XE-150

High Accuracy Large Sample SPM

User's Manual

Version 1.7

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Preface

The Scanning Probe Microscope (SPM) is not only at the top of the list of equipment pioneering the nano scale world, it is also the most fundamental technology. Succeeding the first generation optical microscope, and the second generation electron microscope, the SPM has every right to be known as a “third generation” microscope since it enables us to look into the nano scale world. At the same time it has many advantages over manual microscopes which passively look at the samples. The SPM is like a miniature robot, fabricating specific structures by manipulating atoms on the sample surface and using a probe tip to take measurements of those structures.

The SPM originated with the invention of the Scanning Tunneling microscope (STM). The STM uses a tunneling current between a probe tip and a sample in a vacuum state to measure surface topography. As a result, it is limited in that it can only measure a sample which is a conductor or a semiconductor. Once the Atomic Force Microscope (AFM) was developed, however, a whole new range of measurement capabilities became possible. Now it is not only possible to measure non-conductors in air, but also to measure the physical, chemical, mechanical, electrical, and magnetic properties of a sample’s surface, and even measure live cells in solution.

The SPM is indeed the key to entering the world of nano technology that has yet to flourish, and it is essential equipment for various research in the basic sciences – physics, chemistry, and biology - and in applied industry - mechanical and electrical engineering.

The importance of the SPM stands only to grow greater and greater in the future.

Safety Precautions of System

This preview section describes the procedures related to the general operating safety of the XE-150 in detail. This section should be thoroughly understood before operating the XE-150 for your safety.

CAUTION!

> If the User operates the XE-150 in a manner not specified in this User's Manual, serious damage to the instrument may result.

1. Definition of safety symbols

Table shown below explains the meaning of the safety symbols – **WARNING**, **CAUTION**, **NOTE**.

Table. Safety terms and their meanings

Symbols	Meaning
WARNING!	Alerts Users to potential danger. Consequences and countermeasures are described. If users fail to follow the procedures described in this manual, serious injury or instrument damage may occur. Such damage will NOT be covered by warranty.
CAUTION!	Calls attention to possible damage to the system that may result if Users do not follow the procedures described in this manual.
NOTE!	Draws attention to a general procedure that is to be followed.

Please understand these safety terms thoroughly, and follow the associated instructions. It is important that you read all safety terms very carefully. **WARNING**s, **CAUTION**s, and **NOTE**s include information that, when followed, ensure the operating safety of your XE system.

2. Operating Safety

2-1. General operating safety

The following are most of the **WARNING**s, **CAUTION**s, and **NOTE**s necessary to operate the XE-150 safely.

WARNING!

The XE-150 should be grounded before its components are connected to electric power. The main power plug needs to be connected to a three-prong outlet which includes a protective earth ground contact.

WARNING!

Before the power is turned on, the power selections for the individual components need to be inspected. The voltage selector switch is located on the rear panel of the XE-150 Control Electronics, and it can be set to the following voltages: 100 V, 120 V, 230 V, or 240 V.

WARNING!

Do not open the XE-150 Control Electronics or the AFM head. Doing so may result in serious electrical shock, as high voltages and electrostatic sensitive component are used in the XE-150 Control Electronics and the AFM head.

CAUTION!

You should regularly check to ensure that the XE-150's cables are free from damage and that all connections are secure. If any damaged cables or faulty connections are found, contact your local Park Systems service representative. Never try to operate the equipment under these conditions.

CAUTION!

All parts in the XE-150 system should be handled with extreme care. If not handled properly, these parts can be easily damaged as they are made of fragile electromagnetical equipment.

CAUTION!

An EMI filter must be installed to meet operating safety and EMC (Electromagnetic Compatibility Compliance).

CAUTION!

The AFM head should always be handled with care. When removed from the AFM, the AFM head needs to be carefully placed on a flat surface. This will protect the scanner, the cantilever, and the laser beam adjustment knobs. Never allow anything to impact the AFM head. When separated from the main frame, it is safe to keep the head in its storage box.

CAUTION!

Before the AFM head is mounted or unmounted from the Z stage, the on/off switch for the laser beam must be turned off. Otherwise, the laser diode in the AFM head may be damaged.

CAUTION!

When the AFM head is mounted or unmounted from the Z stage, ensure that the AFM head does not sustain any damage, and that it is properly grounded. The AFM head is extremely sensitive to electrostatic discharge.

CAUTION!

To meet the EMC guidlines, the Acoustice Enclosure should be closed while making measurements with the XE-150.

2-2. Laser Safety Cautions

The SLD used in the XE-150 has a maximum output power of 5 mW, and a wavelength of 830 nm.

WARNING!

Any deviation from the procedure described in this manual may result in hazardous laser exposure.

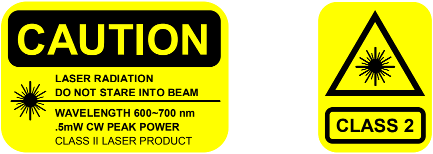

Figure 1. Laser Warning Lables

This Figure shows two laser warning labels found on the AFM head. These warning labels must be strictly followed. Also, Figure 2 shows the position of these two laser warning labels that attached to the AFM head.

Figure 2. Location of warnings posted on the XE head

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Chapter 1. Introduction to XE-150

Among XE SPM series, XE-150 is made to obtain an enhanced image for a small sample as well as a larger sample. XE-150 enables you to take an image from the large size sample (up to 150 mm×150mm). XE-150 is designed with the sufficiently rigid mechanical structure to endure the extended system size. The motorized X-Y stage can make you travel around the larger sample surface with ease. For high rigidity and stability to thermal variation, the Whinstone base and frame is used to XE-150 structure. Furthermore, high quality active vibration cancellation system is provided to effectively eliminate more external noise from a larger sample.

1-1. Primary Components of XE-150 system

The XE-150 SPM System consists of four primary components: the XE-150 SPM stage with an Enhanced Acoustic Enclosure, the XE-150 Control Electronics, a computer & monitor, and a video monitor.

The XE-150 SPM stage is where actual measurements are made, and the XE-150 Control Electronics control the movement of the XE-150 SPM stage according to the commands from the computer.

The Video Monitor, which displays the image from the optical microscope that is mounted on the XE-150 SPM stage, is used to locate the exact spot that is to be measured on the sample surface. It is also used to view the cantilever that will be used to make the measurement.

Figure 1-1. XE-150 SPM System

1-1-1. XE-150 SPM Stage

The XE-150 SPM is much easier to operate than a conventional SPM, and measurements are made faster and more accurately. Figure 1-2 shows overall structure of the XE-150 SPM stage with the acoustic enclosure open. The following explains the individual components in detail.

- **XE-150 Head**

The XE-150 head is the component which actually interacts with the sample and takes measurements. A unique characteristic of the XE-150 compared to that of conventional AFM is that the Z scanner, which controls vertical movement of the AFM tip, is completely separated from the X-Y scanner which moves the sample horizontally.

This structural change provides the user with several operational advantages.

1. The Z scanner, being separate from the X-Y scanner, is designed to have a higher resonant frequency than conventional piezoelectric tube scanners. This enables the tip to precisely follow the topography of a sample’s surface at a faster rate and enhances the speed of the measurement, and protects the tip, resulting in the ability to acquire clear images for an extended period of time.

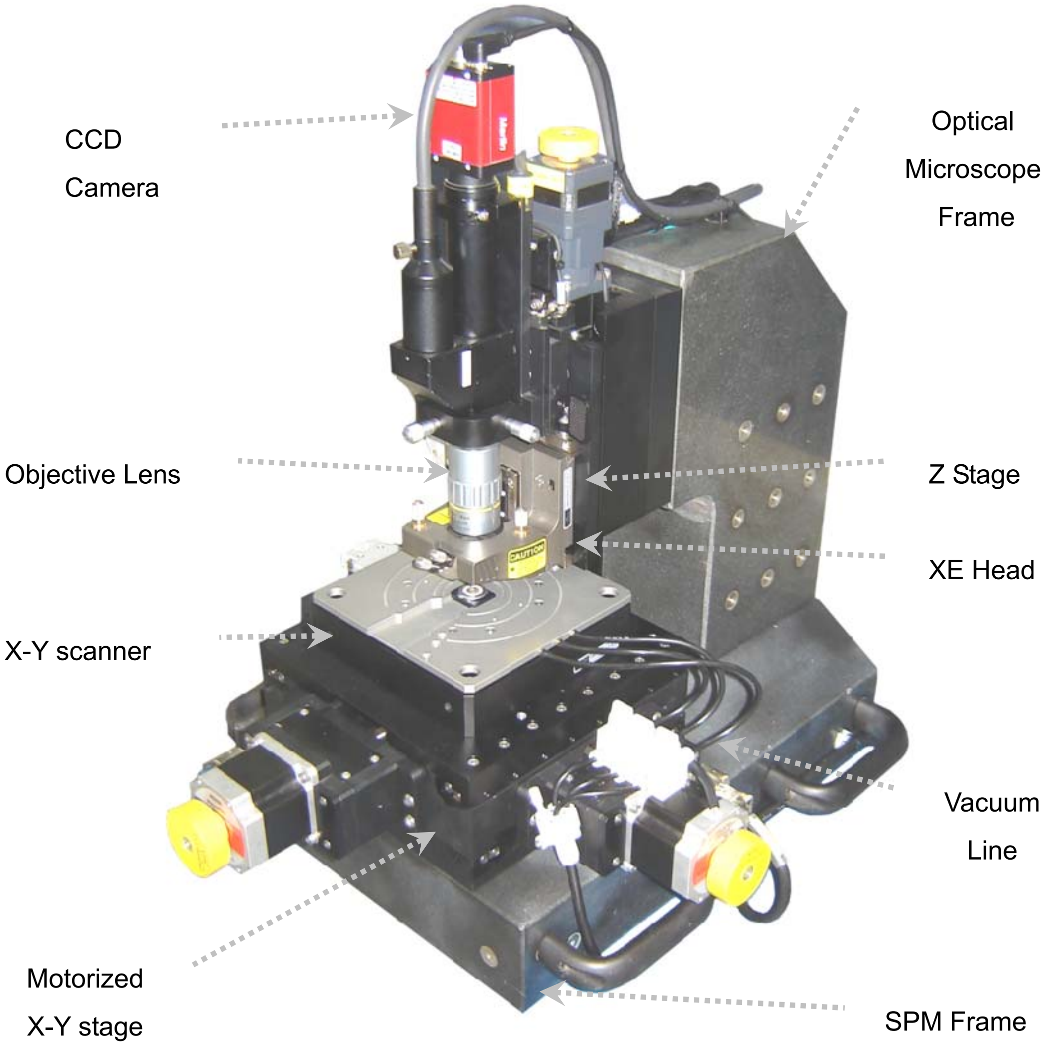


Figure 1-2. XE 150 Scanning Probe Microcope

2. Since the tip wears out eventually, it is necessary to replace it after some amount of usage. The XE-150 has a Kinematic Mount that makes tip exchanges routine and easy.
3. Most AFMs detect probe's movement to measure topographic data by collecting a laser beam signal on a PSPD (Position-Sensitive Photo Detector) after it is reflected from the back side of a cantilever. To align the laser beam, conventional AFMs use additional positioning equipment, the operation which is often difficult and cumbersome. However, Laser alignment becomes very easy

and convenient, with the XE-150. Manageable control knobs on the XE Head can be adjusted manually with the help of the control software and the Video Monitor display, making location and movement of the laser beam easy and accurate.

4. Whenever it is necessary to remove the XE 150 head from the main frame, it is very easy to do so. This procedure can be accomplished by unlocking the dovetail thumb locks and sliding the XE 150 head off the dovetail rail after having disconnected the cable from between the Head and the main frame. Remounting the head is just as easy as removing it.

CAUTION!

Before disconnecting the cable, the Laser switch on the XE-150 head must first be turned off.

WARNING!

Do not disassemble the XE-150 head on your own. Park Systems will not be responsible for any personal, physical damage or degraded performance that may result from unauthorized disassembly.

Figure 1-3. Dovetail Lock Head Mount

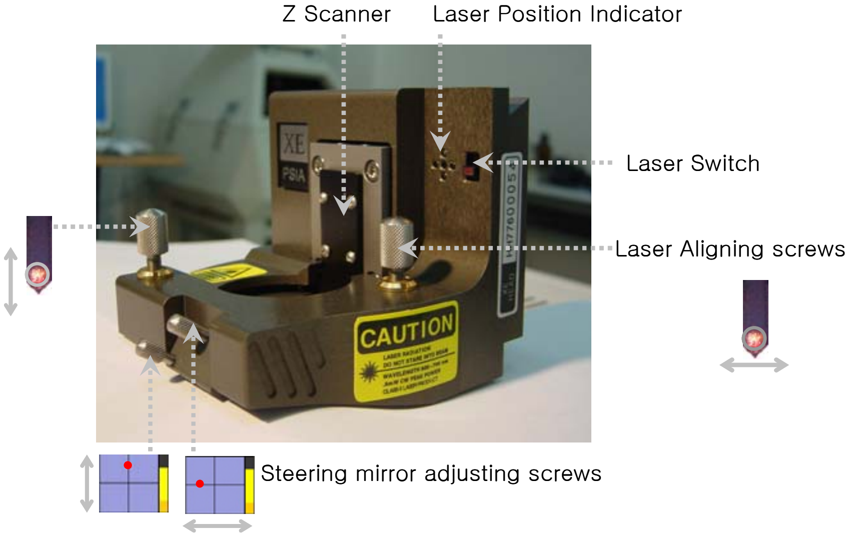


Figure 1-4. XE-150 Head

■ **XE-150 Z scanner**

The Z scanner which is mounted on the XE-150 head makes it possible for the tip to maintain constant feedback conditions (force or distance) as it is moved over a sample surface. The maximum sample height's measurement is determined by the Z scanner range. The XE-150's Z scanner can move up to 12μm. On the other hand, the minimum obtainable vertical resolution is determined by the control unit and the electric voltage that is applied to the Z scanner.

WARNING!

Never disassemble the Z scanner on your own. Park Systems will not be responsible for any personal, physical damage or degraded performance that may result from unauthorized disassembly.

Figure 1-5. Z scanner Assembly

- **XE-150 X-Y scanner**

The XE-150 X-Y scanner is a Flexure Hinge(leaf-spring type) guided system. The X-Y scanner is fabricated from a solid aluminum block. The desired area is cut out from inside the aluminum block, and the lines indicated in Figure 1-6 are then fabricated with a special technique called 'Wire Electric Discharge Machining' - this results in a flexure hinge structure.

An X-Y scanner with a flexure hinge structure has the advantage of highly orthogonal two-dimensional movement with minimal out-of-plane motion. Due to the Parallel Kinematics design, the X-Y scanner has low inertia and axis-independent performance. The 'closed loop'(refer to Chapter 5) scanning is accomplished by means of an optical sensor in the flexure scanner.

X-Y scanner used with the XE-150 has 100 μm $\times$ 100 μm scan range. To hold the sample on the X-Y scanner, there are three vacuum lines – compatible up to 2", 4", and 6" wafer - at the right side of it (see Figure. 1-7).

WARNING!

Never disassemble the X-Y scanner on your own. Park Systems will not be responsible for any personal, physical damage or reduced performance resulting from unauthorized disassembly.

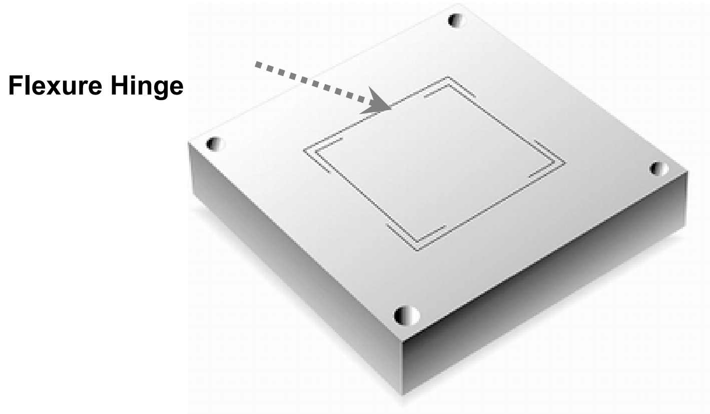


Figure 1-6. Flexure Hinge on X-Y scanner

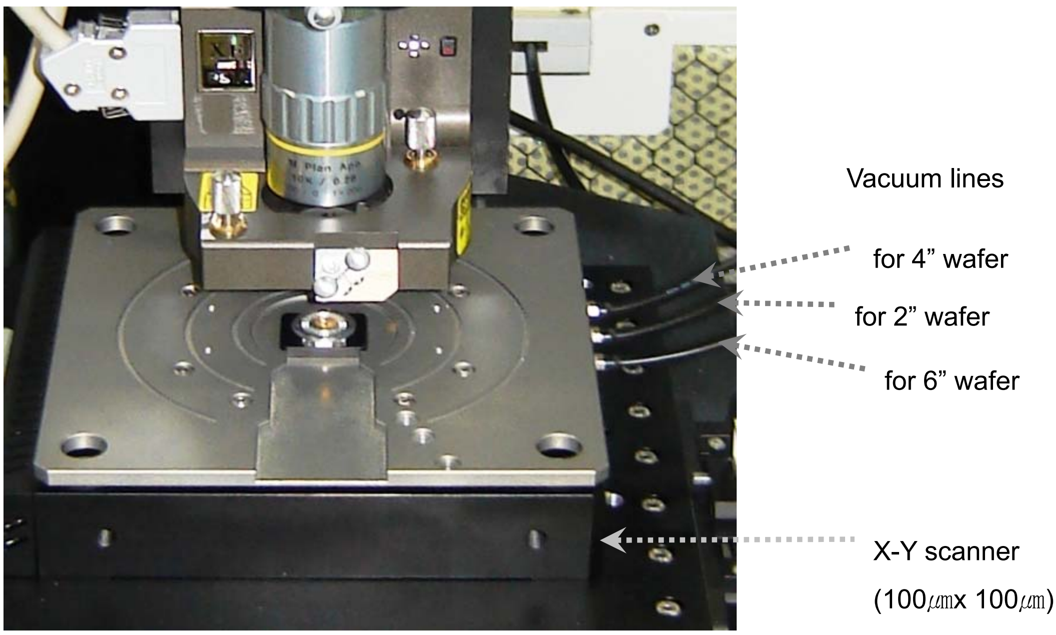


Figure 1-7. X-Y scanner of XE-150 (100μm × 100μm)

- **XE-150 X-Y stage**

The X-Y scanner is affixed to the X-Y stage. Compactly designed X-Y stage uses precision crossed-roller bearing and lead screw to provide high stiffness and accuracy. The motorized X-Y stage can move the sample at a defined location very accurately and swiftly. Also, it is very convenient to make its repeatable motion to same locations. The X-Y stage has a maximum range of 150mm in both X and Y with a mechanical resolution, 1µm with repeatability of 2µm.

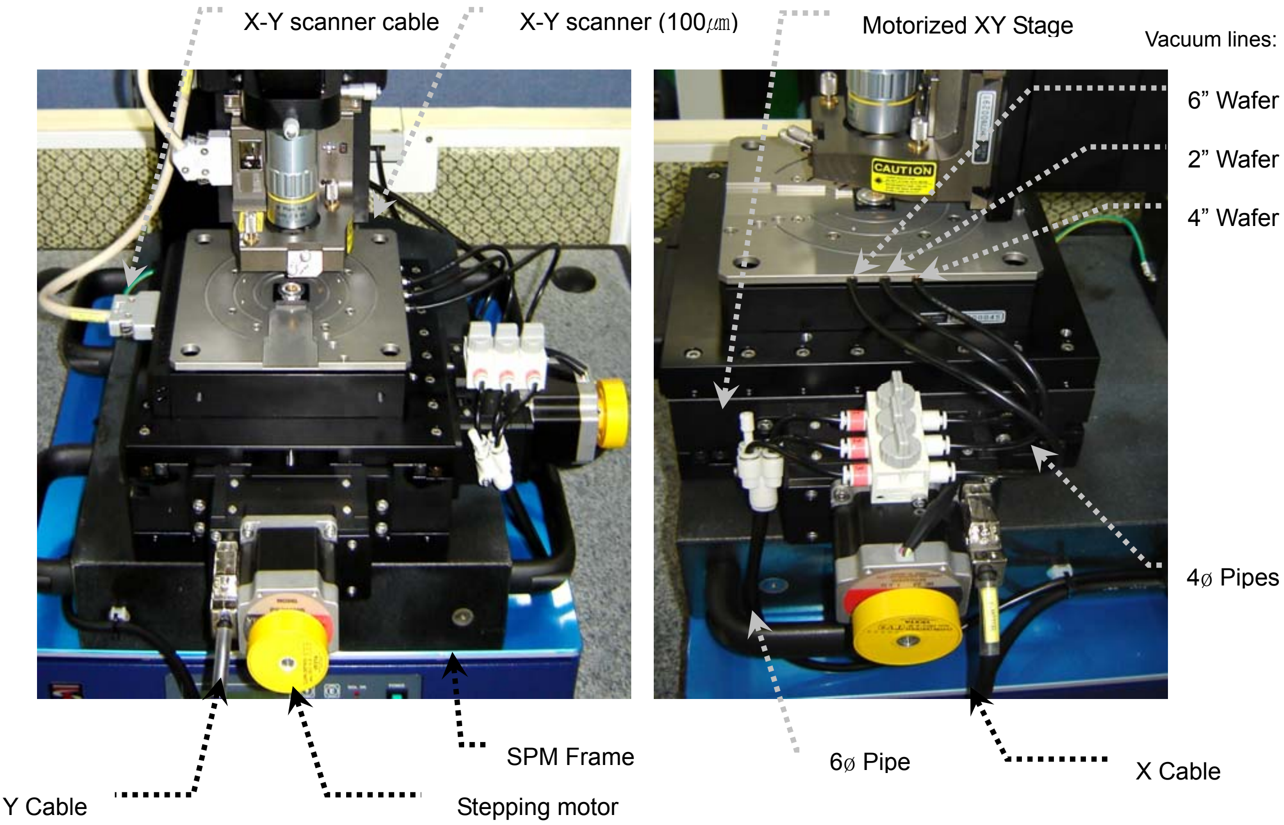


Figure 1-8. Motorized X-Y stage

■ XE-150 Optical Microscope

The Optical microscope is used to focus the laser beam onto the cantilever and to locate the cantilever to interesting region on the sample surface that is to be measured. Since the optical microscope is located parallel with the Z-scanner, it is possible to have a direct on-axis view of the cantilever in conjunction with the sample area that is to be scanned(see Figure 1-9).

All of the components of the optical microscope - the objective lens, tube lens, and CCD camera - are rigidly fixed on a single body. Since the entire assembly moves together for focusing and panning, the axis lining the sample and the CCD camera is always fixed, and therefore the high quality optical view is preserved.

The XE-150's standard 10X objective lens yields about 500 times magnification, and the optional 20X objective lens yields about 1000 times magnification on the 10 inch video monitor

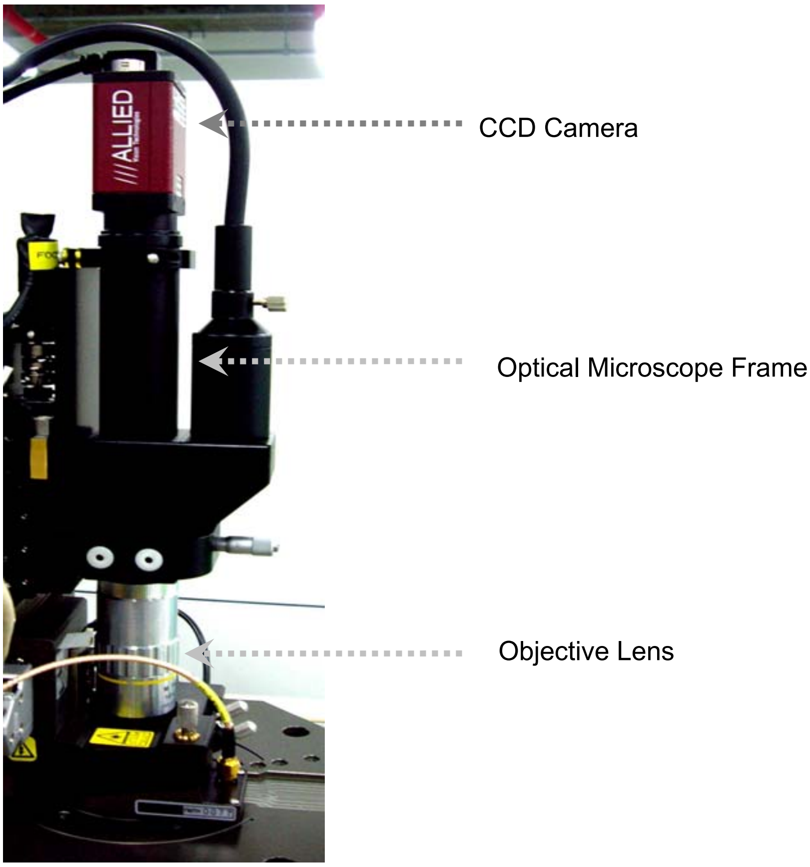


Figure 1-9. Optical Microscope of XE-150

1-1-2. XE-150 Control Electronics

The Control Electronics plays an important role as a mediator between the XE SPM stage and the computer.

In order to maintain fast, effective communication between the computer and the XE-150 Control Electronics, a TCP is used. The DSP contained in the XE-150 Control Electronics is the TMS320C6701, running at 167MHz (1,000MFLOPS).

Figure 1-10. XE-150 Control Electronics

1-1-3. Computer & Monitor

The computer is connected to the XE-150 Control Electronics, via TCP. The computer is equipped with a PentiumⅣ 3GHz or faster CPU/Processor, 1GB RAM, and a 160GB HDD. It uses a Windows XP operating system. Two 19 inch LCD monitor has 1280×1024 pixels with Super VGA graphics. This monitor is digitally connected to the computer via DVI (Digital Video Interface) port. The 256MB graphics card has full-height PCI and Dual DVI w/ TV-out.

1-2. Principle of XE-150's measurements

1-2-1. Scanning Probe Microscope

The Scanning Probe Microscope (SPM) proved false the prevailing concept that an atom is too small to be observed with even the best microscope. It now has every right to be called the third generation microscope, with optical and electron microscopes named as the first and second generation microscope. Whereas the maximum magnifying power of an optical microscope is several thousands and that of a scanning electron microscope (SEM) is tens of thousands, an SPM has the magnifying power of tens of millions, enough to observe individual atoms. Even though a transmission electron microscope (TEM) has the lateral resolution high enough to image at the atomic level, its vertical resolution is much weaker at observing individual atoms. On the other hand, the vertical resolution of SPM is even better than its horizontal resolution making it possible to measure on the scale of fractions of the diameter of an atom (0.01nm). The SPM, with its exceptional resolution, not only makes it possible to understand the various nanoscale worlds which heretofore were not completely revealed, but also to bring the unbelievable into reality, providing such capabilities as allowing a user to change the position of individual atoms or to write letters by transforming the surface of a material at the atomic level.

1-2-2. Atomic Force Microscope

Among SPMs, the first to be invented was the Scanning Tunneling Microscope (STM). The STM measures the tunneling current between a sharp, conducting tip and a conducting sample. The STM can image the sample's topography and also measure the electrical properties of the sample by the "tunneling current" between them. The STM technique, however, has a major disadvantage in that it cannot measure non-conducting material. This problem has been solved by the invention of the Atomic Force Microscope (AFM) which may be used to measure almost any sample, regardless of its electrical properties. As a result, the AFM has greatly extended the SPM's applicability to all branches of scientific research. Instead of a conducting needle, the AFM uses a micro-machined cantilever with a sharp tip to measure a sample's surface. (Please refer to Chapter 3 for a more detailed discussion of the cantilever). Depending on the distance between the atoms at the tip of the cantilever and those at the sample's surface, there exists either an attractive or repulsive force/interaction that may be utilized to measure the sample surface (Please refer to Chapter 6 and Chapter 8 for a detailed explanation of sensing types of forces and the different modes of AFM measurement). Figure 1-11 displays the basic configuration for most AFMs. This scanning AFM is typically used to measure a wide variety of samples, which have relatively small roughness. The force between the atoms at the sample's surface and those at the cantilever's tip can be detected by monitoring how much the cantilever deflects. This deflection of the cantilever can be quantified by the measurement of a laser beam that is reflected off the backside of the cantilever and onto the Position Sensitive Photo Detector (PSPD). The tube-shaped scanner located under the sample moves a sample in the horizontal direction (X-Y) and in the vertical direction (Z). It repetitively scans the sample line by line, while the PSPD signal is used to establish a feedback loop which controls the vertical movement of the scanner as the cantilever moves across the sample surface.

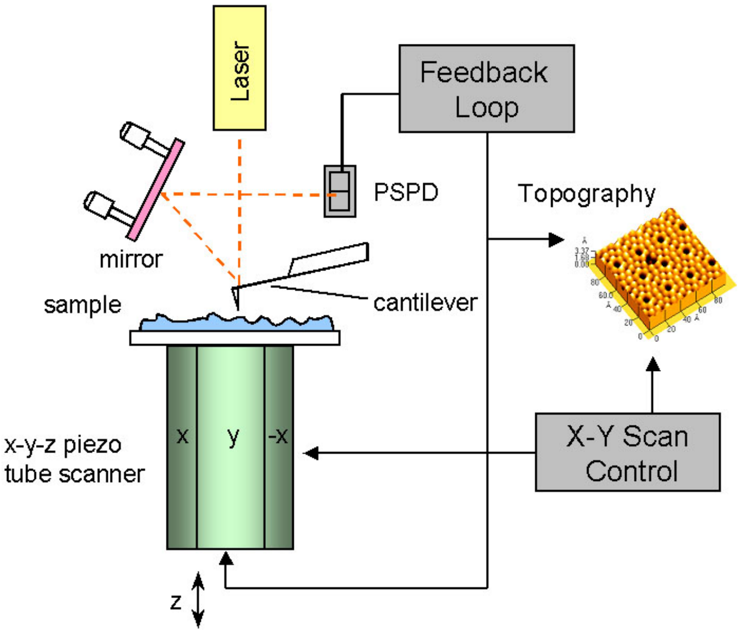


Figure 1-11. Diagram of conventional AFM's scanning

The AFM can easily take a measurement of a conductor, a non-conductor, and even some liquids without delicate sample preparation, unlike SEM or TEM. Also, it is a powerful tool that can measure extremely small structures which other instruments have difficulties investigating.

Despite its many advantages, the AFM does have some drawbacks as well.

1. Since the tip has to mechanically follow a sample surface, the measurement speed of an AFM is much slower than that of an optical microscope or an electron microscope.
2. In general, the scanners used in AFMs are piezoelectric ceramic tubes (Figure 1-11). Due to the non-linearity and hysteresis of piezoelectric materials, this may result in measurement errors as seen in Figure 1-12. (a)~(b).
3. The geometrical and structural restraints imposed by the tube type scanner

results in cross coupling of the individual scan axes. Thus, independent movement in the x, y, and z directions is impossible.

4. Since the tip has a finite size, it is very difficult and sometimes impossible to measure a narrow, deep indentation or a steep slope. Often, even though such a measurement may be possible, the convolution effect due to the shape of the tip and the sample profile may result in measurement errors.

The most inconvenient aspect of using the AFM is its slow speed. As mentioned above, since the image is obtained by the tip's mechanically following a sample surface, it is much slower than other microscopes that use electrons or light. The main factors slowing the speed of the AFM are the Z scanner's response rate and the response rate of the circuit which detects changes in the cantilever's resonant frequency. The resonant frequency of the typical tube scanner is several hundred Hz. In order to accurately measure a sample area with 256×256 pixels (data points), it is necessary to scan at a rate of about one line per second. Thus, it takes approximately 4 minutes to acquire an image.

For most cases, the second and third problems listed above can be minimized by software calibration. This is a reasonably simple and inexpensive procedure that involves imaging a standard sample, (usually a grid structure with a known pitch) in order to create a calibration file that will be used to control the scanner's movements when unknown samples are imaged. Correction using software, however, still depends heavily on the scan speed and scan direction, and such a correction becomes accurate only when the center of the scan range used to measure an unknown sample coincides exactly with the center of the scanning range that was used to image the standard sample and to create the calibration file.

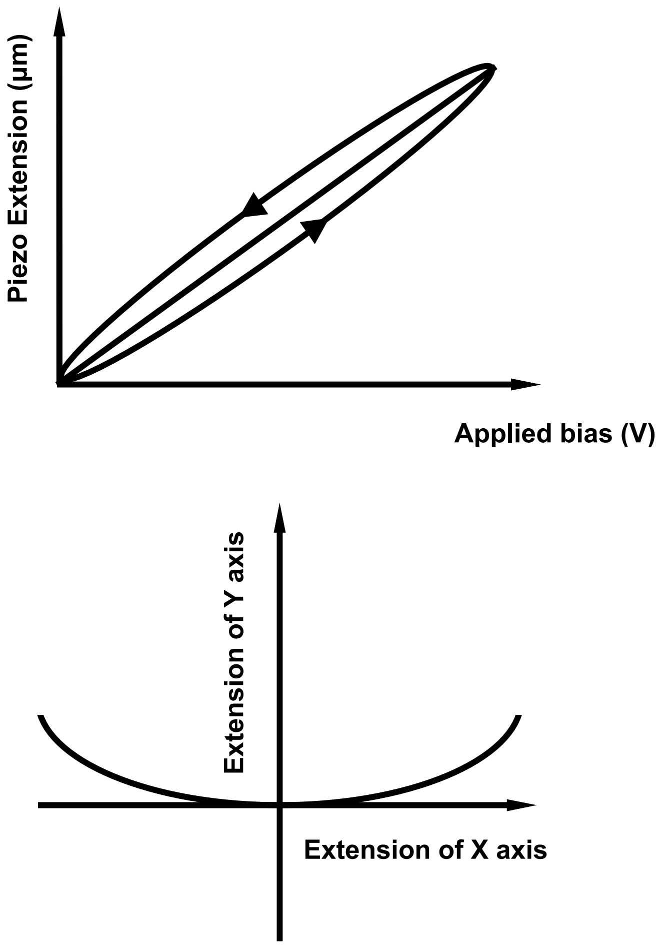


Figure 1-12. Nonlinearity and Hysteresis (a), and Cross Coupling (b) Observed in Piezoelectric Tube Scanners

1-2-3. XE-system's advantages

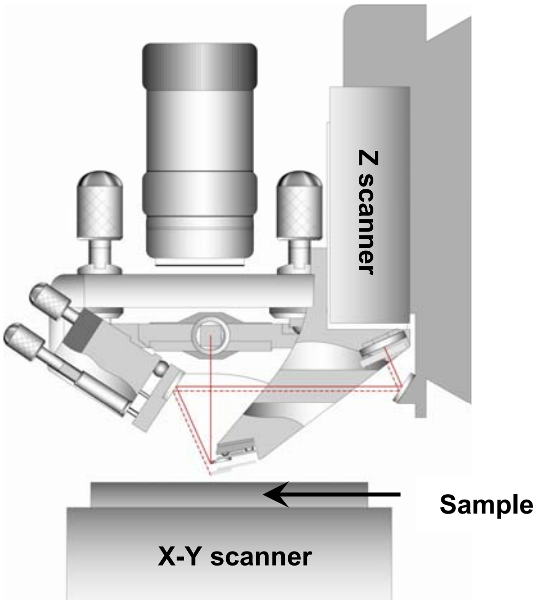
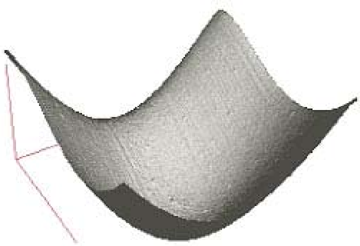


Figure 1-13. Z scanner separated from X-Y scanner

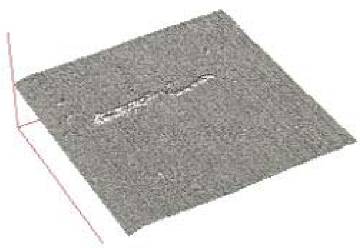
Since the conventional tube type scanner cannot move in one direction independently from other directions, movement in one direction will always simultaneously affect the scanner's movement in other directions. This cross talk and non-linearity (see Figure 1-12) caused by the scanner's three axes being non-orthogonal to another has a more pronounced effect in the case of measuring larger areas or flat samples. This intrinsic problem can be eliminated completely, however, by physical separation of the Z scanner from the X-Y scanner.

The breakthrough that eliminated these cumbersome problems came when the XE-series (Cross-talk Elimination) SPMs introduced a new concept of separating the Z scanner from the X-Y scanner. The XE-scan system is designed so that the X-Y scanner scans a sample in two-dimensional space, while the Z scanner moves the tip only in the z direction. Figure 1-13 shows a diagram of the XE system, in which the Z scanner separated from the X-Y scanner. The symmetrical flexure scanner used in the XE-series SPM moves only in the X-Y plane, and has superb orthogonality. This scanner's design also makes it possible to place much larger samples on the sample stage than could normally be accommodated by a piezoelectric tube type scanner. Furthermore, since the flexure scanner only moves in the X-Y direction, it can be scanned at much higher rates (10~50 Hz) than would be possible with a standard AFM. Because the stacked piezoelectric actuator used for the Z scanner has a very fast response speed, at least 10 kHz, it is able to respond to topographic changes on the sample surface more than 10 times faster than is possible with a conventional tube type scanner.

Having the X-Y scanner separated from the Z scanner in the uniquely designed XE system not only increases the data collecting speed by at least 10 times compared to a conventional tube type scanner, but also isolates the vertical and horizontal scan axes, completely eliminating cross coupling, resulting in a very accurate measurement. Moreover, this independent scanning system improves the error due to the inherent non-linearity of the scanner itself. Figure 1-14 compares the background image of a conventional tube scanner compared to that of the new XE scan system.



(a) Conventional AFM



(b) New scan system of XE

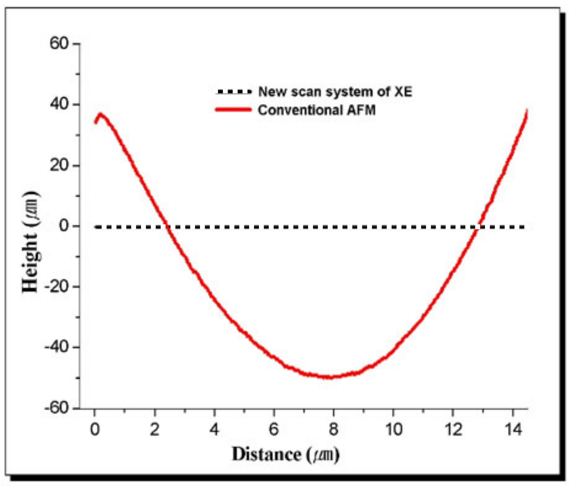


Figure 1-14. Background Flatness Images from a conventional AFM (a) and XE-series AFM (b)

Figure 1-15 shows a diagram that explains the cantilever movement detection mechanism used in the XE-series SPMs. This laser beam/PSPD configuration, which permits the acquisition of stable images at high measurement speeds, is a distinguishing mark of the XE-series and satisfies the following two important imaging conditions:

First, the PSPD should be able to measure only the deflection of the cantilever without interference from the Z scanner.

Second, to improve the response rate in the Z direction, the weight of the Z scanner must be minimized.

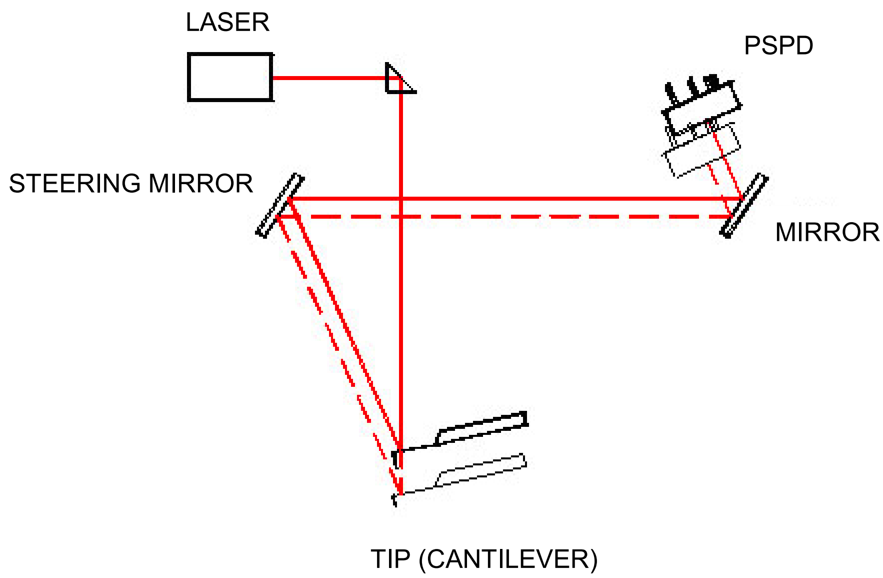


Figure 1-15. Laser beam path related to the cantilever's movement

The cantilever and the PSPD move together with the Z scanner while the laser beam, a steering mirror, and a fixed mirror in front of the PSPD are fixed relative to the scanner frame. The laser beam, positioned at one side of the scanner, is aimed at a prism that is situated above the cantilever. The prism reflects the laser beam downward and onto the back surface of the cantilever. The laser beam will always hit the same spot on the cantilever's surface since the Z scanner only moves vertically. Therefore, once the laser beam is aligned, there is no need to realign the laser beam, even after the Z scanner has been moved up and down to change samples. The steering mirror, located at the front of the Z scanner assembly, adjusts the reflection angle of the laser beam that is reflected off the cantilever's surface. The steering mirror reflects the laser beam to a fixed mirror which, in turn, reflects the beam at once to the PSPD. Another clever feature of this alignment design is that as a result of placing the second (fixed) mirror next to the PSPD, it allows changing of the Z scanner position without having to readjust the position of the PSPD. Therefore, only the deflection of the cantilever will be detected, independent of the Z scanner movement.

Since there is nothing obstructing the view above the cantilever in the structure

(Figure 1-15), the optical microscope is located on the same axis as the laser beam that is reflected at the prism as shown in Figure 1-13.

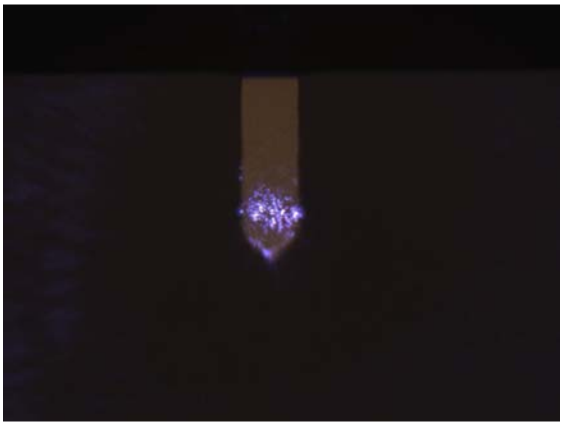


Figure 1-16. Captured optical microscope image

Figure 1-16 shows the cantilever with the laser beam focused on it, as it is displayed on the video monitor. Since the CCD camera is aligned directly with the cantilever with nothing blocking its view, it is very convenient to focus on or to observe the sample while moving the camera up and down. This view also provides superb quality for an optical microscope.

The superiority of the XE-150 system's design, and its intention to accommodate the convenience of the user, appears in many different aspects in addition to the optical microscope. The AFM head, which includes the Z scanner, is easily inserted by sliding it along a dovetail rail and locking it into place with a convenient turn of two thumb locks. There are no additional knobs or springs to adjust as is common with other designs.

The replacement of the tip is just as easy, and no special tools are required for this procedure. Figure 1-18 shows the easy operation of replacing a tip by hand.

Figure 1-17. Dovetail Lock Head

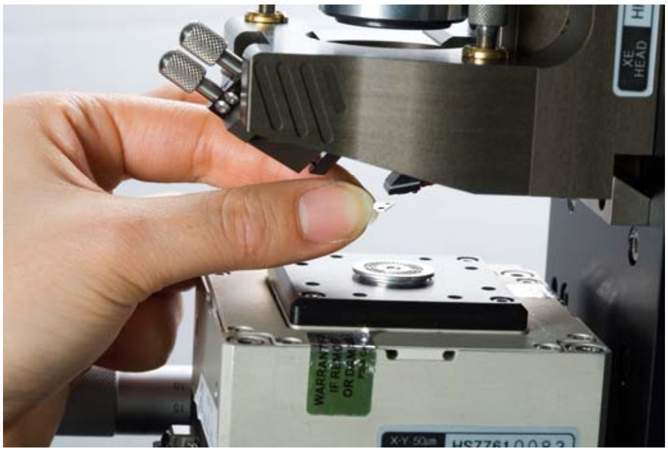


Figure 1-18. EZ Snap Probe Tip Exchange

The XE system not only achieved a structural design change that yielded exemplary SPM efficiency, but it also brought lots of improvements to the electronic controller and to the supporting software. The electronic controller has a fast and powerful DSP (Digital Signal Processor), 14 DACs (Digital to Analog Converters), and 5 ADCs (Analog to Digital Converters). The XE Control Electronics are designed to enable the scanner, the core unit of the AFM, to provide efficient, accurate and fast control, and to facilitate the acquisition of a stable image even beyond a scan speed of 10Hz. In addition, the controller contains input/output terminals that provide a simple means for users to design advanced experiments that extend far beyond and are much more complicated than obtaining basic images.

Furthermore, the up to date computer is equipped with the most recent high-power Pentium chip and Windows XP operating system. A 19" LCD monitor displays crystal clear images using a DVI (Digital Video Interface). All necessary software, including XEP, the Data Acquisition program, and XEI, the Image Processing program, is installed on the computer. Figure 1-19 shows the XEP program's clean and easy-to-use interface, complete with safety functions and various measurement capabilities that are required to perform advanced applications. Figure 1-20 shows the XEI program that is used to convert acquired data into an image and to perform various analyses that meet the user's requirements.

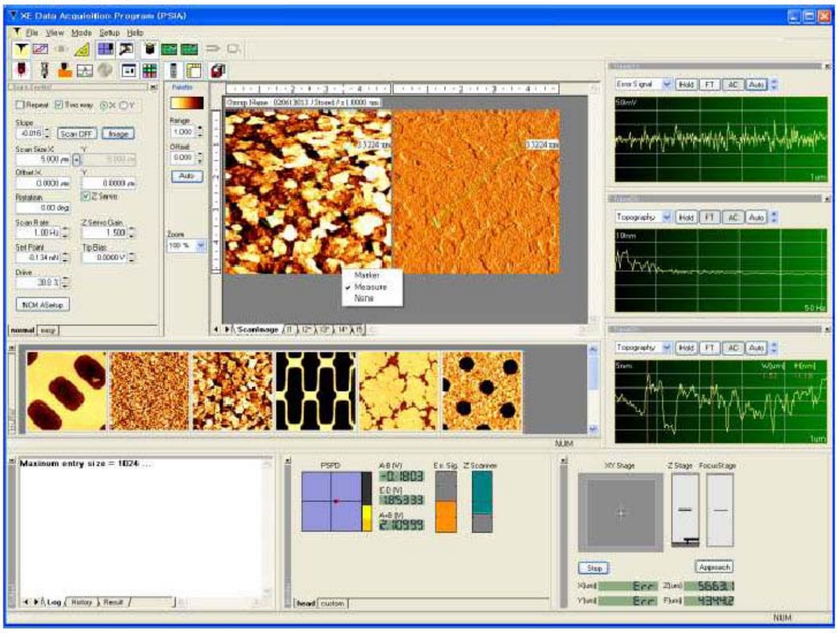


Figure 1-19. XEP - Data Acquisition Program

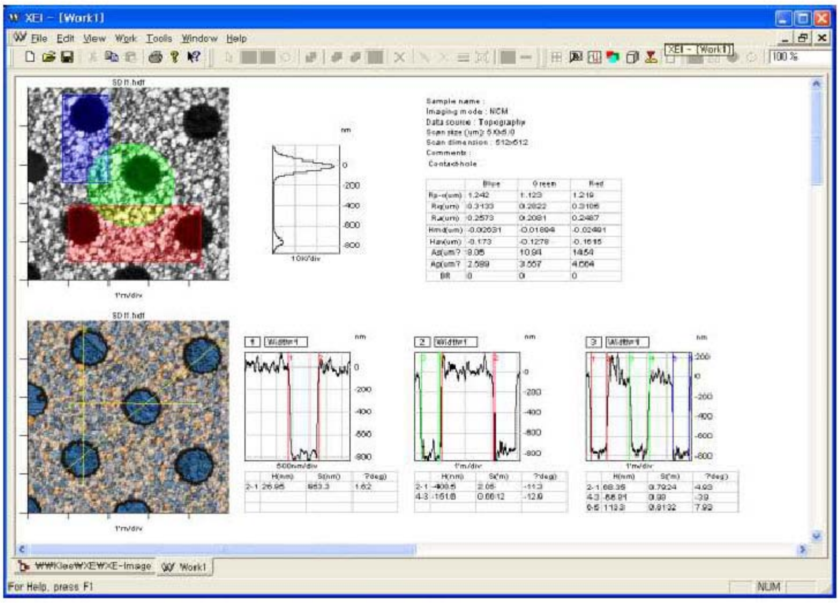


Figure 1-20. XEI - Image Processing Program

Chapter 2. Installation

The installation procedure and environmental specifications for the XE-150 play a significant role in the safe operation of the system. Since the durability, safety and overall performance of the XE-150 depend on the environment and proper installation, please pay close attention to the following installation environment and procedures that are recommended in this chapter.

2-1. Environment

■ **Temperature and Humidity**

Recommended Temperature: 5 °C ~ 35 °C

Recommended Humidity: 30 % ~ 80 % (Not condensing)

The XE-150 should be installed in a clean, dry atmosphere with proper ventilation.

■ **Vibration**

The XE-150 is extremely sensitive to external vibrations. Thus, it is important to isolate all possible vibrations from the equipment's surroundings. It is recommended that an Enhanced steel frame or Active Vibration Isolation System be installed to remove external vibrations.

Floor Vibration: vertical floor vibration, less than 1×10^{-8} m/sec for 0-50 Hz

■ **Acoustic and Electromagnetic Noise**

The XE-150 should be installed where outside noise and light can be minimized.

To eliminate noise and light interference, it is advisable to operate the XE-150 with an Enhanced Acoustic Enclosure closed.

- **Electrical Requirements**

The XE-150 requires an AC power supply.

Power Supply: 100/120 V or 230/240V, 60 Hz, 300 W

Since the XE-150 AFM is highly sensitive equipment, it is ideal to use it with a UPS (Uninterruptible Power Supply) installed to provide a stable power supply.

The resistance in the ground system should be less than 10 ohms to optimize operation.

2-2. Pre-Installation

The XE series SPM (Scanning Probe Microscope) is a precision instrument that can measure up to sub-nanometer scale features. Consequently, it is very susceptible to surrounding noise and vibrations, and the following precautions need to be followed very carefully in order to obtain stable operation and the best measurement results.

- The optimal location to install the XE-150 is a room with no vibrations, such as a basement or the lower floor of a building where the inside and outside vibrations have the least effect.
- If the XE-150 must be installed in a location where there is considerable air flow or electrical noise caused by electromagnetic fluctuations, you may isolate the noise by using an Enhanced Acoustic Enclosure.
- To protect the system from electric shock, the power supply, electric outlet, extension cord, and plugs must be grounded.

2-3. Component List

- XE-150 SPM Main Body
- XE-150 Control Electronics
- XE Manuals
- XE Software Installation CD
- XY 100 µm scanner : Single module parallel-kinematics flexure scanner (100

μm)

- XE SLD Head: Flexure Guided System (12 μm)
- Illuminator
  - Input power : AC 110/220 V (free voltage)
  - 12V-100 W Halogen Lamp
- XE Cables
  - From Computer to Control Electronics
    - TCP Cross Cable 2m
    - RS-232C cable(XY stage control cable) 2m
  - From Control Electronics to XE SPM Main Body
    - Motor cable, 40pin, 3 m
    - Analog cable, 68pin, 3m
    - Optical fiber cable, 3m
  - From vacuum pump(utility) to X-Y stage
    - ϕ6 vacuum tube 5m
  - From XE SPM Main Body to Scanner
    - X-Y scanner cable, 36pin, 30cm
    - Z scanner cable, 26pin, 20cm
  - From XE SPM Main Body to XY stage
    - X motor cable 3m
    - Y motor cable 3m
- Enhanced Acoustic Enclosure with Steel Frame
- Computer
  - Pentium IV, DDR RAM 1GB, 160GB HDD, Window XP Operating System
  - Two 19 inch LCD monitor has 1280×1024 pixels with SuperVGA graphics. This monitor is digitally connected to the computer via DVI (Digital Video Interface) port.
- Active Vibration Isolation System
- Standard Sample
  - 3 μm calibration grating
- Cantilevers
  - Contact Silicon Cantilevers 5ea
  - Non-contact Silicon Cantilevers 5ea
- Multi Tab (110V / 220 V), Ground Type
- Tweezers
  - for wafer 1ea

- for sample and cantilever 1ea
- Sample disk (pucks) 5ea

2-4. Hardware Installation

2-4-1. Installation of Active Vibration Isolation System

■ **Active Vibration Isolation System**

An Active vibration Isolation System (AVIS) uses an electromagnetic transducer to isolate any vibrations generated by the building as well as system. The AVIS (TS-150) available with the XE system consumes in general under 10W, and in extreme cases a maximum of 40W. Either AC 110V or 230V can be used for the power supply, but it should always be connected to an electric outlet with a separate ground. The AVIS can block the vibrations in the frequency range of 0.7Hz~1kHz, but vibrations above 1kHz will penetrate the AVIS.

Figure 2-1 shows the general view of the TS-150; an object of up to 150kg can be placed on the table top. Figure 2-2 shows the power supply connection located on the TS-150's rear panel. On the left hand side of the rear panel, there are two fuses 1.6A/230V. On the right hand side, a BNC socket gives a multiplexed output showing the signals from all six accelerometers that are used to isolate vibrations, and an oscilloscope may be used to display changes due to the AVIS.

Figure 2-1. Active Vibration Isolation System

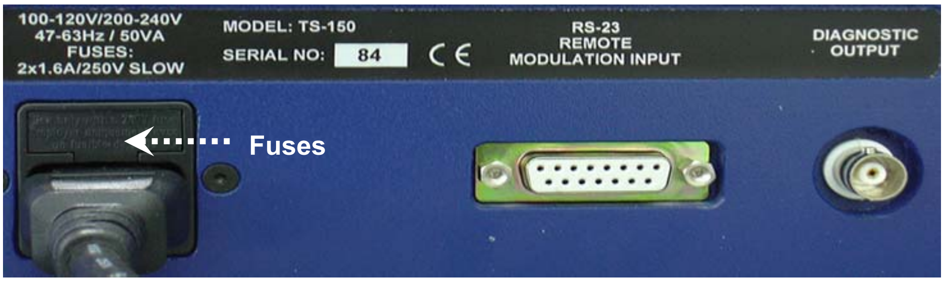


Figure 2-2. Rear panel of AVIS

Before being installed, the AVIS should be in "Lock" mode in order to protect the TS-150 from outside impacts that may occur during shipping or storage.

When the AVIS is initially installed, or after the lock condition has been selected prior to system transport or long-term storage, the lock mode will be automatically released once power is supplied to the AVIS. Be sure to securely place the four corners of the TS-150 on a solid flat surface before turning on the power supply. When the power switch is on, and after the inside motor stops turning, the upper table will be floating, and the "Isolation Disable" sign will be displayed. At this time, if you push the button labeled "E" on the front panel, the active vibration isolation will begin and the red LED will turn on.

Figure 2-3. Front panel of AVIS

If the AVIS is to be kept in storage again or transported, you may scroll the screen while the power is still on, until the message "to lock push↲ " appears. Pushing the "↲ " button will initialize the motor which slowly lowers the isolation stage until it finally halts. You may turn off the power when the "System locked' message appears. The AVIS will remain locked until the power supply is turned on again.

2-4-2. Computer Installation

Please refer to the manual supplied by the computer manufacturer.

2-4-3XE Cable Connections

Before connecting the XE-150 SPM components, for easy connection and operation, please arrange them as shown in Figure 2-4.

Figure 2-4. Basic arrangement of XE-150

Figure 2-5 shows the cables to be checked before the initial installation.

Figure 2-5. Cables needed to be checked prior to installation

- A : TCP cable
- B : Optical fiber
- C : Motor cable
- D : Analog cable
- E: RS-232C cable
- F: X motor cable
- G: Y motor cable
- H: XY scanner cable
- I: Z scanner cable

■ **XE-150 SPM Main Body**

XE-150 SPM main body is attached to your left side of the front of the XE-150 system. As shown in Figure 2-6, in front panel of XE-150 main body, there are two connectors. Connect the upper connector to the Z scanner Head using the Z scanner cable (26pin). Connect the lower connector to the X-Y scanner using the X-Y scanner cable (36pin). Connect two XY stage cables (X and Y direction) between the XE SPM

Main Body and motorized XY stage.

The rear panel of the SPM main body has 4 connectors as shown in Figure 2-7. Connect these cables to where as follows:

Connect Motor cable (B, 40pin) to the XE-150 Control Electronics.

Connect the two X-Y stage cables to the X-Y stage (see Figure 2-6)

Connect the Analog cable to the rear panel of the XE-150 Control Electronics. (see Figure 2-7)

Connect the optical fiber cable to the illuminator(see Figure 2-9)

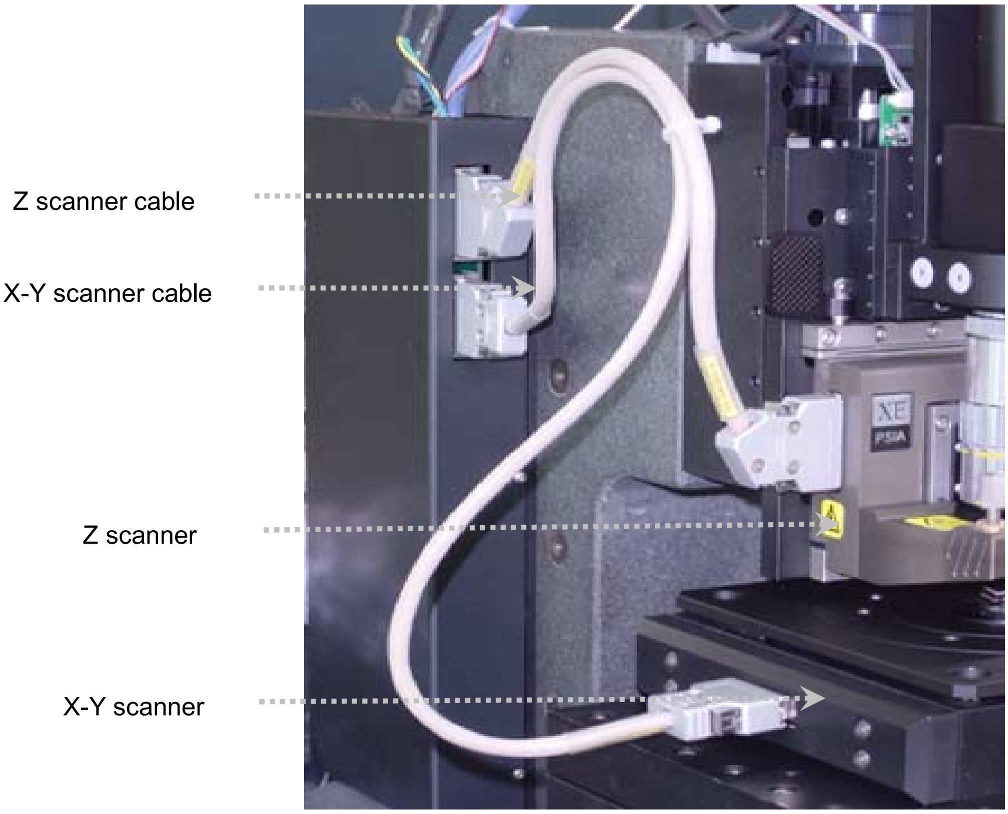


Figure 2-6. Cable Connection from the front panel of SPM main body to the Z scanner Head and X-Y scanner

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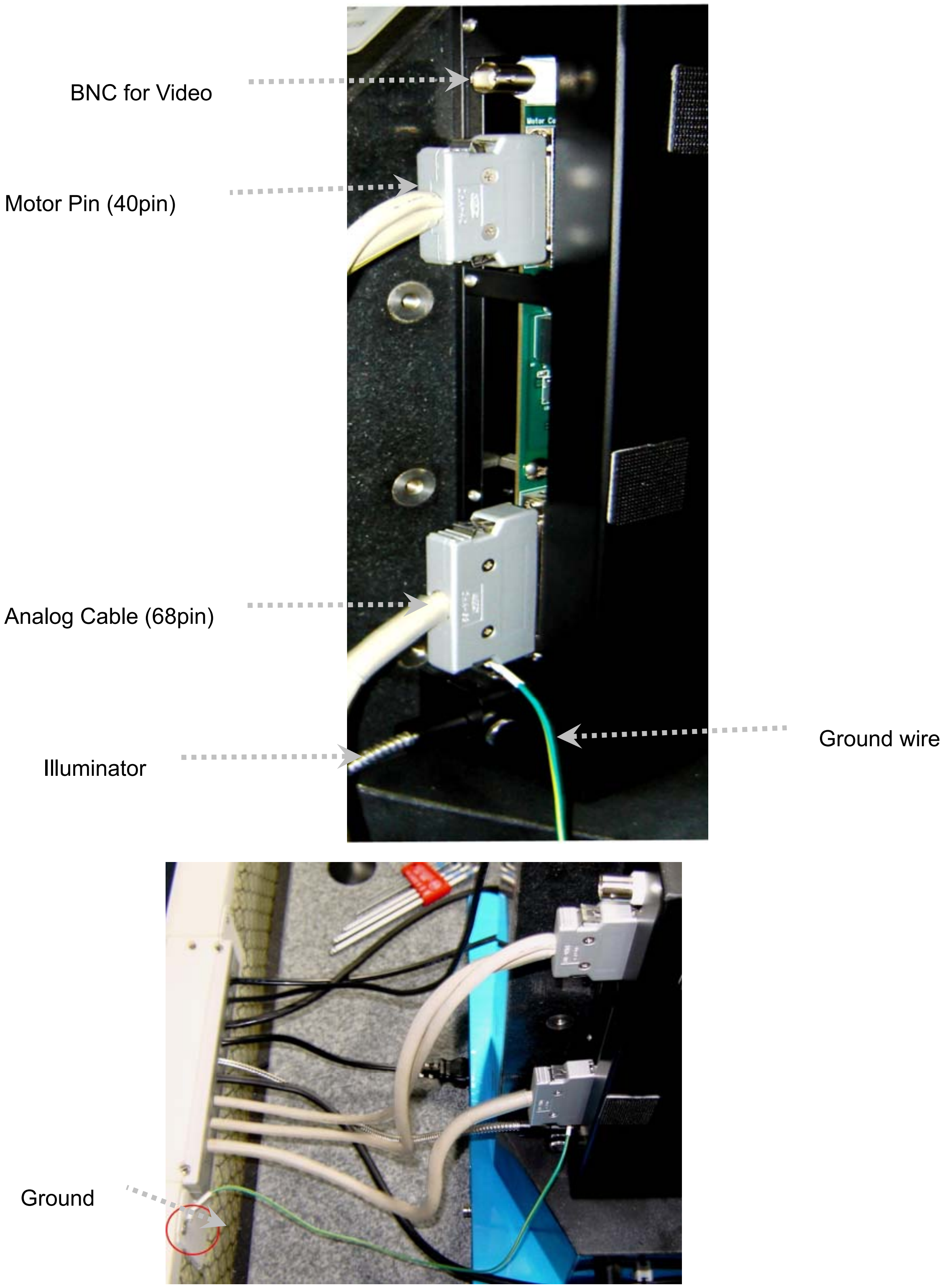

Figure 2-7. Rear panel of the XE-150 SPM Base

■ **XE-150 Control Electronics**

As shown Figure 2-8 below, the XE-150 Control Electronics has three parts on the rear panel. The upper right corner has a fan and several BNC Output connectors for the external application modes and auxiliary Analog Digital converters. The lower part of the XE-150 Control electronics has several connectors for cables

At rightmost, AC power(A) should be connected to the power supply.

As a XY stage control cable, RS-232C cable(B) should be connected from the XE-150 Control Electronics to the computer(see small picture in Figure 2-8).

Connect the "Analog" connector(B) on the rear panel of the XE-150 Control Electronics to the 68pin connector (E) on the side of the main body shown in Figure 2-7 using the Analog cable (50pin).

Connect the "Motor" output(C) on the rear panel of the XE-150 Control Electronics to the 40pin connector (B) on the side of the main body as shown in Figure 2-7 using the 40pin Motor cable.

Connect the TCP connector(F) on the rear panel of the XE-150 Control Electronics to the USB port of the computer using the standard USB cable

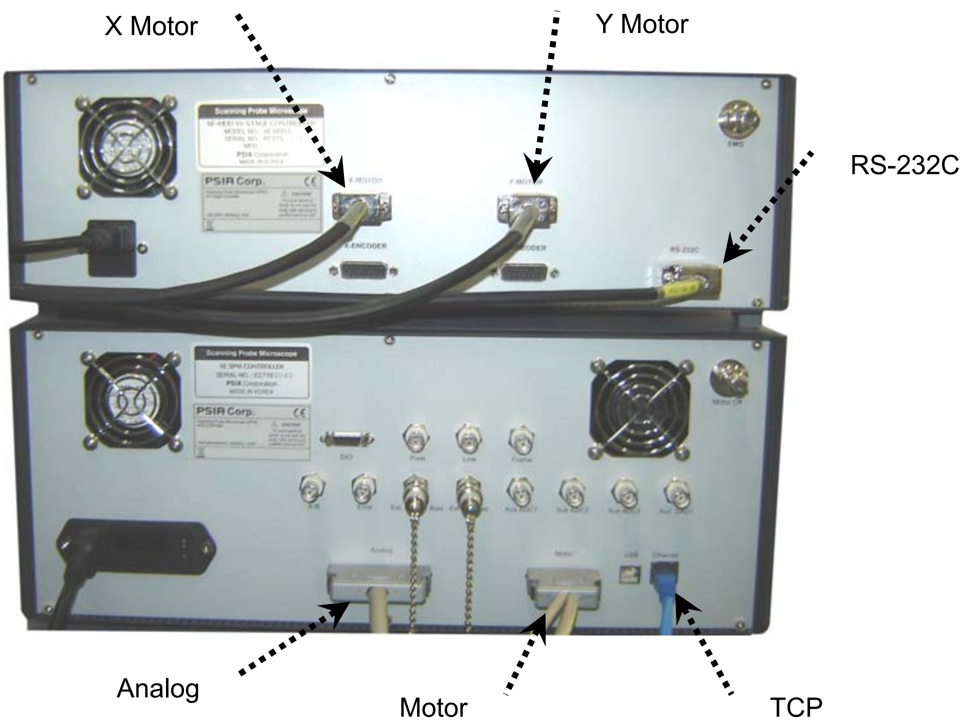

Figure 2-8. Cable connection of the XE-150 Control Electronics

■ **Illuminator**

As shown in Figure 2-10, connect the illuminator to the illuminator connector (referred to as “F” in Figure 2-7) using the Optical fiber.

Figure 2-10. Illuminator

2-4-4. Connection to power supply

Connect the XE-150 Control Electronics, the illuminator, and the 19” monitor to the grounded power supply. Make sure all the switches are turned off to prevent any damage to the equipment.

2-4-5. Installation Checkup

Once the installation is complete, turn the power supply on. If you click the XEP icon on the desktop or in the folder C:\Park Systems\Bin of your computer, the program will start and you can check to ensure that system initialization completes without any error messages. If there is a problem, check whether the power supply is on, and make sure all the components are arranged correctly.

Chapter 3. Cantilever Selection

3-1. Characteristics of the cantilever

Generally speaking, the term ‘cantilever’ includes the silicon chip, a cantilever hanging from the chip, and a tip hanging from the end of the cantilever. Figure 3-1 below shows the overall view and the names of the parts of the cantilever used in the SPM (Scanning Probe Microscope).

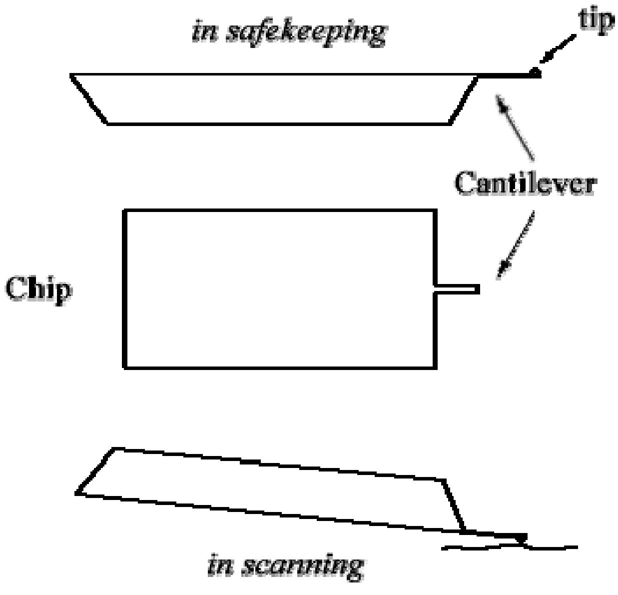

Figure 3-1. Cantilever chip

The chip, the cantilever, and the tip are made from Silicon (Si) or Silicon Nitride (Si_3N_4), and are manufactured using macro-machining techniques.

Because a cantilever has very small dimensions - 10㎛ width, 100㎛ length, and several ㎛ thickness - it is very difficult to handle in the process of attaching to the SPM. To make it easier to use, the SPM uses a relatively large chip of size several millimeters.

Figure 3-2 is the SEM image of a cantilever manufactured this way.

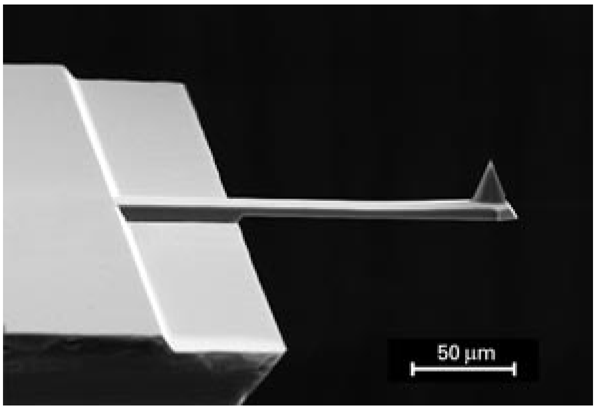

Figure 3-2. SEM image of silicon cantilever

The cantilever is the part sensing the surface properties (for example, the topographic distribution, the physical solidity, electrical properties, magnetic properties, chemical properties, etc.) by detecting the degree of deflection due to the interaction with the sample surface, and is very important component determining the sample resolution.

When viewed from the top, the structures of cantilevers are divided into two groups: those with a rectangular shape and those with a triangular shape. Each design has a different force constant depending on the width, depth, thickness, and the composition of the material. Among these, the Silicon Nitride cantilever is stronger that the Silicon cantilever, but it has some disadvantages:

1. When the thickness is more than 1㎛, contortion may occur.
2. The curvature of the end of the tip is large – on the order of tens of nanometers.
3. It has a low aspect ratio.

Compared to this, the Silicon cantilever has a curvature of the tip of less than 10nm, and is more commonly used. Moreover, in non-contact mode, which has a high resonant frequency, and the cantilever with the high force constant, the rectangular shaped cantilever with a bigger Q-factor is used more than the V shape. The cantilever provided with the XE-150 as a default is a Silicon, rectangular shaped cantilever for use in both contact mode and non-contact mode.

In addition, the upper surface of the cantilever (the opposite side of the tip) is coated very thinly with a metal such as gold (Au) or aluminum (Al) to enhance the high reflectivity. However, for EFM (Electrostatic Force Microscopy) or MFM (Magnetic Force Microscopy), when the whole cantilever and tip is coated to measure the electric or magnetic properties, there is no extra coating on the cantilever to enhance the high reflectivity.

3-2. Cantilever Selection

There are several types of cantilevers varying in material, shape, softness (represented by the spring constant), intrinsic frequency, and Q-factor. The choice of a cantilever from among these is primarily determined by the type of the measurement mode.

In the contact mode, a “soft” cantilever, which has a small spring constant of about 0.01 N/m ~ 3N/m to respond sensitively to the tiny force between atoms is usually chosen. The probe tip used in the contact mode has a thickness of about 1㎛ to achieve a small spring constant. This is because a cantilever with a small spring constant makes a relatively large deflection to a small force, and can thus provide a very fine image of the surface structure.

On the other hand, in non-contact mode, a cantilever has a greater thickness, ~ 4㎛, compared to contact mode. It has a spring constant of 40N/m which is very “stiff”, and a relatively large resonant frequency. While contact mode detects the bending of a cantilever, the non-contact mode vibrates a cantilever at a high resonant frequency, and measures the force gradient by the amplitude and phase change due to the interaction between the probe and the sample, which yields the topography of the sample. When an AFM is operating in the atmosphere, if the probe tip is situated on a moist or contaminated layer, it may often stick to the layer due to the surface tension of the tip. This happens more frequently if the spring constant of the cantilever is smaller. Because of the small spring constant, it is difficult to bring it back to the original position. Therefore we need a cantilever with a spring constant which can overcome the surface tension. The sharper the tip, the more stable operation can be expected because the surface area of the tip and the surface tension are reduced.

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Chapter 4. Setup Procedure

4-1. Turn on the XE-150

To properly initialize the XE-150, turn on the system and start the program in the following order.

1. Turn on the computer.
2. Turn on the illuminator, and the computer monitor.
3. Turn on the Control Electronics.

<u>CAUTION!</u>

> First, turn on the Electronics, then turn on the computer. Since the electronics are connected to the computer at the USB port, the computer can only recognize the electronics after they have been initialized.

4-2. XEP Software

The XE-150 is operated by the XEP software. When you click the XEP icon  in the desktop or in C:\Park Systems\Bin of your computer, you can start the XEP, software program for controlling XE-150.

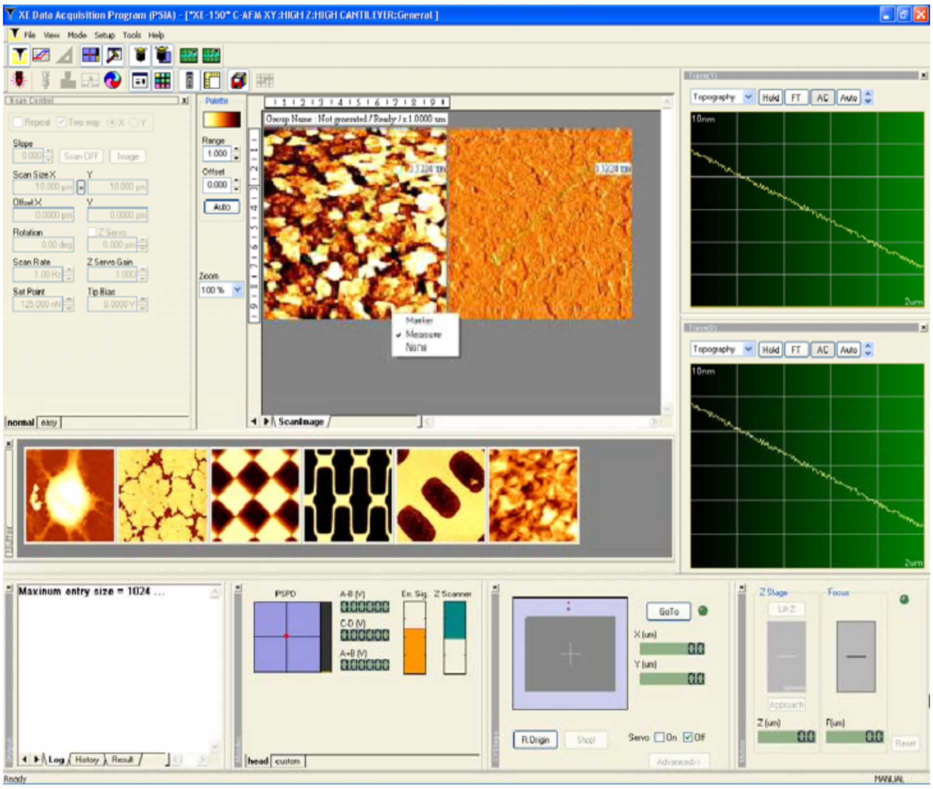


Figure 4-1. XEP User Interface of XE-150

As shown above, the individual windows are separated and may be arranged according to the user’s preferences. For example, the location and the size of the windows may be changed for the user’s convenience. Please refer to the software manual for more detailed information.

4-3. X-Y stage control

For XE-150, you can see both XY and Z stage pads on the screen. If there is no “X-Y stage control window” like Figure 4-2 on your computer screen, you can open this window by clicking the X-Y stage icon . The XY stage pad is used to move the tip around the sample surface before you take an image. The XY stage can be moved in both the x and y directions, which moves the sample relative to the probe tip. The XY stage pad controls both the direction and the speed of the XY stage.

NOTE!

> Before you use the XY stage pad, be sure to lift the tip off the sample by using the Z stage control pad.

Move the cursor with your mouse and click the cursor where you want to get images in the X-Y stage pad, then the X-Y stage will move in the opposite direction so that the XE head move to the defined location. The red point in Figure 4-2 represents the position of the XE head, and you can see its movement by watching this point. This allows for convenient repositioning of the XE head around the sample surface. To increase the speed of movement, click the cursor further from the center cross on the XY stage pad.

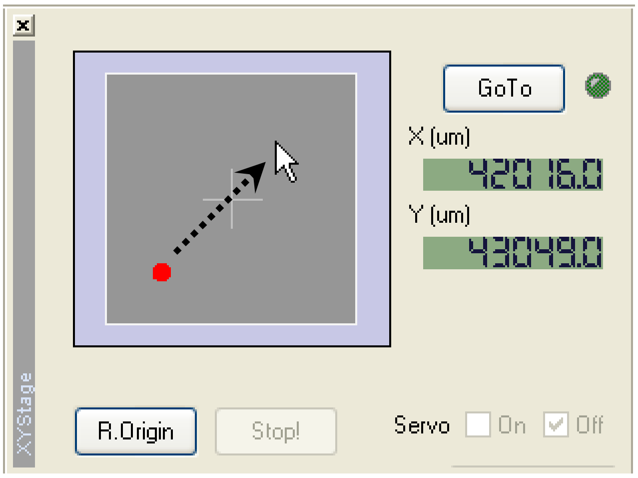


Figure 4-2. X-Y stage Control Window

4-4. Z stage and Focus stage Control

The “Motor Control” window consists of two control pads for the “Z stage” and the “Focus stage”. If you press the upper or lower part of these pads with your mouse, the stage will move up or down accordingly. Extra care should be accompanied when the stage is close to the sample, since the further from the center of the Z stage is clicked, the faster the Z scanner will move toward the sample stage.

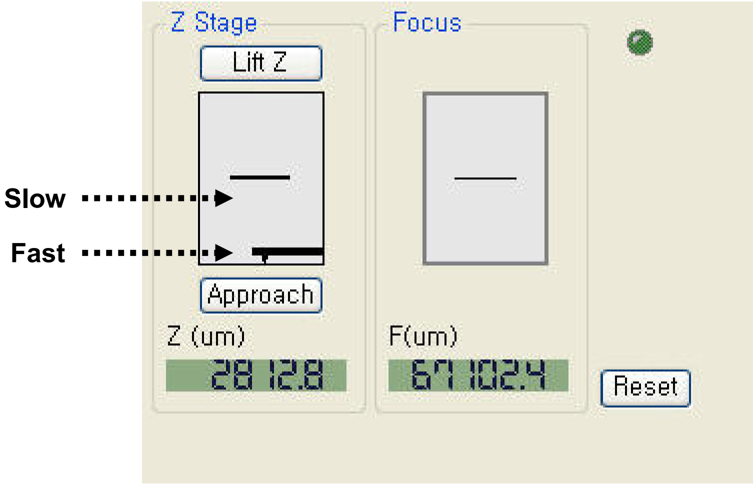


Figure 4-3. Z stage and Focus stage control window

WARNING!

When the Z scanner's arm and the sample are very close, a rapid movement of the Z scanner may cause the scanner's arm to collide with the sample. This may result in severe damage to the probe tip, the sample, and/or the scanner itself.

To preview the sample surface through the optical microscope, focus on the sample surface by clicking and holding the cursor on the downside from the center of the Focus stage pad. The top half of the button will adjust the focus upward, while the lower half will adjust it downward. Also, like X-Y stage and Z stage pad, the speed of the Focus stage also depends on how far the cursor is from the center of the Focus stage pad.

4-5. Cantilever Preparation

The XE-150 is provided with cantilevers for both contact and non-contact modes of operation. The appropriate cantilever should be selected with consideration for the operation mode.

It is very simple to install and replace a cantilever for the XE-150 system, and no extra tools are necessary.

The following is the procedure for changing cantilevers.

1. As shown below, hold the sides of the cantilever chip with your thumb and

index finger and bring it close to the probe arm.

CAUTION!

> To replace a cantilever, it is desirable to raise the Scanner Head to a suitable height so as to allow proper clearance for your fingers to avoid contact with the sample surface.

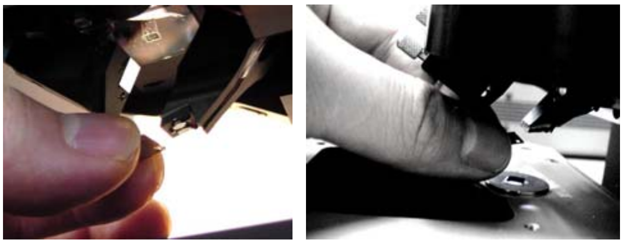


Figure 4-4. EZ snap tip exchange

2. There are two holes in a cantilever chip plate; a round hole, and an elongated slot. When you overlay the two ruby nodules located on the end of the probe arm with these holes, the cantilever chip will be attached into place by a magnet, and the position of the cantilever will be firmly fixed in one position (Figure 4-5).

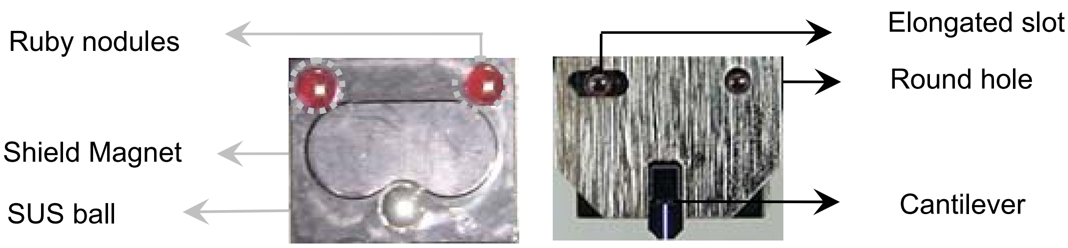


Figure 4-5. Edge of the probe arm beore(left) and after(right) the cantilever chip plate is attached to it

4-6. Laser beam Alignment

The AFM obtains an image by monitoring the deflection of a cantilever. Since this deflection is too tiny to be measured, the actual measurement is made indirectly by utilizing a laser beam. The laser beam is reflected off the backside of the cantilever and onto a PSPD (position sensitive photo detector). When the cantilever deflects, the reflection angle of the laser beam will change, resulting in a change of the location where the laser beam enters the PSPD. This change is, in general, much greater than the deflection of the cantilever (usually smaller than a radius of an atom), which makes the position detection much easier.

There are two major steps in aligning the laser beam on the top of the cantilever. First, adjust the laser beam so that it strikes the backside of the cantilever. This procedure is facilitated by bringing the cantilever relatively close to the sample so that it is easy to find the laser spot when it reflects off of the sample surface.

1. As shown in Figure 4-6, using the two laser aligning screws which are located on the upper part of the head, move the laser beam vertically and horizontally on the video monitor.
2. Move the laser beam from the outside area of the cantilever chip to the outer edge of the chip (from the lower part of the monitor to the upper part accordingly). Once the laser beam reaches the cantilever chip, you will be able to see the reflected laser light at the chip's edge.
3. After the laser beam touches the edge of the cantilever chip, adjust the laser beam (by moving horizontally on the video monitor) to focus it on the cantilever.
4. As shown in Figure 4-6, bring the laser beam to the tip of the cantilever.

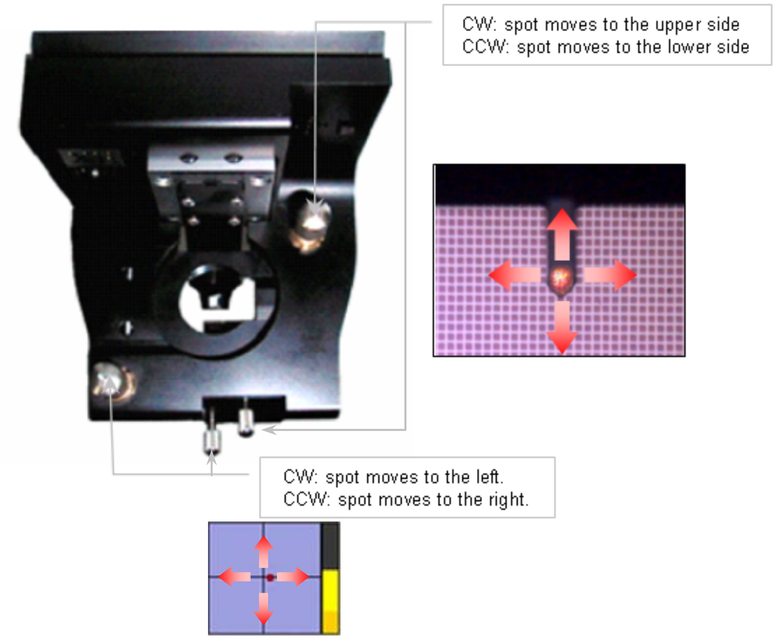
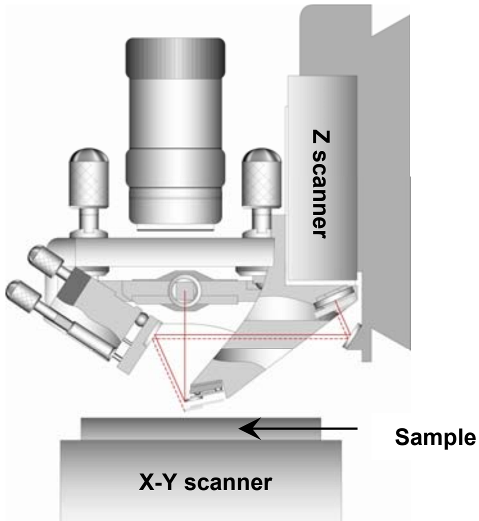


Figure 4-6. Laser beam alignment

Second, place the reflected laser beam on the center of the PSPD as follows.

1. Adjust the steering mirror located on the front side of the head so that the path of the reflected laser beam will reach the PSPD as shown in Figure 4-7. Generally the "A+B" value will be more than 2V when the alignment is optimized (A+B value indicates the total intensity of the laser beam detected by the PSPD. Please refer to Figure 4-7). When the cantilever surface is not coated with metal, the "A+B" value is closer to 1V because of the difference in surface reflectivity. This will be the case with the cantilevers that are provided w ith the XE-150 for contact mode operation.

2. To position the laser beam on the center of the PSPD, adjust the knobs located on the front of the scanner head (Figure 4-6) so that the "A-B" value is smaller than ±0.5V (A-B value indicates the difference in the laser intensity detected in the upper half and the lower half of the PSPD cell). During imaging, this value is related to the deflection of the cantilever. When the above alignment condition is met, the dark red circle will become bright larger one, which will have an increase in the intensity of the small red circle on the PSPD display (Figure 4-7).



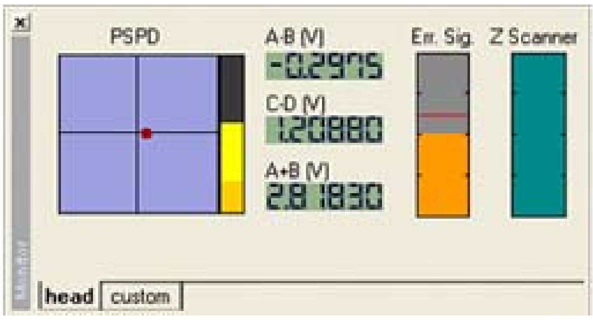


Figure 4-7. XEP laser alignment display

3. Even if the "A-B" value is within the acceptable range, if the "A+B" value is too small, then it may be difficult for the laser beam to approach the center of the PSPD. A proper "A+B" value should be acquired first before adjusting the "A-B" value. If the "A+B" value is too small and cannot be adjusted to ~2V(~1V for uncoated cantilevers), then the laser beam path depicted in Figure 4-6 is thought not to be optimized. In order to maximize the "A+B" signal, try adjusting each of the mirror positioning knobs on the front of the scanner head one at a time. Adjust one of the knobs until a peak in the "A+B" value is observed, and then follow the same process with the other knob. Try fine tuning these knobs individually, until the "A+B" value increases to the appropriate range. If this procedure does not work, other trouble shooting steps may be required. Using an object which shows a laser beam very brightly - like a piece of paper - check to make sure that the laser beam being reflected from the cantilever strikes the fixed mirror, located in the rear of the head, after it passes through the hole in

the center of the probe arm. If you cannot locate the laser beam properly with maximum turns of the mirror adjusting knobs, it may be that either the cantilever is not properly placed, or the cantilever arm is broken. If the cantilever is broken, you can easily see this on the video monitor. In this case, you should exchange the broken cantilever for a new one. Even if the cantilever is not broken, it is still a good idea to try another cantilever before proceeding to troubleshoot other potential alignment problem sources. Also, ensure that the cantilever chip is properly mounted at the end of the scanner arm and is being firmly held in place with the backside of the cantilever facing upwards.

4-7. Sample Loading

XE-150 is fabricated so that even large size sample (up to 150mm×150mm) can be investigated with enhanced images. To satisfy this, XE-150's X-Y scanner is different from XE-150's, which is usually used for smaller samples. Thus, the sample loading procedure for XE-150 is divided into two cases, for large and for small samples, as follows.

1. First, raise the head and the Focus stage high enough for you to have no difficulties in loading the sample onto the magnetic holder or the X-Y scanner.

CAUTION!

If the head and the Focus stage are not rasied high enough, the sample or the cantilever may be damaged.

2-1. If the sample is a larger one, such as wafer (XE-150 is ideal for standardized 2-, 4-, and 6-inch wafers usually used in manufacturing processes), remove the magnetic sample holder and position the wafer on the X-Y scanner using three bearings (see Figure 4-8). To firmly fix this large sample, evacuate the vacuum line, which is connected from the X-Y stage to the vacuum pump.

2-2. If the sample is very small, fix the sample on the sample disk using glues and then place the sample disk on the magnetic sample holder after fixing the magnetic sample holder to the X-Y scanner. (see figure 4-8)

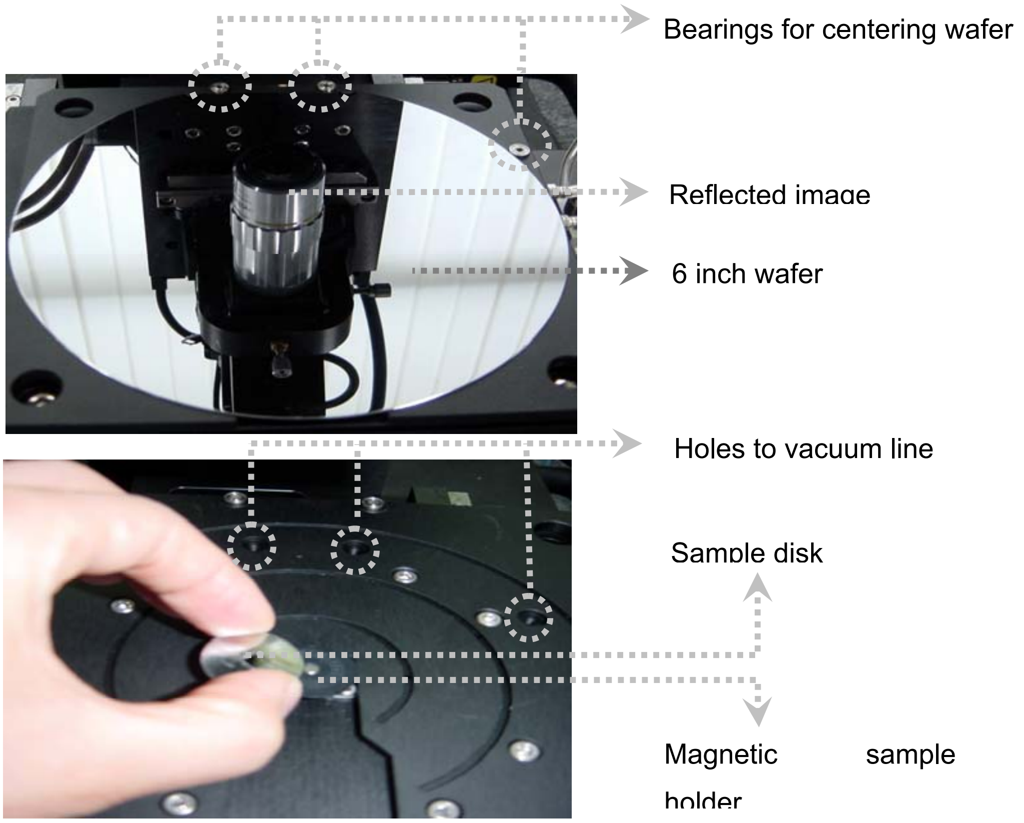


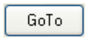
Figure 4-8. (a) Centering sample(wafer) on X-Y scanner using three bearings (b) Small sample loading on magnetic sample holder

4-8. Measurement Procedure

Here we make an assumption that the X-Y, Z scanner is set to use high voltage mode. Once you are ready to proceed, images may be obtained by following the procedures below.

1. When all of the preliminary steps, including the laser alignment and the sample preparation, are completed, open the “X-Y stage control window” by clicking the “X-Y stage control bar” button .
2. Move the XE head using the X-Y stage pad to your interesting region on a sample surface: position the cursor on any place in the X-Y stage pad that relates to the direction you want the head to move. The speed of the X-Y

stage depends on how far point the cursor from the center of the X-Y stage pad. To go fast, click and hold the cursor far from the center which has zero velocity, and to go slow, click and hold the cursor close to the center.

3. Also, you can make the XE head move to a defined location using “GoTo” control box. When click the “GoTo” button, 

, you can open the “GoTo” control box as shown Figure 4-9. After select a defined location from the “GoTo” list box or enter the coordinates X and Y, click “GoTo” button. Please refer to the software manual for XEP for more detailed information about this “GoTo” control box.

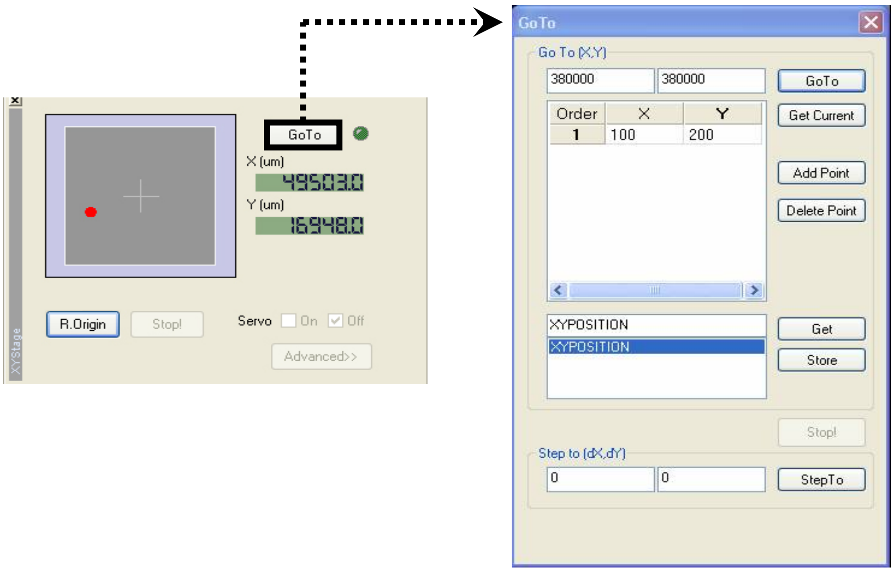


Figure 4-9. XY stage control window and “GoTo” control box

4. After placing the tip to the sample surface you want to get images, open the “Motor control window” by clicking the “motor control bar” button  to perform the Approach. (Usually, the Motor control window is automatically selected on the screen)

5. Place and click the cursor at the lower part of the Z stage pad to position the cantilever roughly close to the sample surface (within 1cm). Like X-Y stage pad, the speed of the Z stage movement is controlled by the location of the pointer on the Z stage pad when clicked. The speed will be adjusted based upon the distance between the pointer and the mid-line indicated on

the Z stage button.

WARNING!

If the Z stage is lowered too fast, the cantilever may "crash" into the sample surface. Such a forceful interaction may break the probe tip, damage or destroy the sample, and/or seriously have a harmful effect on the Z scanner.

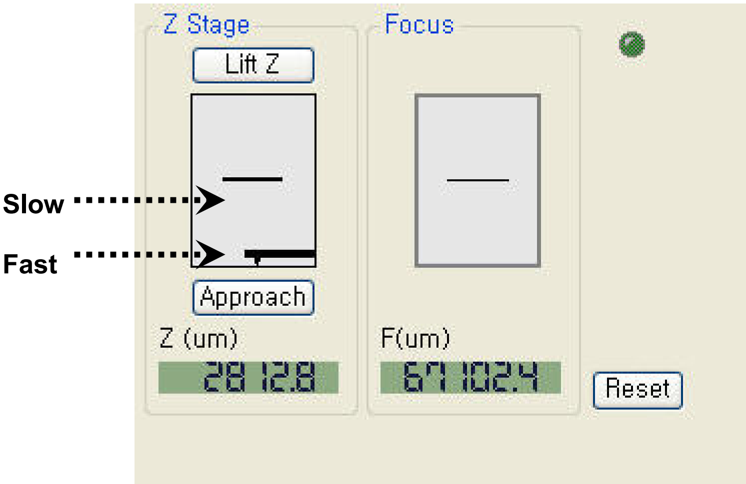


Figure 4-10. Motor control window

6. Focus on a sample surface by pointing the appropriate downside-area of the Focus stage pad. The top half of the button will adjust the focus upward, while the lower half will adjust it downward.

CAUTION!

If the cantilever is too far from the sample surface, it may be very difficult to adjust the focus. In this case, bring the cantilever closer to the surface by clicking the Z stage pad button.

7. If the sample surface is well-focused, slowly lower the Z stage until the shape of the cantilever starts to show faintly on the video monitor.

CAUTION!

When lowering the cantilever, do so very slowly to avoid a potential collision with the sample.

8. Click the “Approach” button  to perform an Auto approach. All possible software selections will be restricted until the completion of a system controlled tip approach except for the “Stop” button .

NOTE!

It might take a long time to complete the Approach process, because the Z stage moves only a few microns per step. Therefore, to minimize the time required to complete a tip approach, the cantilever should first be brought very close to a sample surface. In order to decrease the approach time, become familiar with process 5~7, and practise using the optical microscope to bring the probe very close to the sample surface.

9. After an Auto approach is completed, several parameters should be adjusted in the Scan Control window to get high quality images.

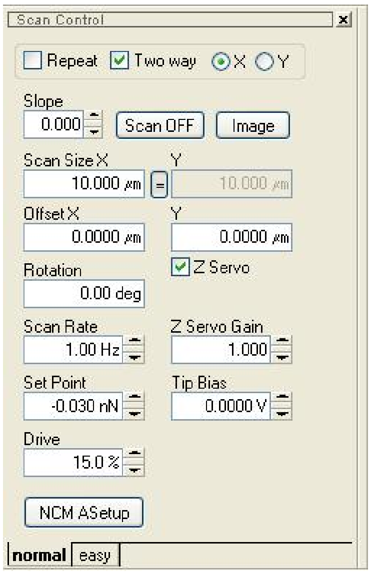
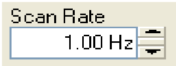


Figure 4-11. Scan Control Window

10. Enter the one dimensional value for the sample "Scan Size"

11. Choose a Scan Rate in the range of 0.5~10Hz (The Hz unit in the Scan Rate window represents the frequency or how many times per second the scanner moves in the fast scan direction.)



12. As shown in Figure 4-12, adjust the Z Servo Gain in order to stabilize the line trace. Increase or decrease the gain, as necessary, until the line trace is repeatable and there are no oscillations present.

13. Once the line trace is stabilized, set the scan direction to "X" or "Y" and then click the Image button 

. Now the measurement will begin.

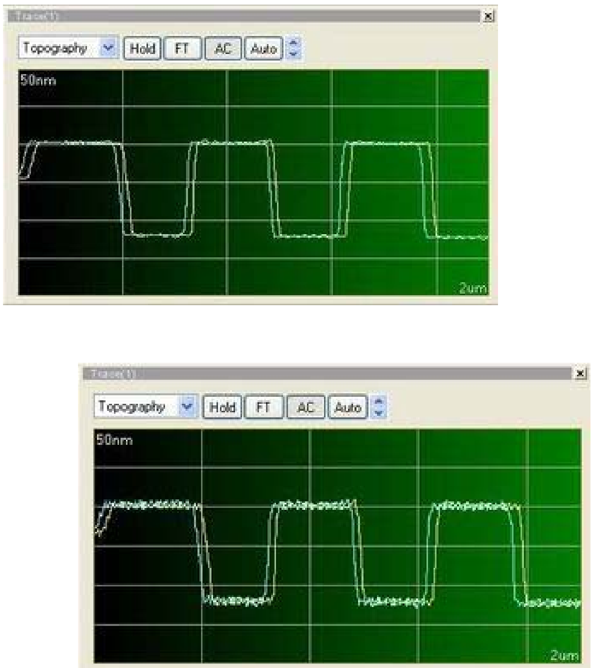


Figure 4-12. Servo gain at the proper level (top). Servo gain too high, resulting in oscillations of the Z scanner (bottom)

4-9. Scan parameter Definitions

The definition of the parameters in the Scan control window is explained below:

- **Repeat**: After selecting "Image", The same area will be imaged repeatedly.
- **Two way**: Successive images will be acquired by alternating the slow scan direction.
- **X,Y**: The fast scan direction can be chosen to be either the X or Y axis.
- **Slope**: The slope of the tip/sample interaction can be adjusted by software.
- **Scan OFF**: The X-Y scanner is stopped while the Z scanner continues to operate and maintain feedback conditions.
- **Offset X, Y**: Specifies the center of the scan area in a relative coordinate system with (0,0) being the center of the X-Y scanner.
- **Rotation**: Allows the direction of scanning to be changed within the range of –45˚~＋45˚.
- **Z Servo**: Select Z scanner feedback on/off
- **Z Servo Gain**: Controls the sensitivity of the Z scanner feedback loop. If this value is too high, the Z scanner will oscillate, producing noise in the image or line scan. If it is too small, then the AFM probe will not track the sample surface properly.
- **Set point**: In Contact mode, specifies the force that will be applied by the end of the tip to the sample surface when the system is in feedback. In Non-Contact Mode, the absolute value of the set point refers to the distance between the tip and the sample surface, representing the cantilever amplitude change due that is due to attractive forces between the AFM probe and the sample surface
- **Tip Bias**: Controls the voltage applied to the tip when EFM or C-AFM modes are used.

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Chapter 5. Set up Scanner Mode

5-1. XE-150 Scanner Configuration

The XE-150 scanner is separated into an X-Y scanner and a Z scanner instead of the single piezoelectric tube scanner used in most other SPMs. The X-Y scanner moves the sample in horizontal direction for the range you want to image. Simultaneously, the Z scanner moves the cantilever in vertical direction to trace the morphology of the sample. These independent movements of the XY direction and the Z direction are combined to make a three-dimensional image. As a result, the sample topography can be investigated very precisely. The XE-150 can be used over a broad range of scan sizes. The High voltage mode is used to investigate large areas, while the Low voltage mode is commonly used to acquire high resolution images of small scan areas down to atomic scales. This chapter describes how to set up these two modes and their functions.

5-2. Select Scanner Mode

When selecting between High and Low voltage mode, it is important to consider several factors including the surface's roughness, structure fluctuation, and the size of the scan area. The proper mode selection will allow you to acquire the best image. Although the High voltage mode is most commonly used, the Low voltage mode should be used in cases where you want to investigate a very small area, a very smooth surface, or possibly atomic level structure.

You can change both modes by following this procedure: you should select High or Low in the XY voltage mode and/or the Z voltage mode

1. Turn off the laser by clicking the Laser On/Off icon  in the Tool bar

2. Open the "XEP Part selection" window by clicking the Select Parts icon  and then select HIGH or LOW.

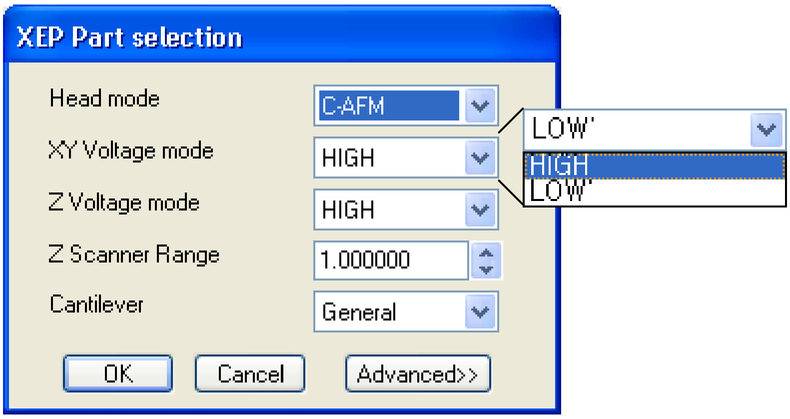


Figure 5-1. Selection of Scanner mode

5-2-1. High Voltage Mode

In the High voltage mode, two measurement types, 'Closed Loop' and 'Open Loop', are possible depending on the status of the XY Servoscan. In general, piezoelectric materials display nonlinear behavior in response to an applied voltage (see Figure 1-12). Therefore, the scanner, which is made of a piezoelectric material displays nonlinearity and hysteresis (Refer to Chapter 1). When the scanner's motion range increases, this nonlinearity and hysteresis can be calibrated by means of hardware corrections. In this case, a detector is used to linearize the scanner's motion throughout the user determined X-Y scanner range. You can decide whether or not to use this detector in the XY Servoscan Setup. 'Closed Loop' operation is the case when the XY Servoscan is 'ON'. When in the High voltage Mode, the XY Servoscan is recommended to be 'ON'.

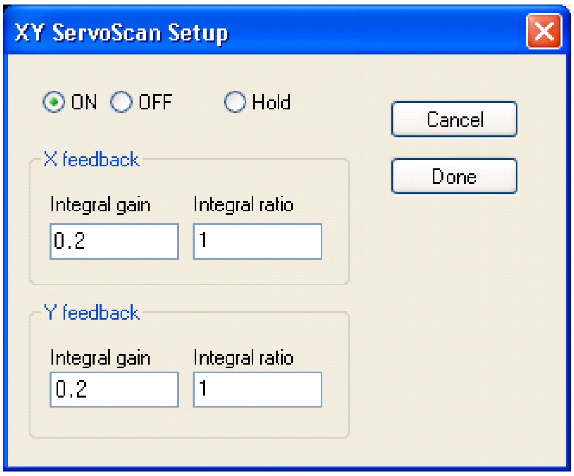


Figure 5-2. XY Servoscan is ON

XE-150 scanners, both X-Y and Z, have a maximum range of movement. In the High Voltage mode, the applied voltage allows the scanner to reach this maximum limit. Figure 5-3 depicts the maximum XY scan range as a solid gray-shaded square. The area outside of this square cannot be observed. For example, if the scanner's maximum range is 50 μm, it is not possible to scan both areas ***A*** and ***C*** even though they have the same scan size (15 μm). Area ***A*** is impossible to scan because its offset (the black point) extends its range over the maximum range of the scanner. Area ***C***, however, is possible to scan. Also, although ***B*** and ***D*** have the same size and the same offset, it is impossible to scan area ***B*** which extends over the maximum range due to its different angle of rotation. Whenever the user enters an "excessive range" like ***A*** and ***B***, the scan range will be changed automatically to an observable area that falls within the scanner's maximum allowable range.

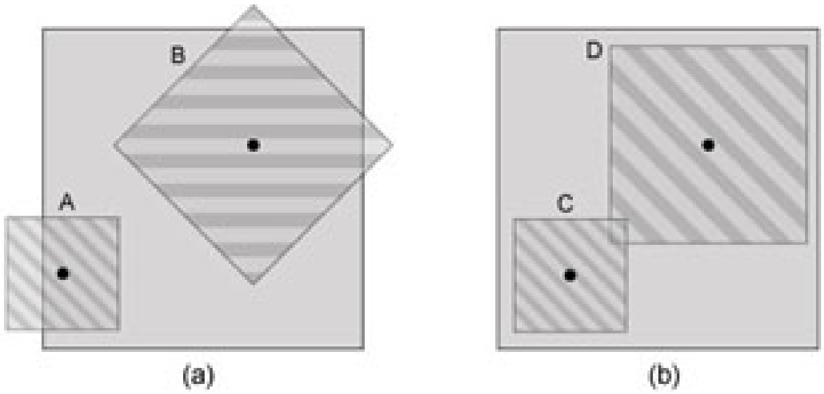


Figure 5-3. Scanner's observable area

5-2-2. Low Voltage Mode

Aside from the High voltage mode, which enables investigation of a wide range of surface structures(from several micrometers to the maximum range the scanner can move), the Low Voltage mode can investigate tiny scales and very fine structure with high resolution. In the Low voltage mode, however, the resolving power increases, but the maximum allowable scan range decreases. For the XE-150, the maximum range of the XY and the Z scanner in the Low voltage mode is reduced to approximately 1/10th and 1/7th respectively of that in the High voltage mode.

In Low voltage mode, the nonlinearity and hysteresis is less than in the High voltage mode because the X-Y scanner's moving distance is much smaller. Furthermore, in this case, the accuracy of the detector itself is inferior to that of the scanner. Therefore, the detector does not have to be used. That is, it is recommended to select XY Servoscan 'OFF' ('Open Loop') when operating in Low voltage mode.

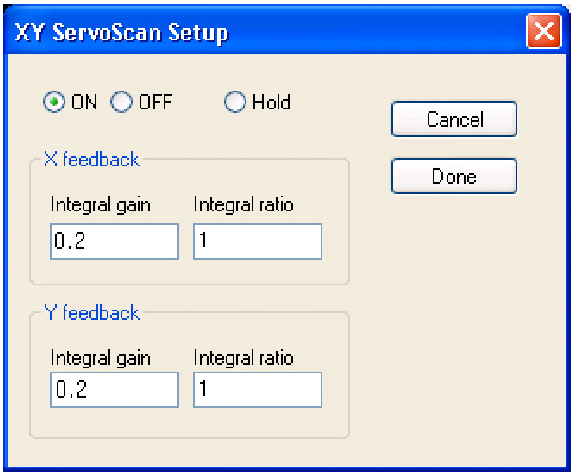


Figure 5-4. XY Servoscan is OFF

The lateral resolution of an image acquired by AFM is calculated by dividing the scan size by the pixel size. If you measure a 10 µm square image with 256 × 256 pixels, the lateral resolution is 10 µm/256 = 39.1 nm. This means the size of one data point in the 10 µm square image is 39.1 nm. Even though you can increase an image's pixel count to get higher lateral resolution, it will take a much longer time to acquire an image. Another solution to get higher resolution data is to decrease the scan size. If you measure a 100 nm image with 256 × 256 pixels, you can get a lateral resolution of 3.91 Å per data point. Therefore, when you want to measure fine structure, it is desirable to reduce the scan size.

Also, the scanner's ability to make an elaborate motion is another factor that influences the lateral resolution. The scanner expands or shrinks in proportion to an applied voltage. Hence, you can manage the scanner's motion more precisely by dividing the applied voltage into smaller units in the DAC (digital-to-analog converter). This is effectively done by operating in Low voltage mode.

The XE-150 system uses a 16-bit DAC for controlling scan movement in X and in Y. A 12-bit DAC is used for determining offset and scale so that the scanner's motion and position can be controlled to a maximum of 2^{28} bits. When an applied voltage that can make the Scanner move 50µm is controlled using a simple 16-bit DAC, the lateral resolution is 50 µm / 2^{16} = 7.6 Å. As mentioned above, the High voltage mode will parse the allowable 16 bits over the scanner's maximum range. On the other hand, in Low voltage mode, the scanner's maximum motion is limited, and the 16-bit DAC is then applied to a much smaller range thus offering higher lateral resolution. This principle can be carried over to the macro-scale for easier interpretation. For example, in measuring a distance of 10cm, a 50cm ruler would make an adequate measurement. To measure a 1cm distance, however, a 5cm ruler would be more sensible. The XE-150's X-Y scanner ratio of high voltage to low voltage is set to 1/10th. Therefore, the X-Y scanner's lateral resolution can be improved by a factor of 10 (5 μm / 2^{16} = 0.76Å resolution in Low Voltage mode). Thus, Low voltage mode can provide more detailed and better control than the High voltage mode.

5-2-3. Z scanner Range

The resolution of the Z scanner can be adjusted by limiting the Z scanner's motion range in addition to selecting between the High and Low voltage mode.

You can regard the number entered in the text box labeled Z scanner Range as a proportionality factor related to the Z scanner's maximum movable range in the user selected mode (High or Low voltage). Basically, if the Z scanner Range is 1.0, then the Z scanner can move through a 12μm range in the High Voltage Mode and a 1.7μm range in the Low Voltage mode. However, if the Z scanner Range is 0.5, then the Z scanner's maximum movable range would be reduced to 6μm and 0.85μm in the High and Low voltage mode, respectively. This adjustment that effectively reduces the Z-scanner's maximum range results in an increase in vertical resolution. The vertical resolution, which is 1.8Å in the High voltage mode and 0.25Å in the Low voltage mode will be improved to 0.9Å and 0.125Å respectively when the Z scanner range is set to 0.5. To use the Z scanner Range feature effectively, you should consider two points: the z-scanner's available maximum range and the vertical resolution. Before adjusting the Z scanner Range, one must first consider the overall height variation of the sample surface. Of course, this height difference should not be greater than the Z scanner's maximum available range. For example, if a sample has 3μm height difference, it cannot be measured in the Low voltage mode since the Z scanner's maximum range will be only 1.7μm. Secondly, the smallest height difference on the sample surface should be greater than the vertical resolution. For example, it is not possible to distinguish atomic scale steps with height differences of 1Å in the High Voltage mode which has a vertical resolution of 1.8Å. Therefore, you should change to Low voltage mode. Also, changing the Z scanner Range from 1.0 to 0.5 will produce even better vertical resolution. If the Z scanner Range is set to 0.5, the height of 1Å would be indicated by eight 0.125Å scaled pixels. When the Z scanner Range is set at 1.0, however, a 1Å step would be indicated by only four 0. 25Å scaled pixels.

Chapter 6. AFM in Contact Mode

6-1. Principle of Contact Mode AFM

The AFM (Atomic Force Microscope) is an instrument that is used to study the surface structure of a sample by measuring the force between atoms.

At the lower end of the Z scanner, there is a cantilever of very tiny dimensions: 100 μm long, 10 μm wide and 1 μm thick, which is manufactured by means of micro-machining techniques. At the free end of the cantilever, there is a very sharp cone-shaped or pyramid-shaped tip. As the distance between the atoms at this tip and the atoms on the surface of the sample becomes shorter, these two sets of atoms will interact with each other. As shown in Figure 6-1, when the distance between the tip and the surface atoms becomes very short, the interaction force is repulsive due to electrostatic repulsion, and when the distance gets relatively longer, the interatomic force becomes attractive due to the long-range van der Waals forces.

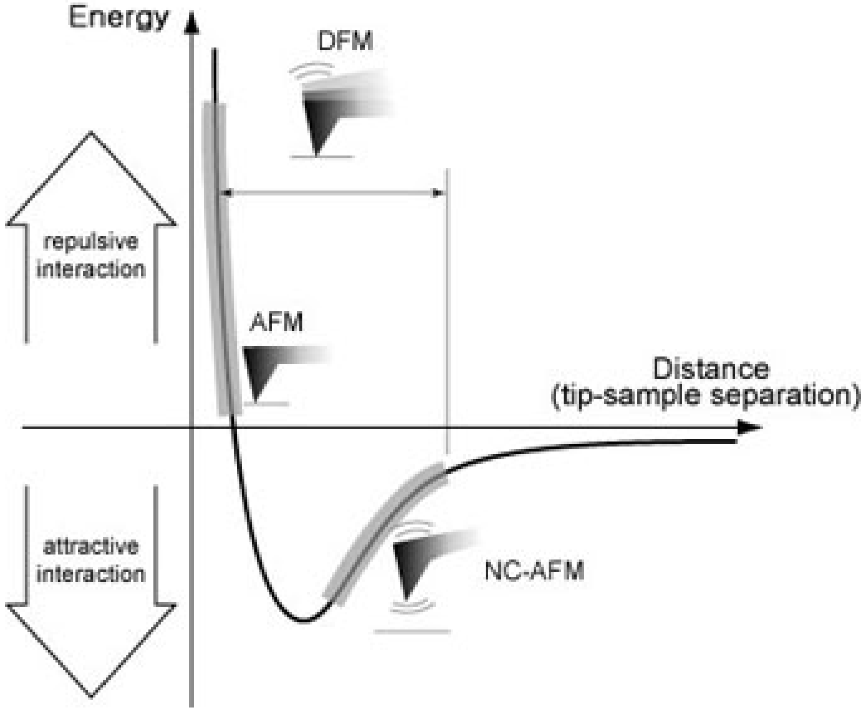


Figure 6-1. Relation between the force and the distance between atoms

This interatomic force between atoms can bend or deflect the cantilever, and the amount of the deflection will cause a change in the reflection angle of the laser beam that is bounced off the upper surface of the cantilever. This change in laser path will in turn be detected by the PSPD (Position Sensitive Photo Detector), thus enabling the computer to generate a map of the surface topography

In contact mode AFM the probe makes "soft contact" with the sample surface, and the study of the sample's topography is then conducted by utilizing the repulsive force that is exerted vertically between the sample and the probe tip. Even though the interatomic repulsive force in this case is merely 1~10 nN, the spring constant of the cantilever is also sufficiently small (less than 1 N/m), thus allowing the cantilever to react very sensitively to very minute forces. The AFM is able to detect even the slightest amount of a cantilever's deflection as it moves across a sample surface. Therefore, when the cantilever scans a convex area (凸)of a sample, it will deflect upward, and when it scans a concave area (凹), it will deflect downward. This probe deflection will be used as a feedback loop input that is sent to an actuator (z-piezo). In order to produce an image of the surface topography, the z-piezo will maintain the same cantilever deflection by keeping a constant distance between the probe and the sample.

6-2. Contact mode setup

To use contact mode AFM, select the appropriate Head mode as follows:

1. Turn off the laser by clicking the "Laser On/Off " button in the Tool bar.
2. Once the laser is off, set the Head mode to C-AFM after clicking the "Select Parts" button .
3. Turn on the laser by clicking the "Laser On/Off" button .

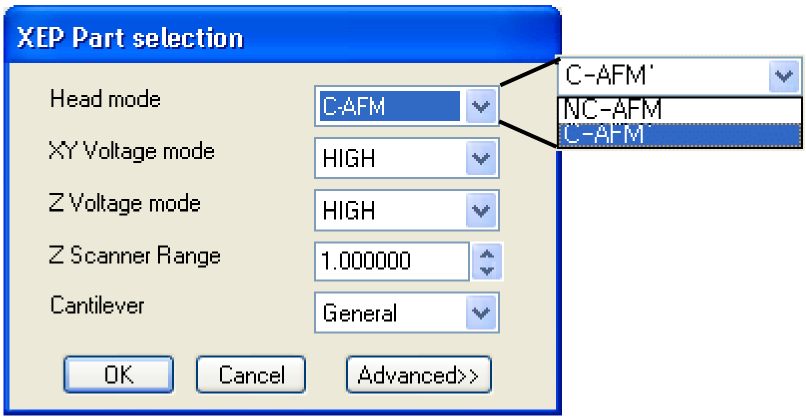


Figure 6-2. Contact mode AFM setup

6-3. Cantilever Selection

Selecting the appropriate probe is a critical aspect of using AFM. Choosing a probe means determining the combination of a tip, which interacts with sample surface atoms, and a cantilever, which deflects depending on the interatomic forces and quantifies the deflection. Generally, the upper surface of a cantilever is coated with a metal such as gold (Au) or aluminum (Al). This coating, which enhances the surfaces reflectivity, has a thickness of about 1000 Å. There are several types of cantilevers that vary in material, shape, softness (represented by the spring constant), intrinsic frequency, and Q-factor. The type of cantilever selected is primarily determined by the measurement mode. As mentioned in Chapter 3, a "soft" cantilever is used for contact mode AFM. Typically, such cantilevers are made of silicon and have a spring constant less than 1~3 N/m. With such a low spring constant, the contact mode cantilever is sensitive to extremely small forces, and it will bend more significantly than a cantilever with a higher spring constant when exposed to an equal force. This allows the AFM to depict even extremely tiny structures.

Figure 6-3 shows the SEM image of a cantilever commonly used for contact mode, the NSC36 series. To improve the laser beam reflectivity, the upper surface of the cantilever (the opposite side of the tip) is coated with aluminum.

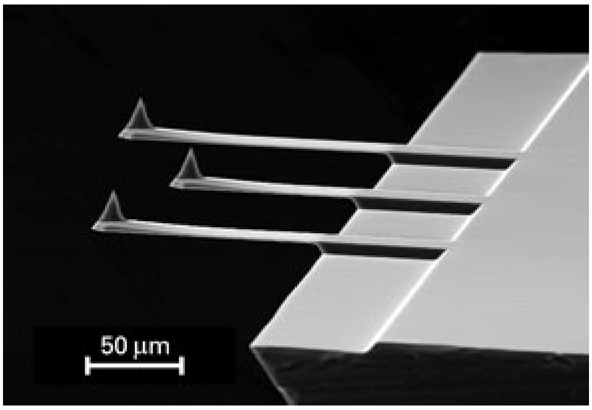


Figure 6-3. SEM image of the shorter cantilevers (A, B, C) from a chip of the NSC36 series

Figure 6-4 shows the detailed standardized gauge of the NSC36 series chip. Altogether, this chip contains six cantilevers, three to a side, all with different spring constants. Among these, the three cantilevers on one side become non-functional during the process of affixing them to the cantilever chip. Thus only the three on the other side are usable, e.g. A,B,C in Figure 6-4. If the unmounted cantilevers are purchased separately, you may choose either set of cantilevers A,B,C or D,E,F.

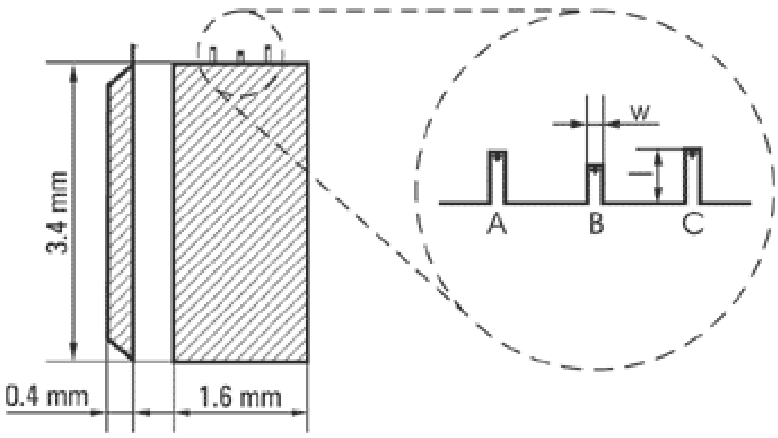


Figure 6-4. Silicon chip of the NSC36 series has 3 rectangular cantilevers.

Table 6-1 gives the dimensions and characteristics of the six cantilevers in the NSC36 series.

Table 6-1. Specifications of NSC36 Series Cantilevers

Cantilever Type	A			B			C		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
Length, l±5, μm		110			90			130	
width, w±3, μm		35			35			35	
Thickness, μm	0.7	1	1.3	0.7	1	1.3	0.7	1	1.3
Resonant frequency, kHz	65	105	150	95	155	230	50	75	105
Force constant, N/m	0.25	0.95	2.5	0.45	1.75	5	0.15	0.6	1.5

6-4. Scanner Setup

Depending on the roughness of the sample or the measurement range, it is necessary to select either the High voltage mode or the Low voltage mode.

In general, High voltage mode is selected(Figure 6-5), but when measuring small areas, or when imaging samples with a low degree of roughness, switching to the Low voltage mode may produce a higher resolution image.

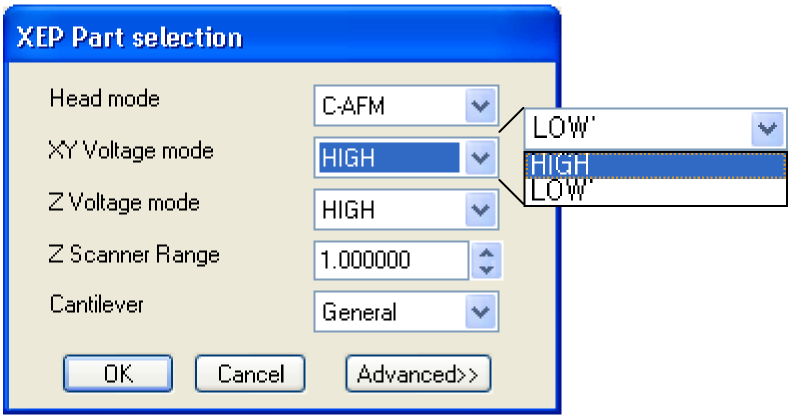


Figure 6-5. Contact AFM setup and voltage mode selection

To change the voltage mode, as is the case with a change to contact mode, click the Select Parts icon  to open the "XEP part selection" menu as shown above, and choose "High" or "Low" in the "XY voltage mode" and/or the "Z voltage mode".

6-5. Measurement Procedure

The measurement procedure hereafter is the same as in Chapter 4. Please review Chapter 4.

Chapter 7. Lateral Force Microscopy (LFM)

7-1. Principle of Lateral Force Microscopy (LFM)

The principle of Lateral Force Microscopy (LFM) is very similar to that of Contact mode AFM. Whereas in contact mode we measure the deflection of the cantilever in the vertical direction to gather sample surface information, in LFM we measure the deflection of the cantilever in the horizontal direction. The lateral deflection of the cantilever is a result of the force applied to the cantilever when it moves horizontally across the sample surface, and the magnitude of this deflection is determined by the frictional coefficient, the topography of the sample surface, the direction of the cantilever movement, and the cantilever's lateral spring constant. Lateral Force Microscopy is very useful for studying a sample whose surface consists of inhomogeneous compounds. It is also used to enhance contrast at the edge of an abruptly changing slope of a sample surface, or at a boundary between different compounds.

Since the LFM measures the cantilever movement in the horizontal direction as well as the vertical one to quantitatively indicate the surface friction between the probe tip and the sample, it uses a PSPD (position sensitive photo detector) that consists of four domains (quad-cell), as shown in Figure 7-1.

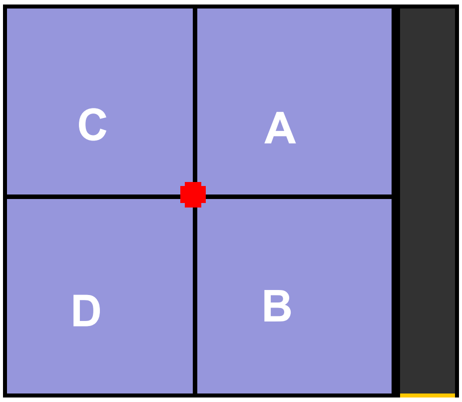


Figure 7-1. Quad-cell PSPD

Generally, in AFM, to measure the topography of a sample surface, the "A-B" signal is used. This signal is related to the difference between the upper cells (A+C) and the lower cells (B+D) of the PSPD.

Topographic information = (A+C)-(B+D)

The LFM signal, which is related to the change in the surface friction on a sample surface, measures the deflection of the cantilever in the horizontal direction and can be represented as the difference in the signals recorded in the right cells (A+B) and the left cells (C+D).

Frictional information = (A+B) – (C+D)

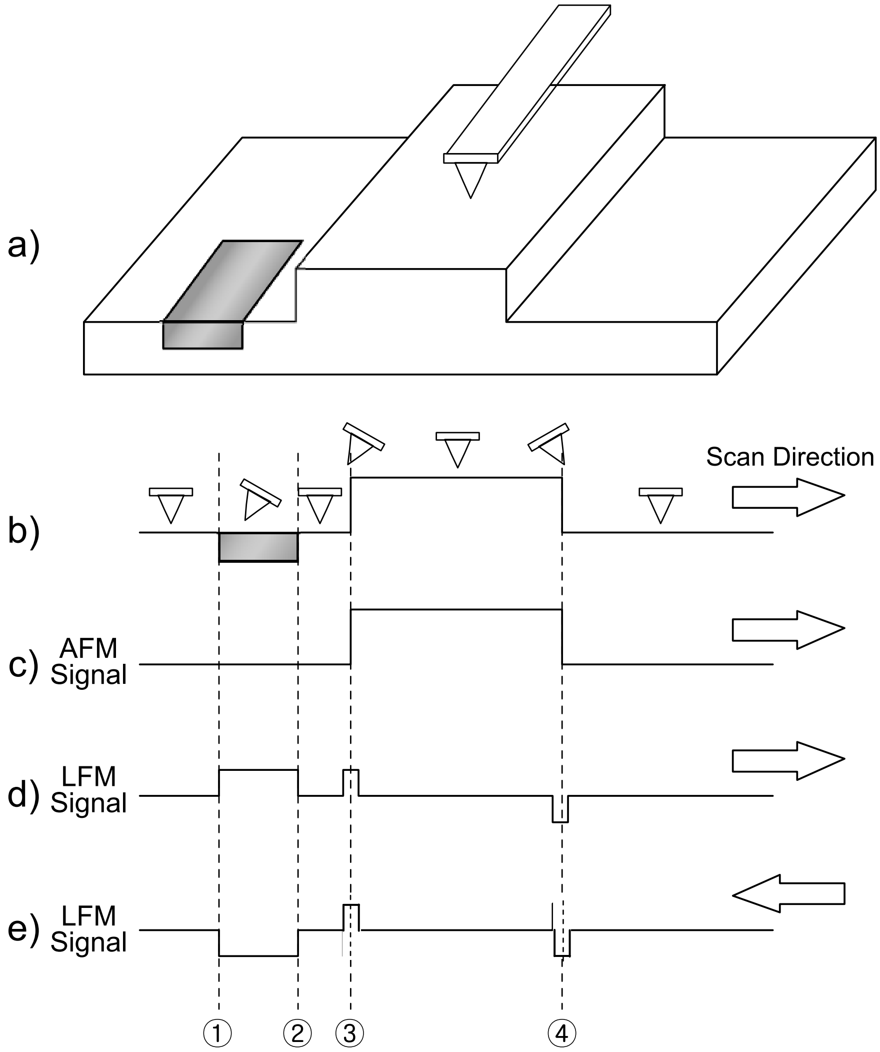


Figure 7-2. AFM and LFM signal

Figure 7-2 (a) shows a surface structure with a centrally located step with low, smooth areas on either side. The flat part on the left contains a domain with a relatively high frictional coefficient. **Profile b** indicates the cantilever's deflection as it encounters topographic features as well as different frictional coefficients as it scans from left to right. **Profile c** is an AFM image of the surface topography and structure; it is represented by the change in the vertical deflection of the cantilever which does not include the horizontal deflection. **Profile d** and **Profile e** show the LFM signal which indicates the horizontal deflection of the cantilever. When scanning left-to-right, the surface structure of a sudden peak will instantaneously twist the cantilever to the right. This results in a lateral force signal with a convex shape as seen in Figure 7-2 (d) ③. The opposite occurs when the probe encounters a sudden downward step as depicted at location ④. The region between ① and ② indicates an area on the sample surface where there is a material with a higher surface frictional coefficient compared to the surrounding area. There are no distinguishable surface features that will allow the user to differentiate this region utilizing the topography signal. Even though the topographical information is the same between ① and ②, there will be a conspicuous difference noticeable in the LFM signal. When the cantilever scans this area from left to right, an increase in relative friction will cause it to tilt to the right, thus producing an increase in the LFM signal.

Figure 7-2 (e) shows the LFM signal when the scan direction is reversed. If the cantilever scans direction as indicated by the arrow, there will be no change in the LFM signal at region ③ and ④ which are related to the topographic features of the sample surface. However, when the scan direction is reversed, the cantilever will now tilt to the left in the area where the frictional coefficient between ① and ② is larger, yielding a decrease in the LFM signal in this area.

Considering the simple comparison described above, the LFM result contains the surface frictional information as well as the surface topographical information.

Hence, when you analyze the result of the LFM measurement, it is necessary to distinguish the information due to difference in the frictional coefficient from the information due to the change in the sample surface topography by taking the AFM image into account.

7-2. Conversion to LFM

As mentioned above, since lateral force mode is an extension of contact mode, the Head Mode will be set to "contact mode".

1. Turn off the laser switch by clicking the "Laser On/Off " button  in the Tool bar.

2. Once the laser is off, set the Head mode to C-AFM by clicking the "Select Parts" button .

3. Turn on the laser by clicking the "Laser On/Off" .

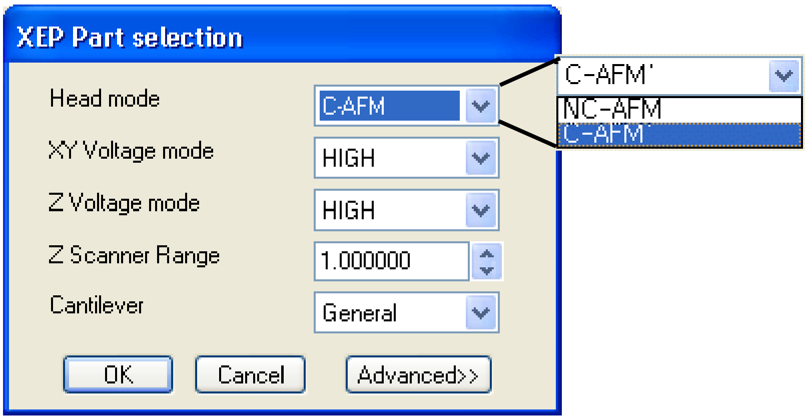


Figure 7-3. Conversion to LFM

7-3. Cantilever Selection

The Lateral Force Microscope (LFM) measures the horizontal cantilever deflection under the same conditions as the contact AFM. Therefore, LFM uses the same type of cantilever as is used for contact AFM. Please refer to Chapter 6, section 3 “Cantilever selection” in contact mode.

7-4. Measurement Procedure

You can obtain an LFM image and a topography image simultaneously when you measure in contact mode. If you press the ”Input Config” button , the “Input Configuration” window will appear as shown below. Here the selections with  will be recorded. If you select ‘Lateral Force’, you can measure in LFM. If ‘Lateral Force’ does not appear, press the “Setup” 

button which will open the “Select Input” window. There you can choose ‘Lateral Force”. Also, LPF, Data processing(AC Track and Auto Flat) and Scan Directions(forward and/or backward) should be selected considering sample’s topographic situation. How to set them is recommended to consult to the software manual for XEP.

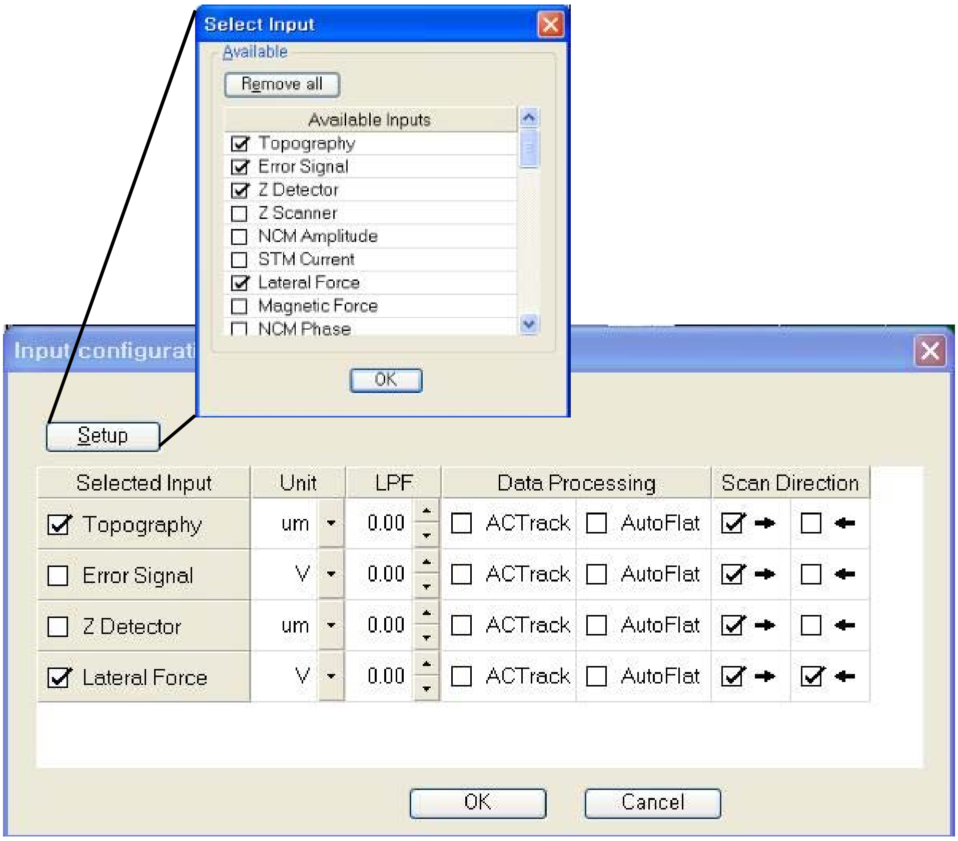


Figure 7-4. Setup for LFM mode

The procedure to measure in lateral force mode is the same as that for contact mode. The measurement method hereafter is the same as in Chapter 4. Please refer to Chapter 4.

Chapter 8. AFM in Non-Contact Mode

8-1. Principle of Non-contact Mode AFM

There are two major forces, the static electric repulsive force and attractive force, existing between atoms a short distance apart: The static electric repulsive forces (F_{ion}) between ion cores and the static electric attractive forces (F_{el}) between valence electrons and ion cores. When the distance between the atoms at the end of the probe tip and the atoms on the sample surface becomes much shorter, the repulsive forces between them become dominant, and the force change due to the distance change becomes greater and greater. Therefore, contact AFM measures surface topography by utilizing the system's sensitive response to the Repulsive Coulomb Interactions that exist between the ion cores when the distance between the probe tip and the sample surface atoms is very small. However, as shown in Figure 8-1, when the distance between the probe tip and the sample atoms is relatively large, the attractive force F_{el} becomes dominant. Ion cores become electric dipoles due to the valence electrons in the other atoms, and the force induced by the dipole-dipole interaction is the van der Waals Force. Non-contact AFM (NC-AFM) measures surface topography by utilizing this attractive atomic force in the relatively larger distance between the tip and a sample surface.

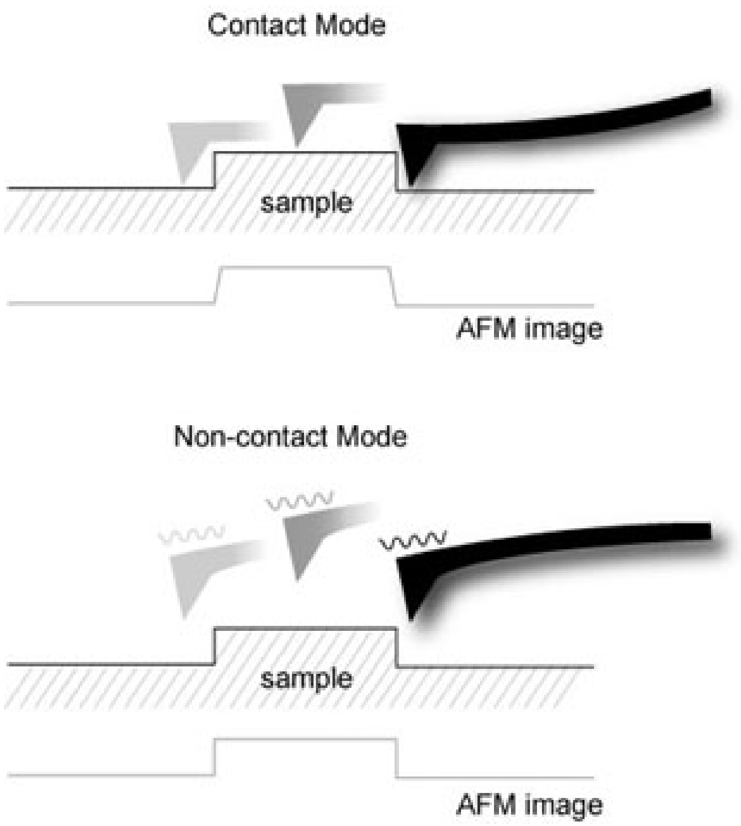


Figure 8-1. Concept diagram of contact mode and non-contact mode

Figure 8-1 compares the movement of the probe tip relative to a sample surface for images being acquired in contact AFM and in non-contact AFM. Contact mode uses the "physical contact" between the probe tip and a sample surface, whereas non-contact AFM does not require this physical contact with the sample. Also, in non-contact AFM, the force between the tip and a sample is very weak so that there is no unexpected change in the sample during the measurement. Therefore, non-contact AFM is very useful for a biological sample or other very soft sample; the tip will also have an extended lifetime because it is not abraded during the scanning process. On the other hand, the force between the tip and a sample in the non-contact regime is very low, and it is not possible to measure the deflection of the cantilever directly. So, non-contact AFM detects the changes in the phase or the vibration amplitude of the cantilever that are induced by the attractive force between the probe tip and a sample while the cantilever is mechanically oscillated near its resonant frequency.

A cantilever used in non-contact AFM typically has a resonant frequency between 100 kHz and 400 kHz with vibration amplitude of a few nanometers. Because of the attractive force between the probe tip and the surface atoms, a cantilever vibration at its resonant frequency near the sample surface experiences a shift in spring constant from its intrinsic spring constant (k_o). This is called the effective spring constant (k_{eff}), and the following equation holds:

$$k_{eff} = k_o - F' \quad (1)$$

When the attractive force is applied, k_{eff} becomes smaller than k_0 since the force gradient F' (=∂F/∂) is positive. Accordingly, the stronger the interaction between the surface and the tip (in other words, the closer the tip is brought to the surface), the smaller the effective spring constant becomes. This alternating current method (AC detection) makes more sensitive responds to the force gradient as opposed to the force itself. Thus, it is also applied in such techniques as MFM (Magnetic Force Microscopy) and DFM (Dynamic Force Microscopy).

A bimorph is used to mechanically vibrate the cantilever. When the bimorph's drive frequency reaches the vicinity of the cantilever's natural/intrinsic vibration frequency (f_0), resonance will take place, and the vibration that is transferred to the cantilever becomes very large. This intrinsic frequency can be detected by measuring and recording the amplitude of the cantilever vibration while scanning the drive frequency of the voltage being applied to the bimorph. Figure 8-2 displays the relationship between the cantilever's amplitude and the vibration frequency. From this output, the cantilever's intrinsic frequency can be determined.

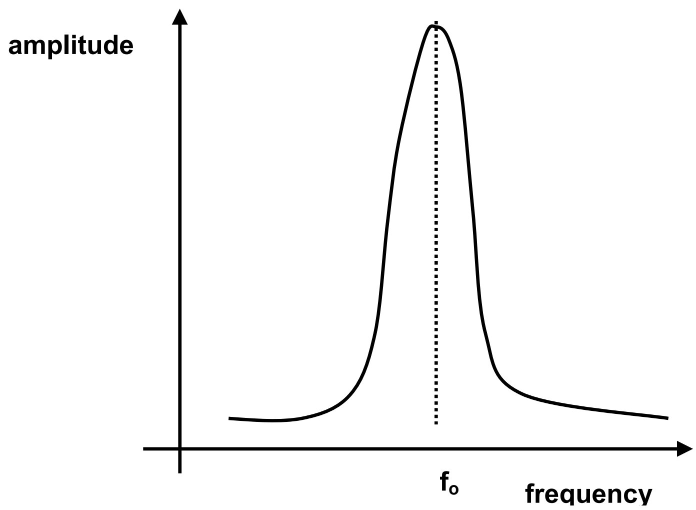


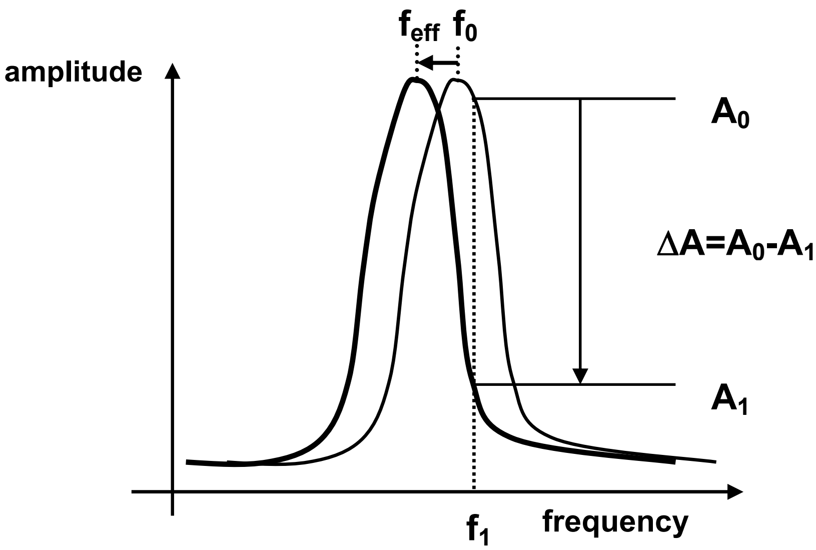
Figure 8-2. Resonant Frequency

On the other hand, the spring constant affects the resonant frequency (f_0) of the cantilever, and the relation between the spring constant (k_0) in free space and the resonant frequency (f_0) is as in Equation (2).

$$f_0 = \sqrt{\frac{k_0}{m}} \quad (2)$$

As in Equation (1), since k_{eff} becomes smaller than k_0 due to the attractive force, f_{eff} too becomes smaller than f_0 as shown in Figure 8-3 (a). On the other hand, if you vibrate the cantilever at the frequency f_1 (a little larger than f_0) where a steep slope is observed in the graph representing free space frequency vs. amplitude, the amplitude change (ΔA) at f_1 becomes very large even with a small change of intrinsic frequency caused by atomic attractions. Therefore, the amplitude change measured in f_1 reflects the distance change (Δd) between the probe tip and the surface atoms.

If the change in the intrinsic frequency resulting from the interaction between the surface atoms and the probe or the amplitude change (ΔA) at a given frequency (f_1) can be measured, the non-contact mode feedback loop will then compensate for the distance change between the tip and the sample surface as shown in Figure 8-3 (b). By maintaining constant cantilever amplitude (A_0) and distance (d_0), non-contact mode can measure the topography of the sample surface by using the feedback mechanism to control the Z scanner movement following the measurement of the force gradient represented in Equation (1).



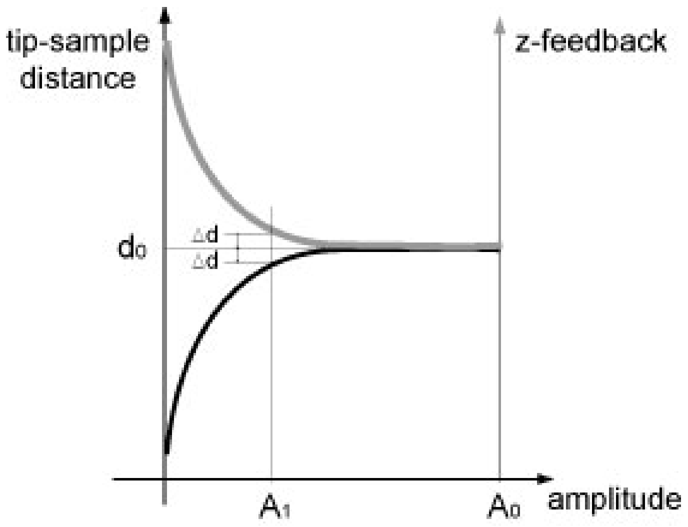


Figure 8-3. (a) Resonant frequency shift (b) Amplitude vs. z-feedback and tip-sample distsance

8-2. Non-contact Mode Setup

The non-contact mode setup can be done easily by selecting NC-AFM as the Head mode, similar to the setup for contact mode explained in Section 2 of Chapter 6.

1. Turn off the laser switch by clicking the "Laser On/Off" button in the Tool bar.
2. Once the laser is off, set the Head mode to NC-AFM by clicking the "Select Parts" button .
3. Turn on the laser by clicking the "Laser On/Off" button .

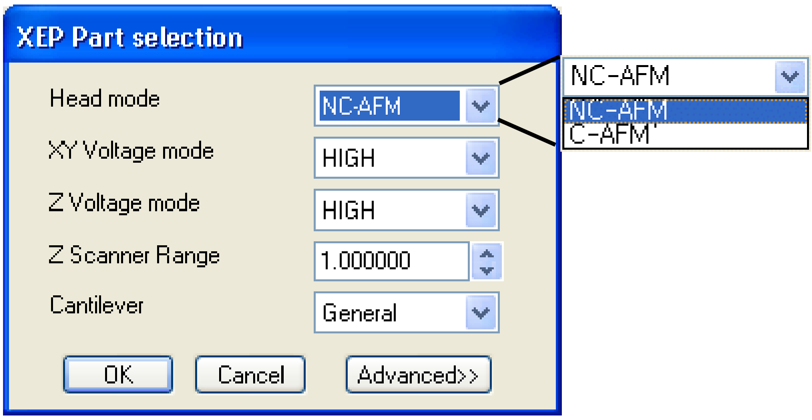


Figure 8-4 Non-contact mode setup

8-3. Resonant Frequency Setup

Once the Head mode is selected as NC-AFM, turn on the laser by clicking the “Laser On/Off” button . The system will then automatically find the resonant frequency. When all selections are completed, click the “OK” button OK.

Besides the method of turning the laser on and off, you can find the resonant frequency for non-contact mode by using the NCM frequency button .

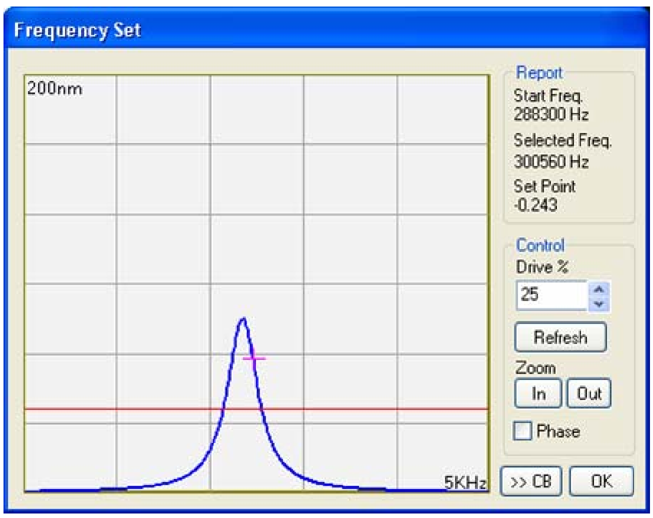


Figure 8-5. Resonant frequency setup in non-contact mode

When the “NCM Frequency Set” window opens, you can manually select the resonance frequency as follows.

1. If the "Refresh" button or Zoom Out button is clicked, one unit on the X-axis represents 5 kHz as shown above.

2. Select the resonance frequency as follows: At first, when press the "Refresh" button, the graph of frequency versus amplitude will appear. While adjusting the drive % (25~0.1) to make the strongest peak fall within the first three units of the y-axis, press the "Refresh" button. After adjusting the height of the peak, press the Zoom In button until the x-axis unit is 1kHz/div.

3. After positioning the mouse pointer on the slope just to the right hand side of the strongest peak (Figure 8-5), click there with the left mouse button and a '+' sign will appear. The location of the '+' sign corresponds to the selected frequency f_1 at which the cantilever will vibrate in non-contact mode. After positioning the mouse pointer on the red horizontal line, move this red line up and down while holding the left mouse button down; this will allow you to change the set point value. In general, make the set point just higher than half of the peak height, and press the "OK" button once to enter the selection.

The value of the drive amplitude(%) and set point value can also be changed in the Scan Control window.

8-4. Cantilever Selection

The non-contact mode cantilever has a relatively large frequency since the non-contact mode uses the vibrating cantilever method which enables to measure the force gradient by the amplitude change and phase change due to the interaction between the probe and a sample surface. Figure 8-6 shown below is a SEM image of a typical non-contact mode cantilever, the NCHR series. The upper surface of the cantilever (the opposite side of the tip) is coated with aluminum (Al) to enhance the laser beam reflectivity.

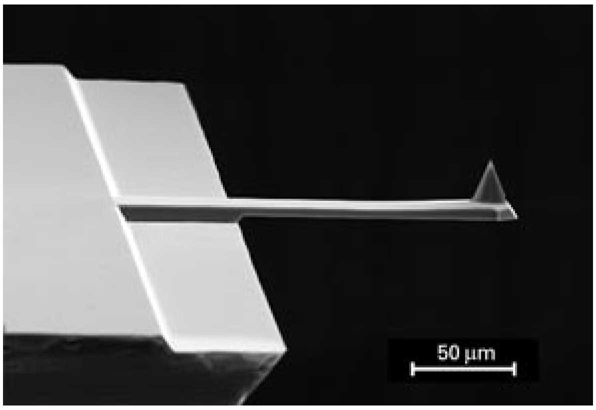


Figure 8-6. SEM image of ULTRASHARP silicon cantilever (the NCHR series)

Figure 8-7 shows the standard dimensions of the NSC15 series chip. The thickness of the chip is 0.4 mm, and a rectangular shaped cantilever is at the end of the chip. Table 8-1 lists the specifications for this cantilever. The non-contact mode cantilever has a thickness of about 4㎛, and the spring constant is very large (40N/m) relative to that of a contact mode cantilever.

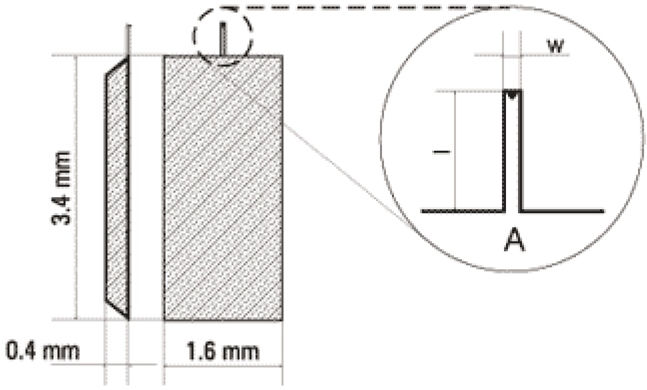


Figure 8-7. Silicon chip of the NCHR series has 1 rectangular cantilever

Table 8-1. Specifications of NCHR series

Cantilever Type	Cantilever Length, l ± 5, μm	Cantilever Width, w ± 3, μm	Cantilever Thickness, μm			Resonant Frequency, kHz			Force Constant, N/m		
			min	typical	max	min	typical	max	min	typical	max
A	125	30	3.0	4.0	5.0	204	330	497	10	42	130

8-5. Scanner Setup

Before measuring a sample surface, select either the High voltage mode or the Low voltage mode, depending on the roughness of the sample and the size of the measurement area.

In general, the High voltage mode is selected, but to measure fine features on samples with a low surface's roughness, the Low voltage mode is used. Changing the voltage mode was already introduced in Chapter 5.

Click the "Select part" button  to open the "XEP part selection" menu as follows, and choose "High" or "Low" for the "XY voltage mode" and for the "Z voltage mode".

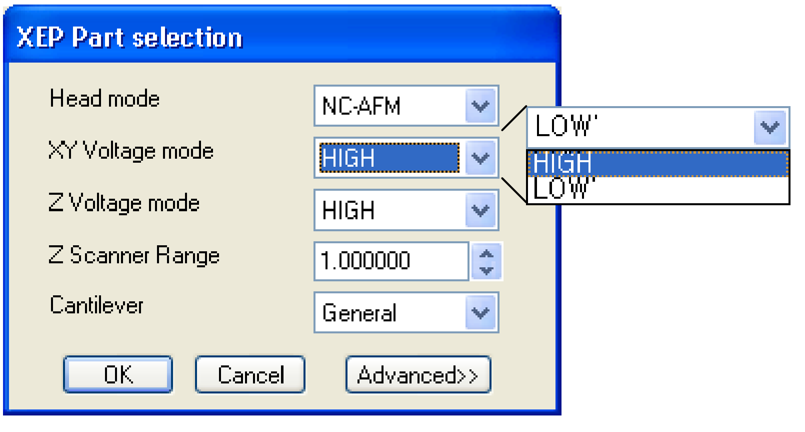


Figure 8-8. Non-contact AFM setup and voltage mode selection

8-6. Measurement Procedure

The measurement method hereafter is the same as in Chapter 4. Please refer to Chapter 4.

Chapter 9. Dynamic Force Microscopy (DFM)

9-1. Principle of Dynamic Force Microscopy

Dynamic Force Microscopy (DFM) is very similar to non-contact mode AFM in many ways such as the applied force and the measurement principle. Before you read this chapter, please read carefully “Chapter 8 AFM in non-contact AFM”.

DFM is a hybrid of the two most fundamental measurement methods, represented by contact mode and non-contact mode. In LFM, the cantilever vibrates in free-space in the vicinity of the resonant frequency like in non-contact mode. At the same time, since the vibrating cantilever gets very close to the sample surface, it taps the surface repeatedly, and the tip “contacts” the sample surface as in contact mode.

If you measure the amplitude of vibration of the cantilever used in DFM while changing the frequency, as shown in Figure 9-1, there appears a special frequency where the amplitude resonates and amplifies greatly. This is called the intrinsic frequency (f_0).

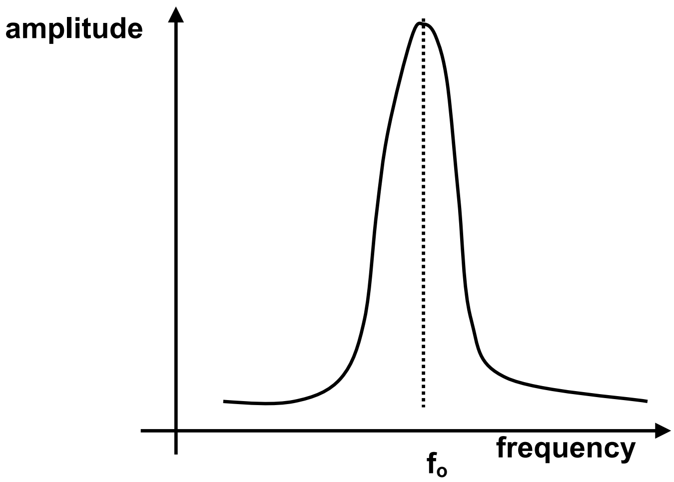


Figure 9-1. Resonant frequency

DFM uses the non-contact mode feedback circuit with keeping the vibrating frequency (f_1) a little bit lower than the resonant frequency while oscillating in free-space. Then, as the tip is lowered, the real spring constant reduces due to the attractive van der Waals force which becomes larger as the tip comes closer to the sample surface, as shown in Figure 9-2 (a). Therefore the resonant frequency changes to effective frequency(f_{eff}) in non-contact regime and the amplitude at the frequency f_1 increases by ΔA. Since the amplitude increases by ΔA, the non-contact mode feedback circuit decreases the distance between the tip and the sample surface by Δd, indicated in the graph of vibration amplitude vs tip-sample distance and z-feedback as shown in Figure 9-2 (b) (This part was explained in detail in Chapter 8, so please refer to Chapter 8, section 1). Therefore, the vibrating cantilever, which is oscillating above the sample, approaches the sample almost in contact or in collision with the surface. This method, keeping intermittent contact between the sample surface and the vibrating cantilever is called Dynamic force microscopy (DFM).

Similar to the initial approach of making contact with the sample, while scanning, larger amplitude reduces the distance between the tip and sample, and smaller amplitude increases the distance depending on the surface roughness to determine the surface topology.

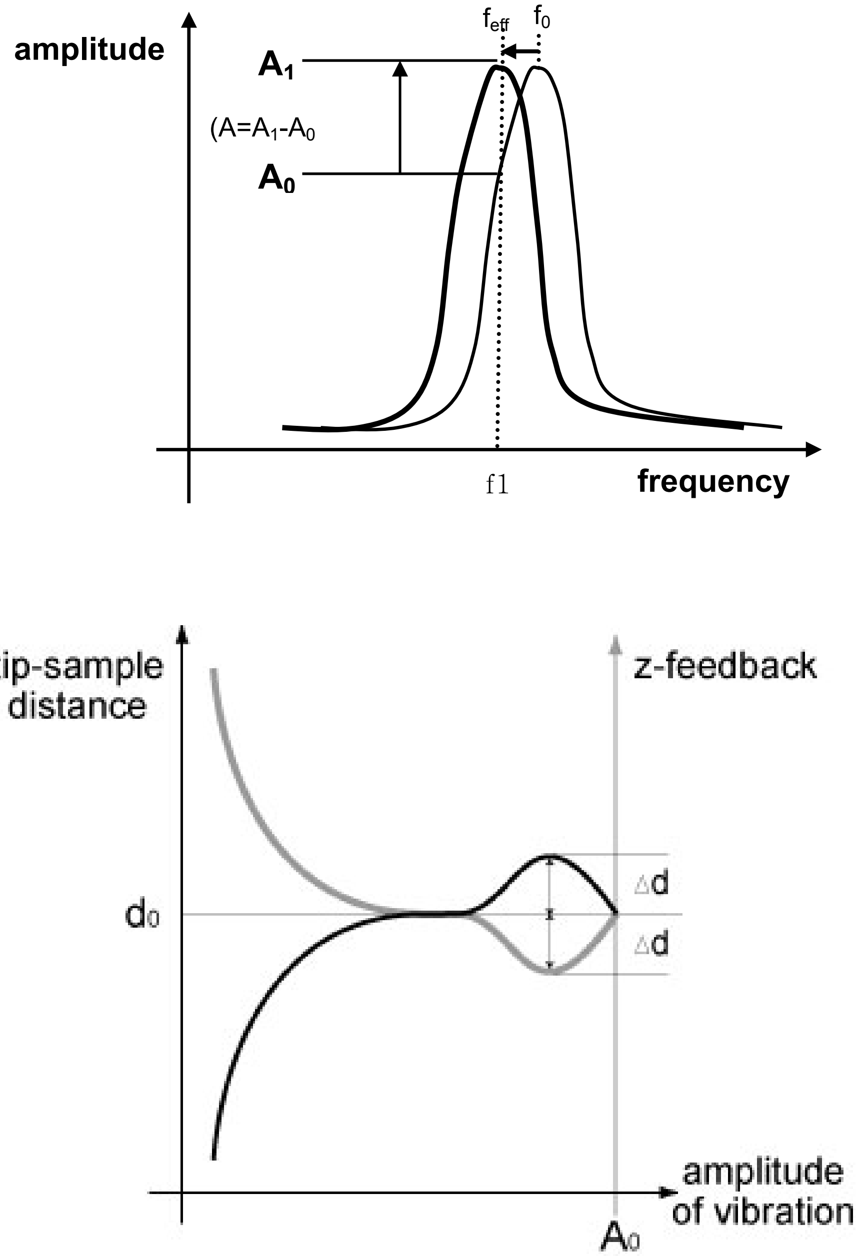


Figure 9-2. (a) Resonant frequency shift (b) Amplitude vs. z-feedback and tip-sample distance

For certain samples, DFM yields better measurements than contact mode or non-contact mode AFM. Dynamic force microscopy (DFM) has an advantage over contact mode in the sense that it will damage the sample less since there is no drag force to pull the sample sideways, frictional or lateral force. Moreover it is more effective than non-contact mode when you measure a sample with relatively rough surface and a large height difference over a large area. The importance and the application of DFM become more significant than before as it overcomes the limit of both contact mode and non-contact mode, while maintaining the merits of both modes.

9-2. Conversion to DFM

In dynamic force microscopy, the Head mode will be set to NC-AFM just as in non-contact mode. However, you must set the resonant frequency 'manually' because DFM uses a different measurement principle than NC-AFM.

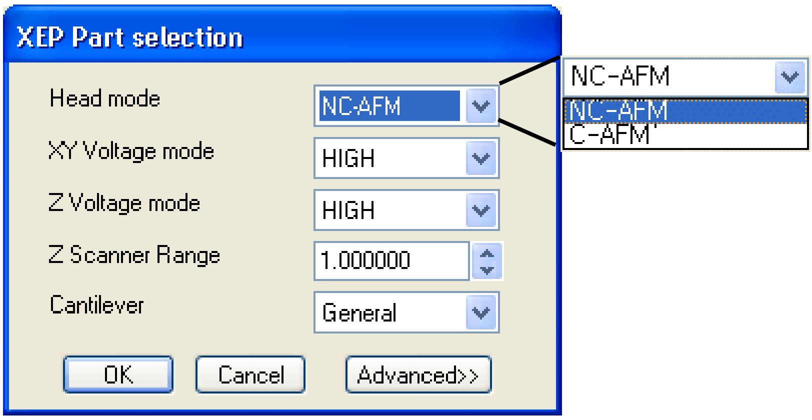


Figure 9-3. Conversion to DFM

9-3. Resonant Frequency setup

As explained in section 1, DFM uses non-contact mode feedback, but, as opposed to non-contact mode, the drive frequency should be selected at the left part of the peak in the graph. The other conditions are the same as the non-contact mode.

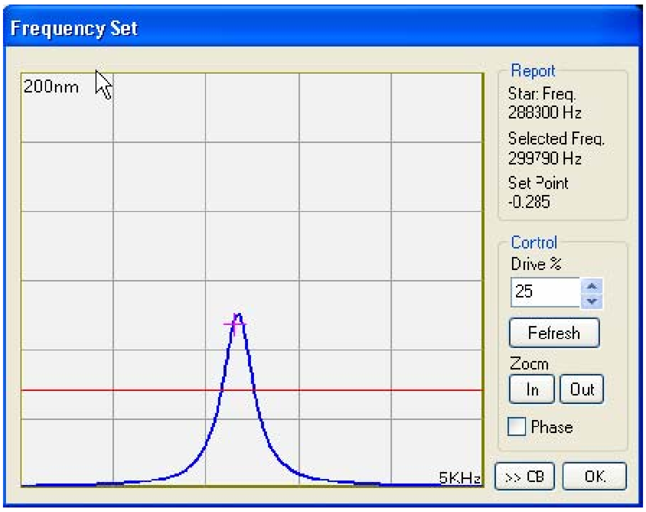


Figure 9-4. Resonant frequency setup in DFM

9-4. Cantilever Selection

Since DFM uses the same method as non-contact AFM, which is to vibrate the cantilever when measuring the sample surface, the same type of cantilevers are used in DFM as in non-contact mode unless the user prefers a different type of cantilever for a specific purpose. Please refer to Chapter 8, section 4 for information of cantilever selection for DFM.

9-5. Measurement Procedure

The method of measurement of DFM is the same as that of non-contact mode. The absolute value of the set point also means the distance between the probe tip and the sample surface, just as in non-contact mode, but the value is much smaller. As explained in Chapter 8, section 1, the vibrating probe tip moves as if it is pecking the sample surface using the same feedback circuit. Determining the set point plays a very important role in obtaining the best image.

The measurement method hereafter is the same as in Chapter 4. Please review to Chapter 4.

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