NanoScope Scanning Tunneling Microscope Operation Manual

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Preface

Overview

Bruker Corporation is the technological leader in the field of scanning probe microscopy (SPM). NanoScope® systems provide fully digital software control of the SPM process, from real time manipulation of the microscope system to offline image viewing, analysis, modification and reporting tools.

The *NanoScope® Scanning Tunneling Microscope Operation Manual* provides the user with a system description, site and safety requirements, installation instructions, facilities requirements, operation procedures, maintenance procedures and troubleshooting information for NanoScope Scanning Tunneling Microscopes (STMs). Refer to the following documentation for more information:

- *Command Reference Manual* (NanoScope software)
- *Electrochemical Manual* (Electrochemical applications)

The preface details the following topics:

- Manual Conventions
- Manual Updates
- Reader Comments
- How to Reach Bruker

Manual Conventions

Typeface Conventions

The following typeface conventions are used throughout this manual.

Table A Typeface Conventions

bold	Highlights software modes, software directories, software menus, software fields, software parameters and software commands
italics	Titles of documentation
8 pt Helvetica	Figure callouts
10PT, BOLD, SMALL CAPS TIMES	Indicates a button, key, or icon
10pt, Blue, Times	Cross references
10pt, Times	Default font
14pt, Bold, Helvetica	Head 1
12pt, Bold, Helvetica	Head 2
10pt, Bold, Helvetica	Head 3

Safety Terms and Symbols

The signal words for safety labels are Caution, Warning and Danger per SEMI S1-0701 guideline for equipment safety labels.

CAUTION: Caution statements indicate a potentially hazardous situation that, if not avoided, could result in moderate or minor injury. This statement may also be used to alert against unsafe practices.

WARNING: Warning statements indicate a potentially hazardous situation that, if not avoided, could result in death or severe injury.

DANGER: Danger statements indicate an imminently hazardous situation that, if not avoided, will result in death or severe injury. This statement is limited to the most extreme situations.

Symbol Specifications

Hazard Identification Symbol A symbol located inside a hazard identification surround shape (black triangle on yellow background) indicates a personal injury hazard (See Figure B).

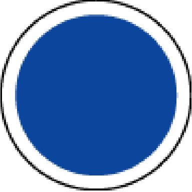
Figure B Hazard Identification Symbol

Prohibition Symbol A symbol located inside a prohibition surround shape (red circle on white background) indicates an action should not be taken or stopped (See Figure C).

Figure C Prohibition Symbol

Mandatory Action Symbol A symbol located inside a mandatory action surround shape (white circle on blue background) indicates that an action should be taken to avoid a hazard (See Figure D).

Figure D Mandatory Action Symbol



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Chapter 1 System Overview

1.1 Overview

This chapter provides an overview of the NanoScope® Scanning Tunneling Microscope (STM) system. The STM system is comprised of the following components: STM, controller, computer, keyboard, mouse, and the display and control monitors. Because the controller and computer are unique to your system, only the STM is discussed in detail in this manual.

This chapter includes the following topics:

- **Overview:** Section 1.1
- **History:** Section 1.2
- **Scanning Tunneling Microscopes:** Section 1.3
- **System Components:** Section 1.4
- **NanoScope Software:** Section 1.5
- **Spectroscopy with the STM:** Section 1.6

1.2 History

The scanning tunneling microscope (STM) was invented by G. Binnig, H. Rohrer and collaborators in the early 1980s. The STM relies on tunneling current between the probe and sample to sense topography of the sample. The STM probe, an atomically sharp metal tip, is positioned a few atomic diameters above a conducting sample which is electrically biased with respect to the tip. At a distance less than 1 nanometer (1 nanometer = 10^{-9} meters = 0.001 micron), a tunneling current flows from sample to tip. In operation, the bias voltages typically range from 10 to 1000 mV while the tunneling currents vary from 0.2 to 10 nA. The tunneling current changes exponentially with tip-sample separation, typically decreasing by a factor of 2 as the separation increases by 0.2 nanometer. The exponential relationship between tip separation and tunneling current makes the tunneling current an excellent parameter for sensing tip-sample separation. A reproduction of the sample surface is produced by scanning the tip over the sample surface and sensing the tunneling current. The first STM operated in ultrahigh vacuum on cryogenically cooled samples. Now, many variations on the STM theme exist in the field.

Scanning tunneling microscopy is generally used under the following conditions:

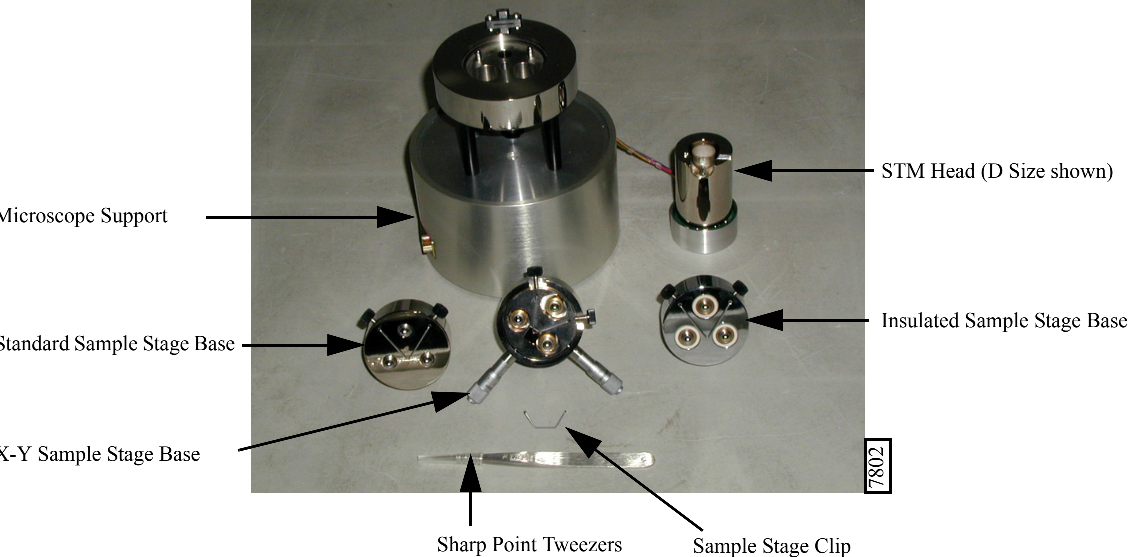
- For samples with deeply relieved features or where feature verticality is very close to 90 degrees.
- For polished samples where you want to image different layers having similar topography but different electrical conductivities.
- Under conditions where contact with the sample surface is prohibited.

1.3 Scanning Tunneling Microscopes

Bruker scanning tunneling microscopes (STMs) rely on precise scanning techniques to produce very high resolution, three-dimensional images of sample surfaces. The STM scans the tip over the sample surface in a raster pattern while sensing and outputting the tunneling current to the NanoScope software control system. The digital signal processor (DSP) controls the Z position of the piezo based on the tunneling current error signal. The STM operates in both constant height and constant current modes depending on gain values set in the software. The DSP always adjusts the height of the tip based on the tunneling current error signal, but if the feedback gains are low, the piezo remains at a nearly constant height while tunneling current data collects. With the gains high, the piezo height changes to keep the tunneling current nearly constant, and the change in piezo height is collected by the system. The exponential relationship between tip separation and tunneling current allows for good tip height control. For example, if the tunneling current stays within 20 percent of the setpoint value (the current maintained by the feedback system), the variation in the tip-sample separation is less than 0.02 nanometer.

NanoScope STMs are designed for high performance atomic resolution scans; their straightforward design also makes them easy to use. The STM consists of three main parts: the scanning head with integral preamplifier, the base with course- and fine-adjustment screws, and the base support housing the stepper motor used in fine-adjustment. The base, which accommodates samples up to 1 centimeter by 2 centimeters and up to 0.5 centimeter in thickness, rests in the raised platform on the base support. The different scanning heads mount magnetically on the tripod formed by the front, course-adjustment screws and the rear, fine-adjustment screw. Optional scan heads for the STM cover the range from atomic resolution to a maximum scan size of 125 microns square.

Figure 1.3a NanoScope STM Assembly



There are two typical configurations of the Bruker scanning tunneling microscopes:

- NanoScope® STM Microscope (Model MS-10)
- Electrochemical STM Microscope (Model ECM)

1.3.1 NanoScope STM Microscope

Standard Components

- Microscope Support
- Standard Sample Stage Base
- X-Y Sample Stage Base
- Sample Stage Clips
- STM Tips
- 37–25-pin Ribbon Cable
- Standard Cover
- X-Y Cover
- Sharp Point Tweezers
- 25x Magnifier and Stand
- Vibration Isolation Pad
- Noise Reduction Hood
- Graphite Sample
- STM Operation Manual

Options

- Insulated Sample Stage Base
- STM Head(s)
- Calibration Standard(s)

1.3.2 Electrochemical STM Microscope

Standard Components

- Electrochemical STM Microscope Support
- Standard Sample Stage Base
- X-Y Sample Stage Base
- Sample Stage Clip(s)
- Electrochemical Stage Base
- 37–25-pin Ribbon Cable
- Standard Cover
- X-Y Cover
- 25x Magnifier and Stand
- Vibration Isolation Pad
- Noise Reduction Hood
- Electrochemical Cell Kit
- Electrochemical Manual
- STM Operation Manual

Options

- Insulated Sample Stage Base
- STM Head(s)
- Calibration Standard(s)

1.4 System Components

The scanning tunneling microscope consists of the following main hardware components:

- **Scan Head(s):** Section 1.4.1
- **Base:** Section 1.4.2
- **Base Support:** Section 1.4.3
- **Tips:** Section 1.4.4
- **Magnifier and Stand:** Section 1.4.5

1.4.1 Scan Head(s)

The scan head houses the piezoelectric scanner and the preamplifier circuit for the tunneling current which together control the three-dimensional motion of the tip. The removable head consists of a piezo tube scanner mounted in an Invar shell. A preamplifier circuit mounts on the top of the head. The Invar shell, piezo tube, and preamplifier circuit are described separately below.

Scan heads with four maximum scan ranges are available:

- A Head (0.7 micron)
- D Head (12 microns)
- G Head (75 microns)
- J Head (125 microns)

Note: The scan ranges listed are the nominal values for each head type. The maximum ranges are frequently larger than the listed values.

Figure 1.4a Bruker A and Bruker Heads

Invar Shell

In order to minimize vertical thermal drifts, it is important to have a good thermal match between the piezo tube and mount. The combination of the Invar and piezo tube has an associated small net expansion coefficient so that the system can tolerate fairly large temperature changes without the vertical piezo drive going out of range. The shell is nickel and chrome-plated. A ceramic ring is pressed into the top of the Invar shell, and the piezo tube is epoxied to this ring.

Piezo Tube

The NanoScope STM head uses a piezoelectric tube approximately 0.5 inch in diameter to control the three-dimensional motion of the tip. The piezo tube provides both rigidity and simplicity. The electrode configuration produces X and Y motions which are perpendicular, minimizes horizontal and vertical coupling, and provides good sensitivity.

Note: The orientation of the electrodes changes slightly for heads with different scan ranges.

The feedback loop drives the Z which controls vertical motion of the piezo tube. Complimentary voltages of opposite signs drive the two electrodes which control X and Y scanning motions. These voltages are called -Y, -X, +Y and +X. Applying complimentary voltages allows a short, stiff tube to provide a good scan range without using large voltages. The piezo tubes are covered with clear polyurethane to minimize leakage currents flowing across the electrode gaps due to moisture or other surface contamination.

The piezo tube, like all mechanical systems, has a resonant frequency which can cause the system to oscillate. The higher the resonant frequency the better, which allows you to drive the tube at higher frequencies and makes the tube (and tip) less sensitive to external vibrations. The motion of the tip due to external vibrations is proportional to

$$\frac{(f_v)^2}{(f_o)^2}$$

where f_v is the vibration frequency and f_o is the resonant frequency. The piezo tube has vertical and horizontal resonant frequencies. These resonant frequencies are nominally 60KHz in the vertical direction and 40KHz in the horizontal direction for the standard A head. The resonant frequencies of the other heads are slightly lower.

Standard Preamplifier

Mounted atop the head is a circuit board which contains the preamplifier for the tunneling current and provides interconnections to the piezo tube electrodes. The standard preamplifier is an FET input amplifier with an input bias current of 25 picoamps, which is small compared to the nanoamps (or fractions of nanoamps) measured. The preamp is configured so the tunneling tip connects through a one megaohm resistor to ground. The tip is also connected to the input of the amplifier which is wired as a x100 non-inverting amplifier with a cutoff frequency of 15KHz. The transimpedance gain of the input resistor/preamp combination is 100 mV/nA with an input range from 0 to 100nA. The noise of the preamp is essentially the Johnson noise in the one megaohm resistor and the standard filtering is 2 mV rms, equivalent to an input tunneling current of 0.02 nA rms. A disadvantage of this amplifier configuration is the voltage drop across the one megaohm resistor which raises the voltage of the tip above ground, reducing the effective bias voltage. The actual bias voltage is equal to:

$$V_{sample} = V_{bias} - I_{tunneling} \times R_{input}$$

This effect is accounted for in the NanoScope software so the actual bias voltage between the tip and the sample agrees with the menu value. Special low-noise preamps exist for spectroscopic functions. The preamps included on scan heads designated as either AI or DI have no voltage drop due to the tunneling current.

Tipholder

A simple tipholder, designed to hold 0.01 inch diameter tips, keeps the mass on the end of the piezo tube low. The holder is a stainless steel tube with a 0.012 inch inner diameter mounted in ceramic. There are two head designs with differences in placement of the tipholder. One design mounts the tip on the front edge of the tube. This design keeps the mounting mass low and the resonant frequency high. This design also positions the tip where it is readily visible for coarse adjustment. This head design typically has a somewhat smaller sensitivity in Y than in X.

The second head design mounts the tip in the center of the piezo tube on a ceramic support element. This design preserves the symmetry of the scanning although it makes it difficult to see the tip-sample interface. This head design is used on the large range, G and J, heads.

1.4.2 Base

The Invar base performs three functions: it holds the sample in position, supports the head, and in the X-Y base, provides X-Y motion for the sample. A spring-steel sample clip with two thumb screws holds the sample in place. Three 1/4 – 80 precision screws arranged in a triangular pattern support the head and provide coarse- and fine-adjustment of the tip height. In the X-Y base, a translation stage allows you to reposition the sample under the tip. The spring-steel sample clip accommodates samples up to one centimeter by two centimeters by one-half centimeter thick. The thumb screw clamps on the sample clip allow you to make adjustments for thicker samples. The steel sample clip also provides additional electrical contact to the sample surface.

Three precision, 1/4 – 80 screws go through the base to form a tripod support for the head. Balls mounted in the ends of the screws mate uniquely with a hole, a slot, and a flat on the head. The balls are magnetized to hold the ferromagnetic head securely in place. The two forward screws have a mechanical advantage close to 1 for coarse positioning of the tip. The rear screw, which the stepper motor turns during tip engage and withdrawal operations, has a mechanical advantage of the 0.12 (raising the screw lowers the tip) for the A and D heads and 0.33 for the G and J heads.

The X-Y translation stage built into the base provides one millimeter of travel parallel and perpendicular to the default, zero degree, scan angle. The micropositioners used in the stage provide precise movement of the sample under the tip.

1.4.3 Base Support

The base support of the microscope consists of the base support ring and the motor housing. The base support ring cradles the base, allowing access to the coarse-adjustment screws and clearance for the fine-adjustment screw to mate with the drive shaft from the stepper motor. The stepper motor enclosed in the motor housing causes the tip to engage and withdraw from the surface automatically.

The stepper motor, which drives the rear screw, rotates at 800 steps per revolution. With mechanical advantages of 0.12 and 0.33, the tip moves approximately 50 nanometers per step for the A and D heads and approximately 130 nanometers per step for the G and J heads.

1.4.4 Tips

Probes for the NanoScope STM must be less than 0.012 inch in diameter to fit into the tipholder. The two most commonly used tips are made from either platinum iridium (PtIr) alloy or tungsten.

Platinum Iridium Tips

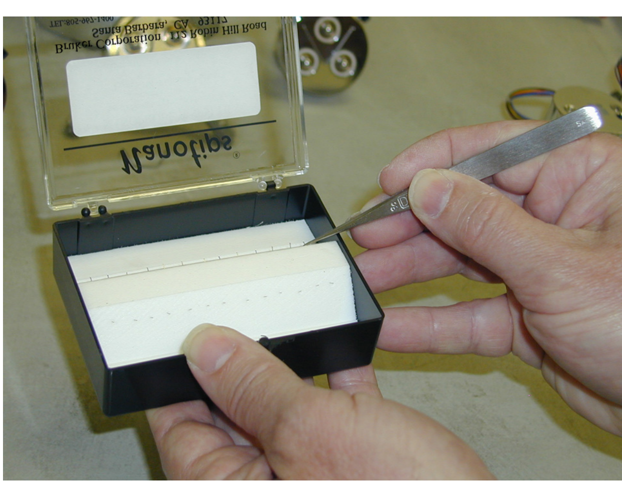
The platinum iridium tips are mechanically formed and can be purchased directly from Bruker. In general, platinum iridium tips provide better atomic resolution than tungsten tips in air and liquids, probably due to the lower reactivity of platinum. However, platinum iridium tips are less uniformly shaped than tungsten tips, so freshly etched tungsten tips may perform better on samples with steeply sloped features (e.g., compact or optical disks).

Tungsten Tips

Also available from Bruker, see Appendix A for instructions on how to etch tungsten tips from tungsten wire with an electrochemical process.

Note: For tunneling on surfaces immersed in conductive liquids, you can use coated tips. Glass coatings are removed from the very end of the tip by briefly applying a high-bias voltage.

Figure 1.4b Tips in Box



1.4.5 Magnifier and Stand

Figure 1.4c Magnifier and Stand

1.5 NanoScope Software

There are two operating modes available on NanoScope Scanning Tunneling Microscopes: **Height** and **Current**. You may select either of the two operating modes in the **Date type** field in the **Channel** panel in the NanoScope software. The two scan modes (height and current) require minor changes in the NanoScope software menu parameters to operate effectively. The parameter changes also affect the application of the two modes.

1.5.1 Height

Height data reflects the change in tip position required to maintain a constant tunneling current. The NanoScope STM senses the tunneling current, calculates the difference from the desired tunneling current, and determines the voltage to apply to the piezo tube to keep the tunneling current constant. Due to the known characteristics of the piezoelectric material, the change in voltage applied to the piezo tube translates directly to a change in distance. This distance data is recorded throughout the scan and displayed on the screen as the height of the sample.

The tip must closely track the sample surface in height mode. The gains must be maximized to force the piezo to respond quickly to the variations in the sample surface. Height mode is used for most applications.

Note: If different atomic species are present in a sample, the height data may not be a direct representation of the topography of the sample surface. Different atomic species within a sample may produce different tunneling currents for a given bias voltage.

1.5.2 Current

Current data is a measure of the tunneling current at each point tested on the sample. The NanoScope STM measures the voltage drop across a resistor in series with the tip and calculates the tunneling current as the tip scans the sample surface. The tunneling current at each data point is recorded and displayed on the screen.

In current mode, the gains must be set very low to keep the piezo from responding while collecting current data. After engaging, the tip scans the surface of the sample with very little variation in the piezo height. This constant height provides a reference from which to measure and record fluctuations in the tunneling current. Current mode is most useful for imaging atoms, with relatively small scan sizes.

1.6 Spectroscopy with the STM

The NanoScope STM performs limited spectroscopic operations under the two scanning tunneling spectroscopy STS modes of operation. The variation of the tunneling current due to variations of the bias voltage or tip-to-sample separation can be tested and recorded at a single point with the **STS Plot** mode.

> **Note:** A related form of imaging, current imaging tunneling spectroscopy (CITS) is described in the *Command Reference Manual*.

In the **STS Plot** modes, the tip is positioned at a point on the surface, and a spectroscopic plot is acquired and displayed in a scope format. Between plots, the feedback is run to establish the tunneling current to the setpoint value. The different types of STS plots are located under the View pop-down menu

- **STS i(v)** – The tunneling current as a function of the bias voltage is displayed. The tip height is held constant while the I-V plot is acquired. In addition to I versus V, $\frac{di}{dv}$, $\frac{d\ln(i)}{dv}$, or $\frac{d\ln(i)}{d\ln(v)}$ versus V can be plotted.
- **STS i(s)** – The tunneling current as a function of the tip height is displayed. The bias voltage is held constant while the I-S plot is being acquired. In addition to I versus S, In(I) versus S can be plotted.

Chapter 2 Safety

2.1 Overview

This chapter details the safety requirements involved in installation and operation of the NanoScope® Scanning Tunneling Microscope (STM). Specifically, these safety requirements include safety precautions, non-physical conditions, and equipment safety applications. Training and compliance with all safety requirements is essential during installation and operation of the NanoScope STM.

This chapter includes the following topics:

- **Overview:** Section 2.1
- **Safety Requirements:** Section 2.2
- **Safety Precautions:** Section 2.3
- **Non-Physical Conditions:** Section 2.4

2.2 Safety Requirements

Table 2.2a Safety Symbols Key

Symbol	Definition
(caution symbol)	This symbol identifies conditions or practices that could result in damage to the equipment or other property, and in extreme cases, possible personal injury.
	Ce symbole indique des conditions d'emploi ou des actions pouvant endommager les équipements ou accessoires, et qui, dans les cas extrêmes, peuvent conduire à des dommages corporels.
	Dieses Symbol beschreibt Zustände oder Handlungen die das Gerät oder andere Gegenstände beschädigen können und in Extremfällen zu Verletzungen führen können.
(electric shock symbol)	This symbol identifies conditions or practices that involve potential electric shock hazard.
	Ce symbole indique des conditions d'emploi ou des actions comportant un risque de choc électrique.
	Dieses Symbol beschreibt Zustände oder Handlungen, die einen elekrischen Schock verursachen können.
(laser symbol)	This symbol identifies a laser hazard. Exposure could result in eye damage.
	Ce symbole indique un risque lié à un laser. Une exposition à ce laser peut entraîner des blessures aux yeux.
	Dieses Symbol bedeutet "Gefährliche Laserstrahlung". Laserstrahlung kann zu Beschädigung der Augen führen.

2.3 Safety Precautions

You must become familiar with the following precautions to avoid injury to yourself and/or damage to the system or samples. This chapter should be read by **all** persons working with or around the system.

2.3.1 Six Rules of Safety

- **Read the manuals.**

  Even if you are an experienced STM user, read the manual before imaging. Also, refer to the Command Reference Manual for a complete explanation of software controls.

- **Follow good rules of engagement.**

  Engagement refers to bringing the tip and surface together. The software routine for controlling this process is complex. Some probes may break if engaged too quickly or too hard. Ensure that engagement settings never exceed the safety limits and never attempt to engage manually using the coarse adjustment screws.

- **Never move the head while imaging.**

  An X-Y translation stage is designed to move the head and tip several millimeters across the sample for coarse adjustment. Even for relatively smooth samples, never move the head with the tip engaged. Always disengage before using the X-Y stage to move the tip.

- **Never leave the controller on while the computer is off.**

  Turn off the controller and computer when you are finished imaging. If the controller is left on for extended periods without an energized computer, you may damage the head.

- **Remove power before disconnecting cables.**

  Unplugging energized hardware may result in equipment damage. Always turn off hardware before making cabling connections.

- **Check all connections before hardwiring external equipment.**

  External equipment hardwired to the STM requires special cautions. Always check connections carefully against documentation before energizing the system.

2.3.2 General Operator Safety

WARNING: Service and adjustments should be performed only by qualified personnel who are aware of the hazards involved.

AVERTISSEMENT: Tout entretien ou réparation doit être effectué par des personnes qualifiées et conscientes des dangers qui peuvent y être associés.

WARNUNG: Service- und Einstellarbeiten sollten nur von qualifizierten Personen, die sich der auftretenden Gefahren bewußt sind, durchgeführt werden.

WARNING: Follow company and government safety regulations. Keep unauthorized personnel out of the area when working on equipment.

AVERTISSEMENT: Il est impératif de suivre les prérogatives imposées tant au niveau gouvernmental qu’au niveau des entreprises. Les personnes non autorisées ne peuvent rester près du système lorsque celui-ci fonctionne.

WARNUNG: Befolgen Sie die gesetzlichen Sicherheitsbestimmungen Ihres Landes. Halten Sie nicht authorisierte Personen während des Betriebs vom Gerät fern.

WARNING: Voltages supplied to and within certain areas of the system are potentially dangerous and can cause injury to personnel. Power-down all components and unplug from power sources before doing **any** electrical servicing (Bruker service personnel, *only*.)

AVERTISSEMENT: Les tensions utilisées dans le système sont potentiellement dangereuses et peuvent blesser les utilisateurs. Avant toute intervention électrique, ne pas oublier de débrancher le système. (Réservé au personnel de Bruker, seulement.)

WARNUNG: Die elektrischen Spannungen, die dem System zugeführt werden, sowie Spannungen im System selbst sind potentiell gefährlich und können zu Verletzungen von Personen führen. Bevor elektrische Servicearbeiten irgendwelcher Art durchgeführt werden ist das System auszuschalten und vom Netz zu trennen. (Nur Bruker Personal.)

WARNING: Never alter wiring on the NanoScope STM.

AVERTISSEMENT: Ne jamais toucher les cables et l'installation pneumatique sur le boîtier accoustique du NanoScope STM.

WARNUNG: Ändern Sie niemals etwas am pneumatischen System oder der Verdrahtung der Schallschutzhaube.

2.3.3 Microscope

To avoid operator injury and equipment damage, observe the following cautions regarding the NanoScope STM.

The STM uses high voltage amplifiers to drive the piezo tube which controls scanning operation. These amplifiers are capable of supplying ±220 volts. Voltages run through the flat-ribbon cable connecting the microscope to the controller and the fine wires connecting the subminiature D-connector to the preamp board on the STM head.

WARNING: Do not touch the preamp board or the electrodes on the piezo tube when power to the instrument is on. If needed, the fuse on the rear panel should be replaced with a 0.75 Amp slo-blow fuse (on 115 and 100 volt models); 0.375 Amp slo-blow on 220 volt models.

WARNING: Avoid wear on the cable connecting the microscope to the controller. Frayed or worn insulation could pose risk of electric shock. Keep the cable away from sharp edges, rough objects, and other hazards likely to result in wear on the cable insulation. If you suspect damage to the insulation, contact Bruker for repair or replacement.

WARNING: Be careful when handling heads to reduce wear on the wiring. If you suspect damage to the insulation, contact Bruker for repair or replacement.

WARNING: The internal electronics of the microscope, controller, and peripheral equipment feature high-voltage components. Because there are no user-serviceable parts, do not attempt system repairs. Disconnect faulty components and ship them to Bruker for repair or replacement.

AVERTISSEMENT: Les parties électroniques du microscope, du controleur et des équipements périphériques comportent des équipements fonctionnant avec de hauts voltages. Ne pas essayer d'effectuer de réparations, aucune de ces parties n'étant concue pour être réparée par l'utilisateur. Déconnecter les équipements défectueux et les envoyer à Bruker pour réparation.

WARNUNG: Die Elektronik des Mikroskops selbst, der Steuergeräte und der externen Geräte ist mit Hochspannungselementen ausgestattet. Diese Elemente dürfen nur von geschultem Personal gewartet werden. Versuchen Sie nicht, das System selbst zu reparieren. Trennen Sie fehlerhafte Komponenten vom System, und schicken sie diese zur Reparatur oder zum Umtausch zu Bruker.

CAUTION: Do not attempt repairs on electrical components. If it is necessary to enter the electrical chassis for any reason (e.g., to replace a computer card), power-down the entire system and disconnect it from its power source.

ATTENTION: Ne pas essayer de réparer les parties électroniques. Si il est nécessaire d'accéder au boitier électronique (pour remplacer une carte dans l'ordinateur par exemple), éteindre tout le système et le déconnecter.

VORSICHT: Versuchen Sie nicht, elektrische Komponenten selbst zu reparieren. Falls es aus irgend einem Grund notwendig sein sollte, ein Gehäuse mit elektrischen Bauteilen zu öffnen (z.B., um eine Computer-Karte auszutauschen), schalten Sie das gesamte System ab, und trennen Sie es von der Spannungsquelle.

CAUTION: Avoid spilling fluids onto the microscope or into electrical assemblies, particularly the STM head. If it is necessary to use fluids, apply only small amounts as needed.

ATTENTION: Eviter d'éclabousser la platine du microscope et les assemblages électriques, en particulier la tête du microscope. Si il est nécessaire d'utiliser des liquides, ne les employer qu'en faibles quantités.

VORSICHT: Vermeiden Sie es, Flüssigkeiten auf dem Probentisch oder über elektronische Bauteile, insbesondere den Mikroskopkopf, zu verschütten. Wenn es notwendig ist, Flüssigkeiten zu verwenden, benutzen Sie dem Bedarf entsprechend nur geringe Mengen.

2.3.4 Sample Safeguards

CAUTION: **Do not** change samples in the middle of operation. Verify that the stage is clear of debris at all times. Use alcohol wipes periodically to keep the stage clean of dust.

ATTENTION: **Ne pas** changer d’échantillon en cours d’utilisation. Vérifier que la platine n’est pas encombrée, par des outils par exemple. Employer des tampons d’alcool régulièrement pour dépoussiérer la platine.

VORSICHT: Tauschen Sie **keine** Proben aus, während sich das System im Betrieb befindet. Der Probentisch sollte von Werkzeug, anderen Objekten und Überresten ständig freigehalten werden. Benutzen Sie ein mit Alkohol getränktes Tuch, um den Probentisch regelmäßig von Staub zu reinigen.

2.4 Non-Physical Conditions

Non-physical conditions that may affect the performance of the NanoScope STM are vibration and noise. The microscope must be isolated from sources of vibration in the acoustic and sub-acoustic frequencies. Atomic-scale imaging is sensitive to ordinary room vibrations. You can obtain reasonable vibration isolation with the vibration isolation pad supplied with the system. In many cases, the pad provides enough vibration isolation to run the microscope on the table, but the pads are especially effective when the microscope and pad are isolated from the fan noise generated by the computer. The best way to reduce coupling from vibrations is to eliminate as many sources of vibration as possible. Remember that vibrations can be transmitted to the STM via cables. Prevent tension in the cable and keep it away from fans and other noise sources. Keep the microscope away from sources of acoustic noise. Loud noises, including conversation, can disrupt atomic images.

Chapter 3 Installation

3.1 Overview

To install your NanoScope® Scanning Tunneling Microscope system, follow the instructions provided below. If the NanoScope software is not already installed on the system, contact your local Bruker technical support representative (See Preface). The STM control program should be installed in a special directory which must be entered to run Z.EXE.

This chapter includes the following topics:

- **Overview:** Section 3.1
- **Unpacking the System:** Section 3.2
- **Power-up Sequence (Installation and Service Only):** Section 3.3
- **Power-Up Sequence (Normal Usage):** Section 3.4

3.2 Unpacking the System

The NanoScope system typically ships in one box containing the STM, cables and hardware.

1. Prepare a minimum table space of 76 x 152 cm (30 x 60 inches) size.

   Note: The table must be level, sturdy, and located in an area free from vibration, sources of heat or cold, windows, air conditioning and heating ducts.

2. Remove all the components from the box and place them on the table.

   Note: If this is a first-time installation, verify that you received all the necessary components (See Section 3.2.1 for a list of components that NanoScope® Scanning Tunneling Microscope systems ship).

3. Place the STM microscope atop the round vibration pad supplied with the system.

3.2.1 NanoScope STM Microscope

Standard Components

- Microscope Support
- Standard Sample Stage Base
- X-Y Sample Stage Base
- Sample Stage Clips
- STM Tips
- 37–25-pin Ribbon Cable
- Standard Cover
- X-Y Cover
- Sharp Point Tweezers
- 25x Magnifier and Stand
- Vibration Isolation Pad
- Noise Reduction Hood
- Graphite Sample
- STM Operation Manual

Options

- Insulated Sample Stage Base
- STM Head(s)
- Calibration Standard(s)

3.2.2 Electrochemical STM Microscope

Standard Components

- Electrochemical STM Microscope Support
- Standard Sample Stage Base
- X-Y Sample Stage Base
- Sample Stage Clip(s)
- Electrochemical Stage Base
- 37–25-pin Ribbon Cable
- Standard Cover
- X-Y Cover
- 25x Magnifier and Stand
- Vibration Isolation Pad
- Noise Reduction Hood
- Electrochemical Cell Kit
- Electrochemical Manual
- STM Operation Manual

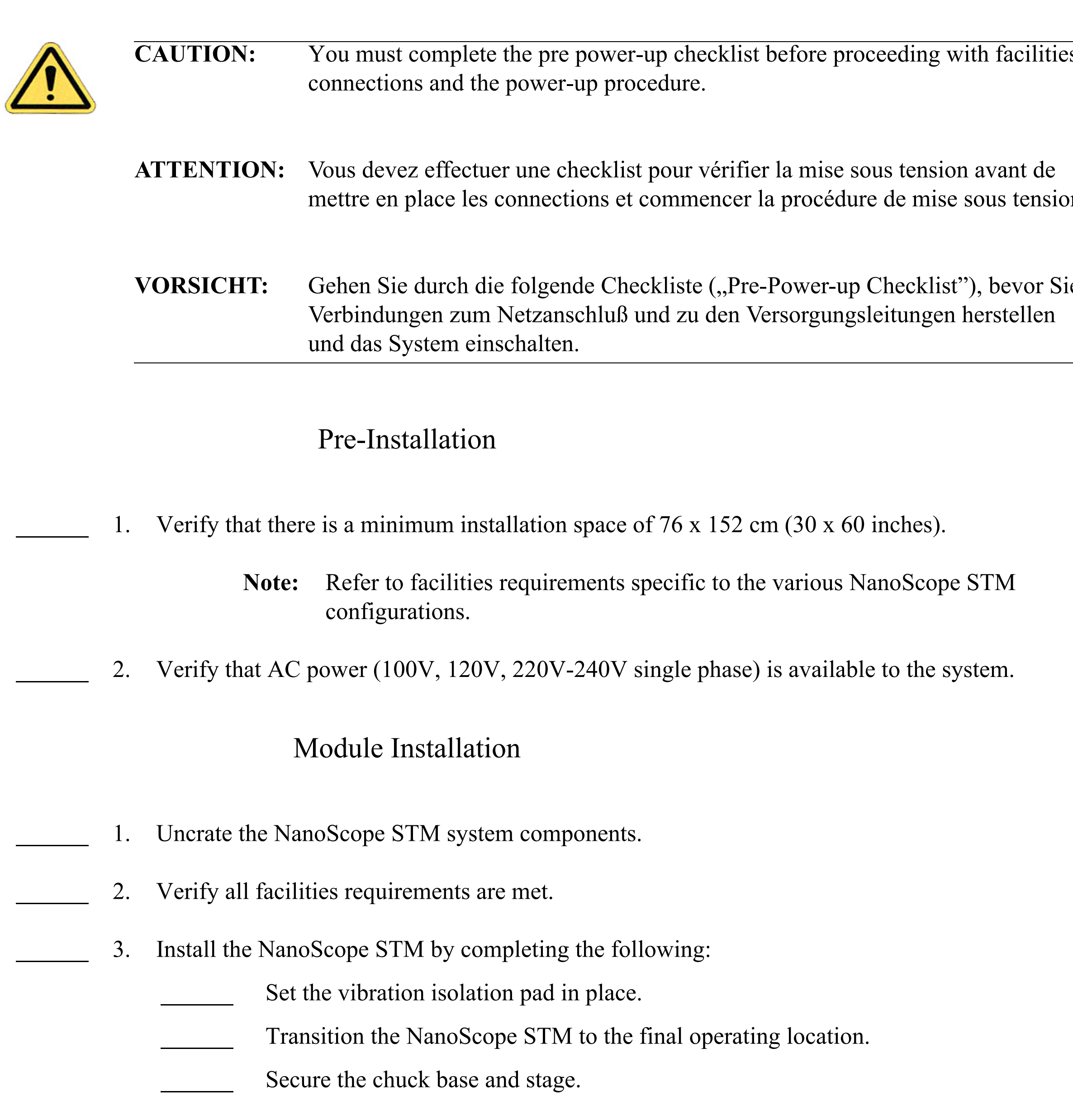
Options

- Insulated Sample Stage Base
- STM Head(s)
- Calibration Standard(s)

3.3 Power-up Sequence (Installation and Service Only)

The following section is required *only* during installation or after servicing. For a description of normal power-up procedures, see Section 3.4.

3.3.1 Pre Power-up Checklist



CAUTION: You must complete the pre power-up checklist before proceeding with facilities connections and the power-up procedure.

ATTENTION: Vous devez effectuer une checklist pour vérifier la mise sous tension avant de mettre en place les connections et commencer la procédure de mise sous tension.

VORSICHT: Gehen Sie durch die folgende Checkliste („Pre-Power-up Checklist”), bevor Sie Verbindungen zum Netzanschluß und zu den Versorgungsleitungen herstellen und das System einschalten.

Pre-Installation

______ 1. Verify that there is a minimum installation space of 76 x 152 cm (30 x 60 inches).

Note: Refer to facilities requirements specific to the various NanoScope STM configurations.

______ 2. Verify that AC power (100V, 120V, 220V-240V single phase) is available to the system.

Module Installation

______ 1. Uncrate the NanoScope STM system components.

______ 2. Verify all facilities requirements are met.

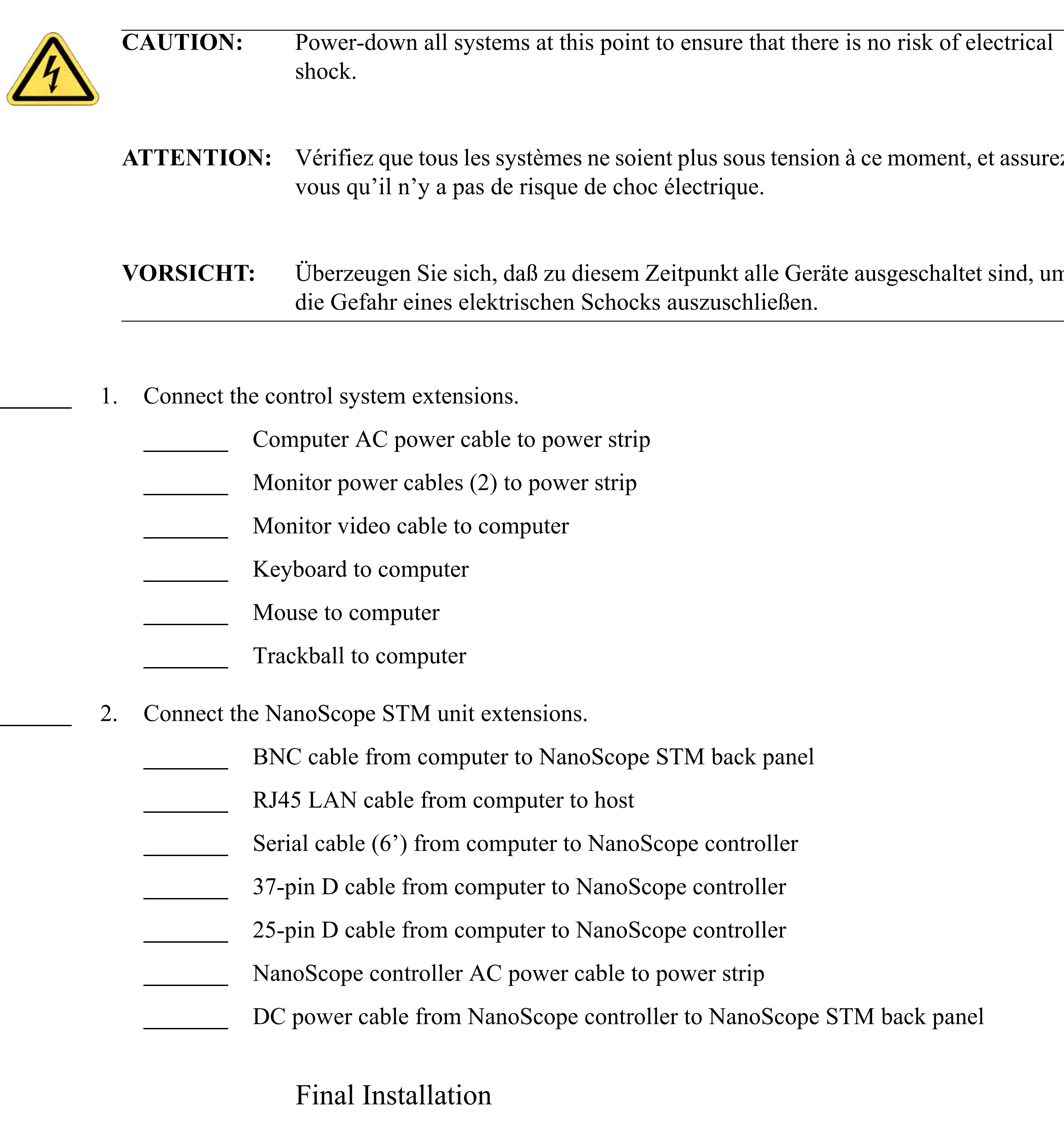
______ 3. Install the NanoScope STM by completing the following:

- ______ Set the vibration isolation pad in place.
- ______ Transition the NanoScope STM to the final operating location.
- ______ Secure the chuck base and stage.

______ 4. Install the control system by completing the following:

- ______ Place the input and display devices on the table (monitors [2], mouse, keyboard and trackball).
- ______ Place the computer and controllers on the table.

Connections



CAUTION: Power-down all systems at this point to ensure that there is no risk of electrical shock.

ATTENTION: Vérifiez que tous les systèmes ne soient plus sous tension à ce moment, et assurez vous qu’il n’y a pas de risque de choc électrique.

VORSICHT: Überzeugen Sie sich, daß zu diesem Zeitpunkt alle Geräte ausgeschaltet sind, um die Gefahr eines elektrischen Schocks auszuschließen.

______ 1. Connect the control system extensions.

- _______ Computer AC power cable to power strip
- _______ Monitor power cables (2) to power strip
- _______ Monitor video cable to computer
- _______ Keyboard to computer
- _______ Mouse to computer
- _______ Trackball to computer

______ 2. Connect the NanoScope STM unit extensions.

- _______ BNC cable from computer to NanoScope STM back panel
- _______ RJ45 LAN cable from computer to host
- _______ Serial cable (6’) from computer to NanoScope controller
- _______ 37-pin D cable from computer to NanoScope controller
- _______ 25-pin D cable from computer to NanoScope controller
- _______ NanoScope controller AC power cable to power strip
- _______ DC power cable from NanoScope controller to NanoScope STM back panel

Final Installation

______ 1. Install the head.

3.3.2 Power-up the NanoScope STM

1. Verify that all system components are plugged into AC power with the correct voltage.
2. Verify that all cables are connected properly.
3. Power-up the monitors (2) using the push-button switches located on the front of the monitors.
4. Power-up the NanoScope controller using the power switch located on the rear of the NanoScope controller.
5. Power-up the computer using the push-button switch located on the front of the computer.

3.3.3 Power-up Checklist

Power-up

______ 1. Connect the facilities.

______ 2. Verify that all system components are plugged into AC power with the correct voltage.

______ 3. Verify that all cables are connected properly.

______ 4. Verify that the computer, controller, and monitors power-up simultaneously.

3.4 Power-Up Sequence (Normal Usage)

3.4.1 Prepare the System for Power-up

1. Verify that all system components are plugged into AC power with the correct voltage.
2. Verify that all cables are connected properly.
3. Power-up the monitors (2) using the push-button switches located on the front of the monitors.
4. Power-up the NanoScope controller using the power switch located on the rear of the NanoScope controller.
5. Power-up the computer using the push-button switch located on the front of the computer.

3.4.2 Power-up Checklist

Power-up

______ 1. Verify that all system components are plugged into AC power with the correct voltage.

______ 2. Verify that all cables are connected properly.

______ 3. Verify that the computer, controller, and monitors power-up simultaneously.

Chapter 4 NanoScope® Software

4.1 Overview

This manual focuses on issues related specifically to software function on NanoScope Scanning Tunneling Microscopes (STMs), highlighting specific STM applications and important control parameters. For more information related to the NanoScope software, refer to the *Command Reference Manual* appropriate for the software version running on your system. The *Command Reference Manual* discusses all of the commands and control parameters used with the STM.

4.2 NanoScope Software

There are two operating modes available on NanoScope Scanning Tunneling Microscopes: **Height** and **Current**. You may select either of the two operating modes in the **Date type** field in the **Channel** panel in the NanoScope software. The two scan modes (height and current) require minor changes in the NanoScope software menu parameters to operate effectively. The parameter changes also affect the application of the two modes.

4.2.1 Height

Height data reflects the change in tip position required to maintain a constant tunneling current. The NanoScope STM senses the tunneling current, calculates the difference from the desired tunneling current, and determines the voltage to apply to the piezo tube to keep the tunneling current constant. Due to the known characteristics of the piezoelectric material, the change in voltage applied to the piezo tube translates directly to a change in distance. This distance data is recorded throughout the scan and displayed on the screen as the height of the sample.

The tip must closely track the sample surface in height mode. The gains must be maximized to force the piezo to respond quickly to the variations in the sample surface. Height mode is used for most applications with the exception of atomic scale scans; in general, height data images are best at higher feedback gains and slower scan rates.

Note: If different atomic species are present in a sample, the height data may not be a direct representation of the topography of the sample surface. Different atomic species within a sample may produce different tunneling currents for a given bias voltage.

4.2.2 Current

Current data is a measure of the tunneling current at each point tested on the sample. The NanoScope STM measures the voltage drop across a resistor in series with the tip and calculates the tunneling current as the tip scans the sample surface. The tunneling current at each data point is recorded and displayed on the screen.

In current mode, the gains must be set very low to keep the piezo from responding while collecting current data. After engaging, the tip scans the surface of the sample with very little variation in the piezo height. This constant height provides a reference from which to measure and record fluctuations in the tunneling current. Current mode is most useful for imaging atoms, with relatively small scan sizes. This mode is not practical for rough surfaces, where the tip may crash into the surface at low feedback gains.

4.3 Important Menu Parameters

To produce quality images, the STM must be capable of controlling tip-sample interaction with great precision. This is accomplished using an electronic feedback loop which safeguards the tip and sample by maintaining forces between them at a user-specified **Setpoint** level. Although signal processing varies according to the operating mode used, the feedback loop performs essentially the same function.

The STM parameter control panel contains three items specific to operation of the STM: **Feedback Type**, **Bias** and **Setpoint**.

4.3.1 Feedback Type

Feedback Type parameters control the transformation performed on the tunneling current prior to feedback calculations. The three available feedback type options are **Linear**, **Log** or **Boost** input transformations. The tip-sample separation is proportional to the log of the tunneling current, therefore the transformation performed on the tunneling current prior to the feedback calculation can have dramatic effects on the performance of the feedback loop.

Linear

Linear sets the error signal for the feedback loop to be the difference between the instantaneous tunneling current and the setpoint current. This setting is more protective of the tip because the feedback error signal responds exponentially to tip-sample separation. When the tip-sample separation decreases, the error signal rises exponentially but unsymmetrically, quickly driving the tip away. The same tip-sample separation change that caused the tip to move away so quickly generates a small error signal when the tip is higher than it is supposed to be. This unsymmetrical response in **Linear** mode distorts data.

Log

Both **Log** and **Boost** calculate the error signal as the difference between the log of the instantaneous tunneling current and the log of the setpoint current. For this reason, **Log** and **Boost** are preferable for most samples because they respond in a more symmetrical fashion to positive and negative sample slopes. The **Log** input has the advantage of having a gain which is insensitive to the value of the **Setpoint** current.

Boost

Boost performs additional operations to optimize feedback performance for high scan rates over rough surfaces. **Boost** mode is preferable for large scans with high vertical features such as compact disc stampers or integrated circuits. You can greatly reduce **Proportional** and **Integral Gains** when using **Boost** mode.

4.3.2 Bias

The **Bias** parameter controls the magnitude and sign of the bias voltage applied between the tip and sample. A bias voltage encourages the tunneling current to flow. Although settings of 20-100 mV are typical for conductive samples, the allowable setting ranges from -10 to 10 volts. Positive settings of the bias voltage induce negative tunneling currents (i.e., electrons flowing from tip to sample).

Optimizing Bias

Bias voltages below 20 mV typically provide the best quality images on samples with surface conductivities equal to or better than graphite, however there are exceptions. The resistivity across the surface of a sample can be measured with an ohmmeter. For samples with high resistivity (greater than 1 megohm/cm), bias voltages of 100 mV or higher may be best. For scans larger than 0.5 µm, it is sometimes better to increase the bias voltage by 50 mV to 100 mV over the value for small scans. A higher bias keeps the tip farther from the surface, giving the feedback loop greater tolerance in tracking the surface at high speeds.

4.3.3 Setpoint

Setpoint refers to how much tip-sample force is maintained. Increasing the **Setpoint** current can be helpful for larger scans. This has the effect of raising the gain, but also brings the tip closer to the surface by a small amount. High setpoint currents, 6 nanoamps or more, can also be useful in improving the signal-to-noise ratio for atomic images on some materials.

4.4 Important Scan Parameters

The process of selecting and optimizing the scan parameters are typically dictated by the sample. **Data Type** is typically the first parameter set. **Proportional** and **Integral Gains** are directly related to the data type. **Scan Size** depends on the sample and features of interest. The maximum **Scan Rate** is typically related to the **Scan Size**.

4.4.1 Feedback Gains

For each new sample, you must optimize the feedback gains system used to control tip-sample interactions and render images. To do this, you can adjust various gains in the STM feedback circuit. This section discusses gains and how they are used to obtain images.

Proportional, Integral and LookAhead Gains

Integral Gain corrects the cumulative error between a system and its target state. The effect of integral gain feedback is to reduce total error by addressing error over a longer period of time. This tends to smooth out the short-term, fluctuating effects of proportional gain while narrowing the error closer to the setpoint value. Unfortunately, if the integral gain is set too high, there is a tendency to overshoot the setpoint. Therefore, integral gain is highly sensitive and must be used carefully.

The user assigns a setpoint value corresponding to a certain amount of tip-sample force, then adjusts gains to track the surface as closely as possible while maintaining the setpoint. The Z-axis piezo uses voltage to retract and lower the probe. In addition, such parameters as **Scan Rate** must be figured in. You must frequently adjust **Scan Rate** and **Setpoint** to track sample surfaces successfully.

The **LookAhead Gain** adds information from the previous scan line into the feedback calculation. It is most useful for samples with long vertical features.

Optimizing Feedback Gains

With **Data Type** set to **Current**, set the **Proportional** and **Integral Gains** as close to zero as possible. Lower the gains for data captured using the **Linear** feedback type, particularly with high **Setpoint** current levels. Image large scale images at higher gains, with the exception of the **LookAhead Gain** which is best maintained at low values.

With **Data Type** set to **Height**, view the real time scan in **Scope** mode with the Y scan disabled to set the gains. This allows you to tune the feedback while looking at a single scan line of data. Increase the **Integral Gain** until oscillations first appear then decrease the gain slightly. Adjust the **Proportional** and **LookAhead Gains**. High frequency noise in the image indicates the **Proportional Gain** is set too high. Oscillations in **Scope** mode images and ripples in top view images indicate the **LookAhead Gain** is set too high which may cause instability in the feedback loop. You may also adjust the **Setpoint** current and **Bias** voltage in **Scope Mode**.

4.4.2 Scan Rate

You cannot conduct large scans at the same scan rate as small scans. When using the large scan heads with scans above a few microns, lower the **Scan Rate** to below **10 Hz**. You will obtain the best results at scan rates of **1 Hz** or less although image taking is slow. At these scan rates, the 128 x 128 and 256 x 256 data formats are most useful, quadrupling and doubling the frame rate over the 512 x 512 format for a given scan rate. To verify there is no image degradation due to too high a scan rate, lower the rate and check for changes in the image. Verify the scan is not slew-rate limited in Z, as evidenced by an artificial sawtooth appearance in the scope trace in **Scope** mode view.

4.4.3 Setpoint

Setpoint refers to how much tip-sample force is maintained.

Chapter 5 Basic Operation

5.1 Overview

This chapter includes information regarding NanoScope® Scanning Tunneling Microscope (STM) basic operation procedures. Specifically, this chapter details removal and installation of the microscope head, mounting the probe, loading and positioning samples and general information regarding engaging and withdrawing the tip.

5.2 Real Time Imaging

5.2.1 Imaging Pyrolytic Graphite Samples

This procedure details how to use the NanoScope STM to image graphite atoms in highly ordered pyrolytic graphite (HOPG).

> **Note:** The procedure includes instructions for cleaving the sample, although typically there is no reason to re-cleave the sample. The sample is already cleaved and clean enough to image.

1. Place the STM on the vibration-isolation pad.
2. Verify the STM is connected to the controller via the 37-25 pin ribbon cable.
3. Carefully remove a layer of the graphite with sharp tweezers or by pressing sticky tape to the surface to cleave the sample.

   > **Note:** The graphite is slippery. Be careful when you handle the sample.

4. Place the sample under the sample-holding clip, with about half the sample extending forward from underneath the wire.
5. Remove a new tip from the small plastic box shipped with the system, grasping the tip near the sharp end with a pair of tweezers.
6. Insert the blunt end of the tip into the tip holder so that it extends approximately 2 millimeters beyond the end of the head and sits securely in the outfielder.

   > **Note:** Handle the head as little as possible to prevent thermal drift. Handling the head by the protective cap on the top reduces warming of the head.

7. Adjust the threaded screws in the base so that the head does not rest on the sample-holding clip nor does the tip touch the sample.

   > **Note:** Adjust the front screws for coarse adjustment by rotating the handles at the end of the screws. Adjust the rear screw by rotating the tube which couples the screw to the stepper-motor drive shaft.

8. Align the hole, groove and flat located on the underside of the head with the three magnetic balls mounted on the threaded screws in the base.
9. Secure the head on the base by aligning and fitting the hole with the right magnetic ball, then rotating the head about the right magnetic ball until the groove fits around the left magnetic ball and finally, the flat comes in contact with the rear magnetic ball.
10. Insert the 9-pin preamp plug into the socket located on the base support.

CAUTION: Do not force the head onto the base. Excessive pitting in the flat area may cause irregular engagement.

11. Lower the tip using the coarse-adjustment screws and the 25x magnifier until the tip is approximately 0.10 millimeter (0.004 inch) or less above the sample, making sure to lower the head parallel to the sample without tilting to one side or another.
12. Verify the end of the tip is slightly above the reflected image of the tip on the sample surface.
13. Verify the power switch located on the rear of the controller is in the **On** position.
14. Start the main software program “Z”.
15. Select **Real Time > Microscope > Select** to select the scan head and the scan parameters appropriate for that scan head.
16. Verify the scan parameters are set as follows (See Table 5.2a).

Table 5.2a Scan Parameters for Graphite Samples

Parameter	Value
Scan Size	2.00 V
X Offset	0.00 V
Y Offset	0.00 V
Data Type	Current
Data Scale	1.00 nA
Line Direction	Retrace
Scan Angle	0 °
Number of Samples	256
Scan Rate	28-122 Hz
Y Scan	Enabled
Integral Gain	2.00
Proportional Gain	2.00
LookAhead Gain	0.00
Feedback Type	Log
Bias	20 mV
Setpoint	2 nA
Filter	None
Offline Planefit	Enable

17. Select **Motor > Engage** to engage the system.

    Note: The status bar located at the bottom of the control monitor screen indicates system status and how far the tip has traveled in microns. If the travel distance exceeds 250 microns, engagement halts and the software prompts you to check tip alignment. Successful engagement is when the tip engages with the surface and tunneling begins, signified by the message **ENGAGED** in the status bar.

18. Verify a good image begins to form on the display monitor screen.

    Note: A good image is one which clearly shows the repeating pattern of the carbon atoms without drift or noise.

19. Adjust the scan parameters (e.g., integral and proportional gains, bias voltage, scan size, X and Y offsets) to make fine adjustments to the image.

20. Select **View > Scope** to view the signal for each trace across the sample.

21. Select **Capture > Capture** to save the current scan image in the directory.

    Note: Use the **Capture Filename** command to define a custom filename or the captured file will be named with the concatenation of the date and time.

22. Use the various offline analysis and modify functions to manipulate your captured and saved images.

5.2.2 Imaging Gold Calibration Rulings

A calibration ruling ships with systems purchased with the 12 μm range, D scan heads. This procedure describes how to image the ruling and assumes you are familiar with the procedure for imaging graphite.

1. Place the STM on the vibration-isolation pad.

2. Verify the STM is connected to the controller via the 37-25 pin ribbon cable.

3. Place the calibration ruling (ruled side up) under the sample-holding clip, with about half the sample extending forward from underneath the wire.

   Note: If the sample tilts up in the front with the pressure of the sample-holding clip, loosen the two thumb screws, lift the sample clip and retighten the thumb screws.

4. Remove a new tip from the small plastic box shipped with the system, grasping the tip near the sharp end with a pair of tweezers.

5. Make a small bend in the tip and insert the blunt end of the tip into the D scan head tip holder so that it extends approximately 2 millimeters beyond the end of the head and sits securely in the outfielder.

Note: Handle the head as little as possible to prevent thermal drift. Handling the head by the protective cap on the top reduces warming of the head.

6. Adjust the threaded screws in the base so that the head does not rest on the sample-holding clip nor does the tip touch the sample.

   Note: Adjust the front screws for coarse adjustment by rotating the handles at the end of the screws. Adjust the rear screw by rotating the tube which couples the screw to the stepper-motor drive shaft.

7. Align the hole, groove and flat located on the underside of the head with the three magnetic balls mounted on the threaded screws in the base.

8. Secure the head on the base by aligning and fitting the hole with the right magnetic ball, then rotating the head about the right magnetic ball until the groove fits around the left magnetic ball and finally, the flat comes in contact with the rear magnetic ball.

9. Insert the 9-pin preamp plug into the socket located on the base support.

CAUTION: Do not force the head onto the base. Excessive pitting in the flat area may cause irregular engagement.

10. Lower the tip using the coarse-adjustment screws and the 25x magnifier until the tip is approximately 0.10 millimeter (0.004 inch) or less above the sample, making sure to lower the head parallel to the sample without tilting to one side or another.

11. Verify the end of the tip is slightly above the reflected image of the tip on the sample surface.

12. Verify the power switch located on the rear of the controller is in the **On** position.

13. Start the main software program “Z”.

14. Select **Real Time > Microscope > Select** to select the scan head and the scan parameters appropriate for that scan head.

15. Verify the scan parameters are set as follows (See Table 5.2a).

Table 5.2b Scan Parameters for Gold Calibration Rulings

Parameter	Value
Scan Size	100.00 V
X Offset	0.00 V
Y Offset	0.00 V
Data Type	Height
Data Scale	150 nm
Line Direction	Retrace
Scan Angle	0 °
Scan Rate	1.53 Hz
Y Scan	Enabled
Integral Gain	5.00
Proportional Gain	7.00
LookAhead Gain	0.00
Feedback Type	Log
Bias	100.0 mV
Setpoint	3 nA
Offline Planefit	Enable

16. Select **Motor > Engage** to engage the system.

    Note: The status bar located at the bottom of the control monitor screen indicates system status and how far the tip has traveled in microns. If the travel distance exceeds 250 microns, engagement halts and the software prompts you to check tip alignment. Successful engagement is when the tip engages with the surface and tunneling begins, signified by the message **ENGAGED** in the status bar.

17. Adjust the scan parameters (e.g., integral and proportional gains, bias voltage, scan size, X and Y offsets) to make fine adjustments to the image.

18. Select **View > Scope** to view the signal for each trace across the sample.

19. Select **Capture > Capture** to save the current scan image in the directory.

    Note: Use the **Capture Filename** command to define a custom filename or the captured file will be named with the concatenation of the date and time.

20. Use the various offline analysis and modify functions to manipulate your captured and saved images.

Chapter 6 Advanced Operation

6.1 Overview

This chapter includes information regarding NanoScope® Scanning Tunneling Microscope (STM) advanced operation procedures. Specifically, this chapter details spectroscopy with the STM.

6.2 Spectroscopy with the STM

The NanoScope STM performs limited spectroscopic operations under the two scanning tunneling spectroscopy STS modes of operation. The variation of the tunneling current due to variations of the bias voltage or tip-to-sample separation can be tested and recorded at a single point with the **View > STS Plot** modes.

6.2.1 STS Plot Modes

In the STS Plot modes, the tip is positioned at a point on the surface, and a spectroscopic plot is acquired and displayed in a scope format. Between plots, the feedback is run to establish the tunneling current to the setpoint value. The different types of STS plots that can be acquired are:

STS i(v)

The tunneling current as a function of the bias voltage is displayed. The tip height is held constant while the I-V plot is being acquired. In addition to I versus V,

$\frac{di}{dv}$, $\frac{d\ln(i)}{dv}$, $\frac{d\ln(i)}{d\ln(v)}$ versus V can be plotted.

STS i(s)

The tunneling current as a function of the tip height is displayed. The bias voltage is held constant while the I-S plot is being acquired. In addition to I versus S, ln(I) versus S can be plotted.

6.2.2 STS Operation

In the following sections, the operation of the spectroscopic functions of the NanoScope STM will be discussed. Additional information can be obtained from the *Bruker Command Reference Manual*.

There are several items that you should be aware of when using the NanoScope to acquire spectroscopic plots with the STS Plot commands. The spectroscopic capabilities can provide information that can help to distinguish different species although exact species identification is difficult, especially in air. The spectroscopic plots should aid in comparative studies between samples or between different regions on a sample, but they will not reveal the precise make up of that sample.

A comparison to STM imaging reveals two somewhat conflicting requirements. As a good starting point, the sample and tip should produce consistent STM images. The images should repeat well from frame to frame and be fairly free of noise or areas on the surface that appear unstable. For I versus V type plots, the spectroscopic plots may be nice and smooth and repeat well, but switching back to the STM imaging mode reveals images which are quite noisy. This can be attributed to the fact that the quality and uniformity of the tip is probably more critical for imaging than for making the rather simple spectroscopic plots. This is generally not true for the I versus S plots. Some general recommendations for acquiring spectroscopic plots are:

- Low settings for the Integral gain are preferred. Since the tip is not tracking any topography, the lower gains are acceptable and tend to make the plots more stable.
- The maximum input range of ±100 nA on the NanoScope with the standard preamps will restrict the I versus V plots.
- The STS Plot modes will not work with old style STMs which include an Absolute Value Preamplifier. This style STM was used with the NanoScope with serial numbers up to about 150. Please call Bruker if there is a question as to which type of preamp your STM contains.
- The spectroscopic functions do not adjust for any loss of bias voltage due to IR losses caused by the input impedance of the preamplifier. This has different effects for the STS i(v) and STS i(s) functions which are discussed individually below.

STS i(v)

The small scan range heads for the NanoScope have the tip holder mounted on the front of the piezo for increased visibility of the tip. Unfortunately, mounting the tip on the front introduces an asymmetry that can become evident when measuring I versus S spectroscopic plots. The problem is that changes in the height of the tip, S, can cause small translations in the X-Y position of the tip. These small translations introduce a structure into the I versus S plot that is due to the translation and is not an actual spectroscopic effect. The G and J heads have the tip mounted in the center which preserves the symmetry. If the asymmetry presents a problem in your application, you may wish to use a G or J head.

A second consideration is that the input impedance of the preamplifier leads to reduced bias voltages at increased tunneling currents. This effect can cause the I versus S plot to be inaccurate. For example, a bias voltage of 20 mV will restrict the upper limit of the tunneling current to 20 nA since that level of current would effectively reduce the bias voltage to zero. Even before the tunneling current gets to 20 nA, the reduced bias voltage will make the measured current appear lower than it should be for a given tip height.

In summary, the following optimizations can be achieved in the hardware to fully accommodate the requirements of acquiring spectroscopic plots:

- Heads with truly grounded inputs (zero input impedance) can be used to alleviate the effects of bias voltage reduction at increased tunneling currents.
- Heads with center-mounted tips can be used to alleviate the problem with tip translation with modulations in tip height.
- Base supports without Absolute Value Preamps can be used to not invert the I versus V plots at positive bias voltages.

Chapter 7 Maintenance

7.1 Overview

This chapter details the following topics:

- **Overview:** Section 7.1
- **NanoScope Controller:** Section 7.2
- **Base:** Section 7.3
- **Base Support:** Section 7.4
- **Tips:** Section 7.5
- **STM Calibration:** Section 7.6
- **Piezoelectric Linearity:** Section 7.7
- **Calibration of A Heads for Atomic-Scale Measurement:** Section 7.8
- **X-Y Calibration Using Capture Calibration:** Section 7.9
- **Autocalibration:** Section 7.10
- **Fine-tuning for X-Y Measuring Accuracy:** Section 7.11
- **Fine-tuning for Z Measuring Accuracy:** Section 7.12

7.2 NanoScope Controller

None of the circuit boards or components in the NanoScope controller is customer serviceable. If you experience any trouble with the unit, return the controller to Bruker for repair or replacement. Enclose the unit in a static-free bag and pack in at least four inches of Styrofoam packing chips on all sides and ship to:

Bruker Corporation
112 Robin Hill Road
Goleta, CA 93117

7.3 Base

The base requires occasional maintenance to ensure consistent error-free operation. The magnetic balls tend to attract small iron pieces and must be cleaned periodically. The entire base, including the screws, can be removed from its support for cleaning or to mount samples. When replacing the base, you may need to rotate the stepper-motor drive shaft to align the hex drive on the rear screw with the hex socket connected to the stepper-motor shaft.

The base can be secured to the support with a 1/4 – 20 socket head screw, but it is not necessary to use this screw.

7.4 Base Support

To prevent excessive vibration of the head during engagement, a low-power stepper motor is used. If the rear screw becomes difficult to turn because of an accumulation of dust in the threads, the motor will not drive the screw. Place a finger lightly on the stepper-motor shaft during engagement advance to feel if it is rotating. If it does not move, or if the motion is erratic, remove the rear screw from the base, clean the threads, and lubricate the threads with a light grease.

7.5 Tips

7.5.1 Replacing the Tip

1. Select **Motor > Withdraw** to stop scanning and retract the probe from the sample surface.

    Note: The message **Secured** appears in the status bar of the control monitor screen.

2. Turn the left coarse-adjustment screw a few turns.
3. Disconnect the cable to the preamplifier.
4. Remove the head.
5. Replace the tip.

    Note: Verify there is adequate clearance between the new tip and sample surface once you install the new tip.

7.6 STM Calibration

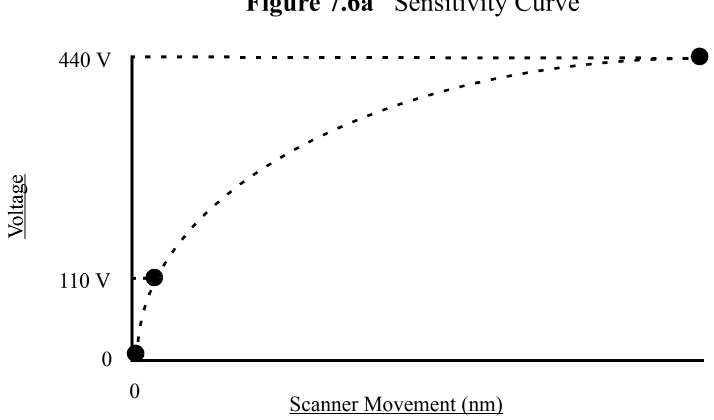
The heads are the only component of the STM requiring calibration. All STM heads are calibrated before shipment; however, to maintain high accuracy, check and recalibrate, if necessary, every 3-4 months. Periodically verifying the measuring accuracy of your STM ensures that images are dimensionally represented within acceptable limits of error.

7.6.1 Calibration Theory

Bruker employs various derating and coupling parameters to model the nonlinear characteristics of the STM heads. By precisely determining points along the scanner's sensitivity curve, then applying a rigorous mathematical model, we can achieve full-range measuring capabilities accurate to better than 1 percent.

Consider the sensitivity curve represented in Figure 7.6a:

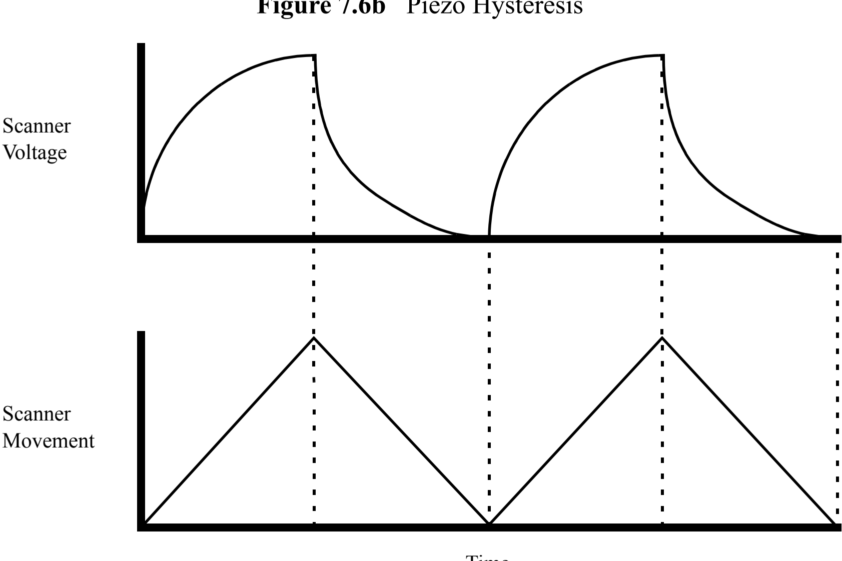
Figure 7.6a Sensitivity Curve



This curve typifies scanner sensitivity across the full range of movement. The vertical axis denotes voltage applied to the scanner. The horizontal axis denotes scanner movement. At higher voltages, the scanner's sensitivity increases (i.e., more movement per voltage applied). At zero volts, the scanner is motionless. Plotting each point along the curve describes a second-order, exponential relationship which provides a rough approximation of scanner sensitivity.

However, because piezo materials exhibit hysteresis, their response to increasing voltage is not the same as their response to decreasing voltage. That is, piezo materials exhibit memory, which causes the scanner to behave differently as voltages recede toward zero. The graph detailed in Figure 7.6b represents this relationship.

Figure 7.6b Piezo Hysteresis



To produce the sharp, linear movements (triangular waveform) required for accurate raster scanning, it is necessary to shape the applied voltage as shown in the top graph in Figure 7.6b. Moreover, the applied voltage must compensate for scan rate and scan size. As scan rate slows, the applied voltage must compensate for increased memory effects in the piezo material. As scan size decreases, the piezo exhibits more linearity. These effects are further complicated by X, Y, Z coupling effects (the tendency for one axis to affect movement in other axes).

Through rigorous quality control of its scanner piezos, Bruker has achieved excellent modeling of scanner characteristics. Two calibration points are typically used for fine-tuning: at 150 and 440 volts. A third point is assumed at 0 nm/volts. These three points yield a second-order sensitivity curve to ensure accurate measurements throughout a broad range of scanner movements.

Because scanner sensitivities vary according to the amount of applied voltage, you must thoroughly scan the calibration standard at a variety of sizes and angles and enter the distance between known features on the calibration standard surface into the software. The parameter is recorded to compensate the scanner's movements. You may calibrate the X, Y and Z axes in any sequential order; however, you must perform the linearization adjustments before attempting any calibrations (otherwise, they will be undone by the linearity adjustments).

The calibration values for all of the heads are maintained in the parameter file associated with the head supplied with your system. For example, the calibration values for the 12 micron D head are in a file named “xxxhd.scn”. All of the parameter files for the heads are in the EQUIP directory.

Complete the following procedure to calibrate your system:

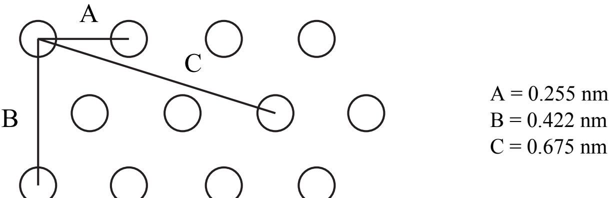
1. Back up the parameter files before starting the calibration procedure.

2. Image the appropriate calibration standard for your system.

Note: Graphite is the calibration standard supplied with systems shipped with the 0.5 micron A head. Two-dimensional grids are used as calibration standards for the longer range heads.

3. Compare the interatomic spacing for your calibration system compared to the known values (See Figure 7.6c).

Figure 7.6c Graphite Calibration Standard Atomic Spacing



Note: Average over as many atoms as possible for best results. Capture several consecutive pairs of up and down scans to average out the effect of drift on sensitivity and orthogonality.

4. If the results are not satisfactory, continue with the remainder of the calibration procedure described below.

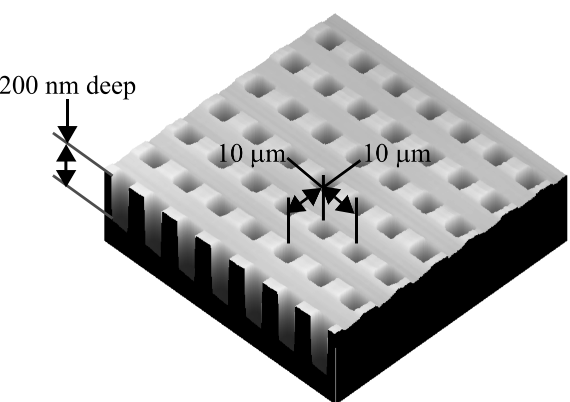
Note: The **Capture Calibration** and **Autocalibration** routines are designed to optimize measuring accuracy over the entire measuring range of the scanner. In order to obtain the finest accuracy possible for a given scan size, the scanner calibration parameters can be manually fine-tuned. This may prove useful in applications where measuring accuracy must be better than 1 percent.

7.6.2 Calibration Standards

Each head exhibits its own unique sensitivities; therefore, it is the task of the user and software to precisely measure these sensitivities, then establish software parameters for controlling the head. This task is accomplished with the use of a calibration height standard (See Figure 7.6d). As the primary tool in STM calibration, calibration standards serve as measuring sticks used to gauge scanner displacement for a given voltage. The STM is capable of measuring a calibration standard with 2 percent or better accuracy when scanning at maximum scan size. Use fine calibration techniques to calibrate the STM with better accuracy.

Note: Older calibration standards are 180nm deep and ship without labels. Newer calibration standards are 200nm deep and ship with labels.

Figure 7.6d Calibration Height Standard



The calibration height standard shown in Figure 7.6d consists of a silicon substrate plated with platinum with a regular series of pits, each 200 nm deep. Pits are spaced at 10µm apart from centers. Other, similar surfaces are available with different dimensions. Atomic-scale calibrations are generally carried out with mica or graphite, which exhibit very regular atomic lattices.

7.7 Piezoelectric Linearity

A linear voltage ramp applied to many piezo heads will not generate a linear position response. To get linear motion out of the heads, a patented nonlinear waveform is applied to the piezo. For heads with relatively small scan ranges such as A, D and F heads, the deviation from linearity is consistent; the values in Table 7.7c should produce a linear response. The linearity of the G heads is are a little more individualistic; the characteristics of the J heads are even more individualistic. Therefore, individual linearity correction parameters have been assigned to all J heads and some G heads.

7.7.1 Nonlinearity Correction Background Information

The scan waveform applied to the head actually consists of a linear ramp added to a decaying exponential of varying magnitude and argument. There are three parameters for both X and Y that describe the shape of the applied scan waveform for a given scan size.

Table 7.7a X and Y Parameters

Scan Size	Parameter	Function
Mag0	Correction Magnitude	Determines the amount of the exponential term to use, and how that amount varies with the scan size.
Mag1	Correction Magnitude Derating	
Arg	Correction Argument	Determines the exponential decay of the nonlinear term.

The normalization is applied so that S=1 corresponds to a scan size of 440 volts, x=1 and t=1 correspond to the scan having made it once across.

$$B = S(\mathrm{Mag0} - \mathrm{Mag1}\ln(S))$$

$$C = \frac{1}{\left(1 + \frac{B}{\mathrm{Arg}}\right)(1 - e^{-\mathrm{Arg}})}$$

$$x' = C(1 + Be^{-\mathrm{Arg}t})$$

$$x = C\left(t + \frac{B}{\mathrm{Arg}} \cdot (1 - e^{-\mathrm{Arg}t})\right)$$

where the symbols are defined as follows:

Table 7.7b Nonlinearity Correction Equation Definitions

Symbol	Definition
B	Derated correction magnitude
C	Normalization constant
S	Scan Size
x’	Derivative of the scan waveform
x	Scan waveform
t	Independent “time” variable of the scan

7.7.2 Linearity Correction Procedure

For applications demanding good linearity, use the linearity correction procedure to optimize the linearity correction parameters for individual heads. As discussed previously, linearity correction is especially important for long-range heads (e.g., G and J heads).

Orthogonality

1. Select **Real Time >Microscope** to set the system for **STM** imaging.
2. Select the appropriate head type under **Scanner**.
3. Check head parameter values.

   Note: If the original head parameter values have been deleted, copy the head parameter values from the software back-up disk shipped with every system. Individually purchased scanners ship with either a disk containing the back-up files or a hard copy of the scanner parameters. Contact Bruker for head calibration records (See How to Reach Bruker in the Preface).

4. Set the correction terms to approximate the values detailed in Table 7.7c.

Table 7.7c Typical Linearity Parameters

	X B0 (X mag0)	X B1 (X mag1)	X K (X arg)	Y B0 (Y mag0)	Y B1 (Y mag1)	Y K (Y arg)
STM/AFM A	0	0	3	0	0	3
STM/AFM D, E	1.30	0	1.24	1.30	0	1.24

	X B0 (X mag0)	X B1 (X mag1)	X K (X arg)	Y B0 (Y mag0)	Y B1 (Y mag1)	Y K (Y arg)
STM/AFM F	1.15	0	5.00	1.15	0	5.00
STM/AFM G	1.19	0.88	2.50	1.09	0.80	2.50
STM/AFM J	1.35	1.09	3.50	1.50	0.85	3.50

5. Load the calibration standard onto the STM.

6. Set the **Scan Angle** to **0 degrees**.

7. Align the calibration standard with the head so that the tip scans parallel to the calibration standard features, with no more than 2 degrees of perpendicularity to the scan axes (See Figure 7.7a).

Note: For D and DI heads, use a 1 micron pitch calibration standard. For G and J heads, use a 10 micron pitch calibration standard.

Figure 7.7a Calibration Standard Alignment

Scan angle = 0°

8. Set **Real Time** parameters as detailed in Table 7.7d.

Table 7.7d Linearity Parameters Menu Settings

Menu Item	Value
Scan Size (volts)	440
X Offset (nm)	0.00
Y Offset (nm)	0.00
Scan Angle (degrees)	0.00
Scan Rate (Hz)	2.44
Number of Samples	256
Slow Scan Axis	Enabled
Z Limit (volts)	440
Units	Volts
Data Type	Height
Data Scale (volts)	20

9. Select **Real Time > Motor > Engage** or click on the **ENGAGE** icon to engage the surface.

10. Verify the scan line is orthogonal relative to the calibration standard features (e.g., pits).

    Note: To improve perpendicularity, select **Real Time > Motor > Withdraw** or click on the **WITHDRAW** icon and rotate the sample. Repeat until the features orient orthogonally with the scan frame.

11. Select **Offline > View > Top View** to check the captured image for orthogonality along both the X and Y axes.

12. Select the **Angle** command.

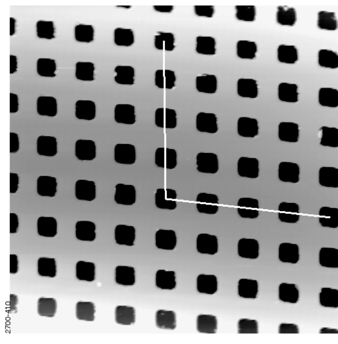
13. Use the mouse and cursor to draw a line between the edges or centers of widely spaced pits (See Figure 7.7b).

14. Measure the angle with the vertex near the center of the image and the vertices in the upper-right or lower-left quadrant.

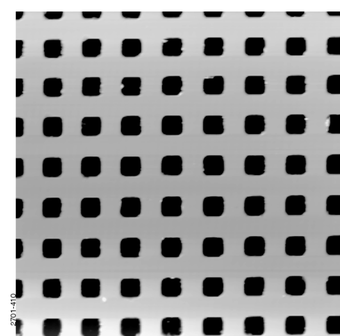
    Note: The angle displays on the white status bar located at the bottom of the display monitor.

15. If the angle differs by more than 0.5 degree, you must correct the scan for orthogonality. If the angle differs less than 0.5 degree, proceed directly to the steps for adjusting linearity.

Figure 7.7b Orthogonality Along X and Y Axes



Non-orthogonal Image



Corrected, Orthogonal Image

16. To adjust scan orthogonality, select **Real Time > Microscope > Calibrate > Scanner** to display the **Scanner Calibration** panel.

17. Enter the difference between 90 degrees and the angle measured in the **Top View** image.

18. Click **OK** to exit the **Scanner Calibration** panel.

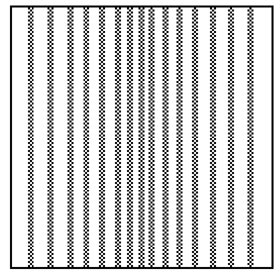
19. Repeat steps 8 through 14 until the captured image measures less than 0.5 degree of error.

Note: Changes to the orthogonality parameter may require physical realignment of the calibration standard to the image frame.

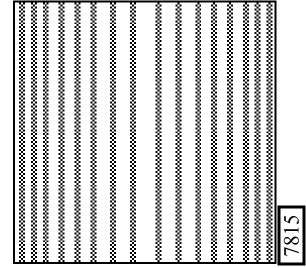
Fast Mag0 and Fast Arg

1. View the **Real Time** image and assess the linearity by apparent compression and expansion of the rulings (See Figure 7.7c).

Figure 7.7c Fast Scan Linearization



Center Compressed



Center Expanded

Note: As parameter values change, the effects display on the display monitor. Only compare the part of the scan drawn since the last parameter change. The display monitor itself is not linear, therefore the best way to assess linearity is

using the zoom box to compare the ruling spacing in different portions of the image.

2. Move the cursor to the display monitor and select **Zoom Out** to display the zoom box.

3. Change the size and position of the zoom box by clicking and dragging the cursor over the image.

4. Adjust the zoom box until the box is approximately one-third the size of the scan.

   Note: Keep in mind which part of the scan is the beginning and which is the end. When **Line Direction** is set to **Trace**, the beginning of the scan is on the left. When viewing vertical scans, check the image against itself, not the residual image from the previous scan.

5. Move the zoom box to the beginning of the fast scan and position and size the zoom box until the beginning-third of the scan features are exactly aligned within the zoom box.

   Note: The beginning-third of the scan is typically the standard for assessing linearity values. Ignore the set of features near the scan edges as these may be slightly distorted.

6. Move the zoom box to the end-third of the scan and position and size the zoom box around the features.

7. Compare the features in the beginning-third of the scan to the end-third of the scan.

8. Select **Real Time > Microscope > Calibrate > Scanner** to display the **Scanner Calibration** panel.

9. Set **Fast Mag0** and **Fast Arg** as detailed in Table 7.7e.

   Note: Change Mag0 values in increments of 0.1 to 0.3 units and Arg values in increments of 0.2 to 0.5 units. Each time you change a parameter value, the entire scan axis is affected; you must resize the zoom box at both the beginning- and end-third of the scan after every change.

Table 7.7e Fast Mag0 and Fast Arg Values

If the Image is	Then
Relative to the beginning third:	
Expanded in the end-third	Decrease Fast Mag0
Compressed in the end-third	Increase Fast Mag0
Compressed in the center but equal at the sides	Increase Fast Arg
Expanded in the center but equal at the sides	Decrease Fast Arg

Note: After making an adjustment in **Fast Arg**, you may need to readjust **Fast Mag0**. Continue alternately adjusting **Fast Mag0** and **Fast Arg** until the rulings are evenly spaced across the fast axis. If you are using a one-dimensional calibration standard, you may want to adjust **Fast Mag1** before continuing; adjusting the slow linearity requires you to rotate the one-dimensional calibration standard 90 degrees. After adjusting **Fast Mag1**, return to this point in the procedure.

10. After setting **Fast Mag0** and **Fast Arg**, insert these values for **Slow Mag0** and **Slow Arg** approximations.

Slow Mag0 and Slow Arg

Note: The **Fast Mag0** and **Fast Arg** values serve as close starting points before adjusting the slow linearities. Setting the slow linearities requires more time because you must wait until a new third of the scan begins with the new parameter change before you can resize the zoom box. Be careful not to confuse top and bottom with beginning and end of the scan because the scan direction alternates.

1. View the **Real Time** image and assess the linearity by apparent compression and expansion of the rulings (See Figure 7.7d).

Figure 7.7d Scan Linearization

Center Compressed

Center Expanded

Note: As parameter values change, the effects display on the display monitor. Only compare the part of the scan drawn since the last parameter change. The display monitor itself is not linear, therefore the best way to assess linearity is using the zoom box to compare the ruling spacing in different portions of the image.

2. Move the cursor to the display monitor and select **Zoom Out** to display the zoom box.

3. Change the size and position of the zoom box by clicking and dragging the cursor over the image.

4. Adjust the zoom box until the box is approximately one-third the size of the scan.

5. Click once on the right mouse button to fix the zoom box position and free the cursor for **Execute**.

   Note: Keep in mind which part of the scan is the beginning and which is the end. When **Line Direction** is set to **Trace**, the beginning of the scan is on the left. When viewing vertical scans, check the image against itself, not the residual image from the previous scan.

6. Move the zoom box to the beginning of the scan and position and size the zoom box until the beginning-third of the scan features are exactly aligned within the zoom box.

   Note: The beginning-third of the scan is typically the standard for assessing linearity values. Ignore the set of features near the scan edges as these may be slightly distorted.

7. Move the zoom box to the end-third of the scan and position and size the zoom box around the features.

8. Compare the features in the beginning-third of the scan to the end-third of the scan.

9. Select **Real Time > Microscope > Calibrate > Scanner** to display the **Scanner Calibration** panel.

10. Set **Slow Mag0** and **Slow Arg** as detailed in Table 7.7f.

Table 7.7f Slow Mag0 and Slow Arg Values

If the Image is	Then
Relative to the beginning third:	
Expanded in the end-third	Decrease Slow Mag0
Compressed in the end-third	Increase Slow Mag0
Compressed in the center but equal at the sides	Increase Slow Arg
Expanded in the center but equal at the sides	Decrease Slow Arg

Note: After making an adjustment in **Slow Arg**, you may need to readjust **Slow Mag0**. Continue alternately adjusting **Slow Mag0** and **Slow Arg** until the rulings are evenly spaced across the slow axis.

Fast Mag1 Initial Adjustment

1. Select **OK** to close the **Scanner Calibration** panel.

   Note: To restore original parameter values select **Restore**.

2. Change the **Scan Size** to **150 volts**.

3. Select **View > Scope Mode**.
4. Select **Dual Trace** on the display monitor.

   Note: If the two scope traces do not overlap, adjust **Fast Mag1**.

5. Select **Slow Scan axis** on the control panel.
6. Use the right or left arrow key on the keyboard to toggle **Slow Scan axis** to **Disabled** when tall features appear on the scope trace.
7. Select **Microscope > Calibrate > Scanner** to open the **Scanner Calibration** panel.
8. Select **Fast Mag1**.
9. Use the left and right arrow keys to change the value until the two traces align.

   Note: The yellow retrace line shifts in the same direction as the arrow.

10. Select **OK** to close the **Scanner Calibration** panel.
11. Set **Slow Scan axi**s back to **Enabled**.
12. Select **View > Image Mode**.

Fast Mag1 Fine Adjustment

Initial adjustment is usually adequate; however, if more precision is desired, do the following:

1. Adjust **Fast Mag1** using the same procedure for adjusting **Fast Mag0**.
2. Set the zoom box for the beginning of the scan and then check the end.

   Note: Because the scan is small, you may need to use a zoom box up to one-half as large as the scan.

3. Set **Fast Mag1** as detailed in Table 7.7g.

Table 7.7g Fast Mag1 Values

If the Image is	Then
Relative to the beginning third:	
Expanded in the end-third	Decrease Fast Mag1
Compressed in the end-third	Increase Fast Mag1

Slow Mag1 Initial Adjustment

1. Verify the **Scan size** is set to **150 volts**.
2. Select **Microscope > Calibrate > Scanner**.
3. Select **Slow Mag1** and input the value from **Fast Mag1**.

   Note: For medium-sized scanners (C to F), you may stop at this point in the procedure, because the **Slow Mag1** value is typically 100-120 percent of the **Fast Mag1** value.

4. Adjust **Slow Mag1** using the same procedure as for adjusting **Slow Mag0**.
5. Set the **Zoom** box for the beginning of the scan and then check the end.

   Note: Because the scan is small, you may need to use a zoom box up to one-half as large as the scan.

6. Set **Slow Mag1** as detailed in Table 7.7h.

Table 7.7h Slow Mag1 Values

If the Image is	Then
Relative to the beginning third:	
Expanded in the end-third	Decrease Slow Mag1
Compressed in the end-third	Increase Slow Mag1

   Note: Wait one complete scan frame with the new value before readjusting the **Slow Mag1** value.

7. Capture an image to check the final linearity adjustment results.
8. Select **Offline > Modify > Zoom** and use the zoom box to check the captured image.

   Note: The head is now ready for calibration of the X and Y parameters.

Linearity Troubleshooting

The following troubleshooting procedures may be useful to access the feature spacing in the image.

Table 7.7i Linearity Correction Procedure Troubleshooting

Issue	Procedure
Compare Line Spacing in Real Time	Use the zoom box and set box size to 2 line widths (x) or 2 line heights (Y) in the center of the screen. Move the box to a new position and compare line spacing.
Measure Line Spacing with Greater Accuracy	To measure line spacing with greater accuracy, capture a picture, view it offline, measure the spacing between each line, and judge compression or expansion.
Screen Distortion	Adjust the picture size with the controls on the monitor reduces the effect of distortion.
Microscope Thermal Instability	Verify the microscope has stabilized thermally before attempting to adjust the linearity-correction parameters.
Overshooting	After a turnaround of the frame at either the top or the bottom, the newly plotted lines or features appear after the same lines in the previous frame. This is normal.
Undershooting	After a turnaround of the frame at either the top or the bottom, the newly plotted lines or features appear before the same lines or features in the previous frame. This is normal.

Piezoelectric Sensitivity and Derating

The sensitivity of the piezoelectric tube in nanometers per volt and the derating of the piezo sensitivity as the scan voltage decreases are calibrated using the **Head Autocalibrate** command in the **Offline > Utility** menu. Prior to using the **Head Autocalibrate** command, you must capture the calibration images with the **Capture Calibration** command in the **Real Time > Capture** menu. Each head type (A, D, G and J) requires a different standard for the calibration, because each head has a different scan range. Graphite is used for the A head while two-dimensional gratings are used for the other heads.

The sensitivity of the piezoelectric tube decreases as the applied range of the applied scan voltage reduces. Over a small scan range, the sensitivity of the piezo is constant and a plot of scan size versus scan voltage is linear. However, for large scans, sensitivity variations are an important factor. For example, the A head is relatively constant in sensitivity, but the D, G and J heads show sensitivity variation.

7.8 Calibration of A Heads for Atomic-Scale Measurement

The A head is the smallest head, with a total travel of approximately 0.4 micron along each axis. Its compact design lends excellent stability for atomic scans, and requires slightly modified X-Y calibration procedures. These modified calibration procedures are detailed in this section. For atomic-scale measurements, graphite atoms are substituted for the pits seen on silicon calibration standards.

1. Prepare the sample.

   Note: Use highly-ordered pyrolytic graphite (HOPG) for STM calibration. See the procedure detailed in Appendix A for cleaving highly-ordered pyrolytic graphite to obtain a good flat surface.

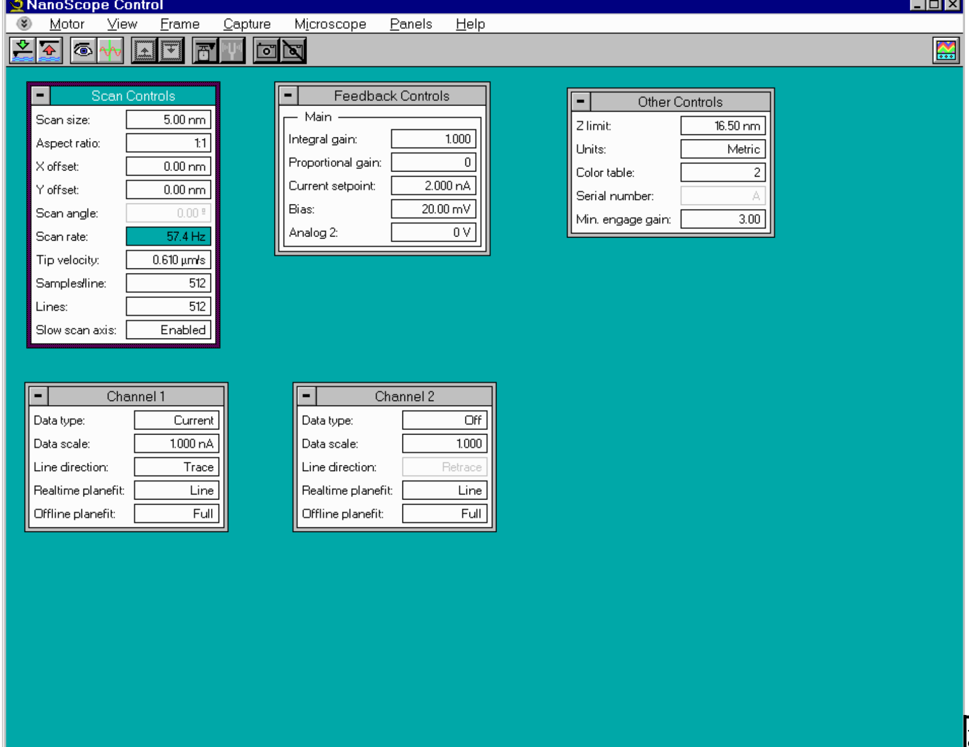
2. Select **Microscope > Profile** to set the microscope to **STM atoms**.

3. Place the sample on one of the bases.

   Note: A base without X-Y capability will have less drift.

4. Verify the **Real Time** parameter settings for A heads (See Figure 7.8a).

Figure 7.8a Typical A Head Parameter Settings



5. Select **Motor > Engage** to engage the surface.

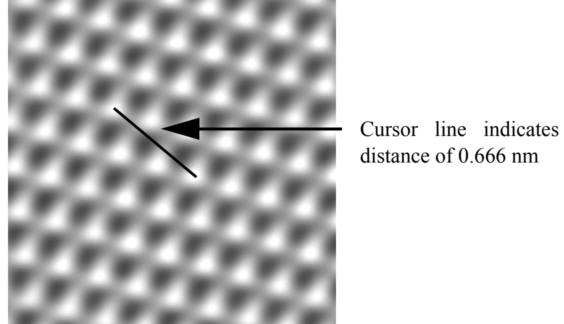
6. Adjust the **Integral gain** and **Setpoint** to obtain a good image in data type current.

   Note: Keep the **Setpoint** low if possible. Notice that the **Scan rate** is set much higher (up to **61 Hz**) for atomic-scale images to defeat some of the variables due to thermal drift. If you find it difficult obtaining an image, **Withdraw** and try a different site on the surface, then **Engage** again. You may find it easiest to obtain good images and measurements if the sample is rotated until atoms are oriented vertically.

7. **Capture** an image.

   Note: The image should appear similar to the image of graphite shown in Figure 7.8b. Note the highly regular lattice of the atoms.

Figure 7.8b Atomic-Scale Image of Graphite

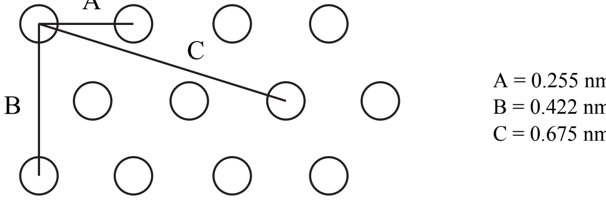


8. Select **Offline > View > Top View**.

9. Measure and record the space between a minimum of 10 atoms using the mouse and cursor.

   Note: The spacings should measure as shown in Figure 7.8c.

Figure 7.8c Atomic Spacing for Graphite



10. Record the space between at least ten atoms observed in the captured image.

Note: For each axis, measure equal numbers of atoms on consecutive images. For example, on consecutive scans, if the atoms align as in Figure 7.8c, then 10 atoms on the X axis average to 2.55 nm (10 atoms x 0.255 nm) and 6 atoms on the Y axis average to 2.60 nm (6 atoms x 0.433 nm).

Correction of the X- and Y-axis is essentially the same procedure as described in the section on Fine-tuning for X-Y Measuring Accuracy. The only significant difference is that the known distances must be adjusted for the smaller, atomic spacings of the atoms. Furthermore, only the sensitivity parameters are adjusted for atomic-scale imaging.

- X fast sens at 0º Scan angle
- Y slow sens at 90º Scan angle

The derating parameters are not adjusted for atomic-scale imaging, including:

- X fast derate
- X slow derate
- Y fast derate
- Y slow derate
- Retracted offset der
- Extended offset der

Complete the following procedure to adjust the **X Fast Sens** value (See Figure 7.8d):

1. Divide the theoretical atomic distance by the measured distance and multiply the quotient by the **X Fast Sens** value used when you collected the image.

$$\frac{\text{Known distance between features}}{\text{STM-calculated distance between features}}$$

2. Enter the new **X Fast Sens** value into the **X Slow Sens** field.

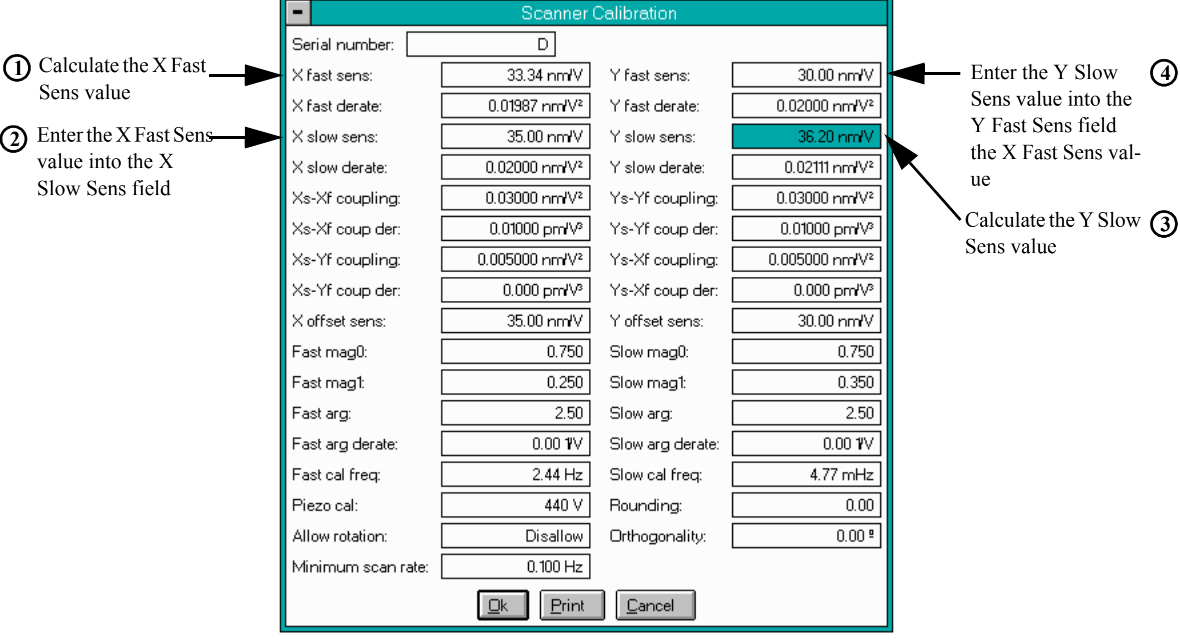
Complete the following procedure to adjust the **Y Slow Sens** value (See Figure 7.8d):

3. Divide the theoretical atomic distance by the measured distance and multiply the quotient by the **Y Slow Sens** value used when you collected the image.

$$\frac{\text{Known distance between features}}{\text{STM-calculated distance between features}}$$

4. Enter the new **Y Slow Sens** value into the **Y Fast Sens** field.

Figure 7.8d Scanner Calibration Panel



7.9 X-Y Calibration Using Capture Calibration

(For Heads Other Than A)

Heads are calibrated by setting parameters in the NanoScope software **Capture Calibration** command. NanoScope software Version 4.XX and later and a 10-micron calibration standard are required for most heads. D and E heads require a 1-micron ruling.

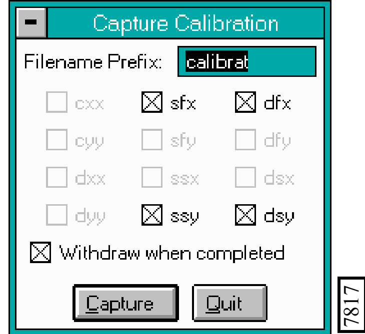
Note: You must perform X-Y calibration with **Capture Calibration** before fine calibration. With the **Scan Rate** set at **2.44 Hz** and **Number of Samples** parameter at **256**, a full **Capture Calibration** requires approximately 70 minutes. Increasing the **Number of Samples**, or decreasing the **Scan Rate** significantly increases the required time.

Complete the following steps to calibrate the X and Y sensitivities and deratings of STM D, G and J heads:

1. Select **Real Time > Microscope** to select the appropriate head type for your system.

2. Select **Real Time > Capture > Calibration** to display the **Capture Calibration** panel (See Figure 7.9a).

Figure 7.9a Capture Calibration Panel



Note: The **Capture Calibration** panel lists twelve parameters used in the calibration procedure. If this is a first-time calibration, or if you have not checked the microscope calibration within the last three months, verify that all parameters are selected. For D and DI heads, rotation is disabled, therefore all but four of the twelve extensions will be grayed out.

3. Click on the **Capture** button to initiate the automatic calibration routine (See Figure 7.9a).

Note: The microscope begins an automatic series of scans on the calibration standard which require approximately one hour total to complete. During each scan, the scanner moves the piezo with carefully calculated movements. Many of these movements are unusual, giving rise to a variety of images which do not look like the normal calibration standard (e.g., pits may resemble trenches, features may be presented at various angles).

4. Adjust the scan to optimize the calibration image using the **Capture Control** panel.

   Note: The **Capture Control** panel displays on the control monitor throughout the calibration routines. Note the status bar at the bottom of the control monitor. The capture status begins at skip 2; the program skips the current and subsequent scan before capturing an image for later calibration. This allows hysteresis and drift to settle when the scan changes direction and size between images. If the scan has not settled by the time the capture status changes to **ON**, click **Skip** to increment the capture to skip 1, skip 2, or skip 3. Do not click on **Abort** unless you want to stop the entire **Capture Calibration** program.

5. Click repeatedly on **Adjust Y Offset / Up** or **Down** if portions of features are missing, or if the image is blank, to display as much of the image as possible (See Figure 7.9b).

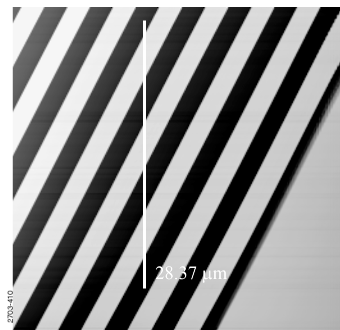
   Note: If portions of features are missing, or if the image is blank, click repeatedly on the button to adjust the scan until more of the features are imaged.

6. Once the image is optimized, allow the software to capture the image.

   Note: The software automatically indexes to the next image.

Figure 7.9b Partial and Adjusted Calibration Images

Partial Calibration Image



Adjusted Calibration Image

Note: Once you have captured the first four images with the diagonal stripe pattern, you may leave the system unattended while the program continues to completion. Some of the images may seem stretched in one dimension; this is normal. Once all calibration images have been obtained, the software prompts the user that it is finished.

7. Open the **Capture** directory (!:) where all **Capture Calibration** files are saved.

8. Select **Offline > File > Browse** or click the **Browse** icon to review all **Capture Calibration** files.

9. Verify all calibration images contain features spanning the full width and height of the image frame.

10. Recapture all images unsuitable for calibration.

11. Record the file name extensions of all unusable files (e.g., .cxy, .dyy) and delete them.

12. Reengage the surface and select **Capture Calibration** again.

13. Verify the file name prefix is identical to that of the usable files, then deselect all usable file name extensions from the last capture.

14. Click the **Capture** icon to recapture the selected files.

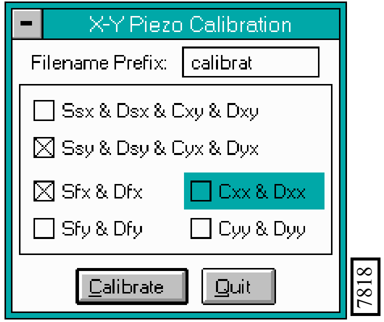
7.10 Autocalibration

Once the **Capture Calibration** routine is complete, you must measure surface features contained within each image and enter their dimensions into the software. The software compares its estimates with the actual (user-entered) dimensions to make final corrections. This section of the calibration is carried out using the **Offline > Utility > Autocalibration** command.

To utilize the **Offline > Utility > Autocalibration** command, complete the following procedure:

1. Select any of the captured calibration images in the **Capture** (!:) directory.
2. Select **Offline > Utility > Autocalibration** to display the **X-Y Piezo Calibration** panel (See Figure 7.10a).

Figure 7.10a X-Y Piezo Calibration Panel



3. Verify the file name prefix assigned to the captured files from the **Capture Calibration** panel (See Section 7.9).
4. Verify the correct parameters are selected in the **X-Y Piezo Calibration** panel.

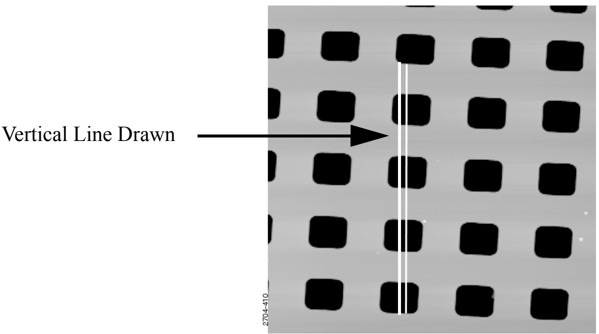
   Note: For D and DI heads, select only **Ssy & Dsy & Cyx & Dyx** and **Sfx & Dfx**.

5. Click **Calibrate** to execute the routine (See Figure 7.10a).

   Note: The software sequentially presents various calibration images on the display monitor.

6. Draw either a vertical line or a horizontal line over the image, spanning as many features as possible; preferably connecting like edges (See Figure 7.10b).

Figure 7.10b Selecting Features for Autocalibration



Note: In Figure 7.10b, a line was drawn from the bottom edge of one feature to the bottom edge of another feature four rows away for a total distance of 40 microns. The control monitor simultaneously displays a dialog box for entering the distance indicated by the white line (See Figure 7.10c). The distance displayed in the box is the software estimate (based on current calibration values) of the length of the line drawn on the image. If the line length is different from the value shown, you must enter the correct value.

Figure 7.10c Autocalibration Sensor Panel

7. Enter the distance covered by the white line drawn on the image.

Note: If you are using a 10-micron calibration standard, like portions of features are spaced 10 microns apart (e.g., between bottom edges, left sides, etc.).

CAUTION: Measure features without regard to how they appear in calibration images. Features may appear stretched, distorted, or angled in appearance due to the unusual movements employed during **Capture Calibration** scanning.

8. Continue drawing lines and entering measured distances until all **Capture Calibration** images are measured.

Note: When the software completes the routine, it prompts the user that it is done. If **Capture Calibration** and **Autocalibration** routines have been completed correctly, the STM should be calibrated within 1-2 percent accuracy over most of the scanner's measuring range. If you require still better accuracy, perform the fine-tuning procedure to obtain maximum measuring accuracy.

7.11 Fine-tuning for X-Y Measuring Accuracy

Fine-tuning is typically performed at two **Scan size** settings: **150** and **440** volts. Both horizontal and vertical measurements of sample features are made then compared with actual distances. Based upon this comparison, computer parameters are fine-tuned. To fine-tune your STM for maximum X-Y measuring accuracy, review each of the steps below.

Complete the procedure below for fine-tuning for X-Y measuring accuracy:

1. Set the **Scan size** parameter on the **Scan Controls** panel to the maximum value (440 volts).
2. Verify the **Scan angle** is set at **0.00** degrees.
3. Mount a calibration standard onto the STM.
4. Engage the surface.

   Note: Possible calibration standards include a generic,10-micron, silicon standard or a sample with features of known dimensions (e.g., grating).

5. Optimize the image quality.
6. Select two widely-spaced features on the sample image of known separation, then use the mouse to draw a horizontal line between them.

   Note: For example, on a 10-micron, silicon calibration standard, draw the line from the left side of one pit to the left side of another pit as far away as possible. The screen displays the measured distance between pits next to the line.

7. Verify the measured distance agrees with the known horizontal distance.

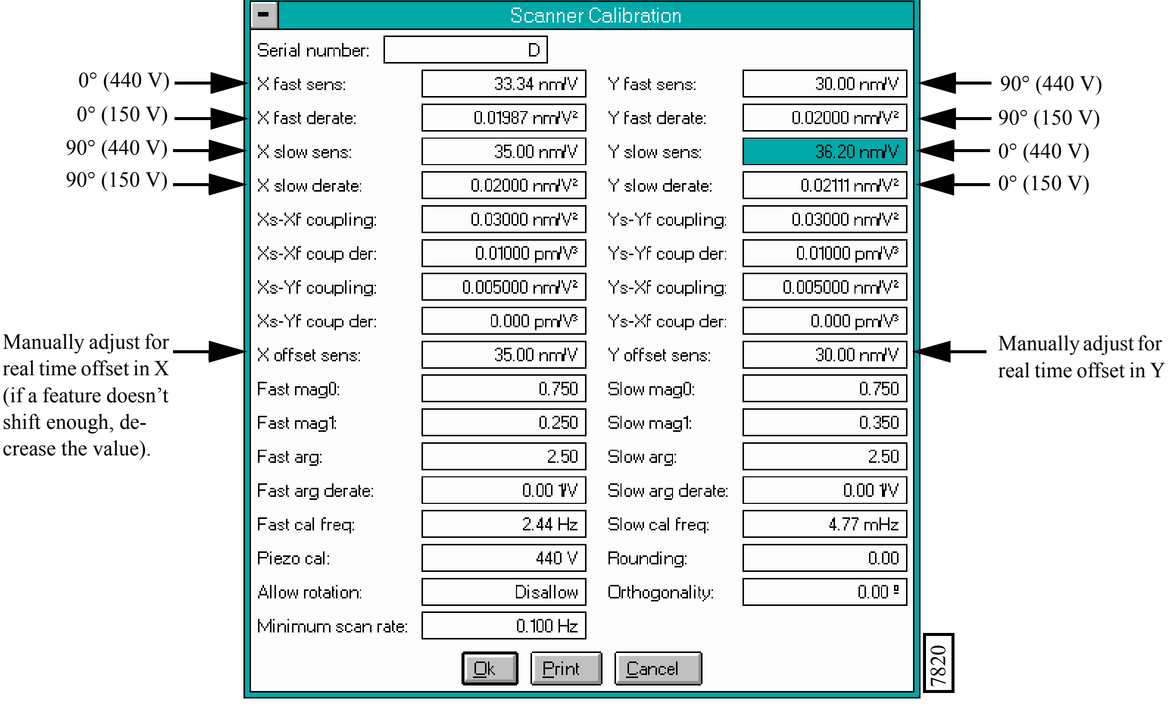
   Note: If there is significant disagreement between the two, fine-tuning is required; proceed to the next step. If the measured distance agrees with the known distance, proceed to Step 16.

8. Divide the known distance by the distance displayed next to the horizontal line drawn over the image and record this quotient.

$$\frac{\text{Known distance between features}}{\text{STM-calculated distance between features}}$$

9. Select **Real Time > Microscope > Calibrate > Scanner** to display the **Scanner Calibration** panel.

Figure 7.11a Scanner Calibration Panel



10. Multiply the quotient by the **X Fast Sens** value (See Figure 7.11a) and enter the new value.

    Note: The new value adjusts the fast axis to more closely match calculated distances with actual feature distances. The new sensitivity setting takes effect immediately after you enter the new value.

11. Click **Ok** to save your changes to the computer hard drive and close the **Scanner Calibration** panel.

12. Return to the image of the calibration standard.

13. Clear the horizontal line drawn by clicking the right mouse button or clicking **Clear**.

14. Draw a vertical line between features.

    Note: The STM displays the calculated distance between features.

15. Verify the measured distance agrees with the known vertical distance.

    Note: If there is significant disagreement between the two, fine-tuning is required; proceed to the next step. If the measured distance agrees with the known distance, proceed to Step 26.

16. Divide the known distance by the distance displayed next to the vertical line drawn over the image and record this quotient

$$\frac{\text{Known distance between features}}{\text{STM-calculated distance between features}}$$

17. Select **Real Time > Microscope > Calibrate > Scanner** to display the **Scanner Calibration** panel (See Figure 7.11a).
18. Record the **Y Slow Sens** value shown on the **Scanner Calibration** panel (See Figure 7.11a).
19. Multiply the quotient by the **Y Slow Sens** value shown on the **Scanner Calibration** panel and enter the new value.

    Note: This adjusts the slow axis to more closely match calculated distances with actual feature distances.

20. Click **Ok** to save the new parameter value.
21. Set the **Scan Size** on the **Scan Controls** panel to one-third the maximum (**150 volts**).
22. Verify the **Scan angle** is set to **0.00** degrees and **Units** (**Other Controls** panel) is set to **Volts**.
23. Select two widely-spaced features on the sample image of known separation and use the mouse to draw a horizontal line between them.

    Note: For example, on a 10-micron, silicon calibration standard, draw the line from the left side of one pit to the left side of another pit as far away as possible. The STM displays the measured distance next to the line.

24. Verify the measured distance agrees with the known horizontal distance.

    Note: If there is significant disagreement between the two, fine-tuning is required; proceed to the next step. If the measured distance agrees with the known distance, proceed to Step 31.

25. Choose either the Trial and Error Method or the Calculation Method to make derating adjustments.

    Note: In the trial and error method you enter values and remeasure until measured distances align with known feature distances. The calculation method calculates a precise correction.

Trial and Error Method

a. Select **Real Time** > **Microscope** > **Calibrate** > **Scanner** to display the **Scanner Calibration** panel (See Figure 7.11a).

b. Select the **X Fast Derate** parameter (or **Y Fast Derate** for Y-axis adjustment).

c. If the measured distance is less than the actual distance, decrease the **X Fast Derate** parameter slightly (or **Y Slow Derate** for Y-axis adjustment) and remeasure image features.

d. Adjust deratings up or down until measured distances accord with known feature distances.

Calculation Method

a. Perform the following calculation:

$$\frac{s - \left(\frac{a}{m} \cdot [s - d(440 - v)]\right)}{440 - v}$$

b. Variables are defined as follows:

Table 7.11a Fine-tuning X-Y Measurements Equation Definitions

Symbol	Definition
d	Derating value
a	Actual distance
s	Sens value
m	Measured distance
v	Scan size (in volts)

c. Select **Real Time** > **Microscope** > **Calibrate** > **Scanner** to display the **Scanner Calibration** panel (See Figure 7.11a).

d. Select the **X Fast Derate** parameter.

e. Record the **X Fast Derate** value shown on the **Scanner Calibration** panel (See Figure 7.11a).

f. Multiply the calculation result by the **X Fast Derate** value shown on the **Scanner Calibration** panel (See Figure 7.11a).

g. Enter the new **X Fast Derate** value.

Note: This adjusts the fast axis to more closely match calculated distances with known feature distances.

h. Click **OK** to set the new parameter value.

31. Select two widely-spaced features on the sample image of known separation and use the mouse to draw a vertical line between them.

Note: For example, on a 10-micron, silicon calibration standard, draw the line from the top edge of one pit to the top edge of another pit as far away as possible. The STM displays the measured distance next to the line.

32. Verify the measured distance agrees with the known vertical distance.

Note: If there is significant disagreement between the two, fine-tuning is required; proceed to the next step. If the measured distance agrees with the known distance, no further calibration is required.

Calculation Method

a. Perform the following calculation:

$$\frac{s - \left(\frac{a}{m} \cdot [s - d(440 - v)]\right)}{440 - v}$$

b. Variables are defined as follows:

Table 7.11b Fine-tuning X-Y Measurements Equation Definitions

Symbol	Definition
d	Derating value
a	Actual distance
s	Sens value
m	Measured distance
v	Scan size (in volts)

c. Select **Real Time > Microscope > Calibrate > Scanner** to display the **Scanner Calibration** panel (See Figure 7.11a).

d. Select the **Y Slow Derate** parameter.

e. Record the **Y Slow Derate** value shown on the **Scanner Calibration** panel (See Figure 7.11a).

f. Multiply the calculation result by the **Y Slow Derate** value shown on the **Scanner Calibration** panel (See Figure 7.11a).

g. Enter the new **Y Slow Derate** value.

Note: This adjusts the slow axis to more closely match calculated distances with known feature distances.

h. Click **OK** to set the new parameter value.

33. Change the **Scan Angle** on the **Scan Controls** panel to **90** degrees

34. Repeat steps for measuring horizontally and vertically at both 440V and 150V scan sizes for the following parameters: **Y Fast Sens**, **X Slow Sens**, **Y Fast Der**, and **X Slow Der**.

Note: This ensures the scanner is calibrated along both X and Y axes.

7.12 Fine-tuning for Z Measuring Accuracy

Although it is generally not difficult to obtain accurate X-Y calibration results, it is much more difficult to obtain accurate or repeatable Z axis results. Z axis calibration is very sample-dependent. It is difficult to control Z piezo dynamics because the Z axis does not move at a constant rate, as the X- and Y-axes do during scans. Furthermore, offsets can effect the piezo over a period of minutes.

High-quality Z-axis calibration standards may cost $2000 or more each. The platinum-coated, silicon calibration standards distributed by Bruker have 200 nm vertical features which are accurate to within ± 3 percent and used throughout the examples detailed in this section. For greater accuracy, choose from the range of appropriate calibration standard and/or metrology heads.

Complete the following procedure for fine-tuning for Z measuring accuracy:

1. Select **Real Time > Microscope** to set the system for **STM** imaging.
2. Engage the surface.
3. Verify the **Scan rate** is set to **2.44 Hz**.
4. Verify the **Z Center Position** value shown next to the image display is **0 ±10 volts**.
5. Select **Real Time > Motor > Tip Up** and **Tip Down** buttons to make adjustments if the **Z Center Position** value is non-zero.

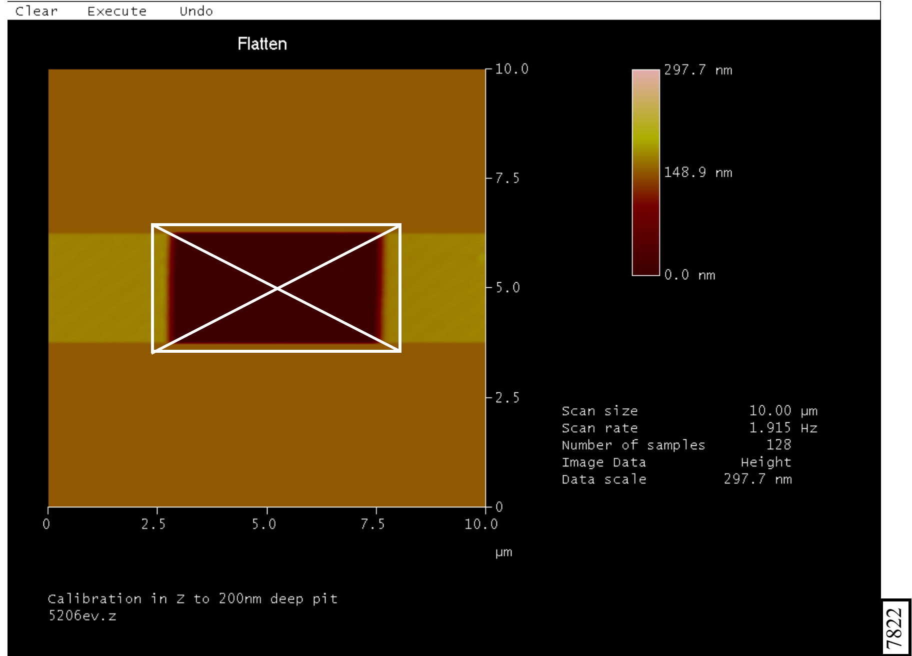
   Note: You may need to increase the step size due to backlash on the STM motor.
6. Adjust the **Scan size** parameter to include part of a pit, or up to 4 pits, within the image along with portions of the surrounding flat area.

   Note: The image should include Z-axis depths from highest to lowest elevations. “A” heads, when set at their maximum **Scan size** (440 volts), may image only a small portion of one pit. Adjust the sample and/or stage until one side of a pit is visible along with portions of the flat, rim area around the periphery of the pit. For heads larger than A, set the scan size to approximately 10 microns.
7. Allow the scanner to stabilize by scanning 2-3 frames.
8. Select **Real Time > Capture** or click on the **CAPTURE** icon to capture an image.

   Note: If the scanner has been running at extreme voltages, this may require a few minutes.
9. Select **Offline > Modify > Flatten** to remove all tilt and scan line errata from the image.
10. Set the **Flatten Order** parameter to **1**.
11. Draw a stopband over the pit(s), covering as much of the pit as possible while leaving the remainder of the top surface exposed (See Figure 7.12a).

Note: Avoid including debris and pits with poorly defined features within the cursor box.

Figure 7.12a Image Flatten Order

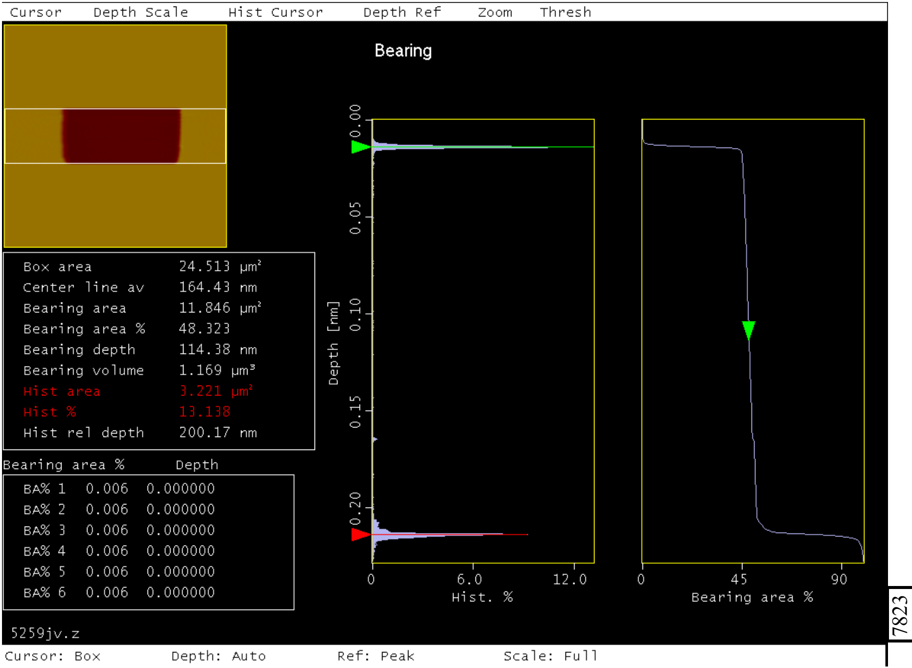


12. Click **EXECUTE** to complete the flattening procedure.

13. Click **Quit** to exit the **Flatten Order** panel.

14. Select **Offline > Analyze > Bearing** to measure vertical features of the image (See Figure 7.12b).

Figure 7.12b Image Bearing Analysis



15. Click **Execute** in the display monitor top menu bar.

Note: Height data within the drawn cursor box graphs on the display monitor as two prominent spikes. These spikes correspond to two elevations on the surface: the bottom of the pit and the top surface.

16. Slide the top line cursor (red) on the **Hist%** graph to the center line of the bottom data spike using the mouse and cursor.

17. Select **Hist Cursor > On** to generate a second line cursor (green).

18. Position the green line cursor on the center line of the top data spike.

19. Record the **Hist Rel Depth** value.

Note: The distance between the two cursors appears in the **Hist Rel Depth** field inside the data box. Depending upon whether the red cursor is positioned over the top or bottom data spike, the **Hist Rel Depth** value may be either positive or negative; take the absolute value. If you are using a 10-micron, silicon calibration standard from Bruker, the **Hist Rel Depth** value should be very close to **200 nm**. Variance from this value gives a good indication of the microscope's measuring error in the Z-axis. If the value is too far from 200 nm, you must make adjustments in Z sensitivity.

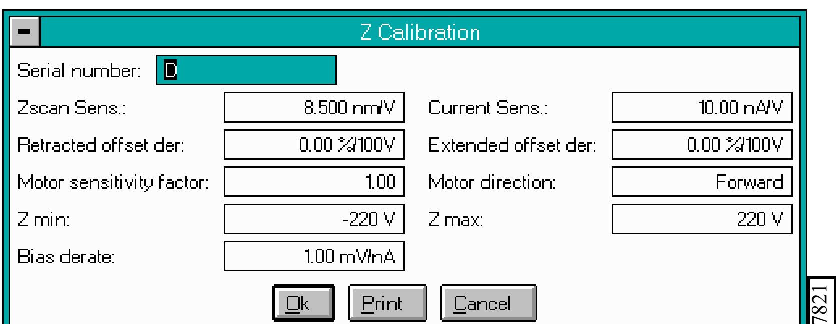
20. Click **Quit** to exit the **Bearing** panel.

Note: If the depth of pits on the 10-micron silicon calibration reference deviates significantly from 200 nm, you must correct the **Z sensitivity** parameter in the **Z Calibration** panel. Corrections here do not change the voltage applied to the scanner's Z-axis piezo crystal, but affect scaling applied throughout the Z-axis measuring range, so make corrections precisely and carefully.

21. Select **Real Time > Microscope > Calibrate > Z** to display the **Z Calibration** panel.

22. Record the value displayed in the **Z Sensitivity** field (See Figure 7.12c).

Figure 7.12c Z Calibration Panel



23. Divide the actual depth of features (200 nm for the 10-micron calibration standard) by the measured depth (indicated in **Bearing** analysis by the **Hist Rel Depth** value).

$$\frac{200\text{ nm}}{\text{Hist rel depth value}}$$

24. Multiply this quotient by the **Z Sensitivity** value in the **Z Calibration** panel, then replace the value with the product.

25. Click **OK** to enter the new **Z Sensitivity** value.

Note: The numerator value above (200 nm) is for Bruker 10-micron silicon calibration standards. For other calibration standards, set the numerator equal to the depth of features.

26. Verify again the Z-axis measuring accuracy of the STM. Repeat the procedure until you obtain the required accuracy.

Note: Bruker STMs are typically calibrated to within 2 nm of accuracy using the 10-micron silicon calibration standard which corresponds to an accuracy of 1 percent. If greater accuracy is required, use a very high-precision calibration height standard with features comparable to those being imaged on samples.

Piezoelectric materials exhibit greater sensitivity at higher voltages. In the procedure above, the Z-axis was calibrated while scanning near the middle of its voltage range (i.e., **Z Center Position** at approximately **0 V**). The following procedure details calibration of the Z-axis piezo while extended and retracted to offset the increased sensitivity.

27. Select **Real Time > Motor > Engage** to engage the surface.

28. Select **Real Time > Motor > Tip Up** to verify the **Z Center Position** reads **100 Volts**.

    Note: By using the motor to move the tip up, the feedback loop forces the Z-axis piezo to extend to continue tracking the surface.

29. Determine the measured depth of the calibration standard with a **Z Center Position** near **100 volt (Extended)** (See above procedure).

30. Record the measured depth.

    Note: It should read 200 nm on a Bruker 10 micron silicon calibration standard. If the depth measured by the extended piezo is in error by more than two percent, you must make an adjustment.

31. Select **Real Time > Microscope > Calibrate > Z** to display the **Z Calibration** panel.

32. Click on the **Extended Offset Der** parameter.

33. Perform the following calculation:

$$(1 + \text{current offset der})\ \frac{200\text{nm}}{\text{meas. depth}} - 1$$

34. Enter the result into the **Extended Offset Der** menu item.

    Note: The procedure for calculating and setting the **Retracted Offset Der** is exactly the same as for the **Extended Offset Der**; however, the piezo must be retracted to -100 V.

35. Repeat the procedure above; however, start by using the **Motor Control** panel and the **Tip Down** button to retract the piezo to a **Z Center Position** of **-100 Volts**.

7.12.1 Calibration of Z Sensitivities

The Z sensitivities of the heads are determined at the factory. A height standard with a 200 nm step height is used to calibrate all heads. The measured Z sensitivity should be accurate for 200 nm feature heights, but be aware that the sensitivity of the Z piezo changes for different applied Z voltages (i.e., different feature heights). Ideally, a derating factor could be applied to the Z sensitivity as it is to the X and Y sensitivities, but unfortunately, the size of the Z excursions (feature heights) is unknown. The next best solution is to have height standards of varying heights and calibrate the Z sensitivity for the anticipated feature height.

7.12.2 Head Offset

For STM heads with trimpots (head cover has access hole) you can measure and correct the value of the head preamplifier offset with the **Offset** command in the **Real Time > Microscope** menu.

Complete the procedure as follows:

1. Withdraw the tip from the sample.
2. Select **Real Time > Microscope > Offset** to observe the offset current of the preamplifier in nanoamps.
3. Null the value to zero by adjusting the blue trimpot on the preamplifier.

   Note: If the reading is equal to ±48 and the head and microscope are connected, there is probably a problem with the preamplifier, or the tip is touching the surface.

7.12.3 Head Leakage

Sometimes the electrical isolation between the tip and the Y electrode can break down. This phenomenon is more prevalent on A and D heads where the tip mounts on the front of the piezo tube. The leakage current between the high voltage Y electrode and the high impedance tip holder can be measured with the **Leakage** command in the **Real Time > Microscope** mode. Null the head offset as described above before completing the following procedure:

1. Withdraw the tip from the sample surface.
2. Select **Real Time > Microscope > Leakage**.
3. Observe the current sensed by the tip in nanoamps as the Y electrode sweeps through its range of motion.

   Note: With the tip off the surface the value should be small, but even small amounts of moisture or contamination near the tip can affect the result.

4. If the reading is larger than 0.2 to 0.5 nA, clean the area around the tip holder with alcohol and let dry before repeating the test.
5. If the problem reappears or if you use the scan head in conductive solutions often, thoroughly clean the area around the tip holder, bake the head, and apply silicon RTV or conformal coating to help keep moisture and contaminates away from the tip holder.

Chapter 8 Troubleshooting

8.1 Overview

This chapter addresses errors or malfunctions encountered during the operation of the NanoScope Scanning Tunneling Microscope (STM).

This chapter includes the following topics:

- **Overview:** Section 8.1
- **Head:** Section 8.2
- **Base Support:** Section 8.3
- **Tips:** Section 8.4
- **Sample Surface:** Section 8.5
- **Vibration Isolation:** Section 8.6

8.2 Head

This section details problems related to the scan heads. If a problem exists with a scan head, try imaging a second time under the same conditions, if possible. Otherwise, the following list of problems and troubleshooting tips may be helpful.

Table 8.2a Scan Head Troubleshooting

Error	Possible Cause	Action
Head Engages Immediately After Initiating **Motor > Engage** Command	Tip on Surface	1. Verify the tip is not touching the sample surface. 2. Adjust the coarse-adjustment screws upward until the tip is far from the surface.
	Head Disconnected	Verify the green 9-pin Micro-D connector on the head is plugged into the microscope and the microscope is plugged into the controller.
	Controller Off	Verify power to the controller is **On** and that the controller is connected to the computer via the beige 25-pin cable.
	Head has Offset	Follow the procedure for adjusting the offset on your scan head (See Chapter 7).
	Head has Leakage	Follow the procedure for dealing with scan head leakage current between the Y electrode and the tip holder (See Chapter 7).
	Wrong Head Type	Verify the correct head type is selected using the **Microscope > Select** command.
Head Never Engages	Head Disconnected	Verify the microscope is connected to the controller.
	Binding on Rear Screw	Feel the rear fine-adjustment screw to see if it rotates when you execute the **Motor > Engage** command. If the motion is erratic, then the screw is binding. Remove the screw, clean the threads with acetone, apply a thick oil or light grease, and reinsert the screw.
	Bias Shorted	Measure the bias by using a voltmeter between the screws holding the stepper motor to the base support (ground) and the upper platform (bias voltage). If this is not in agreement with the settings in the Bias voltage item in the STM parameter control panel and appears to be grounded, then check to see if anything is providing a conduction path between the base and the base support or any other ground.

Error	Possible Cause	Action
Tip Crashes	Dirty Contacts	The magnetic balls on the ends of the coarse and fine-adjust screws tend to attract small metallic particles which may make the surface gritty. Clean them with adhesive tape and then wipe with alcohol. Also, clean the contact points on the scanning head.
	Coarse Screws Need Adjustment	Try engaging at a slightly different angular rotation of the fine-adjustment screw by adjusting one of the coarse-adjustment screws upward slightly. Sometimes, the contact point of the balls will not be exactly in the center or will contact a dimple in the plating at the bottom of the head. Moving the screws will tend to alleviate this problem.
	Binding on Rear Screw	Feel the rear fine-adjustment screw to see if it rotates when you execute the **Motor > Engage** command. If the motion is erratic, then the screw is binding. Remove the screw, clean the threads with acetone, apply a thick oil or light grease, and reinsert the screw.
	Poor Sample Conductivity	The bulk conductivity of the sample may make it difficult to image. If the resistance of the sample is greater than 1 Kohm/cm, try a higher bias voltage. If the resistance is greater than 1 Megohm, use a bias voltage of 100mV or more. Samples with resistances greater than 1 Megohm will be difficult to image even with high bias voltages.*
* Measuring bulk conductivity of the sample with probes may not reveal the true problem. Probes may easily penetrate oxide or contamination layers on the sample surface yielding reasonable resistance measurements. However, oxide and contamination layers on the sample surface can make imaging very difficult. Higher bias voltages are required for these types of samples.		

8.3 Base Support

Table 8.3a Base Support Troubleshooting

Error	Possible Cause	Action
Tip Does Not Reverse Direction	Hex Drive Backlash	When single-stepping the tip in one direction and then reversing, single-step approximately 10 steps to compensate for the backlash.
Motor Does Not Drive Screw	Dust Accumulation	Clean and lubricate rear screw.

8.4 Tips

The quality of the mechanically formed platinum iridium tips varies. Some provide beautiful images at the start of the tunneling scan; others start poorly but improve over time; others start with noise and end with noise. Some tips have very flimsy points which render an image that is stretched out on one side indicating that the tip is unable to reverse well at the ends of the X scan.

Table 8.4a Tip Troubleshooting

<table>
<tr><th>Error</th><th>Possible Cause</th><th>Action</th></tr>
<tr><td rowspan="3">Noisy Signal</td><td>Tip -Sample Interaction</td><td>Alternate Withdraw and Engage commands or replace the tip.</td></tr>
<tr><td>Tip Contamination</td><td>Alternate Withdraw and Engage commands or replace the tip.</td></tr>
<tr><td>Imperfect Manufacturing</td><td>Replace the tip.</td></tr>
<tr><td rowspan="3">No Image Pattern</td><td>Tip -Sample Interaction</td><td rowspan="3">Replace the tip.</td></tr>
<tr><td>Tip Contamination</td></tr>
<tr><td>Imperfect Manufacturing</td></tr>
<tr><td>Image Stretched Out on One Side</td><td>Flimsy Tip Point</td><td>Select Real Time > Microscope > Calibrate and increase the X-rounding or capture large scans and select Offline > Modify > Zoom to focus on the desired information. If either fails to eliminate the artifacts, replace the tip.</td></tr>
</table>

8.5 Sample Surface

Samples to be imaged with a scanning tunneling microscope must conduct electricity to some degree. In many cases, you can coat nonconductive samples with a thin layer of a conductive material to facilitate imaging. The sample surface must be sufficiently conductive to allow a few nanoamps of current to flow from the bias voltage source to the scanned area. NanoScope STMs can scan any of the following: gold, silver, platinum, nickel, copper under oil, chrome plating, doped silicon under oil, conducting polymers, amorphous carbon, blue diamond, diamond-like carbon films, carbon fibers, graphite, iron-oxide compounds, semi-metals, doped semiconductors (molybdenum disulfide), cobalt-chromium compounds, stainless steel, liquid crystals, and other materials. Oxide layers more than a few atoms thick on the sample tend to affect the scanning and wear down the tip as it drags through the oxide. The feedback loop extends the tip until a tunneling current flows, even if it must push the tip through an oxide layer (if it can). If oxide presents a problem, keep the sample covered with oil or operate the microscope in a glove bag filled with nitrogen or argon. The standard NanoScope heads are not designed to operate in UHV.

On samples which are noisy or tend to oxidize, tunneling under oil or scanning in a glove box filled with inert gas can improve imaging. Silicon oil or paraffin oil (mineral oil) also work well with some samples. The only problem with using oil is the decreased difficulty in coarse positioning of the tip. The reflection of the tip comes off the liquid instead of the sample surface. The best approach is to lower the tip until it just touches the surface of the oil, falsely engage the tip (press **CTRL-F** quickly after selecting **Motor > Engage**) then lower the tip with the stepper motor. It may take the motor about a minute or so, but it is preferable to smashing the tip on the sample surface.

8.6 Vibration Isolation

Isolate the microscope from sources of vibration in the acoustic and subacoustic frequencies. You can relax this requirement somewhat for large-scale images, but atomic-scale work is sensitive to ordinary room vibrations.

You can obtain reasonable vibration isolation with the vibration isolation pad of soft silicone rubber supplied with the system. In many cases, the pads provide enough vibration isolation to run the microscope on the table; however the pads are most effective when placed on a massive object isolated from the fan noise of the computer and controller.

Another effective vibration isolation system consists of a large mass (20 or more pounds) suspended from elastic bungee cords. The mass should stretch the cords at least one foot, but not so much that the cords reach their elastic limit. Place the microscope on the large mass. The system, including the microscope, should have a natural frequency of about 1 Hz or less both vertically and horizontally. Test this by gently pushing on the mass and measure the rate at which it swings or bounces.

Air tables often have poor horizontal isolation. Air tables may require additional horizontal isolation for atomic scale images. The best way to reduce coupling from vibrations is to eliminate as many sources of vibration as possible. Remember that vibrations can be transmitted to the microscope over the cable. To reduce this phenomenon, prevent tension in the cable and keep it away from fans and other noise sources. Keep the microscope away from sources of acoustic noise. Loud conversation can disrupt atomic scale images. Air currents can also disturb atomic images, so it is best to run the microscope with the cover in place.

8.6.1 NanoScope Software

This section addresses problems associated with real time operation of the NanoScope software although these problems often are indicative of problems related to the scan head or microscope.

Table 8.6a NanoScope Software Troubleshooting

Error	Possible Cause	Action
Image Goes Out of Range	Sample and Head are Not Level	The Z center position is affected by the sample tilt and the larger-range scan heads, G and J, tend to be less tolerant of sample tilt due to their small vertical range compared to their large lateral scan ranges. Level the head relative to the sample by noting the trend in Z center position and adjusting the head tilt accordingly. Set the real time plane-fit to **Offset** under **View > Scope Mode** to eliminate tilt along the scan direction.
	Test Head Leakage	Leakage between the Y electrode and the tip holder can cause the Z center position to go out of range. Refer to the section on STM calibration for instructions on leakage measurement.
	Measure Coupling	A broken wire to one of the electrodes can cause this problem and will typically result in a large, monotonic increase (or decrease) in Z center position from the bottom of the scan to the top.
Z Drift	Thermal Drift	Hold the scan head body in your hands while replacing the tip but hold the head by the cap over the preamplifier to minimize heating of the head. Allow some time for the temperature to stabilize if the microscope and/or scan head has been stored in a cold place overnight. Drift can be minimized by keeping the STM in a thermally stable environment.
	Tip Not Tight	Verify the tip is held tightly in the tip holder. Push and pull on the tip with the tweezers to see that it is not loose. Change the bend in the tip if the tip seems loose.
	Sample Hold-Down	If the sample holding clip is too tight, it can push the back of the sample up and lift the front of the sample off the base. Loosen the thumb screws and lift the sample clip in the rear so that the sample is flat against the base.
	Stiff Rear Screw	If the rear screw is difficult to turn (due to an accumulation of dust in the threads, etc.) the drive shaft can wind up while driving the screw and unwind after the stepper motor has stopped. This will cause the tip to continue towards the surface. Clean the threads with acetone, apply a light grease and reinsert the screw.
Real Time Image Hides Features	Features are Parallel to X Scan Direction	If the real time image appears to be flat, but captured images reveal detail, then rotate the sample 90° in the microscope. The real time image leveling software tends to hide features that are parallel to the X scan direction.

Error	Possible Cause	Action
Streaky or Wavy Image	Insufficient Vibration Isolation	Atomic scale scans are the most susceptible to vibration in the acoustic and subacoustic frequencies. Try our suggested vibration-isolation platform.
	Microscope Cover	Keep the microscope cover on the microscope to prevent air currents from blowing over the head and sample and to electrically shield the head.
	Bad Tip	Replace the tip.
	Low-Scan Rates	The easiest method for reducing the effects of drift and even low frequency vibration is to simply raise the scan rate. Collect atomic scale images at 156 Hz with 256 X 256 sample points.
Triangular Image Over Step-like Features	Log or Boost Feedback	The most dramatic increase in performance of the feedback over large scans is achieved using the Log or Boost feedback modes. These make the error signal symmetrical for conditions with the tip too far or to close to the surface. Boost mode further optimized the feedback performance for large scans.
	Gain	The settings of the Integral and LookAhead gain terms also tend to be critical for large scans. They should be high enough to produce a little fuzz on the image but not so high as to cause large oscillations.
	Scan Rate	The Scan rate should be lowered for large scans, especially if the sample surfaces are rough or contain large steps. Moving the tip quickly along the sample surface at high scan rates with large scan sizes will usually lead to a tip crash. Essentially, the scan rate should be inversely proportional to the Scan Size since the tip must still be maintained roughly 1 nanometer above the surface.
	Setpoint Current	Raising the setpoint current will effectively raise the gain of the feedback loop which can be quite helpful for large scans. It will also bring the tip closer to the surface but only by a small amount (i Ý e^{-s}).

Appendix A Etching Tungsten Tips

A.1 Overview

This appendix describes the process of etching tungsten tips for use with the NanoScope Scanning Tunneling Microscope (STM).

This chapter includes the following topics:

- **Overview:** Section A.1
- **Equipment Required:** Section A.2
- **Method A (Atomic Scans):** Section A.3
- **Method B (Large Scans):** Section A.4

A.2 Equipment Required

- Variac Auto Transformer
- Optical Microscope (20-100X)
- Sodium Nitrite ($NaNO_2$)
- Potassium Hydroxide (KOH)
- Distilled Water
- Ethyl Alcohol
- WD 40 (Antioxidant)
- Two 50ml Beakers
- Tip Holder
- Platinum Wire
- Tungsten Wire (0.010” Diameter)
- Miscellaneous Wire/Clips

A.3 Method A (Atomic Scans)

This method of etching tungsten tips for atomic scale scans was developed by Dr. Bruce Schardt at Purdue University.

1. Make a solution of 1 molar KOH using distilled water and pour approximately 50ml into a very clean beaker.
2. Construct an electrode out of the platinum wire and insert it into the beaker.
3. Submerge a single tungsten wire 5–10mm into the KOH solution.
4. Adjust the variac for 30V, and with it off, connect one output to the platinum electrode.
5. Connect the other output of the variac to the tungsten tip.
6. Turn on the variac and etch the tip. While the tip is etching, the solution will bubble violently, and the tip will start to glow. As the tip etches towards the surface, the bubbling will be reduced. Continue to etch the tip until it stops.
7. Reduce the variac to 8–10 volts and re-submerge the tip approximately 1mm into the solution.
8. Turn on the variac and re-etch the tip for approximately 15 more seconds. There should be only slight bubbling from the tip and it should not glow.
9. Place the tip into distilled water to rinse it and use immediately. You can make 5 to 10 tips in the 50ml solution before the beaker will need to be cleaned and new solution used.

A.4 Method B (Large Scans)

1. Make a 5% by weight solution of sodium nitrite in water.
2. Pour approximately 40ml of the solution into a beaker.
3. Pour approximately 40ml of WD 40 into a beaker.
4. Construct an electrode out of the platinum wire and insert it into the beaker.
5. Adjust the variac for 30V, and with it off, connect one output to the platinum electrode.
6. Cut 10 to 12 pieces of tungsten wire, each approximately 1.25cm long.
7. Place the tungsten tips into a holder. We like to use an IC socket, with all the pins soldered together.
8. Place the tip holder above the etching solution so that the tips penetrate of the solution during etching, and less than 2mm will result in tips that are too blunt.
9. Connect the other output of the variac to the common of all the tips.
10. Turn on the variac and etch the tips. While the tips are etching, the solution will foam, and the tips will start to glow. As the tips etch towards the surface, the bubbling will be reduced. Continue to etch the tips until the glow is almost gone. If the glow goes out, it will etch the end of the tip and create a blunt tip.
11. Dip the tips into ethyl alcohol to clean them. If you plan to keep the tips around for more than a day, then dip then into the WD 40 after cleaning.
12. Examine the tips under the optical microscope. Ones that are tool long, too blunt, or split at the end will hardly ever be good tips and can be thrown out at this time. Of course, this is a subjective process. As your experience in etching grows, you will get better at throwing out the bad ones.
13. Repeat the etching procedure. Replace the etching solution when a fairly large amount of residue is present. Typically, you can etch 60 to 80 tips in a 40ml solution.

Glossary

Abstract

This glossary defines terms used in the semiconductor and general purpose microscopy industries, as well as terms specific to Bruker Corporation. Some of the terms in this glossary are specific to SEMATECH. This version also includes terminology from other industry organizations, namely ASME, SIA, EIA, IEEE, ASTM, and SEMI. Sources are indicated at the end of each definition.

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Quick Reference

A-E | F-J | K-O | P-T | U-Z

Term	Definition
A-E	
absolute pressure	In mass flow controllers, the pressure measured relative to zero pressure (perfect vacuum). [SEMI E28-92]
accuracy	In statistical process control, the compliance of the measured or observed value to the true value or accepted reference value. [EIA 557]
acetone	A colorless, volatile, and extremely flammable liquid used as a solvent and as a reagent. [SEMATECH]
acoustic isolation	The combination of a complete acoustic enclosure of the isolation platform and a multilayer foam design results in a complete acoustic isolation system which effectively dampens acoustic noise sources.
actuation cycle	The full operation of a valve, such as from a fully opened position to fully closed and back to fully opened. [SEMATECH]
adjusted decibel (dBa)	A unit used to express the relationship between the interfering effect of a noise frequency and a noise power level. [SEMATECH]
AFM	Atomic Force Microscope or **atomic force microscopy**.
air velocity (V_A)	In the thermal testing of semiconductor devices, the velocity of the cooling air at a specified location upstream from the device under test. Air velocity is measured in linear feet per minute. [SEMI G38-87]
aliasing	Electronic image error due to differences in resolution between surface features and the pixels used to represent them.
alignment	1: The accuracy of the relative position of an image on a reticle with reference to an existing image on a substrate. [SEMATECH] 2: a procedure in which a wafer is correctly positioned relative to a reticle. [SEMATECH] 3: the mechanical positioning of reference points on a wafer or flat panel display substrate (also called alignment marks or alignment targets) to the corresponding points on the reticle or reticles. The measure of alignment is the overlay at the positions on the wafer or substrate where the alignment marks are placed. [Adapted from SEMI P18-92 and D8-94]

Term	Definition
ambient pressure	In mass flow controllers, the absolute pressure of the medium surrounding the device. [SEMI E28-92]
ambient temperature	1: the temperature of the surrounding medium, such as air or liquid, that comes into contact with the device or apparatus. [SEMATECH] 2: the temperature of the specified, surrounding medium (such as air, nitrogen, or a liquid) that comes into contact with a semiconductor device being tested for thermal resistance. [SEMI G38-87]
American National Standards Institute (ANSI)	An organization that compiles and publishes computer industry standards. [SEMATECH]
analog	A signal in an electronic circuit that takes on a continuous range of values rather than only a few discrete values; a circuit or system that processes analog signals. [1994 National Technology Roadmap for Semiconductors]
angstrom (Å)	Unit of linear measure equal to one ten billionths of a meter (10^{-10} m). The preferred SI unit is nanometers. 10 Å = 1 nm. [SEMATECH]
area contamination	Foreign matter on localized portions of a wafer or substrate surface. [SEMI M3-88]
artifact	1: A physical standard against which a parameter is measured; for example, a test wafer used for testing parametric drift in a machine. [SEMATECH] 2: a superficial or unessential attribute of a process or characteristic under examination; for example, a piece of lint on a lens that appears through a microscope to be a defect on a die. [SEMATECH] 3: in surface characterization, any contribution to an image from other than true surface morphology (e.g., contamination, vibration, electronic noise, and instrument imperfections). [SEMATECH]
aspect ratio	1: In etch, the depth-to-width ratio of an opening on a wafer. [SEMATECH] 2: in feature profile, the ratio of height to width of a feature. [SEMATECH]
atmosphere (atm.)	A unit of pressure equal to the pressure exerted by a vertical column of mercury 760 mm high, at a temperature of 0°C, and under standard gravity. One technical atmosphere equals 1 kg f/cm 2 (14.7 pounds per square inch). [ASTM D1356 REV A-73]

Term	Definition
atmospheric hood	An enclosure for use with the MultiMode Scanning Probe Microscope (SPM) which enables control of the imaging environment. It is strongly recommended for users who need to control humidity or require specific environmental atmospheres during operation.
atomic force microscopy (AFM)	A microscopy technique based on profilometry using an atomically sharp probe that provides three-dimensional highly magnified images. During AFM, the probe scans across a sample surface. The changes in force between the sample and the probe tip cause a deflection of the probe tip that is monitored and used to form the magnified image. [SEMATECH] The three primary AFM modes used at Bruker are: Contact Mode, Non-Contact Mode and Tapping Mode.
Auto Step Height	The process of collecting all relative height measurements along profile data between defined regions.
automated material handling system (AMHS)	Equipment that helps control the flow of material in a manufacturing facility; e.g., robots, computers, sensors, and protective carriers. [SEMATECH]
automatic valve	A valve with an actuation device that can be operated remotely, such as a pneumatically or electrically controlled valve. [SEMATECH]
bandwidth	The difference between the highest and lowest values in a range of two pattern characteristics, such as efficiency, frequency, or impedance. The bandwidth of significant frequencies (frequencies that conform to standards or that are required for reliable frequencies) within a spectrum is expressed in hertz. [SEMATECH]
bay	Of a cleanroom, a confined area that contains equipment used for one or more steps in a process. [SEMATECH]
BEEM	Ballistic Electron Emission Microscopy.
bellows valve	A packless valve that incorporates a statically sealed bellows to isolate the controlled medium from the atmosphere. [SEMI Chemicals/Gases, Vol. 1, 1990 (no longer in print)]
bias	Electrical potential applied to a tip or sample which causes electron flow to ensue from one to the other (scanning tunnel microscopy and electric force microscopy only).

Term	Definition
Bow	Bow, which increases with scan size, is the result of 2nd order or 3rd order curvatures from an ideal plane. Bow can be removed from a captured image by using Modify >Planefit Auto**.**
calibration	Measurement of known features to ensure accuracy of SPM images.
CITS	Current Imaging Tunneling Spectroscopy.
Classic Control	The name for the NanoScope Control display on the modal, dual display, version of software. The Classic Control displays menu bars, status bars, control panels and file lists.
Classic Control and Image	The name for the NanoScope Control and Image displays combined (See also **Classic Control** and **Classic Image**).
Classic Image	The name for the NanoScope Image display on the modal, dual display, version of software. The Classic Image displays imaging data, menu bars, data boxes and graphs.
Classic Interface	The name for the NanoScope software configured for two displays: control monitor (**Classic Control**) and image monitor (**Classic Image**).
configuration	The definition of equipment and interfaces necessary for a given application. [SEMATECH]
contaminant	An unwanted substance present in the cleanroom or on the product. [SEMATECH]
creep	The drift of the piezo displacement after a DC offset voltage is applied to the piezo.
current	In scanning tunneling microscopy, tunnel current, expressed in nanoamperes (nA), that flows across the tip surface gap. [SEMATECH]
Cutoff	The act of isolating or separating values to obtain data (e.g., cutoff filter).
data	1: information, including programs, program instructions, and the information used or produced by a computer. [SEMATECH] 2: any representation to which meaning is or might be assigned (for example, characters). [SEMI E13-91]

Term	Definition
dielectric	A nonconductive material; an insulator. Examples are silicon dioxide and silicon nitride. [SEMATECH] 2: a material applied to the surface of a ceramic or preformed plastic package to provide functions such as electrical insulation, passivation of underlying metallization, and limitations to solder flow. [SEMI G33-90]
digital signal processor (DSP)	Computer processor used to control Scanning Probe Microscope feedback loop.
drift	In scanning tunneling microscopy or atomic force microscopy, movement of the sample surface with respect to a microscope tip or cantilever due to a lack of thermal equilibrium. [SEMATECH]
DSP	Digital signal processor.
dump	Presentation of intermediate results just prior to an error that stops a software procedure from completing.
ECM	Electrochemical microscopy.
edge effect	Localized structure about the edge of a specimen. [ASTM F1241]
electrochemical microscopy	Use of a scanning probe microscope in a fluid with control over tip and sample voltages.
electromagnetic compatibility (EMC)	The ability of electronic equipment to function properly with respect to environmental electromagnetic interference and electrostatic discharge. [SEMI E33-94]
electromagnetic interference (EMI)	Any electrical signal in the nonionizing (suboptical) portion of the electromagnetic spectrum with the potential to cause an undesired response in electronic equipment. [SEMI E33-94]
electrostatic discharge (ESD)	A sudden electric current flow, such as between a human body and a metal oxide semiconductor, with potential damage to the component. [SEMATECH] 2: the transfer of electrostatic charge between bodies at different electrostatic potentials. [SEMI E33-94]
enabled	Refers to one of the two major SECS communication states (enabled and disabled). The enabled state has two sub-states, communicating and not communicating. In the enabled state, the equipment will periodically attempt to establish communication with a host computer or uphold communications with the host. [SEMI E30-94]

Term	Definition
engagement	Process of bringing a probe tip and sample together in a controlled manner such that useful information about the surface is obtained without damaging either the tip or the sample.
environmental isolation	Separation from the ambient atmospheric environment. [SEMI E21-94]
error	Difference between actual tip-sample current measured at the detector and the setpoint current.
etch	A category of lithographic processes that remove material from selected areas of a die. Examples are nitride etch and oxide etch. [SEMATECH] 2: in the manufacture of silicon wafers, a solution, a mixture of solutions, or a mixture of gases that attacks the surfaces of a film or substrate, removing material either selectively or nonselectively. [SEMI M1-94 and ASTM F1241]

F-J

Term	Definition
false engagement	Condition due to surface effects or insufficient setpoint (too low during contact AFM; too high during TappingMode) in which the feedback controller attempts imaging a sample that is not engaged with the tip.
feature	An area within a single continuous boundary (for example, an aggregate image) that has an optical-density value (gray-level range) that is distinct from the background area outside the feature; for example, the simplest element of a pattern such as a single line, space, or L-bar. [SEMI P19-92]
feature height	In scanning tunneling microscopy and atomic force microscopy, the height of features on a surface profile; the distance in the Z-direction of any point in a microscope's scan area, relative to the lowest point in the scan area, as derived from measurement fluctuations during raster. [SEMATECH]
feedback	In atomic force microscopy, a process by which the cantilever is moved in the Z-direction relative to the sample to maintain a constant force during scanning. 2: in scanning tunneling microscopy, a process by which the tip is moved in the Z-direction relative to the sample to maintain a constant current during scanning. [SEMATECH].
fluid cell	A container for electrochemically interesting fluids with provision for admitting a scanning probe microscope (SPM) probe and possibly allowing fluid to circulate.

Term	Definition
graphical user interface (GUI)	The area on the display monitor that includes all information displayed graphically. A graphical user interface is a combination of icons, scroll bars, windows, help systems, menus, views, dialog boxes and other services to make a program easier to use. [SEMATECH]
hazard	A set of recognizable conditions with the potential for initiating an event that could result in death, injury, or illness to people, and/or facility/equipment damage. [SEMI S1-90]
help interface	A menu item for initializing the help files and Follow Along Help. The help is displayed or hidden using the **View > Help** command. The help interface allows you to view documentation related to using the NanoScope software.
hertz (Hz)	A term applied to the number of repetitions of a periodic wave per second. [SEMATECH]
histogram	A graph obtained by dividing the range of the data set into equal intervals and plotting the number of data points in each interval. [EIA 557]
icon	A small image (e.g., displayed on a computer screen) representing something (e.g. an item on the computer that the user can access).
image	1: any single geometric form appearing in a layout as a part of a master drawing or layout (image, drafting) projected on a screen or viewed, usually at some magnification or reduction (image, optical) etched in the silicon dioxide layer on an oxidized silicon wafer (image, oxide) in a photomask or in the emulsion of a photographic film or plate (image, photographic) an exposed and developed coating on a substrate (image, photoresist) [ASTM F127-84 and SEMI P25-94] 2: in scanning tunneling microscopy, representation of surface topography obtained using the signal from the tip or surface during rastering and runder tunneling conditions. [SEMATECH] 3: in atomic force microscopy, representation of surface topography obtained by using the signal from the cantilever or surface during rastering in constant force conditions. [SEMATECH]
image display	Window of the real time scan or captured image.
image processing	The process of analyzing, modifying or reconstructing real time data (e.g., AFM images or profiles).
integral gain	Amount of correction applied in response to the average error between setpoint force and actual force measured by the detector.

Term	Definition
integrated circuit (IC)	1: two or more interconnected circuit elements on a single die. [SEMATECH] 2: a fabrication technology that combines most of the components of a circuit on a single-crystal silicon wafer. [SEMI Materials, Vol. 3, Definitions for Semiconductor Materials]

K-O

Term	Definition
label	A piece of paper or other material affixed to a container or article, on which is printed information concerning the product or addresses. It may also be printed directly on the container. [ASTM D996-90]
linearity	In the linearity of mass flow devices, the closeness to which a curve approximates a straight line. It is measured as a nonlinearity and expressed as a linearity. [SEMI E27-92]
LookAhead gain	Amount of correction applied in response to the error signal between setpoint force and actual force measured by the detector, based upon recorded information from the adjacent scan line.
maintenance	The act of sustaining equipment in a condition to perform its intended function. [SEMI E10-92]
menu	A list of options visually presented on a terminal by a computer program to allow a user to select a course of action. [SEMATECH]
micrometer (µm)	A metric unit of linear measure that equals 1/1,000,000 meter (10 - 6 m), or 10,000 angstroms. The diameter of a human hair is approximately 75 micrometers. [SEMATECH] Also called micron.
micron	See micrometer.
monitor	A graphical display device for pointing to or selecting individual pixels within a monitor display.
NanoScope™	Trademark name applied to Bruker’ scanning probe microscopy products.
orthogonality	The measure of perpendicularity between the X- and Y-axis of a scanning head.

P-T

Term	Definition
particulate	Discrete particle of dirt or other material. [ASTM F1241] 2: discrete particle of material that can usually be removed by (nonetching) cleaning. [SEMI M10-89] 3: describes material in small, discrete pieces; anything that is not a fiber and has an aspect ratio of less than 3 to 1. Examples are dusts, fumes, smokes, mists, and fogs. [SEMATECH]
piezoelectric	A material property such that an applied voltage causes a change in object size and, inversely, expansion or contraction induces a voltage across the object.
pit	1: in a wafer surface, a depression in a wafer surface that has steeply sloped sides which meet the surface in a distinguishable manner, in contrast to the rounded sides of a dimple. [ASTM F1241] 2: in semiconductor packages, plastic or ceramic, or in the leadframes, a shallow depression or crater. The bottom of the depression must be visible in order for the term to apply. A pit is formed during the component manufacture. [SEMI G61-94] Contrast chip. 3: in flat panel display substrates, a small indentation on the glass substrate surface. [SEMI D9-94]
pitch	The distance between a point on an image and a point on the corresponding image in an adjacent functional pattern that lies in either a row or column on a photomask or reticle. [SEMATECH]
pop-up menu	A floating menu that appears when right-clicking on each window or screen. Configures the properties found on that screen or window (e.g., cursor type, color table in the image display).
precision	The measure of natural variation of repeated measurements. [EIA 557]
proportional gain	Correction applied in response to the error signal between setpoint force and actual force measured by the detector, in direct proportion to the error.
range	The region between the limits within which a quantity is measured, expressed by stating the lower and upper range values. [SEMI E27-92]
raster	The movement or area defined by repetitively scanning (with a microscope) in the X-direction while moving stepwise in the Y-direction. [SEMATECH]
real time	Pertaining to a system designed to control a dynamic process within the timing constraints of the process. [SEMATECH]

Term	Definition
relative humidity (RH)	The quantity of water vapor present in the atmosphere as a percentage of the quantity that would saturate at the existing temperature. [SEMATECH]
resistivity (ρ)	1: of a semiconductor, the ratio of the potential gradient parallel with the current in the material to the current density. Units are Ωcm. [SEMI M4-88] 2: the resistance that a unit volume of semiconductor material offers to the passage of electricity when the electric current is perpendicular to two parallel faces. [SEMI M1-94] 3: the measure of difficulty with which charge carriers flow through a material. Resistivity is the reciprocal of conductivity. [ASTM F1241]
resolution	The fineness of detail revealed by an optical device. Resolution is usually specified as the minimum distance by which two lines in the object must be separated before they can be revealed as separate lines in the image. [ASTM E7-90]
roughness	1: the more narrowly spaced components of surface texture. [ASTM F1241] 2: in flat panel display substrates, the criterion for the smoothness of the sheet surface. [SEMI D9-94]
roughness average	In surface profilometry, the arithmetic average of the absolute values of the measure profile height deviations taken within the sampling length and measured from the graphical center line. [ASME B46.1-85]
scan	In scanning tunneling microscopy, movement of the microscope tip relative to sample surface, continuously in one direction. Contrast raster. [SEMATECH] 2 v to move the microscope tip continuously in one direction. [SEMATECH]
scan area	In scanning tunneling microscopy, area defined by successive, side-by-side scan lengths. [SEMATECH]
scan direction	In scanning tunneling microscopy, the direction in which the tip or sample is continuously scanned, orthogonal to the Y-direction, in the sample plane. [SEMATECH]
scan length	In scanning tunneling microscopy, the distance from start to end of a single scan. [SEMATECH]
scan rate	In scanning tunneling microscopy and atomic force microscopy, the speed at which the tip or cantilever moves relative to the surface. [SEMATECH]

Term	Definition
scanning probe microscopy (SPM)	Generation of graphical portraits of the control signal needed to maintain a particular tip/sample interaction while scanning a sample surface with an atomically-sharp tip. The two primary forms of SPM are scanning tunneling microscopy (STM) and atomic force microscopy (AFM).
scanning tunneling microscope (STM)	An instrument for producing surface images with atomic scale lateral resolution, in which a fine probe tip is raster scanned over the surface and the resulting tunneling current is monitored. [SEMATECH]
scope display	Window that toggles with the **video display** and shows a scope trace of the real time scanning image.
semiconductor	An element that has an electrical resistivity in the range between conductors (such as aluminum) and insulators (such as silicon dioxide). Integrated circuits are typically fabricated in semiconductor materials such as silicon, germanium, or gallium arsenide. [SEMATECH]
sensitivity	Amount of movement produced by a scanner piezo for a given amount of voltage.
setpoint	1: Operator-selected force threshold between tip and sample used as the feedback control loop's target. 2: In mass flow controller testing, the electrical input signal to the device that sets the desired value of the controlled flow. [SEMI E17-91]
sharpness	The visual impression of distinctness in a photographic reproduction, such as the edge of an image; the subjective effect of the physical property acutance. [ASTM F127-84]
SI	Abbreviation for the International System of Units (in its original French, le Système International d'Unités), which is a modernized metric system accepted as the standard by (among others) the American Society for Testing and Materials (ASTM), Semiconductor Equipment and Materials, International (SEMI), and the Institute of Electrical and Electronics Engineers (IEEE). [SEMATECH]
Signal Access Module (SAM™)	An in-line hardware utility that lets you access or interrupt every signal going into and out of your NanoScope controller for experimentation and diagnostic evaluation.
specification	A detailed, precise description of a tool, material, process, method, or procedure. [SEMATECH] 2: a detailed definition of the logic used by an application or a program. [SEMATECH]

Term	Definition
standard	A method, rule, or description subscribed to by the consensus of the appropriate industry and under control of the issuing organization for document revision. [SEMATECH]
standard deviation	A measure of the spread of the process output or the spread of a sampling statistic from the process. The true standard deviation (represented by the Greek letter sigma) is estimated by calculating the difference of each individual observation from the average of the observations, squaring the differences, finding the sum of the squares, dividing by one less than the number of observations, and finding the square root of the result. 2: a measure of the variation among the members of a statistical sample. [SEMATECH] 3: in the pressure testing of fluorocarbon tube fittings, a measure of the variation among the members of a statistical sample. [SEMI F8-92]
Step Height	The value of relative height measurements between two regions (steps) on sample surfaces.
STM	*S*canning tunneling microscopy.
STS	Scanning tunneling spectroscopy.
submenu	Name for a drop-down menu resulting from hovering over a main menu item.
surface	The boundary that separates an object from another object, substance, or space. [ASME B46.1-85] 2: in electron spectroscopy for chemical analysis (ESCA), that volume from which the photoelectrons can escape. [SEMATECH]
tip	In a scanning tunneling microscope probe, a sharpened, nonoxidized, or minimally oxidized conductive point at the end. [SEMATECH]

U-Z

Term	Definition
vibration isolation	Provides the high damping needed for optimum isolation of high ground noise sources.
X-direction	See scan direction.

Term	Definition
Y-direction	In characterizing surface roughness, the direction over which successive scans are taken by a microscope, orthogonal to the scan direction, in the sample plane. [SEMATECH]
Z-direction	In characterizing surface roughness, the direction perpendicular to the sample plane, orthogonal to the X and Y directions. [SEMATECH] Also called feature height direction.