Application Modules: Dimension and MultiMode Manual

Software Version 5.12 r4
(or Beta on or after 4-23-03)

004-112-000 (standard)
004-112-100 (cleanroom)

Document Revision History: App Modules: Dimension and MultiMode Manual

Revision	Date	Section(s) Affected	Reference	Approval
D	12-03-03	Extended TUNA and miscellaneous.	-	C. Kowalski
C	7-29-03	Added Extended TUNA Test	-	C. Kowalski
B	5-20-03	Added SThM, improved TUNA and SCM	-	C. Kowalski
A	3-26-03	Initial Release	-	C. Kowalski

Product Names:
NanoScope®
MultiMode™
Dimension™
BioScope™
Atomic Force Profiler™ (AFP™)
Dektak®

Software Modes:
TappingMode™
Tapping™
TappingMode+™
LiftMode™
AutoTune™
TurboScan™
Fast HSG™
PhaseImaging™
DekMap 2™
HyperScan™
StepFinder™
SoftScan™

Hardware Designs:
TrakScan™
StiffStage™

Hardware Options:
TipX®
Signal Access Module™ and SAM™
Extender™
TipView™
Interleave™
LookAhead™
Quadrex™

Software Options:
NanoScript™
Navigator™
FeatureFind™

Miscellaneous:
NanoProbe®

Table of Contents

List of Figures

Chapter 1 Overview

1.1 Introduction

This manual details the use of application modules with a phase-equipped MultiMode™ Scanning Probe Microscope (SPM) or a Dimension™ SPM operated either by a NanoScope® III or NanoScope® IIIa Controller in conjunction with a Quadrex™ module, or operated by a NanoScope® IV Controller (with Quadrex built-in). Refer to *Support Note 322A, Quadrex* for discussion of the Quadrex module. Refer to the *NanoScope IV Controller Manual* for discussion of Quadrex features for SPMs operated by the NanoScope IV Controller. Quadrex capabilities are identical for phase-equipped SPMs, regardless of which controller is used.

For specifics of your SPM, refer to its accompanying instruction manual. For coverage of all software commands and details of the various modes of operation (Real-time, Offline, Image, Scope, Force, and so on), refer to the *Command Reference Manual*. Similarly, add-on modules, sensors, and even areas of investigation (such as electrochemistry) are introduced in Support Notes and Application Notes. Programmable aspects of NanoScope software applicable even to SPM systems without a robot are described in the *Automation Supplement*. The *Scanning Probe Microscopy Training Notebook* is a compact introduction for getting started on MultiMode and Dimension SPMs.

A Generation II SCM Application Module is required for operation with an NSIV Controller or the Quadrex module. A Generation I SCM Application Module operates with the Quadrex predecessor, the Extender Electronics Module, and a phase-equipped Dimension SPM.

1.2 Conventions

- For brevity, Veeco Instruments Inc. is referred to as *Veeco*.
- In the interest of clarity, certain nomenclature is preferred. An SPM *probe* is comprised of a *tip* affixed to a *cantilever* mounted on a *substrate*, which is inserted in a *probe holder*.
- Three font styles distinguish among contexts. For example:
  Window or Menu Item > **BUTTON NAME** is set to **Value**.
- NSIII(A) is used to refer to either a NanoScope III or NanoScope IIIa. NSIV refers to the NanoScope IV Controller.
- A *phase-equipped* SPM implies that an SPM has the required modification to perform PhaseImaging in any of the following configurations:
  - NSIII(A) Controller and Quadrex Module
  - NSIII(A) Controller and Extender Electronics Module
  - NSIV Controller

  A phase-equipped SPM may also be referred to as *extended*, or *equipped for Quadrex*, or *equipped for Extender Electronics*.
- The *Control Monitor* is generally used for providing access to control parameters and the *Display Monitor* for displaying scanned images or other results (for example., sweep curves).

  Note: There are two versions of MultiMode application module packaging, one of which appears in this manual. They are functionally equivalent and visually similar.

Figure 1.2a Quadrex PhaseImaging Module for NanoScope III, IIIa Controllers

1.3 Safety Precautions

Table 1.3a Safety Symbols Key

Symbol	Definition
	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 Zustaende oder Handlungen die das Geraet oder andere Gegenstaende beschaedigen koennen und in Extremfaellen zu Verletzungen fuehren koennen.
	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 Zustaende oder Handlungen die einen elekrischen Schock verursachen koennen.
	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.
	This symbol identifies a mechanical crushing hazard. Moving parts can result in serious injury to hands or fingers.
	Ce symbole indique un risque d'écrasement. Déplacer des pièces de l'appareil peut entraîner des blessures sévères des mains ou des doigts.
	Dieses Zeichen bedeutet "Quetschungsgefahr durch mechanisch bewegte Teile." Bewegliche Teile können zu erheblichen Quetschverletzungen von Fingern oder Händen führen.

WARNING:	Only qualified personnel aware of the hazards involved may perform service and adjustments.
AVERTISSEMENT:	Toute réparation ou étalonnage doit être effectué par des personnes qualifiées et conscientes des dangers potentiels.
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 gouvernemental 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 fern vom Gerät.

WARNING:	Voltages supplied to and within certain areas of the system are potentially dangerous and can cause injury to personnel. Power-down everything and unplug from sources of power before doing ANY electrical servicing. (Veeco 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 Veeco 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 Veeco Personal).

	**WARNING:**	Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous laser light exposure. The use of optical instruments with this product will increase eye hazard.
	AVERTISSEMENT:	Toute utilisation, ou étalonnage ou essai de modification, autre que ci-dessous décrits, peut entraîner une exposition dangereuse à la lumière du laser. L'utilisation de systèmes optiques avec ce produit peut entraîner un danger pour les yeux
	WARNUNG:	Die falsche Verwendung dieses Gerätes mit nicht in diesem Handbuch beschriebenen Vorgehensweisen kann gefährliche Laserstrahlung freisetzen. Optische Instrumente, die zusammen mit diesem Produkt verwendet werden, können evtl. Augenschäden hervorrufen und verstärken.

Chapter 2 Operating Principles

2.1 Introduction

Although the five application modules have been engineered to share as many characteristics as possible to simplify installation and exchange of sensors (modules), each has a separate measurement function, described in the following five sections:

- **SCM Theory:** Section 2.2
- **TUNA and Extended TUNA Theory:** Section 2.3
- **SSRM Theory:** Section 2.4
- **C-AFM Theory:** Section 2.5
- **SThM Theory:** Section 2.6

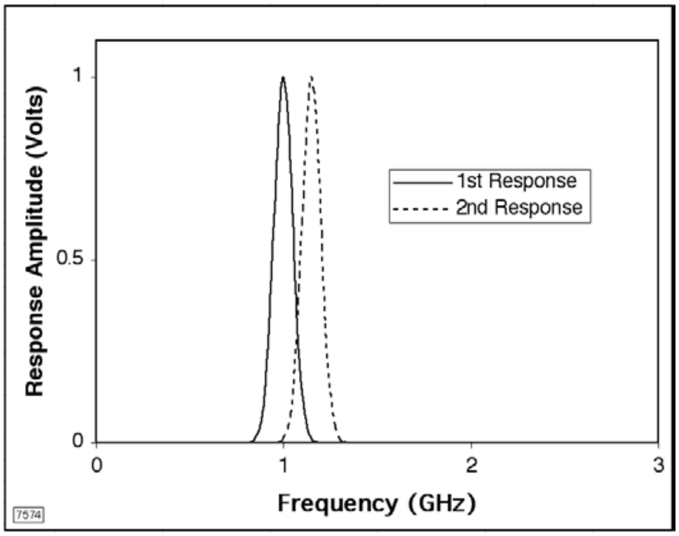
2.2 SCM Theory

Scanning Capacitance Microscopy (SCM) images two-dimensional carrier profiles in semiconductor devices and materials, measuring small capacitance variations with high spatial resolution.

While scanning in Contact Mode, the tip and sample form a small metal-insulator-semiconductor (MIS) capacitor. The capacitance value is monitored using a high frequency resonant circuit. By maintaining a constant force between tip and sample, simultaneous topographic and capacitive images are generated, enabling the direct correlation of local topography with electrical properties. Selectable AC and DC biases are applied between the sample and the conductive tip, with the tip acting as a virtual ground.

An Ultra High Frequency (UHF = 880 to 1050MHz) resonant capacitance sensor is the basis of the capacitance detection. A resonator is formed with the MIS capacitor at the end of a transmission line. Tip-sample capacitance variations change the resonant frequency of the high-Q circuit (Q equals the resonant frequency divided by the width of the resonance at half of its peak amplitude, where resonance refers to the function response amplitude versus driving frequency). Small changes in resonant frequency create enormous changes in response amplitude at frequencies near either the starting or the ending resonant frequency (see Figure 2.2a). The SCM system is capable of 10^{-22}F/$\sqrt{\text{Hz}}$ sensitivity.

Figure 2.2a Example: Compare Response Amplitude at 1GHz Between Two Nearby Resonances



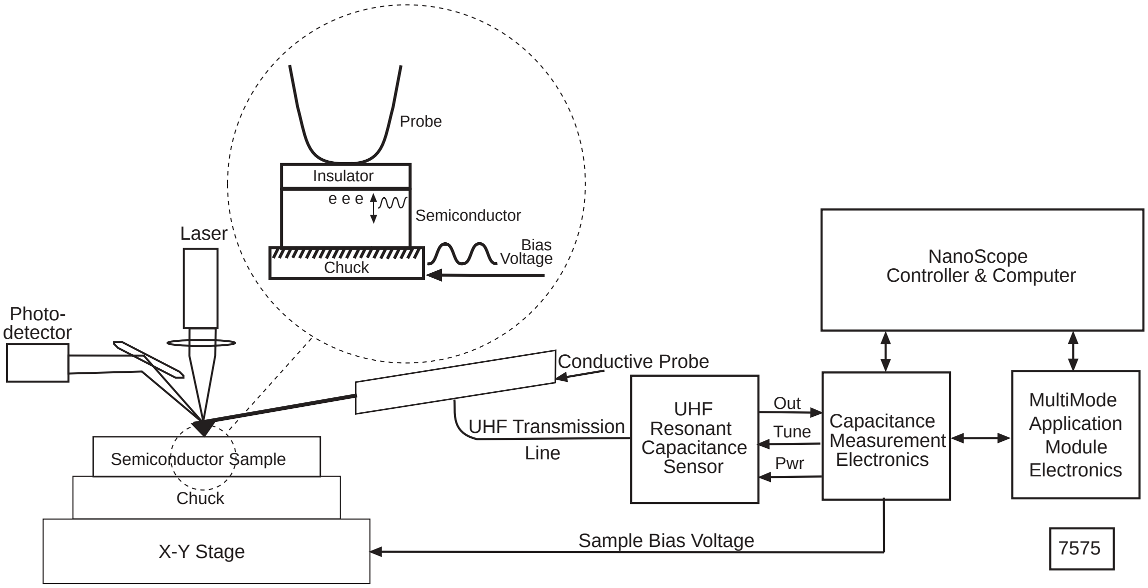
A kilohertz AC bias voltage is applied to the semiconductor to induce capacitance variation in the sample (see Figure 2.2b). The tip alternately attracts and repels free carriers beneath the tip due to the alternating electric field. This carrier behavior may be modeled as a moving capacitor plate (see Figure 2.2c). Three quantities determine the depth of depletion and hence capacitor plate motion:

- The strength of the applied field.
- The quality and thickness of the dielectric (usually an oxide) between the conductive probe and the semiconductor.
- The free carrier concentration.

The absolute resolution is generally a few nanometers greater than the radius of the tip. Lateral resolution is dependent on the following:

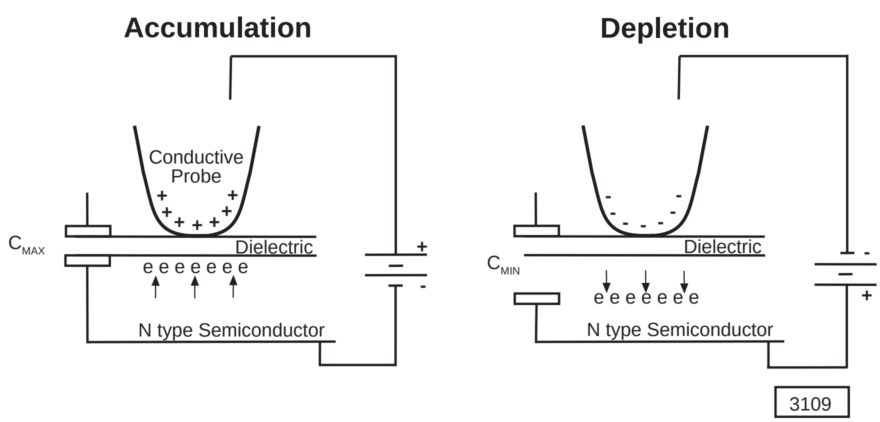
- The effective radius of the tip.
- The thickness of the oxide between the tip and the sample.
- The applied bias between the tip and the sample.

Figure 2.2b Scanning Capacitance Microscopy Block Diagram



Scanning capacitance microscopy measures the rate of change of the MIS capacitance with change in applied voltage, dC/dV. Metal-insulator-semiconductor capacitance varies with the depletion/accumulation depth under the tip.

Figure 2.2c Change from Accumulation to Depletion During SCM Due to Alternating Electric Field



If a semiconductor surface is free of oxide, the tip/sample interface is a Schottky contact (direct metal to semiconductor contact). In this case, the physics of the interaction is more complex and current flows between the capacitor "plates."

Figure 2.2d shows a typical high frequency capacitance-versus-voltage (CV) relationship for high and low concentration N-type semiconductors. For P-type material, the CV curve polarity inverts. With a positive voltage applied to the gate (the conductive probe in this case), the carriers in the material (electrons for N-type) are attracted to the surface and accumulate there. In accumulation, the capacitor plates for the semiconductor are close together and the MIS capacitance is the capacitance across the dielectric oxide. As the voltage on the gate swings negative, the electrons move away from the gate, depleting the material of carriers. This increases the spacing between the semiconductor capacitor plates and lowers the capacitance.

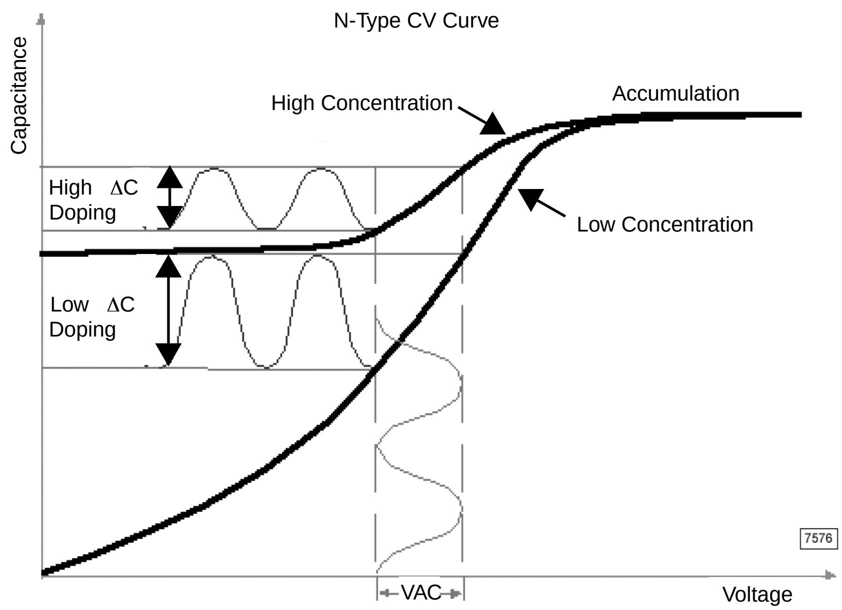
The lower concentration material depletes faster; hence the capacitance decreases faster with voltage. Therefore, the slope of the CV curve (or dC/dV) is larger for the low concentration.

By applying a constant amplitude AC voltage, V_{AC}, while varying the DC voltage, V_{DC}, and measuring the capacitance across the tip/sample dielectric, the derivative of the CV curve is obtained: $dC(V)/dV \approx \Delta C(V_{DC})/V_{AC}$. Integrating, determines the C(V) function:

$$C(V) = \int_{(V_{DC}=0)}^{V_{accumulation}} \left(\frac{d}{dV}C(V)\right) dV$$

To avoid overdriving an uncharacterized semiconductor, use *Constant Depletion SCM Mode* by applying feedback from the measured capacitance to the applied AC voltage to maintain a constant MIS capacitance, so a constant depletion depth.

Figure 2.2d N-type Capacitance versus Applied AC Voltage (CV) Curves, by Carrier Concentration



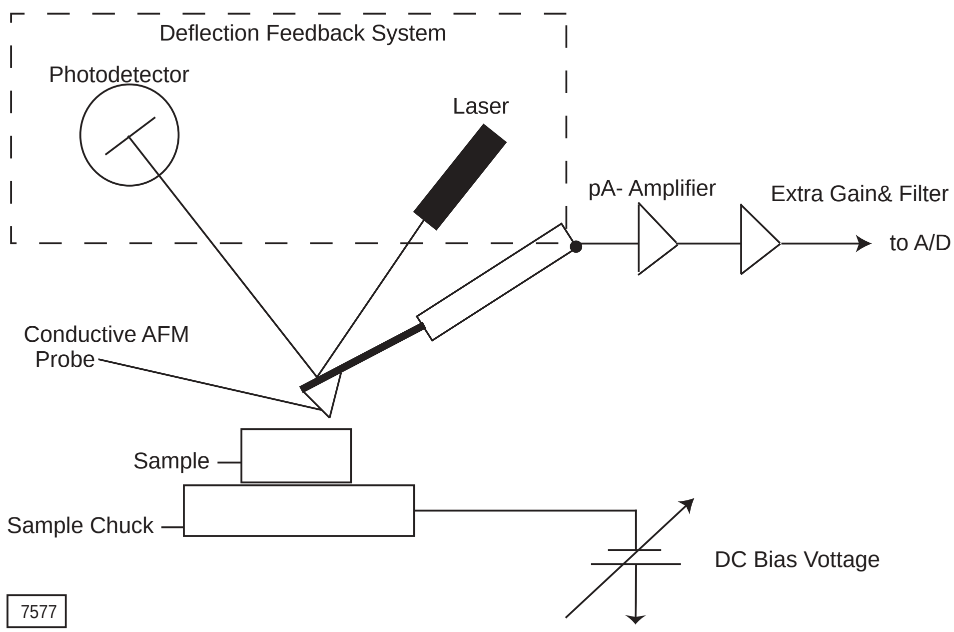
2.3 TUNA and Extended TUNA Theory

Tunneling Atomic Force Microscopy (TUNA) extends to high resistance sample surfaces the original SPM implementation, scanning tunneling microscopy of conductive samples. TUNA measures sub-picoampere tip/sample currents through highly resistive samples.

The geometry of the tip determines the lateral resolution, which is roughly equal to the end radius of the tip. With the tip at virtual ground, a selectable bias voltage is applied between the conductive tip and sample (see Figure 2.3a). While scanning in Contact Mode, a linear amplifier with a range of 80fA to 120pA senses the current passing through the sample. By maintaining a constant force between tip and sample, simultaneous topographic and current images are generated, enabling the direct correlation of local topography with electrical properties.

TUNA is especially useful for evaluating dielectric films subject to breakdown, such as silicon dioxide, SiO_2, and transistor gate oxide. Tip/sample tunneling current depends on film thickness, leakage paths, possibly caused by defects, charge traps and tip geometry. TUNA is also used to test the integrity of tribological films, such as Diamond-Like-Carbon (DLC) as used in magnetic recording head/disk interfaces, and conductivity in small structures, such as light-emitting polymers and carbon nanotubes.

Figure 2.3a Tunneling AFM (and Conductive AFM) Block Diagram



Extended TUNA

Extended TUNA theory is the same as TUNA (see above), with the exception that Extended TUNA has the additional range of C-AFM.

2.4 SSRM Theory

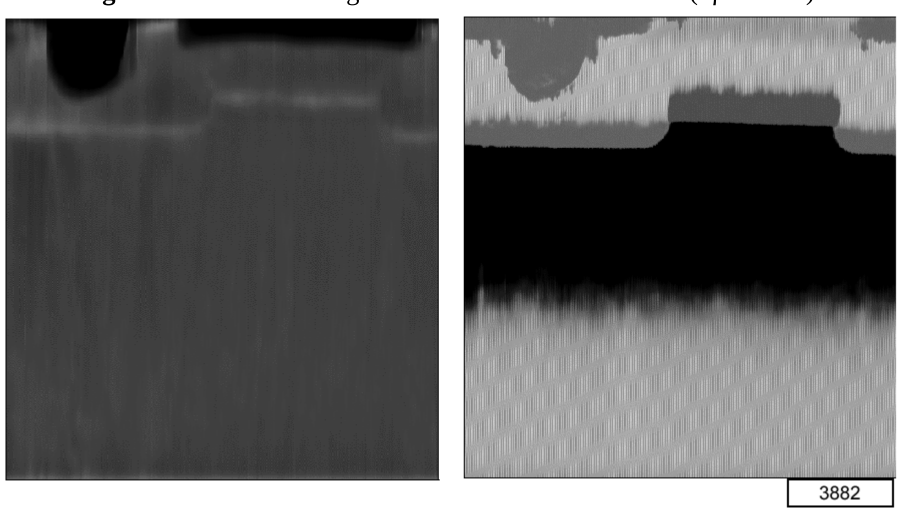
Scanning Spreading Resistance Microscopy (SSRM) exceeds the range of tip/sample currents tolerated by the TUNA Application Module to measure sample surface resistance. SSRM measures the resistivity (the reciprocal of conductivity) of samples spanning a wide range of conductivity, from insulating through semiconducting to metallic. SSRM is especially useful in two-dimensional mapping of electrical carriers in semiconductors.

The geometry of the tip determines the lateral resolution, which is roughly equal to the end radius of the tip. With the tip at virtual ground, a selectable bias voltage, V_{DC}, is applied between the conductive tip and sample. While scanning in Contact Mode, a logarithmic current amplifier with a range of 10pA to 0.1mA senses the current, I, passing through the sample. Resistance is calculated from Ohm's Law: $R = V_{DC}/I$. Material resistivity, in ohm-meters, is defined as the resistance times the cross-sectional area divided by the length of the conducting path made of the material. By maintaining a constant force between tip and sample, simultaneous topographic and current images are generated, enabling the direct correlation of local topography with electrical properties.

The resistance measured is the sum of contact resistance at the tip/sample interface plus the *spreading resistance* radially from the point of contact plus the bulk resistance along the path(s) completing the circuit to the conductive platform supporting the sample. To reduce the material-independent contribution of contact resistance to the total resistance measured, contact area cannot be appreciably increased without losing spatial resolution, so contact force is increased above the minimum necessary to maintain contact. For instance, on silicon, a few micronewtons of force, combined with a low sample bias voltage (e.g., between -1V and 1V) provide a consistent low contact resistance while scanning the surface of most compound (such as InP- and GaAs-based) semiconductor structures. Where a lower force is required (to avoid tip/sample wear), increase the bias by several volts. For an ideal circular, Ohmic contact, the spreading resistance is $R = \rho/4r$, where ρ is the local sample resistivity and r is the radius of the contact.

A sample SSRM image is shown in Figure 2.4a.

Figure 2.4a SSRM Image of a Silicon-based MOSFET (5µm Scan)



a). Topography   b). Resistance

2.5 C-AFM Theory

Conductive Atomic Force Microscopy (C-AFM) expands the range of tip/sample currents used to image surfaces as compared to the TUNA Application Module, while maintaining the same high lateral resolution. While TUNA specializes in very small currents, C-AFM is suitable for imaging samples spanning a wide range of conductivity, particularly, the more conductive.

With the tip at virtual ground, a selectable bias voltage is applied between the conductive tip and sample (see Figure 2.3a). While scanning in Contact Mode, a linear amplifier with a range of 1pA to 1µA senses the current passing through the sample. By maintaining a constant force between tip and sample, simultaneous topographic and current images are generated, enabling the direct correlation of local topography with electrical properties.

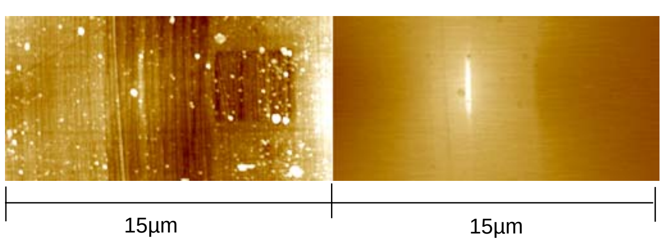
2.6 SThM Theory

Scanning Thermal Microscopy (SThM) allows the user to resolve sample areas by their temperature variation. Current applications include imaging for failure analysis in integrated circuits and magnetoresistive hard disk heads. Factors to consider when performing thermal imaging include the following:

- Four hardware items are required for operation: 1) an Extender™ Electronics Module; 2) thermal application module; 3) thermal tips; and 4) thermal probe holder.
- Because several factors influence thermal imaging, it may prove difficult to precisely determine absolute local temperature. Nonetheless, thermal imaging will give excellent contrast between sites having minor temperature differences.

CAUTION: Thermal tips are easily damaged by electrostatic discharge (ESD). Handle tips *only* when electrically grounded with a wrist strap!

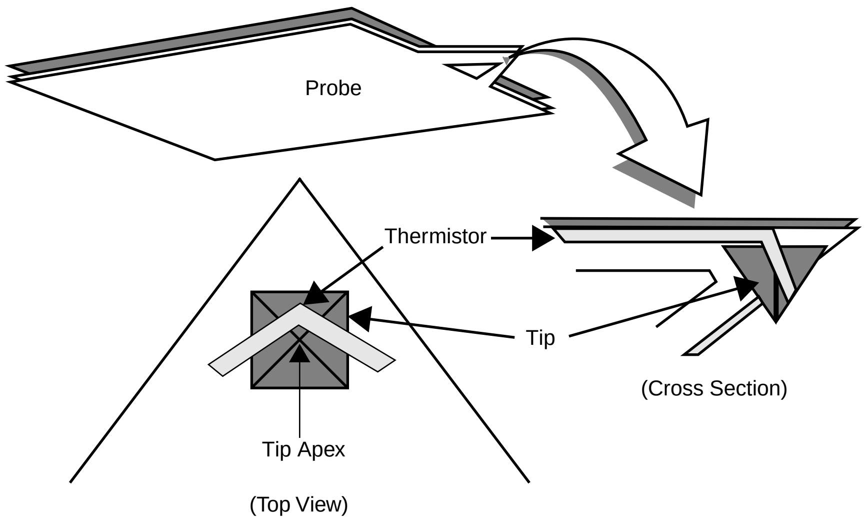
Figure 2.6a Magnetoresistive hard disk head shown topographically (left) and thermally (right)



2.6.1 Thermal Tips

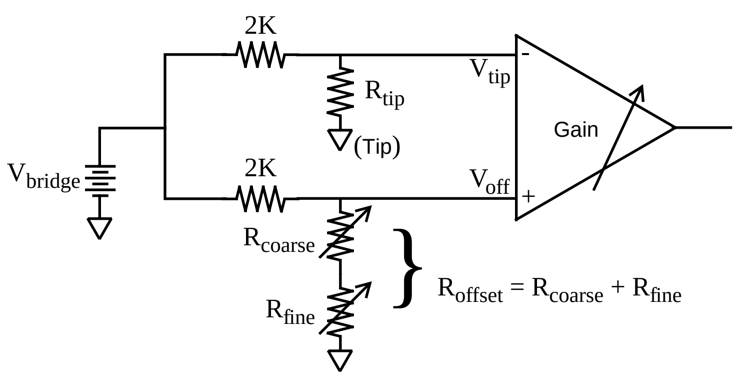
Thermal tips consist of silicon nitride tips with thermistors deposited on the tip.

Figure 2.6b Thermal Tip



The thermistor portion of the tip changes resistance as a function of temperature while being scanned across the sample. These changes are mapped relative to the tip's X- and Y-axis position, resulting in a thermal image of the surface. The electronic circuit used to sense temperature consists of a wheatstone bridge and differential amplifier (see Figure 2.6c). Circuit controls are located on the right side of the SPM thermal head (located on the top when mounted on the MultiMode).

Figure 2.6c Sensor Circuit used with Thermal Tips



Voltage V_{bridge} appears in both branches of the bridge. When the tip is installed, offsets are adjusted so that $R_{off} = R_{tip}$. Once this condition is satisfied, $V_{tip} = V_{off}$ and the bridge is balanced. Then, as R_{tip} heats up or cools down, $V_{tip} \neq V_{off}$, yielding a voltage at the output of the differential amplifier proportional to the temperature at the thermistor. Normal circuit biasing in the wheatstone bridge operates the thermistor at a nominal current of 50 μA, depending upon the resistance (and temperature) of the probe.

Chapter 3 Hardware and Software Installation

3.1 Introduction

This chapter details the installation procedures for the application modules, Quadrex Extender module, and the NanoScope software setup. Please refer to the following sections:

- **System Requirements:** Section 3.2
- **Dimension Application Module Instrumentation and Installation:** Section 3.3
- **MultiMode Application Module Instrumentation and Installation:** Section 3.4
- **Installing the Quadrex Module:** Section 3.5
- **Software Setup:** Section 3.6

3.2 System Requirements

The minimum system requirements needed to install and operate an application module include:

- Software Version 5.12r4 or higher, NT
- Dimension 3000, 3100, or 5000 or MultiMode with NanoScope IV controller or NanoScope IIIa with Quadrex module

Quadrex and application module performance (see Table 5.3a, page 112) assume maintenance of the environmental conditions listed in Table 3.2a.

Table 3.2a Environmental Requirements

Equipment Use	Condition	Requirement
Operation	Temperature	15ºC (59ºF) to 35ºC (95ºF)
"	Relative Humidity	45% to 80%, non-condensing
Storage	Temperature	10ºC (50ºF) to 50ºC (122ºF)
"	Relative Humidity	35% to 90%, non-condensing

3.3 Dimension Application Module Instrumentation and Installation

- **Hardware Description:** Section 3.3.1
- **Dimension Application Module Installation:** Section 3.3.2

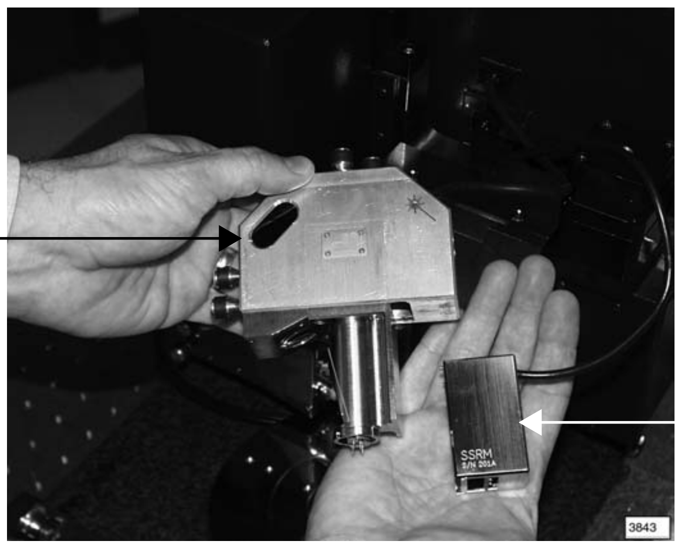
3.3.1 Hardware Description

The Dimension application module hardware consists of the following items:

Application Module AFM Scanner

Allows the user to mount the application module using two screws (size: 2-56, 1 1/4") (see Figure 3.3a).

Figure 3.3a Application Module AFM Scanner and Application Module Sensor



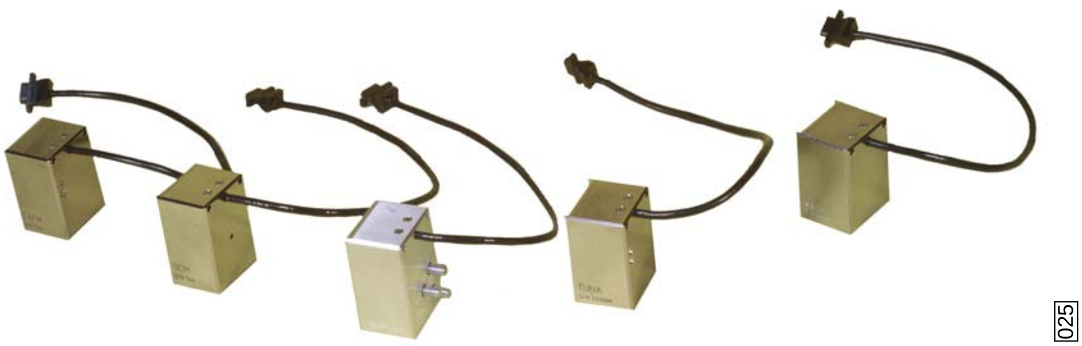
Quadrex Module or NanoScope IV Controller

Contain specialized electronics for standard AFM imaging, extended AFM imaging, and application module (SCM, SSRM, TUNA, C-AFM and SThM) imaging. (See **Installing the Quadrex Module:** Section 3.5 for more information).

Application Module Sensor

The application module sensor contains the resonance circuit necessary for capacitance imaging. You may mount the application module sensor on the application module AFM scanner using two screws. It connects to the application module electronics box using the subminiature D-15 connector (see Figure 3.3a and Figure 3.3b).

Figure 3.3b Application Module AFM Sensors



Application Module Probe Holder

The probe holder provides electrical connection from the tip to the application module sensor, while maintaining standard features for contact mode and tapping mode imaging.

SSRM, TUNA, Extended TUNA and C-AFM share a common probe holder (see Figure 3.3c). SCM and SThM tips have specific probe holders (see Figure 3.3d and Figure 3.3e).

Note: Using the application module AFM scanner and Quadrex module, you can operate all application modules provided that you have the corresponding sensors and probe holders.

Figure 3.3c Dimension SSRM, TUNA, Extended TUNA and C-AFM Probe Holder

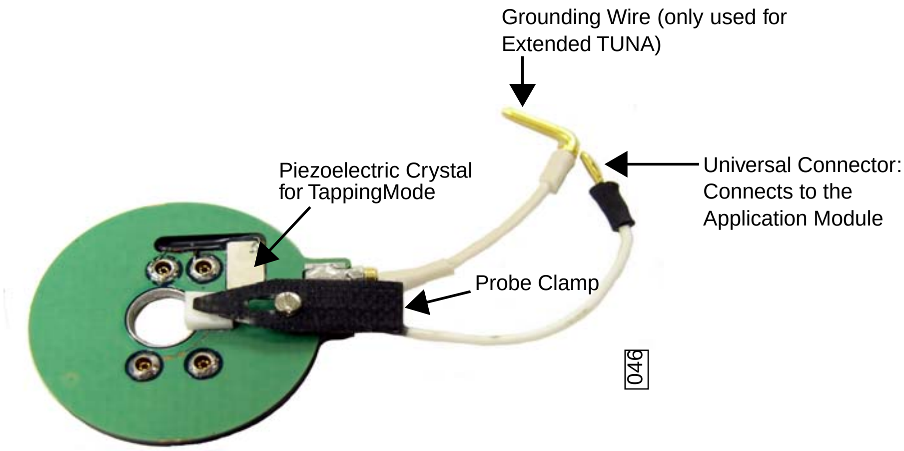


Figure 3.3d Dimension SCM Probe Holder

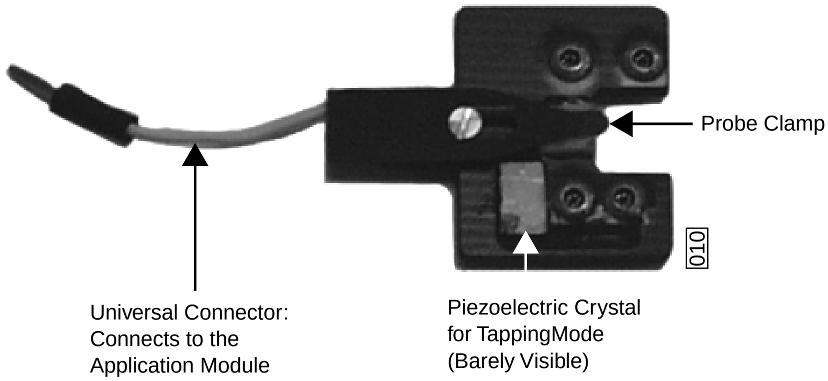
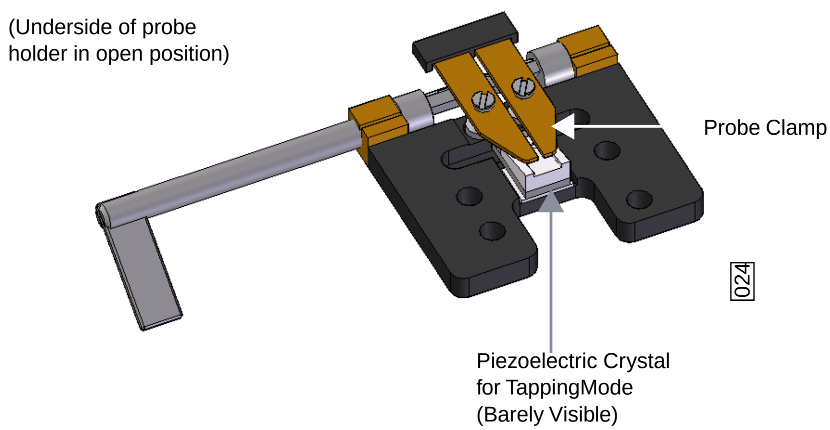


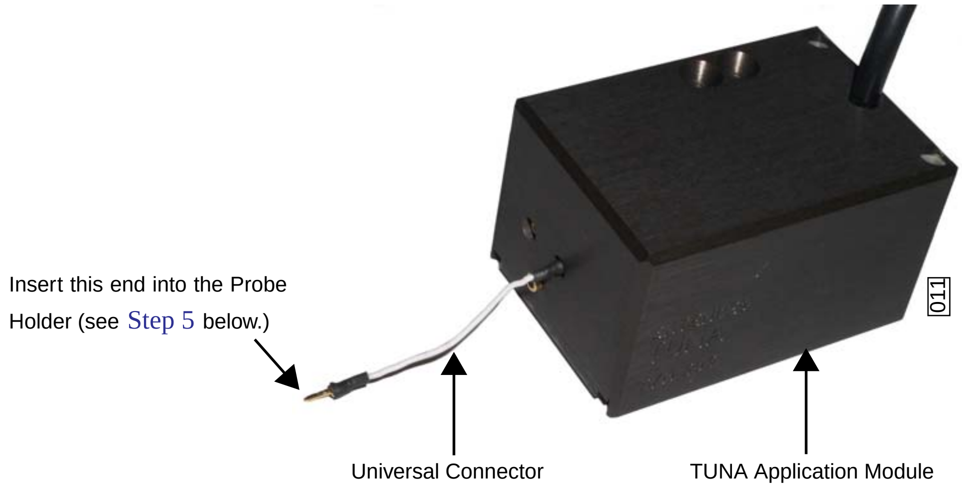
Figure 3.3e Dimension SThM Probe Holder



Probe Module Universal Connector

All Dimension application modules are provided with a tiny wire, the Probe Module Universal Connector (Universal Connector), which is only required when a module is in use (see Figure 3.3f).

Figure 3.3f TUNA Application Module with Universal Connector Inserted



WARNING: Turn power off to all system components before making cabling connections.

3.3.2 Dimension Application Module Installation

Installation of the Dimension system for application modules differs from a standard Dimension system only in the installation of the application module sensor on the AFM scanner head. For other installation issues, see your Dimension instruction manual.

1. Remove the head by completing the following:

    a. Unplug the Dimension head 21-pin connector.

    b. Tighten the clamping screw on the right hand side of the dovetail mount by turning it clockwise.

    c. Gently remove the head.

2. Place the application module sensor flush on the flat part of the piezo guard, and tighten it down using the two #2-56 screws. Be careful not to overtighten (see Figure 3.3g and Figure 3.3h).

   Note: The allen head screws and a matching allen wrench are included in the application module kit.

Figure 3.3g Align Application Module AFM Scanner and Sensor

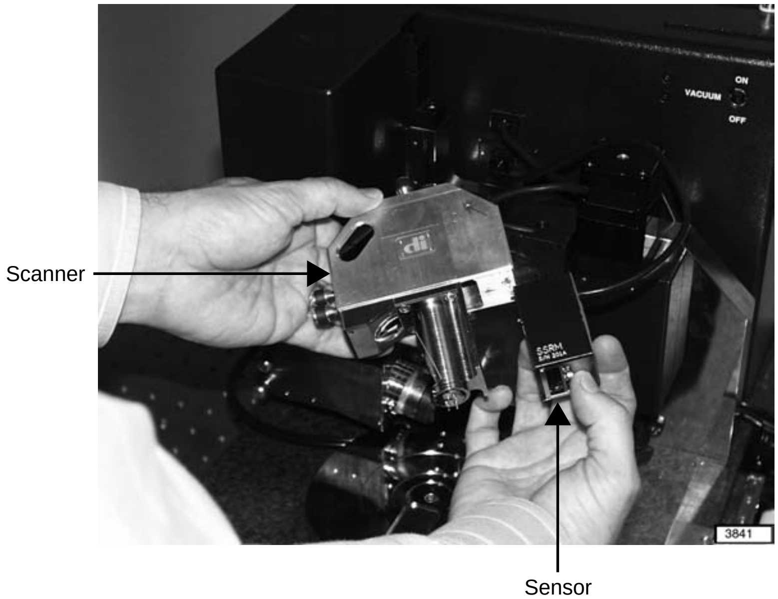
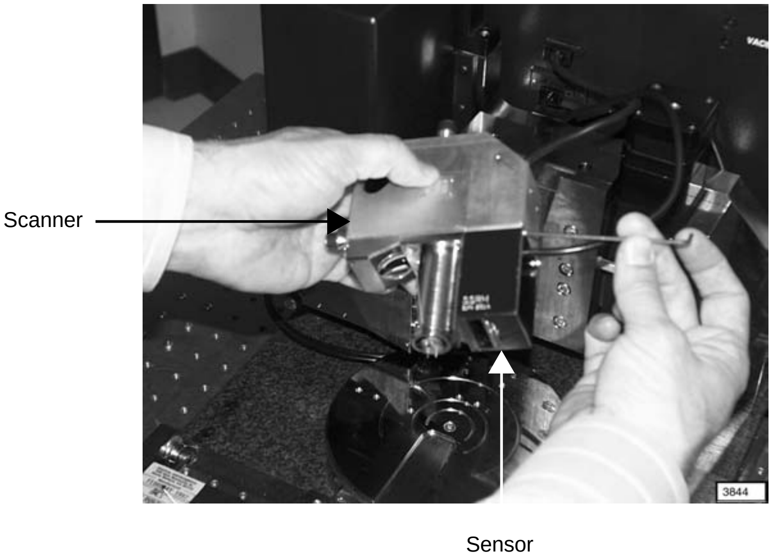


Figure 3.3h Mounting of the Sensor on the Application Module AFM Scanner

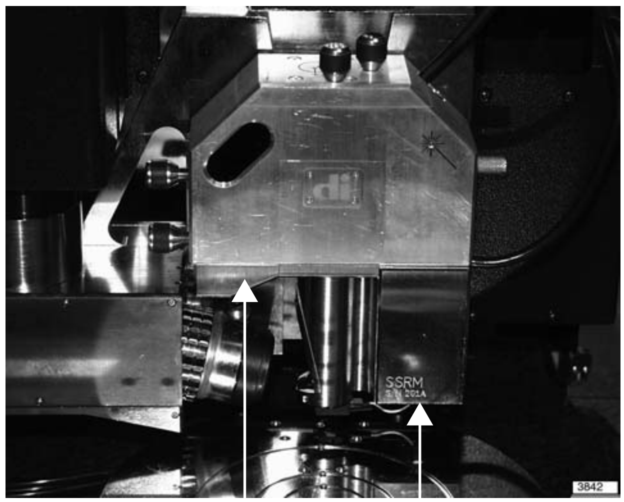


3. Install the Dimension head on the dovetail mount by completing the following (see Figure 3.3i):

    a. Release the clamping screw by turning it counter-clockwise until the head is secure.

    b. Plug the head 21-pin connector and the application module 15-pin connector into the receptacles on the front of the microscope electronics box.

Figure 3.3i Installed Application Module



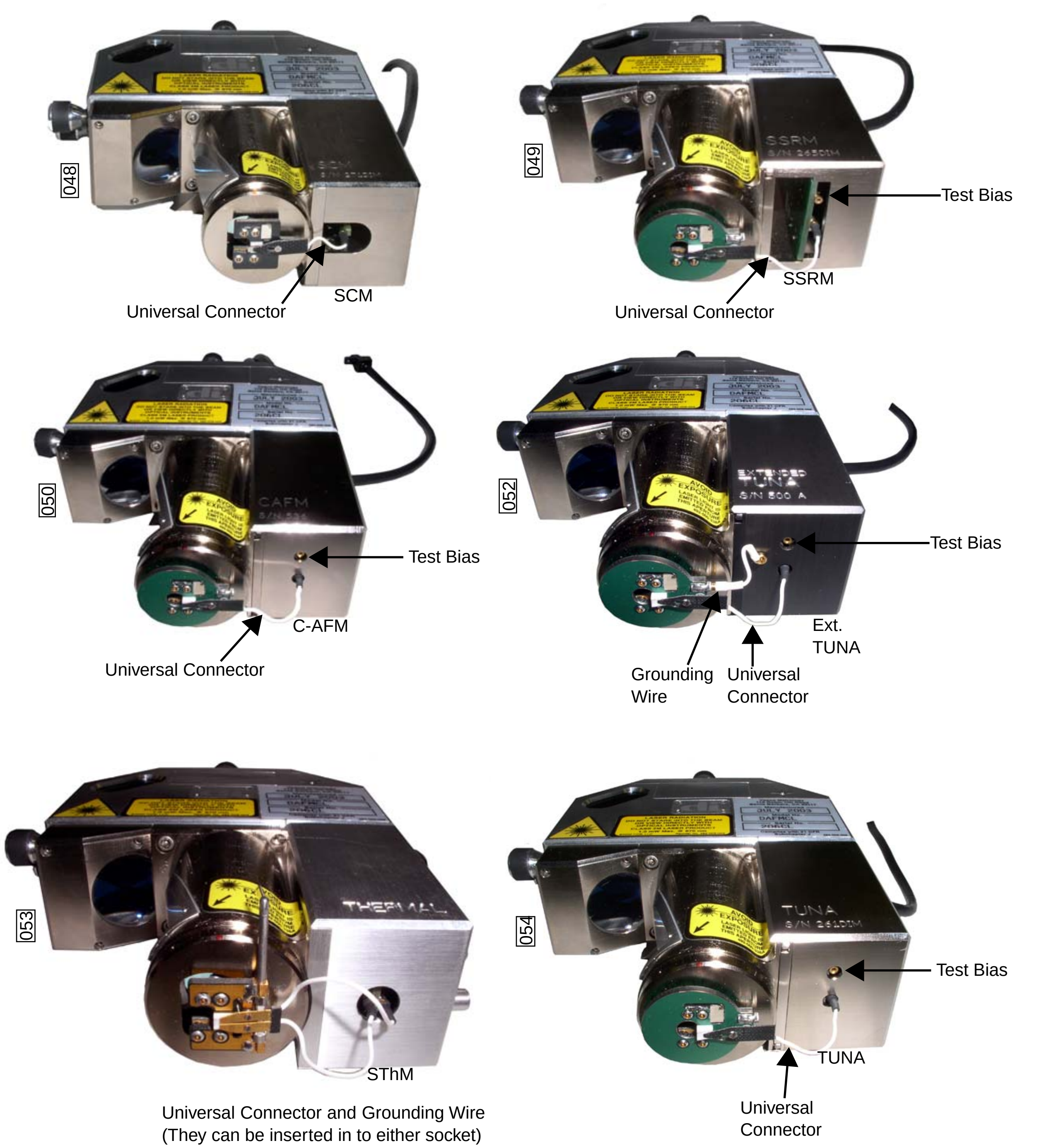
When installing the Dimension head, carefully check the clearance between the sample/stage and the tip/scanner to prevent the tip/scanner from crashing into the sample/stage. If it appears that the tip/scanner may crash when fully inserted, remove the Dimension head completely and execute the **Motor** > **Withdraw** command. You may also select **Stage** > **Focus Surface** and use the trackball to obtain sufficient clearance and avoid a crash

Note: It is very important to release the clamping screw on the dovetail, and ensure the Dimension head is tightly secured in the mount. A loose Dimension head causes a large increase in image noise due to reduced rigidity of the mechanical support of the SPM head.

4. Install a tip in the appropriate Dimension probe holder (see Figure 3.3d and Figure 3.3e); for SCM, C-AFM, SSRM and TUNA, refer to your Dimension instruction manual for guidance; for SThM refer to **Dimension SThM Tip Selection and Mounting:** Section 4.7.2).

5. Insert one end of the Universal Connector into the central single-wire socket of the application module you are installing (see Figure 3.3c and Figure 3.3d). Each application module has an unique location to attach the Universal Connector (see Figure 3.3j).

Figure 3.3j All Application Modules with Probe Module Universal Connector Installed



3.4 MultiMode Application Module Instrumentation and Installation

- **Hardware Description:** Section 3.4.1
- **Application Module Installation:** Section 3.4.2

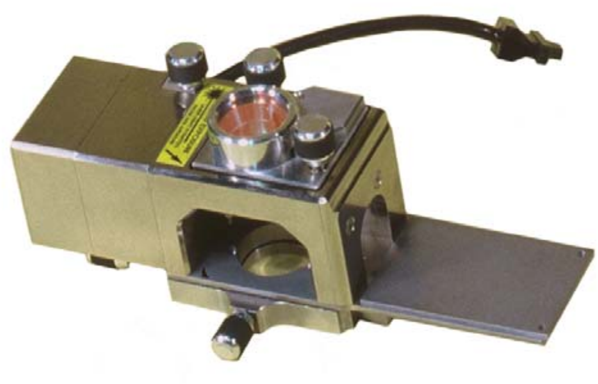
3.4.1 Hardware Description

The MultiMode application module hardware consists of the items listed below.

Application Module AFM Scanner

Allows the user to mount the application module using two springs (see Figure 3.4a). A single modified head platform supports any one of the five modules at a time. Modules are quickly and easily exchanged and installed to facilitate analysis of the same sample by complementary, alternative techniques.

Figure 3.4a MultiMode Applications Module Scanner Head



020

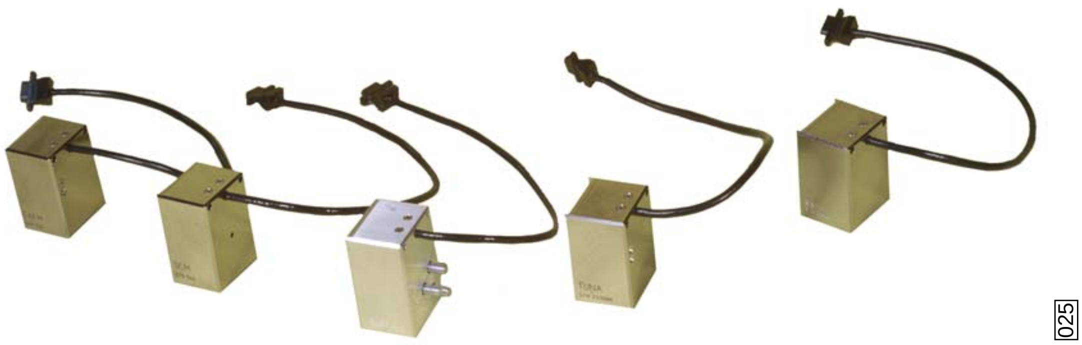
Quadrex Module or NanoScope IV Controller

Contain specialized electronics for standard AFM imaging, extended AFM imaging, and application module (SCM, SSRM, TUNA, Extended TUNA, C-AFM and SThM) imaging. See **Installing the Quadrex Module:** Section 3.5 for more information.

Application Module Sensor

You may mount the application module sensor on the application module AFM head using two screws. It connects to the Quadrex module electronics box using the subminiature D-15 connector (see Figure 3.4b).

Figure 3.4b Application Module AFM Sensors



Application Module Probe Holder

Made from non-conductive materials, the probe holder maintains standard features for contact mode and tapping mode imaging while reducing electrical noise (see Figure 3.4c and Figure 3.4d).

TUNA, SSRM and C-AFM share a common probe holder. SThM has a specific probe holder.

Figure 3.4c MultiMode Application Module Probe Holder (SCM, C-AFM, SSRM and TUNA)

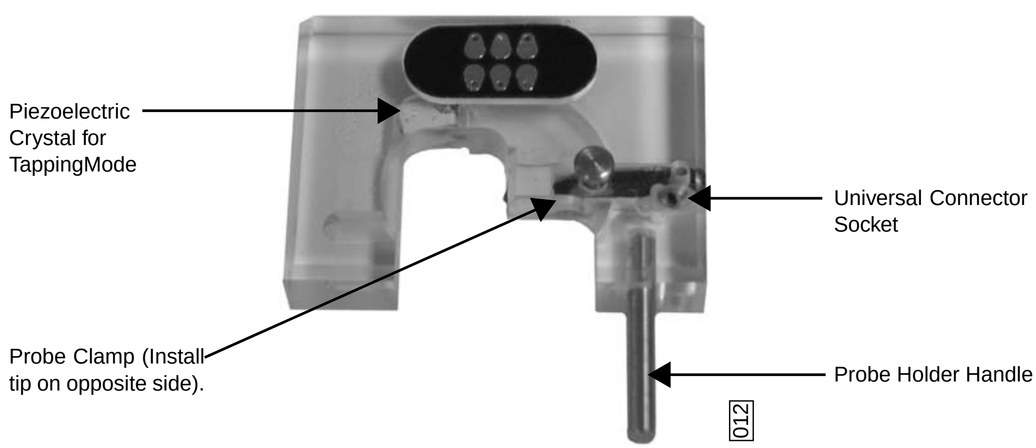
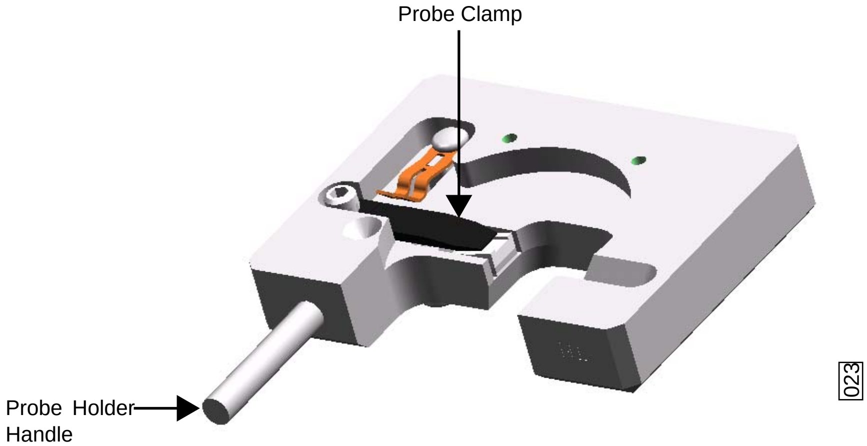


Figure 3.4d MultiMode SThM Probe Holder

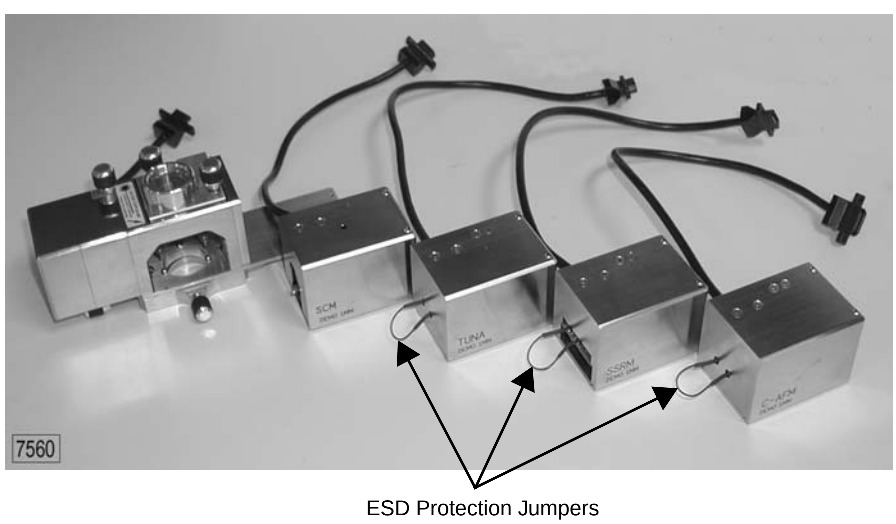


(Underside of probe holder in open/imaging position)

Electrostatic Discharge (ESD) Protection Jumper

Of the currently available MultiMode application modules, four are ESD-sensitive (TUNA, SSRM, C-AFM and SThM). These are supplied with a tiny Static Protection Jumper (see the loop of wire extending from the application modules on the right of Figure 3.4e).

Figure 3.4e Static Protection Jumpers

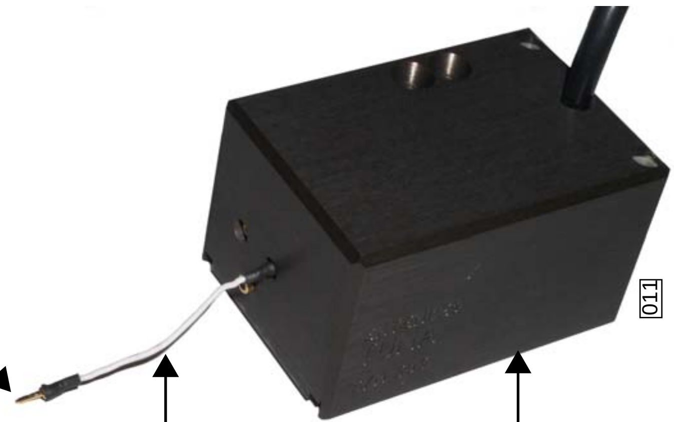


WARNING:	Leave the ESD Protection Jumper connected between the two single-wire connectors on one side of TUNA, SSRM, C-AFM and SThM modules when not in use. To avoid electronics damage, take precautions such as grounding oneself before removing the ESD Protection Jumper to install one of these application modules.

Probe Module Universal Connector

All MultiMode application modules are also provided with another tiny wire, the Probe Module Universal Connector (Universal Connector), which is only required when a module is in use (see Figure 3.4f).

Figure 3.4f TUNA Application Module with Universal Connector Inserted



WARNING:	Turn power off to all system components before making cabling connections.

3.4.2 Application Module Installation

Note: Only one application module may be used at a time.

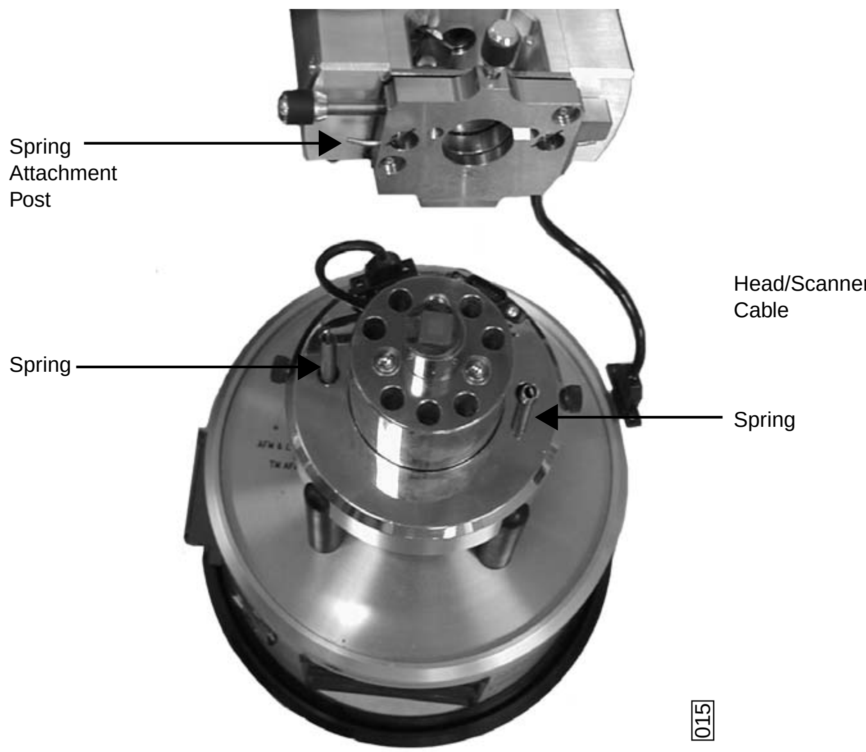
To install an application module:

1. Remove the existing head:

   a. Turn off power to the entire SPM system through the NanoScope Controller.

   b. Disconnect the head connector from the MultiMode scanner (see Figure 3.4g).

Figure 3.4g Remove MultiMode Head from Scanner



   c. Stabilizing the existing MultiMode head in one hand, use a tweezer to lift off the end of the spring on each side holding the head to the MultiMode scanner (see Figure 3.4g). Store the standard MultiMode head for future use.

2. With one hand, stabilize the Applications Module Head (see Figure 3.4h) on the MultiMode scanner. Using a tweezer, loop the free end of the spring on each side of the scanner over the corresponding spring attachment post on each side of the Applications Module Head (see Figure 3.4i).

Figure 3.4h Multiple Views of the MultiMode Applications Module Head

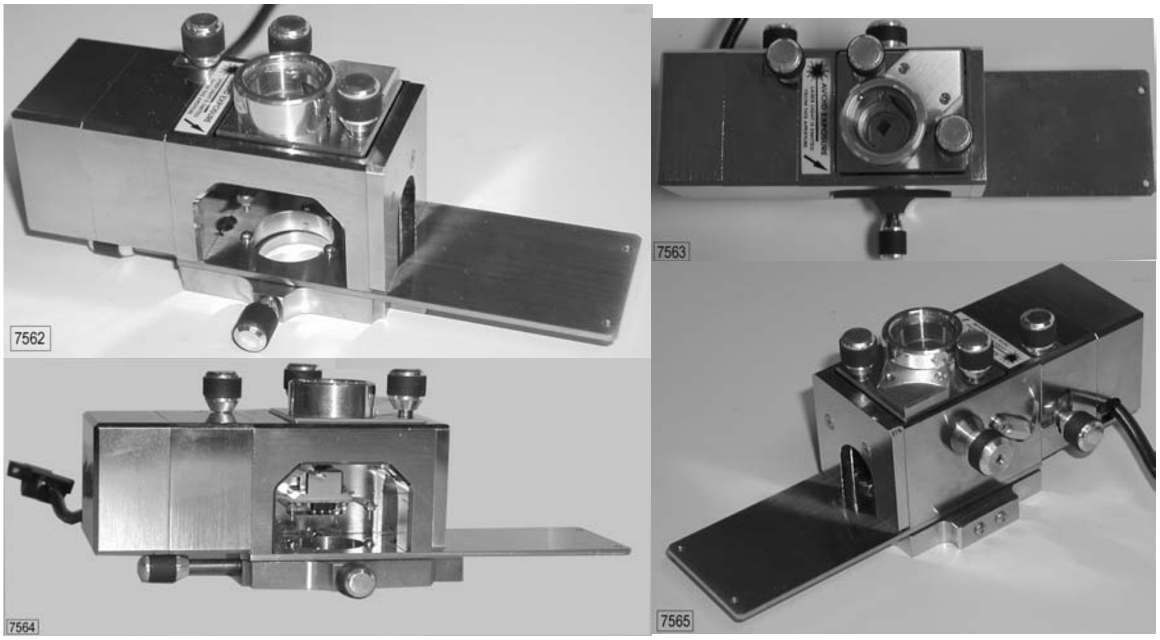


Figure 3.4i Applications Module Head Attached by Springs to Scanner (Probe Holder Included)

3. Install a tip in the MultiMode Application Module Probe Holder (see Figure 3.4c and Figure 3.4d); for SCM, C-AFM, SSRM and TUNA, refer to your MultiMode instruction manual for guidance; for SThM refer to **MultiMode SThM Tip Selection and Mounting:** Section 4.7.3).

   Note: All application modules require a conductive tip (e.g., SCM-PIT tips coated with platinum/iridium, TESP and OTESP tips coated with aluminum or gold-coated MESP tips).

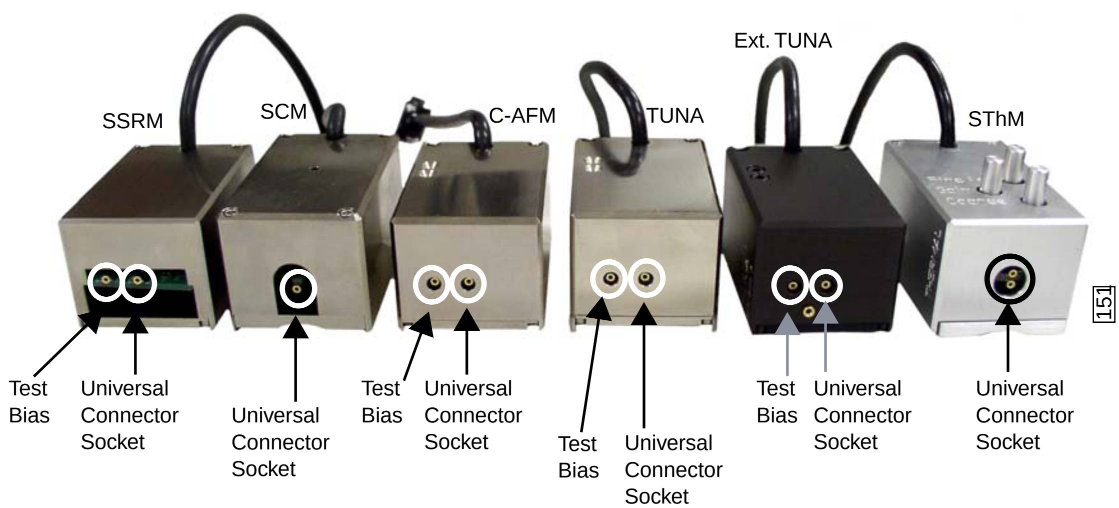
4. Place the probe holder in the MultiMode Applications Module Head and clamp it in place.

	CAUTION:	TUNA, SSRM, C-AFM and SThM Application Module installation only: verify that you and the application module are ESD-protected through garment and/or tabletop mat grounding and/or work area air ionization. Remove the ESD Protection Jumper from the application module being installed (see wire loop protruding from each of the right three modules in Figure 3.4a).

5. Insert one end of the Universal Connector into the central single-wire socket of the application module to be installed (see Figure 3.4f and Figure 3.4j).

Figure 3.4j MultiMode Universal Connector Insertion Locations in the Application Modules

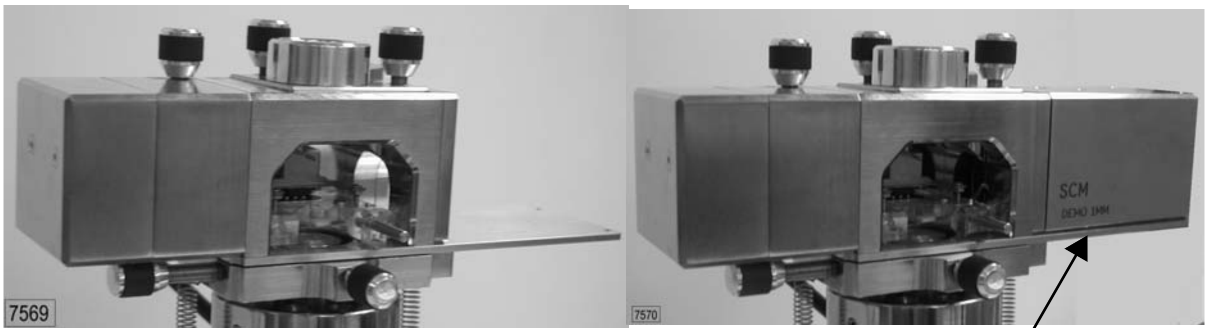
For each module, insert the end of the Universal Connector into the appropriate socket.
The circles below indicate the socket locations for each module.



6. Hold the application module on the head platform while screwing it in place with the screws provided.

   Note: The unattached end of the Universal Connector is positioned over the probe holder (see Figure 3.4k).

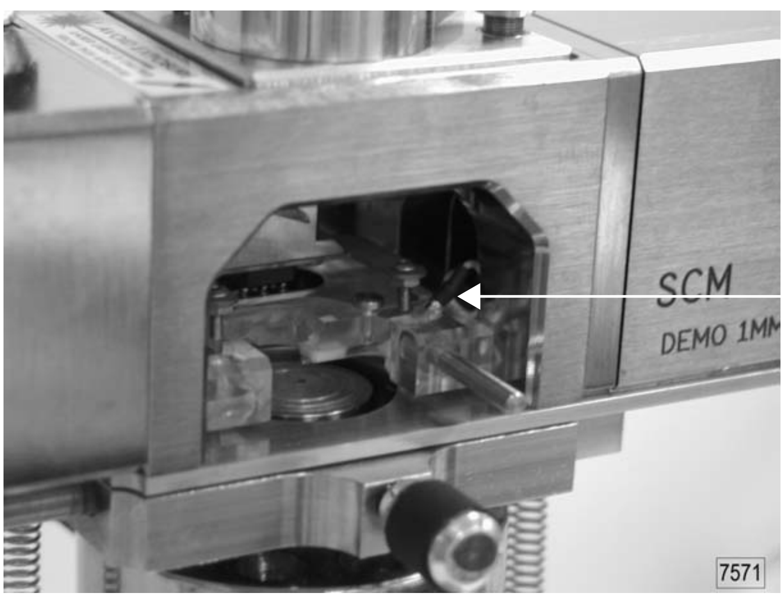
Figure 3.4k Application module Head with SCM Module Installed



7. Using tweezers, insert the free end of the Universal Connector into the socket on the probe holder (see Figure 3.4f and Figure 3.4l).

   Note: ESD precautions for TUNA, SSRM, C-AFM and SThM modules may now be relaxed.

Figure 3.4l SCM Module Universal Connector Inserted into Probe Holder



3.5 Installing the Quadrex Module

An SPM must be phase-equipped to support application modules. That is, the SPM requires hardware modification by Veeco in addition to a Quadrex PhaseImaging implementation, which may be either as an integral part of the NanoScope IV Controller or as a separate module for use with NanoScope III and NanoScope IIIa Controllers. Refer to the *NanoScope IV Controller Manual* or *Support Note 322*, *Quadrex PhaseImaging*, respectively, for discussion of Quadrex quadrature phase detection with each controller. The Quadrex module ships with one 91.5cm (3') cable that connects the NSIII(A) Controller to the Quadrex module.

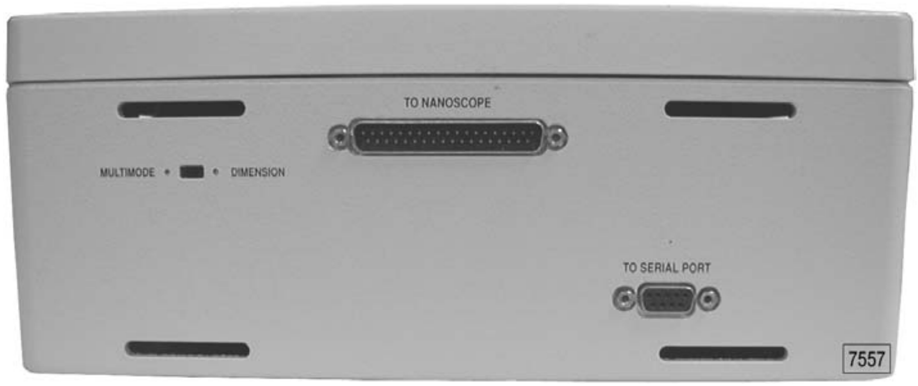
To install the Quadrex Module:

1. Plug the application module cable into the Module Extension Cable. Plug the Module Extension Cable into the application modules connector on the top right of the back of the Quadrex module (see Figure 3.5a and Figure 3.5b). These are subminiature D-15 connectors.

Figure 3.5a Application Module Connected to Module Extension Cable Connected to Quadrex (Rear View)

2. Disconnect at the controller the 37-pin connector to the SPM. Reconnect the detached end to the **To Microscope** connector on the front of the Quadrex module (see Figure 3.5b).

Figure 3.5b Quadrex Module



Front

Back

3. Connect the 37-pin connector shipped with the Quadrex module between the **To Microscope** connector on the NanoScope IIIa Controller and the **To NanoScope** connector on the back of the Quadrex module.

Note: No separate power cord for either the Quadrex module or application modules is required. Power is supplied from the controller.

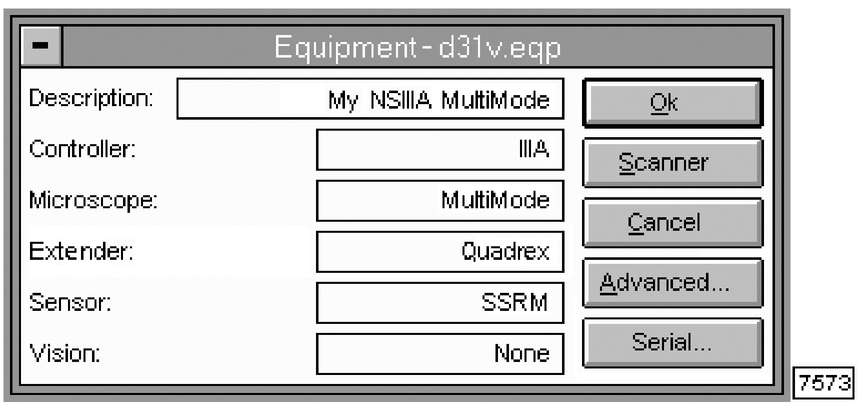
3.6 Software Setup

Quadrex is designed to operate with NanoScope version 5.12r2, or later software. To enable an application module and Quadrex-related features of your NanoScope III(a)-controlled NanoScope system software:

1. Click the Digital Instruments icon (shown) and click **Microscope Select**.
2. Click **Edit** in the **Microscope Select** panel to open the **Equipment** panel (see Figure 3.6a).
3. Select **Quadrex** for the **Equipment** > **Extender** parameter.
4. Select **SCM**, **TUNA**, **SSRM**, **C-AFM** or **SThM** to indicate the installed application module for the **Equipment** > **Sensor** parameter.
5. Select Serial and add Fast Scan to the com port that is connected to the Quadrex module (COM1 for MultiMode, COM4 for Dimension 3100).
6. Click **OK** to close the **Equipment** panel. Click **OK** to close the **Microscope Select** panel.

Note: The above procedure assumes you have added the Quadrex module and an application module to your SPM system, but otherwise have the same configuration of controller, SPM, controller COM port assignments, etc. as the last time the system was used. If not, refer to your SPM instruction manual, the *Command Reference Manual* or the controller manual to respecify your system configuration.

Figure 3.6a The Equipment Panel, Example for the SSRM Application Module



Chapter 4 Operating Procedures

4.1 Introduction

This chapter details the procedures for preparing the sample and operating each application module. Please refer to the following sections:

- **Sample Preparation:** Section 4.2
- **Scanning Capacitance Microscopy (SCM):** Section 4.3
- **Tunneling Atomic Force Microscopy (TUNA and Extended TUNA):** Section 4.4
- **Scanning Spreading Resistance Microscopy (SSRM):** Section 4.5
- **Conductive Atomic Force Microscopy (C-AFM):** Section 4.6
- **Scanning Thermal Microscopy (SThM):** Section 4.7

4.2 Sample Preparation

In some situations, the sample volume of interest is not at a surface. Cross-section a sample to expose the interior at a visible surface. A procedure for preparing finely polished sample cross-section surfaces follows. SCM and SSRM samples are discussed explicitly because these more often require cross-sectioning. The procedures may just as well be applied to cross-sectioning TUNA and C-AFM samples. An animated sample preparation procedure is available from Veeco upon request.

4.2.1 SCM and SSRM Sample Preparation

For 2-D carrier profiling, the region of interest must be accessible to the profiling instrument. If this region is below the sample surface, a cross-section of the sample is required. Preparation of semiconductor cross-sections usually involves cleaving and/or polishing. The most important criteria for a cross-section surface are: low roughness, cleanliness and no surface damage. This portion of this manual overviews possible sample preparation techniques employing a diamond saw, a lapping apparatus and silver epoxy. It may be necessary to apply a sputtered coating. In general, standard electron microscopy techniques for sample preparation work well, though the surface finish required is more exacting for SCM and SSRM. The following technique may be carried out and a sample prepared within a few hours with a little practice.

Equipment and Supplies

Capital Sample Preparation Equipment

- N_2 dry box
- Hot plate
- Nikon Optihot-100 with 10X or 20X wide field eyepieces
- 5X, 20X and 50X Brightfield / Darkfield / Differential Interference Contrast (BF, DF, DIC plan Apo) objectives
- 100X or 150X plan Apo BF/DF objective
- Stereo zoom scope (Nikon SMZ-2 + ringlight and stand)
- Buehler Ecomet 3 or 4 polisher
- Ultraviolet (UV) light source (wavelength below 300)

Consumables

- Cross-section holder (e.g., Allied Hightech PN 69-30000)
- Glass slides
- Epoxy (e.g., Epoxy bond 110 Allied PN 71-10000)
- Silver epoxy (e.g., Dynaloy PN 325 A/B)
- Silver paint (e.g., Ted Pella #16035)
- Replication tape (e.g., Ted Pella #44841)
- Diamond Lapping Films (e.g., 0.1, 0.5, 1, 6 and 15µm, Buehler PN 15-7691, 6795, 6801, 6807, 6815, respectively)
- Diamond suspensions for Texmet 0.1, 0.25µm, Buehler PN 40-6528, 6529, respectively
- Texmet 1000 polish pad, Buehler PN 40-7618

Cross Section Sample Preparation

SCM and SSRM cross section preparation steps are listed below and represented in Figure 4.2a.

1. Cement semiconductors of interest into a stacked “sandwich” using G1 epoxy or equivalent.
   a. Press the pieces together to remove all air bubbles.

      Note: Glass plates may be epoxied to the bottom and top of the sandwich to strengthen and protect the semiconductors within.

   b. Allow the epoxied stack to heat cure thoroughly.
2. Use a diamond saw to slice off approximately 0.5mm of the semiconductor sandwich.

   Note: Do not sputter coat onto the polished surface to be imaged.
3. For optimal electrical contact, sputter the semiconductor stack with gold where it will contact the puck or stage of the SPM.
4. Using silver epoxy or a low temperature wax, attach the mounting side of the sample to the underside of a polishing fixture. Spread the coating evenly to provide a broad contact area.
5. Install the loaded fixture on a lapping plate.
6. Polish the semiconductor sandwich to expose the region of interest. Verify that the sample is polished flat to a root mean square (RMS) roughness of <0.2nm to produce a superior image.

7. By irradiating it with UV light, reduce the conductivity of the surface silicon oxide film that forms:

    - Place the sample on a hot plate at about 200-300ºC for 20 minutes of which 1 minute includes high-intensity UV radiation.

    Note: This preparation step results in a surface which shows no Fermi-level pinning and only a moderate density of surface electronic states.

Details of the Polishing Procedure

Note: When polishing, maintain a small, constant downward pressure against the lapping plate while moving the fixture in small, counter-clockwise circles.

1. Rotate the lapping plate at 90-120rpm.

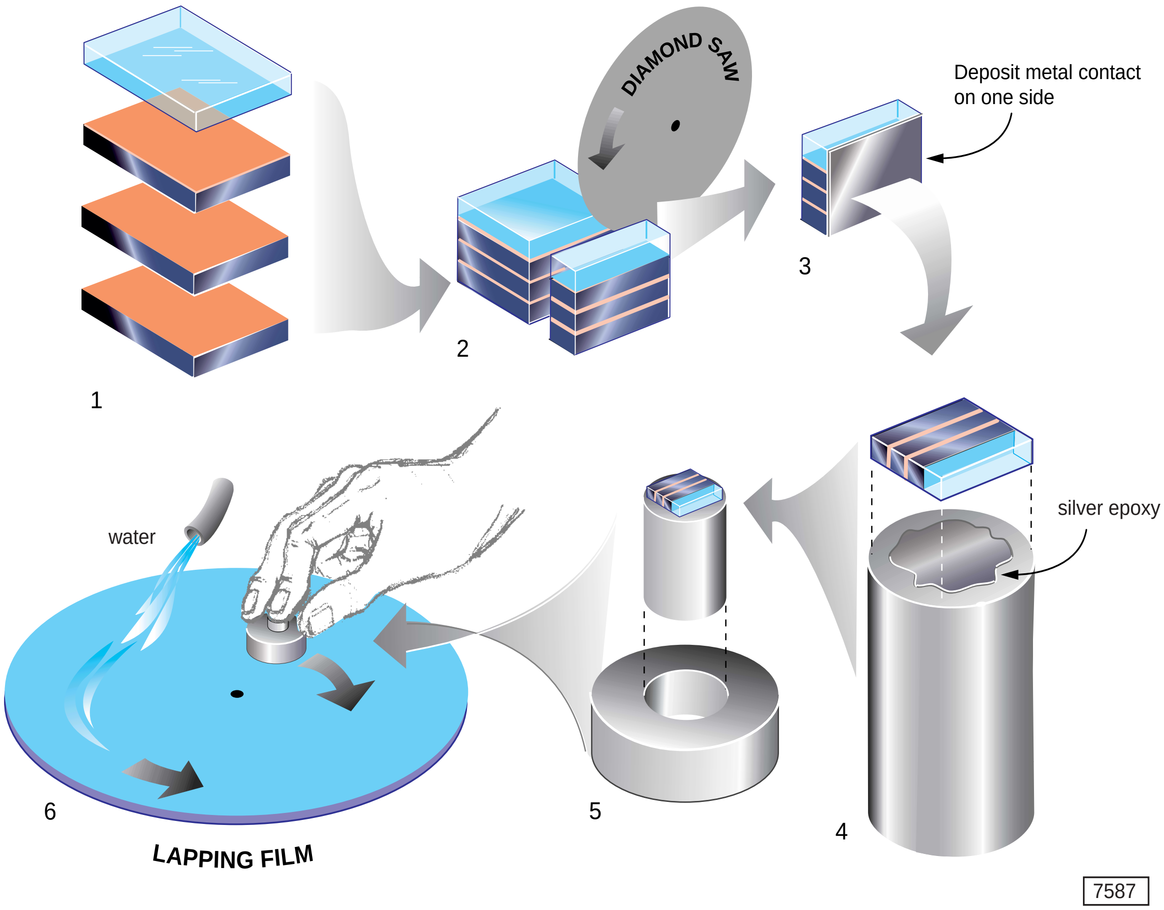
2. Starting with 10µm diamond grit paper, lap the sample until achieving a uniformly flat surface; remove all traces of the saw cut.

3. Use 3µm diamond paper, remove approximately 30µm.

    Note: Before proceeding to a smaller grit remove a thickness of sample material at least three times the particle size of the lapping compound in use. A typical sequence of diamond particle lapping papers to use for achieving a highly polished surface is:

- 10-micron: to remove saw grinding marks and smooth the sample
- 3-micron: polish for 5 minutes
- 1-micron: polish for 5 minutes
- 0.5-micron: polish as needed
- 0.1-micron: polish as needed

Figure 4.2a SCM and SSRM: Semiconductor Cross-Section Preparation



4. Remove the surface damage left by the diamond paper process by using a colloidal diamond slurry. To avoid contamination, use a new polish pad dedicated to one grit (e.g., napless cloth). The following lapping order gives good results:

   - 1-micron: polish for 5 minutes
   - 0.5-micron: polish for 10 minutes
   - 0.25-micron: polish for 20 minutes
   - 0.1-micron: polish as needed

5. Use 0.05-micron colloidal silica for the final cleaning and polishing of the sample surface. Apply for 15-30 seconds. Run clean water for at least 30 seconds.

6. Clean the sample surface with a swab and soapy running water, then wipe or blow dry.

7. If a powered lapping plate is unavailable, lap and polish the sample on a stationary flat surface by moving the fixture and ring in small figure-eight motions while periodically rotating the fixture within the ring to ensure even abrasion.

    Note: Be certain to keep the fixture and lapping surface (plate or paper) wet, and always clean them completely before switching to a smaller grit.

    Note: The most important tools in polishing are patience and a good optical microscope for inspection of the sample surface—e.g., with bright field, dark field and differential interference contrast combined objectives in magnifications of 5X, 20X and 50X.

8. When grinding and polishing are complete, clean the sample thoroughly using water and wipe or blow dry.

Sample Cleaning Procedure

Surface water layers, ionic residue and charges trapped in surface oxide all introduce anomalous conditions to a sample that can distort SCM and SSRM images. Introduced charges offer unrepresentative conductive paths which lower the apparent resistance of an SSRM sample. Because SCM applies a local field between tip and sample and measures the response of carriers to that field, extraneous charge may create a field that counteracts the applied field, nulling the capacitive effect. This appears as a loss of contrast or variation in the expected sample response. Due to the geometry of the tip/dielectric/silicon of the samples, a local packet of charge can produce a localized effect equivalent to many volts of applied field either pinning the carriers at the surface or depleting the surface of free carriers. Each of these charge effects destroy contrast in an SCM image, so it is worthwhile to remove such charges. Both positive and negative charges may become trapped in surface oxide by applying too large a bias voltage—enough to cause current flow (± 8V). Mobile surface charges such as sodium and potassium ions, contaminants usually introduced in skin oil through handling, diffuse into surface oxide. Extraneous charge can be hard to remove, so it is better to prevent its introduction through conservative application of bias voltage and only handling samples with clean tweezers.

WARNING: Do not allow skin contact with surfaces of interest for SCM and SSRM imaging. Only handle samples with clean tweezers. Store samples in a nitrogen atmosphere and/or desiccated dry box, particularly in a humid climate. Preferred cleaning processes provide a hydrophobic (water repelling) surface on the oxide.

Replicating Tape After UV Light Baking

WARNING:	Clean samples with solvents only in a well-ventilated area. Generally avoid skin contact with solvents. With acetone, particularly avoid contact with mucous membranes, such as around eyes. Dispose of all wipes and swabs properly.

1. Cover the sample with a spray of clean acetone.

2. Set a square of acetate replicating tape over the surface.

   Note: Replicating tape, commonly used in electron microscopy, partially dissolves in the acetone and then dries and adheres tightly to the sample surface. As you peel back the tape, sample surface contaminants adhere to it. The tape may also be left on the sample as a protective coating until you are ready to image it.

Colloidal Silica

A second cleaning method is more sophisticated: passivate the surface with an alkali solution found in a common Chemical-Mechanical Polishing (CMP) compound.

1. Wipe the sample with either acetone or alcohol to remove oils. Next apply a standard non-crystallizing 0.05µm colloidal silica suspension to the sample surface and rub it around with a swab.

2. Rinse the silica suspension off with deionized water.

3. Use a few drops of soap and another swab to clean the surface of the silica particles.

4. Rinse the sample again in deionized water and blow dry from one edge, with clean filtered air or nitrogen.

   Note: The silica method may be more effective than replicating tape against a charge layer on the sample surface.

4.3 Scanning Capacitance Microscopy (SCM)

The following topics are discussed in this section:

4.3.1 SCM Sample Mounting

Good electrical contact is required between the chuck and sample. Mount your sample to a standard sample disk, a magnetic puck or stage using conducting epoxy or silver paint. Preparation of a cross-section surface for SCM imaging is given in **SCM and SSRM Sample Preparation,** page 36. Note particularly the importance of avoiding skin contact with the sample surface of interest in **Sample Cleaning Procedure,** page 40.

4.3.2 SCM Tip Selection and Mounting

SCM requires an electrically conductive tip. The potential for tip wear in Contact Mode is another important consideration in selecting a tip. Standard SCM tips include PtIr-coated tips for Contact Mode (SCM-PIC), PtIr-coated tips for Tapping Mode (SCM-PIT) (also used for Contact Mode), and CoCr coated (magnetic) Si tips (MESP). Less conductive alternative tips are diamond coated tips (DCT-ESP) if tip wear is a particular concern or uncoated standard Si tips (TESP) which may be custom coated. Any deposited metal must adhere well to the Si cantilever.

Refer to your instruction manual for mounting a tip in the probe holder and placing the probe holder in the SPM head. See **Hardware Description,** page 24 for making electrical contact between the SCM Application Module and the tip through the probe holder.

4.3.3 Software Selection

You may perform SCM measurements either open loop or closed loop.

1. If you are not already operating in Real-time Mode, select **DI** > **Real-time**.

2. In the **Other Controls** panel, select **SCM** as the **Microscope mode**. The **Feedback Controls** panel displays all SCM control parameters (see Figure 4.3a).

Figure 4.3a SCM: Other Controls and Feedback Controls Panels

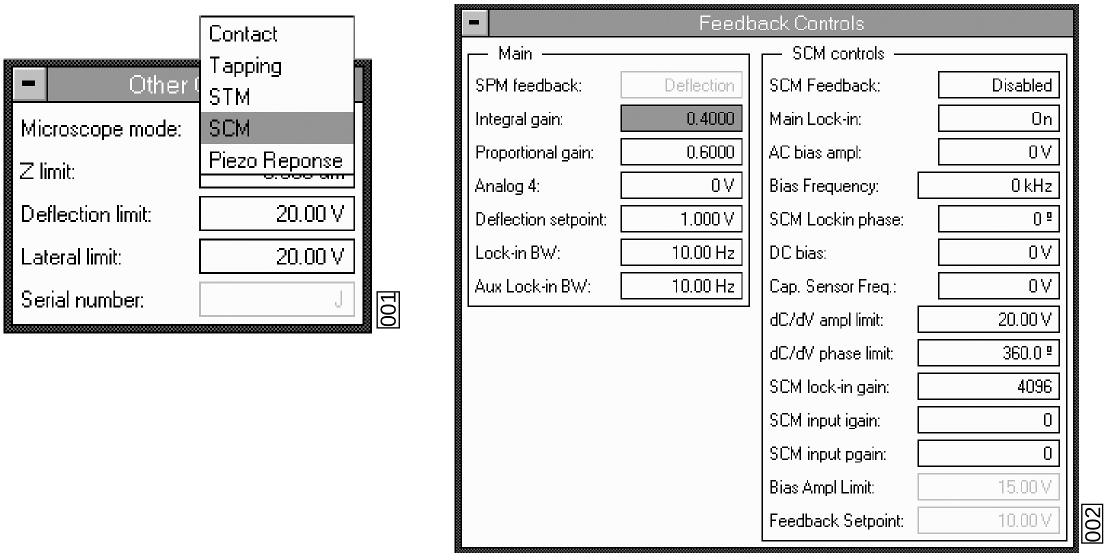


Table 4.3a summarizes the functions of the parameters in the SCM Controls subpanel of the **Feedback Controls** panel.

Table 4.3a SCM Controls Parameters

Parameter	Use with SCM
SCM Feedback	Disabled: open loop. Enabled: closed loop (i.e., Constant Depletion SCM Mode, feedback on dC/dV amplitude).
Main Lock-in	Turn on/off the Main Lock-in Amplifier (For SCM, keep **OFF**).
AC Bias Ampl.	Amplitude of the AC bias applied to the sample.
Bias Frequency	Frequency of the AC bias applied to sample.
SCM Locking Phase	Phase of the SCM lock-in amplifier with respect to the reference bias frequency.
DC Bias	DC bias applied to the sample.
Cap. Sensor Freq.	SCM tuning voltage. Corresponds to the frequency of the oscillation within the scan sensor.
dC/dV Ampl. Limit	Limit on dC/dV Amplitude: lower for higher resolution.
dC/dV Phase Limit	Limit on dC/dV Phase.
SCM Lock-in Gain	Input Gain on SCM lock-in (4096 = gain of 1). Reduce to increase gain.
SCM Input Igain	Igain used for closed-loop mode.
SCM Input Pgain	Pgain used for closed-loop mode.
Bias Ampl. Limit	Limits maximum bias amplitude in closed-loop mode.
Cap. Feedback Setpoint	Not used in open loop mode. Selects the dC/dV setpoint in closed-loop mode.

Open Loop SCM Imaging

1. Set the SCM Controls subpanel parameters in the **Feedback Controls** panel to the following initial settings (see Table 4.3b).

Table 4.3b Initial SCM Settings

Parameter	Setting	Adjustment Range
SCM Feedback	Disabled	Enabled/Disabled
Main Lock-in	Disabled	Enabled/Disabled
AC Bias Amplitude	0.5V	0.1–15V
Bias Frequency	90kHz	5-100kHz
SCM Lock-in Phase	90º	±180º
DC Bias	0.0V	±10V
Cap. Sensor Freq.	See 1st Note	0.0-10.0V
dC/dV Ampl. Limit	20V	1–20V
dC/dV Phase Limit	360º	0-360º
SCM Lock-in Gain	4096	4096–1
SCM Input Igain	20	0–100
SCM Input Pgain	20	0–100
Bias Ampl. Limit	3V	0.05–12V
Feedback Setpoint	2V	0.05–10V

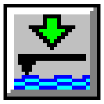
Note: The SCM Application Module **Cap. Sensor Freq.** is set to correspond to the radiated emissions of electromagnetic energy limit of the region to which the application module is shipped. These limits are:

Region	Frequency	Voltage
United States	915±13MHz	3.3V
International	>1000MHz	>7.8V

Note: The data sheet that ships with the unit lists the corresponding voltage. Changing this setting can cause the capacitive sensor frequency to fall outside of the legal limits. Additional shielding may be required.

Note: SCM is a Contact Mode technique. For the initial settings of the **Scan Controls** parameters and the **Feedback Controls** parameters in Contact Mode, refer to your instruction manual.

2. Set the **Data Type** parameter in the **Channel 1** panel to **Height** and, similarly, **Channel 2** > **Data Type** to X_1, Y_1, **dC/dV Amplitude**, **dC/dV Phase** or **SCM Data**. The topographic and dC/dV (open loop SCM) information are displayed simultaneously.



3. For SCM data, set both **Realtime Planefit** and **Offline planefit** to **None**. For topography data, set these two parameters to the desired setting. Select the **Engage** command or its icon (shown) to start scanning.

   Note: It will probably be necessary to make adjustments to a number of parameters (**Integral Gain**, **Proportional Gain**, **Deflection Setpoint**, etc.) before the image is optimized.

4. To minimize tip/sample wear, decrease the tip/sample contact force as much as possible, either by:

   a. obtaining a force plot and adjusting the **Deflection Setpoint** to a level just above the pull-off value, thus minimizing the force (see your instruction manual).

   b. selecting the **Scope Mode** command and observing the **Height** trace while reducing the setpoint. This reduces the force applied to the sample until the tip eventually lifts off the sample surface. You may go back to contact by slightly increasing the setpoint until you obtain a focused image.

5. While scanning, it will probably be necessary to make adjustments to a number of parameters in the **Feedback Controls** panel before the SCM image is optimized. Adjust parameters within the ranges shown in Table 4.3b. As parameters are adjusted, differences in the image become more apparent, leading to a better understanding of SCM. Tune some of the parameters, in particular the **Cap. Sensor Freq.** and the **Lock-In Phase**, using the sweeping features presented in **Sweeping Using the Sweep Generic Command,** page 50.

In open loop SCM operation, you may acquire SCM images in $\mathbf{X_1}$, $\mathbf{Y_1}$, **dC/dV Amplitude** or **dC/dV Phase** modes by selecting different **Data Type** parameters in the **Channel** panels (see Figure 4.3b, Table 4.3a and Figure 4.3c). The lock-in amplifier operates at the same frequency as that used for the AC bias voltage.

Note: The $\mathbf{X_1}$, $\mathbf{Y_1}$ and **SCM Data** signals from the lock-in amplifier are not available on all systems. Older systems do not have **SCM Data** as a channel type, unless the software has been upgraded to Version 5.12r4 or any beta built on or after 4-23-03. $\mathbf{X_1}$ and $\mathbf{Y_1}$ will not be standard on newer systems. It is not possible to upgrade an existing system. The data type **SCM Data** yields similar data to $\mathbf{X_1}$ or $\mathbf{Y_1}$, and therefore may be used instead if $\mathbf{X_1}$ or $\mathbf{Y_1}$ are not available.

Figure 4.3b SCM Data Type Parameters (Channel 2 shown)

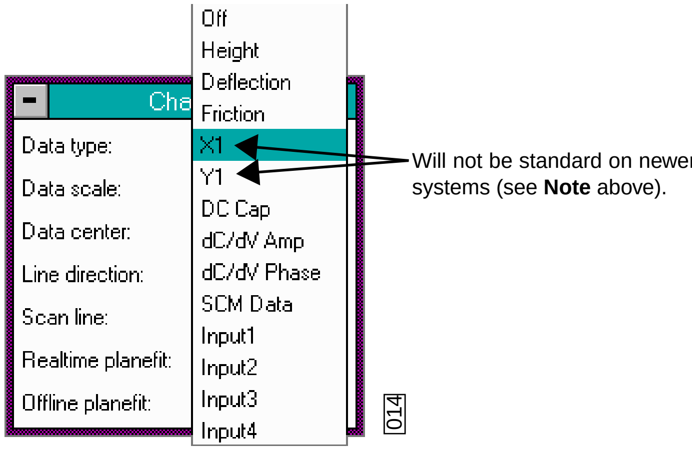
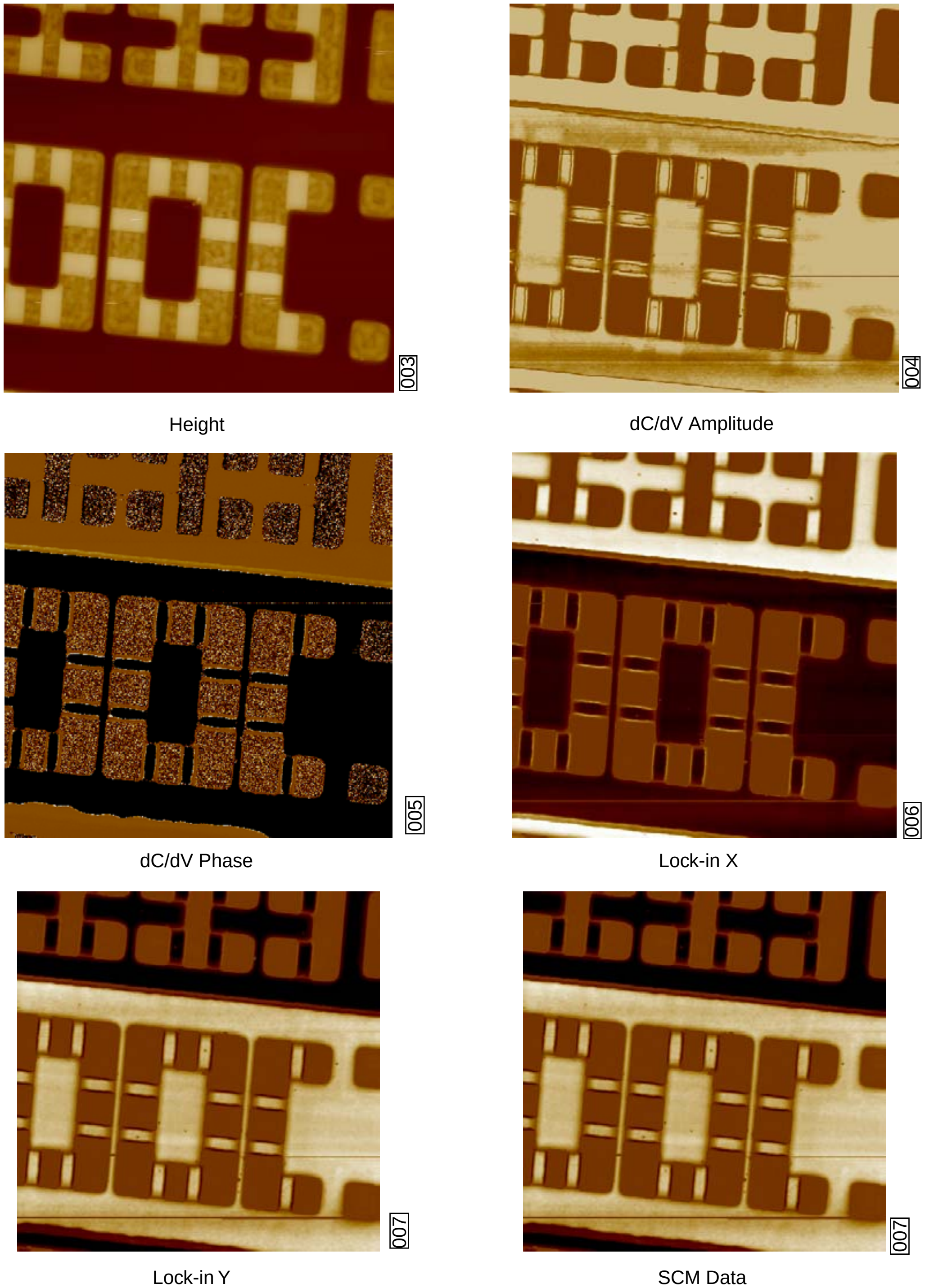


Table 4.3c Data Type Parameter Definitions

Parameter	Description
Height	Height derived from the voltage applied to the Z piezo as the cantilever scans the sample surface in feedback.
dC/dV Amplitude	Amplitude data from the lock-in amplifier.
dC/dV Phase	Phase of the auxilary lock-in amplifier.
Lock-in X	X component data from the lock-in amplifier (see **Note** above).
Lock-in Y	Y component data from the lock-in amplifier (see **Note** above).
SCM Data	Amplitude data lock-in signed by the slope of the dC/dV curve.

Figure 4.3c Open Loop SCM Images of the SRAM Test Sample



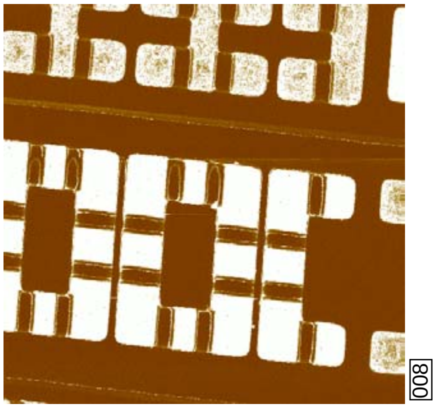
4.3.4 Closed Loop SCM Imaging

1. Complete Step 1 – Step 5 of **Open Loop SCM Imaging,** page 45, to obtain a good open loop SCM image.

2. Set **Feedback Controls** > **SCM Feedback** to **Enabled** to automatically feedback on the amplitude signal from the lock-in amplifier.

3. Set the **Channel 2** > **Data Type** to **Feedback Bias**.

Figure 4.3d Feedback Bias SCM Image in Closed-Loop Mode



4. Set the **Cap. Feedback Setpoint** to the initial value of **0.2V**.

5. The proportional and integral gain controls of the capacitance feedback loop are in the **Feedback Controls** panel (see **SCM Input pgain** and **SCM Input igain** in Figure 4.3a). Adjust the gains as indicated in Table 4.3d, in combination with **Cap. Feedback Setpoint** within its range (see Table 4.3b) to optimize image quality.

Table 4.3d Feedback Settings for Closed Loop SCM in the Other Controls Panel

Parameter	Initial Setting	Adjustment Ranges
SCM Input igain	10	2-100
SCM Input pgain	10	2-100

Note: An example of closed loop SCM operation is shown in Figure 4.3d. The less doped areas result in a low signal, while the highly doped areas result in a high signal. In closed loop mode, N-type and P-type semiconductor material result in the same polarity of output signal.

4.3.5 Sweep Commands

NanoScope software permits sweeping or ramping various signals. Either position the SCM tip at the center of the image, or apply an **X** or **Y Offset** to move the tip to another location. Sweeps may either be performed with the **Sweep Generic** command (see **Sweeping Using the Sweep Generic Command,** page 50) or the **Force Curve** command (see **Ramping Using the Force Curve Command: dC/dV – V Spectra,** page 56).

Sweeping Using the Sweep Generic Command

1. Access Sweep Generic Mode by selecting **View** > **Sweep** > **Generic** (see Figure 4.3e). Several control panels display on the control monitor: **Sweep Controls**, **Channel 1**, **2**, and **3** (see Figure 4.3f). The Graph Controls subpanel parameters are described in Table 4.3e.

Figure 4.3e Sweep Generic Selection

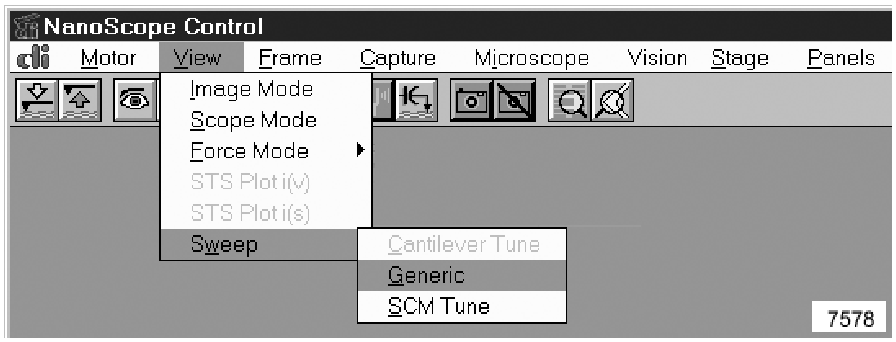


Figure 4.3f SCM: Sweep Generic Panels

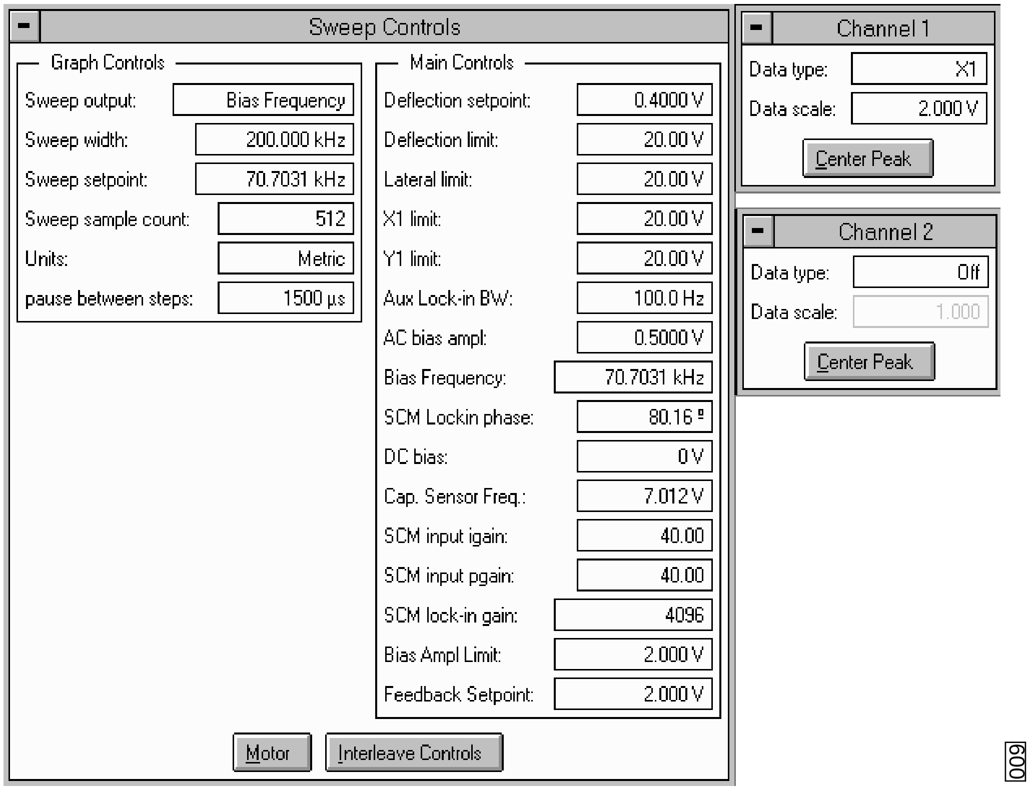


Table 4.3e SCM: Graph Controls Parameters in Sweep Generic Mode

Parameter	Use with SCM
Sweep Output	Select an SCM parameter to sweep, from: **Cap. Feedback Setpoint**, **Bias frequency**, **AC Bias Amplitude**, **DC Bias Lock-In Phase** and **Cap. Sensor Frequency**.
Sweep Width	Set the sweep range.
Sweep Setpoint	Set the midpoint of the sweep.
Sweep Sample Count	Set the number of data points included in a sweep.
Pause Between Steps	Set the amount of time (in µs) between steps in a sweep.

Table 4.3f SCM: Main Controls Parameters in Sweep Generic Mode

Parameter	Description
Deflection Setpoint	Setpoint for engaging contact mode.
Deflection Limit	Redefines the range of deflection values to change the resolution.
Lateral Limit	Limits the magnitude of the fast actuator deflection signal.
X_1 Limit	Limits X output of the Auxilary lock-in.
Y_1 Limit	Limits Y output of the Auxilary lock-in.
Aux Lock-in BW	Bandwidth of the auxilary lock-in (used for capacitance).
AC Bias Ampl.	Amplitude of the AC bias applied to the sample.
Bias Frequency	Frequency of the AC bias applied to sample.
SCM Lockin Phase	Phase of the SCM lock-in amplifier with respect to the reference bias frequency.
DC Bias	DC bias applied to the sample.
Cap. Sensor Freq.	SCM tuning voltage.
SCM Input Igain	Igain used for closed-loop mode.
SCM Input Pgain	Pgain used for closed-loop mode.
SCM Lock-in Gain	Input Gain on SCM lock-in (4096 = gain of 1).
Bias Ampl. Limit	Limits maximum bias amplitude in closed-loop mode.
Feedback Setpoint	Not used in open loop mode. Selects the dC/dV setpoint in closed-loop mode.

2. Select the parameter to sweep in **Sweep Controls** > **Sweep Output**. Adjust **Sweep Width**, **Sweep Setpoint**, **Sweep Sample Count** and the **Main Controls** parameters to desired values.

3. Adjust **Data Type** in **Channel 1, 2** or **3** panels to display the desired property.

Note: Sweeping starts when the Sweep Generic Mode is entered and continues until you exit.

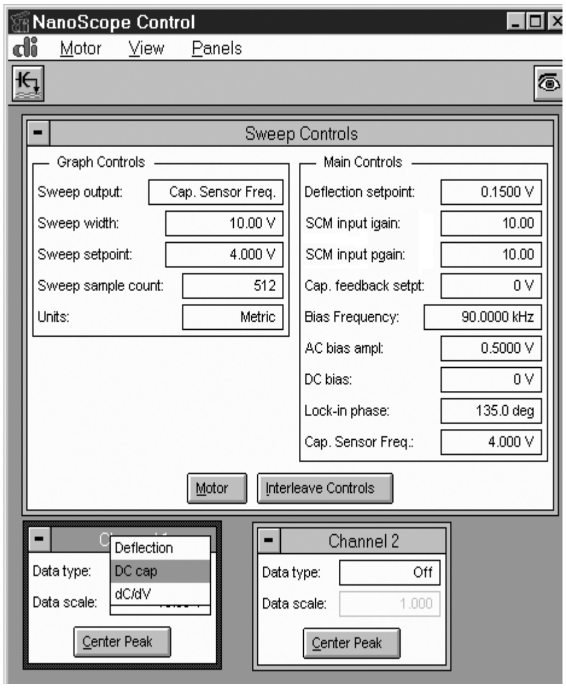
Some examples of sweeping curves obtained with the SCM illustrate the possibilities of the **Sweep** > **Generic** command. The curves are displayed in Figure 4.3j, Figure 4.3k and Figure 4.3l.

Tuning the SCM Sensor

You may tune the SCM sensor for maximum sensitivity using **Sweep** commands:

1. Click **View** > **Sweep** > **SCM Tune** to open the **Sweep Controls**, and **Channel 1, 2**, and **3** control panels (see Figure 4.3g).

Figure 4.3g SCM Sensor Tuning Curve Parameter Settings, Tip Engaged



2. Select **Sensor Output** for **Channel** > **Data Type**. Observe the SCM sensor resonance curve on the Display Monitor (see Figure 4.3h). In earlier versions of the software, the DC component of the **Sensor Output** was called **DC Cap Signal**. The AC component is the source of the X_1, Y_1, R and θ signals.

3. Use **Sweep Controls** > **Sweep Setpoint** or **Display Monitor** > **Offset** to set the **Cap. Sensor Freq.** operating point.

   Note: Sensitivity is optimized when the **Cap. Sensor Freq.** is set to the frequency corresponding to the highest slope of the tuning (sensor resonance) curve.

Tuning the SCM sensor frequency is complicated by the change in resonant frequency with engage. In a sweep width of approximately 890MHz to 1050MHz, the peak may shift 50-100MHz, due to increasing capacitance as the tip approaches the sample. Two tuning curves are displayed in Figure 4.3h (engaged) and Figure 4.3i (withdrawn), illustrating the resonance shift with tip/sample proximity.

Figure 4.3h SCM Tuning Curve (Tip Engaged)

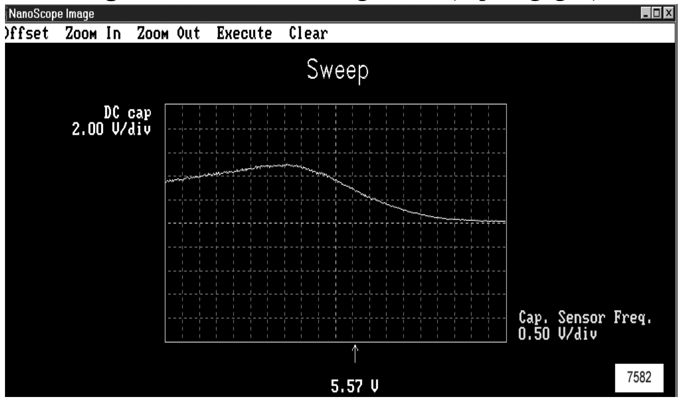
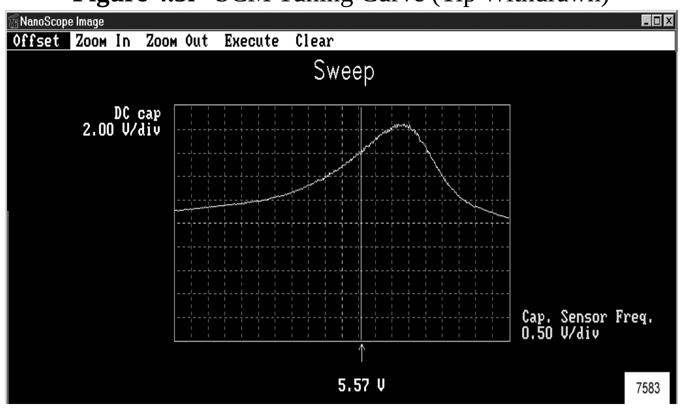
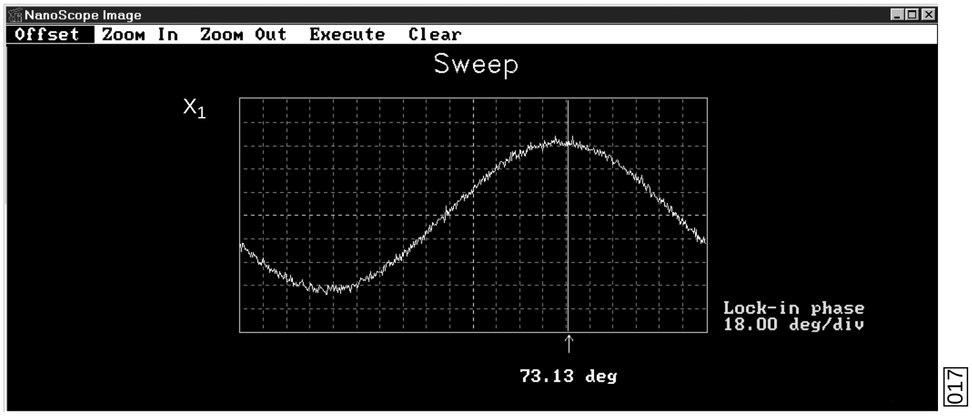


Figure 4.3i SCM Tuning Curve (Tip Withdrawn)



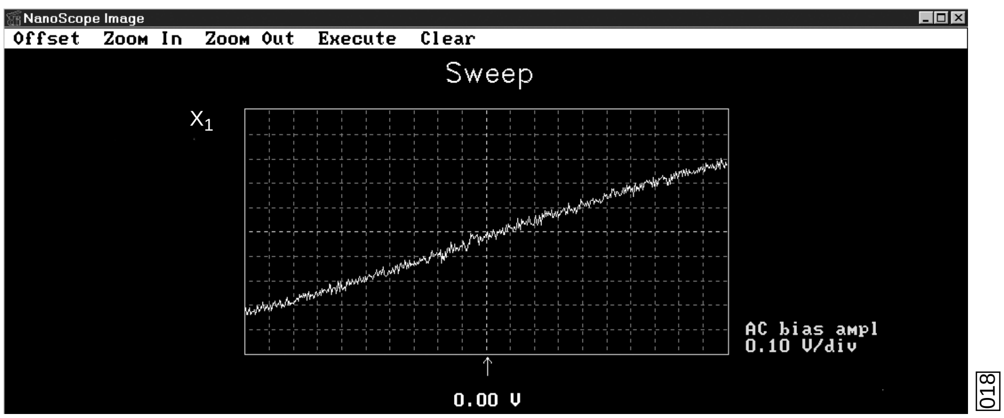
In the first example, (see Figure 4.3j) the dC/dV output of the SCM sensor is a function of the **Lock-In Phase**. The parameters used to obtain this image are displayed in Figure 4.3f. The observed curve shows that the SCM dC/dV output goes through two extrema (one negative and one positive peak) as the **Lock-In Phase** sweeps from –180º to +180º. You may use the **Sweep Setpoint** parameter in the **Sweep Controls** panel or the **Offset** menu item on the **Display** monitor (see Figure 4.3j) to select the **Lock-In Phase** operating point. Choosing the setpoint sets both the intensity and polarity of the dC/dV signal. The value of the **Sweep Setpoint** in the Graph Controls subpanel is automatically copied to the **Lock-In Phase** parameter in the Main Controls subpanel, also of the **Sweep Controls** panel, and is used when acquiring SCM images.

Figure 4.3j SCM: dC/dV Amplitude versus Lock -In Amplifier Reference Phase



In the second example, (see Figure 4.3k) the X_1,Y_1 or SCM Data output of the SCM sensor is a function of the AC bias amplitude. The AC bias amplitude sweeps from 0V to 2V, resulting in an approximately linear response of the dC/dV signal.

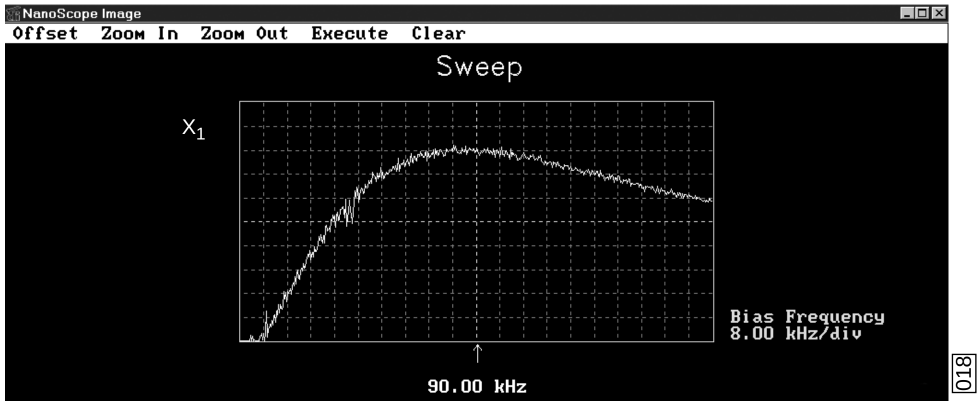
Figure 4.3k SCM: X_1 (Y_1 or SCM Data) output versus AC Bias Amplitude



In the third example, (see Figure 4.3l) the dC/dV output of the SCM sensor is a function of the AC bias frequency, continuously swept from 10 kHz to 170 kHz. The curve illustrates the highest dC/dV amplitude around 90 kHz, which is, therefore, the recommended operating point.

Note: Typical dCdV amplitude values range from 65 kHz to 90 kHz.

Figure 4.3l SCM: X_1 (SCM Data or dC/dV Amplitude) versus AC Bias Frequency



Ramping Using the Force Curve Command: dC/dV – V Spectra

The second method of performing ramps of various SCM signals uses the **Force Curve** command. A typical application is the measurement of dC/dV–V spectra.

1. Click **View** > **Force Mode** > **Advanced** to open the Ramp Controls and Display subpanels of the **Main Controls** panel (see Figure 4.3m). Ramp Controls parameters are summarized in Table 4.3g, Display parameters in Table 4.3h.

Figure 4.3m SCM: The Ramp Controls Subpanel

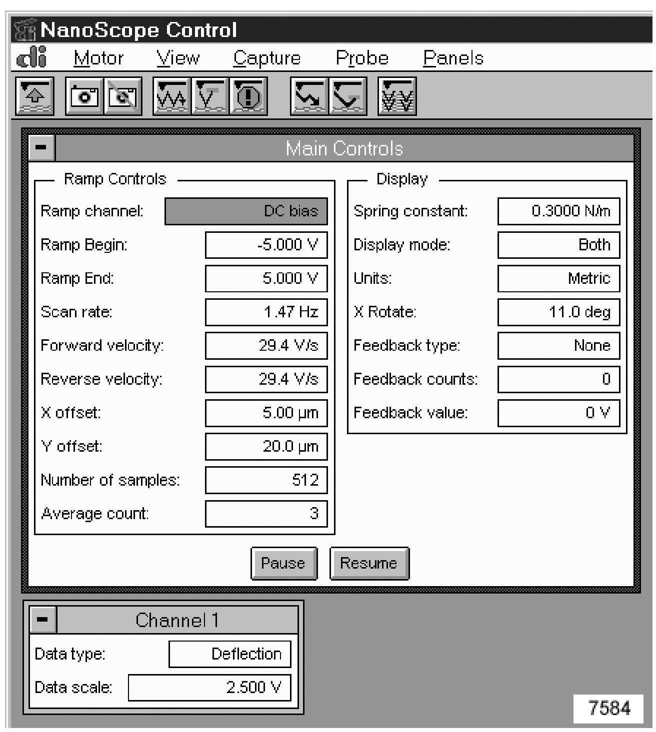


Table 4.3g SCM: Ramp Controls Parameters in the Main Controls Panel

Parameter	Use with SCM
Ramp Channel	Select an SCM parameter to ramp, from: **Z** (for standard force curve measurements), **DC Bias** or **Cap. Sensor Freq.**
Ramp Begin, Ramp End	The beginning and end points of a ramp.
Scan rate	All ramps are *begin-end-begin* cycles. Scan rate refers to one complete cycle.
Forward Velocity, Reverse Velocity	The ramp value from beginning to end, or end to beginning.
X Offset, **Y Offset**	Move the tip to a different location.
Number of Samples	The number of sample points per ramp (minimum **16**, maximum **64,000**).
Average Count	Average (minimum **1**, maximum **1024**) ramp curves.

Note: **Scan Rate**, **Forward Velocity** and **Reverse Velocity** are interdependent. Changing a velocity affects the overall scan rate, and vice versa.

Table 4.3h SCM: Display Parameters in the Main Controls Panel

Parameter	Use with SCM
Units	Metric or Volts
Feedback Type	Ensures that the deflection feedback is **ON** during ramping. **Ramp** enables feedback after each ramp cycle (*start-end* feedback). **Cycle** enables feedback after each ramp cycle (*start-end-start*-feedback). **Pixel** enables feedback after every sample point of the ramp. This might be useful for extremely slow ramps with few sample points.
Feedback Counts	Select **50** for proper feedback.
Feedback Value	Select **0V**.

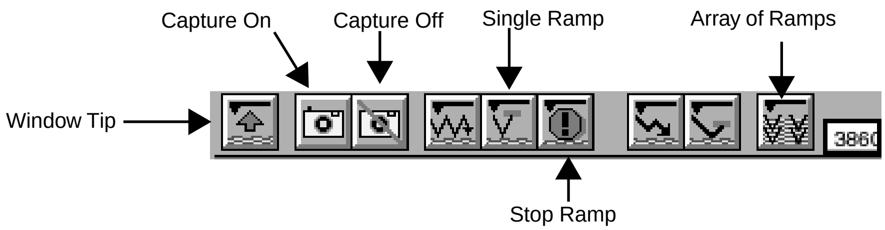
2. Select the parameter you wish to ramp for **Ramp Controls** > **Ramp Channel**.

3. Select desired values for the other parameters in the Ramp Controls and Display subpanels of the **Main Controls** panel (see Figure 4.3f).

4. Select the desired property (e.g., **dC/dV**) for **Channel 1**,**2** or **3** > **Data Type**.

5. Start or stop ramping by clicking the associated toolbar button (see Figure 4.3n).

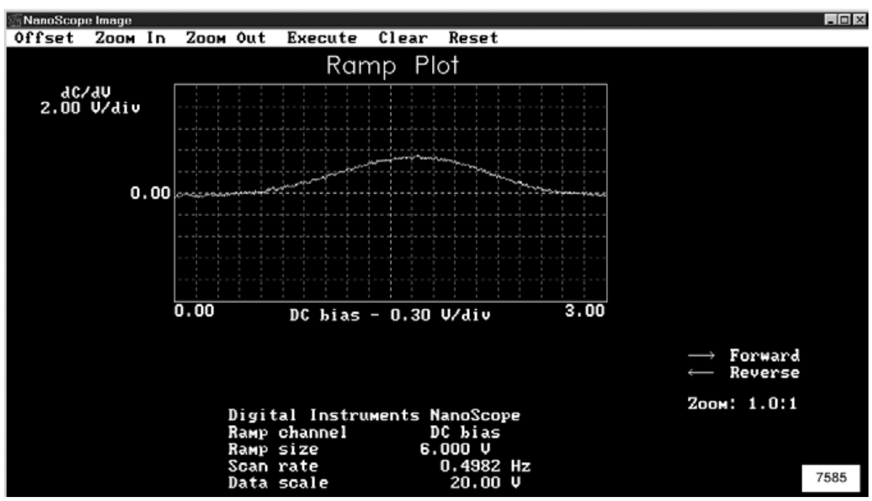
Figure 4.3n Toolbar Buttons: Start, Stop and Capture Ramp Curves



6. Capture ramping curves using the standard **Capture** commands or toolbar buttons.

An example of a dC/dV-V ramping curve is shown in Figure 4.3o: the dC/dV signal as a function of DC bias ramped from –3V to +3V. The dC/dV-V curve is the derivative of the C-V curve of the sample and shows the characteristic bump expected for a high frequency dC/dV-V curve (see **Types of MIS Capacitor C-V Curves,** page 59). Average over 3 cycles (**Average count = 3**) to improve the signal-to-noise ratio.

Figure 4.3o SCM: dC/dV vs.V Curve



4.3.6 Types of MIS Capacitor C-V Curves

There are three main frequencies involved in the generation and interpretation of C-V curves:

- Capacitance sensor measurement frequency (approximately 1GHz)
- Lock-in amplifier reference frequency (5kHz - 100kHz)
- "DC" bias sweep frequency used for C-V curve acquisition

In general, a signal is termed *high frequency* (or *low frequency*) if its period is shorter (or longer) than the delay time associated with the generation of minority carriers, that is, to fill an inversion layer. The three relevant type of C-V curves are discussed next.

Low frequency C-V Curves

If all three frequencies (a, b and c, above) are low enough, minority-carrier generation brings the carrier distribution to the long-term configuration. In a low frequency C-V curve, the capacitance in the inversion region is high, comparable to the accumulation capacitance. The capacitance in the inversion region is high because minority-carrier generation screens the potential variations across the buried depletion layer, effectively shorting it out as a resistor would so the equivalent circuit looks similar to the one for accumulation. Only the oxide capacitance is relevant.

Note: It is impossible to measure low frequency C-V curves at room temperature using SCM since the minority-carrier generation rate is too low to modify the inversion layer population in 1ns (i.e., the period of a 1GHz oscillation).

High frequency C-V Curves

Here the excitation frequency (a) is high; and therefore minority carriers cannot screen the buried depletion layer. The other frequencies (b, c) should be low so that the inversion layer has time to develop as the tip-sample potential is changed. If (b) is not low, the slope measured is not appropriate to this type of curve, since the inversion layer population is not able to follow the lock-in dither voltage.

Note: SCM data generally corresponds to high frequency C-V curves.

Deep-depletion C-V Curves

In this case all three frequencies are high, so the inversion layer population goes unchanged by minority-carrier generation. In this case, potentials at all three frequencies can drop across the depletion layer. Therefore: (1) the depletion-layer capacitance (in series with the oxide capacitance) is sensed in the inversion region; (2) the measured C-V curve slope, dC/dV, appropriately reflects the changing depletion-layer width with sweep voltage; (3) the sweep voltage modulates the depletion-layer width so the bottom edge moves deeper, sampling different doped regions. This is the origin of the pulsed C-V measurements used for device characterization which are used to infer the depth profile of dopants in a fabricated MOS capacitor.

4.3.7 Additional Ramping Options

The ramping software also has some extra features useful for specific experiments. Using the **Auto Panel** (see Figure 4.3p) you can perform ramps at an array of points on the sample surface. The tip moves from one position to the next, while force-feedback is maintained. In each point of the array, a ramp is executed and captured. For each ramping curve the system uses the same set of control parameters. Table 4.3i gives an overview of the different parameters associated with this operation.

Figure 4.3p SCM, TUNA, SSRM, C-AFM: Auto Panel

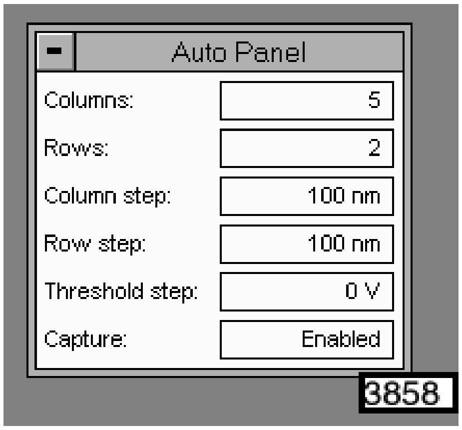


Table 4.3i SCM, TUNA, SSRM: Auto Panel Parameters

Parameter	Use with SCM
Columns, **Rows**	Number of columns (rows) in the array.
Column (Row) Step	Distance between two subsequent columns (rows).
Threshold Step	N/A
Capture	Select **Enabled** to save the ramping curves on disk.

A second set of parameters, in the **Scan Mode** panel (see Figure 4.3q), provides for greater control of ramping curves (see Table 4.3j). The features include the option to limit the output signal (dC/dV in SCM) to user-defined values by using **Trigger Mode**. The **Scan Mode** panel also offers two parameters which may be used to independently delay the end of the *start-end* ramp, or to delay the end of a complete *start-end-start* cycle. The **Scan Mode** panel also displays a number of parameters which are only related to the measurement of force curves (**Start Mode**, **End Mode**, **Z Step Size**, **Auto Offset**). These parameters are described in your instruction manual.

Figure 4.3q SCM, TUNA, SSRM, C-AFM: Scan Mode Panel

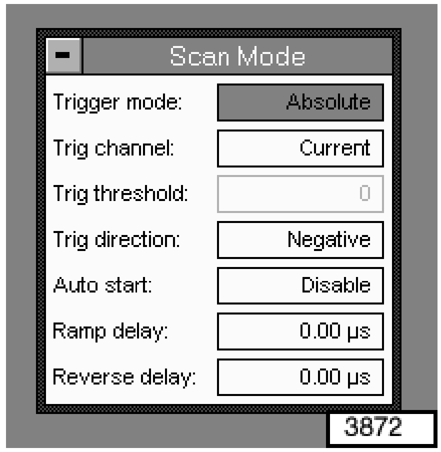


Table 4.3j SCM: Scan Mode Parameters

Parameter	Use with SCM
Trigger Mode	Select **Absolute** to turn on a trigger for dC/dV-V curves.
Trigger Channel	Select **dC/dV** for dC/dV-V curves.
Trigger Threshold	Sets the trigger value.
Trigger Direction	Select either **Negative** or **Positive** for the dC/dV slope required when triggering.
Ramp Delay	A delay of **0** to **250 seconds** following each *start-end* ramp.
Reverse Delay	A delay of **0** to **250 seconds** following each complete *start-end-start* cycle.

4.4 Tunneling Atomic Force Microscopy (TUNA and Extended TUNA)

The operating procedures for both TUNA and Extended TUNA are discussed in this section. Some instructions only apply to Extended TUNA, and are indicated as such. Refer to the following topics:

TUNA Sample Mounting: Section 4.4.1

TUNA Tip Selection and Mounting: Section 4.4.2

Software Selection: Section 4.4.3

Open Loop TUNA Imaging: Section 4.4.4

Closed Loop Extended TUNA Imaging: Section 4.4.5

Extended TUNA Filter: Section 4.4.6

4.4.1 TUNA Sample Mounting

Attach the sample to a magnetic puck provided with the system and place the puck on top of the sample chuck.

When measuring large samples, we recommend use of an electromagnetic interference shielding hood. Large conductive samples can act as an antenna and focus electrical noise from the environment into the input of the TUNA sensor.

WARNING: The sample chuck and its surrounding area are electrostatic sensitive. Employ ESD-protective measures at all times when handling a TUNA sensor or sample.

4.4.2 TUNA Tip Selection and Mounting

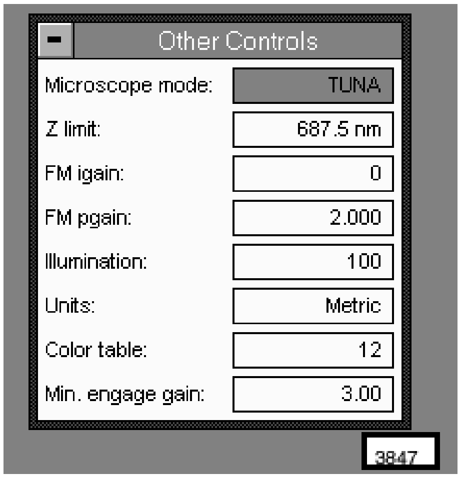
TUNA requires an electrically conductive tip. The potential for tip wear in Contact Mode is another important consideration in selecting a tip. Standard TUNA tips include PtIr-coated tips for Contact Mode (SCM-PIC) and CoCr coated (magnetized) Si tips (MESP). Less conductive diamond coated tips (DCT-ESP) are an alternative if tip wear is a particular concern.

Refer to your instruction manual to mount a tip in the probe holder and place the probe holder in the SPM head. See **Hardware Description,** page 24, for making electrical contact between the TUNA Application Module and the tip through the probe holder.

4.4.3 Software Selection

1. If you are not already operating in Real-time Mode, select **DI** > **Real-time**.

Figure 4.4a TUNA: Other Controls Panel



2. In the **Other Controls** panel, select **TUNA** as the **Microscope mode** (see Figure 4.4a).

Veeco recommends performing standard and Extended TUNA measurements in open loop mode *only*. (For information about Extended TUNA measurements in closed loop mode, refer to **Closed Loop Extended TUNA Imaging,** page 76). Select a DC bias and measure the current passing through the sample. Only a few of the **Feedback Controls** panel parameters are relevant to TUNA; clear all other parameters. To access TUNA control parameters (see Table 4.4a), complete the following:

3. Select the **EXPANSION** button in the top left hand corner of the **Feedback Controls** panel (see Figure 4.4b). A pull-down menu appears. Select **View All** to view additional parameter options.

Figure 4.4b TUNA Controls Subpanel of the Feedback Controls Panel

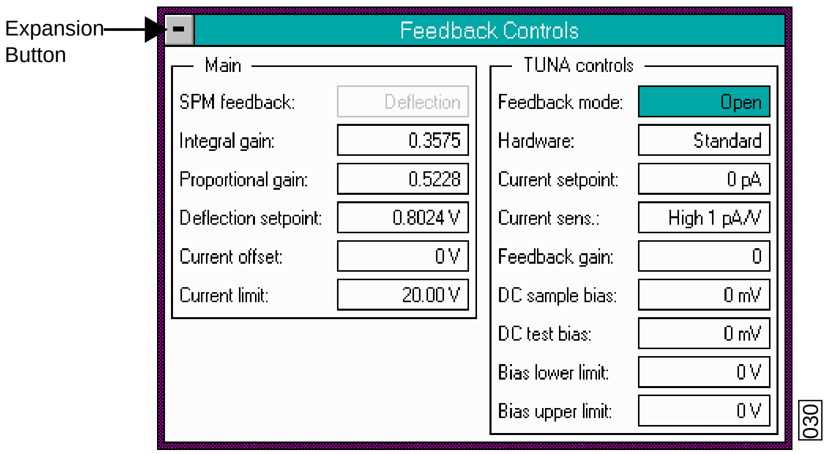


Table 4.4a TUNA Control Parameters

Parameter	Purpose	with TUNA
Feedback Mode	Selects between open and closed loop mode. In TUNA, select **Open**.	Select
Hardware	Selects between standard TUNA and Extended TUNA.	Select
Current Setpoint	Selects the current setpoint in closed loop mode.	Clear
Current Sensitivity	Selects the gain of the TUNA sensor:* **1pA/V** = gain of 10^{12} **10pA/V**= gain of 10^{11} For Extended TUNA, also include: **1nA/V** = gain of 10^{9} **100nA/V** = gain of 10^{7}	Select
Feedback Gain	Adjusts the feedback gain in closed loop mode.	Clear
DC Sample Bias	Selectable bias to chuck/sample.	Select
DC Test Bias	Provides an additional bias for the purpose of testing the TUNA sensor.	Select
Bias Lower Limit	Limits the minimum bias applied to the chuck/ sample in closed loop mode.	Clear
Bias Upper Limit	Limits the maximum bias.	Clear
Bias Limit	Set to **12V,** the maximum bias (±12V) applicable to the chuck/ sample.	Select

Note: * The gains refer to the output voltage of the TUNA sensor. If a Signal Access Module is used, the output voltage can be measured at **AuxD**.

4.4.4 Open Loop TUNA Imaging

Quick Start

For a quick start, use the TUNA profile:

1. Select **Microscope** > **Profile** to open the **Profile Select** panel.
2. Highlight the profile **Tunneling AFM** (file name TUNA) and click **Load Master** to set scan parameters to acceptable values.

Real-time Mode

To perform a measurement in Real-time mode:

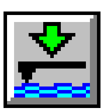
1. Click **DI** > **Real-time**.
2. In the **Other Controls** panel, select **TUNA** as the **Microscope mode** (see Figure 4.4a).
3. Set the TUNA Controls subpanel parameters (see Figure 4.4b) to the values shown in Table 4.4b.

Table 4.4b Initial Settings of TUNA Control Subpanel Parameters

Parameter	Value
DC Sample Bias	0V
Current Sens.	1pa/V
DC Test Bias	0V

TUNA is a Contact Mode technique. For the initial settings of the **Scan Controls** parameters and the **Feedback Controls** parameters in Contact Mode, refer to your instruction manual. Typically, the **Feedback Controls** panel looks similar to what is shown in Figure 4.4b.

4. Set **Feedback Controls** > **Deflection Setpoint** to no more than a few tenths of a volt above the engagement point. This will keep the contact force sufficiently low, thus not causing any damage to the tip or sample. This is especially important for metal coated tips or soft samples.



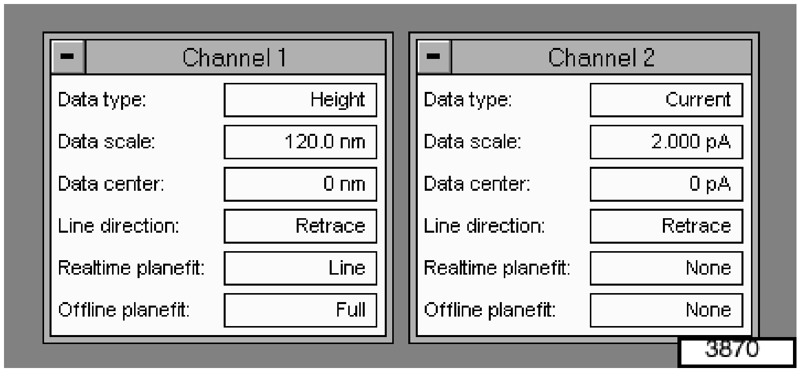
5. Once **Scan Controls** and **Feedback Controls** parameters are set, click **Motor** > **Engage** or the **ENGAGE** icon (shown) and start a measurement.

   Note: It will probably be necessary to make adjustments to a number of parameters (e.g., **Integral Gain, Proportional Gain, Deflection Setpoint**) before the image is optimized.

6. Set **Channel 1** > **Data Type** to **Height** to view the topography and set **Channel 2** > **Data Type** to **Current** to view the current data (see Figure 4.4c).
7. In the **Channel 2** panel, set **Realtime Planefit** to **None** and the **Offline Planefit** to **None**.
8. Verify **Highpass Filter** and **Lowpass Filter** parameters are turned **OFF** in **Channel 2**.

   Note: The **Data Center** parameter in Channel panels is useful for measuring small current variations in a sample with an overall larger background current. It offsets the centerline of the color scale by the amount entered: within the range ±220V, or the metric equivalent if **Other Controls** > **Units** is set to **Metric**.

Figure 4.4c Initial TUNA Setup of Channel 1 and Channel 2 Panels



9. To reduce tip and sample wear, decrease the contact forces between the tip and sample as much as possible in one of the following two ways:

    - Generate a force plot and adjust the **Force Calibration** > **Setpoint** to a level just before the pull-off point, thus minimizing force (refer to your instruction manual).

    - Without a force plot:

        - Click **View** > **Scope Mode** and observe the (**Channel 1**) **HEIGHT** trace.

        - Highlight **Feedback Controls** > **Deflection Setpoint** and click the **LEFT ARROW** key to reduce the force applied to the sample by lowering the setpoint incrementally. Repeat until the tip eventually lifts off the surface.

        - Click the **RIGHT ARROW** key as needed to obtain a focused image.

    Note: Adjusting the **Deflection Setpoint** to a few tenths of a volt above the engagement point provides a low contact force.

10. Slowly increase the **Feedback Controls** > **DC Sample Bias** while watching the current signal in either Image Mode or Scope Mode. For many samples, the current increases rapidly beyond a threshold bias.

    Note: Do not scan too fast. The sensor bandwidth is only 160Hz. The slower a sample is scanned, the higher the spatial resolution the current sensor can detect. Adjust **Scan Controls** > **Scan Rate** for image quality.

WARNING: Increase **DC Sample Bias** carefully: Metal coated tips can melt and the sample be damaged if the current density is too high.

WARNING: Electrostatic forces cause a strong attraction between the tip and most samples when a bias is applied. The electrostatic force does not result in additional deflection of the cantilever, but does induce more wear of the tip, and can damage soft samples, such as polymers. Reduce the **Deflection Setpoint** (see Step 9 to lower the tip/sample force. Alternatively, apply the bias first before engaging. However, the latter method works only for experiments with a well-defined, known bias. In most cases further adjustment of **Deflection Setpoint** is necessary.

11. Save the data as described in Chapter 6 of the *Command Reference Manual*.

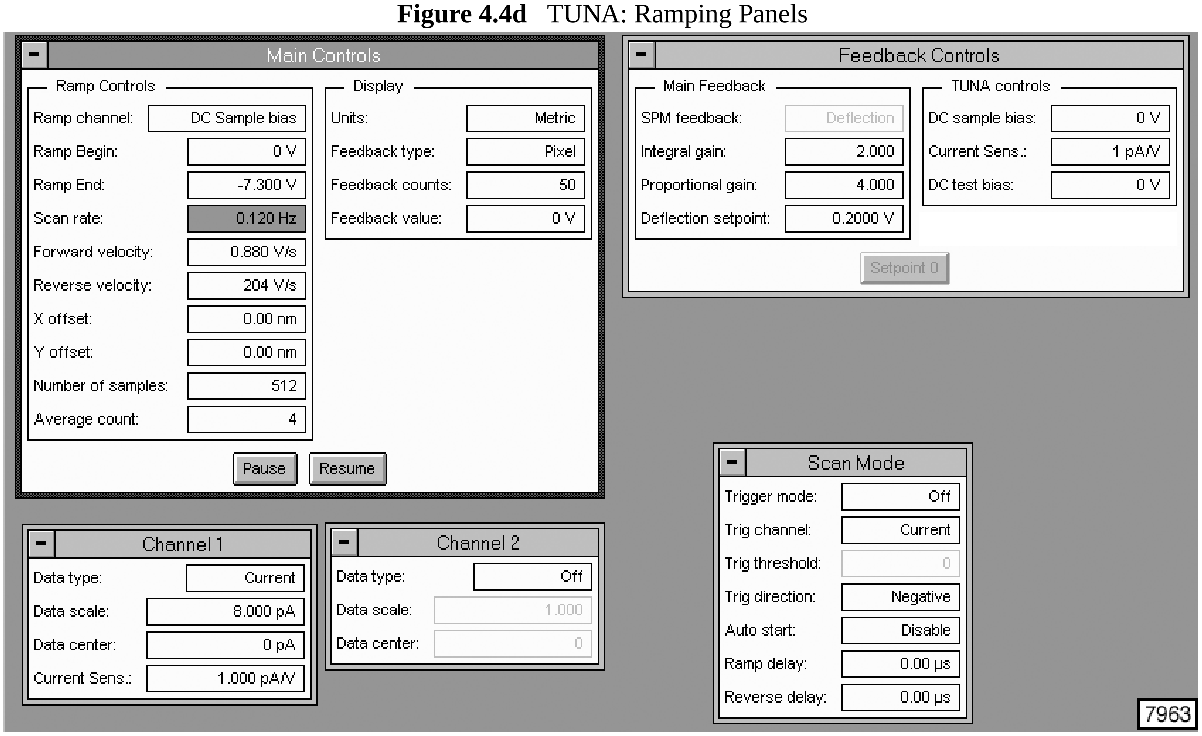
TUNA IV-Spectra

NanoScope software permits “IV” measurements (current, I, as a function of voltage, V) in a specified location on the sample. Typically the SPM tip is placed at the center of an image where an IV-spectrum is captured. By applying **X** and **Y Offsets**, the tip may be moved to other locations.

Perform an IV Measurement

1. Click **View** > **Force Mode** > **Advanced** to open the **Main Controls**, **Feedback Controls**, **Scan Mode** and **Channel** panels (see Figure 4.4d).

Figure 4.4d TUNA: Ramping Panels



Note: Table 4.4c through Table 4.4g summarize the ramping parameters and their functions.

2. Adjust the parameters in the Ramp Controls subpanel of the **Main Controls** panel (see Table 4.4c).

3. Adjust the parameters in the Display subpanel of the **Main Controls** panel (see Table 4.4d).

4. To view IV-spectra, set **Data Type** to **Current** for either **Channel 1** or **Channel 2** (see Table 4.4e).

Start and Save IV-spectra

1. To start and stop voltage ramps, click the appropriate icon in the toolbar (see Figure 4.4e). Descriptions of each button follow.

Note: In order to take IV-spectra, the AFM must be engaged.

Table 4.4c TUNA: Main Controls/Ramp Controls Subpanel

Parameter	Use with TUNA
Ramp Channel	Select **DC Sample Bias** to ramp the bias applied to the chuck/sample
Ramp Begin./Ramp End	Define beginning and end of ramp; both values may be positive or negative
Scan Rate*	All ramps are *begin-end-begin* cycles (V_{start}-V_{end}-V_{start}), and the scan rate refers to one complete cycle.
Forward Velocity* & Reverse Velocity*	Defines the ramp velocity from beginning to end value, and end to beginning value, respectively.
X and Y Offset	Moves the tip to a different location.
Number of Samples	Sets the number of samples per ramp (minimum **16**, maximum **64,000**).
Average Count	Allows several (minimum **1**, maximum **1024**) ramps to be averaged.

Note: *** Scan Rate**, **Forward Velocity** and **Reverse Velocity** are interdependent. Changing a velocity affects the scan rate, and changing the scan rate affects both velocities.

Table 4.4d TUNA: Main Controls/Display Subpanel

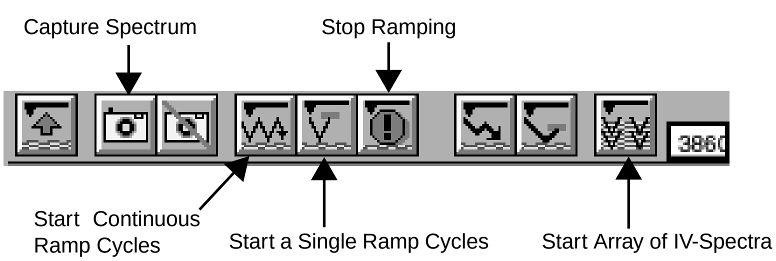
Parameter	Use with TUNA
Units	Select **Metric** for IV-spectra
Feedback Type	Ensures that deflection feedback is on while ramping DC sample bias; select **Ramp**, **Cycle** or **Pixel**: **Ramp** enables feedback after each ramp or half cycle (V_{start}-V_{end} feedback). **Cycle** enables feedback after each ramp cycle (V_{start}-V_{end}-V_{start} feedback). **Pixel** enables feedback after every sample point of the ramp. This is useful for extremely slow ramps with few sample points.
Feedback Counts	Select **50** for proper feedback.
Feedback Value	N/A

Table 4.4e TUNA: Channel Panel Parameters

Parameter	Use with TUNA
Data Type	For IV Spectra, select **Current.**
Data Scale*	Adjust according to data.
Data Center	Offsets IV-spectrum along the vertical (current) axis.
Current Sensitivity*	Display the sensitivity selected in the **Feedback Controls** > **TUNA** Controls subpanel.

Note: ***Data Scale** and **Current Sensitivity** parameter settings in a **Channel** panel automatically adjust the setting of **Feedback Controls** > **Current Sensitivity**.

Figure 4.4e Toolbar Buttons Used for Starting, Stopping and Capturing Ramp Curves



- **START CONTINUOUS RAMP Icon**: begins repeated cycling and permits the averaging of several spectra. To select the number of averaged spectra, click **Main Controls** > **Ramp Controls** > **Average count**. The measurement continues until you click the **STOP RAMPING** icon (see Figure 4.4e).

Note: The voltage ramp stops at whatever value is applied at the time the **STOP RAMPING** button is clicked. To stop multiple voltage ramps at a specific voltage, switch to the **SINGLE RAMP CYCLE** icon before pressing the **STOP RAMPING** button; this adds a single ramp to the multiple ramps and leaves the bias voltage at V-start.

- **SINGLE RAMP Icon**: starts a single ramp at the **Ramp Begin** voltage value, increases or decreases the voltage until the **Ramp End** value is reached, then ramps back to the **Ramp Begin** level.
- **STOP RAMP Icon**: ends the ramping process.
- **START AN ARRAY OF IV-SPECTRA Icon**: starts multiple IV-spectra (see **Multiple IV-Spectra,** page 73).
- **CAPTURE Icon**: saves the spectrum acquired during a measurement.

Note: At the bottom of the **Main Controls** panel are two buttons, **PAUSE** and **RESUME**. **PAUSE** interrupts the voltage ramp and holds the voltage at the current value until the user continues the measurement. To continue with the measurement, click **RESUME**.

Figure 4.4f TUNA: IV-spectrum of a 40Å Thick Gate Oxide

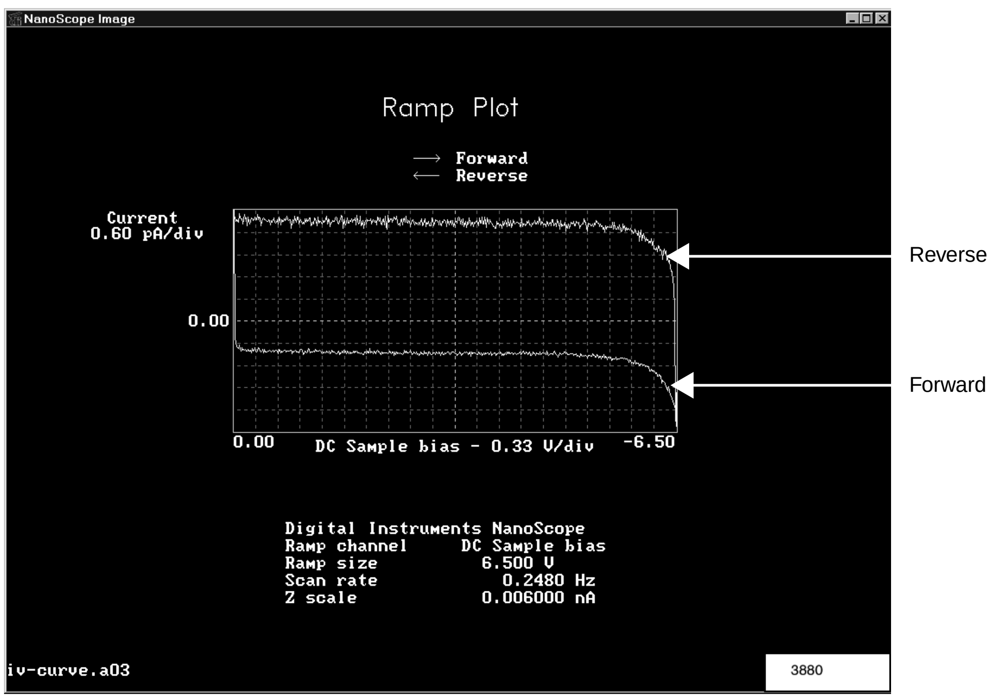


Figure 4.4f shows a typical IV-spectrum measured on a 40Å thick gate oxide. The ramp rate of the spectrum is 0.248Hz, with a forward (ramp voltage) velocity of 1.63V/s and a reverse velocity of 181V/s. Forward and reverse currents are offset from the zero current line due to displacement currents. When comparing IV-spectra, we recommend slowly ramping in one direction, the direction of interest (e.g. forward in this case), to reduce the displacement current, and rapidly ramping in the reverse direction. The reverse ramp should then be ignored due to artifacts that may occur at high ramp velocities. Another way to reduce displacement currents is to lower the ramp rate to 0.1Hz or 0.01Hz. This will allow you to see both forward and reverse IV curves.

Trigger Mode Function and Operation

Trigger Mode enables limiting the current passing through a sample to protect it. See the **Real-time** > **Force Mode...Advanced** > **Scan Mode** panel (see Figure 4.3q) for trigger parameters. Table 4.4f and Table 4.4g describe trigger parameter functions.

Table 4.4f TUNA: Scan Mode Panel Parameters

Parameter	Use with TUNA
Trigger Mode	Triggering is either **Off**, **Relative** or Absolute. For IV-spectra select **Absolute** to turn the trigger on (see following caution).
Trigger Channel	For IV-Spectra, select **Current** for triggering on the current.
Trigger Threshold	This sets the trigger value. For a current sensitivity of 1pA/V, select any value between **+10pA** and **-10pA**. For a current sensitivity of 10pA/V, select any value between **+100pA** and **-100pA**.
Trigger Direction	(see explanation below)
Auto Start	Set to **Disable**.

CAUTION: **Trigger Mode** must be set to **Absolute** when performing TUNA IV-spectra. Ignore parameters which share the same control panels but are relevant only to force curves.

Explanation of Trigger Direction

Triggering requires specifying the **Trigger Direction**.

1. If the **Ramp Begin** value is larger than the **Ramp End** value (i.e., the ramp voltage as a function of time, V(t), has a negative slope), select **Negative** for **Trigger Direction** (see Figure 4.4g).

2. If the **Ramp Begin** value is smaller than the **Ramp End** value (i.e., the ramp voltage as a function of time, V(t), has a positive slope), select **Positive** for **Trigger Direction** (see Figure 4.4h).

Figure 4.4g TUNA, SSRM: Negative Trigger Direction for $V_{Start} > V_{End}$

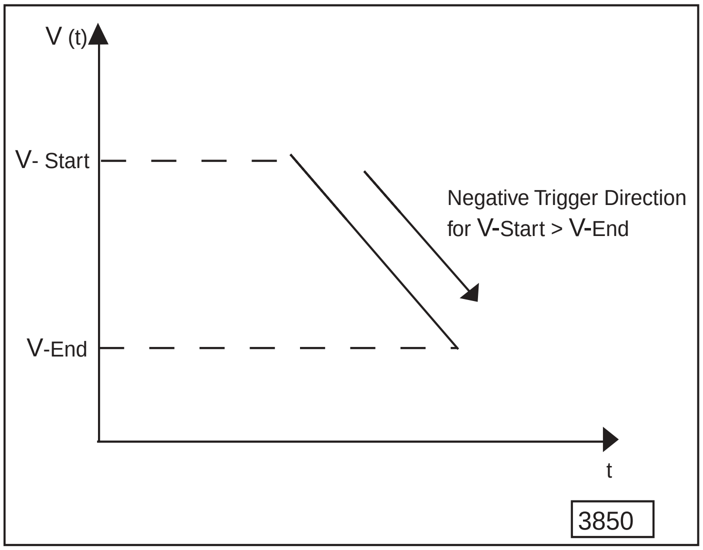
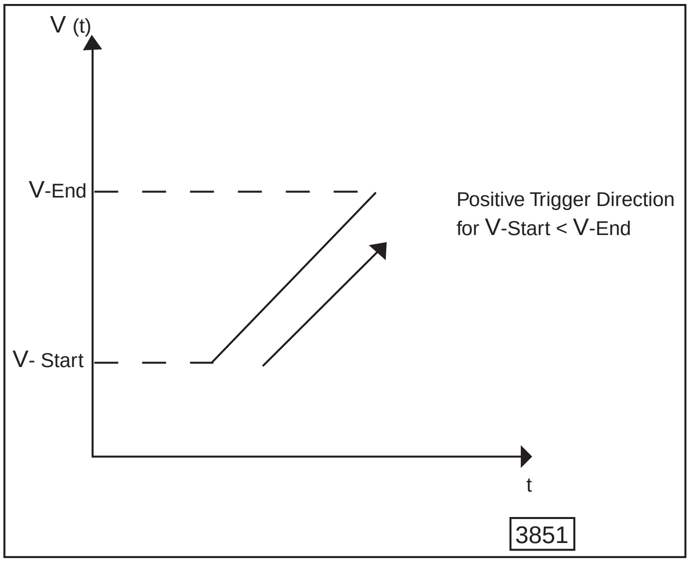


Figure 4.4h TUNA, SSRM: Positive Trigger Direction for $V_{Start} < V_{End}$



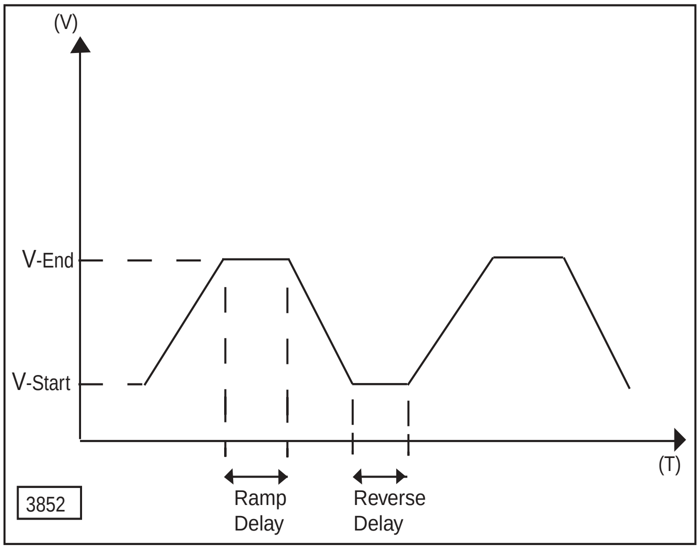
Delaying Ramps

The **Scan Mode** panel offers two more parameters that are used to independently add delay times at the end of a *start-end* ramp, or at the end of a complete *start-end-start* cycle (see Figure 4.4i).

Table 4.4g TUNA, SSRM: Ramp Delays

Parameter	Use with TUNA
Ramp Delay	A delay is added following each *start-end* ramp.
Reverse Delay	A delay is added following each complete *start-end-start* cycle.

Figure 4.4i TUNA, SSRM: Delaying Ramps



Note: Delay times are not included in the **Scan Rate** parameter.

Note: When switching from one start/end value to another, **Scan Rate** is kept at a constant value. **Forward** and **Reverse Velocity** automatically adjust to maintain **Scan Rate**.

Multiple IV-Spectra

1. Open the **Auto Panel** by selecting **Panels** > **Auto** (see Figure 4.3p).
2. Set the number of IV-spectra in the array using the **Columns** and **Rows** parameters—the number of IV-spectra to be performed in the X and Y directions, respectively (see Table 4.3i).

3. Set the spacing between the columns and rows in the array using the **Column Step** and **Row Step** parameters—which define the distance between two neighboring IV-spectra along the X and Y directions, respectively.

4. Set **Scan Mode** > **Trigger Threshold** and **Auto Panel** > **Threshold Step** to set the trigger currents for an array of IV-spectra. For automated IV-spectra, increment the trigger threshold current in the X-direction:

   a. Set **Trigger Threshold** to the initial value for the first IV-spectrum in each row.

   b. Increment **Trigger Threshold** according to the value of **Threshold Step** for every subsequent IV-spectrum in each row.

An Example

If a **Trigger Threshold** is **1.0pA** and the **Threshold Step** is **0.1pA**, then subsequent rows of the IV-spectra use a trigger threshold current varying from 1.0, to 1.1, to 1.2, . . . pA. To execute an array of IV-spectra with the same trigger threshold current, set **Trigger Threshold** to the desired threshold and set **Threshold Step** to **0.0pA**.

1. To execute an array of IV-spectra, click the **START ARRAY** toolbar button (see Figure 4.4e).

2. To capture the IV-spectra set **Auto Panel** > **Capture** to **Enable** before starting the array. Each spectrum of the array is saved separately. If **Capture** is set to **Off**, the spectra are lost.

Export IV-Spectra

To export IV-spectra in ASCII or any other format offered by the NanoScope software, complete the following steps:

1. Save the current data.

2. Export the saved data. The export function is located in the **Offline** > **Utility** menu.

Offset Correction

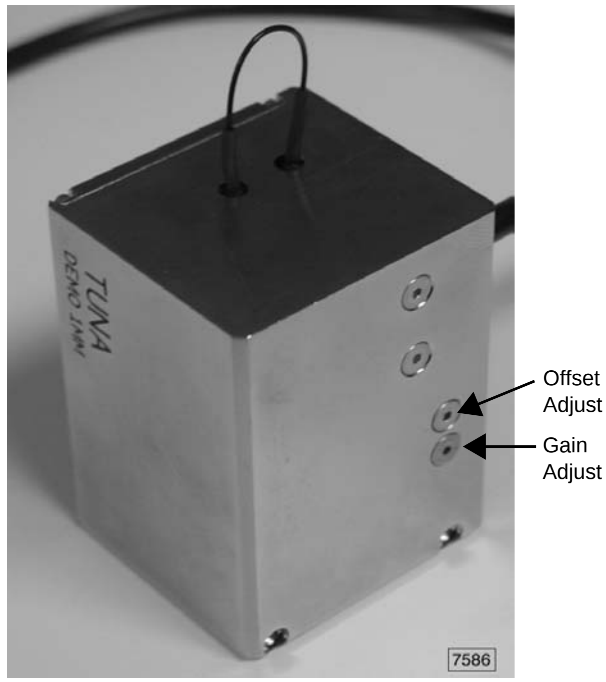
Any TUNA sensor offset is adjusted with a potentiometer, which is covered by the flat head screw on the bottom of the sensor housing (see Figure 4.4j).

1. Go to **Real-time** > **View** > **Scope Mode**.

2. Remove the screw on the sensor housing and carefully adjust the **Offset Adjustment** potentiometer with the screw driver (provided in the application module accessory kit) until the signal is along the horizontal zero line. A limited range is available on the adjacent **Gain Adjustment** potentiometer.

3. Adjust the **Data Scale** for better alignment.

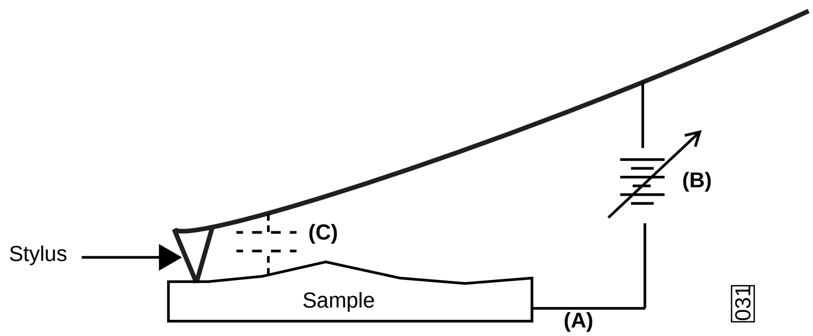
Figure 4.4j TUNA Offset Correction Access



4.4.5 Closed Loop Extended TUNA Imaging

Both standard and Extended TUNA can be operated in open and closed loop modes. However, due to the strong capacitance between the tip and sample (see **(C)** in Figure 4.4k), measuring with standard TUNA or with high gain settings in Extended TUNA (e.g., 1nA/V and 10 nA/V) may not yield the desired results.

Figure 4.4k Feedback Loop in Closed Loop Mode



The tip-sample capacitance is on the order of a few pF and yields a current (I).

$I = C \frac{\partial V}{\partial t}$, where:

- I = current
- C = tip/sample capacitance
- $\partial V/\partial t$ = rate of change of voltage

As the voltage changes rapidly (due to the feedback loop), it is possible for the feedback current (see **(A)**, Figure 4.4k) to become greater than the current being measured. Therefore, using lower gain settings in Extended TUNA (e.g.,1nA/V and 100nA/V) is recommended when operating in closed loop mode.

Closed Loop Procedure

Prior to engaging in closed loop mode, follow the procedure in **Open Loop TUNA Imaging:** Section 4.4.4. Be sure to adhere to the control parameters set forth in Table 4.4a. After finishing the procedure and while still in open loop mode, complete the following:

1. In the Feedback Controls panel:

   a. Select the **Bias lower** and **upper limits**. Start with a low setting (+/- 2V) and slowly increase the voltage while observing the current at the selected feedback point.

   b. Select the **Feedback Current**. This value is dependent on the gain setting.

   c. Set the **Feedback mode** to **closed** (you are now operating in closed loop mode).

2. In the appropriate channel, set the **Data Type** to **Feedback Bias** to view the applied bias.

3. In the appropriate channel, set **Realtime Planefit** and **Offline Planefit** to **None**.

The feedback current and bias limits will depend upon the sample being imaged and the gain settings for the TUNA sensor.

4.4.6 Extended TUNA Filter

When measuring very low currents with high gain setting (1nA), environmental noise in the 50-60Hz range (such as fluorescent lighting or computer feedback) might appear in the data (see Figure 4.4r). Extended TUNA offers a filter that may help to reduce this noise.

Figure 4.4l Noise with Filter Off

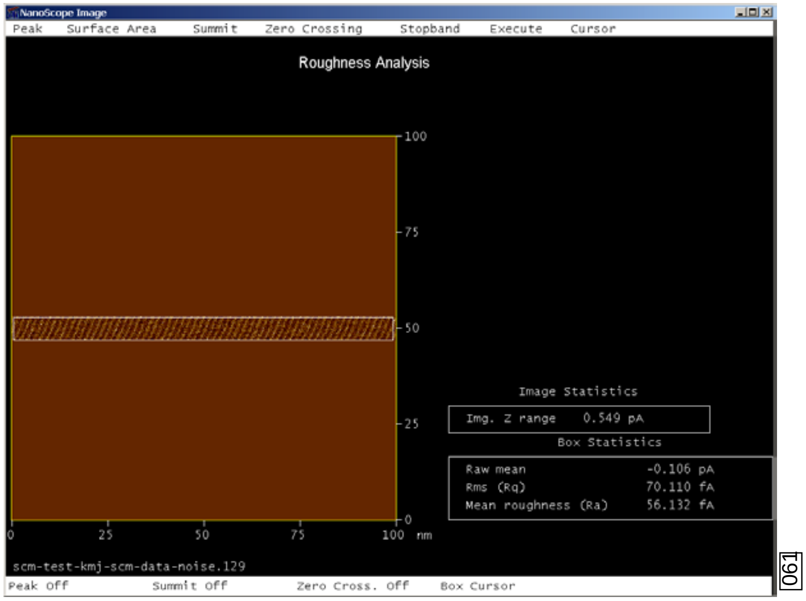
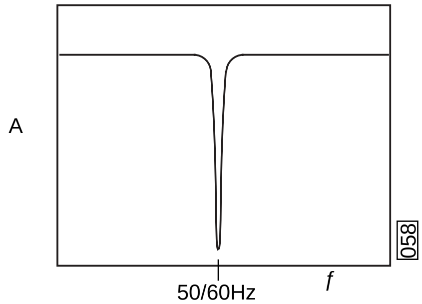


Figure 4.4m Notch Filter Characteristics with Notch at 50/60Hz



To use this filter, refer to these sections:

- **Select Filter Level (-16dBV or -32dBV),** page 79
- **Turn Filter On/Off,** page 81
- **Ringing in Filtered Data,** page 81

Select Filter Level (-16dBV or -32dBV)

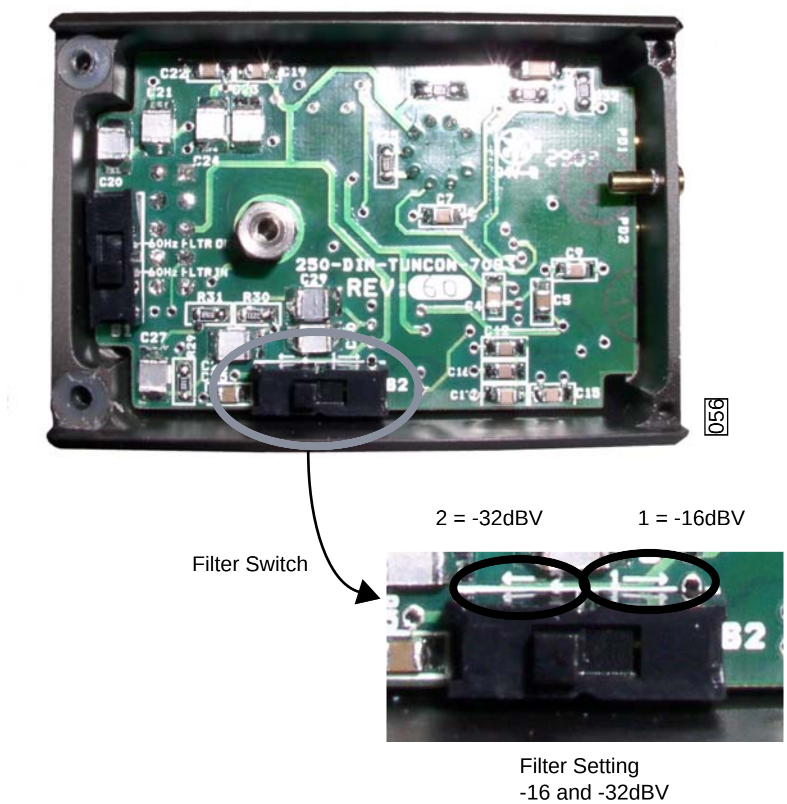
The filter level must be selected inside the Extended TUNA Module. You can choose from two settings: -16dBV or -32dBV. This filter should only need to be set once, assuming the environmental conditions stay the same.

1. Remove the top panel of the Extended TUNA module by unfastening the 2 bottom screws and the screw in the middle (see Figure 4.4n).

Figure 4.4n Unscrew These TUNA Screws to Remove the Top Panel

2. Flip the black switch to set the filter level (see Figure 4.4o). The small white “**1**” above and to the right of the switch indicates the -16dBV side and the small white “**2**” above and to the left of the switch indicates the -32dBV side.

Figure 4.4o Extended TUNA Board



3. Replace the top panel by reinserting and fastening the 2 corner and 1 middle screws.

Turn Filter On/Off

To turn the filter on, push the labeled filter switch on the outside of the Extended TUNA module to ON. To turn the filter off, push the switch down to OFF (see Figure 4.4p).

Figure 4.4p Filter Switch on Extended TUNA Module

Ringing in Filtered Data

Occasionally if the filter is on, high frequency transient noise causes ringing in the collected data (see Figure 4.4q).

Figure 4.4q Current Transition with Filter

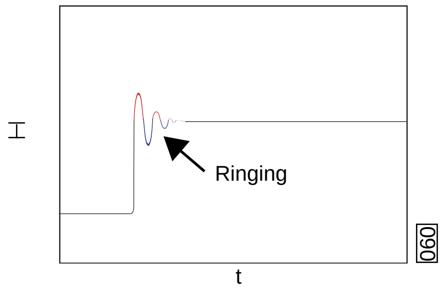
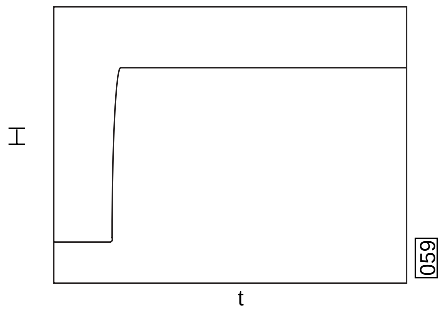


Figure 4.4r Current Change with no Filter Selected



To reduce ringing, complete one of these actions:

- Turn the filter off when it is not required.
- If the filter is set at -32dBV (2), reduce it to -16dBV (1).
- If filter must be on, scan slowly (for example, at 0.2Hz).

4.5 Scanning Spreading Resistance Microscopy (SSRM)

The following topics are discussed in this section:

4.5.1 Sample Mounting

Good electrical contact is required between the chuck and sample. Mount the sample to a standard sample disk or stage using conducting epoxy or silver paint. Preparation of a cross-section surface for SCM imaging is given in **SCM and SSRM Sample Preparation,** page 36. Note particularly the importance of avoiding skin contact with the sample surface of interest in **Sample Cleaning Procedure,** page 40.

4.5.2 SSRM Tip Selection and Mounting

SSRM requires an electrically conductive tip. Different tips are preferred for different sample material. We recommend using boron-doped diamond-coated silicon tips for silicon-based structures, and metal tips, metal-coated tips or diamond-coated tips for compound semiconductor materials (such as InP and GaAs-based structures). SSRM is operated in Contact Mode and requires a stable electrical contact necessitating reasonably high contact force. Diamond or diamond-coated tips are often preferred to support the stress on the tip.

Refer to your instruction manual for mounting a tip in the probe holder and placing the probe holder in the SPM head. See **Hardware Description,** page 24, for making electrical contact between the SSRM Application Module and the tip through the probe holder.

4.5.3 Software Selection

1. If not already operating in Real-time Mode, select **DI** > **Real-time**.

2. In the **Other Controls** panel, select **SSRM** as the **Microscope Mode**. The **Feedback Controls** panel displays all SSRM control parameters (see Figure 4.5a and Table 4.5a).

Figure 4.5a SSRM: Other Controls and Feedback Controls Panels

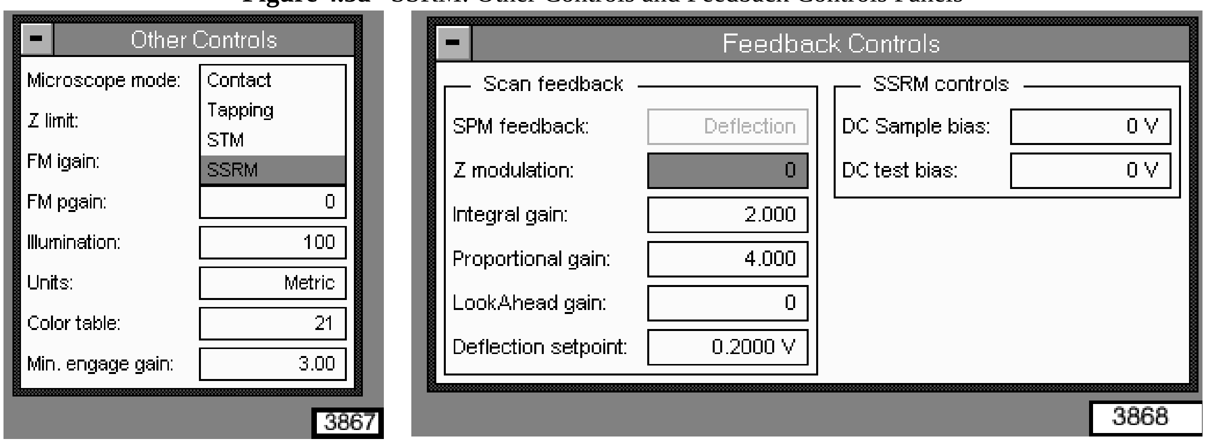


Table 4.5a SSRM Control Parameters

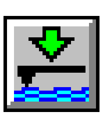
Parameter	Use with SSRM	Initial Setting
DC Sample Bias	Selectable DC bias to chuck/sample	**0V**
DC Test Bias	Selectable DC bias to test pin on SSRM sensor	**0V**

4.5.4 SSRM Imaging

1. For initial settings of the **Scan Controls** parameters and the **Feedback Controls** parameters in Contact Mode, refer to your instruction manual.

2. Set **Channel 1** > **Data Type** to **Height** and **Channel 2** > **Data Type** to **Resistance**. The topographic and SSRM resistance information display simultaneously.

3. Set (resistance) **Channel 2** > **Realtime Planefit** and **Offline Planefit** to **None**.



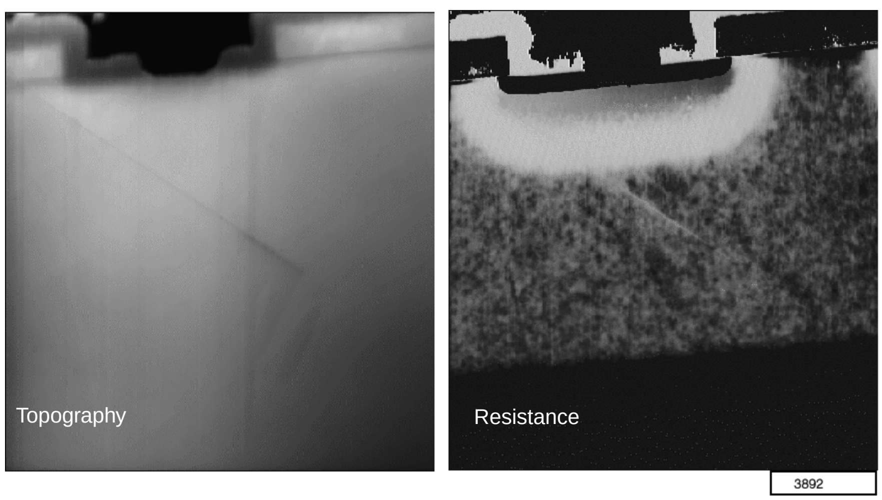
4. Click **ENGAGE** (icon shown) to initiate tip/sample contact and start the measurement.

   Note: You will probably want to adjust a number of parameters (**Integral Gain**, **Proportional Gain**, **Deflection Setpoint**, etc.) to optimize an image.

DC Sample Bias and **Deflection Setpoint** are the two most important parameters for SSRM imaging. A higher **Deflection Setpoint** corresponds to a higher force between the tip and sample. In order to obtain a stable electrical contact in SSRM, a minimum force is required. At low forces, the observed resistance values will be high (and often out of range). Upon increasing the force, the electrical contact becomes more stable, and the resistance drops to a lower, more stable value. An effective setting of **Deflection Setpoint** depends on the sample material and the tip used. In general, higher forces are needed for SSRM imaging of Si-based structures, as compared to other materials (e.g., metals, III-V semiconductor structures, etc.).

The optimum **DC Sample Bias** for SSRM imaging depends on the sample material. For Si-based and metal structures, **DC Sample Bias** can be small values (**-0.5V** to **0.5V**), whereas compound semiconductor structures often require several volts of positive or negative sample bias. As tip contact with some samples produces non-Ohmic behavior (not according to Ohm's Law: voltage equals current times resistance), the polarity of **DC Sample Bias** can have an important effect on measured values. Try different magnitudes and polarities of **DC Sample Bias** to optimize SSRM images. An example of simultaneously obtained topography and SSRM resistance images of a cross-sectioned silicon DMOS transistor show differently doped regions in Figure 4.5b.

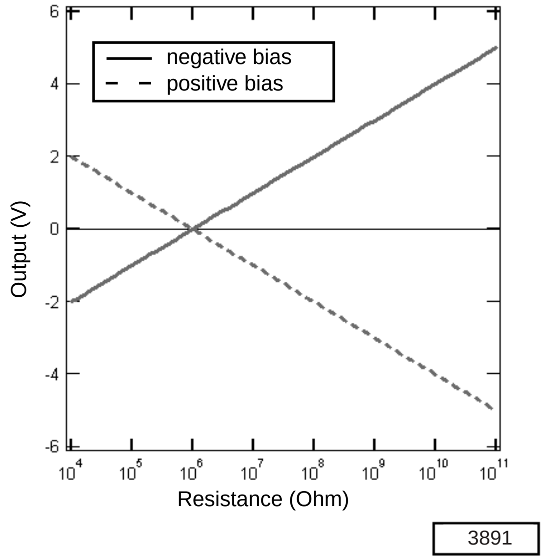
Figure 4.5b 12 Micron Scan SSRM Topography (Left), Resistance (Right) Images of a DMOS Transistor



Resistance data is provided in units of volts. A one volt change corresponds to a resistance change of one order of magnitude. One megaohm (i.e., 1MΩ) resistance corresponds to 0V output, independent of the applied bias voltage. The relation between output voltage, V_{out}, and input current, I, is:

- $V_{out} = sign(V_{bias}) * \log (I * 10^6/V_{bias})$, where
    - $sign(V_{bias}) = +1$ if $V_{bias} > 0$ and
    - $sign(V_{bias}) = -1$ if $V_{bias} < 0$, (see Figure 4.5c)

Figure 4.5c Transfer Curve of the SSRM Logarithmic Current Amplifier



4.5.5 SSRM Ramping and RV-spectra

NanoScope software permits sweeping or ramping various signals. Either position the SSRM tip at the center of the image, or apply an **X** or **Y Offset** to move the tip to another location.

The **Force Curve** command enables sweeps of various signals. A typical application is an RV-spectrum (resistance, R, as a function of voltage, V).

1. Click **Real-time** > **View** > **Force Mode** > **Advanced** to open ramping panels (see Figure 4.5d). **Main Controls** > **Ramp Controls** parameters are summarized in Table 4.5b. **Main Controls** > **Display parameters** are summarized in Table 4.5c.

   Note: **Scan Rate**, **Forward Velocity** and **Reverse Velocity** are interdependent. Changing a velocity affects the scan rate, and changing the scan rate affects both velocities.

2. For **Main Controls** > **Ramp Controls** > **Ramp Channel** (see Figure 4.5e), select a ramping option from the pull-down menu (e.g., choose **DC Sample Bias** for RV spectra).

3. Set the values of the other parameters in the Ramp Controls and Display subpanels of the **Main Controls** panel.

4. Select an option (e.g., **Resistance**) for **Data Type** in a **Channel** panel.

5. Start and stop ramping by clicking buttons on the toolbar (see Figure 4.4e and the button definitions that follow on page 69).

6. Capture ramping curves with **Real-time** > **Capture** commands or toolbar buttons.

Figure 4.5d SSRM Ramping Panels in Force Mode/Calibrate

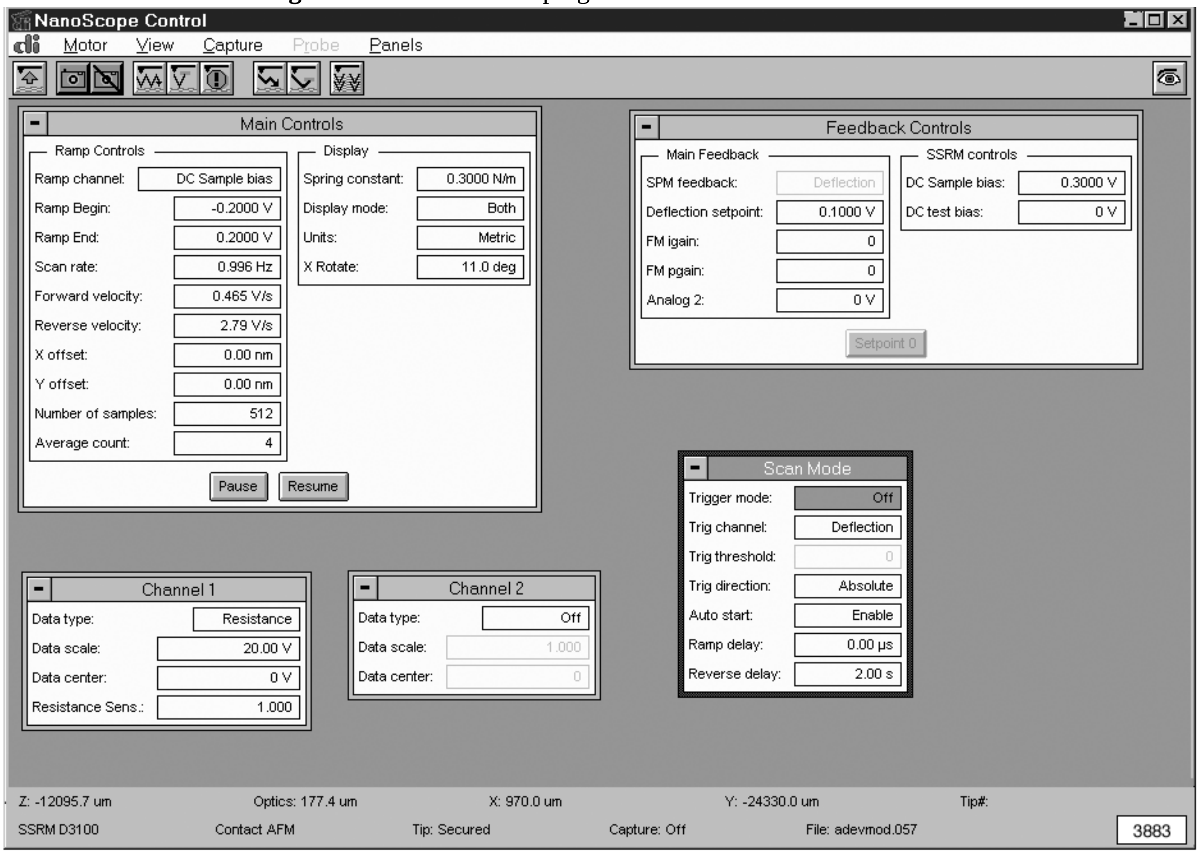


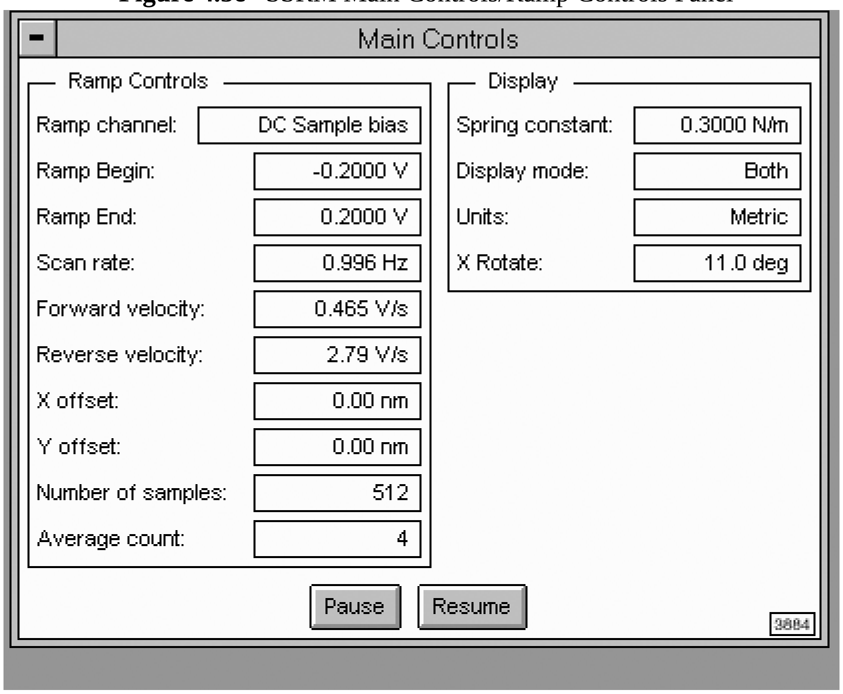
Table 4.5b SSRM Ramp Control Parameters in the Main Controls Panel

Parameter	Use with SSRM
Ramp Channel	Selection of SSRM property to ramp from options: **Z** (for standard force curve measurements), **DC Sample Bias** and **DC Test Bias**.
Ramp Begin/Ramp End	The start and end of a ramp, as positive or negative values.
Scan Rate	All ramps are *begin-end-begin* cycles. **Scan Rate** refers to one full cycle.
Forward Velocity & Reverse Velocity	The ramp velocity from beginning to end, and end to beginning, respectively.
X and Y Offset	Move the tip to a different location.
Number of Samples	The number (minimum **16**, maximum **64,000**) of samples per ramp.
Average Count	Average several (minimum **1**, maximum **1024**) ramps.

Table 4.5c SSRM Display Parameters in the Main Controls Panel

Parameter	Use with SSRM
Units	Metric or Volts
Feedback Type	Ensures that deflection feedback is on during ramping; select **Ramp**, **Cycle** or **Pixel**. **Ramp** enables feedback after each ramp cycle (*start-end* feedback). **Cycle** enables feedback after each ramp cycle (*start-end-start* feedback). **Pixel** enables feedback after every sample point of the ramp. This is useful for slow ramps with few sample points.
Feedback Counts	Select **50** for proper feedback.
Feedback Value	Select **0V**.

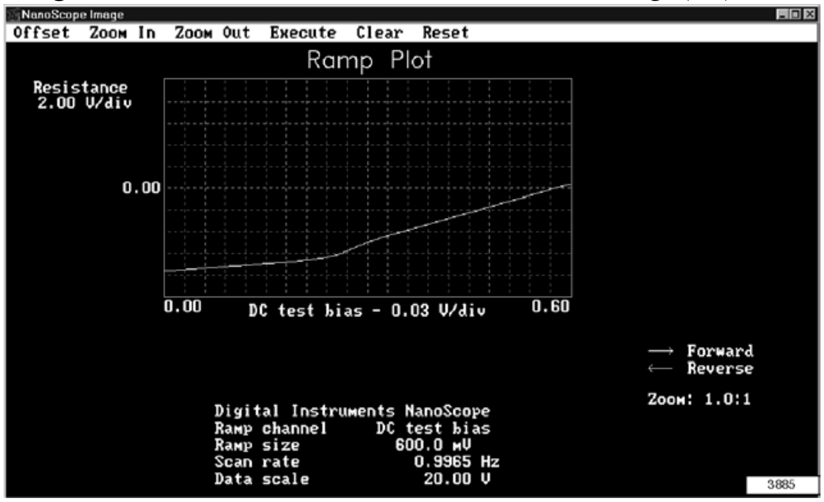
Figure 4.5e SSRM Main Controls/Ramp Controls Panel



An Example

An RV ramping curve example is shown in Figure 4.5f. Resistance varies from approximately $10^{14}\Omega$ (represented as -8V) to $10^{6}\Omega$ (0V) as the **DC Test Bias** ramps from 0V to +0.6V. An **Average Count** of **3** was used to improve the signal-to-noise ratio.

Figure 4.5f SSRM Resistance versus DC Test Bias Voltage (RV) Curve



Trigger and Delay

SSRM triggering direction for RV-spectra has the same meaning as with TUNA IV-spectra: see **Explanation of Trigger Direction,** page 71.

CAUTION:	**Trigger Mode** must be set to **Absolute** when performing SSRM RV-spectra. Ignore parameters which share the same control panels but are relevant only to force curves.

Adding delays to SSRM RV-spectra is done the same way as with TUNA IV-spectra: see **Delaying Ramps,** page 73.

4.5.6 Multiple RV Spectra

You may perform ramps on an array of sample surface points, defining the array in the **Auto Panel** (see Figure 4.3p). A ramp is executed and captured, then the tip moves to the next point of the array, each time using the same control parameter values (see Table 4.3i).

For additional ramp curve control, **Scan Mode** panel parameters (see Figure 4.3q) include the option to limit the output signal (R in SSRM) to user-defined values in Trigger Mode. The **Scan Mode** panel also offers two parameters you may use to independently delay times at the end of the *start-end* ramp, or at the end of a complete *start-end-start* cycle. Ignore **Scan Mode** panel force curve parameters (e.g., **Start Mode**, **End Mode**, **Z Step Size**, **Auto Offset**).

Table 4.5d SSRM: Scan Mode Panel Parameters

Parameter	Use with SSRM
Trigger Mode	For RV curves, select **Absolute** to turn on the trigger.
Trigger Channel	For RV curves, select **Resistance** to trigger on the resistance signal.
Trigger Threshold	Sets the trigger value.
Trigger Direction	Select **Negative** or **Positive** ramp slope.
Ramp Delay	A delay following each *start-end* ramp.
Reverse Delay	A delay following each complete *start-end-start* cycle.

4.6 Conductive Atomic Force Microscopy (C-AFM)

The following topics are discussed in this section:

Sample Mounting: Section 4.6.1

C-AFM Tip Selection and Mounting: Section 4.6.2

Software Selection: Section 4.6.3

C-AFM Imaging: Section 4.6.4

4.6.1 Sample Mounting

Attach the sample to a sample disk or magnetic puck provided with the system and place them on top of the sample chuck.

When measuring large samples, we recommend use of an electromagnetic interference shielding hood. Large conductive samples can act as an antenna and focus electrical noise from the environment into the input of the C-AFM sensor.

WARNING: The sample chuck and its surrounding area are electrostatic sensitive. Employ ESD-protective measures at all times when handling a C-AFM sensor or sample.

4.6.2 C-AFM Tip Selection and Mounting

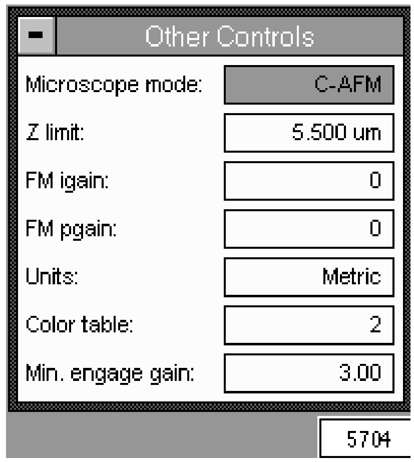
C-AFM requires an electrically conductive tip. The potential for tip wear in Contact Mode is another important consideration in selecting a tip. Standard C-AFM tips include PtIr-coated tips for Contact Mode (SCM-PIC) and CoCr coated (magnetized) Si tips (MESP). Less conductive diamond coated tips (DCT-ESP) are an alternative if tip wear is a particular concern.

Refer to your instruction manual to mount a tip in the probe holder and place the probe holder in the SPM head. See **Hardware Description,** page 24 for making electrical contact between the C-AFM Application Module and the tip through the probe holder.

4.6.3 Software Selection

1. If you are not already operating in Real-time Mode, select **DI** > **Real-time**.
2. In the **Other Controls** panel, select **C-AFM** as the **Microscope Mode** (see Figure 4.6a).

Figure 4.6a C-AFM: Other Controls Panel



Note: C-AFM measurements can be performed in closed loop or open loop mode. In open loop mode, the user selects a fixed DC bias and the current passing through the sample is measured. For these standard measurements, only a few of the parameters available in the C-AFM Controls subpanel of the **Feedback Controls** panel are necessary. You may clear all other parameters. Table 4.6a summarizes all C-AFM Controls parameters and their functions. To access parameters not currently displayed:

3. Click the **EXPANSION** button in the top left corner of the **Feedback Control** panel (see Figure 4.6b). Select **View All** (parameters) in the pull-down menu that appears, or click in the boxes to the left of the names of those of interest.

Figure 4.6b C-AFM: Feedback Controls Panel

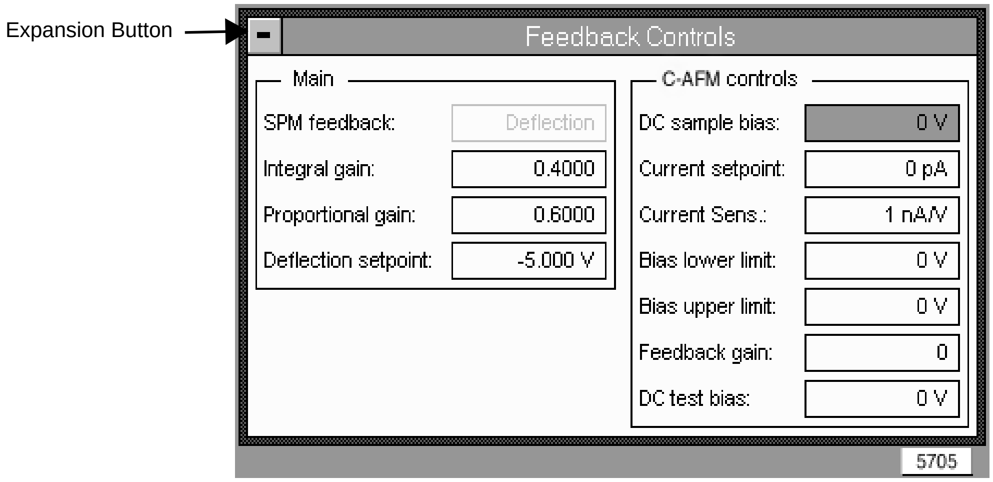


Table 4.6a C-AFM Controls Parameters

Parameter	Use with C-AFM
Feedback Mode	Either **Open** or **Closed**.
DC Sample Bias	Selectable bias to chuck/sample.
Current Setpoint	The closed loop mode controlled current target.
Current Sensitivity	Sets the gain of the C-AFM sensor:* **1nA/V** = gain of 10^{9} **100nA/V** = gain of 10^{7}
Bias Lower Limit	Limits the minimum bias applied to the chuck/ sample in closed loop mode.
Bias Upper Limit	Limits the maximum bias.
Feedback gain	Adjusts the feedback gain in closed loop mode.
DC Test Bias	Provides an additional bias for the purpose of testing the C-AFM sensor.

* nA/V and 100nA/V refer to the output voltage of the C-AFM sensor. If a Signal Access Module is available, the output voltage can be measured at **AuxD**.

4.6.4 C-AFM Imaging

Quick Start

For a quick start, use the C-AFM profile.

1. Select **Microscope** > **Profile** and the **Profile Select** panel appears.

2. Highlight the profile **C-AFM** (file name C-AFM) and click **Load Master** to set scan parameters to acceptable values.

Real-time Mode

To perform a measurement in Real-time mode:

1. Click **DI** > **Real-time**.

2. Set **Other Controls** > **Microscope mode** to **C-AFM** (see Figure 4.4a).

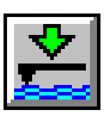
3. Set the C-AFM Controls subpanel parameters (see Figure 4.6b) to the values shown in Table 4.6b.

Table 4.6b Initial Settings of C-AFM Control Parameters

Parameter	Use with C-AFM
DC Sample Bias	0V
Current Sens.	1nA/V
DC Test Bias	0V

C-AFM is a Contact Mode technique. For the initial settings of the **Scan Controls** parameters and the **Feedback Controls** parameters in Contact Mode, refer to your instruction manual. Typically, the **Feedback Controls** panel looks similar to what is shown in Figure 4.4b.

4. Set **Feedback Controls** > **Deflection Setpoint** to no more than a few tenths of a volt above the engagement point. This will keep the contact force sufficiently low, thus not causing any damage to the tip or sample. This is especially important for metal coated tips or soft samples.



5. Once **Scan Controls** and **Feedback Controls** parameters are set, click **Motor** > **Engage** or the ENGAGE icon (shown) and start a measurement.

   Note: It will probably be necessary to make adjustments to a number of parameters (**Integral Gain**, **Proportional Gain**, **Deflection Setpoint**) before the image is optimized.

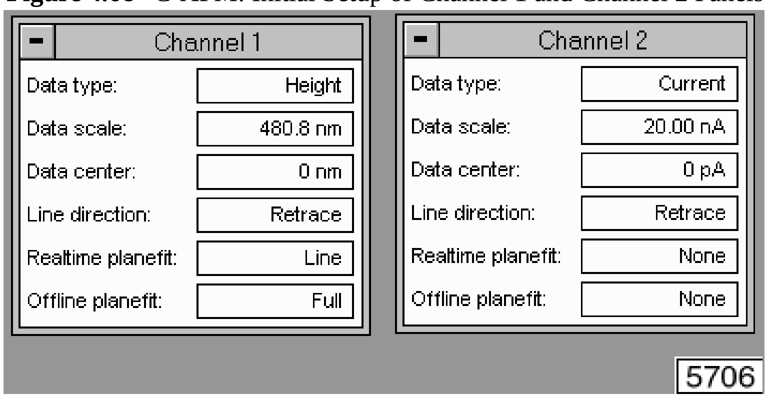
6. Set **Channel 1** > **Data Type** to **Height** to view the topography and set **Channel 2** > **Data Type** to **Current** to view the current data (see Figure 4.4c).

7. In the **Channel 2** panel, set **Realtime planefit** to **None** and the **Offline planefit** to **None** or **Full**.

8. Verify **Highpass filter** and **Lowpass filter** parameters are turned **Off** in **Channel 2**.

Note: The **Data Center** parameter in Channel panels is useful for measurement of small current variations in a sample with an overall larger background current. It offsets the centerline of the color scale by the amount entered: within the range ±220V—or the metric equivalent if **Other Controls** > **Units** is set to **Metric**.

Figure 4.6c C-AFM: Initial Setup of Channel 1 and Channel 2 Panels



9. To reduce wear of the tip and sample, decrease the contact forces between the tip and sample as much as possible. This is done in one of the following two ways:

   - Generate a force plot and adjust the **Force Calibration** > **Setpoint** to a level just before the pull-off point, thus minimizing force (refer to your instruction manual),
   - Without a force plot:
     - Click **View** > **Scope Mode** and observe the (**Channel 1**) **Height** trace.
     - Highlight **Feedback Controls** > **Deflection Setpoint** and left-click the mouse to reduce the force applied to the sample by lowering the setpoint incrementally. Repeat until the tip eventually lifts off the surface.
     - Click the **RIGHT ARROW** key as needed to obtain a focused image.

   Note: Adjusting the **Deflection Setpoint** to a few tenths of a volt above the engagement point provides a low contact force.

10. Slowly increase the **Feedback Controls** > **DC Sample Bias** while watching the current signal in either Image Mode or Scope Mode. For many samples, the current increases rapidly beyond a threshold bias.

Note: Do not scan too fast. The sensor bandwidth is only 160Hz. The slower a sample is scanned, the higher the spatial resolution the current sensor can detect. Adjust **Scan Controls** > **Scan Rate** for image quality.

WARNING: Increase **DC Sample Bias** carefully: metal coated tips may melt and the sample may be damaged if the current density is too high.

WARNING: Electrostatic forces cause a strong attraction between the tip and most samples when a bias is applied. The electrostatic force does not result in additional deflection of the cantilever, but does induce more wear of the tip, and can damage soft samples, such as polymers. Reduce the **Deflection Setpoint** (see Step 9) to lower the tip/sample force. Alternatively, apply the bias first before engaging. However, the latter method works only for experiments with a well-defined, known bias. In most cases, further adjustment of **Deflection Setpoint** will be necessary.

11. Save the data as described in Chapter 6 of the *Command Reference Manual*.

C-AFM IV-Spectra

NanoScope software permits "IV" (current, I, as a function of voltage, V) measurements in a specified location on the sample. Typically the SPM tip is placed at the center of an image where an IV-spectrum is captured. By applying **X** and **Y Offsets**, the tip may be moved to other locations.

Perform an IV Measurement

1. Click **View** > **Force Mode** > **Advanced** to open the **Main Controls**, **Feedback Controls**, **Scan Mode** and **Channel** panels (see Figure 4.6d).

Figure 4.6d C-AFM Ramping Panels

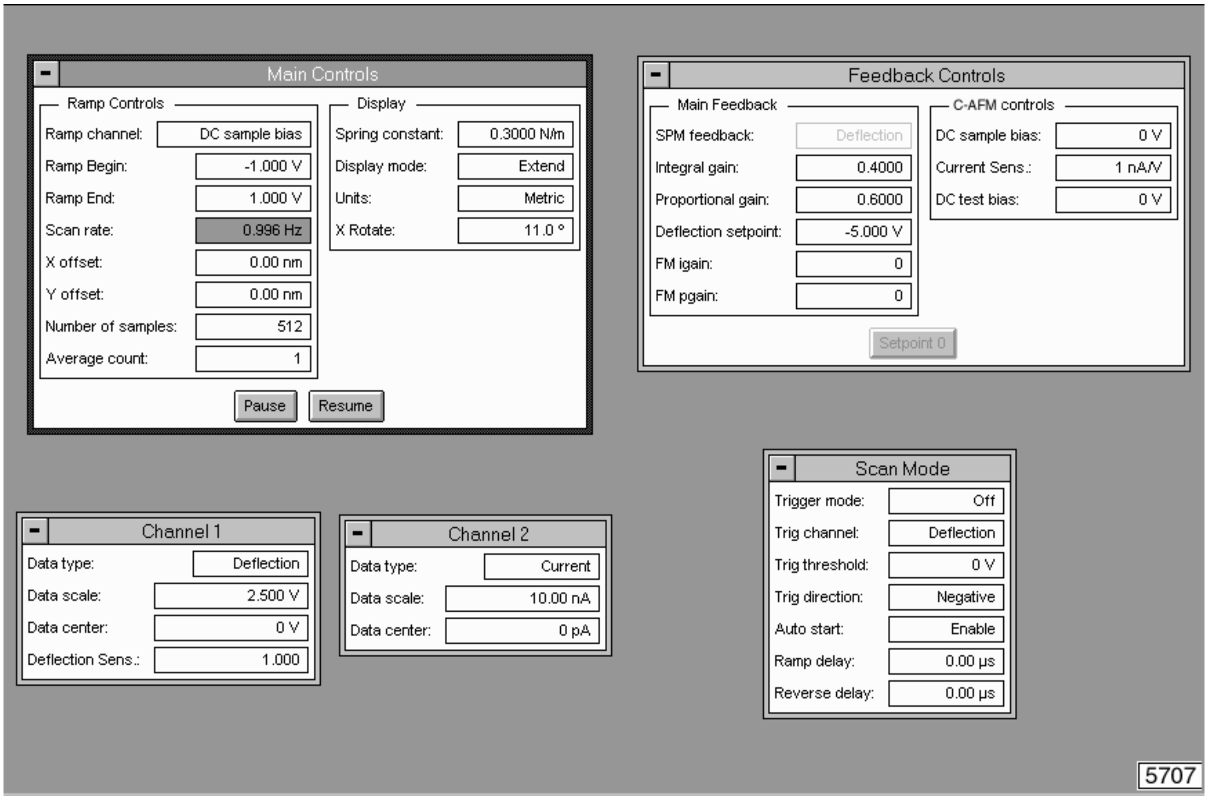


Table Note: through Table 4.6d summarize the ramping parameters and their functions:

Note: C-AFM: Main Controls/Ramp Controls Subpanel

Parameter	Use with C-AFM
Ramp Channel	Select **DC Sample Bias** to ramp the bias applied to the chuck/sample.
Ramp Begin/Ramp End	Define beginning and end of ramp; both values may be positive or negative.
Scan Rate*	All ramps are *begin-end-begin* cycles (V_{start}-V_{end}-V_{start}), and the scan rate refers to one complete cycle.
Forward Velocity* & Reverse Velocity*	Defines the ramp velocity from beginning to end value, and end to beginning value, respectively.
X and Y Offset	Moves the tip to a different location.
Number of Samples	Sets the number of samples per ramp (minimum **16**, maximum **64,000**).
Average Count	Allows several (minimum **1**, maximum **1024**) ramps to be averaged.

Note: ***Scan Rate**, **Forward Velocity** and **Reverse Velocity** are interdependent. Changing a velocity affects the scan rate, and changing the scan rate affects both velocities.

2. Adjust the following parameters in the Display subpanel of the **Main Controls** panel (see Table 4.6c):

Table 4.6c C-AFM: Main Controls/Display Subpanel

Parameter	Use with C-AFM
Units	Select **Metric** for IV-spectra.
Feedback Type	Ensures that deflection feedback is on while ramping DC sample bias; select **Ramp**, **Cycle** or **Pixel**: **Ramp** enables feedback after each ramp or half cycle (V_{start}-V_{end} feedback). **Cycle** enables feedback after each ramp cycle (Vstart-Vend-Vstart feedback). **Pixel** enables feedback after every sample point of the ramp. This is useful for extremely slow ramps with few sample points.
Feedback Counts	Select **50** for proper feedback.
Feedback Value	N/A

3. To view IV-spectra, set **Data Type** to **Current** for either **Channel 1** or **Channel 2** (see Table 4.6d).

Table 4.6d C-AFM: Channel Panel Parameters

Parameter	Use with C-AFM
Data Type	For IV Spectra, select **CURRENT**.
Data Scale*	Adjust according to data.
Data Center	Offsets IV-spectrum along the vertical (current) axis.
Current Sensitivity*	Display the sensitivity selected in the **Feedback Controls** > **C-AFM Controls** panel.

Note: ***Data Scale** and **Current Sensitivity** parameter settings in a **Channel** panel automatically adjust the setting of the **Feedback Controls** > **Current Sensitivity** parameter.

Start and Save IV-spectra

1. To start and stop voltage ramps, click the appropriate icon in the toolbar (see Figure 4.4e and the button definitions that follow on page 69).

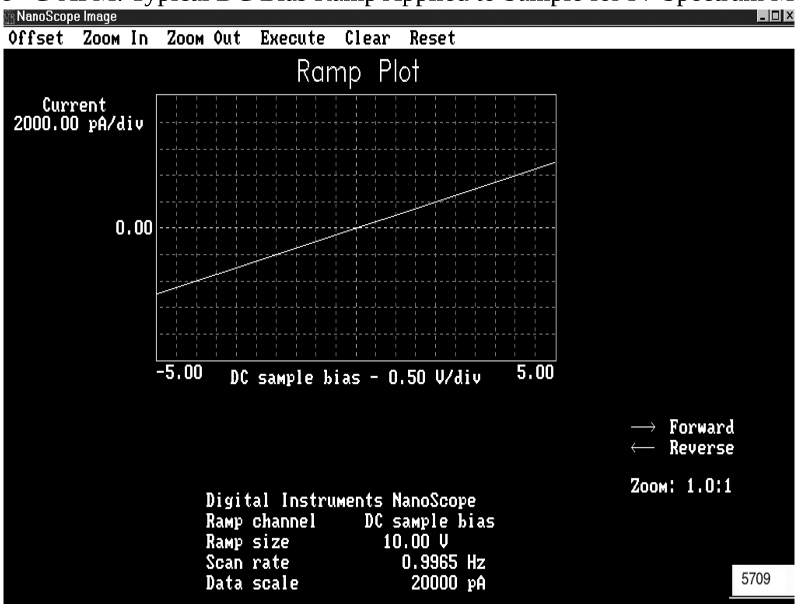
Note: In order to take IV-spectra, the AFM must be engaged.

2. Capture ramping curves with **Real-time** > **Capture** commands or toolbar buttons.

A C-AFM Example

Figure 4.6e shows ramp control settings for a typical IV-spectrum measured using C-AFM. The DC sample bias ranges from -5V to +5V.

Figure 4.6e C-AFM: Typical DC Bias Ramp Applied to Sample for IV-Spectrum Measurement



Trigger Mode Function and Operation

Trigger Mode enables limiting of the current passing through a sample to protect it. See the **Real-time** > **Force Mode...Advanced/Scan Mode** panel (see Figure 4.3q) for trigger parameters. Table 4.6e and Table 4.4g describe trigger parameter functions.

Table 4.6e C-AFM: Scan Mode Panel Parameters

Parameter	Use with C-AFM
Trigger Mode	Triggering is either **Off**, **Relative** or **Absolute**. For IV-spectra select **Absolute** to turn the trigger on.
Trigger Channel	For IV-Spectra, select **Current** for triggering on the current.
Trigger Threshold	This sets the trigger value. For a current sensitivity of 1nA/V, select any value between **-10nA** and **+10nA**. For a current sensitivity of 100nA/V, select any value between **-100nA** and **+100nA**.
Trigger Direction	(see explanation below)
Auto Start	Set to **Disable**.

Trigger and Delay

C-AFM triggering direction for IV-spectra has the same meaning as with TUNA (see **Explanation of Trigger Direction,** page 71).

CAUTION:	**Trigger Mode** must be set to **Absolute** when performing C-AFM IV-spectra. Ignore parameters which share the same control panels but are relevant only to force curves.

Adding delays to C-AFM IV-spectra is done the same way as with TUNA (see **Delaying Ramps,** page 73).

Multiple IV-Spectra

1. Open the **Auto Panel** by selecting **Panels** > **Auto** (see Figure 4.3p).
2. Set the number of IV-spectra in the array using the **Columns** and **Rows** parameters—the number of IV-spectra to be performed in the X and Y directions, respectively (see Table 4.3i).
3. Set the spacing between the columns and rows in the array using the **Column Step** and **Row Step** parameters—which define the distance between two neighboring IV-spectra along the X and Y directions, respectively.
4. Adjust **Scan Mode** > **Trigger Threshold** and **Auto Panel** > **Threshold Step** to set the trigger currents for an array of IV-spectra. For automated IV-spectra, increment the trigger threshold current in the X-direction:
   a. Set **Trigger Threshold** to the initial value for the first IV-spectrum in each row.
   b. Increment **Trigger Threshold** according to the value of **Threshold Step** for every subsequent IV-spectrum in each row.

An Example

If a **Trigger Threshold** is **1.0nA** and the **Threshold Step** is **0.1nA**, then subsequent rows of the IV-spectra use a trigger threshold current varying from 1.0, to 1.1, to 1.2,... nA. To execute an array of IV-spectra with the same trigger threshold current, set **Trigger Threshold** to the desired threshold and set **Threshold Step** to **0.0nA**.

1. To execute an array of IV-spectra, click the **START ARRAY** toolbar button (see Figure 4.4e).
2. To capture the IV-spectra set **Auto Panel** > **Capture** to **Enable** before starting the array. Each spectrum of the array is saved separately. If **Capture** is set to **Off**, the spectra are lost.

Export IV-Spectra

To export IV-spectra in ASCII or any other format offered by the NanoScope software, complete the following steps:

1. Save the current data.

2. Export the saved data. The export function is located in the **Offline** > **Utility** menu.

Offset Correction

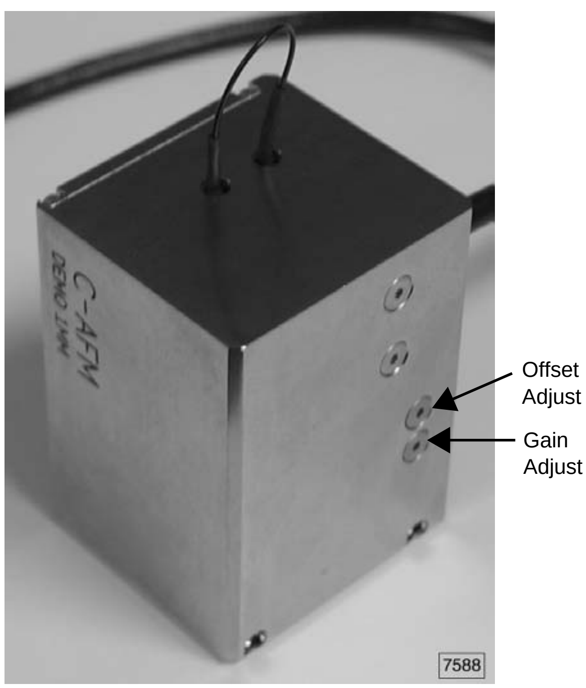
Any C-AFM sensor offset is adjusted with a potentiometer, which is covered by the flat head screw on the bottom of the sensor housing (see Figure 4.6f).

1. Go to **Real-time** > **View** > **Scope Mode**.

2. Remove the screw on the sensor housing and carefully adjust the **Offset Adjustment** potentiometer with the screw driver (provided in the application module accessory kit) until the signal is along the horizontal zero line. A limited range is available on the adjacent **Gain Adjustment** potentiometer.

3. Adjust the **Data Scale** for better alignment.

Figure 4.6f C-AFM Offset Correction Access



4.7 Scanning Thermal Microscopy (SThM)

The following topics are discussed in this section:

Sample Mounting: Section 4.7.1

Dimension SThM Tip Selection and Mounting: Section 4.7.2

MultiMode SThM Tip Selection and Mounting: Section 4.7.3

Parameter Settings for Thermal Imaging: Section 4.7.4

4.7.1 Sample Mounting

Attach the sample to a sample disk or magnetic puck provided with the system and place them on top of the sample chuck.

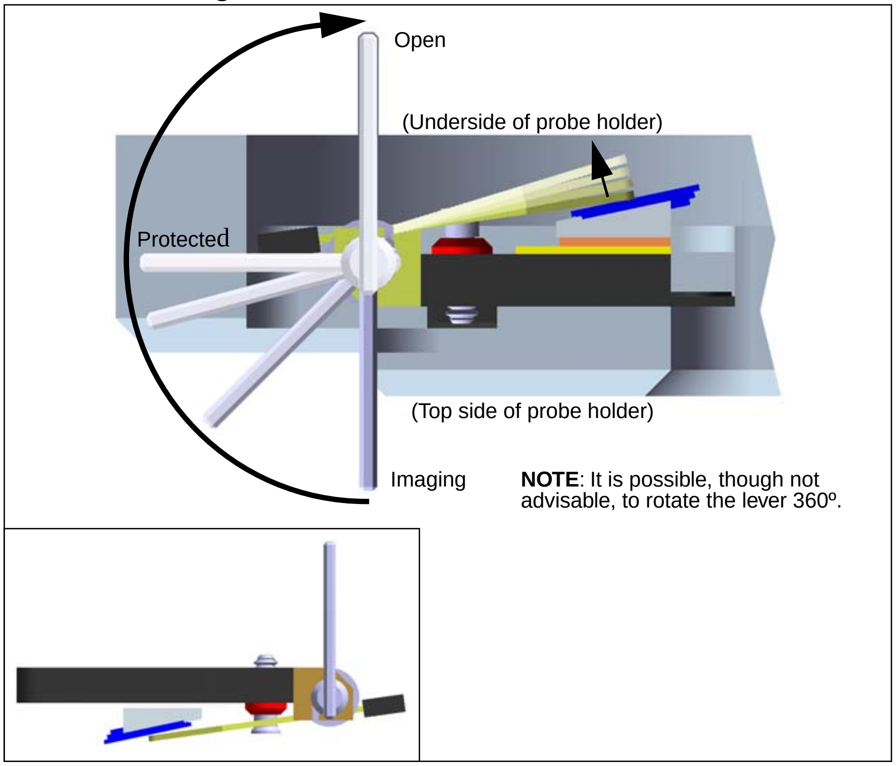
4.7.2 Dimension SThM Tip Selection and Mounting

WARNING: Because they are significantly more expensive than standard SPM tips, thermal tips must be handled with extraordinary caution. The resistors deposited on their tips are easily destroyed by electrical static discharge (ESD) ≥ 800 μA; therefore, they must never be removed from their protective packaging until the user is electrically grounded. Preventative measures for the handling of sensitive electronic components are detailed in numerous publications. For more information, Veeco refers the reader to the Electrical Specialties Division of 3M Corporation, which offers a complete program in ESD safeguarding. 3M Electrical Specialties Division may be reached at 1-800-858-5373.

Installation of Dimension thermal tips is similar to standard silicon nitride tips; however, the Dimension thermal probe holder features a slightly modified holding mechanism consisting of a miniature vise operated with a cammed lever. The lever has three basic positions: open, protected and imaging (see Figure 4.7a). These positions are defined as follows:

- **Open**— Lever points toward probe holder's underside.
- **Protected**— Lever points to either edge of the probe holder. In this position, electrical contacts on the thermal tip are grounded to protect the sensitive resistor.
- **Imaging**— Lever points toward probe holder's upper side. DO NOT rotate the lever to the "imaging" position until the probe holder is securely mounted inside the SPM and ready to image.

Figure 4.7a Dimension Thermal Probe Holder



Installing a Thermal Tip

IMPORTANT! Before installing the sample and thermal tip, first verify that all tip-sample adjustments have been properly made. Many thermal imaging experiments involve outside hardware (e.g., electrical leads to the sample, special mountings, etc.) which can destroy the very expensive thermal tip. For this reason, always start with a standard SiNi tip in the probe holder while making the following checks:

- Can the tip reach the sample surface?
- Is the sample surface electrically insulated (passivated) from the tip?
- Are electrical leads to the sample clear of the probe holder and tip? Are leads secured using cable ties or tape? If an electrical lead is accidentally snagged, will it destroy the tip and/or sample?

To install a thermal tip, employ the following procedure:

1. Prepare an electrically grounded work space near the SPM, for example, a grounding pad, tin foiled bench with electrical grounding, etc. Attach a grounding strap to your wrist. The prepared area should include metal tweezers and thermal tips in their (closed) protective case.

WARNING: Your grounding strap should feature a limiting resistor to protect you from electrical shock!

2. Withdraw the tip several times from the sample surface to ensure good clearance. Remove the thermal probe holder from the SPM and rotate the lever to the protected position. Place the probe holder upside down on the probe holder changing station. Rotate the probe holder’s lever upward to the open position.

3. If a thermal tip is already in the probe holder, use tweezers to remove it. Take a new thermal tip from the protective case and install it in the probe holder. Close the protective case with the remaining thermal tips.

4. Verify that the tip is seated in the probe holder’s groove, then rotate the probe holder’s lever to the protected position. This will close the probe holder’s vise and secure the tip.

5. If a new sample has been placed in the SPM, verify sufficient separation exists between the probe holder mount and sample to prevent bottoming out the new tip on the sample. Select **Real Time** > **Motor** > **Step Motor** to position the probe holder mount properly, then place the probe holder into the SPM.

6. Verify that the SPM head is plugged in and the NanoScope software is operating. Also, verify that the Quadrex module is in line between the microscope and controller (NanoScope IIIa only).

7. Finally, rotate the probe holder’s lever to the imaging position by swinging it straight up. The tip is now “active” and ready to use.

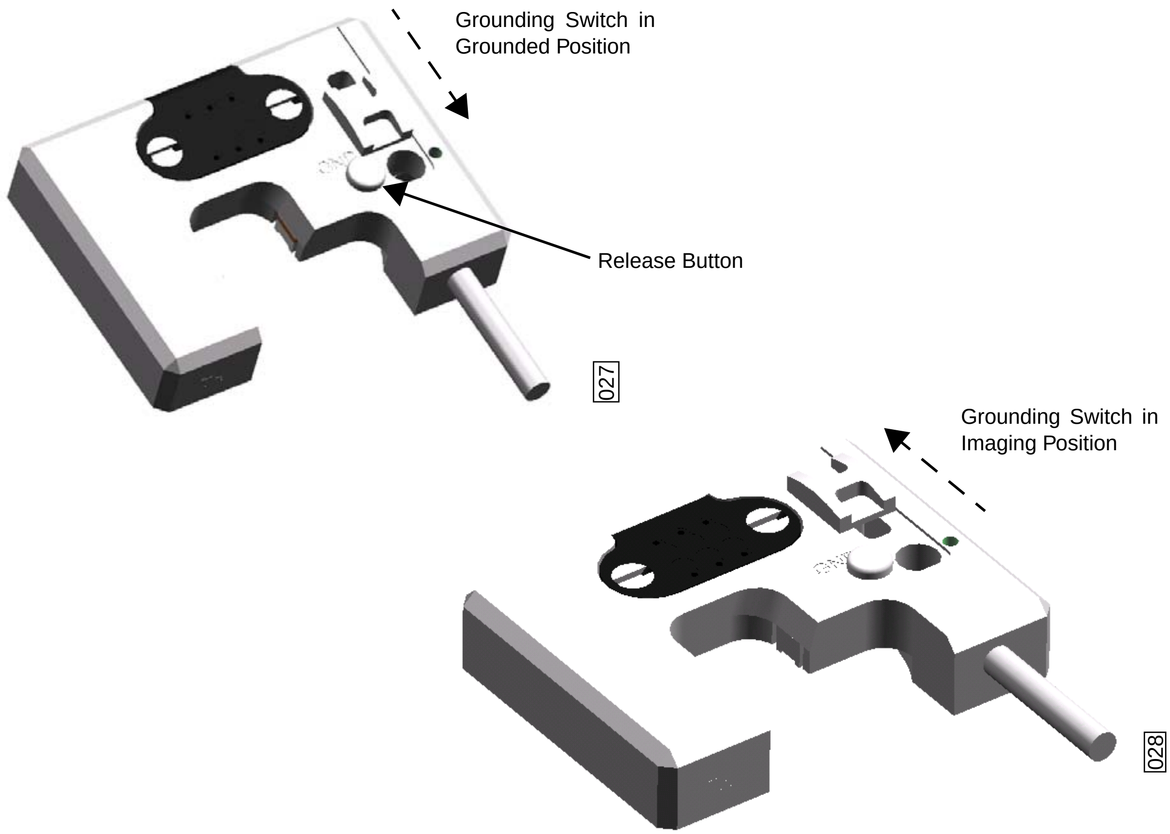
4.7.3 MultiMode SThM Tip Selection and Mounting

WARNING: Because they are significantly more expensive than standard SPM tips, thermal tips must be handled with extraordinary caution. The resistors deposited on their tips are easily destroyed by electrical static discharge (ESD) ≥ 800 μA; therefore, they must never be removed from their protective packaging until the user is electrically grounded. Preventative measures for the handling of sensitive electronic components are detailed in numerous publications. For more information, Veeco refers the reader to the Electrical Specialties Division of 3M Corporation, which offers a complete program in ESD safeguarding. 3M Electrical Specialties Division may be reached at 1-800-858-5373.

Installation of MultiMode thermal tips is similar to standard silicon nitride tips; however, the thermal probe holder features a slightly modified holding mechanism consisting of a grounding switch and a release button. The switch has two positions: grounding and imaging (see Figure 4.7b). These positions are defined as follows:

- **Grounding**— Switch position is at the back of the probe holder. In this position, electrical contacts on the thermal tip are grounded to protect the sensitive resistor from ESD.
- **Imaging**— Switch position is towards the front of the probe holder. DO NOT push the switch to the imaging position until the probe holder is securely mounted inside the SPM and ready to image.

Figure 4.7b MultiMode Thermal Probe Holder



Installing a Thermal Tip

IMPORTANT! Before installing the sample and thermal tip, first verify that all tip-sample adjustments have been properly made. Many thermal imaging experiments involve outside hardware (e.g., electrical leads to the sample, special mountings, etc.) which can destroy the very expensive thermal tip. For this reason, always start with a standard SiNi tip in the probe holder while making the following checks:

- Can the tip reach the sample surface?
- Is the sample surface electrically insulated (passivated) from the tip?
- Are electrical leads to the sample clear of the probe holder and tip? Are leads secured using cable ties or tape? If an electrical lead is accidentally snagged, will it destroy the tip and/or sample?

To install a thermal tip, employ the following procedure:

1. Prepare an electrically grounded work space near the SPM, for example, a grounding pad, tin foiled bench with electrical grounding, etc. Attach a grounding strap to your wrist. The prepared area should include metal tweezers and thermal tips in their (closed) protective case.

CAUTION: Your grounding strap should feature a limiting resistor to protect you from electrical shock!

2. Withdraw the tip several times from the sample surface to ensure good clearance. Push the grounding switch to the grounding position and remove the thermal probe holder from the SPM.
3. With the probe holder upside down, press and hold the release button to release the old thermal tip from its position beneath the spring clip. Use tweezers to remove the old tip from the probe holder.
4. Remove a new thermal tip from the protective case and place it in the probe holder. Close the protective case with the remaining thermal tips. The **Realtime** and **Offline Planefit** parameters should both be set to **None** on the thermal **Channel** panel.
5. Verify that the tip is seated in the probe holder’s groove, then let go of the release button.
6. If a new sample has been placed in the SPM, verify sufficient separation exists between the probe holder mount and sample to prevent bottoming out the new tip on the sample. Use the **Tip Up** switch and/or **Real Time** > **Motor** > **Step Motor** command to position the probe holder mount properly, then place the probe holder into the SPM.
7. Secure the probe holder by tightening the clamping screw at the rear of the SPM head.
8. Move the grounding switch from the grounding position to the imaging position at the back of the probe holder.
9. Verify that the SPM head is plugged in and the NanoScope software is operating. Also, verify that the Quadrex module is in line between the microscope and controller (NanoScope IIIa only).

4.7.4 Parameter Settings for Thermal Imaging

Thermal imaging utilizes the controller's STM line to convey the thermal tip signal. Typically, two imaging channels are used at the same time. As the sample is scanned, the tip is kept in contact and is used to generate a contact AFM topography image on one imaging channel. Meanwhile, a second imaging channel generates the actual thermal image. Parameter settings for thermal imaging are as follows:

1. Verify that the tip is not engaged with the sample. If engaged, click on the **Withdraw** icon (**Real Time** > **Motor** > **Withdraw**) to disengage the tip.

2. Set the **Microscope mode** parameter on the **Real Time** > **Other Controls** panel to **Thermal**. Verify that the **Interleave Controls** panel is disabled (**Interleave mode** parameter set to **Disabled**).

3. Set the **Thermal Hardware** parameter under **Thermal Controls** in the **Feedback Controls** panel to **App Modules** (or **Thermal Head**, if you have an older thermal application module**)**.

4. Set the **Data type** parameter on the **Channel 1** panel to **Height**; set **Channel 2** to **Thermal**. **Channel 1** will be used to show the sample's topography; **Channel 2** will produce the thermal image.

5. Set the **Z range** parameter on the thermal **Channel** panel to its maximum value (**20.0 V**). Set the **Realtime Planefit** parameter to **None** (this is only temporary). Set the **Scan rate** parameter on the **Scan Controls** panel to **10 Hz**.

6. Verify that the probe holder lever is pointed upward in the "imaging" position. The thermal circuit is ready for adjustment using a two-step process:

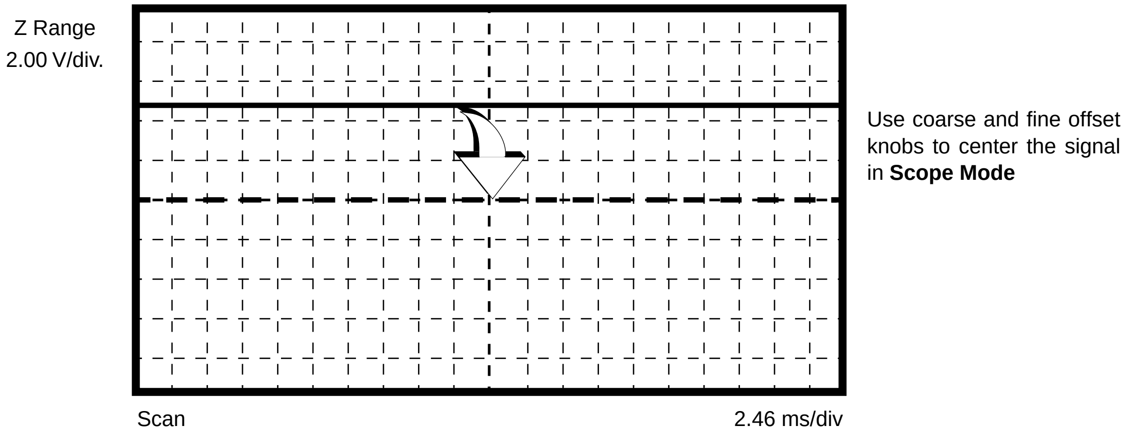
    a. The signal voltage is first adjusted with the laser *off* the cantilever.

    b. The signal voltage is then adjusted with the laser *on* the cantilever. If the laser is aligned with the cantilever, move it off of the cantilever now by turning either of the laser aiming screws.

7. Set voltage coming from the circuit by monitoring the signal using **Scope Mode**. To put the SPM into scope mode, select the **Real Time** > **View** > **Scope Mode** command (or click on the **Scope Mode** icon). A plot of the DC output signal from (thermal) **Channel 2** displays on the display monitor (see Figure 4.7c).

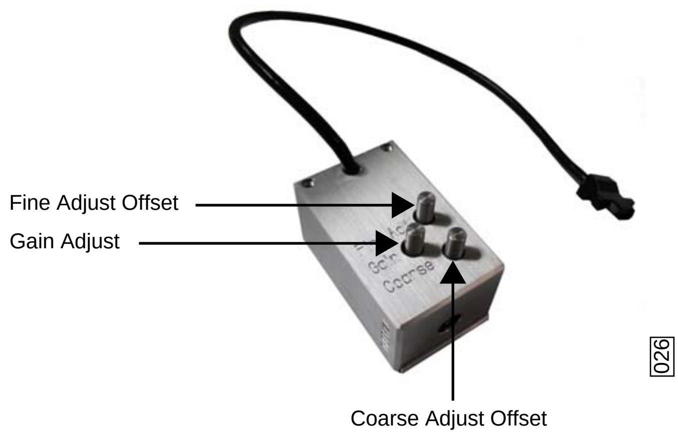
    Note: Where the signal appears on the graph (or whether it appears at all) will depend upon what the output voltage is.

Figure 4.7c Scope Trace of Thermal Sensor Output



8. The SThM sensor contains additional circuitry for the thermal tip. Electronic controls are located on the sensor for adjustment of offset and gain. Center the thermal signal on the graph by turning the **Coarse** and **Fine** offset adjustment knobs on the sensor (see Figure 4.7c and Figure 4.7d).

Figure 4.7d SThM Sensor

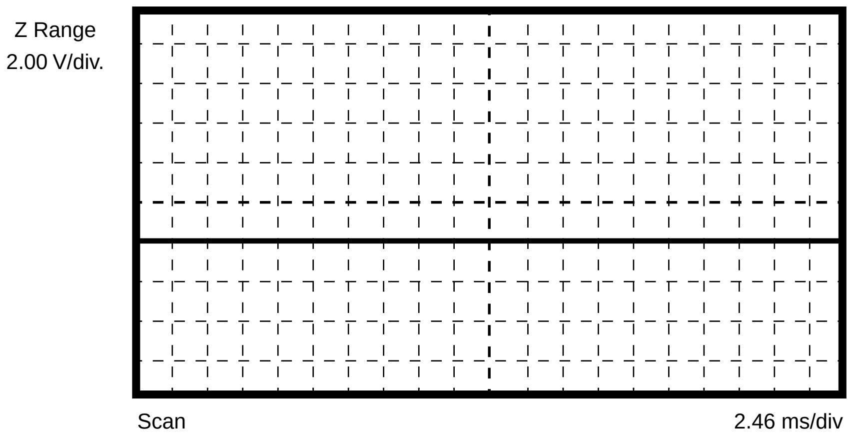


9. With the thermal signal voltage centered, the next adjustment will be performed with the laser aligned *on* the cantilever. Use the laser adjustment screws to align the laser beam on the cantilever in the normal fashion. While the microscope's sum signal is optimized, the thermal signal voltage should stray from center due to heat from the laser beam upon the cantilever.

10. Adjusting one axis of the laser alignment at a time, move the laser beam around until the white line on the scope dips to a minimum; this will require repeatedly switching between axes. If the scope trace dips offscale, reduce the **Gain** knob on the side of the head until the trace reappears on the scope. Continue alternating between axial adjustment of the laser beam until the signal is as negative as possible. Finally, use the gain knob to position the signal trace 2.0 volts below the centerline on the scope.

Note: The purpose of this step is to adjust gain in the thermal head so that each tip will have approximately the same sensitivity. Since the laser produces a constant power level. The cantilever will absorb a constant amount of heat and quickly come into thermal equilibrium with the rest of the system.

Figure 4.7e Scope Trace of Thermal Sensor Output at -2.0V



11. Depending upon the tip, sample, and noise conditions, it may be necessary to finely readjust all the aforementioned knobs to achieve an ideal signal. Once the signal is adjusted and the laser is aligned, you may exit **Scope Mode** to reenter **Image Mode**.

12. Lastly, return the **Scan rate** parameter on the **Scan Controls** panel to **1-2 Hz** (DO NOT engage at 10Hz!). Reduce the **Z range** parameter on the **Channel** panel to accord with the sample. You are ready to begin thermal imaging.

Chapter 5 Maintenance

5.1 Introduction

- **Cleaning: Section** 5.2
- **Specifications: Section** 5.3
- **Troubleshooting: Section** 5.4
    - **SCM: Section** 5.5
    - **TUNA: Section** 5.6
    - **Extended TUNA: Section** 5.7
    - **SSRM: Section** 5.8
    - **C-AFM: Section** 5.9
    - **SThM: Section** 5.10
- **Warranty: Section** 5.11

5.2 Cleaning

The exterior of an SP —away from the probe and sample area—may be cleaned with a dry wipe as needed. Veeco recommends a camera lens cleaning kit to gently clean the fragile probe holder.

Whenever the contacts are contaminated, or at least every three-to-six months, clean the electrical contacts for the Tapping Mode probe holder—both on the probe holder and on the scanner—using a swab dipped in alcohol and a slight scrubbing motion.

WARNING: Always remove the sample puck from the magnetic chuck before cleaning. Do not allow any liquid on the scanner as it could short circuit its piezoelectric elements, permanently damaging them. Only clean the chuck with a dry wipe. The sample puck, once isolated, may be cleaned with a lint-free wipe soaked in alcohol.

5.3 Specifications

Basic performance specifications for the six application modules appear in Table 5.3a.

Table 5.3a Technical Specification

Application Module	Parameter	Range of Values
SCM	Capacitive Frequency Range	900MHz to 1050MHz
"	Maximum Sensitivity	$10^{-22}F*Hz^{-1/2}$
"	Maximum Spatial Resolution	20nm
TUNA	Current Range	80fA to 120pA
"	Maximum Lateral Resolution	10nm
Ext. TUNA	Current Range	80fA to 1µA
	Maximum Lateral Resolution	10nm
SSRM	Current Range	10pA to 0.1µA
"	Maximum Lateral Resolution	15nm
C-AFM	Current Range	1pA to 1µA
"	Maximum Lateral Resolution	10nm
SThM	Maximum Lateral Topographic Resolution	10nm
"	Maximum Lateral Thermal Resolution	40nm to 50nm
"	Maximum Thermal Resolution	0.1K

The above performance assumes the Quadrex and application modules are stored and operated according to the environmental conditions listed in Table 3.2a, page 16.

5.4 Troubleshooting

- **SCM: Section** 5.5
- **TUNA: Section** 5.6
- **Extended TUNA: Section** 5.7
- **SSRM: Section** 5.8
- **C-AFM: Section** 5.9
- **SThM: Section** 5.10

5.5 SCM

5.5.1 Problem: The Microscope Will Not Engage

Do not allow the spring clip on the probe holder to touch the sample before the tip. Lower the profile of the clip if it does.

5.5.2 Problem: No SCM Signal Is Received

Verify the sample and probe are suitable for SCM measurements:

1. If the tip does not have a metal coated tip, replace it with an appropriate tip.
2. Verify you are using an SCM probe holder, and that it is electrically connected to the SCM Application Module and the Module is connected to the SPM controller either directly (e.g., a NanoScope IV Controller) or indirectly (e.g., through a Quadrex module) (see **Application Module Installation,** page 28).
3. Verify the parameter values selected in the **Equipment Select** panel (see **Software Setup,** page 34).
4. Verify appropriate **AC Bias Ampl.** and **DC Bias Ampl.** values (see **Open Loop SCM Imaging,** page 45).
5. Try a Veeco practice sample; if it produces a reasonable SCM image, try recleaning the sample surface, or even relapping a cross section.
6. Make sure you are looking at the desired location on your sample.

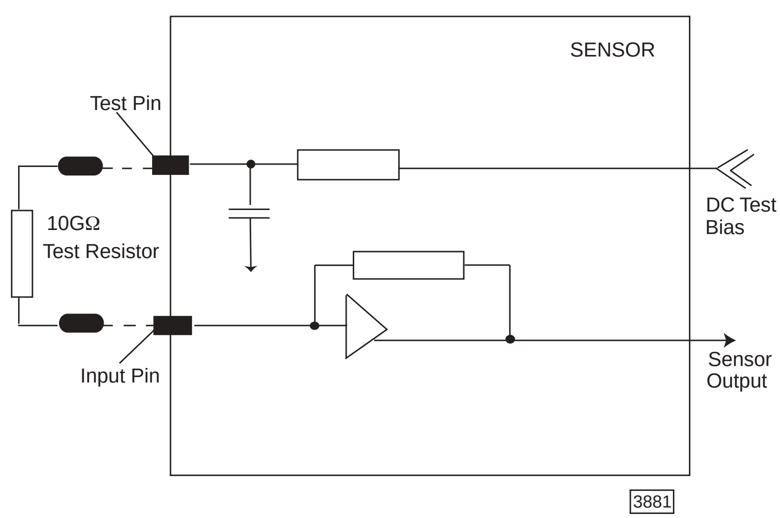
5.6 TUNA

5.6.1 Problem: No TUNA Signal Is Received

If a current signal is not detected, although you expect the sample to be adequate for this type of measurement, check for several possible problems with the system/setup as follows:

1. Apply a DC bias to the chuck and measure it with a voltmeter.
   a. If there is no bias, reset the microscope by clicking on **Microscope** > **Reset**.
   b. If the problem persists, contact Veeco.
2. Verify the sample is in electrical contact with the chuck.
3. If you suspect a problem with the TUNA sensor, complete the following procedure:
   a. Unplug the 15-pin sensor connector from the Quadrex module.
   b. Plug a 10GΩ resistor between the input pin and the test pin of the sensor.

Figure 5.6a Schematic Test Circuit of TUNA Sensor



CAUTION: Be careful not to touch the resistor with your hands. The resistance of the oil from your hands left on the resistor leads can decrease the effective resistor value. Use tweezers.

c. Before reattaching the 15-pin sensor connector to the Quadrex module, make sure that the **TUNA Controls** subpanel parameters are set to the values shown in Table 5.6a.

d. Attach the sensor to the SPM head and connect its cable to the 15-pin connector on the Quadrex module.

e. Click **View** > **Scope Mode** and select values for the **Channel 2** panel parameters according to Table 5.6b.

f. Apply a **DC Test Bias** of **+0.01V** then **-0.01V**. Verify that the current signal increases by +1pA and decreases by -1pA, respectively.

g. Check if current signals scale properly by applying ± 0.01V, ± 0.02V, ± 0.03V and ± 0.04V. The current signal should change by ±1pA, ±2pA, ±3pA, up to ±4pA.

Note: If the scanner does not perform according to the previous description, something is wrong. In such a case, contact Veeco.

Note: The values of large resistors are often approximate and can easily be inaccurate by > 5%. Thus the output signal at a given test bias might reflect a consistent gain error.

Note: Parameters whose option is shown as "May be cleared" in Table 5.6a are used in closed loop, not open loop TUNA. Capacitive current coupling between the cantilever and chuck complicates closed loop operation.

Table 5.6a TUNA Controls Parameters

Parameter	Use with TUNA	Option
Feedback Mode	**Open**	May be cleared
DC Sample Bias	**0V**	Select
Current Setpoint	**0V**	May be cleared
Current Sensitivity	**1pA/V**	Select
Bias Lower Limit	**0V**	May be cleared
Bias Upper Limit	**0V**	May be cleared
DC Test Bias	**0V**	Select

Table 5.6b Channel 2 Parameters

Parameter	Use with TUNA
Data Type	**Current**
Data Scale	**10pA**
Data Center	**0pA**

Parameter	Use with TUNA
Line Direction	N/A
Realtime Planefit	**None**
Offline Planefit	**None**
Lowpass Filter	**Off**

CAUTION: Extreme sensitivity to small currents also results in significant amplification of external disturbances. Examples of sources of disruptions include electronic equipment such as: oscilloscopes, fluorescent light in conjunction with certain samples, etc.—especially when operated nearby.

5.7 Extended TUNA

5.7.1 Extended TUNA Module Test Procedure

Introduction

Extended TUNA offers the range of TUNA and C-AFM in a single sensor. The Extended TUNA sensor has four separate gain stages, and each needs to be tested separately. Two of these gain settings correspond to the old TUNA sensor (1 or 10pA/V), and the second two correspond to the old C-AFM sensor (1 or 100nA/V). This testing is an implementation of Ohms law in that a voltage is applied to a known resistor. The current flow is measured by the sensor, converted to a voltage and finally displayed in the NanoScope software.

It is important when testing the sensor that the correct resistor is used with each gain setting. For the TUNA gain settings (1 or 10pA/V), you should only use the 10 Giga Ohm test resistor. If the 100 Mega Ohm resistor is selected, small variations in the noise of the test bias will saturate the sensor even though you may have zero volts selected in the software. This will make the offset adjustment impossible to do. The same applies to the C-AFM settings of the sensor (1 or 100nA/V). You should only use the 100 Mega Ohm resistor for these modes. If the resistor is incorrectly set in this mode, you will not be able to apply enough test bias (maximum of 10 volts) through the 10 Giga Ohm resistor to see a current reading from the sensor.

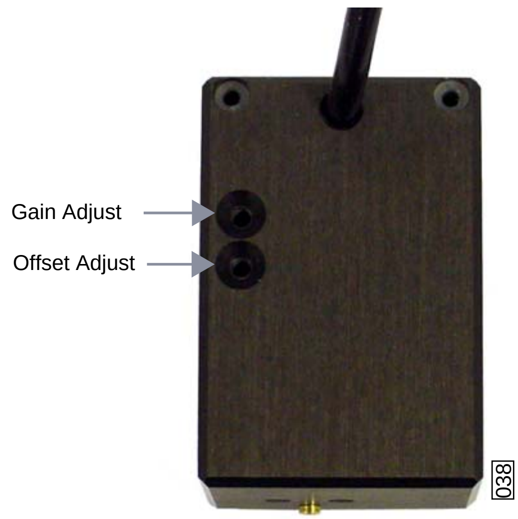
Figure 5.7a Test Resistor supplied with Extended TUNA Sensor

You must trim the sensor gain and offset adjustments before conducting any noise test, or the noise test will be inaccurate. To adjust gain and offset use the two trim pots accessible via holes in the side of the sensor housing (see Figure 5.7b). These holes are normally sealed with two socket-head cap screws that must be removed to access to the trim pots.

WARNING:	Be careful to not damage the anodized coating on the sensor housing and lid, as this provides essential electrical isolation that is required for the sensor to meet the noise specifications.

WARNING:	Be careful when adjusting these trim pots, as excessive force will damage the board.

Figure 5.7b Offset and Gain Adjustment Trim Pots on Extended TUNA



Offset Adjustment

Mount the sensor to the head (Dimension) and insert the test resistor between the TUNA connector and test bias sockets. The test resistor should be oriented so that the resistor selector switch is facing away from the scanner (see Figure 5.7c and Figure 5.7d).

Note: The MultiMode the sensor need not be connected to the AFM head at this point. It can be connected to the SAM-I-AM and placed in a convenient location for future use.

Figure 5.7c Extended TUNA Connectors (Underside of Sensor)

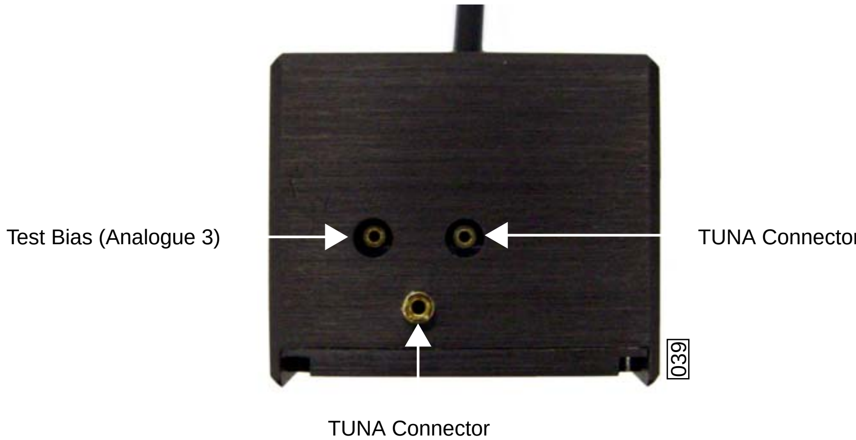
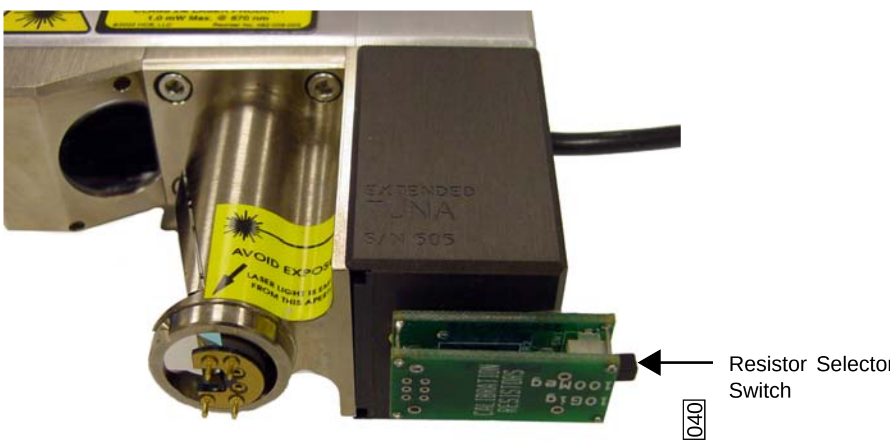


Figure 5.7d Dimension Extended TUNA Test Resistor on Sensor



1. On the Dimension, loosen the scanner locking screw so that the head will not hit the sample stage and place the head into the dovetail of the microscope.

   Note: There is no need for the microscope to be engaged during the offset or gain adjustments on either the Dimension or MultiMode systems.

2. Start the software and set up the system for TUNA. NanoScope Version 5.12r4 or any beta built on or after 4-23-03 is required to support the Extended TUNA hardware.

3. In the **Feedback Controls Panel**, select **Extended** as the **Hardware** type.

4. Set the **DC Test Bias** (test bias) to **0mV** and plug in the head and sensor, ensuring that the TUNA sensor 15-pin cable passes through the signal access module.

5. Use the voltmeter to verify that the test bias is zero, as there may be an offset on the controller. This can be found on the “SIG 2” BNC Connector on the breakout box. If the test bias is not zero, then an offset should be applied to the test bias until it is zero. If the offset of the test bias is greater than ±20mV, you should have the Analog 3 line on the controller adjusted (Contact Veeco for a procedure).

   Note: With a 10mV offset on the test bias and the sensor set to a maximum gain of 1pA/V, the sensor output would be 1 volt when the 10 Gig Ohm test resistor is used.

6. In the **Feedback Controls Panel**, set **Current Sens** to **1nA/V** and select the 100 Mega Ohm resistor on the test resistor assembly. This is the easiest of the gain settings to adjust, and once complete the other gain states should only need minor adjustments.
7. Switch the software to **Scope Mode** and set **Channel 1** data type to **TUNA Current**.
8. Set both the **Realtime** and **Offline Plane Fit** options to **None**.
9. Set the **Scan Rate** to **2Hz** and the **Number of Samples** per line to **512**, ensuring that the display is updated at a reasonable rate.
10. Measure the current on the scope trace and use the offset adjustment trim pot (bottom) to move this data line to the center of the display range (zero). Once the data is centered the initial offset adjustment is complete.

You may need to repeat this procedure after the gains have been set and for different gain levels.

Gain Adjustment

Perform gain adjustment immediately following the offset adjustment. It is assumed that the offset adjustment has been completed and the system is in the state described above. If this is not the case, review the above process and ensure that settings are correct before continuing.

1. Set the **DC Test Bias** to **500mV**. Verify that this is correct with the voltmeter as discussed above. With an applied test bias of 500mV and a resistance of 100 MΩ you should see a current of 5nA. If not, then adjust the gain trim pot (top) until you do.
2. Check the symmetry about zero by applying a negative bias of -500mV and check that the sensor now reads -5nA. If not, then adjust the gain until it does and re-check the 500mV level. You may find that adjusting the gain in this way will move the zero offset of the sensor. You should therefore switch between ±500mV and zero volts until all three values are displayed correctly.
3. In the **Feedback Controls** panel, set the **Current Sens** to **100nA/V** and the **DC Test Bias** to **±10 volts**. This should yield a current of ±0.1µA. Do not adjust the gain or offset at this gain level, simply verify that the sensor is working.
4. Set the **DC Test Bias** to **0mV** and verify this with the voltmeter.
5. Once there are **0V** applied to the sensor, change the test resistor setting to 10 GΩ.

6. In the **Feedback Controls** panel, set the **Current Sens** to **1pA/V**, and check the system for offsets. If there is a significant offset on the sensor at this gain level, then you can again use the offset trim pot (bottom) to remove it.

   Note: The **1nA/V** setting is usually the most critical and so any adjustment performed at this gain level should be small.

7. Apply a **DC Test Bias** of **50mV** and read the current. With the settings described above there should be 5pA of current on the display. If this is not the case, then you should adjust the gain trim pot (top).

   Note: It should require only small adjustments if any at all. Once this is complete, check the sensor with -50mV applied to verify that the gain is symmetrical about zero.

8. In the **Feedback Controls** panel, set the **Current Sens** to **10pA/V** and verify the gain by applying 500mV to the test bias. There should be no further need for adjustment of the gain at this time.

9. Lastly, verify this gain state by selecting -500mV and finally checking the offset with 0V applied.

Noise Test

It is important that the gains have been correctly adjusted as described previously before performing the noise test. The measured noise is a function of the gain of the sensor, therefore incorrect gain settings will result in an inaccurate noise measurement.

1. If not already complete, mount the sensor to the scanner of the system under test (Dimension) or fix the sensor to the AFM head (MultiMode).

2. Mount a cantilever into the cantilever holder provided. This should be a conducting lever such as MESP, SCM-PIC/PIT, etc.

3. Affix the cantilever holder to the Dimension scanner, or place the cantilever holder in the MultiMode head. Connect the fly lead from the cantilever holder to the socket at the center of the TUNA sensor (ensure that you do not connect it to the test bias socket, which is offset to one side).

4. Connect the ground lead from the cantilever holder to the ground socket on the sensor if using a Dimension system. A short wire with gold pins on either end is supplied to enable this connection to be made. The straight connector should be connected to the cantilever holder and the 90-degree plug inserted into the sensor (see Figure 5.7e)

Figure 5.7e Mounted Extended TUNA Sensor

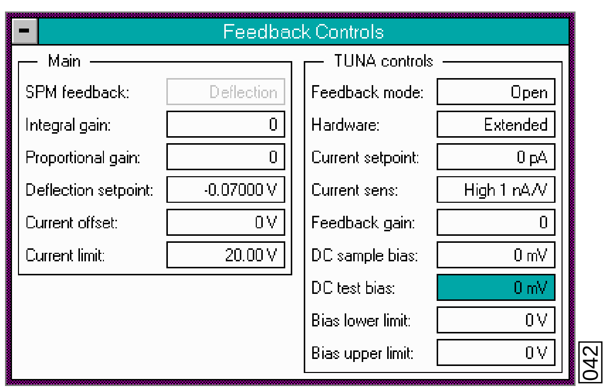
5. Start the software and set it up for TUNA. Version 5.12r4 or any beta built on or after 4-23-03 is required for Extended TUNA support.

6. Adjust the laser on the cantilever for Contact Mode with 0V of horizontal and vertical offset.

7. In the Feedback Panel, set the Hardware Parameter to **Extended**.

8. Set the **Integral** and **Proportional Gains** to **0** and the **Deflection Setpoint** to the value the vertical deflection is currently reading. This will protect the scanner by ensuring that it does not move in the Z-axis after false engaging the microscope (see Figure 5.7f).

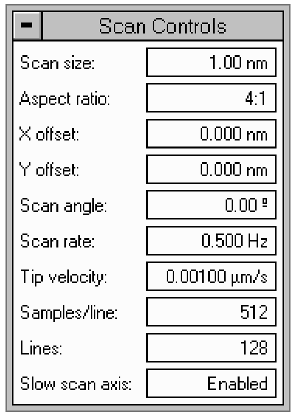
Figure 5.7f Noise Test Feedback Control Parameters



9. Mount the head onto the system, ensuring that there are several millimeters of clearance between the tip and sample.

10. Set the **Scan Size** to **1nm** and the **X** and **Y offsets** to **0.000nm** (see Figure 5.7g).

Figure 5.7g Noise Test Scan Control Parameters



043

11. In the **Feedback Controls Panel**, set the **DC Sample Bia**s and **DC Test Bias** to **0**. Verify these with the voltmeter. The test bias can be accessed on the breakout box as SIG 2. The sample bias can be measured at the sample chuck for the Dimension and at the piezo end cap for the MultiMode.

12. False engage the microscope by pressing **Ctrl-Alt-F**. The MultiMode will engage immediately, while the Dimension will engage following the fast approach stage.

13. Select **TUNA Current** as the data type for **Channel 1** and set the **Plane Fit** options to **None** for both Realtime and Offline.

14. In the **Feedback Controls Panel**, set the **Current Sens** to **1pA/V**.

15. Capture an image with an **Aspect Ratio** of **4:1**, a **Scan Speed** of **0.5Hz** and **512 samples/ line**.

16. Withdraw.

17. Switch to Offline mode and open the captured image.

18. Use the flatten function to apply a 1st order correction to the data. The data can then be analyzed with the roughness function and the RMS noise for the data recorded. The specification for this noise level is 100fA RMS.

19. Review the data for periodicity. If periodic, perform a section analysis to determine the main frequency components. There should be no significant frequencies in the data.

20. Once testing is complete, close the two trim pot access holes in the side of the sensor with the two small screws remaining from the build kit.

When the sensor is not in use, the static protection terminator should be inserted across the two sockets on the underside of the sensor.

5.8 SSRM

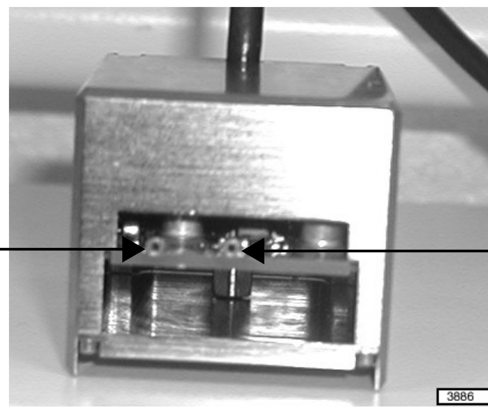
5.8.1 SSRM Module Test Procedure

Using a reference resistor of known value, test the SSRM module using the following procedure:

1. Connect the SSRM Application Module to the Quadrex module using the 15-pin cable.

2. Plug the two lead wires of the reference resistor into the two connectors of the SSRM module (see Figure 5.8a).

Figure 5.8a SSRM Sensor (Displaying Two Connectors)



Note: Be sure that the wires are not too far into the connectors. If this happens, the wires only make contact with the connectors and not with any other part of the module.

3. Click **Real-time** > **Force Mode... Advanced** > **Scan Mode** to display **Resistance** data on **Channel 1** or **2**. Change **DC Sample Bias** and **DC Test Bias** to test the SSRM module.

4. Set both **Feedback Controls** > **SSRM Controls** > **DC Sample Bias** and **DC Test Bias** to the same value (e.g., **1V**). The **Resistance** should now take a value corresponding to the reference resistor and the curve in Figure 4.5c.

Note: For a 100MΩ resistor, the **Resistance** output should be -2V at **DC Test Bias** and **DC Sample Bias** of +1V. The **Resistance** output should be +2V if the **DC Test Bias** and **DC Sample Bias** are set to -1V.

Note: If the test resistor is changed, the resistance output should change accordingly.

5.8.2 Problem: The Microscope Will Not Engage

Do not allow the spring clip on the probe holder to touch the sample before the tip. Lower the profile of the clip if it does.

5.8.3 Problem: No SSRM Signal Is Received

Verify the sample and tip are suitable for SSRM measurements:

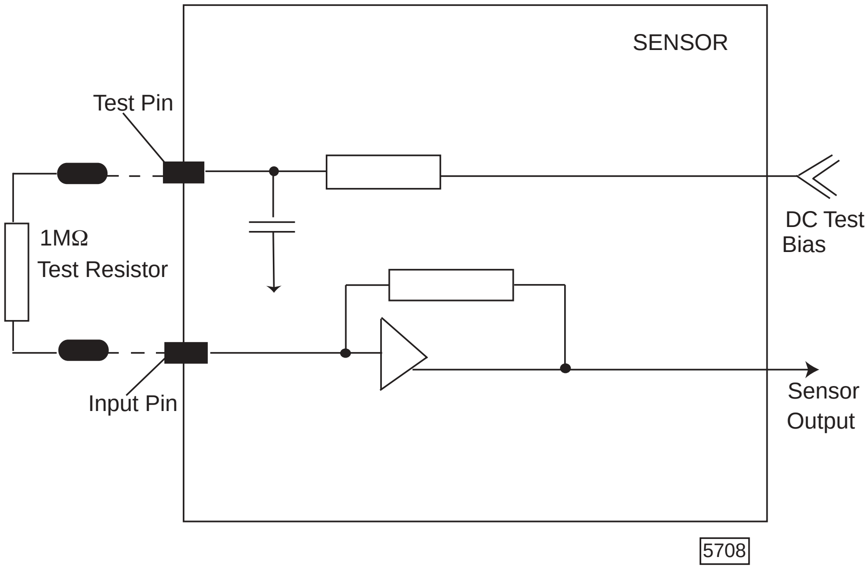
1. Replace the tip with a suitable SSRM tip if it is not one.
2. Verify you are using an SSRM probe holder, and that it is electrically connected to the SSRM Application Module and the Module is connected to the SPM controller either directly (NanoScope IV Controller) or indirectly (through a Quadrex module) (see **Application Module Installation,** page 28).
3. Verify the parameter values selected in the **Equipment Select** panel (see **Software Setup,** page 34).
4. Verify appropriate **DC Sample Bias** and **DC Test Bias** values (see **SSRM Imaging,** page 84).
5. Try a Veeco practice sample; if it produces a reasonable SSRM image, try recleaning the sample surface, or even relapping a cross section.
6. Make sure you are looking at the desired location on your sample.

5.9 C-AFM

If a current signal is not detected, although you expect the sample to be adequate for this type of measurement, check for several possible problems with the system/setup as follows:

1. Apply a DC bias to the chuck and measure it with a voltmeter.
   a. If there is no bias, reset the microscope by clicking on **Microscope** > **Reset**.
   b. If the problem persists, contact Veeco.
2. Verify the sample is in electrical contact with the chuck.
3. If you suspect a problem with the C-AFM sensor, complete the following procedure:
   a. Unplug the 15-pin sensor connector from the Quadrex module.
   b. Plug a 1MΩ resistor between the input pin and the test pin of the sensor.

Figure 5.9a Schematic Test Circuit of C-AFM Sensor



WARNING: Be careful not to touch the resistor with your hands. The resistance of the oil from your hands left on the resistor leads can decrease the effective resistor value. Use tweezers.

c. Before reattaching the 15-pin sensor connector to the Quadrex module, make sure that the C-AFM Controls subpanel parameters are set to the values shown in Table 5.9a.

Note: Parameters with options shown as “May be cleared” in Table 5.9a are used in closed loop, not open loop C-AFM.

Table 5.9a C-AFM Controls Parameters

Parameter	Use with C-AFM	Option
Feedback Mode	Open	May be cleared
DC Sample Bias	0V	Select
Current Setpoint	0V	May be cleared
Current Sensitivity	100nA/V	Select
Bias Lower Limit	0V	May be cleared
Bias Upper Limit	0V	May be cleared
DC Test Bias	0V	Select

d. Attach the sensor to the SPM head and connect its cable to the 15-pin connector on the Quadrex module.

e. Click **View** > **Scope Mode** and select values for the **Channel 2** panel parameters according to Table 5.9b.

Table 5.9b C-AFM: Channel 2 Parameters

Parameter	Use with C-AFM
Data Type	Current
Data Scale	100nA
Data Center	0nA
Line Direction	N/A
Realtime Planefit	None
Offline Planefit	None
Lowpass Filter	Off

f. Apply a **DC Test Bias** of **+0.01V** then **-0.01V**. Verify that the current signal increases by +10nA and decreases by -10nA, respectively.

g. Verify current signals scale properly by applying ±0.01V, ±0.02V, ±0.03V and ±0.04V. The current signal should change by ±10nA, ±20nA, ±30nA, up to ± 40nA.

Note: If the scanner does not perform according to the previous description, something is wrong. In such a case, contact Veeco.

Note: The values of large resistors are often approximate and can easily be inaccurate by > 5%. Thus the output signal at a given test bias might reflect a consistent gain error.

WARNING: Extreme sensitivity to small currents also results in significant amplification of external disturbances. Examples of sources of disruptions include electronic equipment such as: oscilloscopes, fluorescent light in conjunction with certain samples, etcetera—especially when operated nearby.

5.10 SThM

5.10.1 Problem: No signal is visible from the thermal probe in *Scope Mode*; no thermal image present.

- Verify the coarse offset adjustment has been rotated from one extreme to the other to locate the signal trace somewhere on the scope.
- Verify the probe holder is clamped inside the head (MultiMode SPMs) and that the lever is pointed upward.
- Check that electrical contacts on the probe holder are in full contact with electrical contacts on the probe. (Do this using an optical microscope, with the probe holder's lever rotated to the "protected" position, and while wearing a grounding strap).
- Check the resistance of the thermistor on the tip using a fixed range ohmmeter with an output current of less than 50 μA through a 1 kΩ resistor (higher resistance ranges are better; see "**Final Precautions: Section** 5.10.5" below). If the tip is good, you should get a nominal reading of ~ 1 kΩ. If the tip has been blown out due to ESD or physical damage, resistance will register at ∞. Blown tips must be replaced.
- Make absolutely certain the sample is electrically insulated (passivated) from the tip. If ANY electrical current flows between tip and sample, the thermal tip will be instantly destroyed!

5.10.2 Problem: Thermal signal is noisy

In **Scope Mode**, the thermal signal should appear relatively flat and noise-free. If not, check for the following:

- The thermal probe may be in poor electrical contact with the probe holder. Ensure that the probe holder's gold, electrical contacts are in full contact with the probe's electrical traces.
- The thermal probe may be partially blown out or damaged due to ESD or physical damage. If so, replace it.
- Verify that the sample is electrically insulated from the tip.

5.10.3 Problem: Poor Thermal Image

- Check that all scanning parameters are properly set as described in this manual.
- If you are imaging an electrically active sample, verify that the sample is properly configured with its outside power source(s). Too much current will cause a short circuit

in the sample, killing it electrically and leaving it without any thermally active regions. Too little current may not provide the sample with sufficient heat for imaging.

- See “**Problem: Thermal signal is noisy: Section** 5.10.2” notes above to check for noise problems.

5.10.4 Problem: Diagonal Banding in Image

- If diagonal banding is seen in the image, this may be due to a 60 Hz ground loop. Try connecting the ground of your sample’s power supply to the head casing, which is at microscope ground.

5.10.5 Final Precautions

- If the system (SPM head and controller) are operated incorrectly they can destroy the tip! If the controller is powered up while the tip is attached to an installed probe holder, power-up electrical spikes may deliver transient pulses with an amplitude up to 4x normal bias conditions. A similar effect can be observed when plugging the head into the controller with the tip attached. To prevent these kinds of problems, always keep the probe holder lever turned to the “protected” position until the SPM is fully powered and ready for imaging. A line conditioner is advisable in areas where power failures and spikes are possible.

- Measurement of resistance across the probe’s thermistor must be done on a fixed range ohmmeter. (Autoranging multimeters will blow out or damage the tip.) Also, many high-precision multimeters force high levels of current through the probe, again blowing out the tip. Digital Instruments uses a BK Tool Kit multimeter, model 2706, which is approximately $80 US. The measurement of the nominal 1 kΩ resistance is usually performed on the 200 kΩ range (full scale), which only displays 0.1 kΩ increments. This is sufficient for most applications and forces only 200 μA through the probe. The leads of the ohmmeter should be touched to ground prior to probing the sensor to prevent any possibility of static discharge.

- Cheap power supplies should not be used with the sample being tested due to the possibility of power transients which can damage the probe. Power Designs precision 20 volt source is a good power supply and is can be set to four digits of precision (100 mV increments). A Keithly current source is recommended with a small compliance (limiting) voltage. Do NOT use high ripple or noisy power supplies, as these will contribute to signal noise (i.e., thermal noise), or possibly damage the probe’s tip.

5.11 Warranty

This product is covered by the terms of the Veeco standard warranty as in effect on the date of shipment and as reflected on Veeco's Order Acknowledgement and Quote. While a summary of the warranty statement is provided below, please refer to the Order Acknowledgement or Quote for a complete statement of the applicable warranty provisions. In addition, a copy of these warranty terms may be obtained by contacting Veeco.

WARRANTY. Seller warrants to the original Buyer that new equipment will be free of defects in material and workmanship for a period of one year commencing (x) on final acceptance or (y) 90 days from shipping, whichever occurs first. This warranty covers the cost of parts and labor (including, where applicable, field service labor and travel required to restore the equipment to normal operation).

Seller warrants to the original Buyer that replacement parts will be new or of equal functional quality and warranted for the remaining portion of the original warranty or 90 days, whichever is longer.

Seller warrants to the original Buyer that software will perform in substantial compliance with the written materials accompanying the software. Seller does not warrant uninterrupted or error-free operation.

Seller’s obligation under these warranties is limited to repairing or replacing at Seller’s option defective non-expendable parts or software. These services will be performed, at Seller’s option, at either Seller’s facility or Buyer’s business location. For repairs performed at Seller’s facility, Buyer must contact Seller in advance for authorization to return equipment and must follow Seller’s shipping instructions. Freight charges and shipments to Seller are Buyer’s responsibility. Seller will return the equipment to Buyer at Seller’s expense. All parts used in making warranty repairs will be new or of equal functional quality.

The warranty obligation of Seller shall not extend to defects that do not impair service or to provide warranty service beyond normal business hours, Monday through Friday (excluding Seller holidays). No claim will be allowed for any defect unless Seller shall have received notice of the defect within thirty days following its discovery by Buyer. Also, no claim will be allowed for equipment damaged in shipment sold under standard terms of F.O.B. factory. Within thirty days of Buyer’s receipt of equipment, Seller must receive notice of any defect which Buyer could have discovered by prompt inspection. Products shall be considered accepted 30 days following (a) installation, if Seller performs installation, or (b) shipment; unless written notice of rejection is provided to Seller within such 30-day period.

Expendable items, including, but not limited to, lamps, pilot lights, filaments, fuses, mechanical pump belts, V-belts, wafer transport belts, pump fluids, O-rings and seals ARE SPECIFICALLY EXCLUDED FROM THE FOREGOING WARRANTIES AND ARE NOT WARRANTED. All used equipment is sold ‘AS IS, WHERE IS,’ WITHOUT ANY WARRANTY, EXPRESS OR IMPLIED.

Seller assumes no liability under the above warranties for equipment or system failures resulting from (1) abuse, misuse, modification or mishandling; (2) damage due to forces external to the machine including, but not limited to, acts of God, flooding, power surges, power failures, defective electrical work, transportation, foreign equipment/attachments or Buyer-supplied replacement parts or utilities or services such as gas; (3) improper operation or maintenance or (4) failure to perform preventive maintenance in accordance with Seller's recommendations (including keeping an accurate log of preventive maintenance). In addition, this warranty does not apply if any equipment or part has been modified without the written permission of Seller or if any Seller serial number has been removed or defaced.

No one is authorized to extend or alter these warranties on Seller's behalf without the written authorization of Seller.

THE ABOVE WARRANTIES ARE EXPRESSLY IN LIEU OF ANY OTHER EXPRESS OR IMPLIED WARRANTIES (INCLUDING THE WARRANTY OF MERCHANTABILITY), AND OF ANY OTHER OBLIGATION ON THE PART OF SELLER. SELLER DOES NOT WARRANT THAT ANY EQUIPMENT OR SYSTEM CAN BE USED FOR ANY PARTICULAR PURPOSE OR WITH ANY PARTICULAR PROCESS OTHER THAN THAT COVERED BY THE APPLICABLE PUBLISHED SPECIFICATIONS.

NO CONSEQUENTIAL DAMAGES. LIMITATION OF LIABILITY. Seller shall not be liable for consequential damages, for anticipated or lost profits, incidental, indirect, special or punitive damages, loss of time, loss of use, or other losses, even if advised of the possibility of such damages, incurred by Buyer or any third party in connection with the equipment or services provided by Seller. In no event will Seller's liability in connection with the equipment or services provided by Seller exceed the amounts paid to Seller by Buyer hereunder.

Documentation Feedback

Veeco is dedicated to the ongoing improvement of our products and technical documentation. If you have any comments regarding this manual or any other Veeco documentation, please e-mail us at: **SBOTechPubs@veeco.com**.

Service

Field service is available nationwide. Service and installations are performed by factory trained Veeco service personnel. Contact the Veeco Metrology sales/service office for prompt service.

Veeco Metrology
112 Robin Hill Road
Santa Barbara CA 93117
Attn.: Service Center

Phone: (805) 967-2700
Fax: (805) 967-7717

Index