the sample puck, skip to step 7.



Figure 3.21: Mounting the Sample



Figure 3.22: Fit the Sample Puck into pin hole on the base puck.

7. Replace the puck in the stage by setting it down so the guide pin on the bottom fits into the pin hole on the base puck and tighten the screws (Figure 3.22).
8. Rotate the puck so that the PNI reference sample is square with the scanner head.

9. Click the Restore button on the Load Sample wizard. The motorized X-Y stage will return the puck to its original position (Figure 3.23).

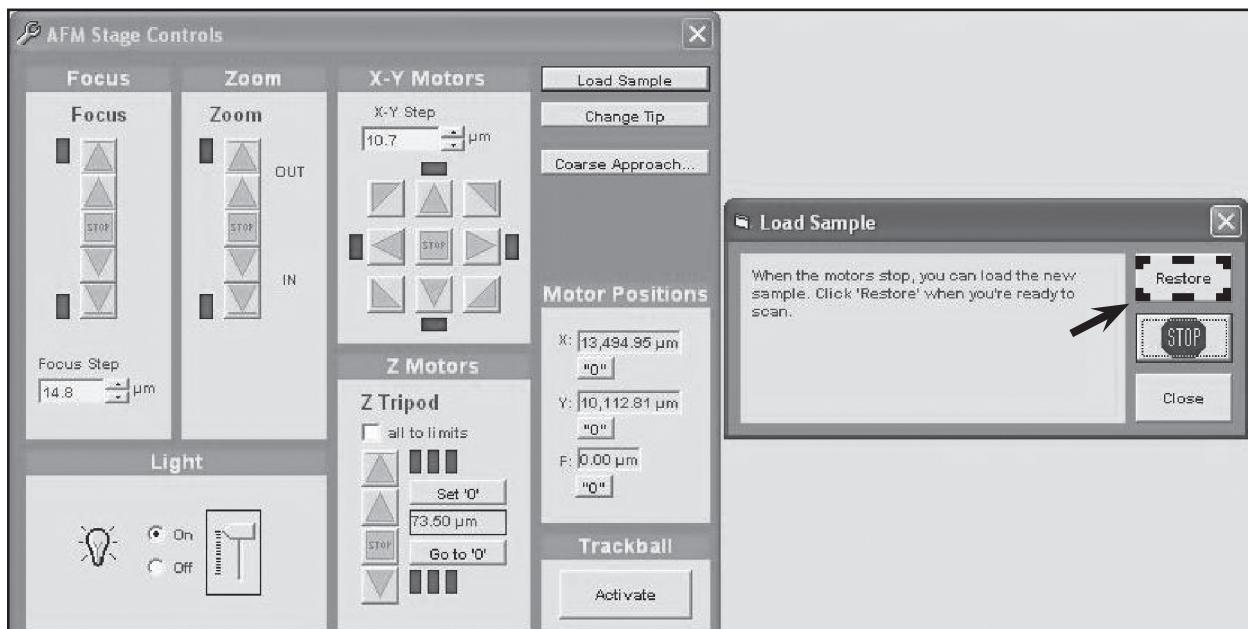


Figure 3.23: Return sample puck to initial X-Y position

ALIGN LASER AND DETECTOR

The probe cantilever should already be in focus on the video monitor (per step 2 of the Load Sample section). If you cannot find the probe on the monitor:

- The probe may not have been installed properly. Repeat the probe installation procedure to make sure the probe is seated squarely in the "L" mount.
- The focus lens field of view may need to be adjusted in X-Y, using the adjustment screws. This is usually necessary when switching between a contact and close-contact probe, due to the difference in cantilever length.
- You may need to reposition the focus lens up or down.

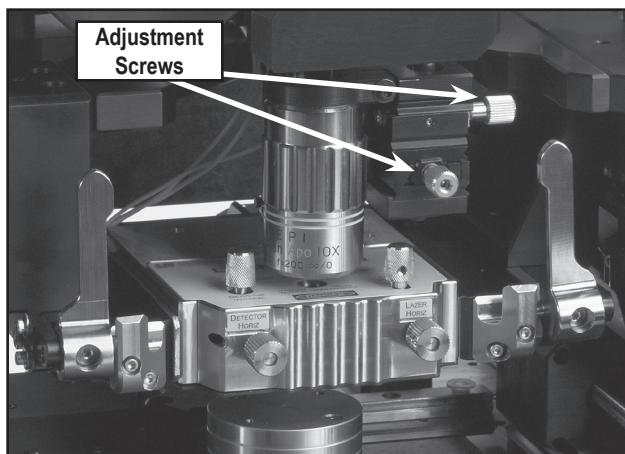


Figure 3.24: Field of View knobs

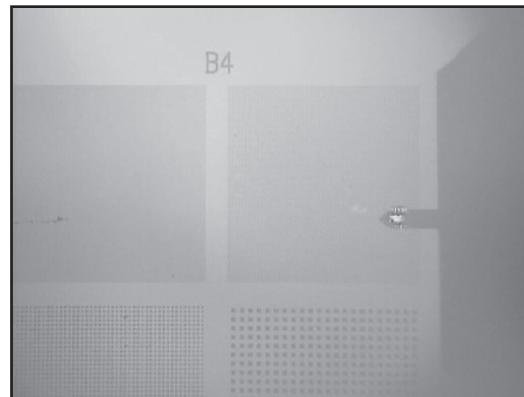


Figure 3.25: Close Contact Probe as seen in video monitor

ALIGN LASER

To align the laser, open the Red Dot Alignment window by clicking Align Laser on the EZMode™ Toolbar.



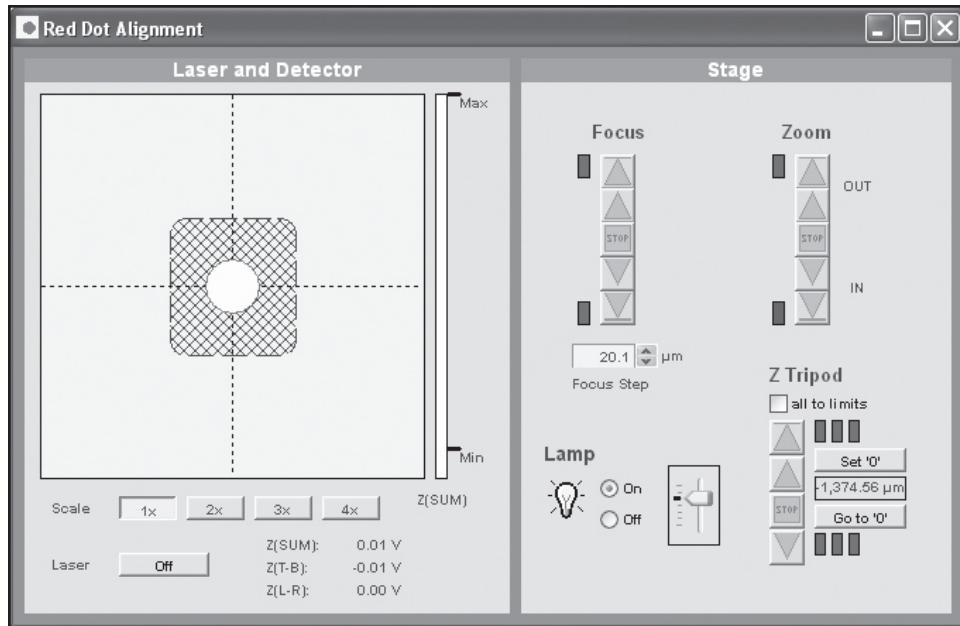


Figure 3.26: Red Dot window controls

The red dot alignment procedure has 3 goals:

1. Position the laser spot on the back of the cantilever.
2. Position the photo detector in the center of the reflected laser beam.
3. Achieve a maximum measured signal strength, Z[SUM].

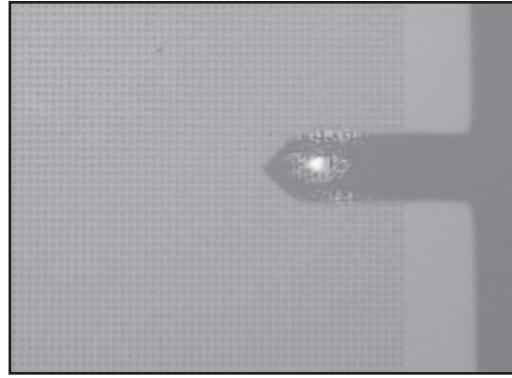


Figure 3.27: Centering the Laser Spot on the Cantilever

Watch the video monitor as you adjust the laser alignment knobs on the scanner head to bring the laser spot onto the back of the cantilever. The laser spot should be centered on the cantilever, **not too close to the end**, as shown in Figure 3.27.

ALIGN DETECTOR

Using the horizontal and vertical photo detector knobs on the scanner, watch the red dot (in the Red Dot Alignment window) as you turn the knobs to bring the red dot to the center of the crosshatched box, as shown in Figure 3.28.

Please note: When you are adjusting the detector alignment knobs, if the red dot moves toward the center but the Z[SUM] value is going down, you are moving the wrong direction. Therefore rotate the knob in the opposite direction and verify that Z[SUM] increases.

Make sure the Z[SUM] value (signal intensity) is above the minimum. If it is not, you need to re-seat or replace the probe.

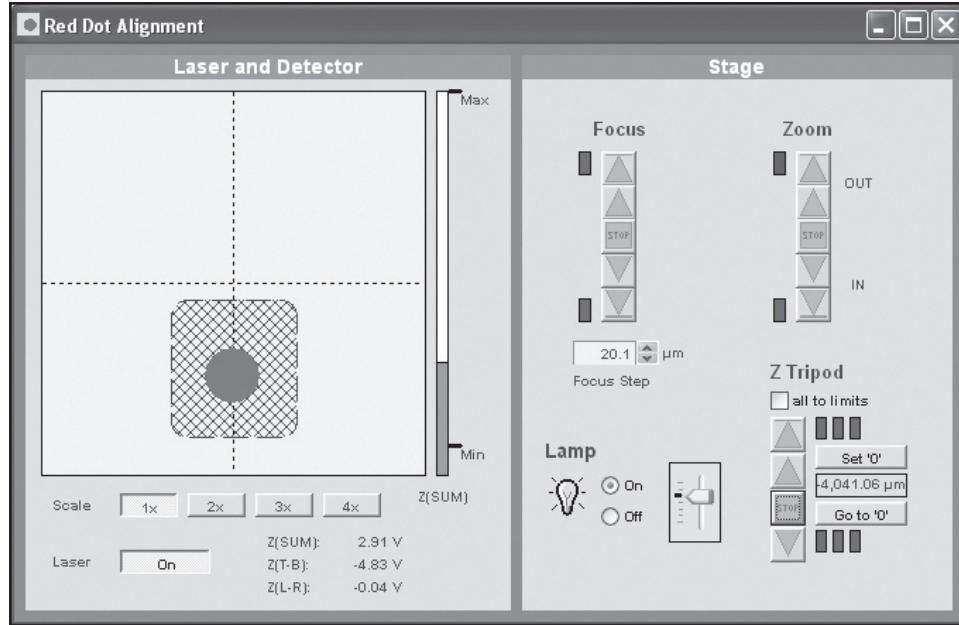


Figure 3.28: Aligning the Detector

TUNE PROBE

After aligning the detector, the resonant frequency of the installed probe must be determined.

1. Click Tune Probe on the EZMode™ Toolbar.



2. Click the Tune button as shown in Figure 3.29 below.

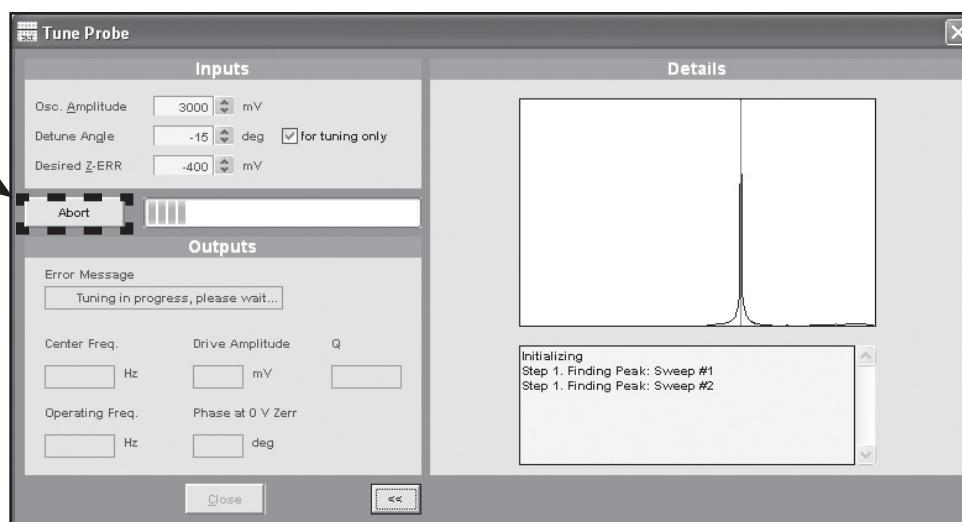


Figure 3.29: Auto-tune Window

Auto-tune is completed when the window appears as shown below:

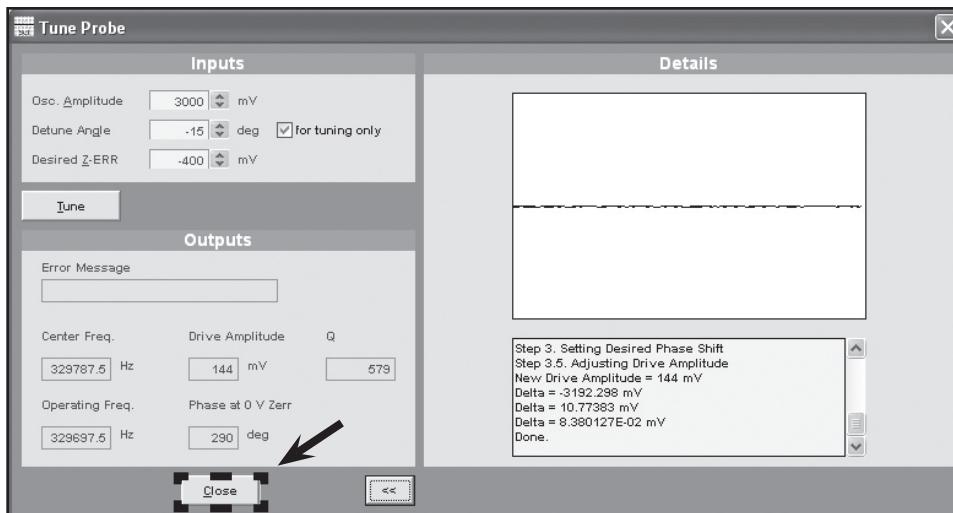


Figure 3.30: Auto-tune Complete Window

- Click the Close button to apply the settings.

APPROACHING THE SAMPLE

Positioning the probe to scan a sample is accomplished in three steps: Course Approach, Locating Features of Interest, and Final Tip Approach.

COARSE APPROACH

Coarse Approach is used to bring the probe into close proximity to the sample surface.

- Click Coarse Approach on the Stage Controls Window.

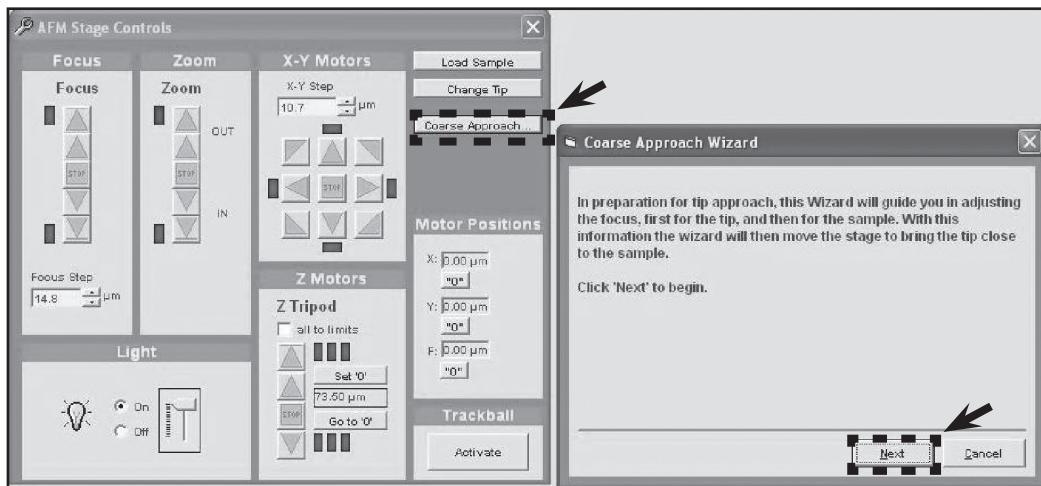


Figure 3.31: Coarse Approach Wizard

2. Click Next on the Coarse Approach Wizard and follow the instructions as shown below. First, focus on the probe, then focus on the sample. Click Next after each step.

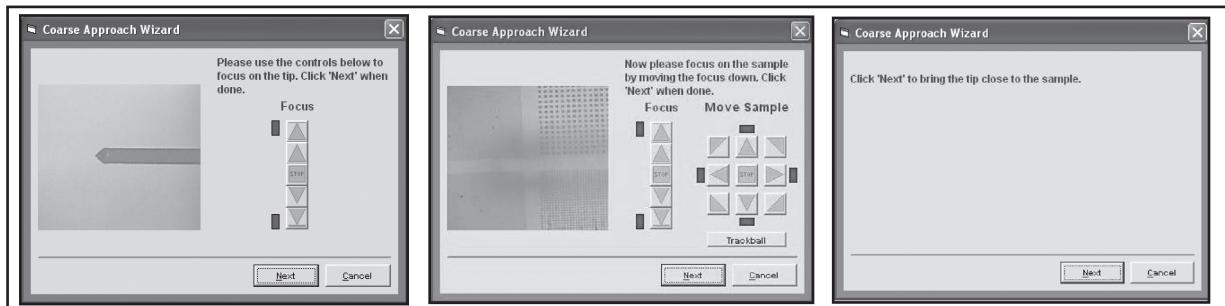


Figure 3.32: Coarse Approach Wizard Screens

LOCATING FEATURES OF INTEREST

After Coarse Approach is complete, features of interest can be located by using the X-Y motor step controls. Both coarse and fine movement are possible. If necessary, you can orient the Sample by simply rotating the Puck by hand.

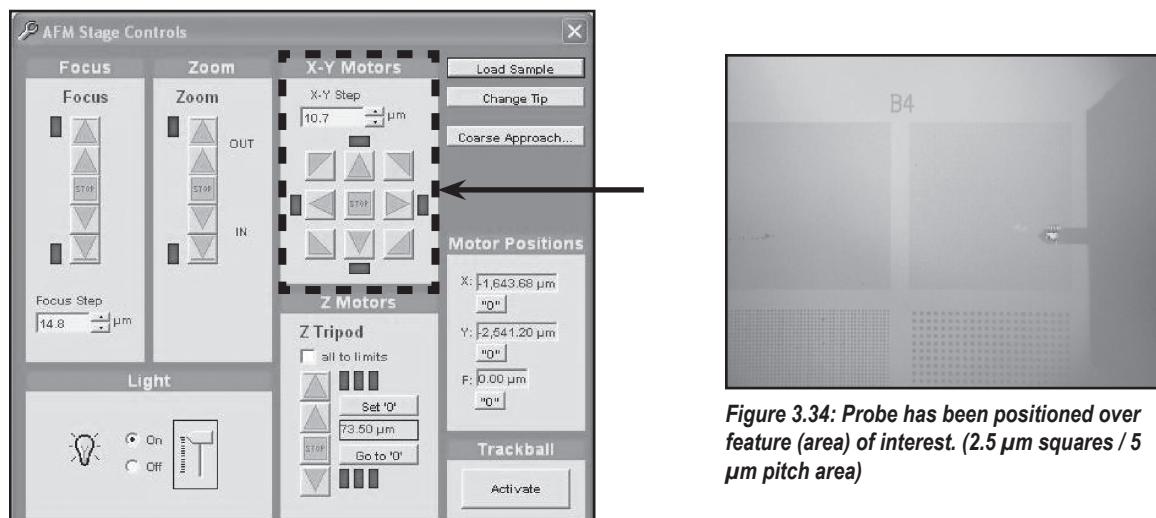


Figure 3.33: X-Y Stage Controls

FINAL TIP APPROACH

You are now ready to perform the final approach to the sample. Make sure the cantilever is in focus, then click the Tip Approach button on the Toolbar.



CAUTION: Once the Tip Approach is complete, and the tip is in contact with the sample surface, do not exit the SPM Cockpit™ software or turn off the Controller without first retracting the tip. Doing so may cause damage to the tip, scanner, and sample.

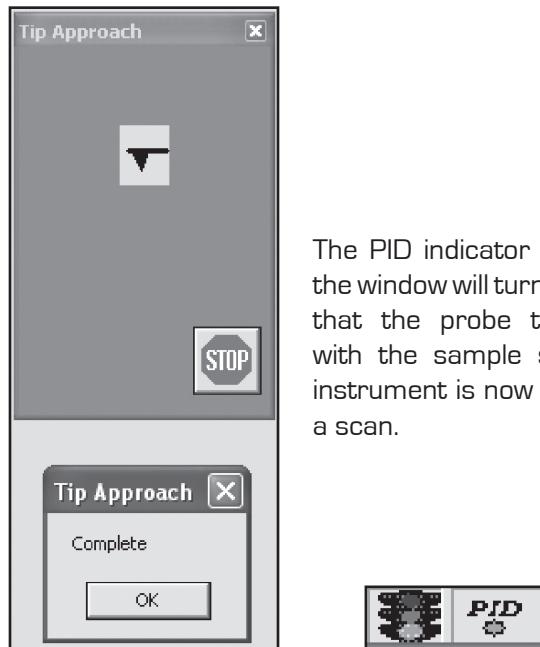


Figure 3.35: Tip Approach Confirmation and PID indicator

SCAN SAMPLE

1. Click the Scan Sample button on the Toolbar

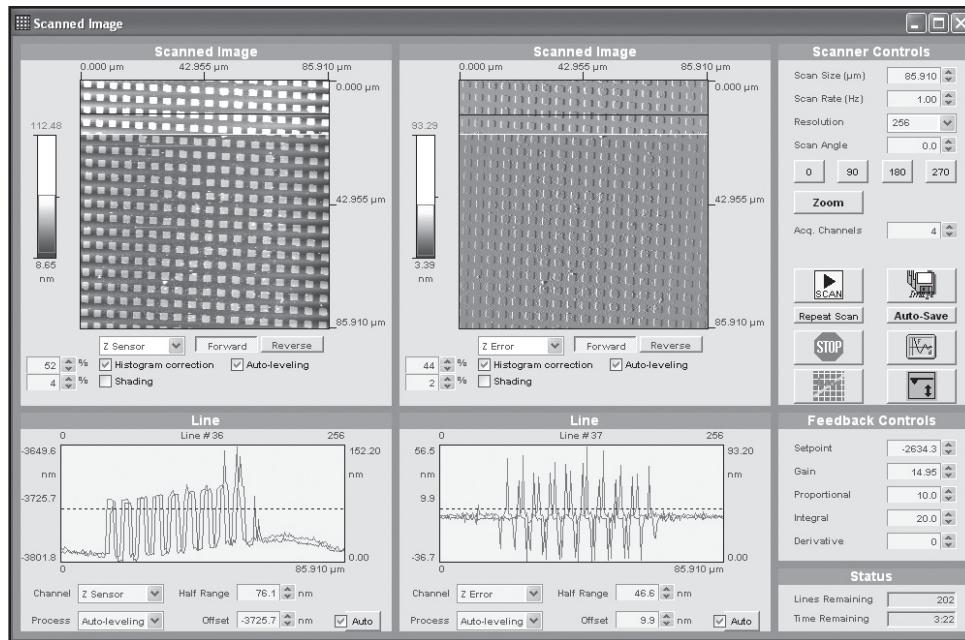


Figure 3.36: Scanned Image Window

2. Set the scanner controls as follows:

- Scan Size: Leave as is – the default size, which is entered by the system when the calibration routine is performed, is the maximum scan area for your scanner.
- Scan Rate: 1 Hz
- Resolution: 256
- Scan Angle: 0
- Acq. Channels: 4
- Topography Gain: 1x

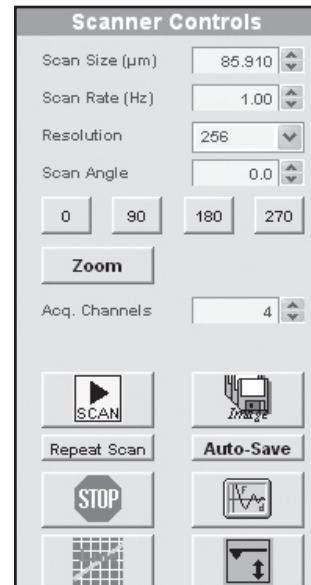


Figure 3.37: Scanner Controls

3. Set the feedback controls as follows:

- Setpoint: Leave as is
- Gain: 5
- Proportional: 5
- Integral: 10
- Derivative: 0

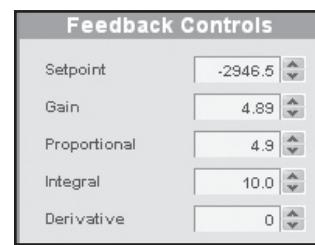


Figure 3.38: Feedback Controls

4. Select the Z-Sensor and Z-Error channels from the drop-down menus beneath the two image displays, and for each display, select Forward (or Reverse), Histogram Correction, and Auto-Leveling.

5. Select the Z-Sensor and Z-Error channels from the drop-down menus of the two corresponding line scan displays.

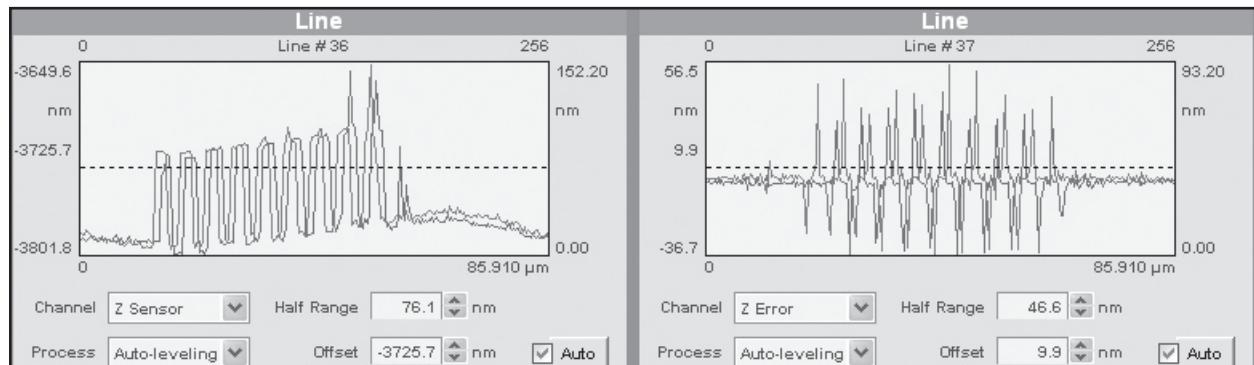


Figure 3.39: Image Display Settings

6. Click the Scan button to start a scan.

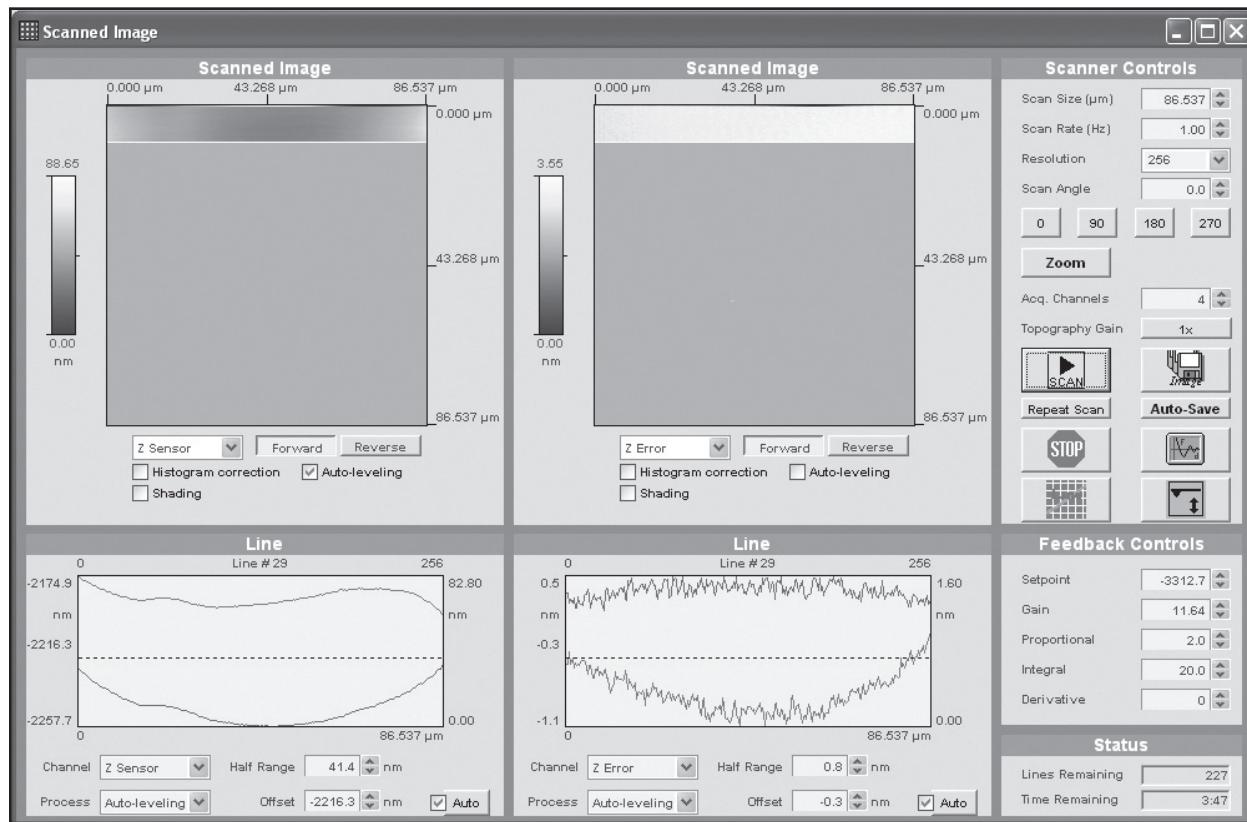


Figure 3.40: Scan in progress

- The images of the selected channels gradually appear line-by-line in the displays, starting at the top. If no data is generated, the detector may be out of alignment. In this case, click Tip Retract from the Toolbar, re-align the red dot, and try another scan.
 - Sometimes the generated image and line profiles look like those shown in Figure 3.40. If this is the case, it's necessary to adjust the set point as described in the next section, Adjusting the Set Point. The image and the line profile should look similar to that shown in Figure 3.41.
7. To perform additional scans, click Scan again, or click the Repeat Scan button to take continuous scans of the same region.
8. To zoom to a new scan region:
- Left-click and drag in the image display to define a scan area.

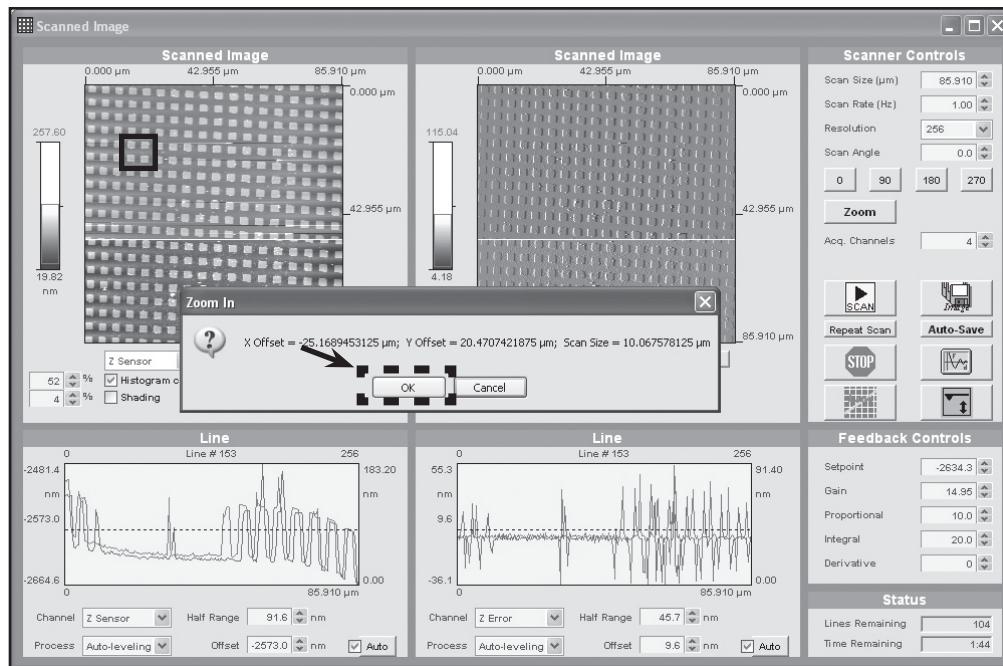


Figure 3.41: Zooming in on features dialog box

- b] Click OK to confirm the new scan region.

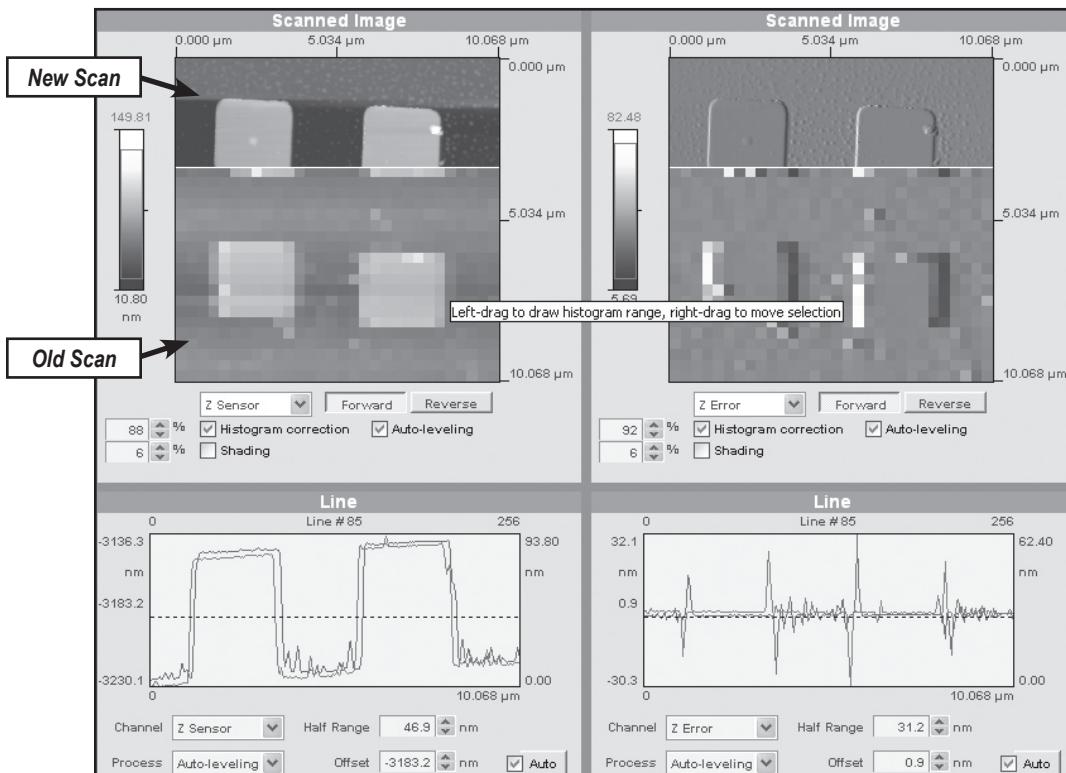


Figure 3.42: Acquiring smaller scan size

- c] Now click the Scan button to take a new scan of the area or feature you have selected.

9. To scan at an angle, enter the desired scan angle (from 0 to 360°) in the Scan Angle box. Click the Scan button to start a new scan.

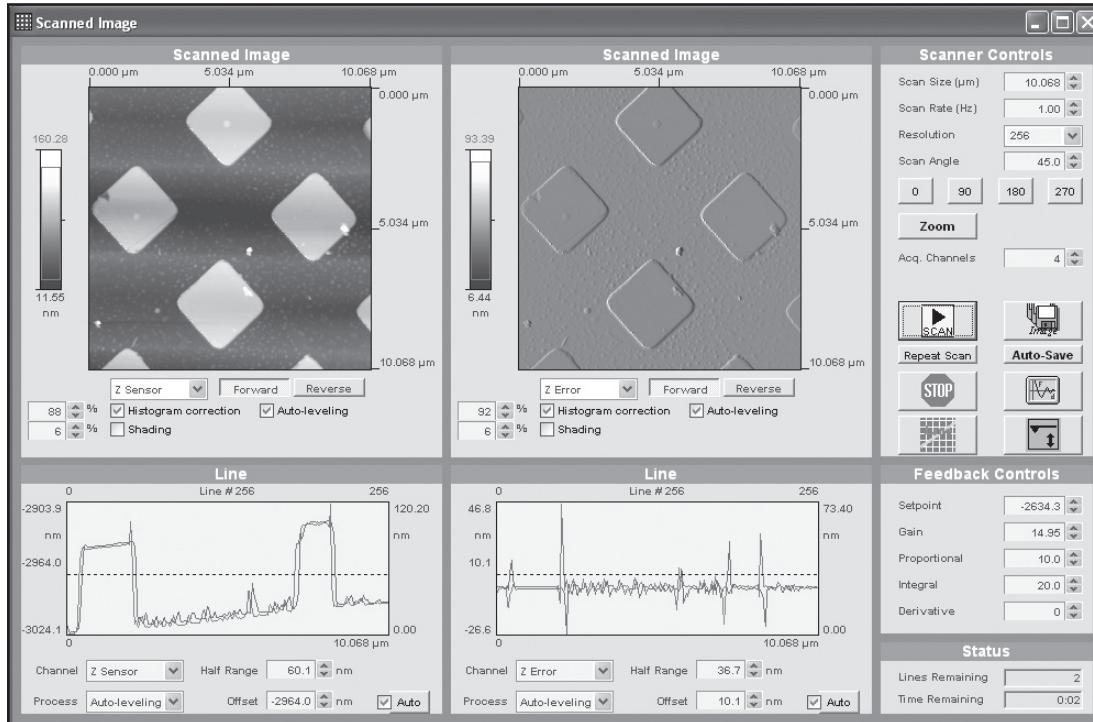


Figure 3.43: Scanning at an angle

The scan size will change depending on the angle selected, and the previously taken scan will rotate by the designated angle. As scanning progresses, the newly acquired image will appear over the previous scan and eventually replace it.

ADJUSTING THE SET POINT

- Click the Up arrow in the Set Point box to increase the interacting forces (decrease the distance between the probe and the surface) while monitoring the shape and voltage on the Z Actuator line profile. In Figure 3.47, the starting set point is -2940mV and the piezo voltage -875mV.
- Click the Up arrow once or twice and see if the line profile starts to trace the topography. The voltage reading will change to a more negative value. Figure 3.47 shows a scan in progress while the set point is being adjusted. You can see that the adjusted set point is -2867mV.
 - To adjust the Z scale of the images, left-click and drag in the bar to the left of each display to select a Z height range.
 - To view a single line scan, hold down the SHIFT key and left click in either image display to define a horizontal line across the image; make sure the line includes the square features. The Z line scan profile for the Z Actuator channel should resemble the scale shape and size of the 10 μm features as in Figure 3.44.

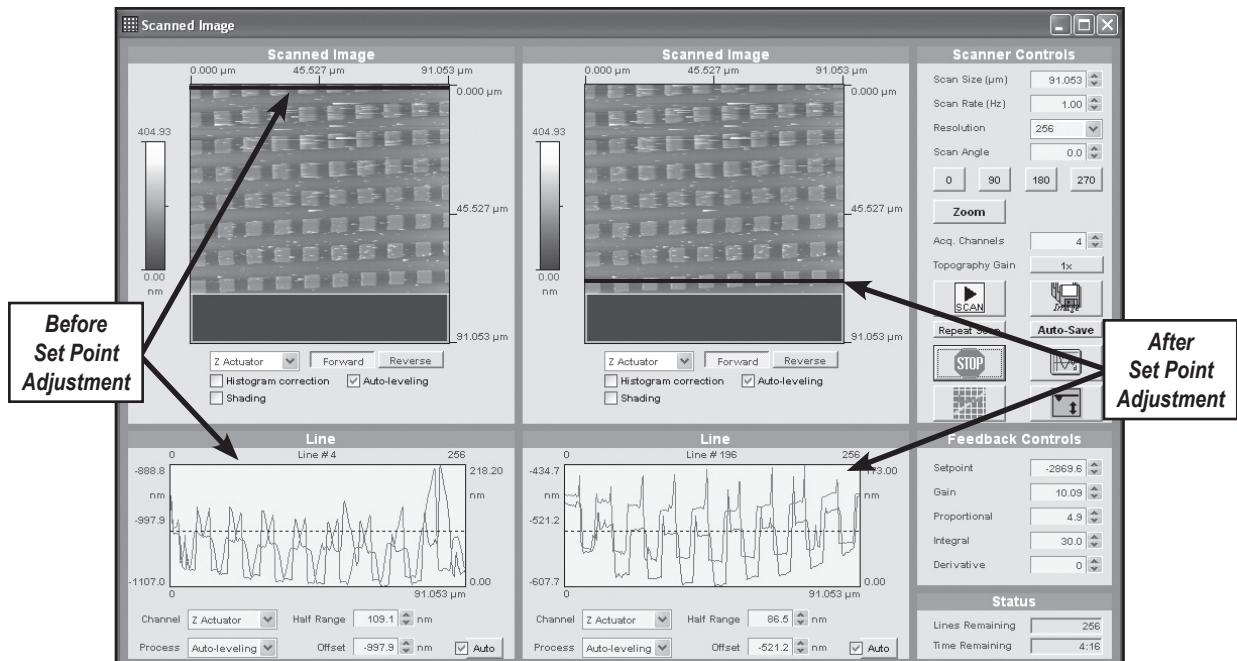


Figure 3.44: Adjusting the Set Point while scan is in progress



Figure 3.45: Selection of Z Height Range

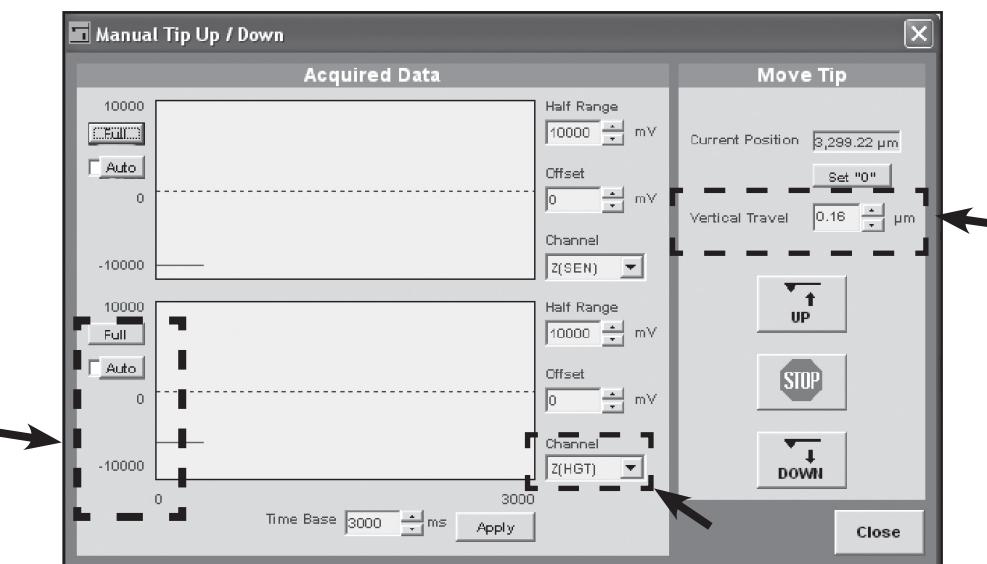


Figure 3.46: The Manual Tip Up / Down Window

3. If by doing step 2 you find the piezo voltage at -10000mV and the line profile did not change much, click the Manual Tip up/down toolbar button  to open the Manual Tip Up/Down window.

- Make sure the Z(HGT) and Z(SEN) channels are selected. The trace line moves from left to right at about -10000mV. Make sure the Vertical Travel for the Z motors is set to its minimal value [0.16microns].
- Start clicking the tip Down button, once at a time, and observe the Z(HGT) voltage trace incrementally increase, Figure 3.50.
- Once the Z(HGT) voltage is near 0mV [within ±1000mV], click the Close button and resume scanning. You still may find it necessary to adjust the set point and piezo voltages.
- Eventually the scan and voltages should look similar to those shown in figure 3.51. In this example, the final adjusted set point is -1090mV and the Piezo voltage near the middle of the range is +769mV. [Full range is ± 10,000mV].

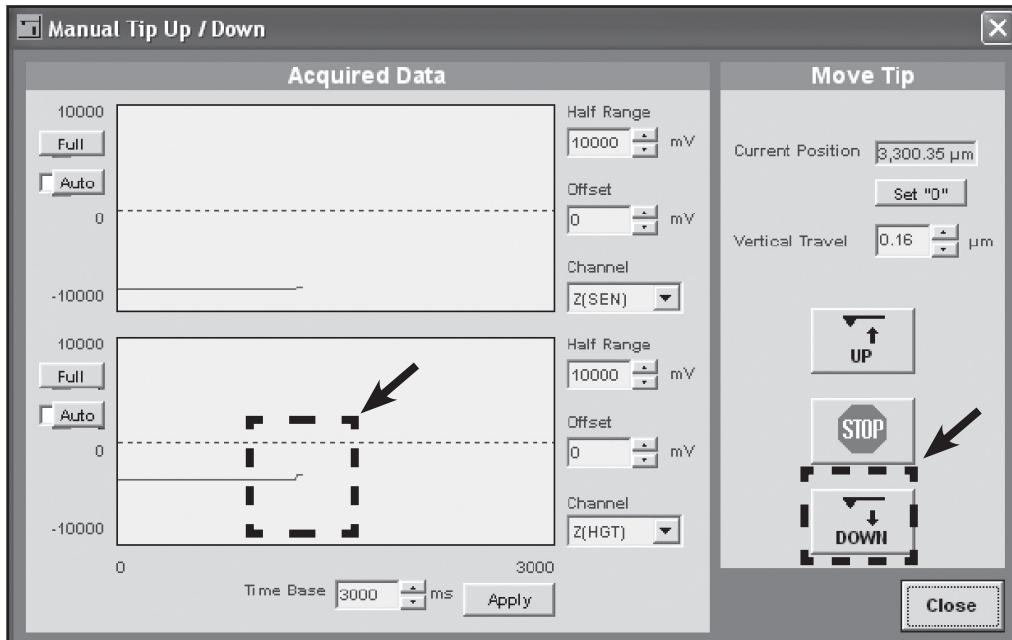


Figure 3.47: Adjusting the distance between the probe and the sample using the Z motors, so the Z(HGT) voltage is approximately zero mV.

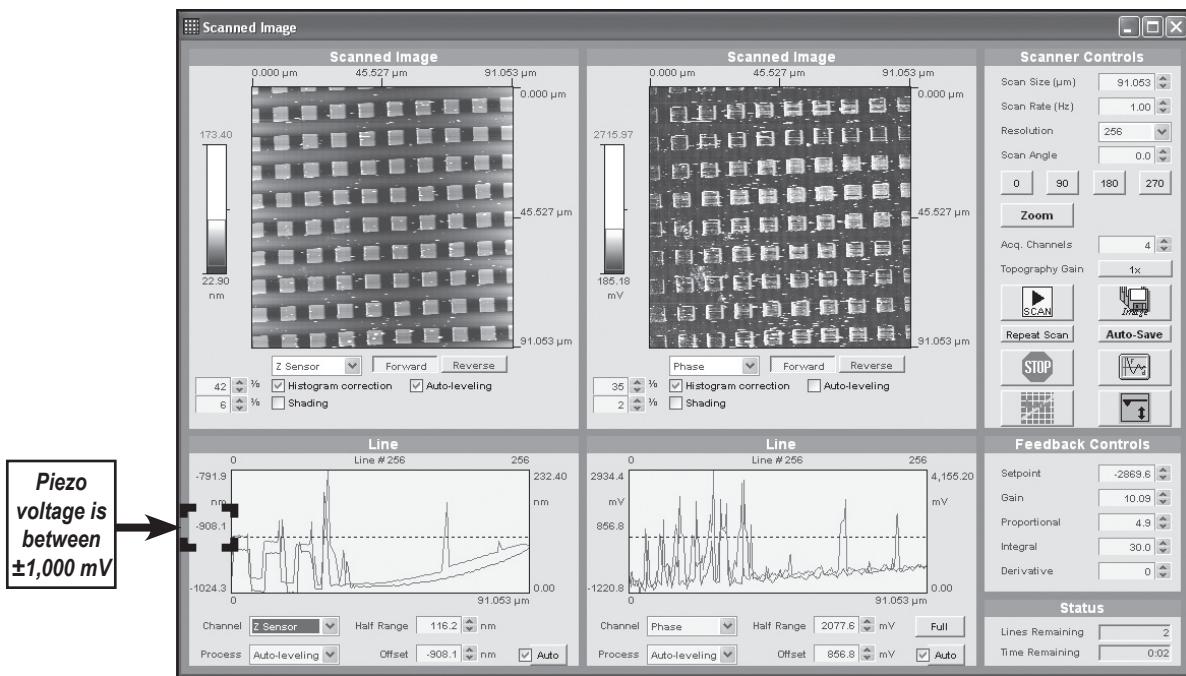


Figure 3.48: Example of images and line profiles after the set point voltage has been properly adjusted.

IMAGE PROCESSING

1. Click Image Processing on the EZMode™ toolbar



2. Click Select Source to open an image for processing



3. Select the desired acquisition channel and direction for the image to be processed. The raw image data will not resemble the image in the scan image window, because real-time image processing was applied as it was being acquired.



Figure 3.49: Selecting the Source File for Image Processing

4. Click the Plane Correction button to apply Plane Correction.



- Under Select Correction Model, select:
 - Polynomial surface XY leveling
 - Polynomial order: 1
- Under Select Area to Analyze, select:
 - Entire Scan Area
- Click Apply. The leveled image appears in the right-hand display.

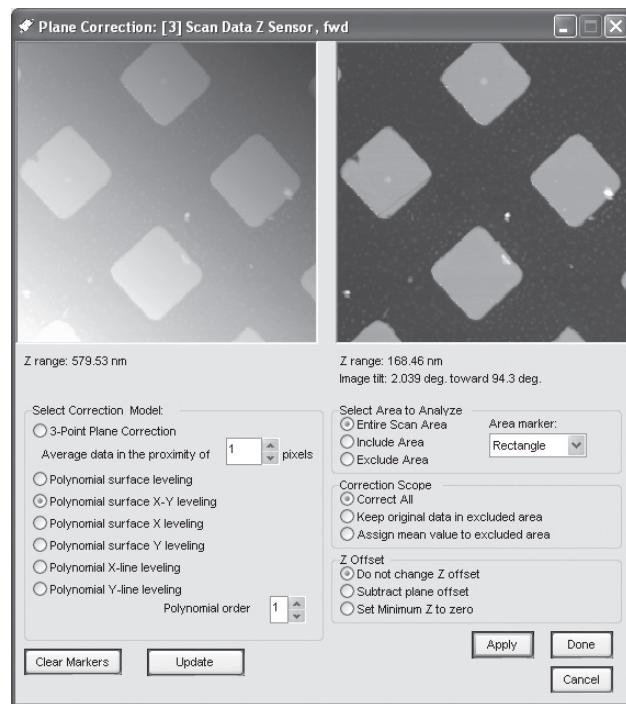


Figure 3.50: Plane Correction Window

5. To do Line Profile Measurements, select the button shown:

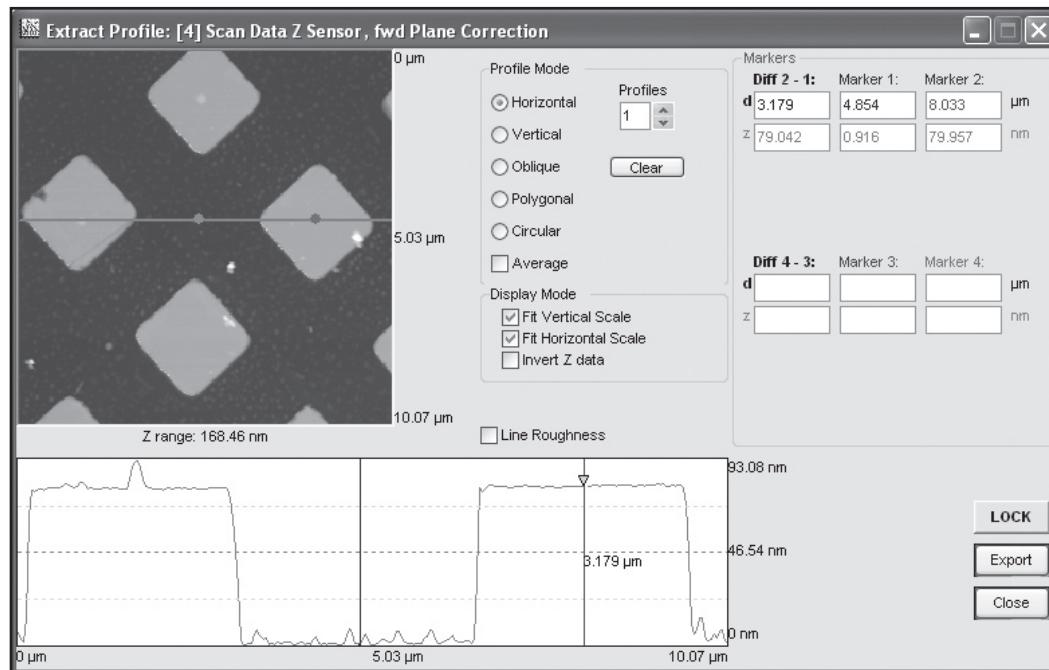
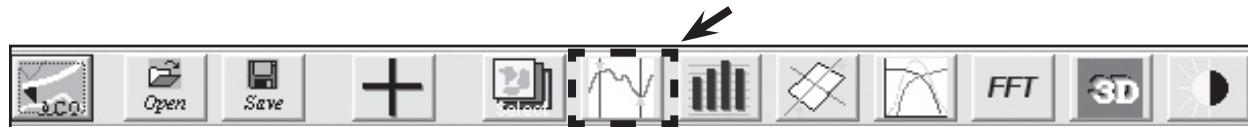


Figure 3.51: Line Profile Tool

- Under Profile Mode, select Oblique.
- Under Display Mode, check Fit Vertical and Horizontal Scale
- Left-click and drag in the image window to draw a line.
- Left-click in the line display window to make measurement markers.

In the example above, measurements are made between the edges of two consecutive features on the PNI AFM reference. The Diff calculation displayed to the right indicates a height of approximately 79 nanometers.

NOTE: These measurements should not be used to calibrate your instrument!

6. Select the histogram tool and use the slider bars to mark the middle of the two ranges where the Z data points are clustered.

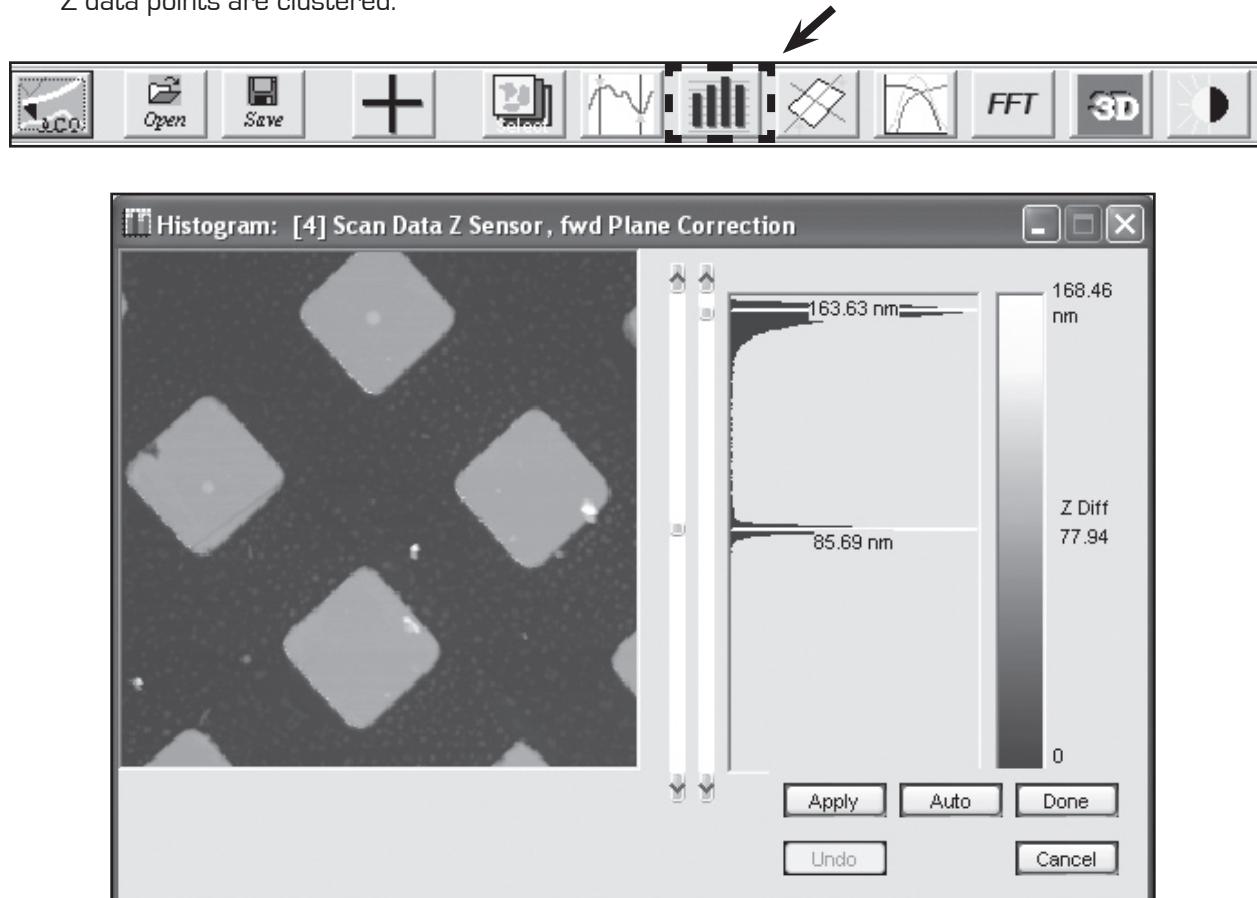


Figure 3.52: Histogram Tool

The Z Diff measurement on the vertical bar displays the approximately 78 nm height of the PNI AFM reference features.

7. To save any of your processed images, select File / Save Image(s).

8. To view 3-D images of the topography, select the 3D button.

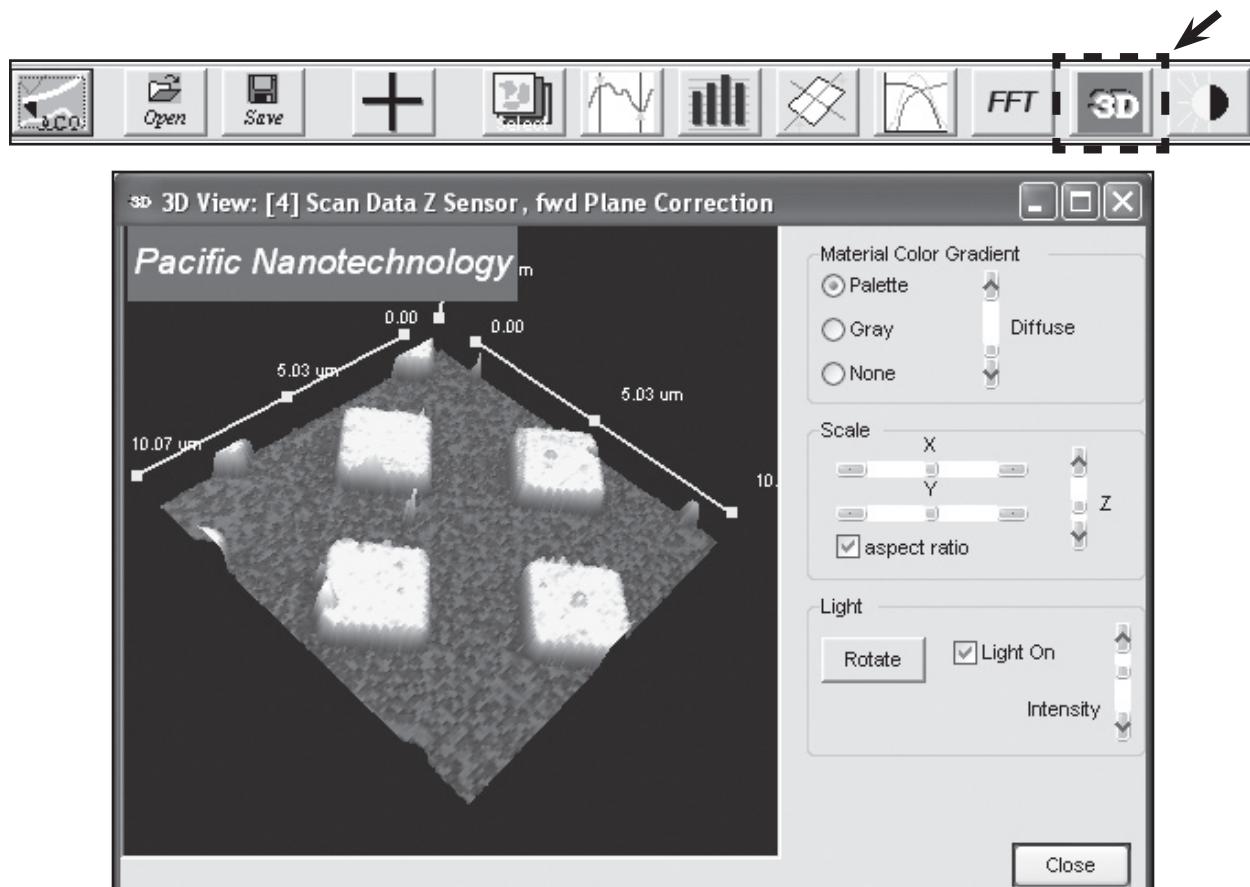


Figure 3.53: 3D View

9. Click the  button to return to the acquisition module.

- Click Tip Retract on the EZMode™ Toolbar. It is now safe to exit SPM Cockpit™ software and turn off the Controller.



CAUTION: To prevent damage to your scanner, probe, and sample, be sure to retract the tip before exiting SPM Cockpit™ software or turning off the Controller.

Chapter 4 • Tutorial: Rapid Scan™

BEFORE YOU BEGIN

This tutorial details the steps for taking a rapid AFM image of the PNI AFM reference sample in EZMode™. Make sure that Rapid Scanner is installed as shown in Figure 4.1.

WARNING: Before operating the Nano-DST™ AFM, make sure you are familiar with the safety information on page iv.

POWERING UP THE SYSTEM

1. Turn on the Master Computer.
2. Launch the SPM Cockpit software.
3. Turn on the Controller.
4. Turn on the video monitor.

START

1. Select Settings | Toolbar Mode | EZMode™.
2. Click the Start button on the EZMode™ Toolbar.



Figure 4.3: EZMode™ Toolbar

3. Click Load Configuration, select the PNI-supplied crystal mode configuration file, and click Open. This file should be located in the ConfigFiles folder in the SPM Cockpit™ directory. It has the format nfxxxxRapidScan.PNI_Config, where xxxx is the serial number of your Rapid scanner.

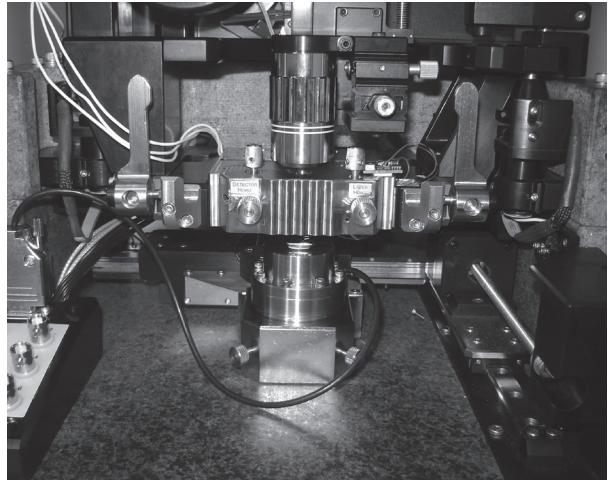


Figure 4.1: Rapid Scanner installed on Nano-DST™

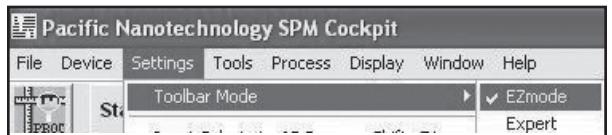


Figure 4.2: SPM Cockpit™



Figure 4.4: Load Configuration

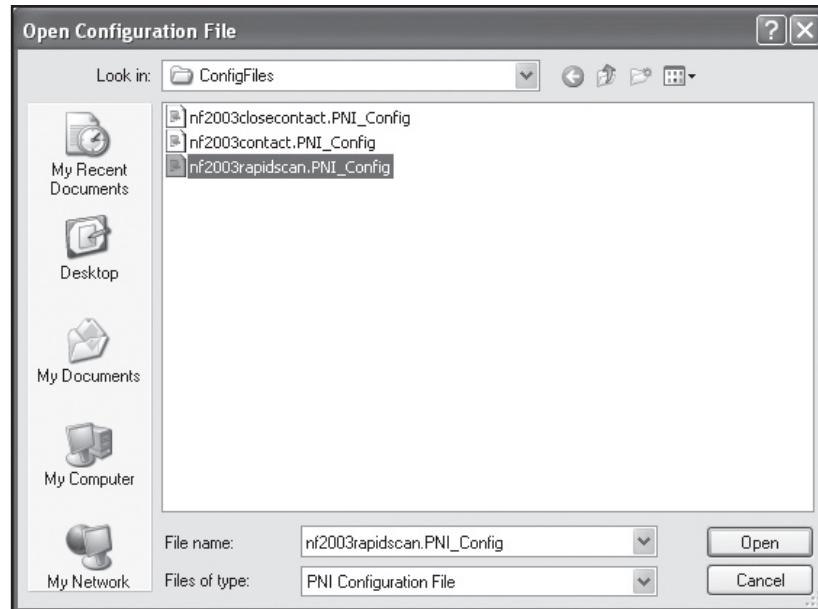


Figure 4.5: Loading a Configuration File

CHANGE PROBE

To operate in rapid mode, you need to use a contact probe. If contact probe has already been installed, skip this section and go to Load Sample section

1. Click Stage from the EZMode™ Toolbar, and click Change Tip in the AFM Stage Controls window, then click start in the Tip Exchange wizard (Figure 4.6).

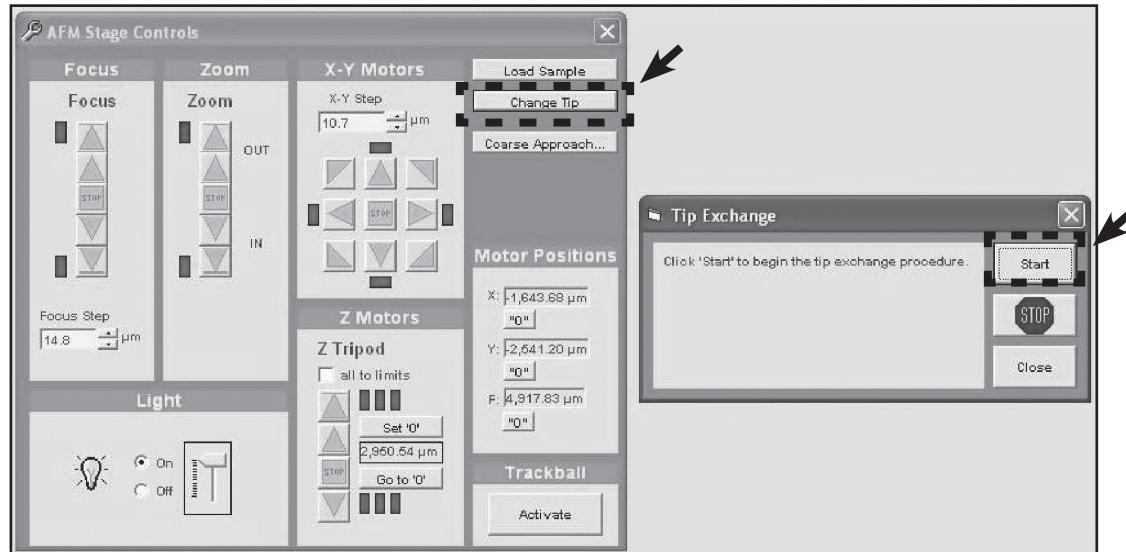


Figure 4.6: Stage Controls Window. Change Tip puts the scanner head into the appropriate position to replace the tip. The Start button in the dialog box will raise the probe tip away from the sample.

2. When motor movement is complete, remove the sample puck. Rotate the probe exchange knobs on the side of the scanner head backwards [away from you] 1/4 turn [Figure 4.7]. The scanner head is now able to slide forward about an inch.

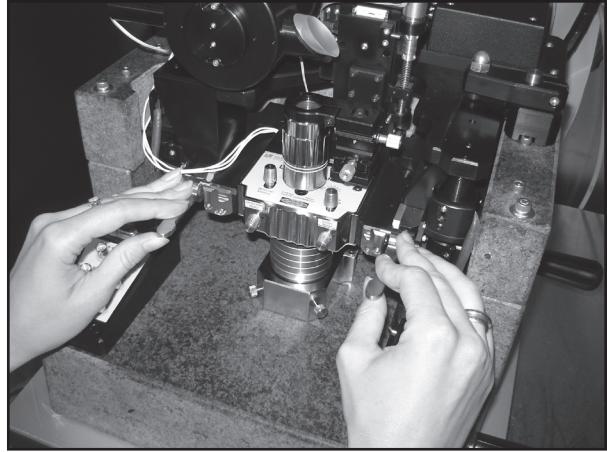


Figure 4.7: Turn the knobs to release the scanner head

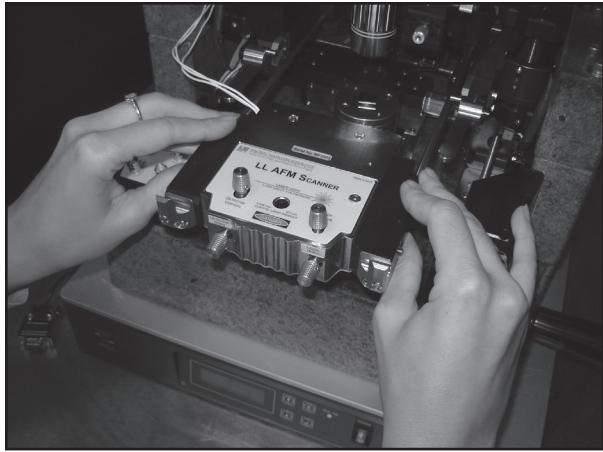


Figure 4.8: Slide the scanner head toward you

Carefully rotate the scanner head up approximately 90 degrees (see Figures 4.9 and 4.10).

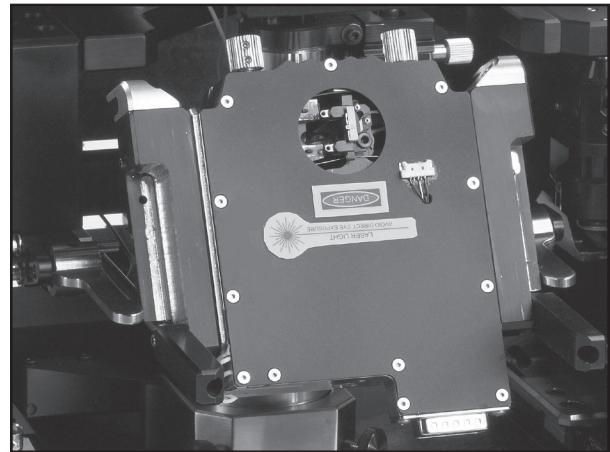


Figure 4.10: Probe Exchange Position



CAUTION: Handle AFM probes with care. The cantilever can break off easily if it touches anything or snaps down too forcefully during handling.

- The scanner is now in the Tip Exchange position, ready for the old probe to be removed and the new probe to be installed.

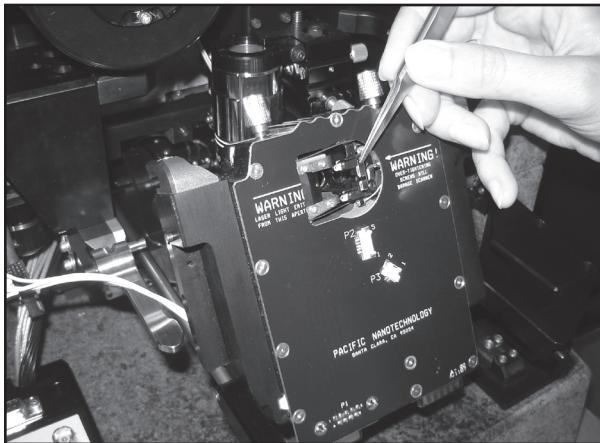


Figure 4.11: Removing the Probe



Figure 4.12: Box of Contact Probes

- Hold the scanner head by the handles and rotate it back to the level position.
- Gently slide the scanner back toward the stage until you feel some resistance.
- Turn the probe exchange knobs 1/4 turn to lock the scanner head into place.
- Once the scanner is locked in position, click the Restore button. This restores the Focus and Z-motors to their previous positions.

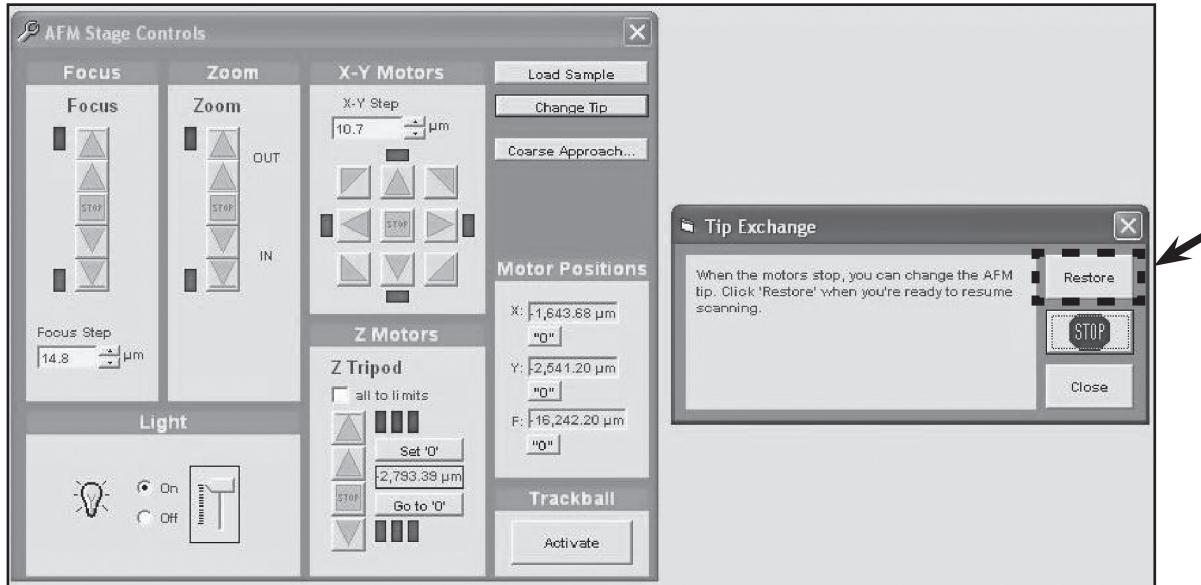


Figure 4.13: Restore is the final step of the Probe Change process

ALIGN LASER AND DETECTOR

The probe cantilever should already be in focus on the video monitor (per step 2 of the Load Sample section). If you cannot find the probe on the monitor:

- The probe may not have been installed properly. Repeat the probe installation procedure to make sure the probe is seated squarely in the "L" mount.
- The focus lens field of view may need to be adjusted in X-Y, using the adjustment screws. This is usually necessary when switching between a contact and close-contact probe, due to the difference in cantilever length.
- You may need to reposition the focus lens up or down.

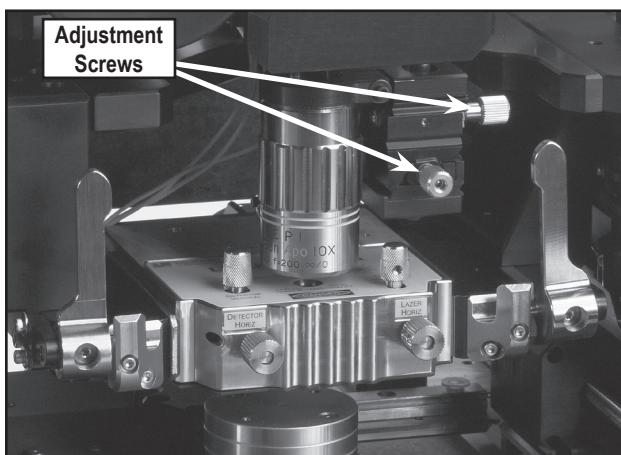


Figure 4.14: Field of View Knobs

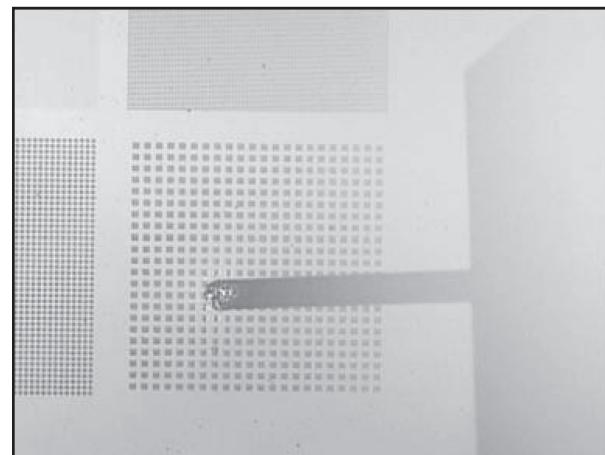


Figure 4.15: Contact Probe as seen in Optical View

You can confirm that you have installed a contact cantilever by noting the difference in length between contact and close-contact cantilevers, as shown in Chapter 1.

ALIGN LASER

To align the laser, open the Red Dot Alignment window by clicking Align Laser on the EZMode™ Toolbar.



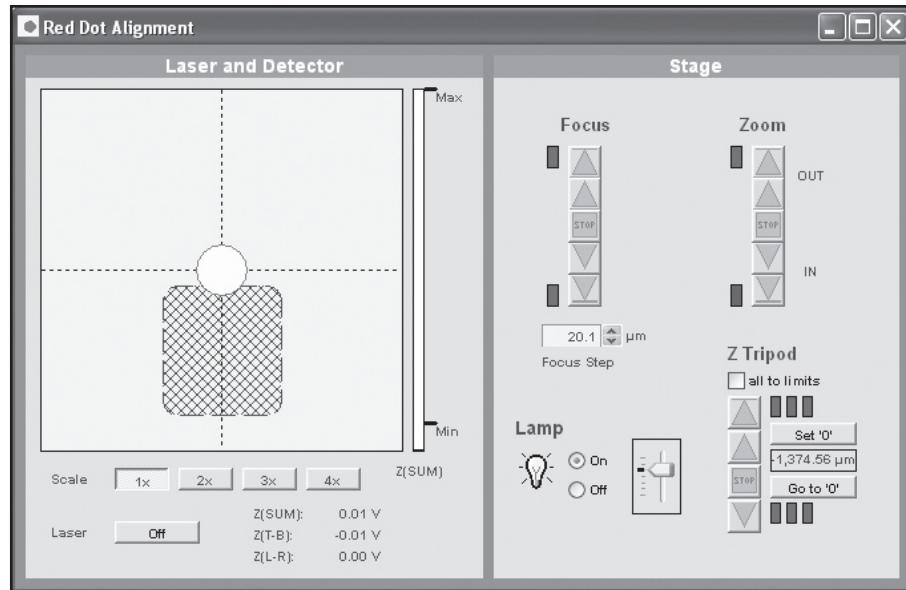


Figure 4.16: Red Dot Window Controls

The red dot alignment procedure has 3 goals:

1. Position the laser spot on the back of the cantilever
2. Position the photo detector in the center of the reflected laser beam
3. Achieve a maximum measured signal strength, Z[sum]

Watch the video monitor as you adjust the laser alignment knobs on the scanner head to bring the laser spot onto the back of the cantilever. The laser spot should be centered on the cantilever, **not too close to the end**, as shown in Figure 4.17.

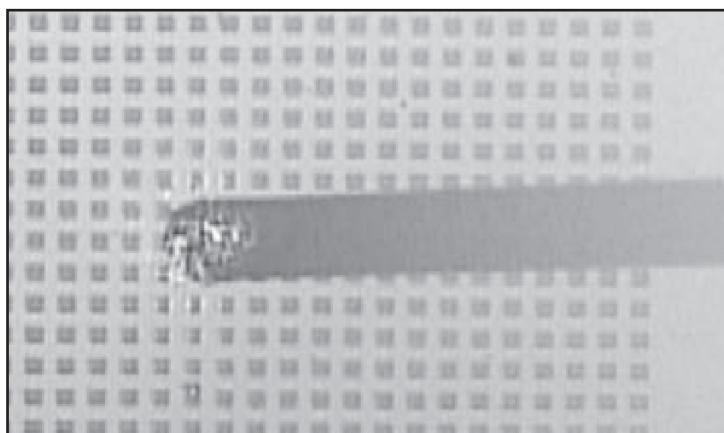


Figure 4.17: Centering the Laser Spot on the Cantilever

ALIGN DETECTOR

Watch the red dot (in the Red Dot Alignment window shown in Figure 4.18) as you turn the detector alignment knobs to bring the red dot into the top of the crosshatched box. The red dot should be positioned just below the upper border of the crosshatched box and be centered on the vertical axis.

Please Note: When you are adjusting the detector alignment knobs, if the red dot moves toward the center but the Z(SUM) value is going down, you are moving in the wrong direction. Therefore, rotate the knob in the opposite direction and verify that Z(SUM) increases.

Make sure the Z(SUM) value (signal intensity) is above the minimum. If it is not, you need to re-seat or replace the probe.

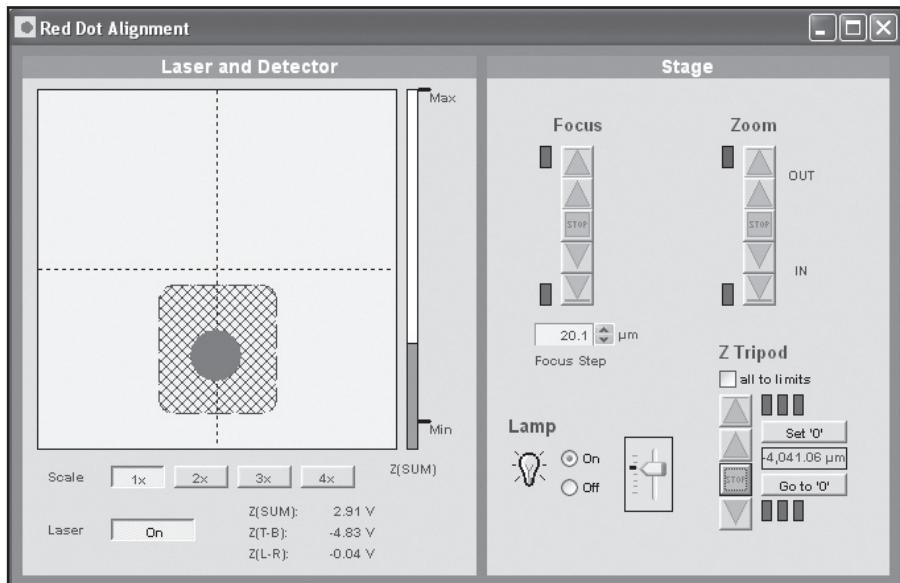


Figure 4.18: Aligning the Detector

LOAD SAMPLE

In this section you can load or replace a sample or install a Rapid Scanner. Sometimes the presence of a sample can make visibility of the probe in the video monitor more difficult. Therefore you may want to load the sample after aligning the laser in some instances.

To load a sample:

1. Click Stage from the EZMode™ Toolbar.



CAUTION

CAUTION: Whenever you engage the motorized X-Y stage, be sure the probe is a safe distance above the sample/puck.

2. Use the focus controls to bring the crystal arm into focus on the video monitor. Then focus on the diagonally mounted tip.
3. Click the Up button [Figure 4.19] to raise the Z motors until there is at least a few millimeters of clearance between the probe and the sample surface [or puck, if no sample is loaded].

CAUTION

CAUTION: To prevent damage to your scanner, probe, and sample, be sure you have retracted the tip and raised the Z scanner (as described in the preceding steps) before moving the puck.

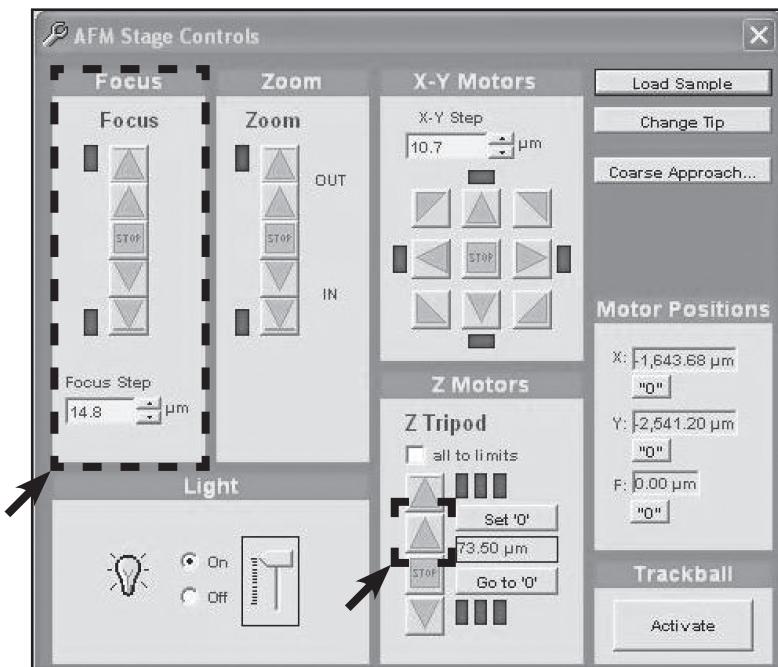


Figure 4.19: The AFM Stage Control window is used to raise the probe away from the sample

4. Click the Load Sample button and then the Start button (see Figure 4.20).

CAUTION

CAUTION: Whenever you engage the motorized X-Y stage, be sure the probe is a safe distance above the sample/puck.

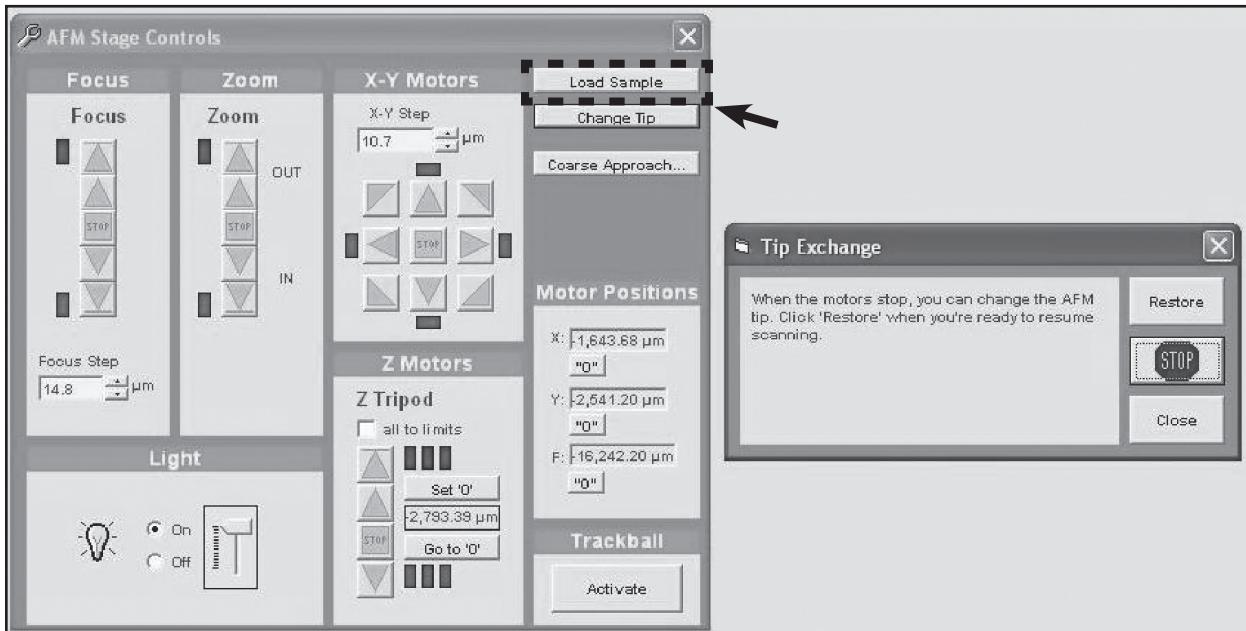


Figure 4.20: Load Sample Wizard (accessed from AFM Stage Controls window)

5. The motorized X-Y stage will move the puck fully forward (Figure 4.21).



Figure 4.21: Front Load Sample

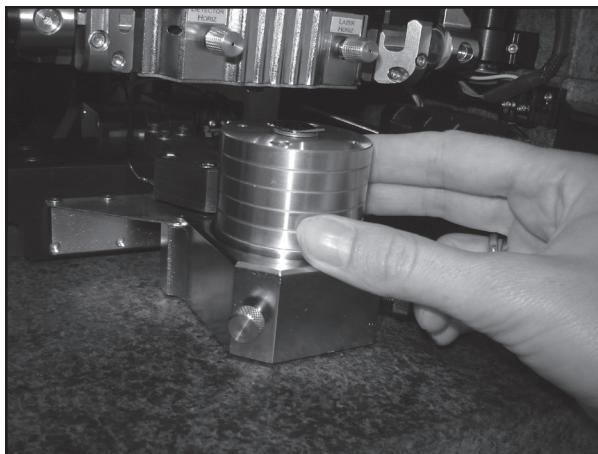


Figure 4.22: Remove Puck

6. Being careful not to touch the probe, then lift it out of the pin hole. Loosen the screws. See Figure 4.22.

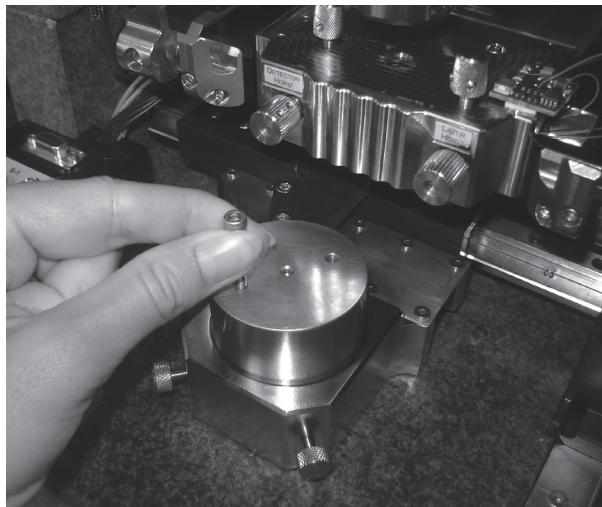


Figure 4.23: Remove base puck by lifting it up with the screw

7. To remove the base puck, put the screw into the threaded hole and lift the base puck up out, as shown in Figure 4.23

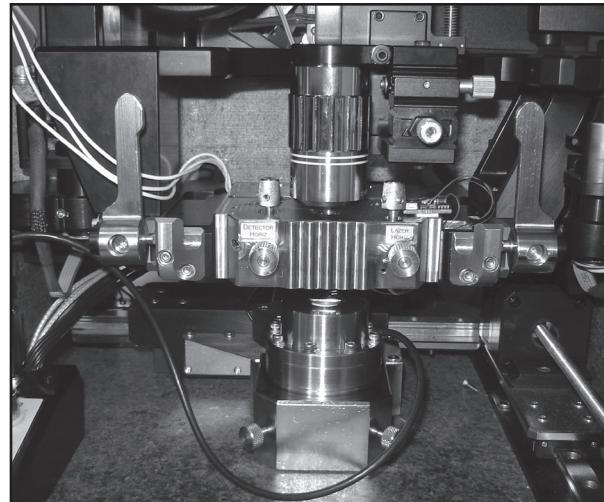


Figure 4.24: Rapid Scanner with the sample is in “ready” position.

8. Put the Rapid Scanner in, plug the connector into the stage SAC. Tighten the screws. Make sure that the scanner cable is in either the 3 p.m. or 6 p.m. position with the metrology scanner. Rotate the puck so that the PNI reference sample is square with the scanner head (Figure 4.24).

APPROACHING THE SAMPLE

Positioning the probe to scan a sample is accomplished in three steps: Coarse Approach, Locating the Feature of Interest, and Final Tip Approach.

COARSE APPROACH

Coarse approach is used to bring the probe into close proximity to the sample surface.

1. Click Coarse Approach on the Stage Controls Window [see Figure 4.25].

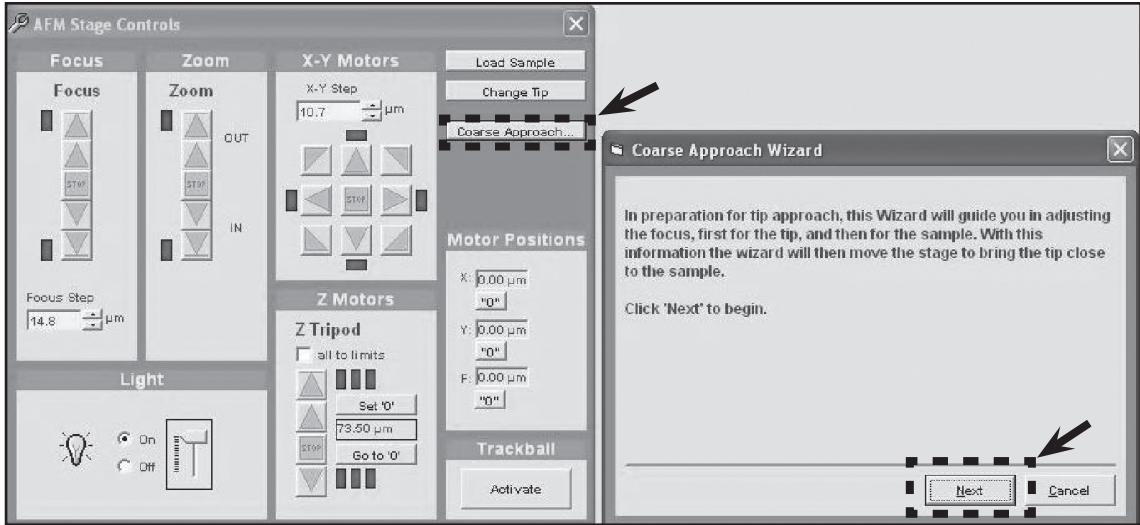


Figure 4.25: The Course Approach Wizard opens when Coarse Approach is selected in the AFM Stage Controls window.

2. Click Next on the Coarse Approach Wizard and follow the instructions as shown below. First focus on the Probe, then focus on the Sample. Click Next after each step.

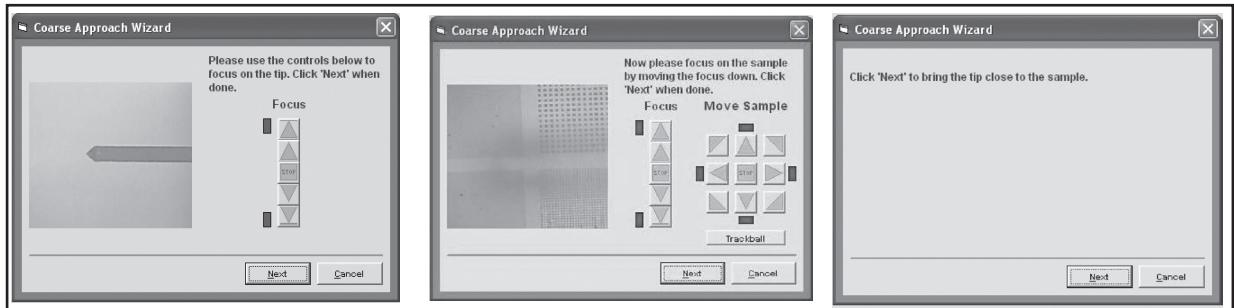


Figure 4.26: Coarse Approach Wizard Screens

LOCATING FEATURES OF INTEREST

After Coarse Approach is complete, Features of Interest can be located by using the X-Y motor step controls. Both coarse and fine movement are possible. If necessary, you can orient the Sample by simply loosening the screws on the Rapid Scanner by hand.

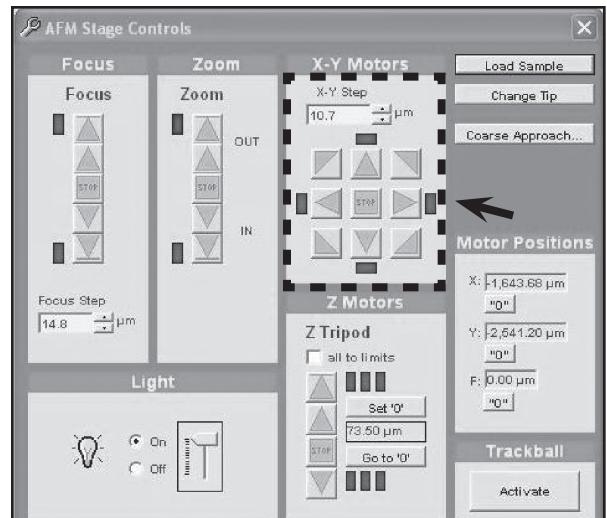


Figure 4.27: X-Y Stage Controls

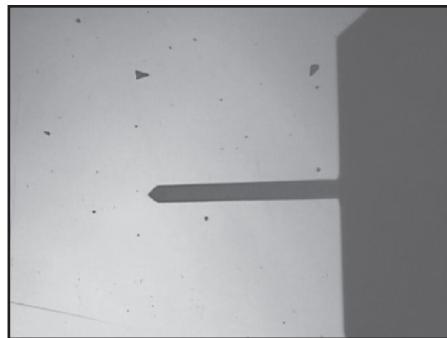


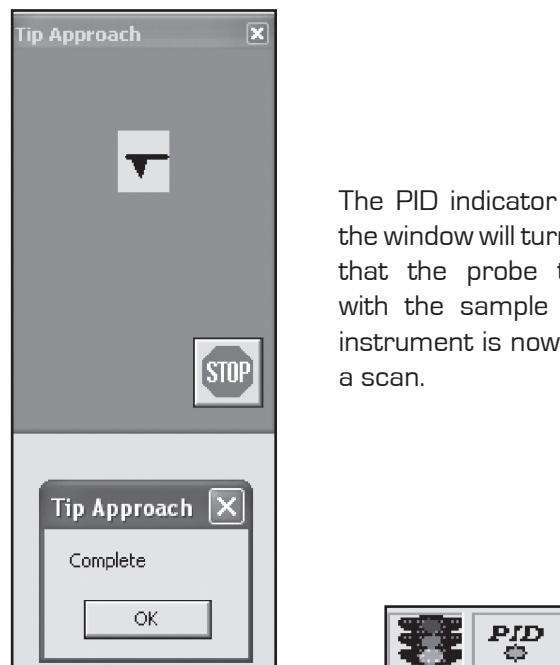
Figure 4.28: Probe is positioned over the area (feature) of interest

FINAL TIP APPROACH

You are now ready to perform the final approach to the Sample. Make sure the probe point (not the crystal arm) is in focus, then click the Tip Approach button on the Toolbar.



CAUTION: Once the Tip Approach is complete, and the tip is in contact with the sample surface, do not exit the SPM Cockpit™ software or turn off the Controller without first retracting the tip. Doing so may cause damage to the tip, scanner, and sample.



The PID indicator at the bottom of the window will turn green to indicate that the probe tip is in contact with the sample surface, and the instrument is now ready to perform a scan.

Figure 4.29: Tip Approach confirmation and PID indicator

SCAN SAMPLE

- Click the Scan Sample button on the Toolbar

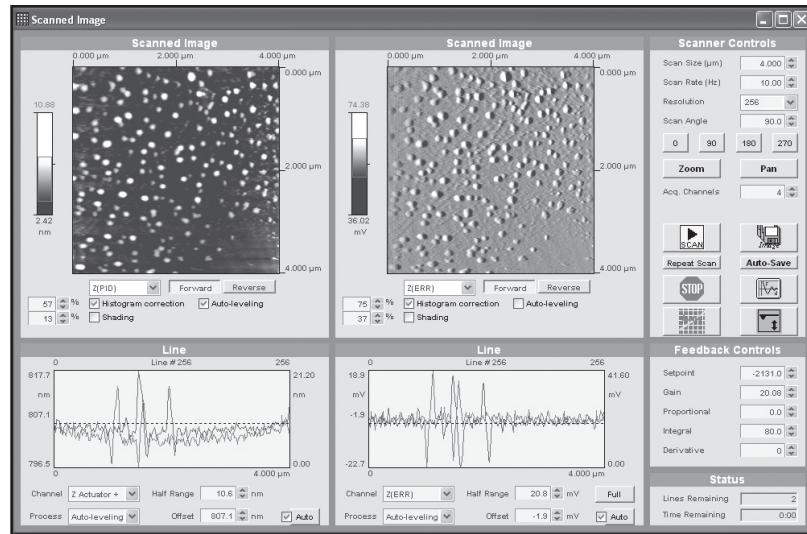


Figure 4.30: Scanned Image Window

- Set the scanner controls as follows:

- Scan Size: 4mm is maximum scan size
- Scan Rate: up to 512 Hz
- Resolution: 256
- Scan Angle: 90
- Acq. Channels: 4

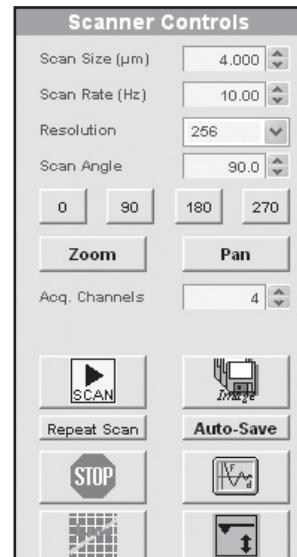


Figure 4.31: Scanner Controls

- Set the feedback controls as follows:

- Setpoint: leave as is.
- Gain: 20
- Proportional: 0
- Integral: 80
- Derivative: 0



Figure 4.32: Feedback Controls

4. Pan - this feature allows to pan around the area . An increment of panning is defaulted to 1 micron in all directions. Put cursor on the red dot and move it around. Watch how corresponding image changes (Figure 4.33).

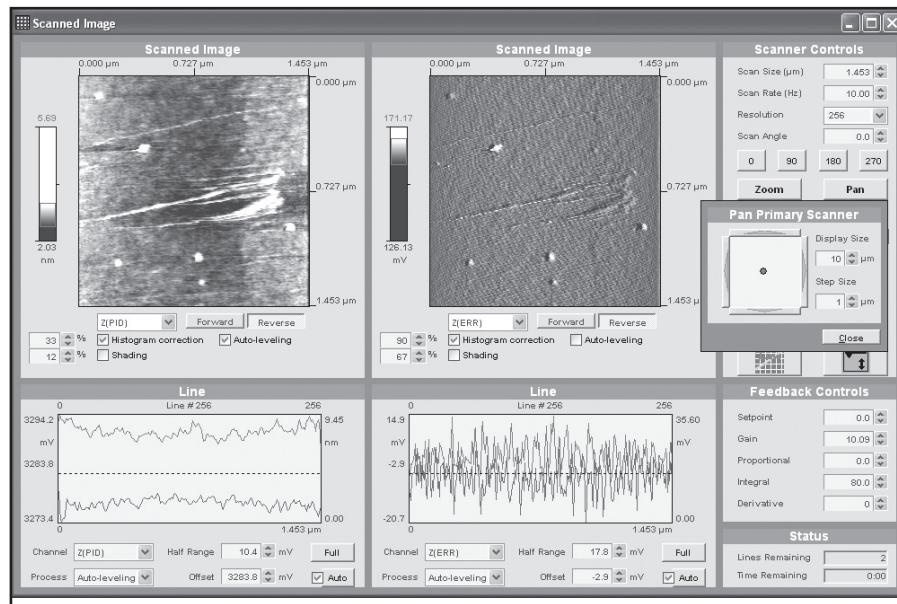


Figure 4.33: Pan Window Controls and Corresponding Scan

Zooming-in and Data Analysis can be performed using the same methods explained in Chapters 2 and 3 (Figure 4.34).

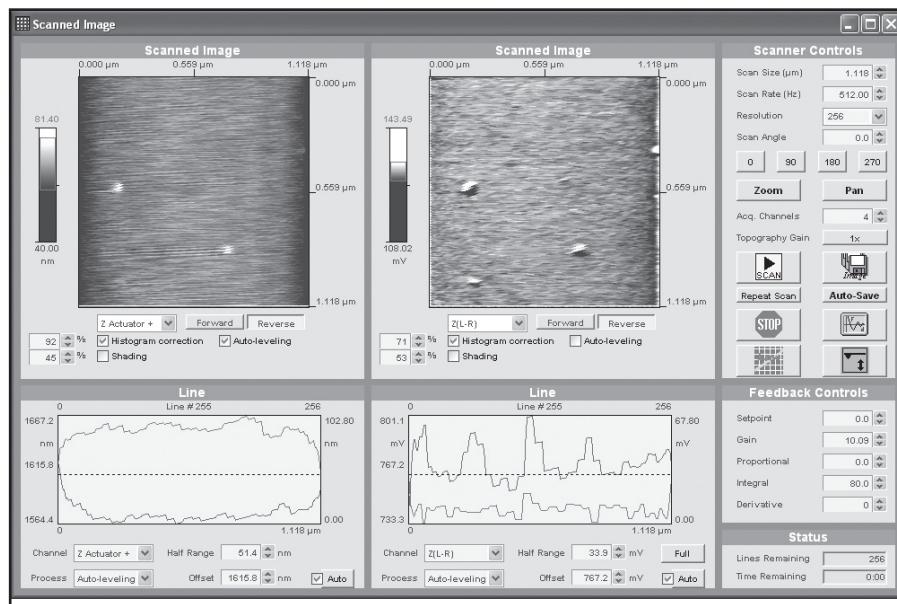
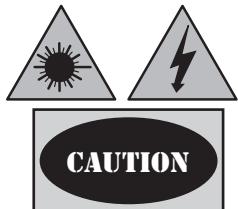


Figure 4.34: Zooming In - in Rapid Scan at 512Hz

Chapter 5 • X'pert™ Mode & More

INTRODUCTION

The tutorials in Chapters 2, 3, and 4 guide you through the minimal steps required to capture an AFM image. This chapter covers some of the Nano-DST™ features and functions that can help you take more advanced images. The contents are organized functionally, roughly following the basic steps for taking an image.



WARNING: Before operating the Nano-DST AFM, make sure you are familiar with the safety information on page iv.

CAUTION: To prevent damage to your scanner, probe, and sample, make sure you are familiar with the caution statements in Chapters 2, 3, and 4.

X'PERT™ MODE

Once you are comfortable taking images in EZMode™, you may find it preferable to operate in X'Pert™ Mode. Select Settings/Toolbar Mode/Expert to display the X'Pert™ Mode short-cut buttons, which provide access to all the steps required for taking an AFM image, as well as other functions and tools.

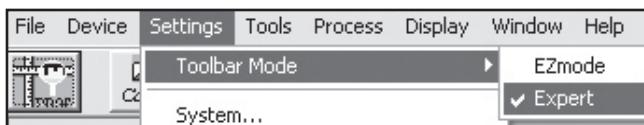


Figure 5.1. Expert Mode Selection Buttons



Display the image processing toolbar.



Open the configuration file to be used for this session.



Save the current parameters and settings as a new configuration file.



Save the image file.



Discover available controllers.



Test the connection with the Controller.



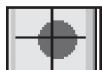
Display the tabs for all the System Settings menu items.



Display the tabs for all the settings on primary XYZ board.



Display the tabs for all the settings on secondary XYZ board.



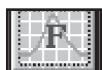
Open the Red Dot Alignment window.



Time mode oscilloscope.



Line mode oscilloscope.



Open Frequency sweep window.



Dual-trace oscilloscope.



Perform X-Y scanner linearization routine.



Automatic tip approach and retract.



Manual up/down tip control, with signal monitoring.



Advanced AFM stage controls.



Open Scanned Image window.



Open Force-distance curve window.

STATUS BAR

The Status Bar is located on the bottom of the SPM Cockpit screen, Figure 5.2, and displays controller IP address, current status of the controller, current status of the feedback loop and the name of the configuration file.

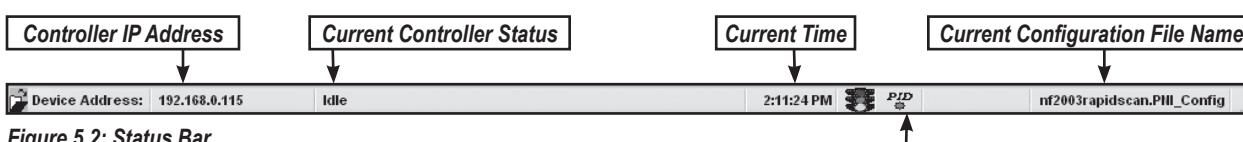


Figure 5.2: Status Bar

CONFIGURATION FILES

Three configuration files are supplied with the Nano-DST™:

- Contact Operation
- Close-Contact Operation
- Rapid Scan Operation

These files contain information that is unique to your particular instrument. Therefore, it is very important that back-up copies of these files be kept in a safe place in the event that the ones on your Master Computer are accidentally altered or deleted.

These files also contain the factory default values for all the default software settings that control your instrument.

OPENING

At the start of each session, you need to load a configuration file. The filenames for the three supplied configuration files are in the following format [xxxx is the serial number of your Nano-DST™ instrument]:

- for contact mode: nfxxxxContact.PNI_Config
- for close-contact mode: nfxxxxCloseContact.PNI_Config
- for rapid scan: nfxxxx.RapidScan.PNI_Config



You can use one of the supplied files or a user-created file containing the settings from a previous session. However, the type of configuration file – Contact, CloseContact, or Rapid – must match the imaging mode for your session (see below). Once you have loaded a configuration file in X'Pert™ mode, there is no need to also select the imaging mode, as required in EZMode™.

SAVING

In the course of taking images, you will invariably change many settings and parameters. At any point, the current settings, which may apply to a particular sample and/or application, can be conveniently saved for future use by saving them in a new configuration file.



When saving new configuration files, the filename should identify the file as either Contact, CloseContact, or Rapid Scan. If you load a Contact or Rapid Scan configuration file and attempt to operate in CloseContact mode using a close-contact probe, you will not be able to do so.

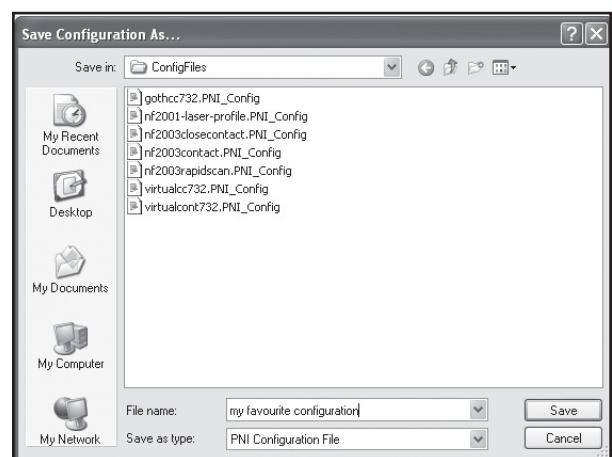


Figure 5.3: Save Configuration File Dialog Window

CONTROLLER IP ADDRESS

The controller or controllers available on the network can be identified with the help of this option. The display window shows the list of the controller's IP's and gives a hint as to what controller the workstation was connected to last (Figure 5.4).

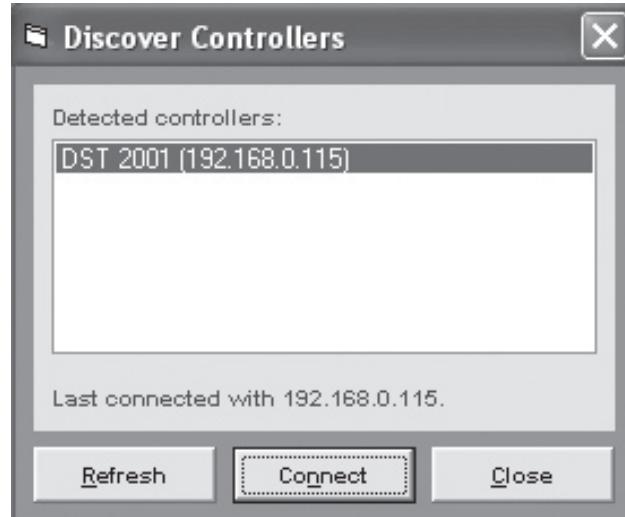


Figure 5.4: Available IP Address of the Controller

STAGE CONTROLS

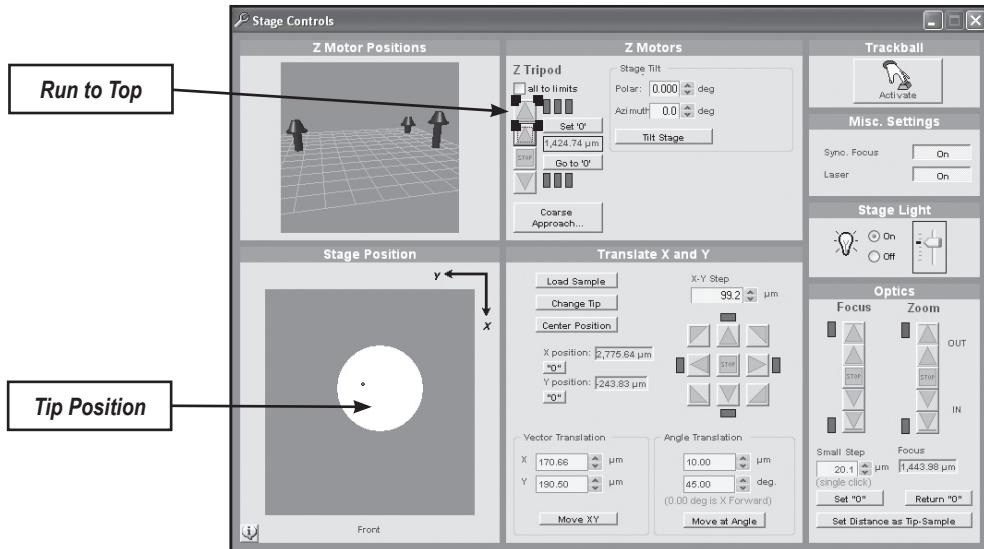


Figure 5.5: Advanced Stage Controls Window

Click the Stage toolbar button to access the advanced stage controls. Buttons in the Translate X and Y box provide a quick, automated way to perform the stage translations for changing the probe and sample.

The Load Sample button automatically moves the puck to the limit of the X-Y stage range to facilitate

changing the sample. Once a sample has been mounted and the puck replaced, click the Restore button to return the puck to its original position.

The Change Tip button will run the Z motors to the top of their range (both the scanner head and the focus lens), to facilitate installing a new probe. The Run to the TOP button in the Z Motors section does the same thing.

The X'Pert™ Mode Stage Position graphic (in the lower left window) shows the position of the tip in relation to the sample puck. See Figure 5.5.

COARSE TIP APPROACH

The Coarse Approach button in the Zmotors section initiates the Optical Tip Approach assist wizard (Figure 5.6).

Manual Optical Tip Approach assistance may be performed instead (if preferred), and involves the following steps:

- Focus on the cantilever – then click Set “0” button
- Focus on the sample surface – then click Set Distance as Tip Sample button
- Make sure that there is a safe offset distance, (~100 µm in offset box before approaching.)
- Click the Approach Sample button.

STAGE TILT

It is possible to physically tilt and level the stage. Leveling is accomplished by using plane correction information from the image processing portion of Cockpit to adjust the stage motors.

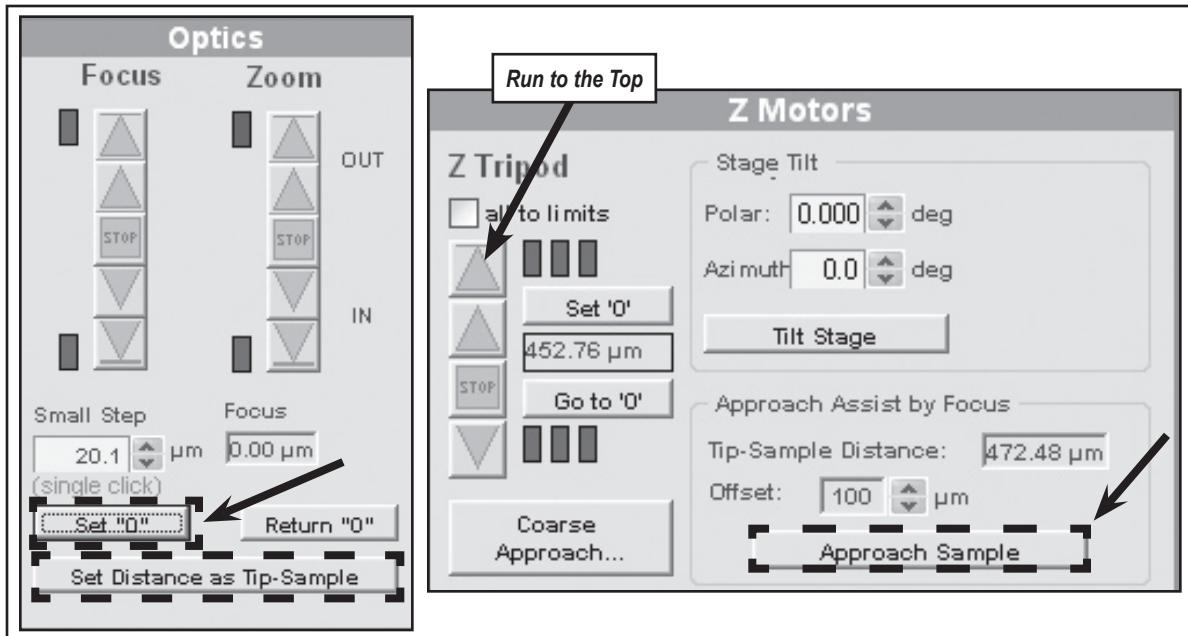


Figure 5.6: Advanced Stage Controls sections in the Stage Controls window

Tilt is defined by two angles. The first angle is the **polar angle** defining the **angle** of the tilt. The second angle is the **azimuth angle** defining the **direction** of the tilt (Figure 5.7).

- A polar angle of 0° means no tilt. The allowed range is 0 to 2°.
- An azimuth angle of 0° indicates a tilt toward the right (of the scanned image, with no scan rotation); 90° indicates a tilt toward the top; 180° indicates a tilt toward the left; 270° indicates a tilt toward the bottom. The allowed range for the azimuth angle is 0 to 360°.

The following procedure is used to tilt the stage:

1. Make sure the tip is retracted (however, the Z motors should not be close to their limits).
2. Click the Stage button on the toolbar to open the Stage Controls window.
3. Enter the desired tilt angles in the Stage Tilt section of ZMotors.
4. Click the Tilt Stage button.

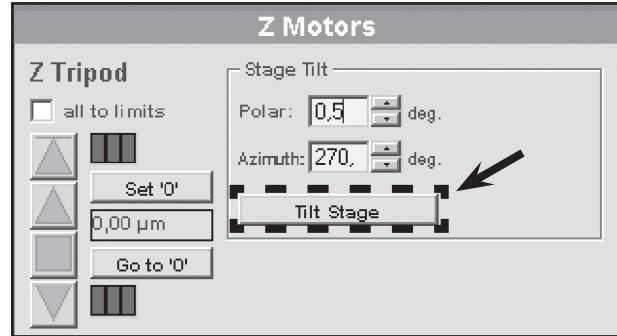


Figure 5.7: Stage Tilt Controls

Two of the stage motors will move in order to tilt the stage. (Motors always move so that the tip-sample distance increases.)

Note: It is possible for a Z motor to trip its limit switch. In this case a message will explain that the intended tilt could not be achieved.

The tip is re-focused after tilting or leveling is completed.

When the stage is to be leveled, the tilt angles must be calculated from a scanned image. The plane correction window will indicate the tilt angle present in the image. This information can then be used to correct for this tilt. In order to counteract the measured tilt, the stage needs to be tilted in the opposite direction. Cockpit will therefore add (or subtract) 180° from the measured tilt direction to obtain the azimuth angle for the stage tilt.

SCANNER LEVELING

The following procedure is used to level the scanner:

1. Load a sample and acquire a maximum scan, typically 90 x 90 microns (scan size should be more than 40 microns for accurate leveling). Stage leveling works for both the Z Sensor and Z Height channels.
2. Retract the tip.
3. Click the Image Processing button (PROC) on the Toolbar, then the Select Source Image button. Select the Z Sensor channel (forward or reverse).

4. Click the Plane Correction button (Figure 5.8). Select polynomial surface leveling with polynomial order 1, or select 3-point plane correction.
5. Click Apply. You will notice information about the measured image tilt (for example 0.194 deg. toward 92.1 deg.) below the processed image. This information is stored internally and is available for stage leveling (Figure 5.8).

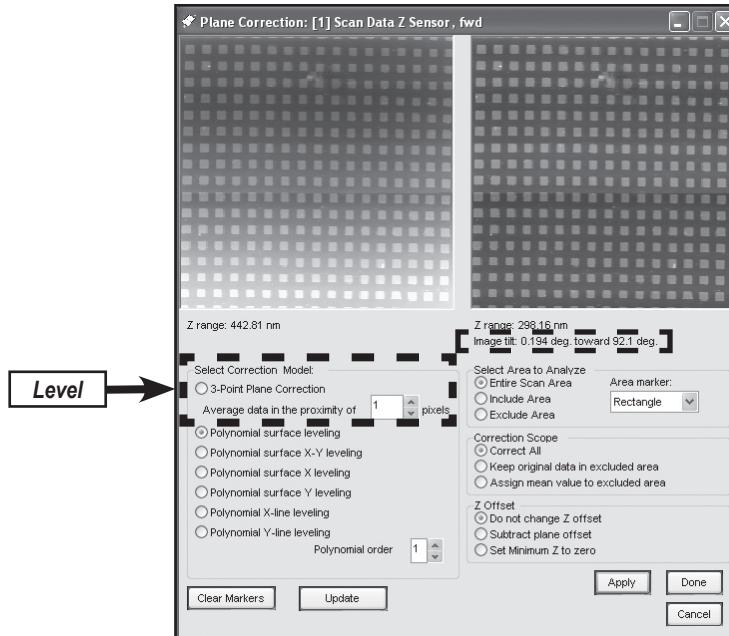


Figure 5.8: Plane Correction window shows calculations for leveling stage

6. Close the window by clicking Cancel or Done.
7. Click the acquisition button [ACQ] on the toolbar and open the AFM Stage Controls window by clicking the Stage button. In the Stage Tilt block of the Z Motors section, a Level Stage button is now available that will correct the measured image tilt [0.194° and 92.1° for the above example].

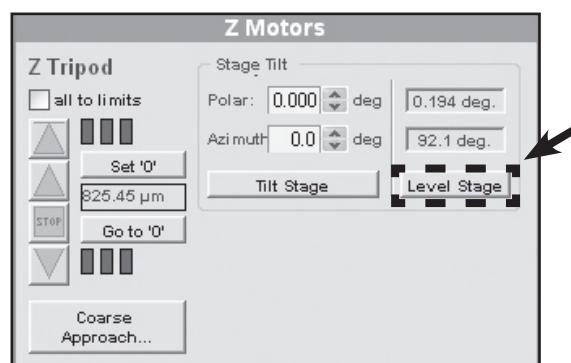


Figure 5.9: Level Scanner Controls

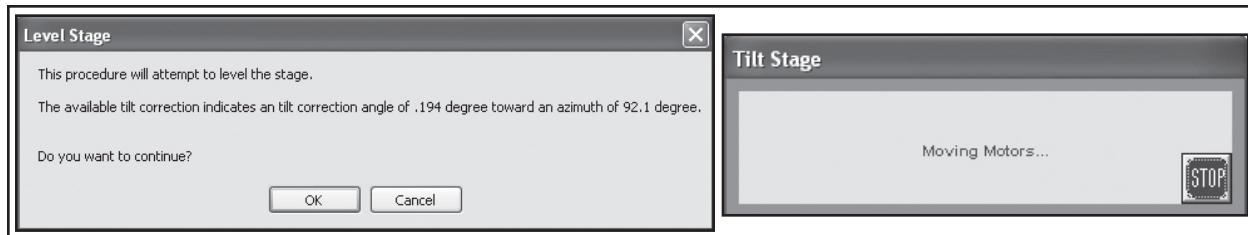


Figure 5.10: Level Stage Dialog Boxes

8. Click the Level Stage button and then OK to start the procedure. Two of the three Z motors will move (always to increase the tip sample distance) to correct for the measured tilt.
9. Depending on the magnitude of the tilt correction and the scan size it may be necessary to reposition the tip to the area of interest on the sample.
10. Focus remains on the tip during leveling.
11. Approach the sample. The tilt of the acquired image should now be minimal. Typical values for Z-range are less than 500nm for the full frame of unleveled data taken on a flat sample.

TRACKBALL

A trackball is supplied with the Nano-DST™ system as an alternative way of accessing the motorized stage controls. The trackball can be activated from the stage controls window in either EZMode™ or X'pert™ Mode (or Tools/NanoR2™ Stage).



Figure 5.11: Trackball Button

Trackball Stage Control		
	<u>Left Button</u>	<u>Right Button</u>
X-Y Stage	Off	Off
Z Stage	Off	On
Zoom	On	On
Focus	On	Off



Figure 5.12: Trackball Photo

SAMPLE MOUNTING

The sample should be mounted so that it is stable and relatively flat. The magnet at the center of the puck is a convenient way to secure samples mounted on magnetic (steel) sample disks. Double-sided tape may also be used. The rapid scanner is also equipped with 2 magnet to hold the sample (Figure 5.13).

The height of the sample puck on both conventional and rapid scanner (Figure 5.13) can be adjusted to accommodate samples of varying heights. The puck is composed of 5 layers each measuring 1/4" in height. Therefore, if your sample is taller than 1/4", you should remove one layer for each 1/4" of height of your sample.

Use a 1/16" Allen wrench to loosen one of the screws on the top of the puck. Loosen it only until you feel some resistance, then loosen the other screw completely. Finally, finish loosening the first screw and remove the puck layer. To add a layer, tighten the screws in the same way.

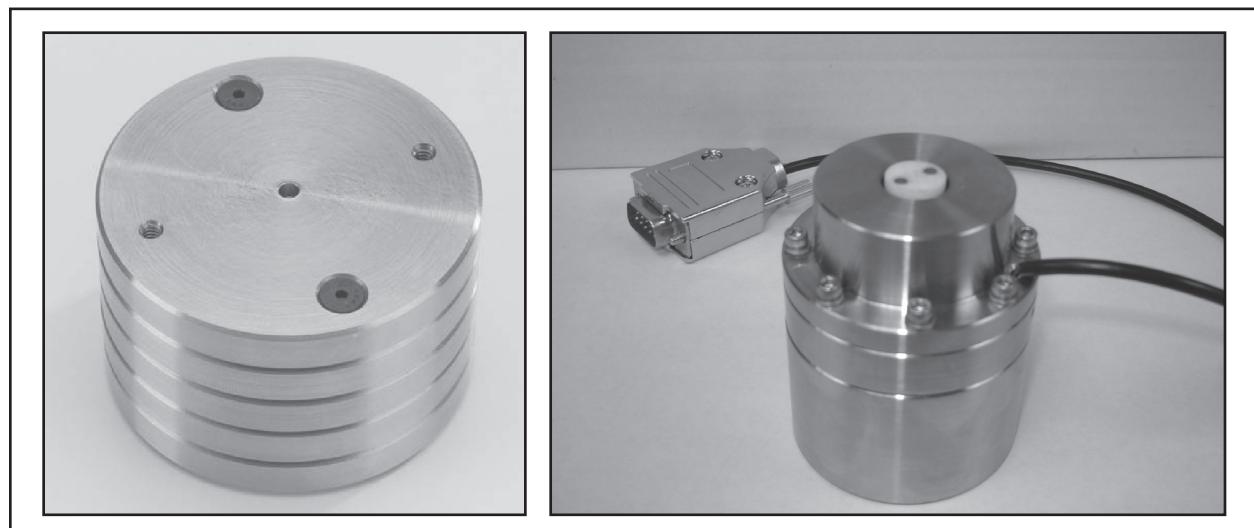


Figure 5.13: Conventional Sample Puck and Rapid Scanner

SCANNING

The Display Scanned Image button on the X'Pert™ Mode Toolbar opens the Scanned Image window. While this is the same window used in EZMode™, the descriptions below provide additional details about the meaning of the various settings.

Scan Size

The maximum scan area that your instrument's scanner can accurately scan is automatically entered in the Scan Size field each time the linearization routine is performed. Typical values range between 90 and 100 microns for the primary scanner. The maximum scan size for the secondary (rapid) scanner is 4 microns. Changing the scan size expands or contracts the scan area symmetrically. Scanner Controls setting are available in Scan Window under Scanner controls (Figure 5.14) and under System setting option (Figure 5.15).

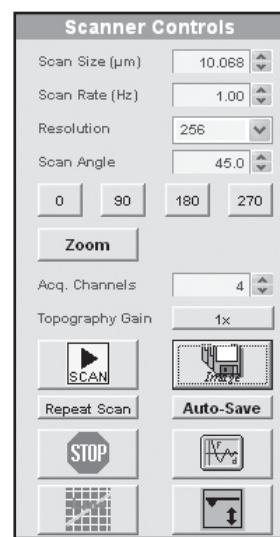


Figure 5.14: Scan Controls

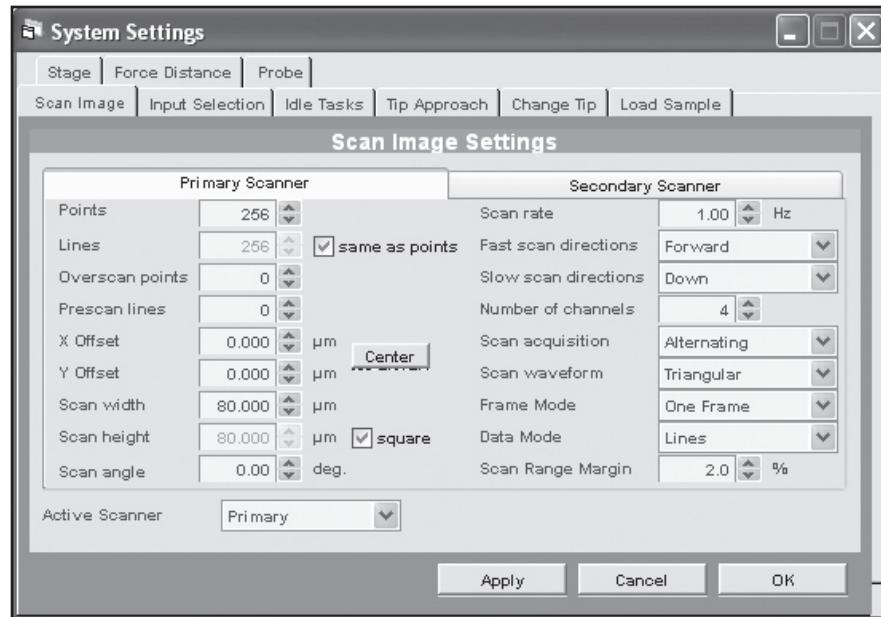


Figure 5.15: Scan Image Settings

Scan Rate

As a general rule, the slower the scan rate, the better the feedback electronics track the sample topography. Therefore, the optimum scan depends on how rough or smooth the sample is. If the sample is very flat, scanning at a slow rate is of no benefit; and if a rough sample is scanned too quickly, information is likely to be lost. The scan rate capabilities for the secondary scanner extend up to 256 lines per second (or one frame per second with a pixel resolution of 256, or 2 frames per second with a pixel resolution of 128). Switching between primary and secondary boards can be done by selecting corresponding board under Scan Image Settings under Active Scanner (Figure 5.15). Please, refer to Chapter 4 for details on installation and operating procedures with a Rapid Scanner. Rectangular scans can be acquired by specifying scan width and length (Figure 5.16).

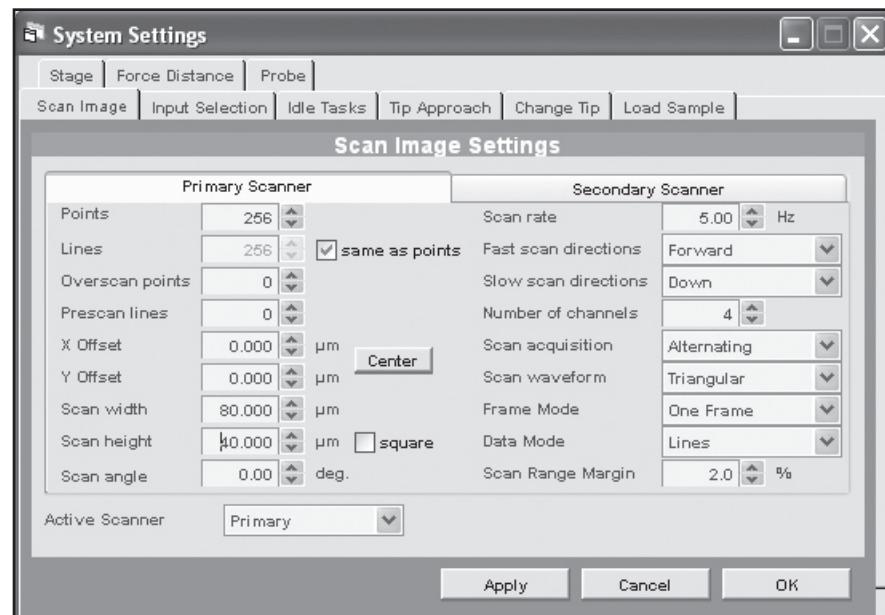


Figure 5.16: Scan Settings Parameters for Rectangular Scan, 80x40microns

Resolution

This value represents the number of pixels per line in the image. The default setting, 256, will result in a 256x256 pixel image (i.e., 256 line scans, each consisting of 256 data points). The resolution ranges from 16 pixels to 4,096 pixels for any scan size on both the primary and secondary boards (16/24 control XYZ boards). Pseudo-rectangular scan sizes can be acquired by typing the desired number of pixel and lines into corresponding boxes under Scan Image Settings (Figure 5.18).

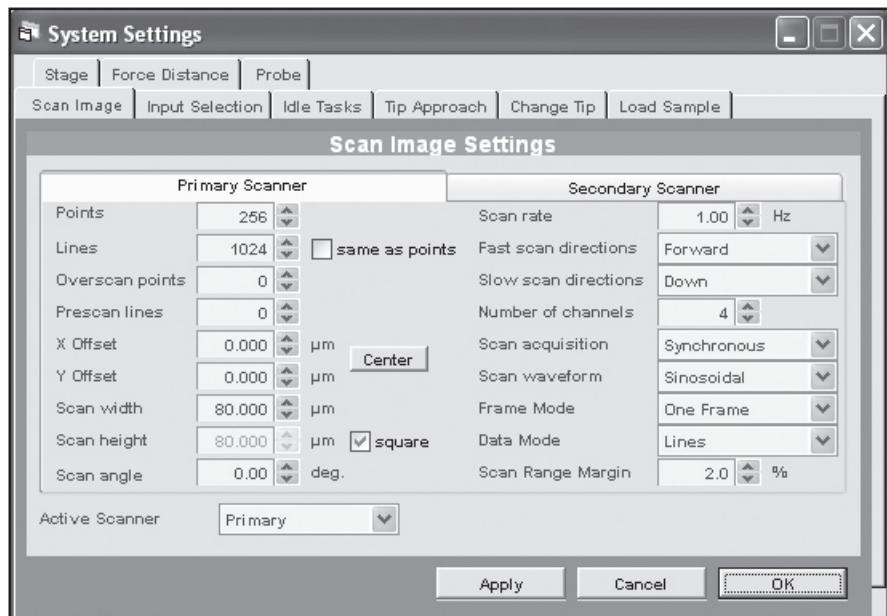


Figure 5.17: Pseudo-Rectangular Scan Settings

Scan Angle

The scan region is a square area that can be rotated as desired, rather than physically rotate the sample. Note that the scan size may be automatically reduced in the event that the rotation causes some of the scan area to extend beyond the range of your scanner's maximum range. A new scanned image is overlaid on the scaled and rotated previous scanned image.

Topography Gain

Increasing the topography gain from 1x to 10x is often useful when imaging very small features (< 5 nm). This is a way of increasing the gain without losing resolution. The Z(PID) channel should be monitored in this situation (instead of the Z sensor), as the Z feedback sensor is not sensitive enough to resolve small features. The Z sensor is not sensitive enough to sufficiently resolve small features. The Z actuator can be monitored for reference purposes, however applied attenuation is always 1x for Z actuator channel due to the Z feedback circuit design. The Topography Gain/Attenuation feature can be turned on and off under Settings for Primary Board/Z feedback (Figure 5.18). To learn more about how to use the attenuation and hold feature read the Gain Reduction/Attenuation and Hold Mode section in this chapter.

Line Scan

Sometimes it is convenient to scan the same line over and over again while adjusting scan parameters.

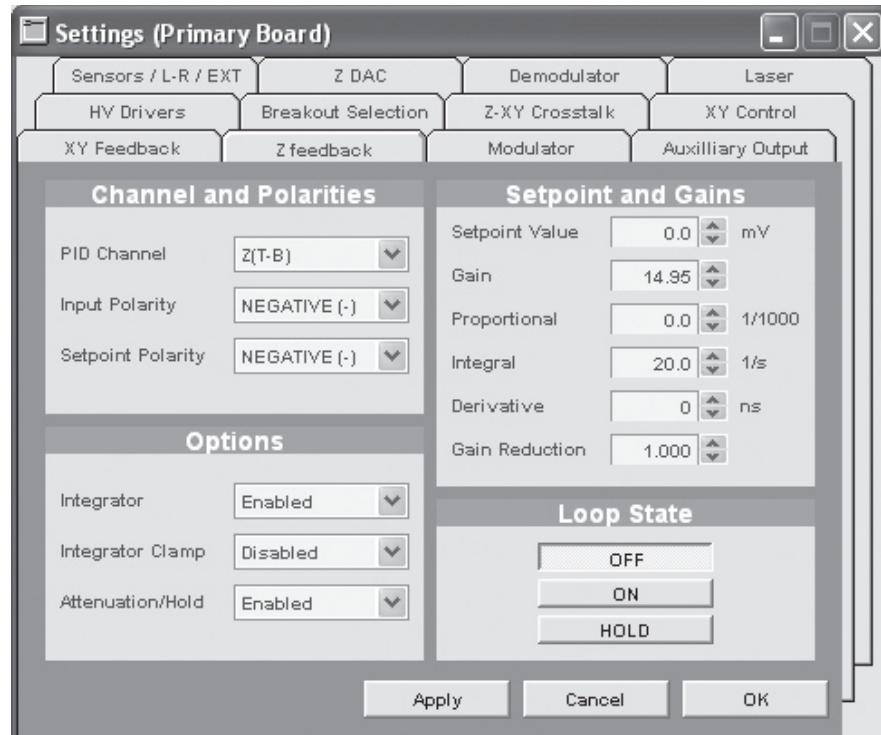


Figure 5.18: Z feedback Controls for Primary board

RAW AND VIRTUAL CHANNELS

A new set of signals can be selected on the Input Selection tab in the System Settings window. These new signals are called Virtual Signals and they differ from the regular [raw] signals in that the controller applies scaling and corrections.

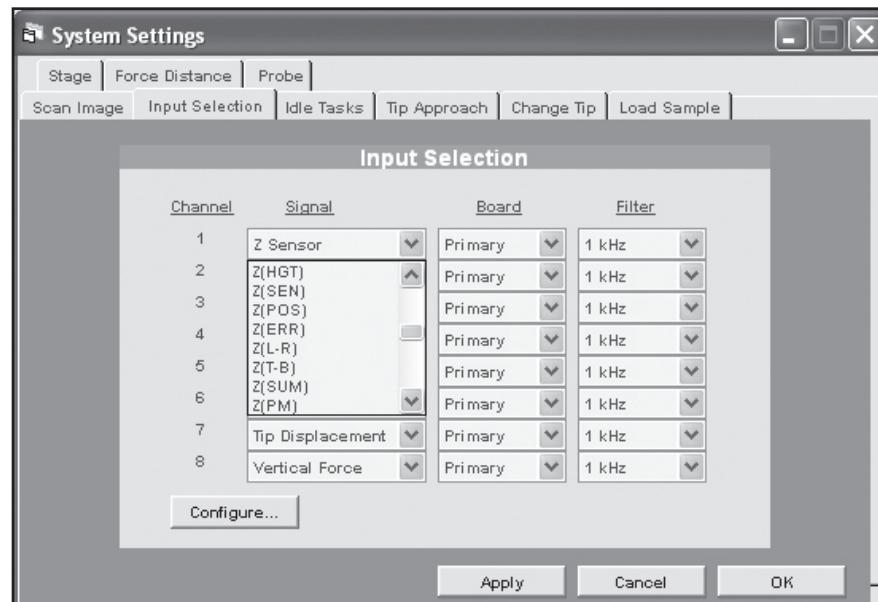


Figure 5.19: Input Selection of the Channels

The following is a list of the new signals:

- Z Actuator: The position of the Z piezo based on the measured piezo voltage. Choose from the following raw signals: Z(HGT), Z(HGT)-24, Z(PID), Z(T&H), Z(T&H)-24, Z(PIZ). Any non-linearity corrections that are defined for the Z piezo can be applied.
- Z Sensor: The position of the Z piezo based on the measured Z sensor voltage. Choose from the following raw signals: Z(SEN), Z(SEN)-24. The Z sensor non-linearity correction can be applied.
- Z Error: The deviation of the feedback signal from the setpoint. Choose from the following raw signals: Z(ERR), Z(POS), Z(POS)-24. If the feedback signal is Z(T-B), Z(AM), or Z(SEN) the deviation is calculated in spatial units. Otherwise the raw unit [mV] is retained.
- Z Actuator +: Z Actuator blended with the error signal. The same raw channels as for Z Error are available. A blend factor can be specified.
- Z Sensor +: Z Sensor blended with the error signal. The same raw channels as for Z Error are available. A blend factor can be specified.
- Z Tip Displacement: The displacement of the cantilever as measured by the photo detector. Choose from the following raw signals: Z(T-B) or Z(T-B)-24. The Displacement Sensitivity from the Probe settings group is used to calculate this signal in spatial units.
- Vertical Force: The force on the cantilever as measured by the photo detector. The same raw channels as for Z Tip Displacement are available. The Displacement Sensitivity and Spring Constant settings from the Probe group are used.
- Lateral Force: The lateral force signal as measured by the photo detector. Choose from Z(L-R) and Z(L-R)-24. This signal retains the raw mV unit.
- Amplitude: The oscillation amplitude of the cantilever as measured by the demodulation circuit. The raw signal is Z(AM). It is assumed that the demodulator channel is Z(T-B). The Displacement Sensitivity from the Probe settings group is used to calculate this signal in spatial units.
- Phase: The phase signal as measured by the demodulation circuit. The raw signal is Z(PM). This signal retains the raw mV unit.
- X Actuator: The position of the X piezo based on the measured X piezo voltage. Choose from the following raw signals: X(DRV), X(PIZ+), X(PIZ-). Any non-linearity corrections that are defined for the X piezo can be applied.
- X Sensor: The position of the X piezo based on the measured X sensor voltage. The raw signal is X(SEN). The X sensor non-linearity correction can be applied.
- Y Actuator: The position of the Y piezo based on the measured Y piezo voltage. Choose from the following raw signals: Y(DRV), Y(PIZ+), Y(PIZ-). Any non-linearity corrections that are defined for the Y piezo can be applied.

- Y Sensor: The position of the Y piezo based on the measured Y sensor voltage. The raw signal is Y[SEN]. The Y sensor non-linearity correction can be applied.
- User 1: A user defined virtual signal based on the addition of two selectable channels multiplied by two selectable factors. The raw units [mV] are retained.
- User 2: A user defined virtual signal based on the addition of two selectable channels multiplied by two selectable factors. The raw units [mV] are retained.

Units for the Z Actuator, Z Sensor, Z Error, Z Actuator +, Z Sensor +, Z Tip Displacement, and Amplitude signals are set by the Z Unit setting.

Units for the X Actuator, X Sensor, Y Actuator, and Y Sensor signals are set by the XY Unit settings.

The unit for the Vertical Force signal is set in the Vertical Force Unit setting.

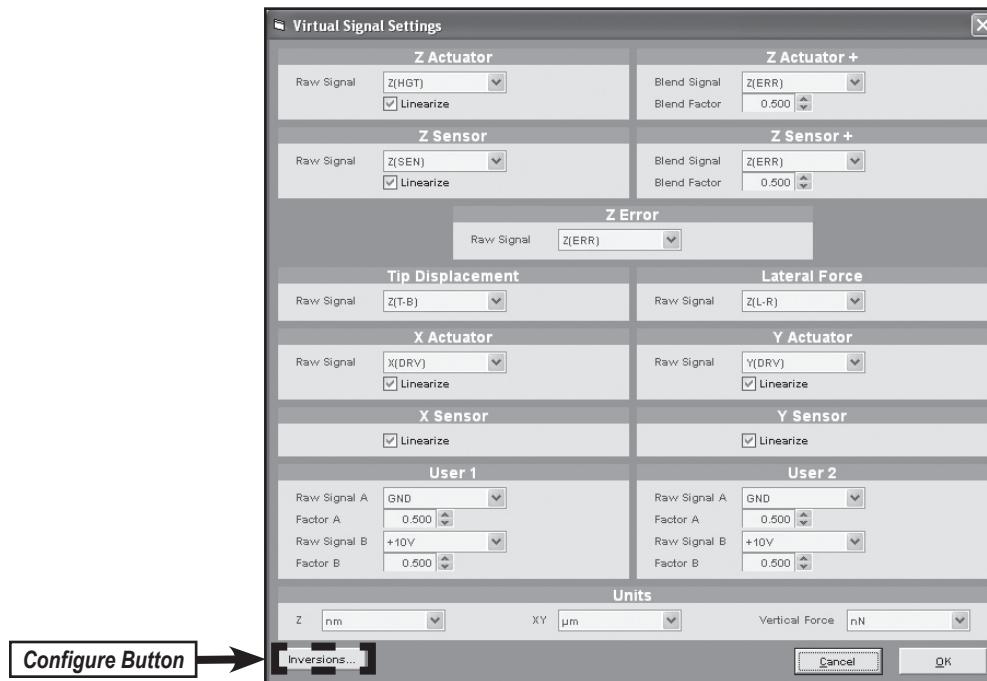


Figure 5.20: Configure Settings for Virtual Channel

Additionally, it is possible to combine two raw signals into a new signal. Click the Configure... button on the Input Selection tab to access parameters that control the behavior of these signals (Figure 5.20). In order to use the gain reduction and hold mode features please make sure that the Attenuation Hold option on the Z feedback tab in the [primary-board] settings window is set to Enabled (Figure 5.18).

ZOOM FEATURE

The Zoom feature provides tools for refining your scan area: XY Offset and Zoom window, scan size window and click and drag on image display.

The red box drawing can be accomplished by clicking and dragging in the image display to define the new scan area (Figure 5.21)

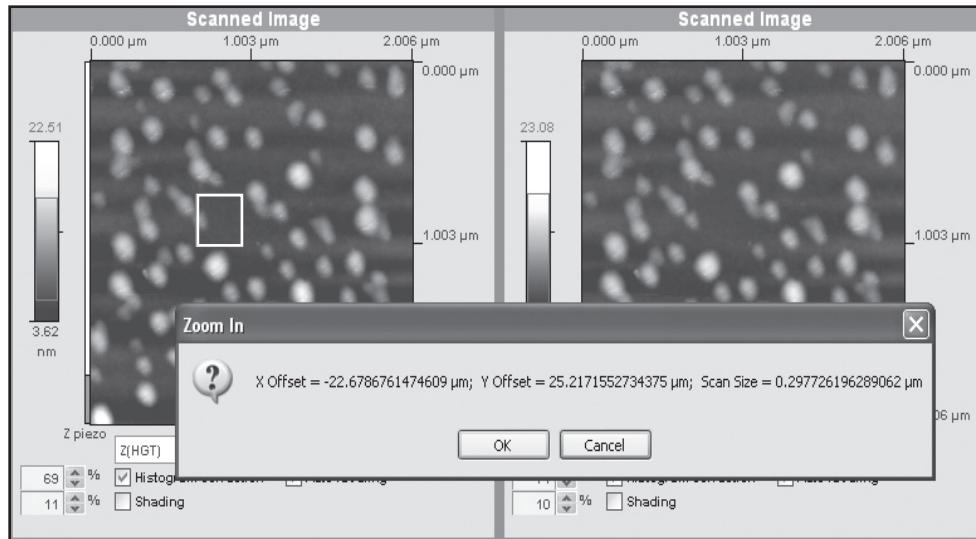


Figure 5.21: XY Offset and Zoom window. The red arrow indicates the direction of slow scan.

The simplest zoom can be accomplished by entering the desired scan size into scan size box (Figure 5.22). Click Zoom to see the corresponding scan location on the overall linear area in the XY Offset and Zoom window display (Figure 5.22).

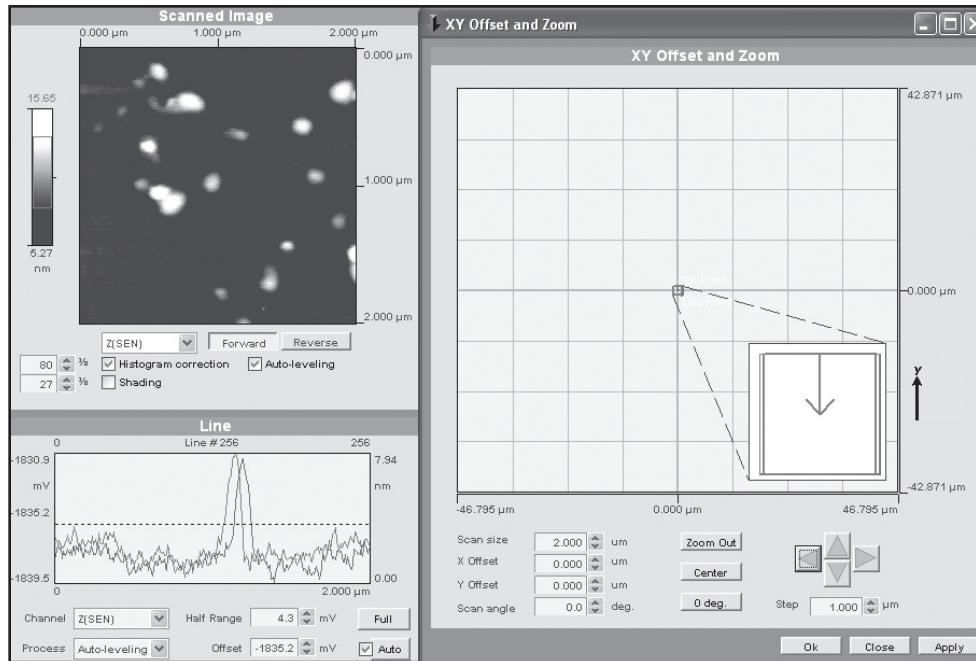


Figure 5.22: 2 Micron scan and corresponding XY offset and zoom window

If you want to zoom-out, either type the desired scan size in the scan size window or in the XY Offset and Zoom window. Zooming-out happens symmetrically, so your small scan appears in the center of the larger scan [Figure 5.23].

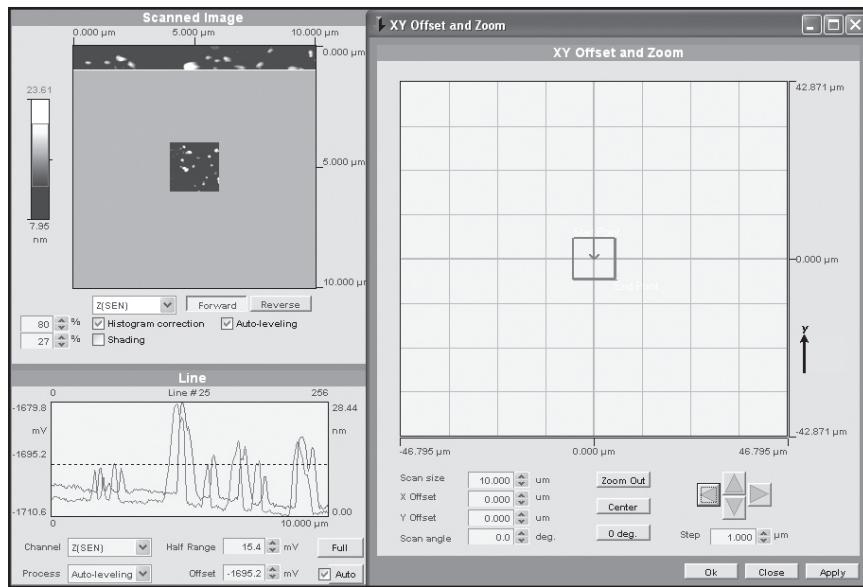


Figure 5.23: 10 microns scan zoomed-out from 2 microns, as it appears on Scan Image window and XY Offset and Zoom window

If you want to apply offset , you can either type the desired offset value in XY Offset and Zoom window or move the red box around [Figure 5.24]. If you want to zoom-in, you can either type the desired scan size in XY Offset and Zoom window or move the red box around [Figure 5.24].

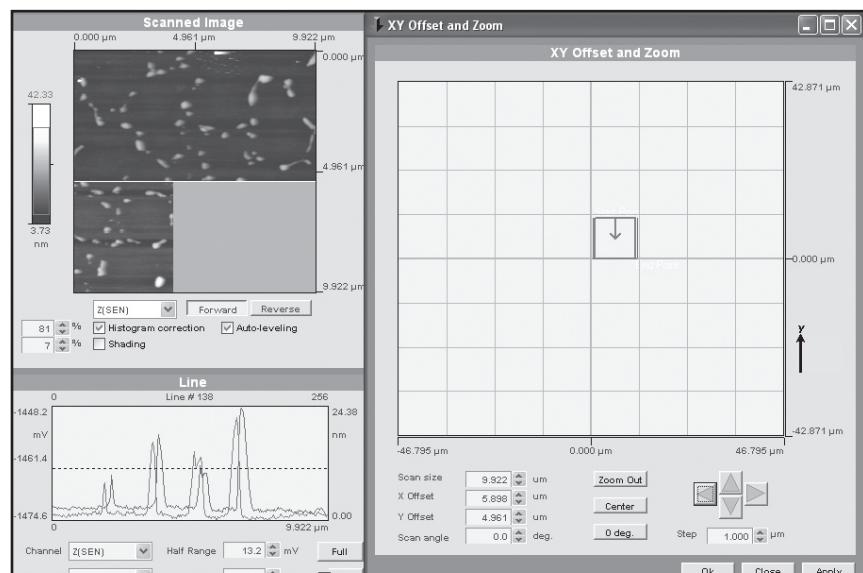


Figure 5.24: 9.9 microns scan is offset to the left by 5.9 microns(X-axis) and up 5.0 microns up (Y-axis)

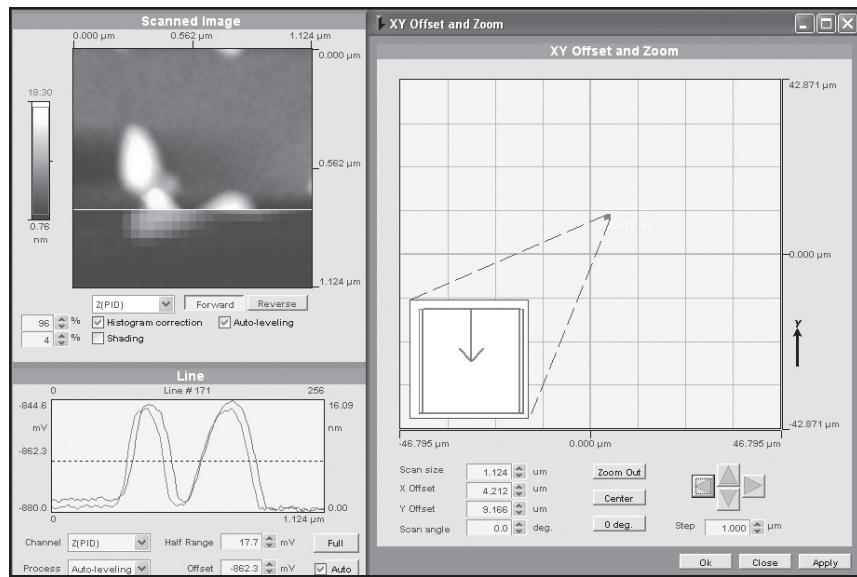


Figure 5.25: Zooming in from 9.9 microns scan size to 1.1 micron scan.

REPEAT SCAN OPTION

When this option is checked, the system takes continuous scans of the same region. This allows you to keep adjusting the scanner and feedback controls until they are optimized. The user can set a delay between repeat scans and the number of repetitions can be limited.

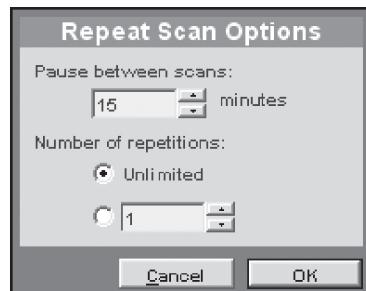


Figure 5.26 Repeat Scan Controls

AUTO-SAVE OPTION

Scanned images can be automatically saved when a scan is completed. The file name is either a date/time stamp or a custom Base File name plus an incremental number. This option is particularly useful in conjunction with the repeat scan option.

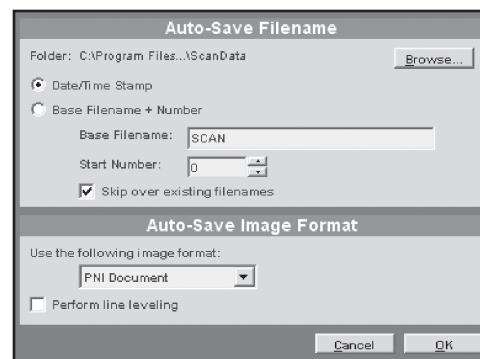


Figure 5.27: Auto-Save Controls

FEEDBACK CONTROLS

Setpoint

The setpoint is related to the strength of the tip-sample interaction that the feedback electronic maintains as the tip is scanned over the sample surface. In Contact mode, this corresponds to a tip-sample force (in nanonewtons); raising the value increases the force of the interaction. In Close-contact mode, the set point is related to the voltage required to maintain a particular interaction level between the probe and sample. The set point in Close-contact mode is set automatically when tuning is performed. Increasing this value (making it less negative) brings the tip closer to the sample.

When you begin scanning, use the default feedback control settings, GPID=5,0,10,0. These can then be adjusted while scanning to optimize the acquired image. The parameters should be adjusted one at a time, in small increments. Allow the system to scan a few lines after each adjustment so you can see the result before making further adjustments. Adjust these settings carefully, as it is possible to damage your scanner, tip, and sample.

Additional access to feedback controls is provided under Setting for primary board/ Z feedback. See Figure 5.23.

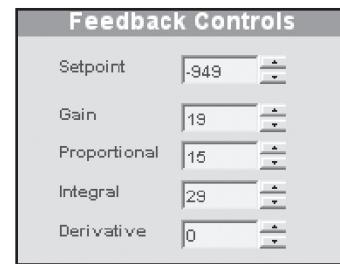


Figure 5.28: Feedback Controls

GPID

Use the following guidelines for tuning the proportional, integral, and derivative gains (PID):

- In Contact mode, the derivative should be kept at 0, otherwise the scan may be unstable.
- For relatively flat samples, use a high proportional gain while keeping the derivative low.
- For relatively rough samples, use lower proportional values and increase the integral.

Note: Please see appendix B for additional information on feedback control.

TIP APPROACH OPTIONS

Tip approach options are available by selecting choices in a drop-down menu (Figure 5.30). Open loop tip approach implies approaching in a woodpecker manner with feedback loop turning On and Off on every step of iterations. Closed loop approach implies approaching with feedback On all the time. The tip approach setting can be modified in the tip approach tab under System setting. However, please remember doing so can lead to unreliable operation and can cause damage of the tip.

NOTE: Using a tip approach from one of the two sets with parameters optimized for the other can lead to unreliable operation and can cause damage to the tip.

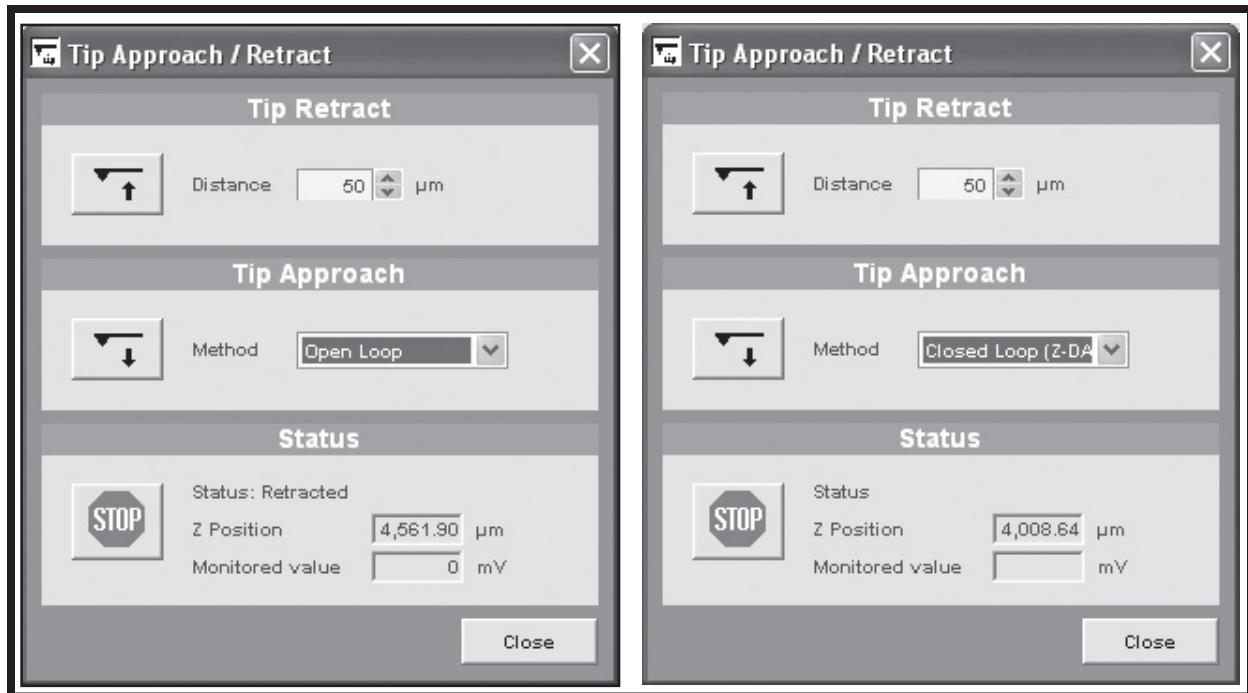


Figure 5.29: Recommended and Advanced Tip Approach Options

FFT AND LEVELING OPTIONS

Fast Fourier Transform analysis is available during image acquisition. This option is available as a processing option along with auto-leveling for line profiles.

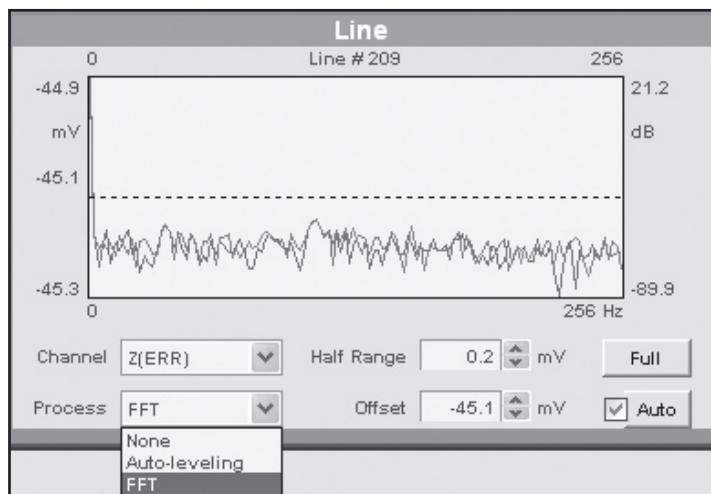


Figure 5.30: FFT and Leveling Options

GAIN REDUCTION / ATTENUATION AND HOLD MODE

Make sure that this option is enabled. If topography gain 1x is displayed in Scan window, it indicates attenuation is enabled. If not, open Z feedback window under the Setting for primary board and enable it. See Figure 5.23. Please use the following procedures to explore the gain reduction feature:

1. Do a usual tip approach.
2. Start a scan in the scan window.
3. Click the button next to Topography Gain.
4. A small window is displayed that allows changing topography gain and offset (Figure 5.31).
5. Default values are: 1 for the gain and 0 for the offset.
6. Select Z(HGT) and Z(PID) in the line profile controls and note the Z(HGT) center voltage on the left of the graph (without line leveling).
7. Enter this voltage as the offset in the Topography Gain box.
8. The line profile will soon stabilize close to zero.
9. Enter 4 for the topography gain.
10. The measured Z(PID) voltages are now increased by a factor of 4 for the same height difference. Please note that Z(HGT) will recover to the original voltage because this signal reflects the input to the high-voltage amplifier.
11. The Gain setting in the Feedback Controls is automatically adjusted to compensate for the topography gain.

Please note that the topography gain will reduce the available Z range by the gain factor. The topography gain display on the scan window will change to the specified gain factor (Figure 5.32).



Figure 5.31: Topography Gain

Use the following procedure to explore the hold mode:

1. Do a usual tip approach.
2. Open the Manual Tip Up/Down window. Make sure that when you move the Z motors the indicated Z(HGT) signal shifts up or down.
3. Open the Settings (primary board) window and select the Z feedback tab.

4. Click the HOLD button under Loop State and click Apply. This puts the feedback loop into hold mode. The PID ON/OFF indicator on the status bar will turn yellow.
5. In the Manual Tip Up/Down window, you may now move the Z motors away from the surface. This will not cause a shift in the Z[HGT] signal as before.
6. Click the ON button on the settings window and click Apply. Hold mode is now released and the indicated Z[HGT] will ramp to a new level depending on how far the Z motors were moved in step 5.

Note: The signal name Z[HGT] on the DST controller refers to the (bipolar) input to the Z high-voltage amplifier and includes Z[DAC]. This is different from the PScan controller, where the Z[HGT] channel referred to a bipolar voltage derived from the unipolar output of the PID circuit. The DST controller supplies the additional signals Z[PID] and Z[T&H]. The following summarizes these signals:

- Z[HGT] reflects the input to the Z high-voltage amplifier and therefore does not capture the effect of a gain reduction.
- Z[PID] reflects the output of the feedback circuit. This signal is boosted when a gain reduction is set but will rail when hold mode is entered.
- Z[T&H] is a copy of Z[PID] but will not rail when hold mode is entered.

CURSOR DISPLAY OPTION

Simple distance measurements can be made in the scanned image by CTRL-dragging the mouse on the image between two points of interest.

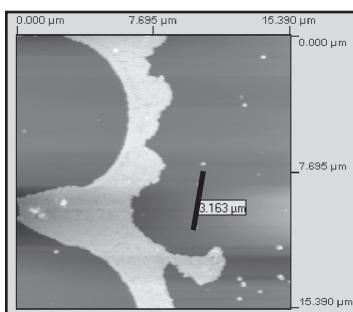


Figure 5.33: Measured Distance Display

REMAINING TIME DISPLAY

The time remaining to complete a scan along with the number of lines remaining to complete the frame, is displayed in the lower right corner of the Scanned Image window.



Figure 5.34: Lines and Time Remaining Display

FORCE-DISTANCE WINDOW

Once the FD-button is clicked you will be asked a question as shown in Figure 5.36. The recommended reply is "Yes". The FD-window (as shown in Figure 5.35) will appear. The procedure for taking FD-measurements is available in Chapter 6.

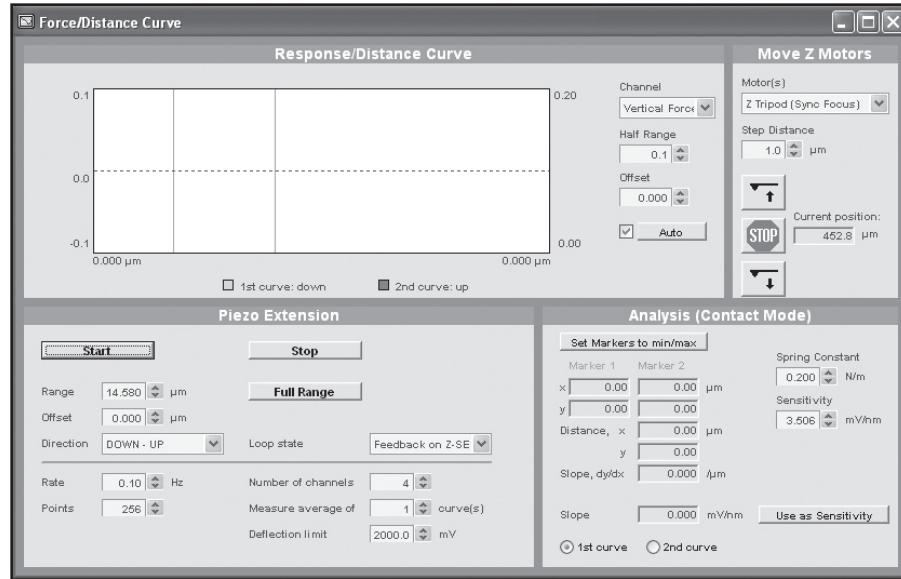


Figure 5.35: Force / Distance Window

SAVING IMAGES

The Save button on the X'Pert™ Toolbar accesses the save options. By default, images are saved in the ScanData folder. By default all images are saved in *.PNI format. Alternatively, you may save data in DigitalSurf, Nanoscope or Topometrix formats.

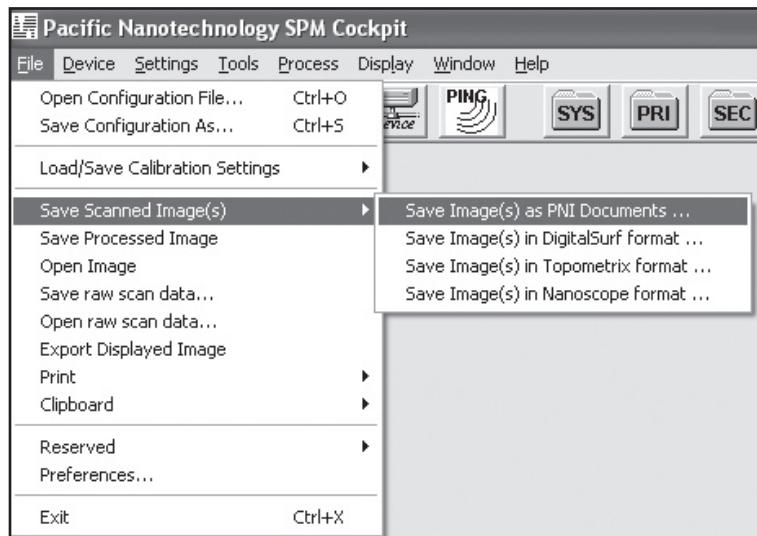


Figure 5.36: Image Saving Options

By default, four channels are selected (in the Scanned Image window). So when an image is saved, a total of eight files are created and saved (the forward and reverse scan data for the four channels selected). If some channels are not needed for your application, you may want to reduce the number of active acquisition channels in order to reduce the number of files generated. To make sure the channels you are interested in are active, select Settings/Input Selects and make sure these are listed as the primary channels. For example, if the Acq. Channels setting (in the Scanned Image window) is set to "2," the signals designated as Channel 1 and Channel 2 will be used.

IMAGE BLENDING

The blending feature enables blending of any two previously saved images. To use this option, select two images, enter a blending coefficient for each image, then save the combined (blended) image. It is important to note that the scaling of the final image is based on Image 1. This means that in order to blend a Z error image with a Z Height image, the Z Height image should be loaded as image 1. The blended image in this case will be scaled in nm, rather than mV.

It is also possible to subtract images. This is accomplished by loading the images and making one of the blending coefficients negative, for example A1 = 1 and A2 = -1.

To use the blending feature, first select Image Processing on the SPM Cockpit toolbar, then click the ADD Images button.



Figure 5.37: Image Processing Toolbar

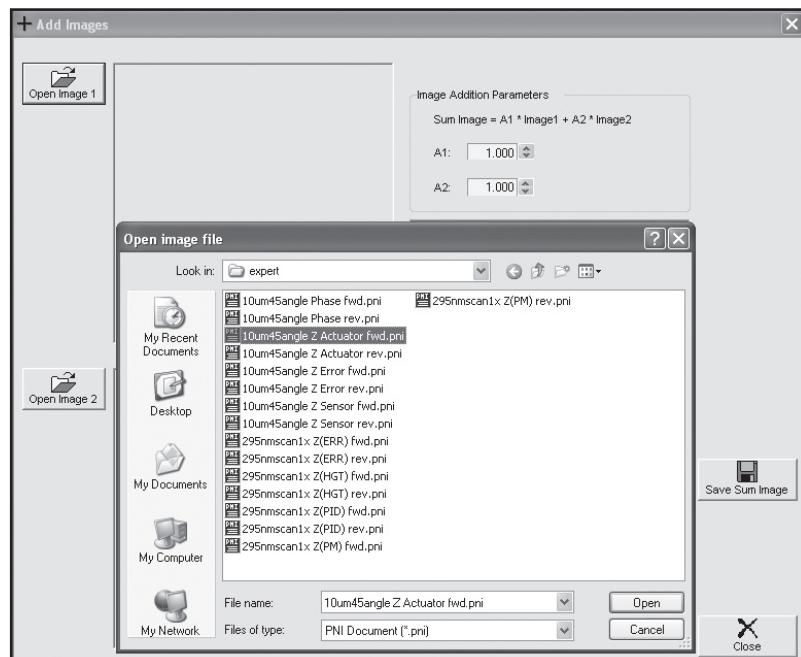
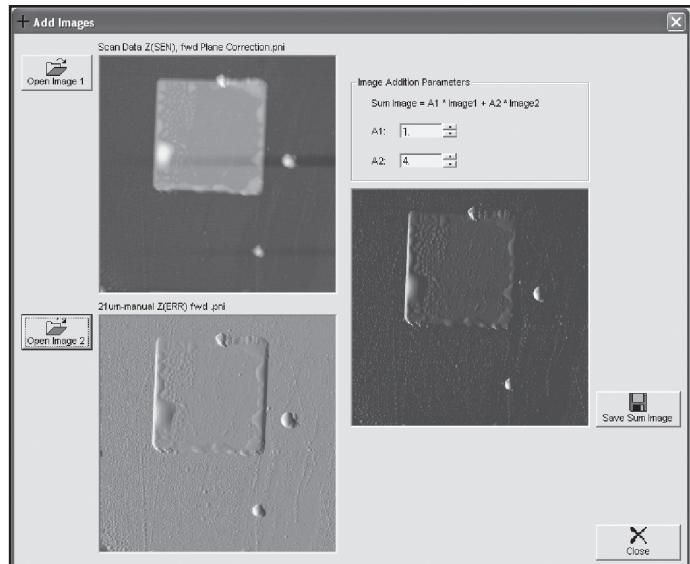


Figure 5.38: Add Images Window



**Figure 5.39: Add Images Window with Z(SENS) and Z(ERR) images open.
Blended image is on the right.**

There is also a special case of image blending that is available in the Scanned Image window, and does not involve the Image Processing module. Channels identified as Zsens+ and Zhgt+ are available as the last two items in the Channel drop-down menu under the Image and Line displays. Zsens+ blends Zerr with the Zsens image. Zhgt+ blends Zerr with the Zhgt image. These are display options only. The blended images are displayed but are not saved as the data is acquired. Only the unblended data is saved.

Chapter 6 • Material Sensing Modes

INTRODUCTION

The Nano-DST™ AFM is capable of providing much more than topographical information about your sample. By monitoring other signal channels, which are available when taking an AFM image, information about the properties of your sample surface can be obtained.

Material sensing modes include, but are not limited to, lateral force microscopy (LFM), phase imaging, and force vs. distance curves. Refer to the AFM Tutorial for more information.



WARNING: Before operating the Nano-DST™ AFM, make sure you are familiar with the safety information on page iv.

LATERAL FORCE MICROSCOPY (LFM)

LFM studies are done while operating in contact mode. The raw Z[L-R] channel, or virtual Lateral Force channel, one of the four channels available in contact mode, provides lateral force information. The resulting LFM image can then be compared to the images generated by the other channels.



CAUTION: To prevent damage to your instrument, probe, and sample, make sure you are familiar with the caution statements in Chapter 2.

In contact mode, a cantilever undergoes lateral bending and twisting either due to the variation of topography or because of variation in friction on a topographically flat surface. In many instances it is a combination of both factors. The bending and twisting motion of the probe translates into L-R and T-B motion of the reflected laser on the 4-quadrant photo detector (Figure 6.1). Monitoring changes in the L-R signal yields an image that is related to the localized frictional properties of the surface.

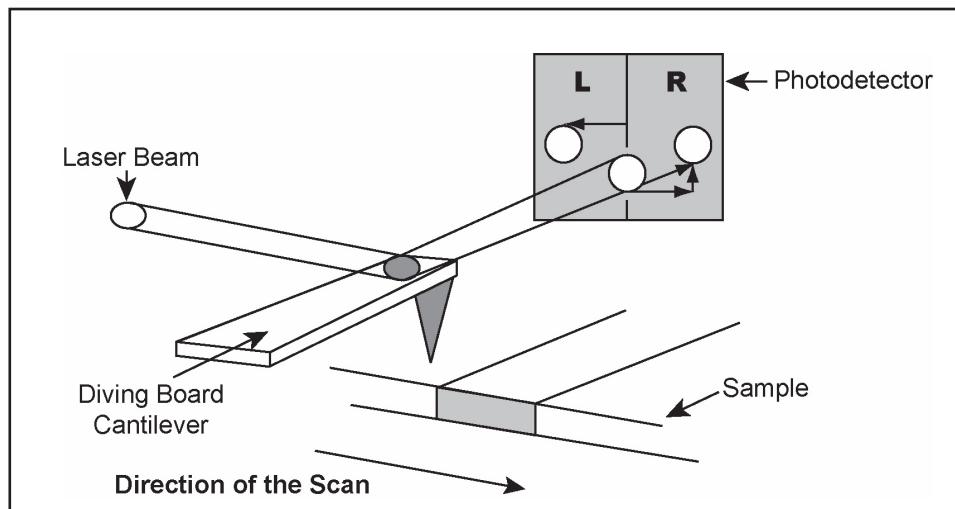


Figure 6.1: LFM signal comes from twisting and bending of the probe in lateral directions

1. Set up the Nano-DST™ to take an image in contact mode, as described in Chapter 2.
2. The Lateral force channel is the default setting for the 4th channel in standard configuration. If you want to change gain or offset parameters, use the Settings (Primary Board) Window (Figure 6.2). Default settings are for gain=1, for offset=0mV.
3. Click the Start Button to take a scan.

While scanning, you can monitor the image and line scan of any of the four channels.

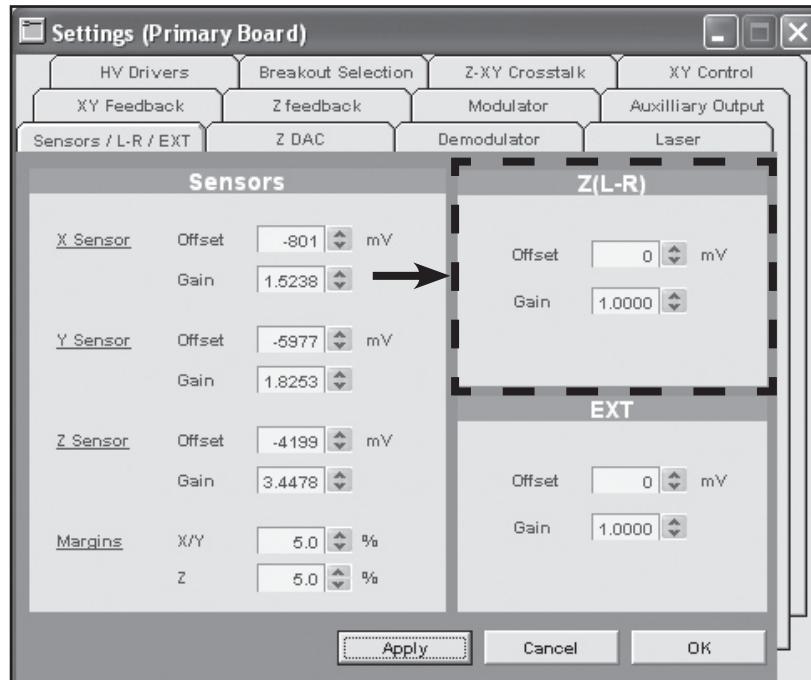


Figure 6.2: Sensors/Z(L-R)/EXT Settings

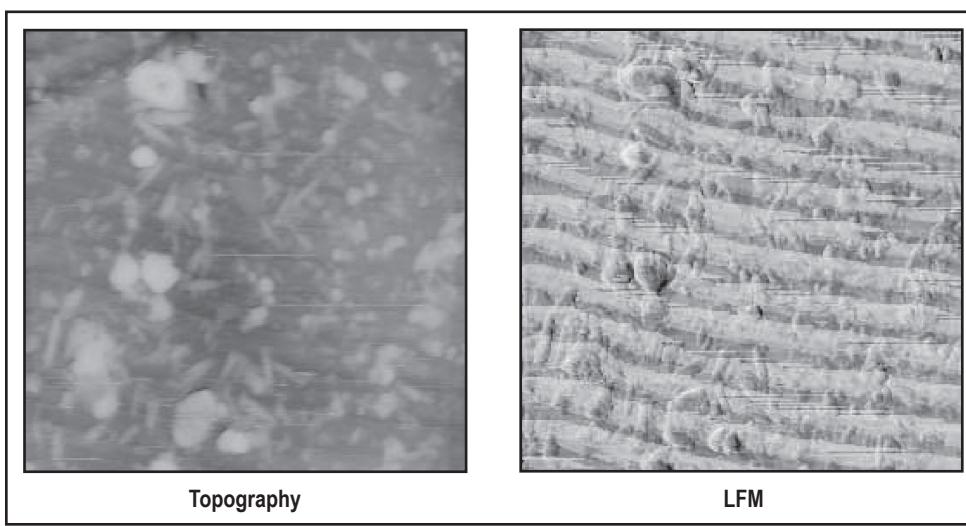


Figure 6.3: Topography and LFM images of composite material, 6x6 microns. The LFM image clearly shows regions having different frictional properties. Both images are obtained simultaneously.

In some instances topography images do not reveal much contrast, while frictional contrast is very strong. It happens when the imaged surface is very flat and most of the signal originates from the frictional properties of the sample. For example, this happens when mercaptohexadecanoic acid (MHA) is patterned on gold substrate [Figure 6.4]. The quantitative measurements of frictional forces using PNI instruments can be found on the web-site: <http://www.pacificnanotech.com/frictionalforce.html>.

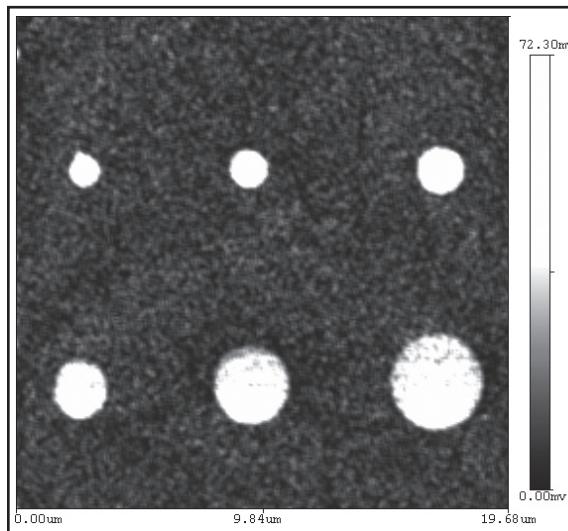


Figure 6.4: LFM image of MHA-ink dots deposited on gold substrate

PHASE IMAGING

PRINCIPLE OF OPERATION

In Close-Contact mode, a cantilever is vibrated at a frequency near its resonance and its amplitude is maintained constant while scanning. Monitoring changes in phase lag between the input voltage and the response of the cantilever yields an image that is related to the localized material properties of the surface, such as adhesion and stiffness.

Phase imaging is done in close-contact mode. The virtual phase or raw Z[PM] channel, one of the four channels available in close-contact mode, provides phase information. This channel can be set to represent changes in either the phase or the amplitude of the cantilever vibration, while holding the other constant.

Phase virtual channel is a default acquisition channel in close contact mode.

CAUTION

CAUTION: To prevent damage to your instrument, probe, and sample, make sure you are familiar with the caution statements in Chapter 3. The subjects of laser and detector alignment, probe choice, probe installation, as well as basic imaging in close contact mode, are also covered in Chapter 3.

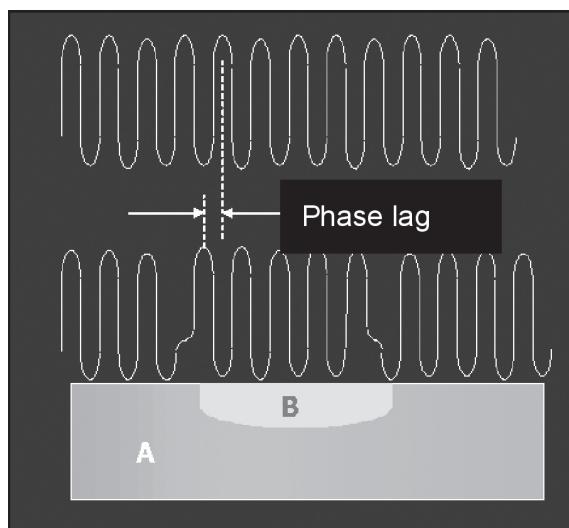


Figure 6.5: Phase shift results from the difference between response and drive signals as the probe scans across a surface having variations in material properties.

AUTO-TUNE

The tuning procedure is explained in Chapter 3. Operating Frequency, Amplitude, and Phase Shift are all determined as a function of the settings selected. Set Point is determined as well. In EZMode™, Auto-Tune is the only available tuning option. In X'pert™ Mode, the user may use Auto-Tune or Manual Tune. To use Manual Tune, click the Advanced>> button in the Frequency Sweep (tuning) window, as shown in Figure 6.6.

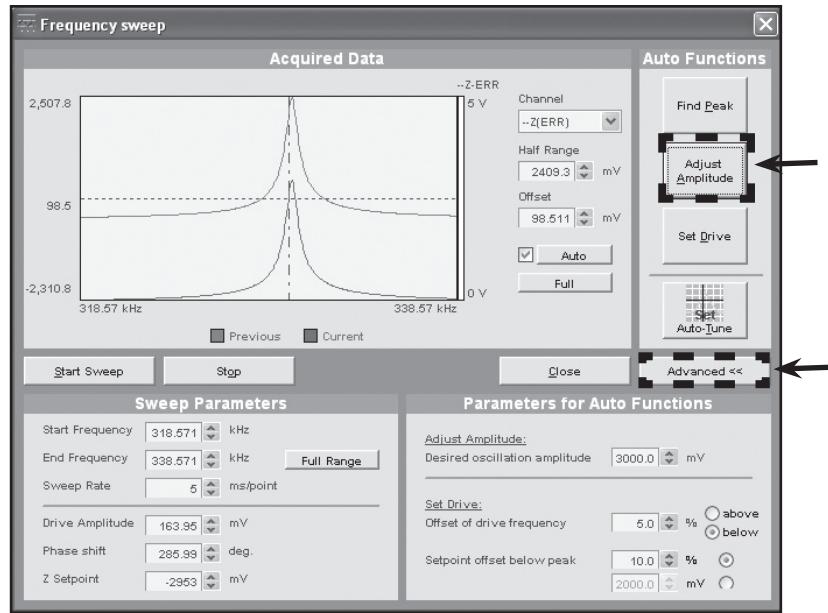


Figure 6.6: Frequency Sweep window in X'Pert™ Mode

MANUAL TUNE

The X'pert™ Mode Frequency Sweep (tuning) window permits many user-selected parameter settings for tuning, such as: Operating Frequency Offset, Drive Amplitude, Phase Shift, Setpoint Offset, Single Frequency Sweep, Oscillation Amplitude, and Frequency Range. Figure 6.7 shows the standard parameter selections. In order to perform Manual Probe Tuning, and determine the phase settings for phase mode imaging, use the following procedure:

1. Select the Frequency Sweep button from the toolbar (the Frequency Sweep window is displayed).
2. Click the Find Peak button. In the graph, the frequency sweep plot is automatically zoomed to the resonant frequency region. Next click the Adjust Amplitude button, and then the Set Drive button, to set the drive frequency and drive amplitude. Click Yes to apply the calculated Set Point (Figure 6.7).

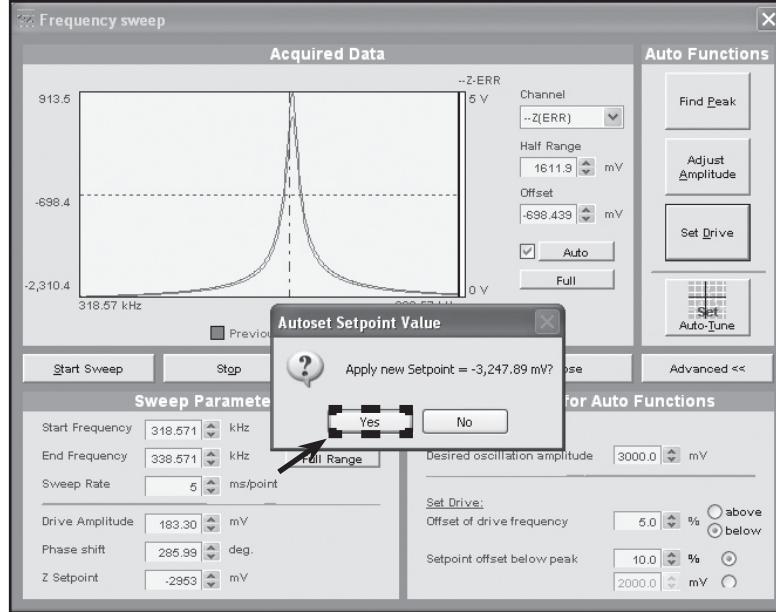


Figure 6.7: Applying Setpoint after finding peak and adjusting amplitude.

3. Switch the signal channel from Z[ERR] to Z[PM]. Shift the initial curve of Z[PM] by adjusting the Phase Shift so that the green Z[PM] curve crosses the point where the dotted black vertical line and the dotted black horizontal line intersect. The steep negative slope should pass through this intersection point, as shown in Figure 6.8.
4. After determining the desired phase shift in Step 3, (the value of phase shift can be any value from 0 to 360), click the Start Sweep button to update the signal. Once the phase shift trace looks like that shown in Figure 6.8, click the Set Drive button. This initiates the Setpoint calculation using the one newly determined phase shift.

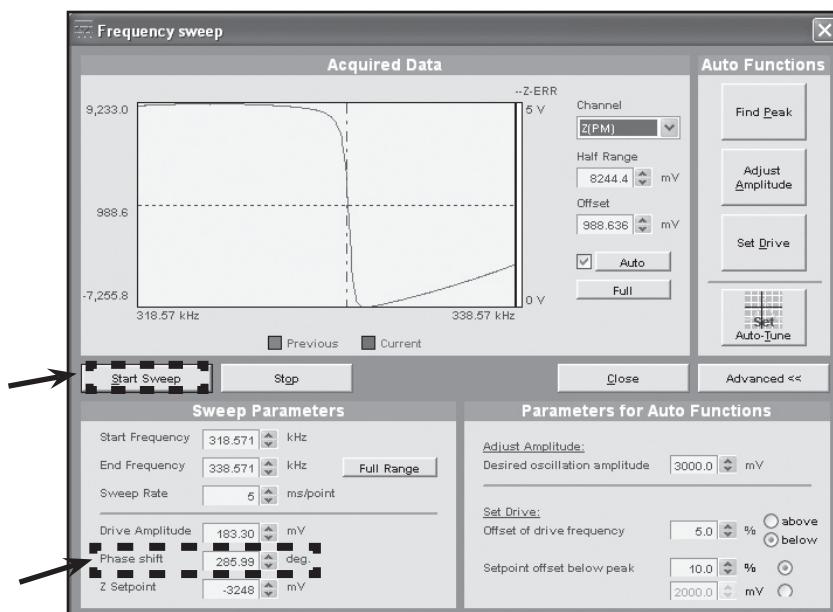


Figure 6.8: Adjusting the Phase Shift

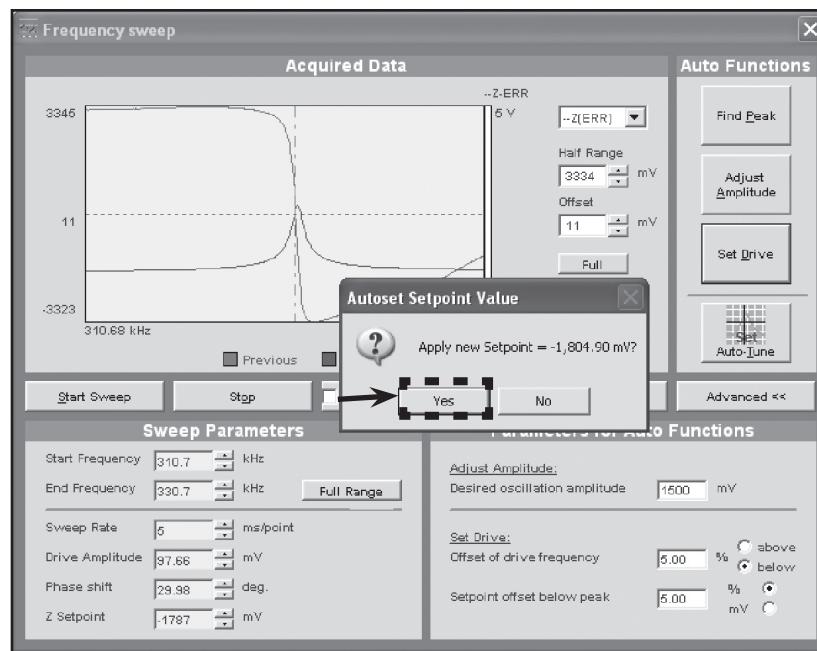


Figure 6.9: Applying new Setpoint after phase adjustments

5. When the new Setpoint has been calculated, you are ready to approach the sample and begin scanning. It may be necessary to further adjust the set point in the Scanned Image window (as described in detail in Chapter 3). Adjust Setpoint and Gain, using the up/down buttons next to the displayed settings, until the green and red line profiles of Z Actuator become nearly identical.
6. Next display the Phase Image by switching one of the images to the Z[PM] channel or Phase channel (it depends if your input selections are virtual or raw channels). Evaluate the Phase Signal by checking to see if the green and red Z[PM] traces in the line profile window coincide. Also, the forward and reverse images of the Phase Signal should show the same contrast, Figure 6.10.

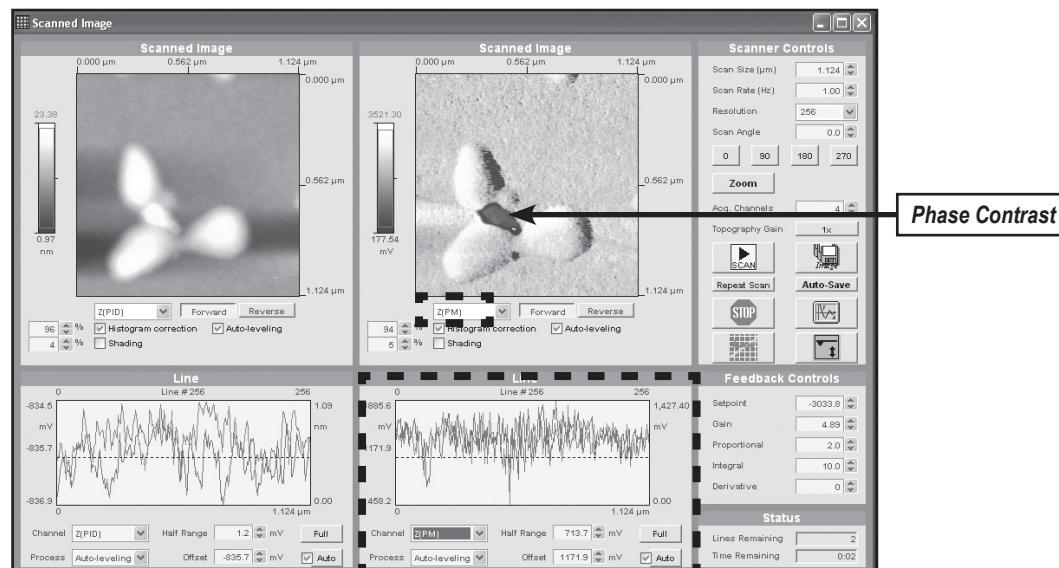


Figure 6.10: Phase Image obtained simultaneously with topography image

7. Click the  button, and save your images.

Always select Tip Retract from the toolbar when completing a session.

Notes: When having difficulty obtaining the Phase Signal, try the following:

- Increase the force between the probe and sample by increasing the Setpoint
- Change the free amplitude. After selecting tip retract from the toolbar, open the Frequency Sweep window and modify the Drive Amplitude setting.
- Try a different probe

Dark regions in the phase image correspond to increased phase shift. If the contrast variations in the phase image are minimal, this is indicative of a homogeneous material. Significant variations in contrast indicate the existence of non-homogeneous surface properties.

FORCE-DISTANCE CURVES

Force distance curves can help in understanding the physical properties of materials and molecules on a surface. Single-point measurements can be taken at selected locations on your sample surface. In Force-Distance measurements, the probe is moved toward the sample surface, to a pre-set voltage-defined position, and then retracted. The extent of cantilever deflection over the course of this movement is expressed by the Z[ERR], Z[T-B], Z[error] or the vertical force. The Vertical Force is used to generate a force-distance curve. The definition of the virtual channels is available in Chapter 5 in the Raw and Virtual Channels section.

CAUTION

CAUTION: To prevent damage to your instrument, probe, and sample, make sure you are familiar with the caution statements in Chapter 2.

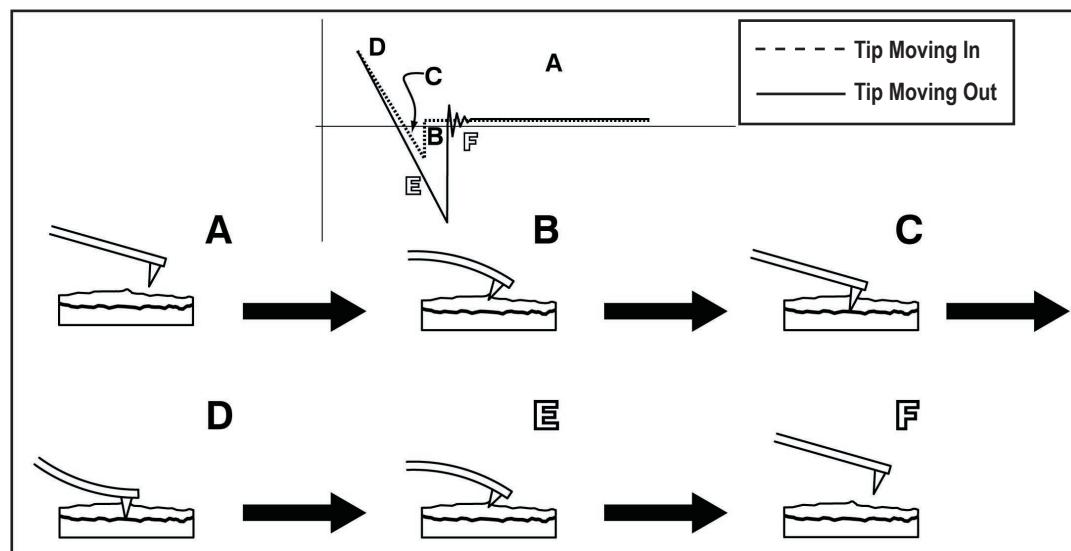


Figure 6:11: Force Distance Curve

- A: Free air tip position.
- B: Jump to contact, probe is pulled in, Van Der Waals attractive forces predominant.
- C: Contact with surface, defined as attractive forces are balanced with repulsive forces.
- D: Repulsive region, probe is pushed up.
- E: Probe is retracted from the surface, contamination layers can be measured.
- F: Far from the surface, free air.

The Force-Distance procedure is as follows:

1. Scan desired area on sample.
2. Select the point where the FD curve needs to be measured by clicking **Ctrl+left_mouse_click**, Figure 6.12.
3. Click OK to position tip in selected location.
4. Click  button to bring up the FD window.
5. Vertical Force is a default real-time acquisition channel.
6. Enter Start voltage and End voltage.
7. Press Start.
8. Observe response data plotted against Z Sensor (Figure 6.13).

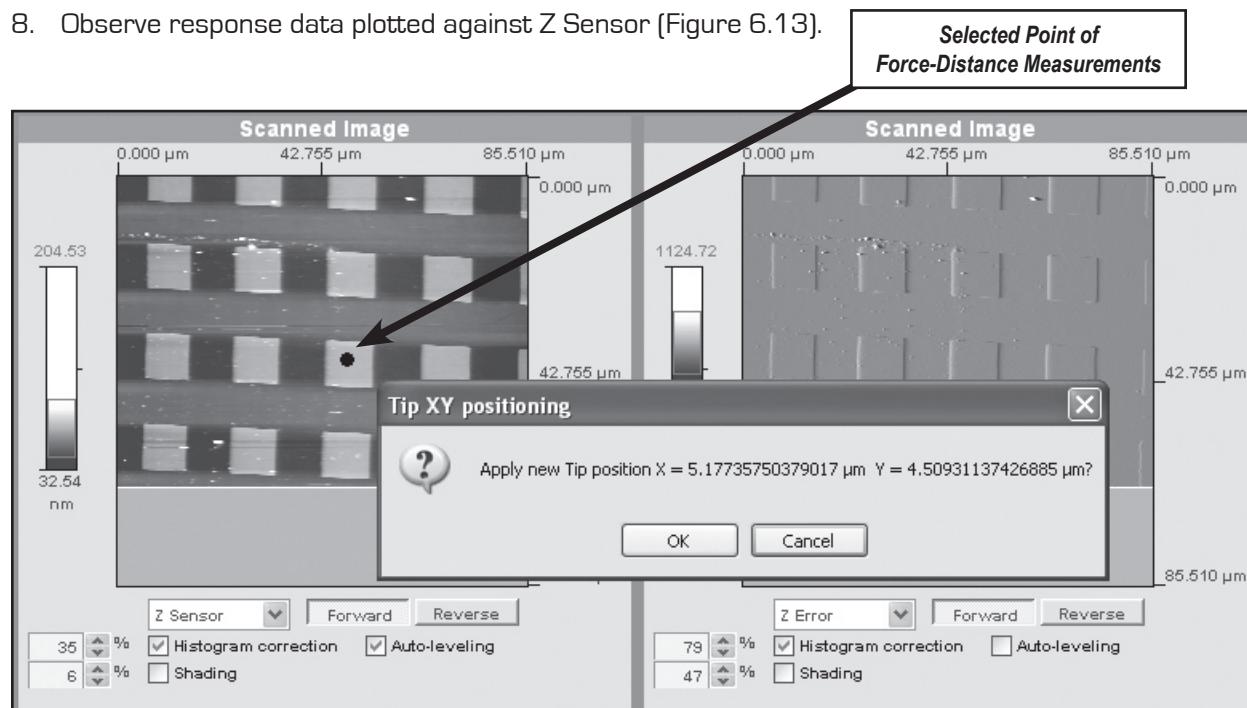


Figure 6.12: Position the probe where you would like Force-Distance measurements to be taken, step 2.

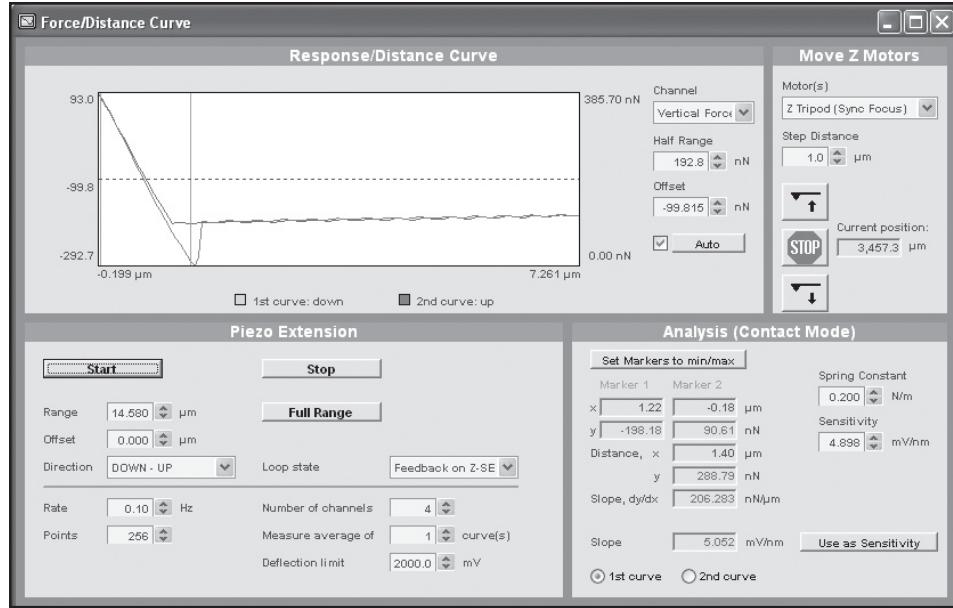


Figure 6.13: Typical Force Distance Curve

There are a few options for F/D data acquisition:

1. Zoom In on the selected region: Select the region by clicking and dragging the mouse. Then click Yes.

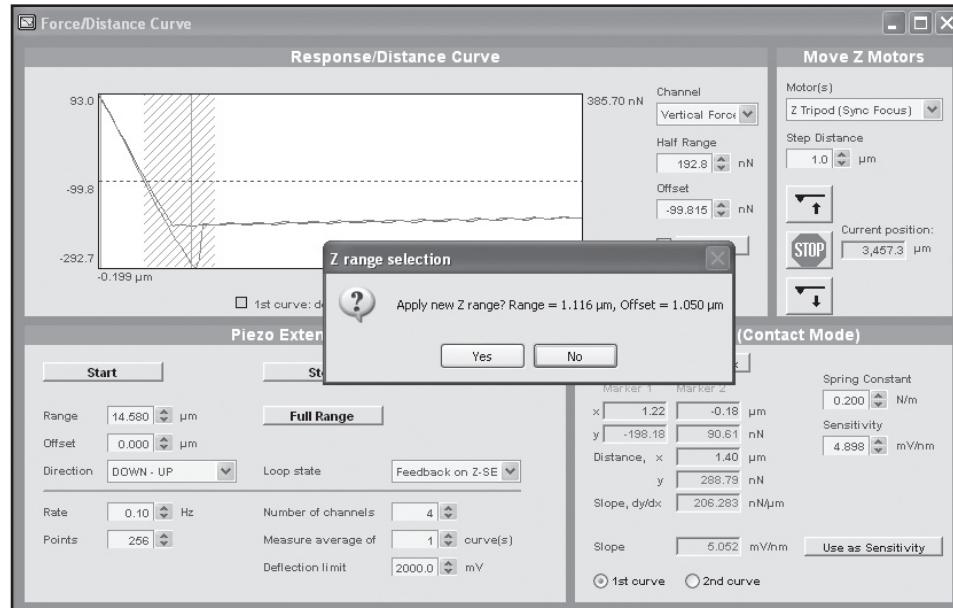


Figure 6.14: Zooming in on F/D curve.

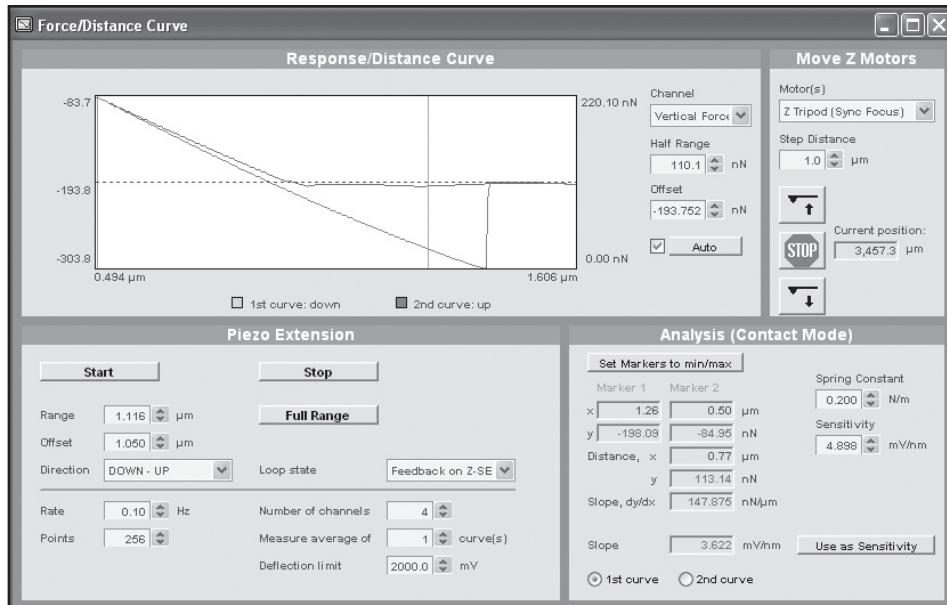


Figure 6.15: Zooming in on F/D curve.

- Force distance can be acquired in “down-up” mode as well as “up-down” mode. Down-up means that the probe is first retracted to free-air position, then it goes down toward the surface and then back up again. In “up-down” mode, the probe is pressed against the surface, retracts first (up) and approaches second (down).

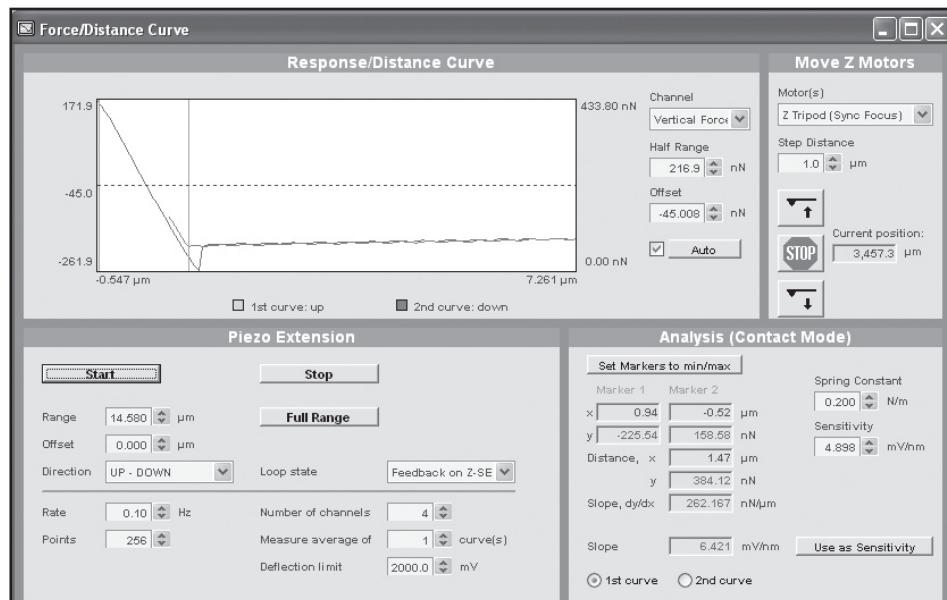


Figure 6.16: FD measurements with reversed voltages. Note green and red line swap positions compared to Figure 6.13.

To obtain meaningful F/D information, it is necessary to update the force calibration each time a new cantilever is used and whenever the adjustment of the laser or photo detector has been changed. The following describes how to update the force calibration:

1. Enter the nominal spring constant of the probe (typically 0.2N/m = 0.2nN/nm).
2. Obtain a force distance curve on a hard sample (like silicon, i.e. the PNI Reference Sample).
3. Set markers on the green line so that the slope in the repulsive region can be calculated.
4. Click “use as sensitivity” button.
5. Observe the updated sensitivity value (in mV/nm) and the updated force scale on the graph. It is possible to calibrate either on approach or retract curve.

The force scale is shown on the right-hand side of the F/D window. The sensor distance is along the top of the window. For the example shown, the force scale is 433.8nN and the distance is 6,714 microns.

Force Distance data can be saved in ASCII format (Figure 6.17). There are 11 parameter columns:

- | | |
|-------------------------------|-----------------------------|
| 1. The number of data points | 7. Z - up (μm) |
| 2. Z-down (μm) | 8. Vertical Force - up (nN) |
| 3. Vertical Force - down (nN) | 9. Z Actuator - up (nm) |
| 4. Z Actuator - down (nm) | 10. Z Error - up (nm) |
| 5. Z Error - down (nm) | 11. Lateral Force - up (mV) |
| 6. Lateral Force - down (mV) | |

***** FORCE DISTANCE CURVE 8/29/2007 12:27:02 PM *****						
# COMMENT:						
# RESOLUTION: 256; RATE: 0.10 Hz;						
# Z RANGE: 1.116 μm;						
# DIRECTION: DOWN-UP;						
# DEFLECTION LIMIT: 2,000.0 mV; AVERAGE OF 1 CURVE(S);						
# SPRING CONSTANT: 0.200 N/m; SENSITIVITY: 4.898 mV/nm.						

POINT	Z - down (μm)	Vertical Force - down (nN)	Z Actuator - down (nm)	Z Error - down (nm)		
0	1.606 -195.675	278.181 -3.713	-67.633 0.494	-83.696 -210.946	1.474	-214.312
1	1.602 -195.642	304.535 -1.287	-67.795 0.498	-84.595 -206.308	0.753	-212.505
2	1.597 -195.606	314.254 0.586	-66.224 0.503	-86.139 -200.797	0.674	-209.391
3	1.593 -195.541	319.447 0.924	-63.801 0.507	-87.398 -195.533	0.799	-205.392
4	1.589 -195.403	322.427 1.516	-61.167 0.511	-88.428 -190.619	0.825	-203.290
5	1.584 -195.283	324.154 1.730	-58.484 0.516	-89.078 -185.721	0.756	-201.363
6	1.580 -195.189	325.345 1.641	-55.971 0.520	-91.014 -180.825	0.878	-197.518
7	1.576 -195.080	325.414 2.066	-53.283 0.524	-92.362 -176.276	0.880	-197.177
8	1.571 -194.969	325.367 1.940	-50.911 0.529	-93.587 -171.537	0.831	-197.359
9	1.567 -194.841	324.868 2.024	-48.553 0.533	-94.942 -167.077	0.838	-195.728
10	1.562 -194.723	324.129 2.044	-46.337 0.538	-96.183 -162.326	0.914	-195.946
11	1.558 -194.633	323.348 2.106	-44.529 0.542	-97.290 -157.979	0.952	-192.380
12	1.554 -194.568	322.642 2.051	-43.125 0.546	-98.632 -153.482	0.907	-192.316
13	1.549 -194.487	321.496 2.133	-41.523 0.551	-99.779 -149.346	0.985	-192.717
14	1.545 -194.411	320.094 2.365	-40.193 0.555	-101.028 -144.920	0.873	.
15	1.541 -194.345	319.047 1.980	-39.263 0.560	-102.409 -140.484	0.890	.
16	1.536 -194.289	317.466 2.495	-38.356 0.564	-103.574 -136.360	1.019	.
17	1.532 -194.212	315.367 2.120	-37.587 0.568	-104.824 -132.036	0.890	.
18	1.528 -194.159	314.422 2.188	-37.134 0.573	-106.182 -127.576	0.948	.
19	1.523 -194.137	312.713 2.342	-37.102 0.577	-107.302 -123.468	0.972	.
20	1.519 -194.108	310.816 2.258	-37.081 0.581	-108.680 -119.207	0.918	.
21	1.515 -194.104	309.167 2.310	-37.523 0.586	-109.810 -114.716	0.915	.
22	1.510 -194.053	307.258 2.314	-37.804 0.590	-110.945 -110.909	1.054	.
23	1.506 -194.035	304.930 2.393	-38.525 0.594	-112.164 -107.071	1.090	.
24	1.502 -194.049	303.322 2.250	-39.607 0.599	-113.541 -102.619	0.852	.

Figure 6.17: Force Distance Data in ASCII Format

More settings for force calibration, probe parameters are available under System Settings/Probe and Force Distance tab (Figure 6.18).

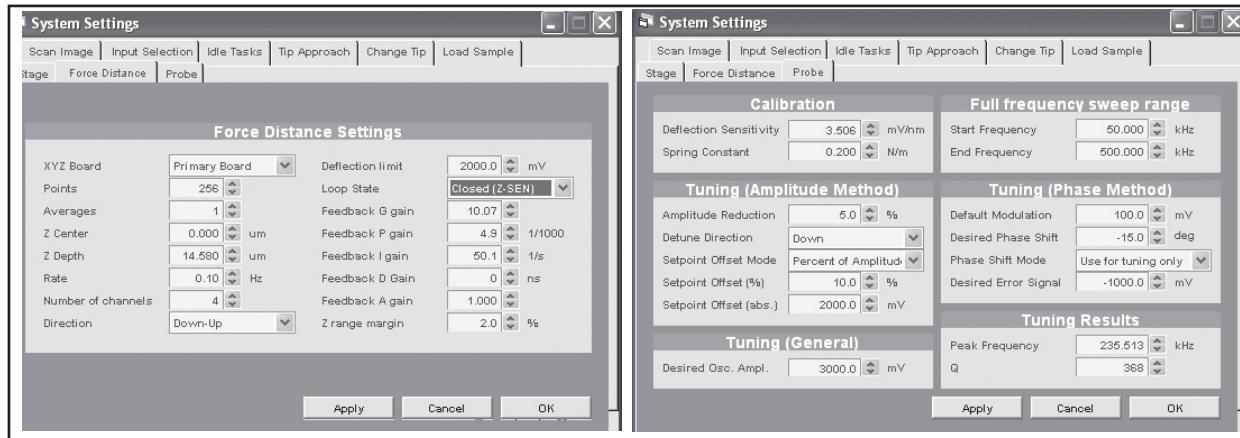


Figure 6.18: System Settings

It is possible to open Force Distance data in Excel or any other data analysis software package that imports ASCII files. An example of replotted data is shown on Figure 6.19. The data shows the comparative measurements taken on nanocomposite materials with and without reinforcing additives. Reinforced material has a much steeper loading curve slope and less adhesion, while material with no additive shows much less slope and greater adhesion.

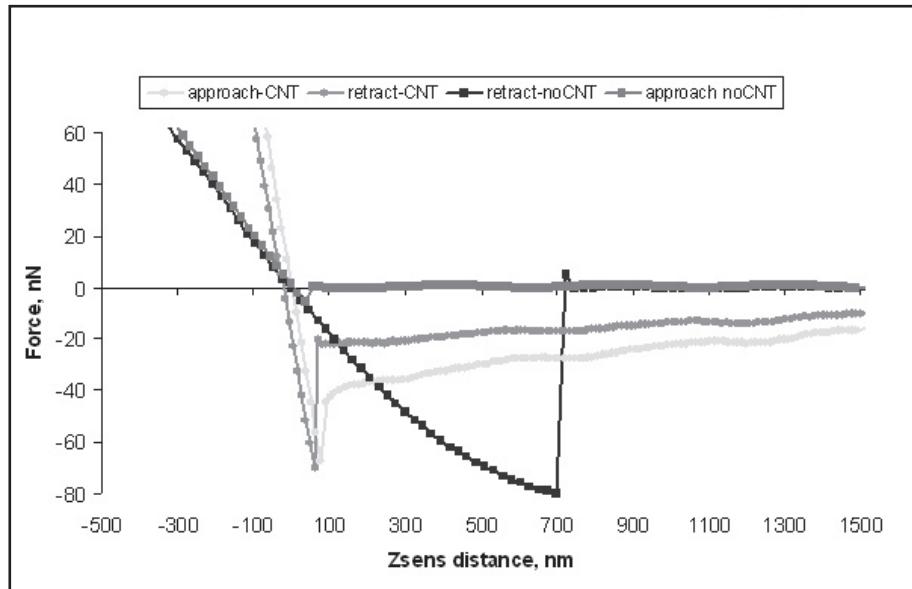


Figure 6.19: Force Distance Data Replotted in Excel

Appendix A • A Guide to AFM Image Artifacts

INTRODUCTION

All measurement instrumentation used by scientists and engineers for research development and quality control generates results that may have artifacts. This appendix serves as a guide to identify common artifacts that occur in AFM images. It is organized into the following sections, covering the four primary sources of AFM artifacts:

- Probes
- Scanners
- Image Processing
- Vibrations

PROBE ARTIFACTS

Images measured with an atomic force microscope are always a convolution of the probe geometry and the shape of the features being imaged. If the probe is much smaller than the features of the images being measured, then the probe-generated artifacts will be minimal, and the dimensional measurements derived from the images will be accurate.

Avoiding artifacts from probes is achieved by using the optimal probe for the application. For example, if the features of interest on the sample are in the 100 nanometer range, a probe with a diameter as large as 10 nanometers will be adequate for getting good images with no artifacts. In some cases, even if the probe is not as sharp as the object being imaged, it is still possible to get accurate information from the image.

Following are some of the more common probe artifacts.

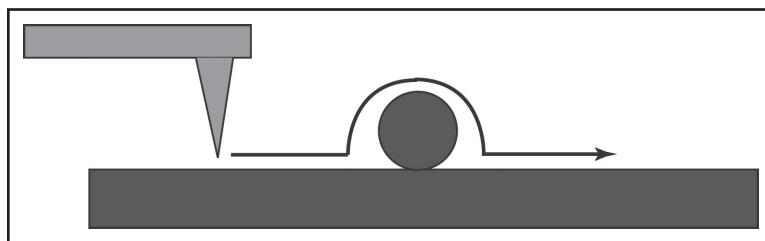


Figure A.1: AFM probe scanning over a spherical feature

SURFACE FEATURES APPEAR TOO LARGE

Often the size of surface features, such as nanotubes and nanospheres, look larger than expected. In the measurement illustrated in Figure A.1, the side of the probe will cause a broadening of features in the image. However, the height of the feature is correct when measured by a line profile.

In Figure A.2, the line profile of the image shows a diameter of 92 nm and a height of 8 nm. The broadening in the image is caused by the shape of the probe.

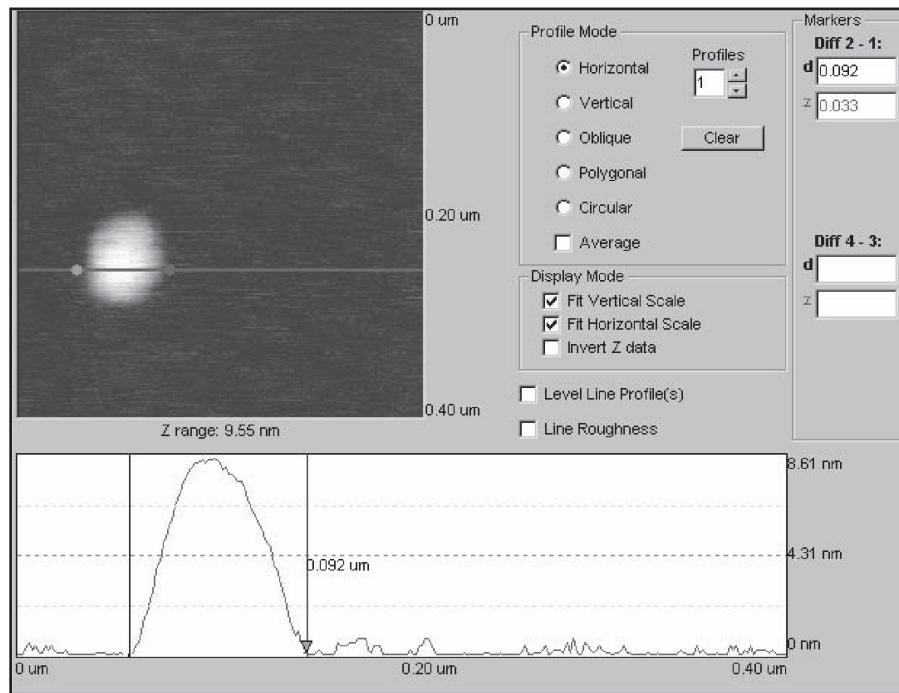


Figure A.2: AFM Image and line profile of an 8nm diameter sphere. Scan size: 400 x 400 nm.

SUB-SURFACE FEATURES APPEAR TOO SMALL

When the probe measures a feature below the sample surface, the size of the feature can appear too small. The line profile in these cases is established by the geometry of the probe rather than the geometry of the sample. For example, in the measurement illustrated in Figure A.3, the width of the probe prevents it from reaching the bottom of the feature.

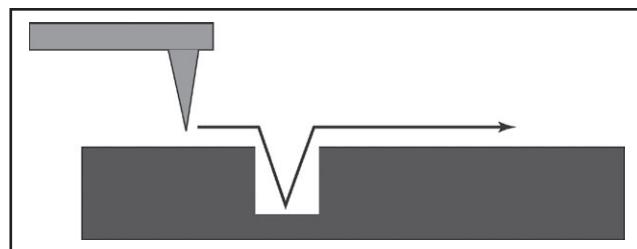


Figure A.3: AFM probe scanning over a depression in the surface topography.

However, it is still possible to measure the opening of the hole from this type of image. Also, the pitch of repeating patterns can be accurately measured with probes that do not reach the bottom of the features.

In Figure A.4, the SEM image shows the sides of the squares in the test pattern to be equal. In the AFM image, because the probe is not sharp, the squares appear much smaller than they are, and as rectangles, not squares.

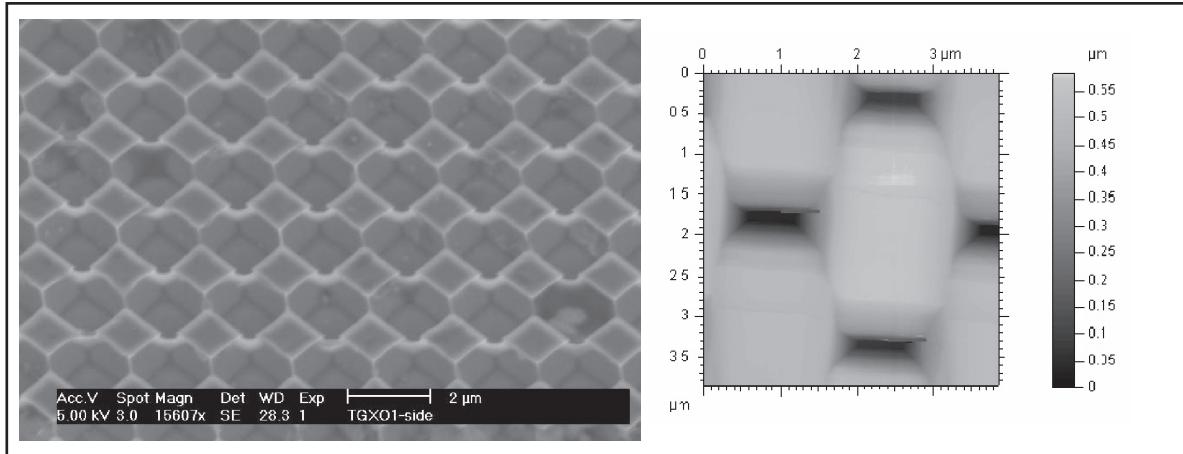


Figure A.4: SEM (left) and AFM (right) images of a test pattern of squares (NT MDT TX01).

STRANGELY SHAPED OBJECTS

If the probe is broken or chipped, the resulting image may have strangely shaped objects that are difficult to explain. The chipped probe in Figure A.5 follows the surface geometry in a way which creates an image with a substantial artifact.

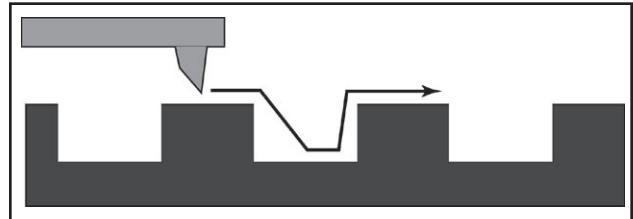


Figure A.5: Chipped AFM probe scanning over a sample surface.

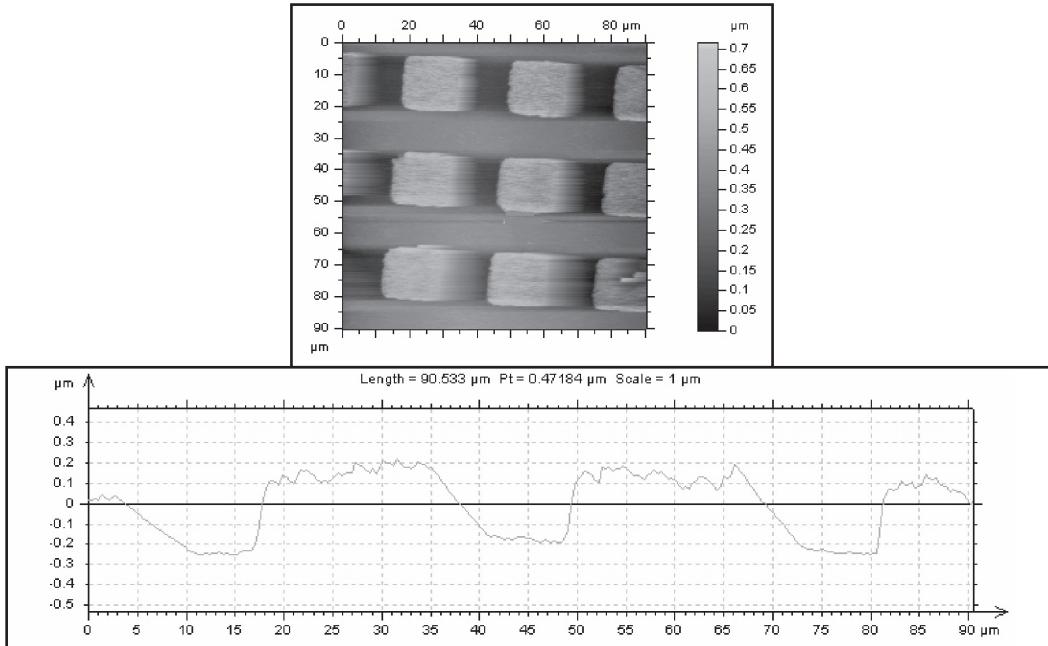


Figure A.6: AFM Image of a semiconductor test pattern and the corresponding line profile showing an artifact. Scan size: 91 x 91 μm.

The dark right edges in the image in Figure A.6 would indicate that the tip was scanned at a large angle to the surface, as described below. However, the probe-sample angle would have to be extreme to explain this artifact. The artifact can be easily seen in the line profile.

REPEATING STRANGE PATTERNS

If the surface features are much smaller than the probe, it is possible to see large numbers of repeating patterns in the image. The patterns will often appear as triangles, especially if silicon probes are used.

Figure A.7 shows AFM images of colloidal gold particles that reflect the shape of the tip rather than their own geometry. Compare the AFM images of the nanospheres, which should be perfect spheres, with the SEM images of the tips used to take the AFM images. Because the chipped tips are much larger than the nanospheres, the geometry of the probes is reflected in the AFM images.

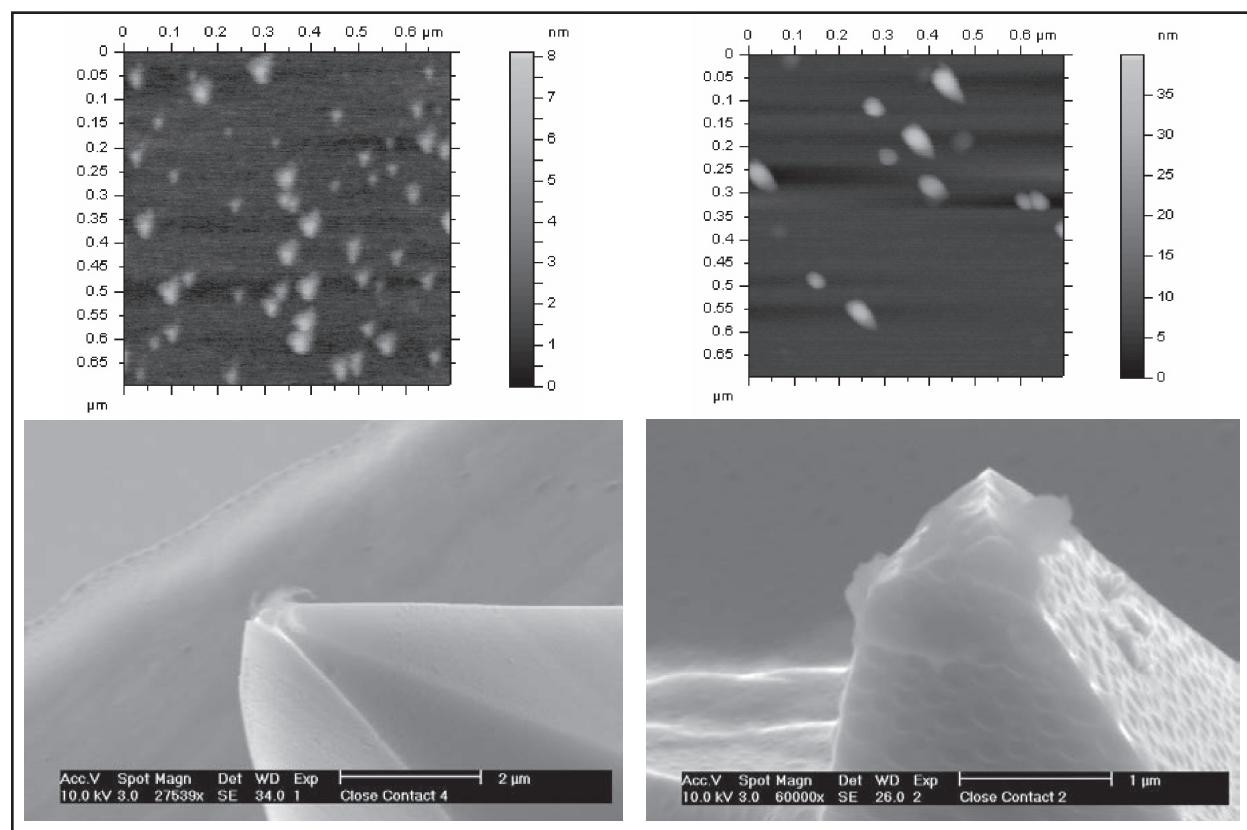


Figure A.7: AFM Images of nanospheres (top) and SEM Images of the probes used (bottom). Diameter of nanosphere: 5nm (left) and 28 nm (right). Scan size: 700nm x 700 nm.

SCANNER ARTIFACTS

The scanners in an atomic force microscope that move the probe in the X, Y, and Z directions are typically made from piezoelectric ceramics. As electromechanical transducers, piezoelectric ceramics are capable of moving a probe very short distances. However, when a linear voltage ramp is applied to piezoelectric ceramics, the ceramics move in a nonlinear motion. Furthermore, the piezoelectric

ceramics exhibit hysteresis effects caused by self-heating. Artifacts can also be introduced into images due to the geometry of the scanner and the positioning of the scanner relative to the sample.

PROBE-SAMPLE ANGLE

If the surface features are much smaller in profile than the probe, and the image does not seem “correct,” the artifact may be caused by a non-perpendicular probe surface angle. Ideally, the probe tip should be perpendicular to the surface.

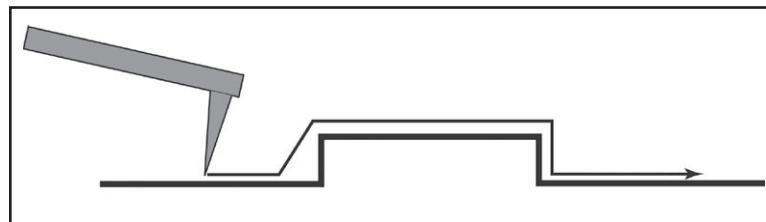


Figure A.8: A sharp probe scanning at an angle

In the measurement illustrated in Figure A.8, the probe is much sharper than the feature, so the image should be correct. However, because of the extreme probe sample angle, the line profile will show an artifact at the left edge of the feature.

Solving this problem is achieved by adjusting the angle between the probe and the sample so it is perpendicular. In some AFM microscopes, the probe is designed to be at a 12 degree angle with respect to the sample. Some microscopes do not have mechanical adjustments to control the probe-sample angle.

X-Y CALIBRATION / LINEARITY

All atomic force microscopes must be calibrated in the X-Y axis so that the images presented on the computer screen are accurate. Also, the motion of the scanners must be linear so that the distances measured from the images are accurate. With no correction, the features on an image will typically appear smaller on one side of the image than on the other.

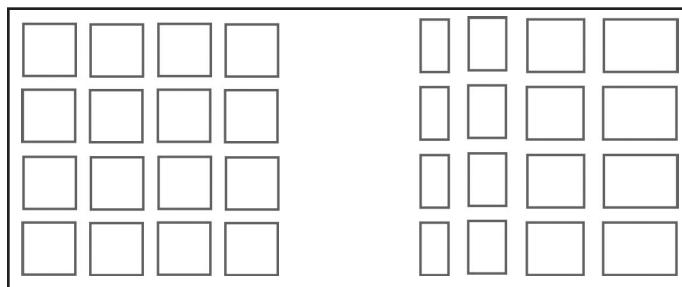


Figure A.9: A test pattern of squares (left) will appear severely distorted (right) if the Piezoelectric scanner in the AFM is not linear.

The AFM image of the test pattern in Figure A.10 is very linear. It appears as it should, with consistent spacing of the squares on all sides.

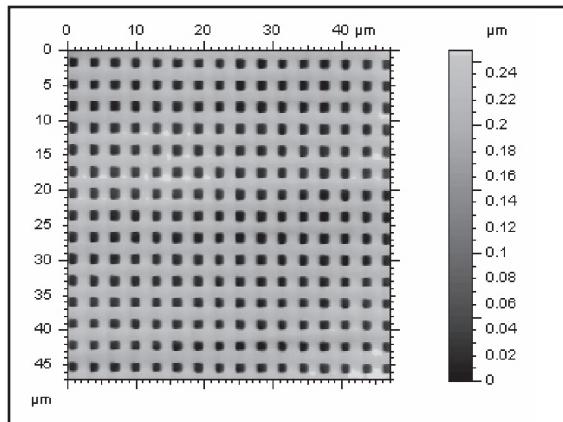


Figure A.10: Linear AFM image of a test pattern.

Once the scanner is properly linearized, it is also critical that it be calibrated. If it is linear but not calibrated correctly, the X-Y values measured from line profiles will be incorrect.

A common method for correcting the problems of X-Y nonlinearity and calibration is to add calibration sensors to the X-Y piezoelectric scanners. These sensors can be used to correct the linearity and the calibration in real time.

Z CALIBRATION / LINEARITY

Accurate AFM height measurements depend on the piezoelectric ceramics in the Z axis being both linear and calibrated. If the microscope is calibrated at only one height, the height measurements will only be correct if the relationship between the measured Z height and the actual Z height is linear.

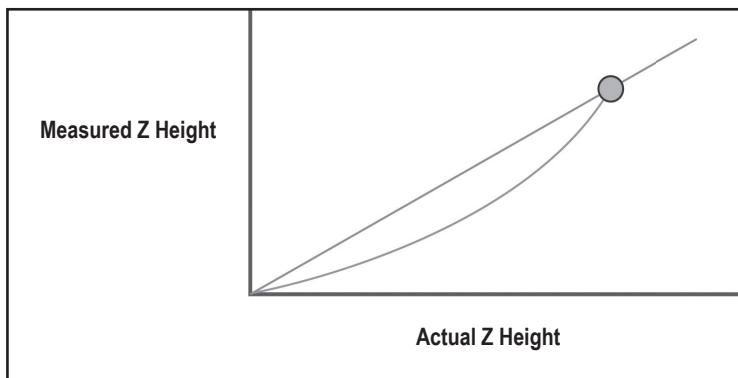


Figure A.11: Z Calibration at only one point.

The graph in Figure A.11 shows the relationship between an actual Z height and a measured Z height in an AFM. In cases where only one calibration point is measured, as represented by the grey circle, the Z ceramic is assumed to be linear, as shown by the straight line. However, as is often the case, the ceramic is nonlinear, as shown by the bowed line. When this is the case, the microscope will measure incorrect Z heights unless the feature being measured is close to the calibration measurement.

BACKGROUND BOW / TILT

The piezoelectric scanners that move the probe in an atomic force microscope typically move the probe in a curved motion over the surface. The curved motion results in a “bow” in the AFM image. Also, a large planar background or “tilt” can be observed if the probe-sample angle is not perpendicular.

In cases where a background bow and background tilt are larger than the features of interest, the background must be subtracted from the image. This is often called “leveling” or “flattening” the image. Typically, leveling the image makes the desired features clearly visible.

The piezoelectric scanner is often supported at the top by a mechanical assembly, as shown in Figure A.12, and the motion of the probe is therefore nonlinear in the Z axis as it is scanned across a surface. The motion can be spherical or even parabolic, depending on the type of piezoelectric scanner.

In Figure A.13, the bow introduced into the image is seen at the edges. The line profile across the image shows the magnitude of the bow (90nm vertical, 25 μm horizontal).

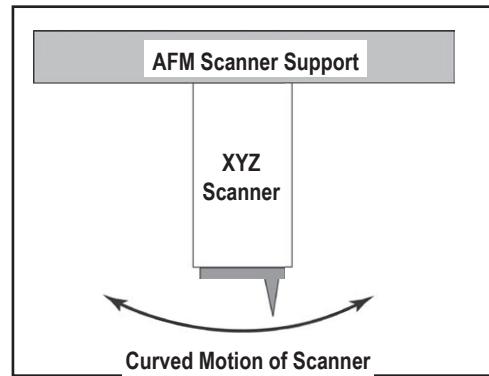


Figure A.12: Nonlinear Z scanner motion

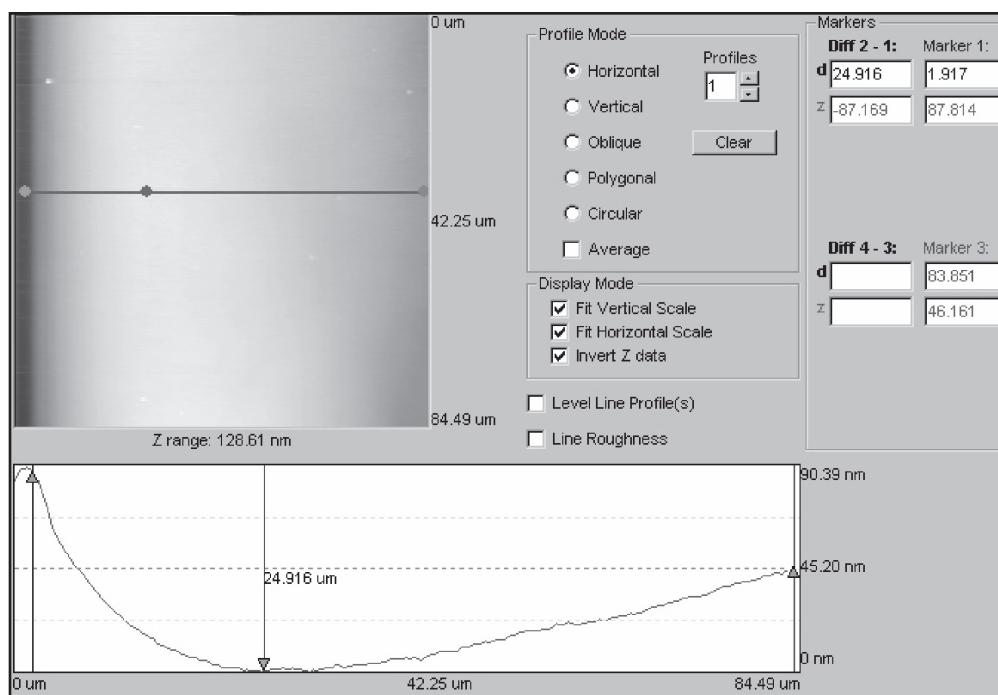


Figure A.13: Bow in AFM image and line profile of a flat piece of silicon. Scan size: 85 x 85 μm .

Z EDGE OVERSHOOT

Hysteresis in the piezoelectric ceramic that moves the probe in the Z direction can cause what is known as “edge overshoot.” This problem is most often observed when imaging micro-fabricated structures such as patterned Si wafers or compact discs. The effect can visually improve the images by making the edges appear sharper. However, a line profile of the structure shows errors.

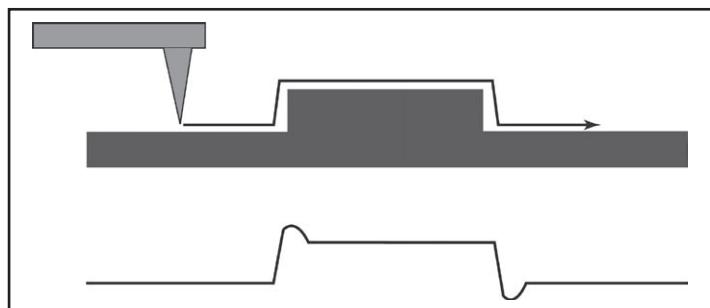


Figure A.14: Overshoot in scan (top) is apparent in the line profile (bottom).

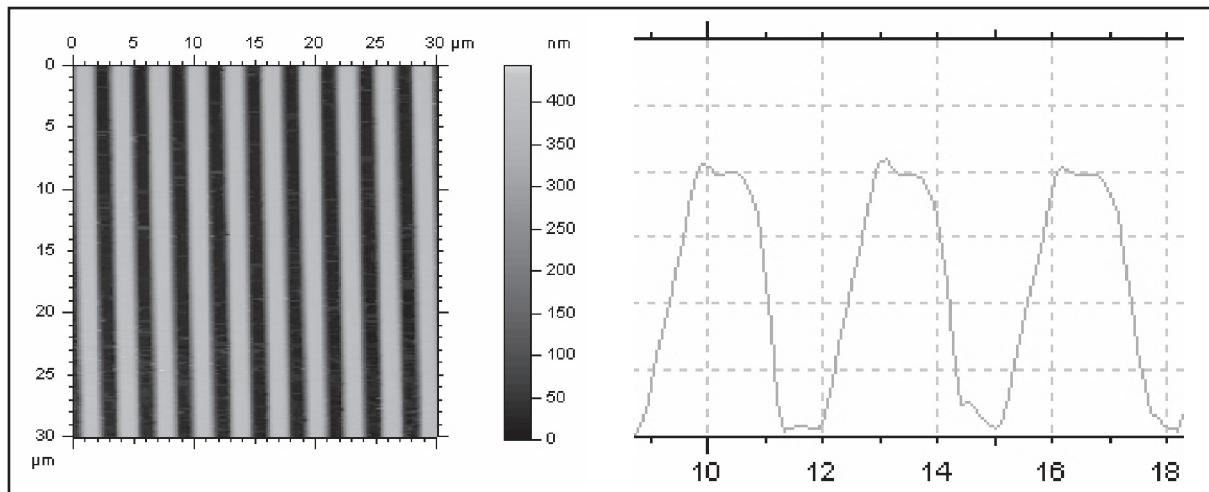


Figure A.15: This AFM image of a test pattern appears to have no artifacts, but the line profile shows overshoot at the top of each line.

Any overshoot that occurs as the probe is scanned over a surface feature would be apparent in the line profile of the resulting image, at the leading and trailing edges of the structure, as shown in Figure A.14 and Figure A.15.

SCANNER DRIFT

Drift in AFM images can be due to thermal drift in the piezoelectric scanner and the susceptibility of AFMs to external temperature changes. In AFM imaging, it is common to zoom in to a small area of a scanned region and take a new scan in order to get a higher magnification. The most common type of drift shows up as distortion at the beginning of such a scan, as shown in Figure A.16. Drift artifacts are most easily observed when imaging test patterns: lines that should appear straight have curvature.

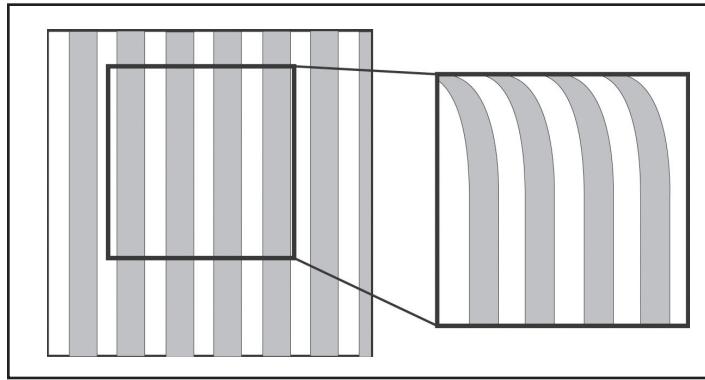


Figure A.16: Distortion due to drift in the initial part of a scan of a zoomed-in area.

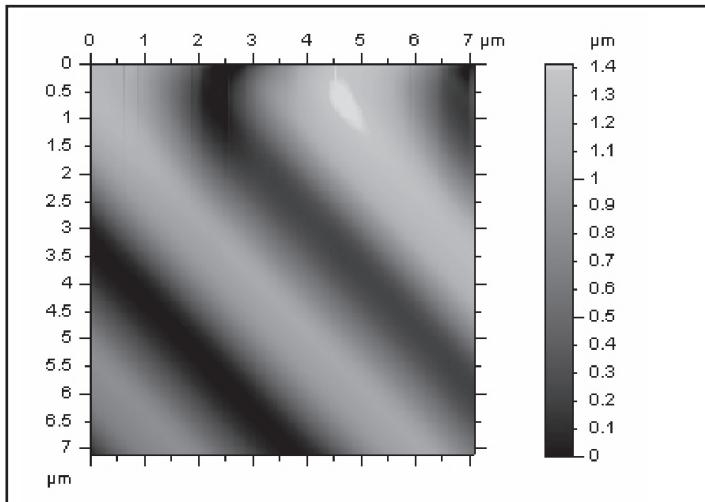


Figure A.17: Zoomed image showing a distortion at the beginning of the scan (scan angle 45°).

X-Y ANGLE MEASUREMENTS

Errors in the horizontal measurements in an image can result if the motion generated by the X-Y scanner is not orthogonal. This error, or artifact, can best be seen when imaging a test pattern with squares. The error in orthogonality can be measured by using a straight edge to measure “orthogonal” lines in the image. The lines drawn on the test pattern image in Figure A.18 show no measurable cross-talk between the X and the Y axis.

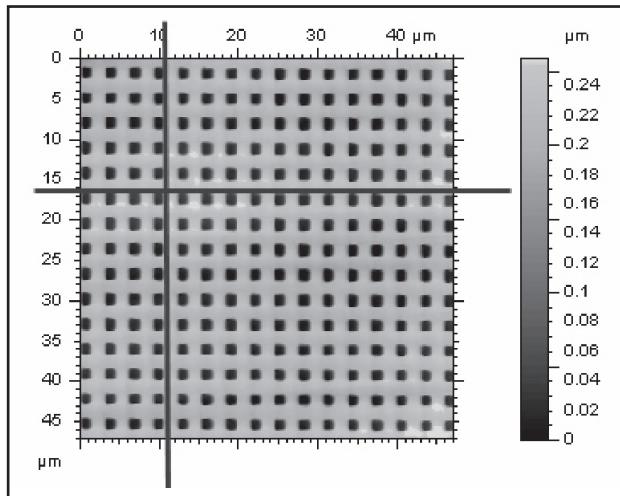


Figure A.18: AFM image of a test pattern with lines drawn to measure any error in orthogonality.

Z ANGLE MEASUREMENTS

Mechanical coupling between the piezoelectric ceramics that move the probe in the Z direction and those that move the probe in the X or Y directions can cause substantial errors when trying to measure side wall angles. This error can best be measured with a sample that has repeating triangular structures, as illustrated in Figure A.19 and Figure A.20.

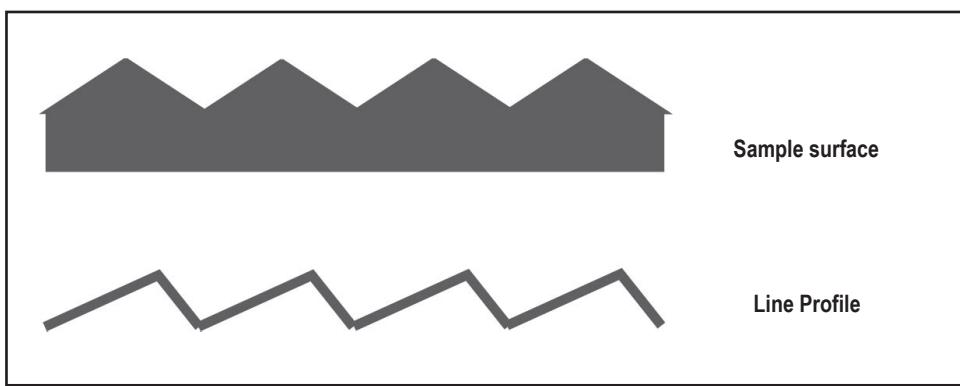


Figure A.19: Asymmetry caused by mechanical coupling between Z and X or Y piezoelectric ceramics.

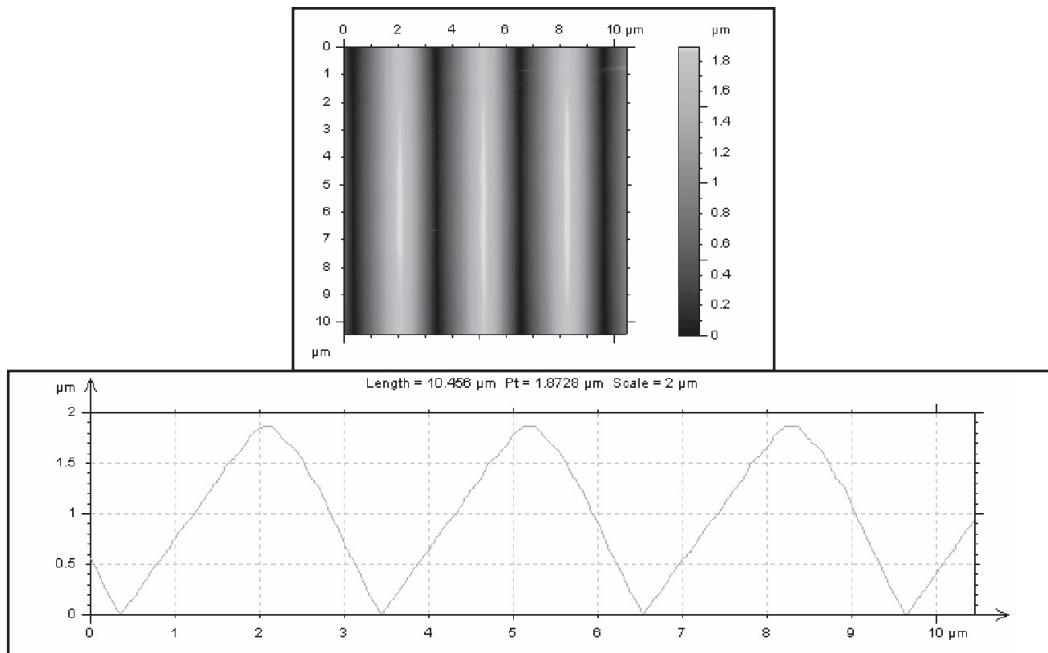


Figure A.20: AFM image of a sample with a repeating triangle pattern and the extracted line profile.

IMAGE PROCESSING

This section presents some of the common artifacts that can be introduced into AFM images by image processing software. Almost all AFM images require some image processing before viewing or analysis, and most AFM products are supplied with very powerful image display and analysis software. Properly used, the image processing software will typically not introduce artifacts into an image.

LEVELING

Most AFM images have some tilt and bow caused by the scanner or stage configuration (as described above). A number of background subtraction options are possible. The two most common types are:

- Line-by-line leveling: 0 to 4th order
- Plane Leveling: 0 to 4th order

Image processing software typically allows you to exclude areas from the leveling. When an area is excluded, it is not used for the calculation of the background in the image.

A typical leveling routine is illustrated in Figure A.21. In the original image [A], before any image processing, tilt is easily recognized: the right side of the image appears darker than the left side. The second image [B] is the result of line-by-line leveling with a first-order background correction. The dark band is caused by the image processing and is not a real structure. The third image [C] was derived by excluding particles from the background subtraction process.

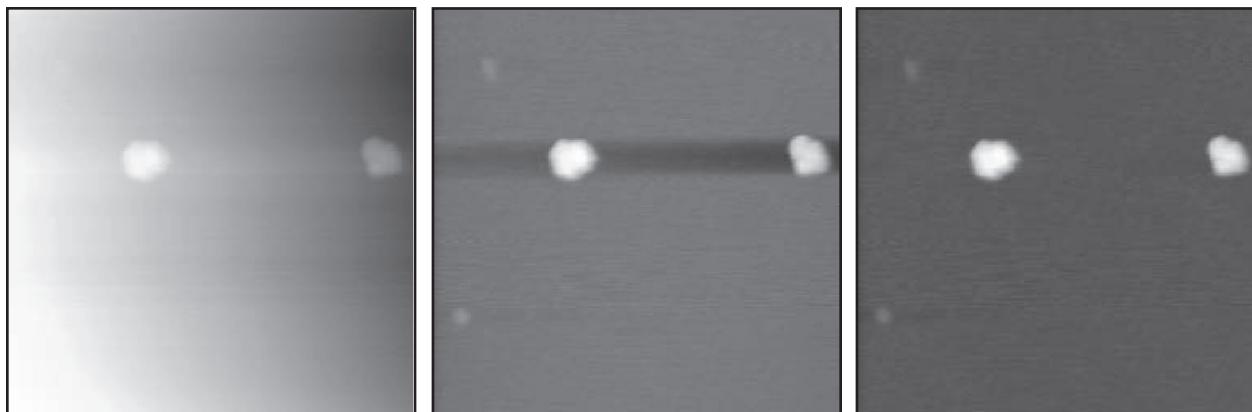


Figure A.21: Leveling of a $1.6 \times 1.6 \mu\text{m}$ AFM image of nanospheres.

HIGH-PASS FILTER

A high-pass filter is often used to “smooth” data before it displays. In images with substantial high-pass filtering, features like the step in Figure A.22 can appear distorted. The amount of distortion depends on the amount of filtering applied to the image. Other image artifacts can appear as a sharpness at the edge of steps.



Figure A.22: Image distortion due to high-pass filtering.

FOURIER FILTERING

Fourier filtering can easily introduce periodic structures into images. For example, an image of “white noise” can be filtered to give periodic structure that looks like atomic structure.

MATRIX-FILTER SMOOTHING

Matrix filtering is a very effective way of “smoothing” images and removing noise. However, the filtering process often reduces the resolution. As a rule of thumb, if the image has no noise in it, the data has probably been compromised. The example in Figure A.23 shows how filtering can reduce the noise, as shown in the line profiles, but it also caused the shape of the nanospheres to be altered.

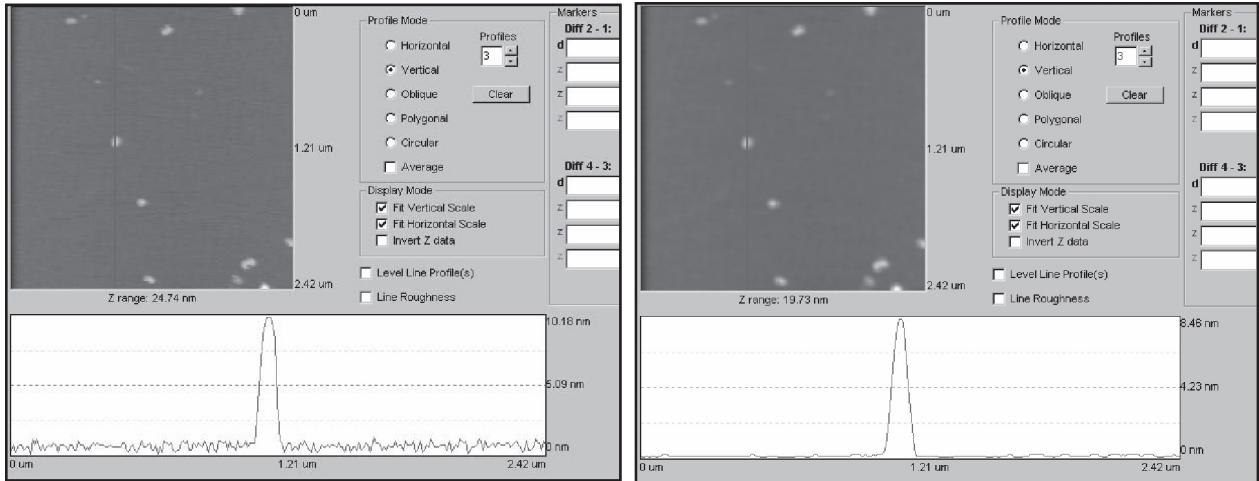


Figure A.23: AFM image of nanospheres before and after matrix smoothing.

IMAGE LOOKS TOO GOOD

If an AFM image looks too good to be true, it probably is. All measurement techniques have some noise associated with them. Because AFM data is completely electronic, it is possible to take an image and alter it with image enhancement techniques to create a beautiful picture that does not represent the structure of the surface.

The image in Figure A.24 was derived from an image with substantial noise. Filtering has added the “nodules,” which make it seem like a much higher resolution image.

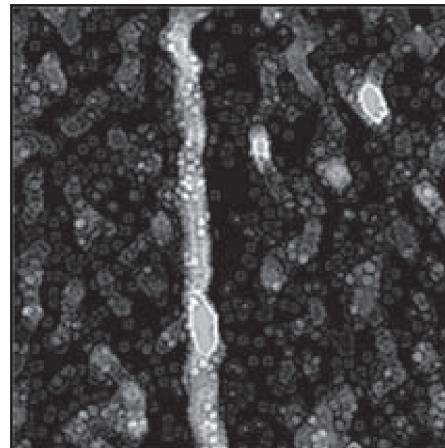


Figure A.24: AFM image of a nanotube showing “nodules” due to filtering. Scan size: 850 x 850 nm.

VIBRATIONS

Vibrations in an AFM’s operating environment can cause the probe to vibrate, resulting in image artifacts. Typically, the artifacts appear as oscillations. Both floor and acoustic vibrations can excite vibrational modes in an AFM and cause artifacts.

FLOOR VIBRATIONS

Often, the floor in a building can vibrate up and down several microns at frequencies below 5 Hz. The floor vibrations, if not properly filtered, can cause periodic structure in an image. This type of artifact is most often noticed when imaging very flat samples. Sometimes the vibrations can be started by an external event such as an elevator in motion, a train going by, or even people walking in a hallway.

ACOUSTIC VIBRATIONS

Sound waves can cause artifacts in AFM images. The source of the sound may be from an airplane going over the building or from the tones in a person's voice. The images and line profiles in Figure A.25 illustrate the effects of noise derived from a person talking in the same room as the microscope.

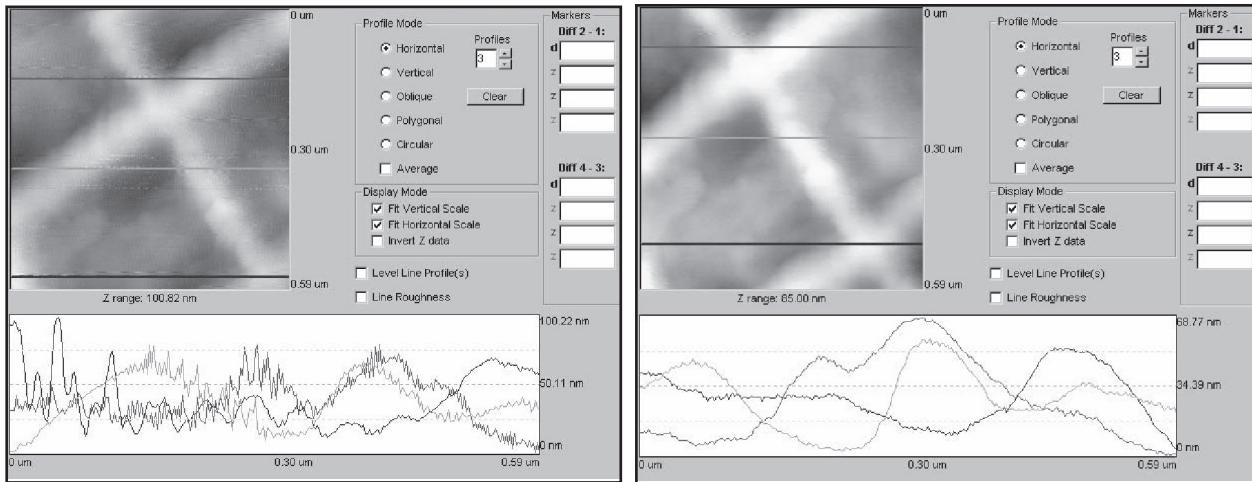


Figure A.25: High resolution images of a test grid with acoustic noise present in the room (left) and without noise (right).

OTHER SOURCES

ELECTRONICS

Faulty electronics can be a cause of artifacts in AFM images. Most often, these appear as oscillations or unexplainable repeating patterns. Electronic ground loops and broken components are usually the source of electronic noise. The electronic noise in the image in Figure A.26 was the result of not having a ground wire attached to the stage. The artifact is identified by the oscillations.

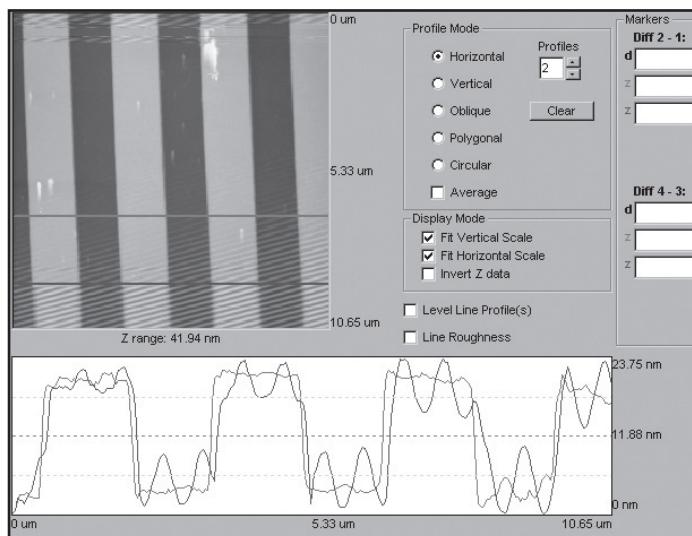


Figure A.26: Test pattern image with electronic noise at the top and bottom of the scanned image.

SURFACE CONTAMINATION

Substantial contamination at the sample surface, such as a fingerprint or oil film, can cause AFM image artifacts. Such artifacts appear as streaks on the image, as seen in the top of the image in Figure A.27. Streaks tend to appear in areas of the sample surface having “sharp” features and edges. Often the streaking can be reduced or even eliminated by cleaning the sample with a high purity solvent.

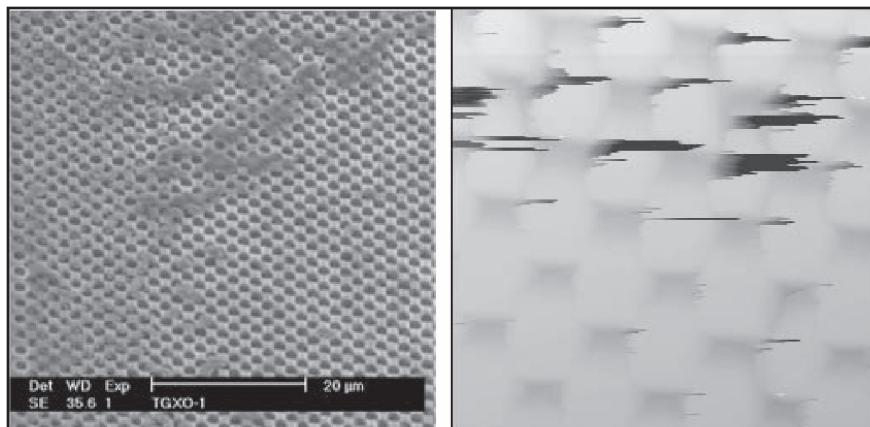


Figure A.27: SEM image (left) and AFM image (right) of a contaminated test pattern.

VACUUM LEAKS

Atomic force microscopes that are designed for imaging wafers and discs often use a vacuum chuck to hold the wafer or disc while scanning images. A leak in the vacuum between the specimen holder and the specimen can introduce image artifacts which cause a loss of resolution. Cleaning the vacuum chuck and sample often eliminates this problem.

Appendix B • Frequently Asked Questions

1. WHAT IS THE MEANING OF GPID?

A GPID (gain-proportional-integral-derivative) or PID controller is a common feedback technique employed in instrumentation control applications. The controller compares a measured value obtained from a particular process with a reference (or setpoint) value. The difference or "error" signal is then processed to establish a new drive level for the output device, such that the measured value is made nearly equal to the setpoint (zero error). Unlike simpler control algorithms, the PID controller adjusts process inputs based on the preceding error signal as well as its rate of change, resulting in more accurate and stable control.

GPID (Gain, Proportional, Integral, and Derivative) refers to coefficients in the following equation:

Output Voltage = $G * [P * V + I * \int V dt + D * (dV/dt)]$, where V = error voltage, t = time

The generic transfer function for a PID controller is: $H(S) = G * \frac{P * S + I + S^2 * D}{S}$

A simplified explanation of the function of proportional, integral, and derivative feedback is as follows:

Proportional - Proportional feedback control reduces steady-state error, but also increases overshoot and reduces rise time.

Integral - Integral control eliminates steady-state error, but may make the transient response worse.

Derivative - Derivative control improves transient response, reduces overshoot, and increases system stability.

The table below summarizes the system response to the three types of feedback. Please note that P, I, and D controls are interdependent. Changing one variable can impact the effectiveness of the other two. Therefore, the table should be used as a general guideline only for determination of P, I, and D values.

CONTROL	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
Proportional	Decrease	Increase	Small Change	Decrease
Integral	Decrease	Increase	Increase	Eliminate
Derivative	Small Change	Decrease	Decrease	Small Change

2. WHY CAN'T I SEE THE LASER ON THE CANTILEVER (IN THE VIDEO MONITOR DISPLAY)?

If you cannot see the laser spot on the cantilever in the optical video monitor, first check to be sure the laser is On (verify the software laser setting is set to "on", and make sure you can see the red laser light shining on the puck or sample). After verifying the laser is on, load the PNI reference sample and then focus on the cantilever. Next reduce the light intensity to its minimum level. In most cases the laser spot will now be clearly visible. If not, turn the light completely off, and see if the laser spot is visible. Now align the laser on the cantilever, and then align the photo detector. If following the above procedure does not work, please call PNI customer service, 800-246-3704.

3. WHY CAN'T I SEE THE PROBE CANTILEVER IN THE VIDEO MONITOR DISPLAY?

First make sure that the probe is installed and undamaged (the cantilever is not broken off). Install the PNI reference sample to provide good optical contrast. Now locate the probe in the optical field of view, using the x-y focus translation knobs on the Stage. Depending on the optical properties of your sample and probe, the laser spot may not be seen clearly. If this is the case, perform all alignments with the PNI reference sample installed, then change to the desired sample.

4. WHY DOESN'T THE FREQUENCY SWEEP (TUNE) RESULT SHOW A PEAK?

The probe may not be installed properly, check this first. Also, check drive amplitude and that the laser is aligned correctly in the Red Dot window (according to the chosen scan mode).

5. HOW DO I KNOW WHETHER TO USE CONTACT OR CLOSE CONTACT MODE?

Close contact mode is usually used for soft surface specimens, like polymers, bio-tissues, and coatings or for scanning delicate samples, or for features having weak adhesion to the surface (e.g. DNA, cells, or most types of particles). Close contact mode is often useful for imaging contaminated samples, because the vertical oscillations of the tip enable it to penetrate the contamination layer and image the underlying surface.

Contact mode is typically used with "hard" samples like metals, semiconductors, ceramics, and glass. Contact mode often results in more rapid tip (and sample) degradation.

If not sure which mode to use, start with close contact mode.

6. WHAT ARE THE PROBE CHARACTERISTICS?

Available probe types and specifications can be found on the probe-store website at:

<http://www.probestore.com/>

7. HOW DO I KNOW IF THE PROBE IS DULL/WORN/BROKEN?

Accurate assessment of the condition of your probe requires some practice and experience. In general, broadening or blurring of features in the topographical image are usually a clear indication of probe wear (or dullness), shown in Figure B. A repeated pattern of the same geometry throughout the entire image (usually a “triangle” pattern) is a common indication of a damaged or broken probe. Streaking in the image in the same axis as the fast scan direction typically indicates excessive contamination on the sample (or the probe). Excessive contamination also causes tip approach problems, in addition to poor images. Refer to Figure B.2 for examples of triangle patterns and streaking. Please also refer to the Probe Artifacts section in Appendix A.

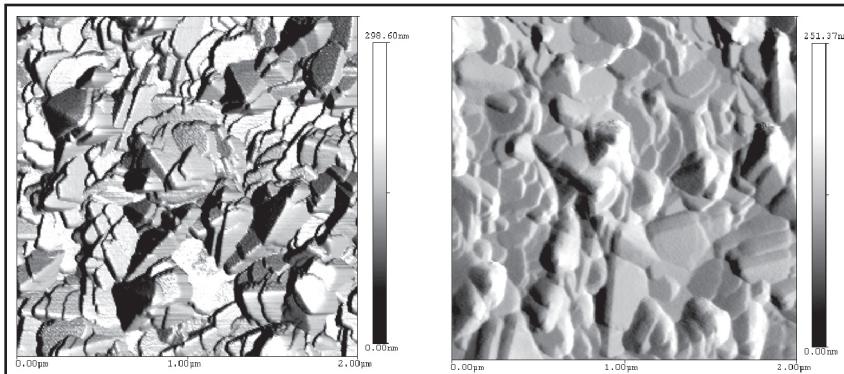


Figure B.1: Images of a Tip Checker sample, 2x2 microns in size, taken with a sharp probe (on the left) and with a somewhat dull probe on the right. For more information on the Tip Checker sample, please see:
http://www.pacificnanotech.com/standards-references_tip-visualization.html

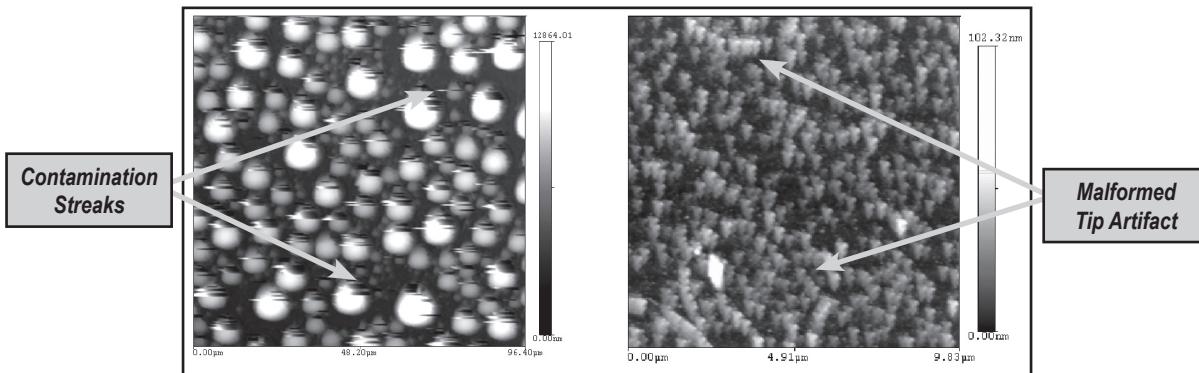


Figure B.2 The image on the left, (96x96 microns), indicates contamination present on the surface, horizontal streaking along the scan lines can be clearly seen. The image on the right, (9.8x9.8 microns), shows the repeating triangle-shaped pattern obtained on 100nm spheres.

8. WHY DO I SEE “TAILS” OR STREAKS IN THE TOPOGRAPHICAL IMAGE?

“Tails”, as well as edge overshoots and undershoots, result from GPID and Setpoint settings that are not optimized. Optimization of these settings requires practice and experience [and some trial and error], but is essential in order to obtain topographical images that are free of artifacts.

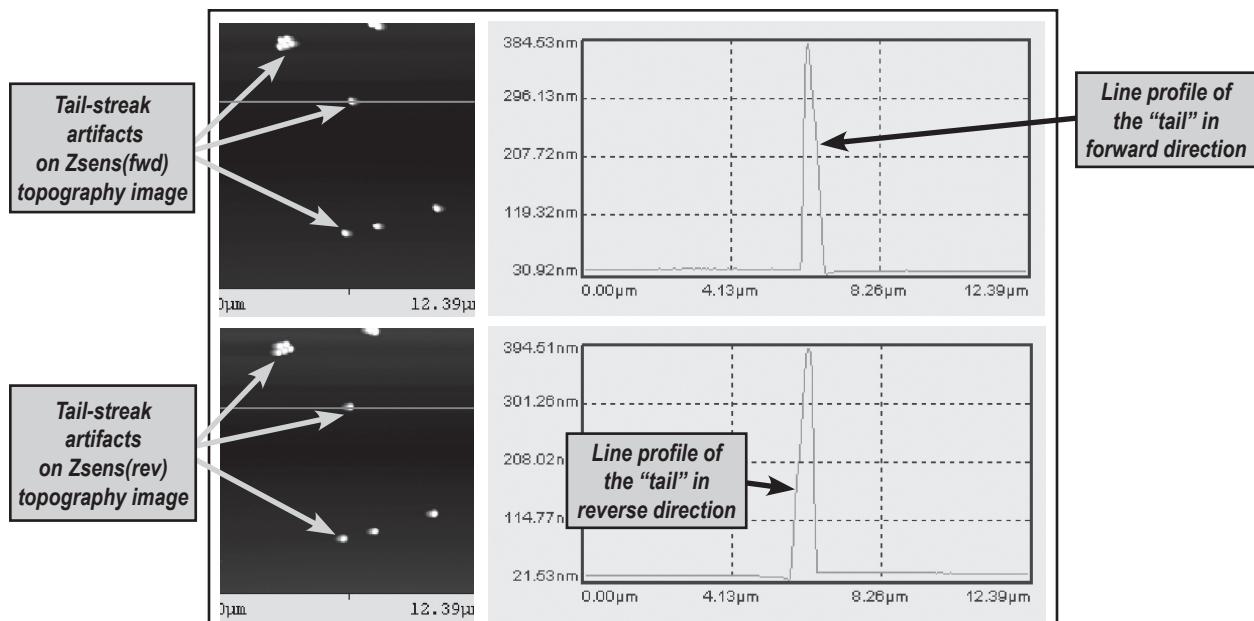


Figure B.3: Two $12 \times 12 \mu\text{m}$ images of 300nm polystyrene particles with corresponding line profiles examples of “tail” artifact. The top image is taken in the forward direction, and tails are visible on the right sides of the particles. The bottom image is taken in the reverse (right-to-left) direction, and the same particles now appear to have tails on their left edges.

As you can see in Figure B.3, forward and reverse artifacts appear as symmetrically mirrored images, dependent on scan direction. In order to eliminate this type of artifact, the user must find the optimum combination of the set point, GPID values, and scan speed. Please also refer to the Probe Artifacts section in Appendix A for overshoot/undershoot examples.