THERMOMICROSCOPES

User's Guide to AutoProbe CP

ThermoMicroscopes
1171 Borregas Avenue
Sunnyvale, California 94089
Tel: (408) 747-1600
Fax: (408) 747-1601

Part II: Learning to Use AutoProbe CP: Advanced Techniques
48-101-1100, Rev. C
For ThermoMicroscopes ProScan Software Version 1.5
August 4, 2000

Copyright Notice

Trademarks

Contents

Part II Learning to Use AutoProbe CP: Advanced Techniques

Chapter 5 I-V Spectroscopy 5-1

Chapter 6 Scanner Calibration..6-1

Preface

Operating Safety

This section includes important information about your AutoProbe CP system. It describes in detail procedures related to the operating safety of AutoProbe CP and therefore must be read thoroughly *before* you operate your AutoProbe CP system.

> ***WARNING!***
>
> The protection provided by the AutoProbe CP system may be impaired if the procedures described in this User's Guide are not followed exactly.

Safety Symbols

Table 0-1 lists symbols that appear throughout this User's Guide and on the AutoProbe CP system. You should become familiar with the symbols and their function. The symbols are used to alert you to matters related to the operating safety of the AutoProbe CP system.

Table 0-1. Safety symbols and their functions.

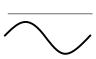
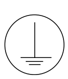
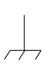
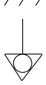
Symbol	Function
	Direct current source.
	Alternating current source.
	Direct and alternating current source.
	Three-phase alternating current.
	Ground (earth) terminal.
	Protective conductor terminal.
	Frame or chassis terminal.
	Equipotentiality.
|	Power on.

Table 0-1 (continued). Safety symbols and their function.

Symbol	Function
	Power off.
	Equipment protected by double or reinforced insulation.
	Refer to system documentation.
	Electric shock risk.

Definitions: Warning, Caution, and Note

There are three terms that are used in this User's Guide to alert you to matters related to the operating safety of AutoProbe CP—warning, caution, and note. These terms are defined in Table 0-2, below.

Table 0-2. Safety terms and their definitions.

Term	Definition
Warning	Alerts you to possible serious injury unless procedures described in this User's Guide are followed exactly. Do not proceed beyond a warning until conditions are fully understood and met.
Caution	Calls your attention to possible damage to the system or to the impairment of safety unless procedures described in this User's Guide are followed exactly.
Note	Calls your attention to a rule that is to be followed or to an out of the ordinary condition.

It is important that you read all warnings, cautions, and notes in this manual carefully. Warnings, cautions, and notes include information that, when followed, ensures the operating safety of your AutoProbe CP system.

Summary of Warnings and Cautions

This section includes warnings and cautions that must be followed whenever you operate AutoProbe CP.

WARNING!

AutoProbe CP must be properly grounded before you turn on the power to its components. The mains power cord must only be inserted into an outlet with a protective earth ground contact. See the section "Grounding AutoProbe CP" later in this preface for more information.

WARNING!

The line voltage selection must be checked before you turn on the power to AutoProbe CP's system components. The line voltage selector switch is on the rear panel of the AEM. The line voltage selector switch can be set to the following voltages: 100 V, 120 V, 220 V, and 240 V. See the section "Setting the Line Voltage" later in this preface for more information.

WARNING!

Do not open the AutoProbe electronics module (AEM) or the CP base unit. The AEM and the CP base unit use hazardous voltages and therefore present serious electric shock hazards.

WARNING!

ThermoMicroscopes requires that you routinely inspect the cables of the AutoProbe CP system to make sure that they are not frayed, loose, or damaged. Cables that are frayed, loose, or damaged must be immediately reported to your local ThermoMicroscopes service representative. Do not operate AutoProbe CP when wires are frayed, loose, or damaged.

CAUTION

All AutoProbe CP system components must be handled with care. System components contain delicate electromechanical instrumentation that can easily be damaged by improper handling.

CAUTION

The power to the AEM must be turned OFF before you remove or install the scanner.

CAUTION

The LASER ON/OFF switch of the probe head must be in the OFF position before you remove or install the probe head on the XY translation stage. Otherwise, damage to the light-emitting diodes (LEDs) of the probe head may result.

CAUTION

When removing and installing the scanner, you must be grounded via a grounding strap to ensure that the scanner is not damaged. The scanner is sensitive to electrostatic discharge.

CAUTION

The four screws that connect the scanner to the CP base unit must be securely fastened to ensure proper grounding. When the four screws are securely fastened, maximum instrument performance is ensured since vibrations are reduced.

CAUTION

To preserve safety and EMC compliance, AutoProbe CP must be used with the EMI filter supplied with the AutoProbe CP system.

CAUTION

To preserve EMC immunity, place the metal cover on the CP base unit while imaging.

Grounding AutoProbe CP

AutoProbe CP must be properly grounded *before* you turn on the power to its components. The mains power cord must be inserted into an outlet with a protective earth ground contact. If you do not have access to an outlet with a protective earth ground contact, you must ground the AutoProbe CP system using the ground connection of the AEM. The location of the ground connection is shown in Figure 0-1, below.

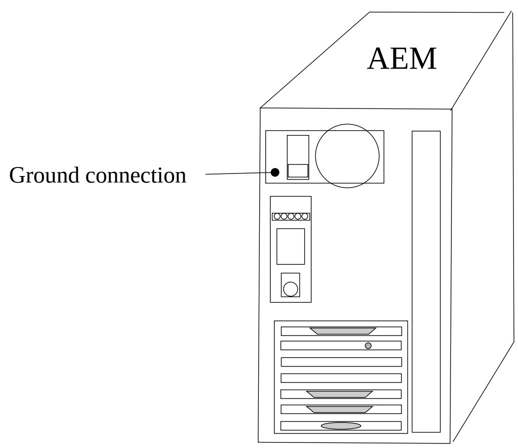


Figure 0-1. Rear panel of the AEM, showing the location of the ground connection.

Setting the Line Voltage

The line voltage selection must correspond to the line voltage of the country where the AutoProbe CP system is operated. The line voltage selection is made using a line voltage selector. The line voltage selector unit is located on the rear panel of the AEM. The line voltage can be set to the following voltages: 100 V, 120 V, 220 V, or 240 V.

To change the line voltage selection, follow these steps:

1. Make sure the power to the AEM is turned off.

2. Unplug the AEM's power cord from the power outlet.

3. Remove the cover of the line voltage selector unit using an appropriately sized screwdriver.

4. Insert an appropriately sized tool into the line voltage selector slot and use the tool to remove the line voltage selector wheel from the unit.

5. Set the line voltage on the line voltage selector wheel to the desired value—100 V, 110 V, 220 V, or 240 V.

6. Put the line voltage selector wheel back into its location in the unit. Make sure that the desired voltage is shown in the window.

7. Install the cover onto the line voltage selector unit.

The line voltage should now be set to the appropriate value.

Laser Safety

Note: Throughout this section, the drawings refer to the AFM probe head for the standard system configuration of AutoProbe CP unless otherwise noted.

AutoProbe CP contains a diode laser powered by a low voltage supply with a maximum output of 0.2 mW CW in the wavelength range 600 to 700 nm. Diode laser power up to 0.2 mW at 600 to 700 nm could be accessible in the interior. AutoProbe CP should always be operated with the probe head properly installed.

WARNING!

Use of controls or adjustments or performance of procedures other than those specified herein could result in hazardous laser light exposure.

Figure 0-2 shows the two laser warning labels of the probe head. Strict observance of these laser warning labels is required.

Figure 0-2. Laser warning labels of the probe head.

The left warning label in Figure 0-2, above, specifies that the probe head is a Class II laser product per 21 CFR 1040.10 and 1040.11. The right warning label in Figure 0-2, above, specifies that the scanning head is a Class 2 laser product per EN60825.

Figures 0-3 through 0-7 below show the location of all instrument controls and indicators pertaining to laser operation for AutoProbe CP systems. They also show the locations of all laser safety warning labels, the aperture label, and the compliance label.

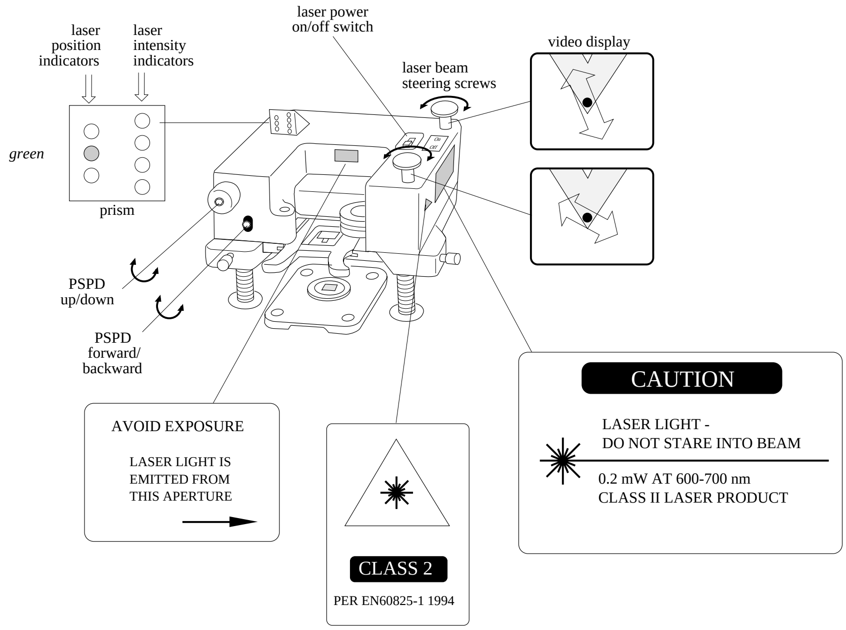


Figure 0-3. Location of laser controls, indicators, and labels on the probe head.

The controls and indicators shown above in Figure 0-3 have the following functions:

Laser power on/off switch: Turns the laser in the probe head on or off. A red light in the switch is lit when the laser power is on.

Laser beam steering screws: The two laser beam steering screws located on the top right side of the probe head are used to adjust the position of the laser beam hitting the cantilever. The screws move the laser spot in two directions, as shown in Figure 0-3, above. If your system includes the optional CP optics, you can monitor these adjustments using the optical view displayed on your video monitor.

PSPD adjustment screws: There are two PSPD (position-sensitive photodetector) screws on the probe head—up/down and forward/backward. These screws adjust the position of the PSPD in the probe head to center the reflected laser light on the photodetector. The forward/backward adjustment screw is useful for PSPD alignment on all probe heads. The up/down adjustment is useful primarily for the AFM/LFM probe head of the standard system configuration.

Laser intensity indicators: Indicates the intensity of reflected laser light hitting the PSPD.

For the standard configuration, there are three probe heads that require laser intensity indicators—AFM, AFM/NC-AFM, and AFM/LFM. There are different indicators for the different probe heads.

Note: The AFM probe head comes with the standard system configuration. The AFM/NC-AFM and AFM/LFM probe heads can be purchased separately for the standard system configuration.

The indicators for the AFM probe head are shown in Figure 0-3, above. For this probe head, the intensity of laser light hitting the PSPD is maximized when the column of four red lights is lit. The indicators for the AFM/NC-AFM and AFM/LFM probe heads are shown in Figure 0-4, below. For these probe heads, when the brightness of the center green light (which has variable brightness) is maximized, the laser intensity hitting the PSPD is maximized.

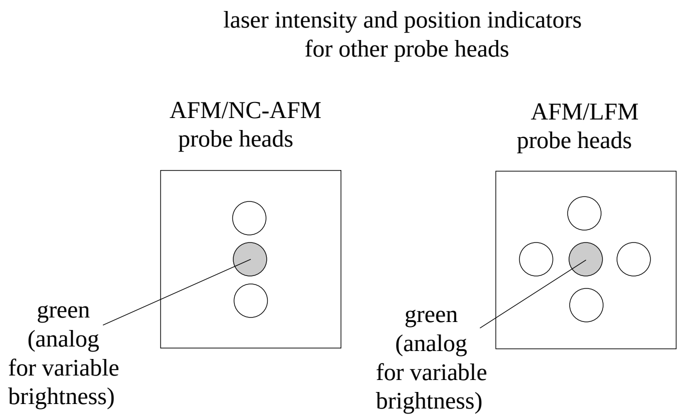


Figure 0-4. Laser intensity and position indicators for the AFM/NC-AFM and AFM/LFM probe heads of the standard system configuration.

For the multitask configuration, when the brightness of the center green light (which has variable brightness) is maximized, the laser intensity hitting the PSPD is maximized. See Figure 0-5, below.

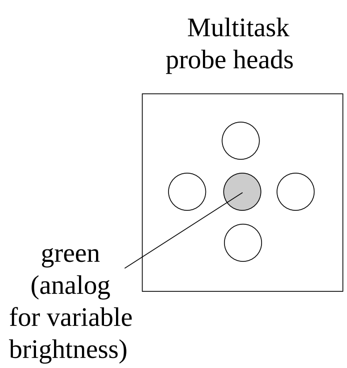


Figure 0-5. Laser intensity and position indicators for the multitask probe head.

Laser position indicators: Indicate the position of the reflected laser light hitting the PSPD. When the laser spot is centered on the photodetector, the center green light is lit, as shown in Figures 0-4 and 0-5, above.

Figure 0-6, below, shows the location of the laser warning labels on the outer housing of AutoProbe CP.

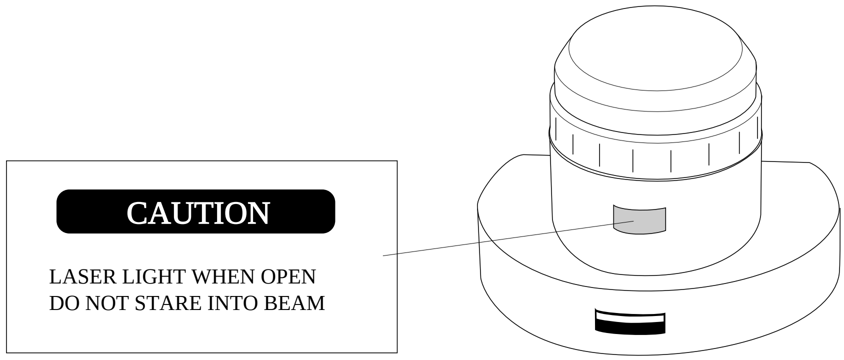


Figure 0-6. Laser warning location on AutoProbe CP housing.

Figure 0-7, below, shows the location of the laser safety compliance label on the rear panel of the AutoProbe electronics module (AEM).

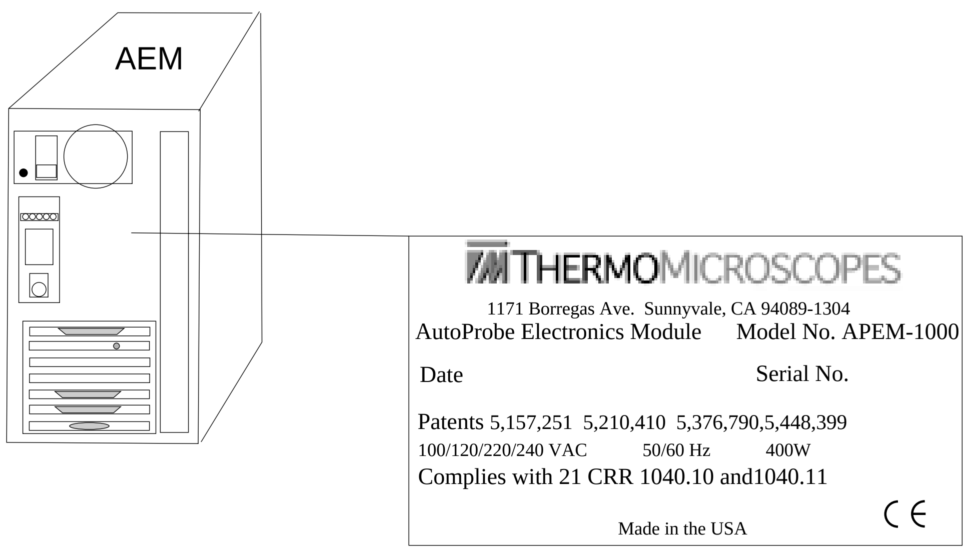


Figure 0-7. Rear panel of the AEM,
showing location of laser safety compliance label.

Specifications and Performance for AutoProbe CP

System Configurations:

Standard	Includes an AFM probe head for operation in AFM mode. Optional AFM/NC-AFM probe head can be purchased for operation in AFM, non-contact AFM, intermittent-contact AFM, and MFM modes. Optional AFM/LFM probe head can be purchased for operation in AFM and LFM modes. Optional STM toolkit can be purchased for operation in STM mode.
Multitask	Includes a multitask probe head for operation in the following modes: contact, non-contact, and intermittent-contact AFM, MFM, LFM, and STM.

Measurement Performance:

Standard:	
Scanner	5 µm piezoelectric scanner.
Scan range	Maximum lateral scan range: 5 µm. Maximum vertical scan range: 2.5 µm.
Control resolution	Maximum lateral resolution: 0.0013 Å. Maximum vertical resolution: 0.009 Å.
Multitask:	
Scanner	100 µm piezoelectric scanner.
Scan range	Maximum lateral scan range: 100 µm. Maximum vertical scan range: 7.5 µm.
Control resolution	Maximum lateral resolution: 0.25 Å. Maximum vertical resolution: 0.025 Å.

Microscope Stage:

Translation range	8 mm x 8 mm.
Sample size	50 mm (w) x 50 mm (l) x 25 mm (h) for the standard configuration. 50 mm (w) x 50 mm (l) x 20 mm (h) for the multitask configuration.
Tip-to-sample approach	Automatic with 3 independent stepper motors.
Optical microscope	Optional on-axis microscope with color video monitor for probe tip and sample view. 5:1 zoom, up to 3,500X magnification.
Acoustic isolation	Optional acoustic isolation chamber.

Workstation:

AEM	20-bit DACs for x, y, and z axes. 16-bit DACs for system control.
Computer	100 MHz Pentium processor, 256 Kbyte cache memory, 16 MB RAM.
Mass storage	1 GB hard drive, 3 1/2 in. 1.4 MB floppy disk drive.
Software	ProScan Data Acquisition and Image Processing operates under Windows 95.
Graphics	Windows graphics accelerator, 17 in. high-resolution color monitor.
System power	115/230 V AC, 50/60 Hz, 600 W.

Dimensions and Weights:

CP base unit	10.5 in. (267 mm) x 8 in. (203 mm); 22 lb (10 kg).
AEM	17 in. (432 mm) x 7 1/2 in. (191 mm) x 17 1/2 in. (445 mm); 43 lb (20 kg).
Computer	17 in. (432 mm) x 7 1/2 in. (191 mm) x 17 1/2 in. (445 mm); 27 lb (12 kg).

Operating Environment:

Temperature	0°C to 30°C, 32°F to 112°F.
Humidity	90%; noncondensing.

Cleaning Agents:

CP base unit	Isopropyl alcohol.
Probe head	Isopropyl alcohol.
AEM and computer	Isopropyl alcohol.

WARNING!

To avoid risk of electric shock, do not clean AutoProbe CP system components when power to the components is turned on.

CAUTION

Do not use acetone to clean AutoProbe CP system components. Acetone may damage important safety warning labels.

ThermoMicroscopes Warranty Statement

Warranty on New Systems and Accessories

ThermoMicroscopes warrants to the original purchaser of the equipment that the equipment will be free from defects in material and workmanship for a period of one year from date of delivery. ThermoMicroscopes agrees as its sole responsibility under this limited warranty that it will replace or repair, at its option, the warranted equipment at no charge to the purchaser and will perform services either at ThermoMicroscopes's facility or at the customers facility, at ThermoMicroscopes's option. For repairs performed at ThermoMicroscopes's facility, the customer must contact ThermoMicroscopes in advance for authorization to return the equipment and must follow ThermoMicroscopes's shipping instructions. If returned, the equipment must be insured.

ThermoMicroscopes will supply replacement parts on loan, whenever possible, to enable field repair by customers with minimum downtime; once the system is operational the defective parts are then returned to ThermoMicroscopes.

Specifically excluded from this warranty are all consumable parts including, but not limited to, Microlevers, Ultralevers, and tips. The warranty of equipment sold for use outside the United States depends on the condition of each sale. Equipment which has been subjected to misuse, accident, abuse, disaster, unreasonable use, damage caused by third party systems with which the equipment is used, operational error, neglect, unauthorized repair, alteration or installation is not covered by this warranty.

Warranty on Replacement Parts

ThermoMicroscopes warrants all replacement parts to be sold free from defects in materials or workmanship for a period of 90 days from the date received by the customer. ThermoMicroscopes will repair or replace, at its discretion, such parts when returned to ThermoMicroscopes. Customers must contact ThermoMicroscopes in advance to obtain authorization to return parts and follow ThermoMicroscopes's shipping instructions.

Except as herein provided, seller makes no warranties, express or implied, and seller expressly excludes and disclaims any warranty of merchantability or fitness for a particular purpose. Under no circumstances shall ThermoMicroscopes be liable for any loss or damage, direct, special, indirect or consequential, arising from the use or loss of use of any product, service, part, supplies or equipment. Nor shall ThermoMicroscopes be liable under any legal theory, including, but not limited to, lost profits, down-time, goodwill, damage to or replacement of equipment or property, and any cost of recovering, reprogramming, or reproducing any program or data stored in or used with ThermoMicroscopes products.

Some states do not allow limitations on the period of time an implied warranty lasts and/or the exclusion or limitation of special, incidental or consequential damages, so the above limitations and/or exclusions may not apply to you. This warranty gives you specific legal rights, and you may also have other rights which vary from state to state.

Manufacturer Information

AutoProbe CP systems contain no user serviceable parts. All service issues should be addressed to your local ThermoMicroscopes representative.

ThermoMicroscopes, USA
1171 Borregas Avenue
Sunnyvale, CA 94089
T: (408) 747-1600
F: (408) 747-1601

ThermoMicroscopes, USA
6 Denny Road, No. 109
Wilmington, DE 19809
T: (302) 762-2245
F: (302) 762-2847

ThermoMicroscopes, SA
16 rue Alexandre Gavard
1227 CAROUGE
Geneva, Switzerland
T: 41-22-300-4411
F: 41-22-300-4415

ThermoMicroscopes, Korea
Suite 301, Seowon Building
395-13, Seokyo-dong, Mapo-ku
Seoul, Korea
T: 82-2-325-3212
F: 82-2-325-3214

If you return system components to ThermoMicroscopes for service that have come into contact with harmful substances you must observe certain regulations. Harmful substances are defined by European Community Countries as "materials and preparations in accordance with the EEC Specification dated 18 September 1979, Article 2." For system components that have come into contact with harmful substances, you must do the following:

- Decontaminate the components in accordance with the radiation protection regulations.
- Construct a notice that reads "free from harmful substances.” The notice must be included with the components and the delivery note.

How to Use This User's Guide

The User's Guide to AutoProbe CP is divided into three, easy-to-use parts. The parts include the following:

- Part I: *Learning to Use AutoProbe CP: Basic Imaging Techniques*
- Part II: *Learning to Use AutoProbe CP: Advanced Techniques*
- Part III: *Software Reference*

The contents of the above-listed parts are described in detail in the sections below.

Part I: Learning to Use AutoProbe CP: Basic Imaging Techniques

Part I of this *User's Guide, Learning to Use AutoProbe CP: Basic Imaging Techniques*, contains an introductory chapter and three hands-on tutorials, Chapters 2 through 4. By working through the tutorial chapters, you will learn the basic skills needed to set up the instrument and to take an AFM image.

Start by reading Chapter 1, "AutoProbe CP Basics," for an introduction to the system configurations and the components of AutoProbe CP. Then, work through the tutorial in Chapter 2, "Setting Up to Take an Image" to learn how to set up the system hardware and software for AFM mode. More specifically, you will learn the procedures for connecting cables, removing and installing a probe head and a scanner, and loading a sample and a probe.

Chapter 3, "Taking an AFM Image," guides you through setting up the system software, approaching the sample, and taking an AFM image. Chapter 4, "Taking Better Images," teaches you how to optimize scan and feedback parameters to take higher quality images and how to save and retrieve images.

Part II: Learning to Use AutoProbe CP: Advanced Techniques

Part II of this User's Guide, *Learning to Use AutoProbe CP: Advanced Techniques*, includes hands-on tutorials for operation in the following modes: NC-AFM, IC-AFM, MFM, STM, and LFM. It also includes tutorials that introduce you to advanced capabilities of AutoProbe CP, such as force vs. distance and current vs. voltage data acquisition, and scanner calibration.

Chapter 1, "NC-AFM, IC-AFM, and MFM Imaging," provides step-by-step instructions for taking NC-AFM, IC-AFM, and MFM images. Chapter 1 also describes the principles behind NC-AFM, IC-AFM, and MFM modes of operation.

Chapter 2, "STM Imaging," guides you through taking an STM image. In this chapter, you learn procedures for preparing an STM tip and using a STM cartridge, setting up the hardware and software for operation in STM mode, and taking an STM image.

Chapter 3, "LFM Imaging," leads you through taking simultaneous LFM and AFM images. Chapter 3 also includes information on how LFM images are produced and the usefulness of having both LFM and AFM images available.

Chapter 4, "Force vs. Distance Curves," describes how to use the F vs. D Spectroscopy window of ProScan Data Acquisition to generate force vs. distance curves at x, y locations on the sample surface. A force vs. distance curve is a plot of the vertical force that the tip applies to the cantilever as a function of the tip-to-sample distance. Variations in the shape of force vs. distance curves provide information about the local elastic properties of the sample surface.

Chapter 5, "I-V Spectroscopy," teaches you how to use the I-V Spectroscopy window of ProScan Data Acquisition to generate current vs. voltage (I-V) and dI/dV curves. These curves are used to provide important information about surface electronic properties.

Chapter 6, "Scanner Calibration," describes how the scanner of your AutoProbe CP instrument works and how to calibrate it to maintain its optimal performance.

Part III: Software Reference

Part III of this User's Guide, *Software Reference*, is the reference manual for ProScan Data Acquisition and Image Processing and includes information for the following AutoProbe systems: CP, LS, and M5. The chapters in this part of the User's Guide provide more detailed information about the software features and controls than the information that is provided in the tutorial chapters. The chapters are designed so that you can skip straight to the feature or control that you are interested in learning more about.

Chapter 1, "ProScan Data Acquisition," describes in detail the software features of ProScan Data Acquisition. This chapter discusses each region of the screen, giving special attention to each control and its function. This chapter also discusses the menus, with a description of each menu item and its function.

Chapter 2, "ProScan Image Processing," describes in detail the software features of ProScan Image Processing. This chapter explains how to process images, how to make surface measurements, and how to prepare images for printout in a variety of formats.

Vorwort

Betriebssicherheit

Dieses Kapitel enthält wichtige Informationen über ihr AutoProbe CP System. Es beschreibt im Detail den Arbeitsablauf in Bezug auf die Betriebssicherheit des AutoProbe CP und muss daher vollständig durchgelesen werden *bevor* sie ihr AutoProbe CP System bedienen.

WARNUNG!
Der durch das AutoProbe CP System versehene Schutz ist beeinträchtigt, falls die in diesem Benutzerhandbuch beschriebenen Arbeitsabläufe nicht genaustens befolgt werden.

Sicherheits Zeichen

In Tabelle 0-1 sind die im Benutzerhandbuch und auf dem AutoProbe CP System vorkommenden Zeichen aufgelistet. Sie sollten mit der Wirkung der Zeichen vertraut werden, in welcher Weise sie mit der Betriebssicherheit des AutoProbe CP in Zusammnehang stehen.

Tabelle 0-1. Sicherheits Zeichen und ihre Wirkung.

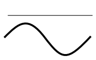
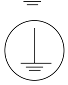
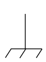
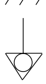
Zeichen	Wirkung
	Gleichstromquelle.
	Wechselstromquelle.
	Wechselstrom- und Gleichstromquelle.
	Dreiphasenstromquelle.
	Erdungsanschluss.
	Schutzerdungsanschluss.
	Gehäuse- oder Rahmenanschluss.
	Äquipotentialanzeige.
I	Schaltet Stromversorgung ein.

Tabelle 0-1(Fortsetzung). Sicherheits Zeichenund ihre Wirkung.

Zeichen	Wirkung
	Schaltet Stromversorgung aus.
	Bezeichnet doppelte oder verstärkte Isolierung des Gerätes.
	Weisst den Benutzer auf eine in der Dokumentation enthaltene Information hin.
	Zeigt eine Berührungsgefahr an.

Definitionen: Warnung, Vorsicht und Beachte

Im Benutzerhandbuch werden drei verschiedene Bezeichnungen, Warnung, Vorsicht und Beachte, benutzt, um auf die Betriebssicherheit des AutoProbe CP hinzuweisen. Diese Bezeichnungen sind in Tabelle 0-2 definiert.

Tabelle 0-2. Sicherheits Bezeichnungen und ihre Definition.

Bezeichnung	Definition
Warnung	Warnt vor möglicher ernsthafter Verletzungsgefahr, falls dem im Benutzerhandbuch beschriebenen Arbeitsablauf nicht unbedingt Folge geleistet wird. Der Arbeitsablauf darf nicht fortgeführt werden, bis nicht alle Voraussetzungen verstanden und erfüllt sind.
Vorsicht	Macht auf mögliche Schädigung des Systems oder Verschlechterung der Sicherheit aufmerksam, falls dem im Benutzerhandbuch beschriebenen Arbeitsablauf nicht unbedingt Folge geleistet wird.
Beachte	Macht auf eine zu beachtende Benutzungsregel oder ungewöhnliche Voraussetzung aufmerksam.

Es ist wichtig, dass alle Warnungen, Vorsichts, und Beachte in diesem Handbuch achtsam gelesen werden, um die Bedienungssicherheit ihres AutoProbe CP Systems zu gewährleisten.

Zusammenfassung der Warnungen und Vorsichts

Dieser Abschnitt beinhaltet die Warnungen und Vorsichts, die unbedingt befolgt werden müssen, wann immer das AutoProbe CP betrieben wird.

WARNUNG!

Das AutoProbe CP muss ordnungsgemäss geerdet werden, bevor Spannung an seine Komponenten angelegt werden darf. Das Versorgungskabel darf nur mit einen Anschluss verbunden werden, der mit einem Erdungspol versehen ist. Für weitere Informationen soll der Teil “Erdung des AutoProbe CP” folgend in diesem Vorwort beachtet werden.

WARNUNG!

Vor dem Einschalten der AutoProbe CP Systemkomponenten muss der Versorgungsspannungsschalter überprüft werden. Der Versorgungsspannungs-schalter befindet sich an der Rückwand des AEM und kann folgendermassen eingestellt werden: 110 V, 120 V, 220 V und 240 V. Für weitere Informationen soll der Teil “Einstellen der Versorgungsspannung” folgend in diesem Vorwort beachtet werden.

WARNUNG!

Das AutoProbe Elektronik Modul (AEM) oder die CP Grundeinheit dürfen nicht geöffnet werden. Das AEM und die CP Grundeinheit führen Hochspannung, welche bei Freilegung zu ernsthaften Verletzungen führen kann..

WARNUNG!

ThermoMicroscopes verlangt eine routinemässige Überprüfung der Kabel des AutoProbe CP Systems um sicherzustellen, dass sie nicht durchgescheuert, lose oder beschädigt sind.. Kabel welche durchgescheuert, lose oder beschädigt sind, müssen augenblicklich dem örtlichen ThermoMicroscopes Servicevertreter gemeldet werden. Das AutoProbe CP soll nicht benutzt werden, falls Kabel durchgescheuert, lose oder beschädigt sind.

VORSICHT!

Alle AutoProbe CP Systemkomponenten müssen mit Vorsicht behandelt werden. In den Systemkomponenten befinden sich empfindliche elektromechanische Messgerätausrüstungen welche bei unsachgemässer Behandlung beschädigt werden können.

VORSICHT!

Um eine Berührungsgefahr zu vermeiden muss beim Entfernen und Installieren des Scanners die Spannung des AEM immer ausgeschaltet sein.

VORSICHT!

Der LASER ON/OFF Schalter des Tastkopfes muss immer ausgeschaltet (OFF Stellung) sein, bevor der Tastkopf entfernt oder an der XY -Bühne installiert wird. Bei Nichtbefolgen des letzteren können die Laserdioden (LEDs) des Tastkopfes beschädigt werden.

VORSICHT!

Um ein beschädigen des Scanners zu vermeiden. müssen sie beim Entfernen und Installieren des Tastkopfesopfes über ein Erdungskabel geerdet sein. Der Tastkopf ist sehr empfindlich gegen elektromagnetische Entladungen.

VORSICHT!

Um eine ordungsgemässe Erdung des CP Scanners zu gewährleisten, müssen die vier Schrauben die den Scanner mit der CP Grundeinheit verbinden, sicher angezogen werden. Wenn die vier Schrauben sicher angezogen sind, ist eine maximale Instrumentenauflösung gewährleistet, da die Vibrationen reduziert sind.

VORSICHT!

Um die EMV Beständigkeit zu gewährleisten, sollte während dem Aufnahmen die CP Grundeinheit mit dem metallenen Deckel geschlossen werden.

Erdung des AutoProbe CP

Das AutoProbe CP muss ordungsgemäss geerdet werden, *bevor* seine Komponenten eigeschaltet werden. Das Versorgungskabel darf nur mit einen Anschluss verbunden werden, der mit einem Erdungspol versehen ist. Falls sie keinen Anschluss mit einem Erdungspol haben müssen sie das AutoProbe CP System über den Erdungspol am AEM mit Erde verbinden. Die Position des Erdungspoles is im folgenden Bild 0-1 eingezeichnet.

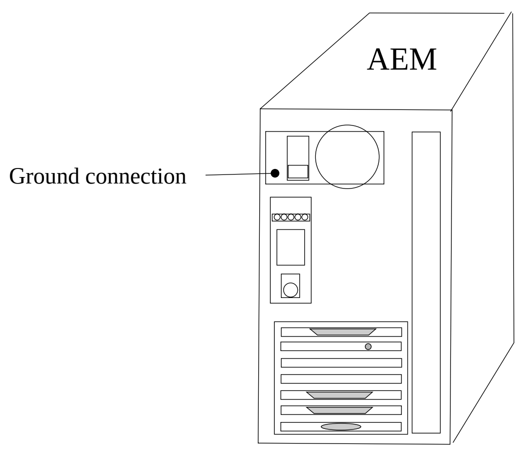


Bild 0-1. Rückwand des AEM, zeigt die Position des Erdungspoles.

Einstellen der Versorgungsspannung

Die Einstellung der Versorgungsspannung muss mit der Versorungsspannung des Landes übereinstimmen, in dem das AutoProbe M5 betrieben wird. Die Einstellung erfolgt über einen Spannungs-Wahl-Schalter, der sich an der Rückseite des AEM befindet. Die Spannung kann folgendermassen eingestellt werden: 100V, 120V, 220V oder 240V.

Um die Einstellung der Versorgungsspannung zu ändern, müssen folgende Schritte befolgt werden:

1. Versichern sie sich, dass die Spannung des AEM ausgeschaltet ist.
2. Stecken sie das Versorgungskabel des AEM aus.
3. Entfernen sie die Abdeckung der Spannung-Wahl-Schalter-Einheit mit Hilfe eines passenden Schraubenziehers.
4. Führen sie ein passendes Werkzeug in den Schlitz des Spannung-Wahl-Schalters und lösen sie mit dessen Hilfe das Spannungs-Wahl-Rad aus der Einheit.
5. Stellen sie das Spannungs-Wahl-Rad in der benötigte Spannung ein; 100V, 120V, 220V oder 240V.
6. Stecken sie das Spannungs-Wahl-Rad zurück in seine Position in der Einheit. Versichern sie sich, dass die gewählte Spannung im Fenster sichtbar ist.
7. Befestigen sie die Abdeckung über der Spannungs-Wahl-Schalter-Einheit.

Die Versorgungsspannung sollte nun ordnungsgemäss eingestellt sein.

Laser Sicherheit

Beachte: In diesem Teil beziehen sich alle Darstellungen auf den AFM Tastkopf der standard system Konfiguration des AutoProbe CP, ansonsten ist es anderwertig bezeichnet.

Das AutoProbe CP enthält eine Laserdiode welche von einer Niederspannungsquelle betrieben wird und eine maximalen Arbeitsleistung von 0.2 mW CW in der Wellenlänge 600-700 nm hat. Im innern des Gerätes könnte eine Diodelaserleistung bis zu 0.2 mW bei 600-700 nm zugänglich sein. Das AutoProbe CP sollte nur bedient werden wenn der Scanner-Kopf ordnungsgemäss montiert ist.

<u>WARNUNG!</u>

Die Benutzung von Steuerungen, Reglern oder das Ausführen von Verfahren anders als bis hierhin beschrieben, kann zu Freisetzung von gefährlichem Laserlicht führen.

Bild 0-2 zeigt die zwei Laserwarnungsmarkierungen des Tastkopfes Strickte Beachtung dieser Warnungsmarkierungen ist erwartet:

Bild 0-2. Laserwarnungsmarkierungen des Tastkopfes.

Die linke Warnungsmarkierung in Bild 0-2, oben, stuft den Tastkopf als ein Klasse II Laserprodukt nach 21 CFR 1040.10 und 1040.11 ein. Die Warnungsmarkierung in Bild 0-2, oben, , stuft den Tastkopf als ein Klasse 2 Laserprodukt nach EN60825 ein.

Bild 0-3 bis 0-7 unten, bezeichnen die Orte aller Instrumentensteuerungen und Anzeiger im Zusammenhang der Laserbedienung des AutoProbe CP Systems. Weiter werden auch die Orte der Lasersicherheitskennzeichnungen, der Srahlenöffnungskennzeichnungen und der Übereinstimmungskennzeichnungen angezeigt.

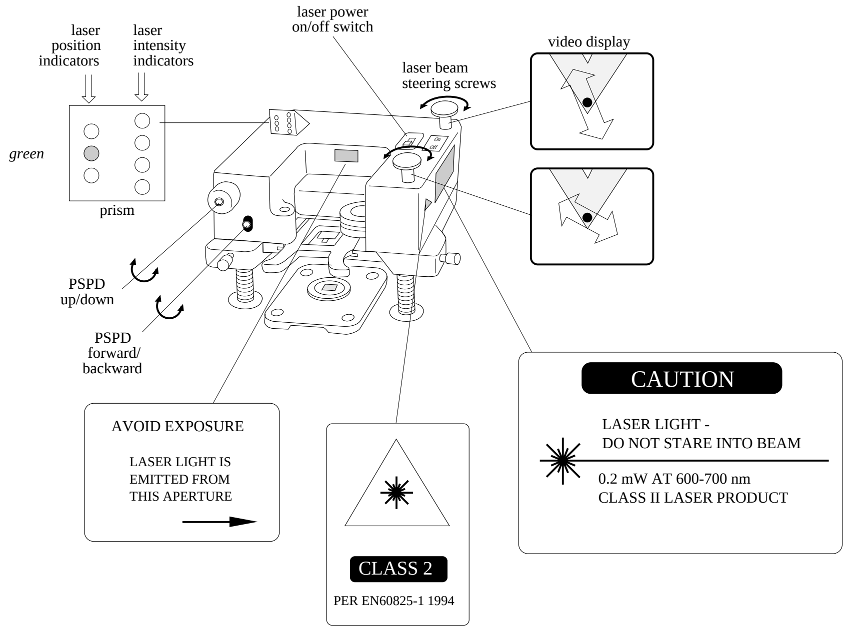


BILD 0-3. Ort der Lasersteuerung des Tastkopfes.

Die Steuerungen und Anzeigen, bezeichnet in Bild 0-3, oben, haben folgende Funktionen:

Laser power on/off switch: Schaltet den Laser des Tastkopfes ein oder aus. Ein rotes Licht im Schalter leuchtet auf, falls der Laser eingescchaltet ist.

Laser beam steering screws: Die zwei Laserstrahl-Steuerungsschrauben, welche sich oben and der rechten Seite des Tastkopfes befinden, dienen zur justierung der Position des Aufteffpunktes des Laserstrahles auf den Balken. Die Schrauben bewegen den Laserpunkt in zwei Richtungen, wie in Bild 0-3, oben, gezeigt wird. Falls ihr System die zusätzliche CP Optics enthält, können sie diese Justierung überwachen indem sie die optische Ansicht auf ihrem Videobildschirm darstellen.

PSPD adjustment screws: Am Tastkopf befinden sich zwei PSPD Schrauben —auf/ab und forwärts/rückwärts. Diese Schrauben justieren die Position des PSPD’s im Tastkopf um das reflektierte Laserlicht auf dem Photodetektor zu zentrieren. Die forwärts/rückwärts Justierungsschraube kann an allen Tastköpfen zur PSPD-Einstellung benutzt werden. Die auf/ab Justierung kann hauptsächlich für den AFM/LFM Tastkopf der Standardkonfiguration benutzt werden.

Laser intensity indicators: Zeigt die Intensität des reflektierten Laserlichtes das auf den PSPD (Positions-sensiblen Photodetektor) trifft an.

Es gibt drei Tastköpfe für die Standardkonfiguration, —AFM, AFM/NC-AFM, AFM/LFM. Die verschiedenen Tastköpfe haben verschiedene Indikatoren.

Beachte: Der AFM Tastkopf kommt mit der Standardsystemkonfiguration. Die AFM/NC-AFM und AFM/LFM Tastköpfe sind zusätzlich zur Standardsystemkonfiguration erhältlich.

Die Indikatoren des AFM Tastkopfes sind in Bild 0-3, oben, eingezeichnet. Bei diesem Tastkopf ist die maximale Laserlichtintensität, die die PSPD teffen kann, erreicht, wenn die Reihe der vier roten Lichter erleuchtet ist. Die Indikatoren der AFM/NC-AFM und AFM/LFM Tastköpfe sind in Bild 0-4, unten, eingezeichnet. Bei diesen Tastköpfen ist die maximale Laserlichtintensität, die die PSPD teffen kann, erreicht, wenn die Helligkeit des mittleren grünen Lichtes (welches eine veränderliche Helligkeit aufweisst) maximal ist.

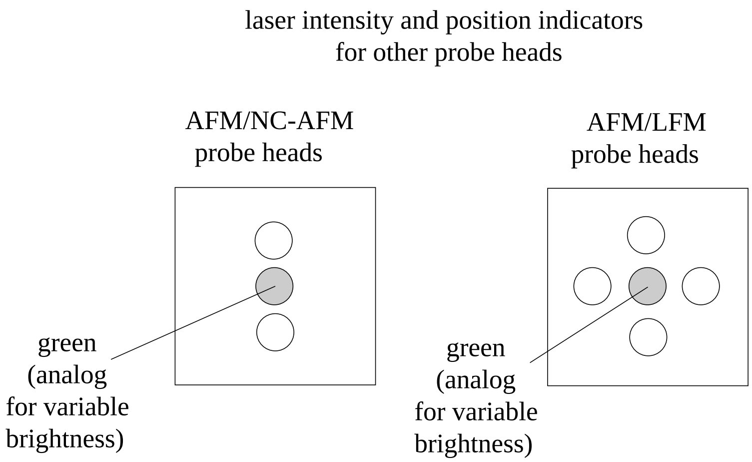


Bild 0-4. Laserintensität und Position des Indikators der AFM/NC-AFM und AFM/LFM Tastköpfe der Standardsystemkonfiguration.

Bei der Multitaskkonfiguration, ist die maximale Laserlichtintensität, die die PSPD teffen kann, erreicht, wenn die Helligkeit des mittleren Lichtes (welches eine veränderliche Helligkeit aufweisst) maximal ist. Eingezeichnet in Bild 0-5, unten.

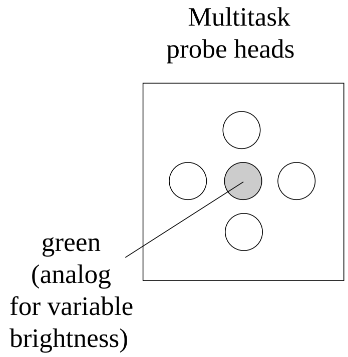


Bild 0-5. Laserintensität und Position des Indikators des Multitasktastkopfes.

Laser position indicators: Zeigen die Position des reflektierten Laserlichtes, das die PSPD trifft, an. Wenn der Laserpunkt auf dem Photodetektor zentriert ist, leuchtet das mittlere grüne Licht auf, wie in Bild 0-4 und 0-5, oben, gezeigt wird.

Bild 0-6, unten, zeigt den Ort der Laserwarnungsmarkierungen auf dem äusseren AutoProbe CP Gehäuse an.

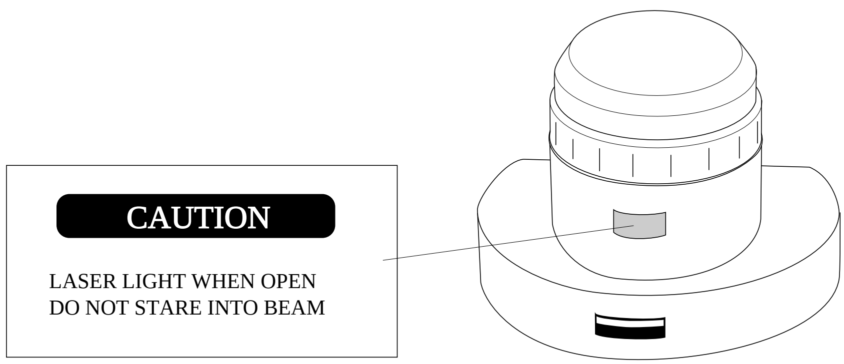


Bild 0-6. Laserwarnungsort des AutoProbe CP Gehäuses.

Bild 0-7, unten, zeigt den Ort der Lasersicherheitsübereinstimmungskennzeichnung auf der Rückseite des AutoProbe Elektronic Modules (AEM) an.

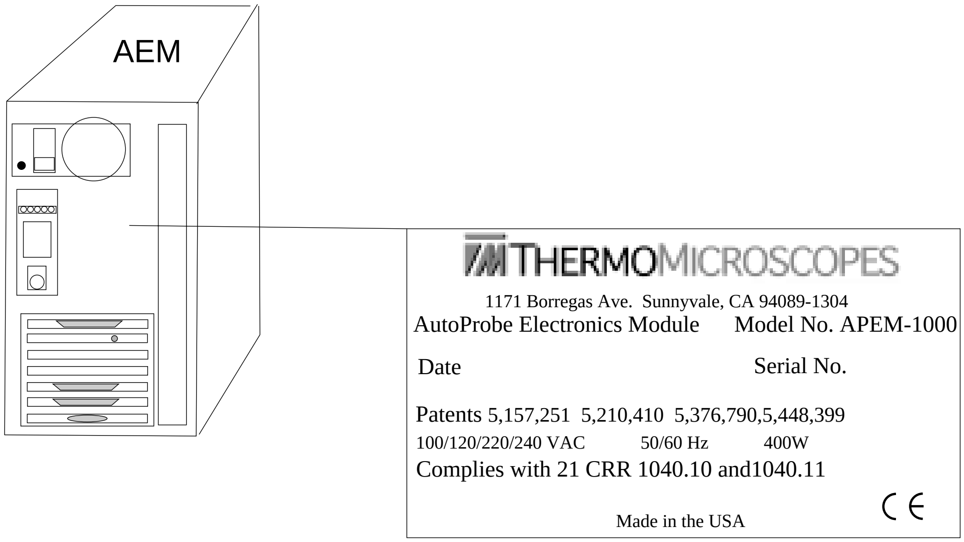


Bild 0-7. Rückseite des AEM,
den Ort der Lasersicherheitsübereinstimmungskennzeichnung anzeigend.

Spezifikationen und Ausführungen des AutoProbe CP's

System Ausführungen:

Standard	Beinhaltet einen AFM Tastkopf für Tätigkeit in der AFM Betriebsart. Ein AFM/NC-AFM Tastkopf für Tätigkeit in AFM, berührungsfreies AFM, periodisch kontaktierendes AFM, und MFM Betriebsarten ist zusätzlich erhältlich. Ein AFM/LFM Tastkopf für Tätigkeit in AFM und LFM Betriebsarten ist zusätzlich erhältlich. Ein STM Werkzeugset für Tätigkeit in STM Betriebsart ist zusätzlich erhältlich.
Multitask	Beinhaltet einen Multitasktastkopf für Tätigkeit in den folgenden Betriebsarten: berührendes, berührungsfreies, und periodisch kontaktierendes AFM, MFM, LFM und STM.

Messleistung:

Standard:	
Scanner	5 µm piezoelektrischer Scanner.
Scannreichweite	Maximale laterale Scannreichweite: 5 µm. Maximale verticale Scannreichweite: 2.5 µm.
Reglerresolution	Maximale Lateralresolution: 0.0013 Å. Maximale Verticalresolution: 0.009 Å.

Multitask:	
Scanner	100 µm piezoelectrischer Scanner.
Scannreichweite	Maximale laterale Scannreichweite: 100 µm. Maximale verticale Scannreichweite: 7.5 µm.
Reglerresolution	Maximale Lateralresolution: 0.25 Å. Maximale Verticalresolution: 0.025 Å.

Mikroscopbühne:

Verschiebbarkeit	8 mm x 8 mm.
Probengrösse	50 mm (w) x 50 mm (l) x 25 mm (h) für die Standardkonfiguration. 50 mm (w) x 50 mm (l) x 20 mm (h) für die Multitaskkonfiguration.
Spitze-zu-Probe Einfahrt	Automatisch mit 3 unabhängigen Schrittmotoren.
Optisches Mikroscop	Zusätzliches axiales Mikroscop mit Farbvideobildschirm zur Ansicht von Messfühlerspitze und Probe. 5:1 Zoom, bis zu 3,500X Vergrösserung.
Akustische Isolation	Zusätzliche akustische Isolationskammer.

Arbeitsplatz:

AEM	20-bit DACs für x, y, und z Achsen.. 16-bit DACs für Systemüberwachung.
Computer	100 MHz Pentium Prozessor, 256 Kbyte Cachespeicher 16 MB RAM.
Massenspeicher	1 GB Hard Drive, 3 1/2 in. 1.4 MB Floppydisk Drive..
Software	ProScan Data Acquisition und Image Processing arbeitets mit Windows 95.
Graphik	Windows Graphikbeschleuniger, 17 in. hochauflösender Farbmonitor.
Systemspannungen	115/230 V AC, 50/60 Hz, 600 W.

Dimensionen und Gewicht:

CP Grundeinheit	10.5 in (267 mm) x 8 in (203 mm); 22 lb (10 kg).
AEM	17 in (432 mm) x 7 1/2 in (191 mm) x 17 1/2 in (445 mm); 43 lb (20 kg).
Computer	17 in (432 mm) x 7 1/2 in (191 mm) x 17 1/2 in (445 mm); 27 lb (12 kg).

Betriebssumgebung:

Temperatur	0°C bis 30°C, 32°F bis 112°F;
Luftfeuchtigkeit	90%; nicht kondensierend.

Reinigungsmittel:

CP Grundeinheit	Isopropylalkohol.
Messkopf	Isopropylalkohol.
AEM und computer	Isopropylalkohol.

WARNUNG!

Um eine Berührungsgefahr zu vermeiden sollen während dem Reinigen der AutoProbe CP Systemkomponenten diese immer ausgeschaltet sein.

VORSICHT

Es sollte kein Aceton verwendet werden um die Komponenten des AutoProbe CP Systems zu reinigen, da dabei wichtige Sicherheits Warnungs Etiketten von den Komponenten losgelöst werden könnten.

ThermoMicroscopes Garantieerklährung

Garantie von neuen Systemen und Zubehörteile

ThermoMicroscopes garantiert dem Orginalkäufer des Gerätes, das dieses frei von Material- und Verarbeitungsfehlern ist. Diese Garantie gilt für ein Jahr ab dem Lieferdatum. ThermoMicroscopes übernimmt die Verantwortung, das Gerät, welches unter diese begrenzte Garantie fällt, nach eigenem Ermessen zu reparieren oder zu ersetzen, ohne Kosten für den Käufer. Alle Serviceleistungen werden je nach ermessen von ThermoMicroscopes in ThermoMicroscopes Niederlassungen oder beim Kunden durchgeführt. Bei Reparaturen, welche in ThermoMicroscopes Niederlassungen durchgeführt werden, muss ThermoMicroscopes vorzeitig kontaktiert werden, um eine Genehmigung für die Rücksendung des Grätes zu erhalten. Für den Transport des Gerätes muss den ThermoMicroscopes Transportanleitungen unbedingt Folge geleistet werden. Falls das Gerät zurückgesendet wird, muss es versichert werden.

Wenn immer möglich liefert ThermoMicroscopes Ersatzteile als Leihgabe, um eine Reparatur beim Kunden mit möglichst geringer Stillstandzeit zu ermöglichen. Wenn das System wieder betriebsbereit ist, müssen die defekten Teile umgehend zu ThermoMicroscopes zurück gesandt werden.

Speziell ausgeschlossen von dieser Garantie sind alle Verbrauchsartikel wie Piezolevers, Microlevers, Ultralevers, Spitzen und ähnliches. Für Geräte, die ausserhalb der Vereinigten Staaten verkauft wurden, gelten die Garantiebedingungen des individuellen Verkaufes. Geräte, welche Gegenstand von falscher Benutzung, Unfall, Missbrauch, Missgeschick, unzumutbarer Benutzung, Beschädigung durch Drittgeräte, mit welchen das Gerät benutzt wurde, Bedienungsfehler, Vernachlässigung, unerlaubtes Reparieren, Verändern oder Installieren sind nicht gedeckt durch diese Garantie.

Garantie von Ersatzteilen

ThermoMicroscopes garantiert, das alle verkauften Ersatzteile frei von Material- und Verarbeitungsfehlern sind. Diese Garantie gilt für 90 Tage ab dem Lieferdatum. ThermoMicroscopes repariert oder ersetzt solche Teile nach eigenem Ermessen, falls sie zu ThermoMicroscopes zurück gesandt werden. Der Kunde muss ThermoMicroscopes vorzeitig kontaktieren, um eine Genehmigung für die Rücksendung des Teiles zu erhalten. Für den Transport des Teiles muss den ThermoMicroscopes Transportanleitungen unbedingt Folge geleistet werden.

Ausser den bis anhin bestimmten Bedingungen, ob ausgedrückt oder stillschweigend angenommen, übernimmt der Verkäufer keine Garantie. Der Verkäfer schliesst ausserdem ausdrücklich jegliche Garantie für eine Marktgängigkeit oder Tauglichkeit für besondere Zwecke aus. Unter keinen Umständen kann ThermoMicroscopes für Verlust oder Schädigung jeglicher Art haftbar gemacht werden, ob direkt, speziell, indirekt oder Folgeschäden, welche durch die Benützung oder Benützungsausfall eines Produktes, einer Serviceleistung, eines Teils, einer Lieferung oder eines Gerätes entstehen. Noch soll ThermoMicroscopes unter jeglichem Rechtssystem für Schäden, Einschliesslich aber nicht begrenzt auf, wie Profitverluste, Stillstandzeiten, Firmenansehen, Schädigung oder Auswechslung des Gerätes oder Eigentum und jeglicher Kosten für Rückgewinnung, Umprogrammierung oder Reproduktion jeglicher Programme oder Daten gespeichert oder benützt in ThermoMicroscopes Produkten, haftbar gemacht werden.

Gewisse Staten erlauben keine zeitliche Begrenzung einer unausgesprochenen Garantie und/oder der Ausschliessung spezieller, nebensächlicher oder Folgeschäden. In diesem Falle treffen die obenstehenden Einschränkungen und/oder Ausschliessungen für sie nicht zu. Diese Garantie gibt ihnen spezielle juristische Rechte neben den möglichen anderen Rechten die sie haben, welche von Staat zu Staat varieren..

Hersteller Information

Das AutoProbe CP beinhaltet keine Teile, die vom Benutzer selber gewartet werden dürfen. Alle Unterhaltsprobleme sollten unverzüglich den örtlichen ThermoMicroscopes Vertretern gemeldet werden.

ThermoMicroscopes, USA
1171 Borregas Avenue
Sunnyvale, CA 94089
T: (408) 747-1600
F: (408) 747-1601

ThermoMicroscopes, USA
6 Denny Road, No. 109
Wilmington, DE 19809
T: (302) 762-2245
F: (302) 762-2847

ThermoMicroscopes, SA
16 rue Alexandre Gavard
1227 CAROUGE
Geneva, Switzerland
T: 41-22-300-4411
F: 41-22-300-4415

ThermoMicroscopes, Korea
Suite 301, Seowon Building
395-13, Seokyo-dong, Mapo-ku
Seoul, Korea
T: 82-2-325-3212
F: 82-2-325-3214

Falls sie ihre Systemkomponenten, welche mit Schadstoffen in Berührung kamen, zu Unterhaltszwecken zu ThermoMicroscopes zurücksenden, müssen folgende Regeln beachtet werden.

Schadstoffe wurden von den Ländern der Europäischen Gemeinschaft als "Stoffe und Zubereitungen gemäss EG-Richtlinie vom 18.9.1979, Artikel 2." definiert. Mit Systemkomponenten, welche mit Schadstoffen in Kontakt kamen, muss folgendes beachtet werden:

- Kontaminierte Komponenten sind vor der Rücksendung zu ThermoMicroscopes entsprechend den Strahlenschutzvorschriften zu dekontaminieren.
- Zur Reparatur oder Wartung eingehende Geräte müssen mit deutlich sichtbarem Vermerk "Frei von Schadstoffen." versehen sein Derselbe Vermerk ist auch auf dem Lieferschein und Anschreiben anzubringen.

Über die Benutzung dieser Bedienungsanleitung

Die Bedienungsanleitung zum AutoProbe M5 ist in drei, einfach zu benützende Abschnitte unterteilt. Die Abschnitte beinhalten das folgende:

- Abschnitt I: *Lernen das AutoProbe CP zu gebrauchen: Grundaufnahmetechniken*
- Abschnitt II: *Lernen das AutoProbe CP zu gebrauchen: Fortgeschrittene Aufnahmetechniken*
- Abschnitt III: *Software Verweis*

Die Inhalte der oben aufgeliesteten Abschnitte sind im Detail in den folgenden Sektionen beschrieben.

Abschnitt I: Lernen das AutoProbe CP zu gebrauchen: Grund Aufnahmetechniken

Abschnitt I dieser Bedienungsanleitung, *Lernen das AutoProbe CP zu gebrauchen: Grund Aufnahmetechniken,* beinhaltet ein Einführungskapitel , und drei praktische Schulungen, Kapitel 2 bis 4. Beim Durcharbeiten der Schulungskapitel, lernen sie die Grundkentnisse, welche benötigt werden, um AFM Bilder aufzunehmen.

Beginnen sie mit lesen des Kapitel 1, "AutoProbe CP Basics," zur Einführung in die Systemkonfigurationen und Komponenten des AutoProbe CP. Arbeiten sie sich dann durch die Schulung in Kapitel 2, "Setting Up to Take an Image" lehrt sie die Systemharware und Software für AFM Mode zu konfigurieren . Genauer gesagt werden sie die folgenden Prozeduren lernen, das Verbinden der Kabel, entfernen und einrichten des Messkopfes und des Scanners sowie das laden einer Probe und eines Messfühlers.

Kapitel 3, "Taking an AFM Image," lehrt sie die Software für AFM Mode zu konfigurieren, ein Auto Approach einzurichten und auszuführen und ein AFM Bild aufzunehmen. Kapitel 4, "Taking Better Images," erklärt wie ein Scan und die Rückkoppelungsparameter für bessere Aufnahmen optimiert werden können sowie das sichern und laden von Bildern.

Abschnitt II: Lernen das AutoProbe CP zu gebrauchen: Fortgeschrittene Aufnahmetechniken

Abschnitt II dieser Bedienungsanleitung, *Lernen das AutoProbe CP zu gebrauchen: Fortgeschrittene Aufnahmetechniken,* beinhaltet praktische Schulungen über die Bedinung des Gerätes mit den folgenden Methoden: STM, LFM, NC-AFM, IC-AFM, und MFM. Er führt sie aussedem in die fortgeschrittenen Fähigkeiten des AutoProbe CP’s ein, wie Kraft-Abstand-Kurven, Strom-Spannungs-Kurven und das kalibrieren des Scanners.

Kapitel 1, "STM Imaging," führt sie durch das Aufnehmen eines STM Bildes. In diesem Kapitel werden sie lernen eine STM Spitze zu preparieren, eine STM Kartusche zu benutzen, die Hardware und Sofrware für die Aufnahmen von STM Bildern einzustellen, und ein STM Bild aufzunehmen.

Kapitel 2, "LFM Imaging," führt sie durch das gleichzeitige Aufnehmen von LFM und AFM Bildern. Kapitel 2 enthält des weiteren Informationen darüber wie LFM Bilder entstehen und über den Nutzen beides, LFM und AFM Bilder zur Verfügung zu haben.

Kapitel 3, "NC-AFM, IC-AFM, and MFM Imaging," beschreibt die Grundsätze hinter NC-AFM, IC-AFM, und MFM Betriebsart. Kapitel 3 beinhaltet weiterhin schrittweise Anweisungen zur Aufnahme von NC-AFM, IC-AFM, und MFM Bilder.

Kapitel 4, "Force vs. Distance Curves," beschreibt das Aufnehmen von Kraft-Abstands-Kurven an x,y Orten auf der Probenoberfläche in ProScan Data Acquisition. Eine Kraft-Abstands-Kurve ist die Dartellung der Vertikalkraft die die Spitze auf den Balken überträgt als Funktion des Abstandes zwischen Spitze und Probe. Unterschiede in der Form der Kraft-Abstands-Kurve lassen auf die örtliche Elastizitätskonstante der Probenoberfläche rückschliessen.

Kapitel 5, “I-V Spectroscopy, “ lernt ihnen das I-V Spectroscopy Fenster in der ProScan Data Acquisition zu benutzen um eine Strom-Spannungs-Kurve (I-V) und dI/dV-Kurven aufzunehmen. Diese Kurven enthalten wertvolle Informationen über die electrischen Eigenschaften von Oberflächen.

Kapitel 6, “Scanner Calibration, “ beschreibt die Arbeitsweise des AutoProbe CP Scanners und die Kalibration des selben um eine optimale Funktion zu erhalten.

Abschnitt III: Software Verweis

Abschnitt III dieser Bedienungsanleitung, *Software Verweis*, ist ein Verweishandbuch für ProScan Data Acquisition and Image Processing und schliesst Informationen über folgenden AutoProbe Systeme ein: CP, LS, and M5. Die Kapitel in diesem Abschnitt der Bedienungsanleitung vermitteln mehr detailierte Informationen über die Softwareeigenschaften und -steuerungen als die in den Schulungskapiteln vermittelten Informationen. Der Aufbau der Kapitel erlaubt ihnen ein direktes Angehen der Eigenschaft oder der Steuerung mit welcher sie sich vertieft befassen möchten.

Kapitel 1, "ProScan Data Acquisition," beschreibt im Detail die Softwareeigenschaften von ProScan Data Acquisition. Dieses Kapitel diskutiert jede Region des Bildschirms, mit spezieller Beachtung jeder Steuerung und seiner Funktion. Dieses Kapitel diskutiert auch die Menus, mit einer Beschreibung jedes Menuelementes und seiner Funktion.

Kapitel 2, "ProScan Image Processing," beschreibt im Detail die Softwareeigenschaften von ProScan Image Processing. Dieses Kapitel erklärt das Bearbeiten der Bilder, wie Oberflächenmessungen gemacht werden und wie Bilder vorbereitet werden um sie in unterschiedlichen Formaten auszudrucken.

Préface

Sécurité lors de l'utilisation

Ce chapitre comprend des informations importantes à propos de votre système AutoProbe CP. Les procédures relatives à la sécurité lors de l'utilisation de l'AutoProbe CP y sont décrites et par conséquent, doivent être lues scrupuleusement *avant* toute mise en route de votre système AutoProbe CP.

> ***ATTENTION!***
>
> Les protections prévues par le système pourraient être inefficaces si les procédures décrites dans ce manuel ne sont pas suivies scrupuleusement.

Symboles de sécurité

Le tableau 0-1 présente les symboles utilisés tout au long de ce manuel d'utilisation ainsi que sur le système AutoProbe CP. Vous devrez vous familiariser avec leurs symboles et définitions car elles sont utilisées pour vous mettre en garde des problèmes liés à la sécurité lors de l'utilisation de l'AutoProbe CP.

Tableau 0-1. Symboles de sécurité et leur définition.

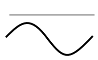
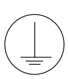
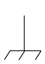
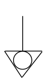
Symbole	Définition
	Source de courant continu.
	Source de courant alternatif.
	Source de courant alternatif avec une composante continue.
3 	Source de courant alternatif triphasé.
	Borne de mise à la masse (terre).
	Borne conductrice isolée.
	Borne connectée au châssis ou à la structure.
	Indique un niveau équipotentiel.
I	Interrupteur enclenché

Table 0-1(suite). Symboles de sécurité et leur définition.

Symbole	Définition
	Interrupteur déclenché.
	Equipement protégé par une isolation renforcée ou par une double isolation.
	Se référer à la documentation.
	Indique un risque de choc électrique.

Définitions: ATTENTION, AVERTISSEMENT et REMARQUE

Ces trois termes sont utilisés dans ce manuel d'utilisation pour vous mettre en garde des problèmes liés à la sécurité lors de l'utilisation de l'AutoProbe CP—ATTENTION, AVERTISSEMENT ET REMARQUE.

Ces termes sont définis dans le tableau 0-2 suivant.

Tableau 0-2. Description des termes.

Terme	Description
Attention	Vous alerte des blessures sérieuses pouvant survenir dans le cas ou les procédures décrites dans ce manuel ne sont pas suivies correctement. N'outrepassez pas un message de ce type si les conditions ne sont pas comprises et remplies.
Avertissement	Vous met en garde des dommages possibles que le système pourrait subir ou à des altérations de sécurité dans le cas ou les procédures décrites dans ce manuel ne sont pas suivies correctement.
Remarque	Vous met en garde des règles à suivre ou des conditions d'utilisations particulières.

Il est important que vous lisiez attentivement tous les messages "Alerte, Avertissement et Remarque" de ce manuel afin de garantir les mesures de sécurité mises en place pour l'utilisation de votre système AutoProbe CP.

Récapitulatif des messages d'Alerte et d'Avertissement

Cette section comprend les messages d'alerte et d'avertissement auxquels vous devrez être attentifs à chaque fois que vous utiliserez l'AutoProbe CP.

ATTENTION!

L'AutoProbe CP doit être correctement mis à la terre avant l'enclenchement de ses composants. Le cordon d’alimentation principal doit simplement être inséré dans une prise munie d'une fiche de mise à la terre. Pour les instructions, reportez vous à la section "Mise à la masse de l'AutoProbe CP" dans la préface.

ATTENTION!

Le choix et le contrôle de la tension d'alimentation doivent être effectués avant l'enclenchement des composants de l'AutoProbe CP. L’ interrupteur pour le choix de la tension d'alimentation est situé sur le panneau arrière de l'AEM. Le sélecteur de tension d'alimentation permet un choix parmi les tensions suivantes : 110 V, 120 V, 220 V, et 240 V. Pour plus d’informations, reportez-vous à la section “Configuration de la tension d’alimentation” dans la préface.

ATTENTION!

Ne pas ouvrir l’AEM ou l’unité de base du CP. L’AEM et l’unité de base du CP utilisent des tensions potentiellement dangereuses et peuvent présenter de sérieux dangers de choc électrique.

AVERTISSEMENT!

ThermoMicroscopes vous demande d'inspecter régulièrement les fils conducteurs du système AutoProbe CP afin de vous assurer qu'ils ne soient pas emmêlés, déconnectés ou endommagés. Les fils conducteurs emmêlés, déconnectés ou endommagés doivent immédiatement être signalés à l’équipe de support technique de ThermoMicroscopes. Ne pas utiliser l'AutoProbe CP lorsque les fils conducteurs sont emmêlés, déconnectés ou endommagés.

AVERTISSEMENT!

Tous les composants du système AutoProbe M5 doivent être manipulés avec précaution. Les composants du système contiennent une instrumentation électromécanique délicate qui peut facilement être endommagée par de mauvaises manipulations.

AVERTISSEMENT!

Le courant du AEM doit être coupé (position OFF) avant d'enlever ou d'installer le scanner.

AVERTISSEMENT!

L'interrupteur laser ON/OFF de la tête du microscope doit être en position OFF avant de retirer ou d'installer la tête du microscope sur l'étage de translation en XY. Dans le cas contraire, des dommages aux diodes électroluminescentes de la tête du microscope (LEDs) peuvent survenir.

AVERTISSEMENT!

En retirant et en installant le scanner, vous devez être mis à la terre à l'aide d'un bracelet conducteur vous reliant à la terre pour vous assurez que le scanner n'est pas endommagé. Le scanner est sensible aux décharges électrostatiques.

AVERTISSEMENT!

Les quatres vis qui connectent le scanner à l'unité de base du CP doivent être serrées proprement pour assurer une mise à terre correcte. Lorsque les quatres vis sont serrées correctement les performances maximum de l'instruments sont assurées puisque les vibrations sont réduites.

AVERTISSEMENT!

Afin de protéger le EMC, placer le couverde métallique sur la base du CP lors de l'acquisition de l'image.

Mise à la terre de l' AutoProbe CP

L'AutoProbe CP doit être correctement mis à la terre avant l'enclenchement de ses composants. Le câble d'alimentation générale doit être inséré dans une prise munie d'une fiche de mise à la terre. Si vous n’avez pas accès à une prise munie d’une fiche de mise à terre, vous devez mettre l’AutoProbe CP à la terre en utilisant la connection de mise en terre de l’AEM. La Figure 0-1, ci-dessous, montre ou est situé la connection de mise à terre.

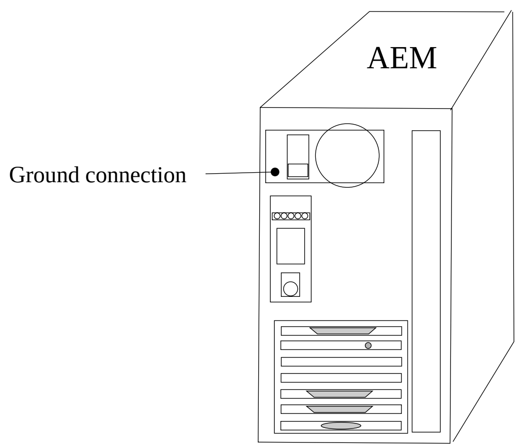


Figure 0-1. Panneau arrière du AEM, montrant l’emplacement du connecteur de mise à la terre

Configuration de la tension d’alimentation

Le choix de la tension d’alimentation doit correspondre à la tension d’alimentation du pays où le sytème AutoProbe CP est utilisé. Le choix de la tension d’alimentation se fait à l’aide d’un sélecteur de tension. Ce sélecteur est situé sur le panneau arrière du AEM. Le sélecteur de la tension d’alimentaion permet un choix parmi les tensions suivantes : 100 V, 120 V, 220 V, or 240 V.

Pour changer la tension d’alimentation, procédez comme suit :

1. Assurez vous que l’interrupteur de l’AEM soit déclenché.

2. Débranchez le cordon secteur de l’AEM de la prise d’alimentation.

3. Enlevez le couvercle du sélecteur de tension d’alimentation en utilisant un tourne-vis de taille appropriée.

4. Insérer un outil de taille appropriée dans la fente du sélecteur d’alimentation et utiliser cet outil pour enlever le disque du sélecteur de tension.

5. Positionner le disque de sélection de tension enlevé précedemment sur la tension de ligne appropriée (100V, 110V, 220V ou 240V).

6. Remettre le disque de sélection de tension en place dans l’unité. Assurez-vous que la tension de ligne désirée apparait dans la fenêtre.

7. Installer le capôt sur le sélecteur de tension de ligne.

La tension d’alimentation devrait à présent être sélectionnée à la valeur appropriée.

Recommandations à l’usage du laser

Note : Tout au long de cette section, les schémas se réfèrent à la tête du microscope AFM pour la configuration standard du système AutoProbe CP, sauf notifications contraires.

L’AutoProbe CP contient une diode laser alimentée par une basse tension avec une puissance maximum de 0.2mW CW d’une longeur d’onde de 600-700nm. La diode laser alimentée jusqu’à 0.2mW à 600-700nm doit être accessible à l’intérieur. L’AutoProbe CP doit toujours fonctionner avec la tête du microscope correctement installée.

ATTENTION!

Les contrôles, les ajustements et l’exécution de procédures autres que ceux spécifiés ici peuvent provoquer une exposition dangereuse aux rayons laser.

Figure 0-2 Montre les deux étiquettes d’avertissement à propos du laser de la tête du microscope.
Il est recommandé de respecter rigoureusement les étiquettes d’avertissement sur le laser.

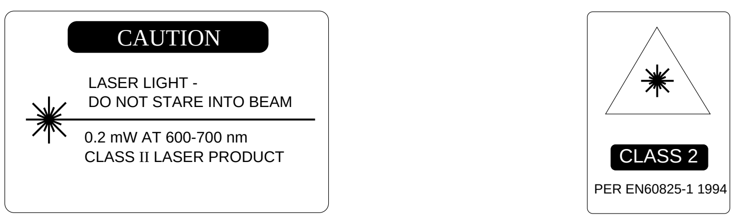


Figure 0-2. Etiquettes d’avertissement à propos du laser de la tête du microscope.

L’étiquette d’avertissement de gauche dans la Figure 0-2, ci-dessus, spécifie que la tête du microscope est un laser de Classe II selon 21 CFR 1040.10 et 1040.11. L’étiquette d’avertissement de gauche dans la Figure 0-2, ci-dessus, spécifie que la tête du microscope est un laser de Classe II selon EN60825.

Les figures 0-3 à 0-7 ci-dessous montrent l’emplacement de tout les instruments de contrôle et indicateurs se rapportant aux opérations effectuées avec le laser du système AutoProbe CP. Ils montrent également l’emplacement de toutes les étiquettes d’avertissements sur le laser, d’orifices et de conformité.

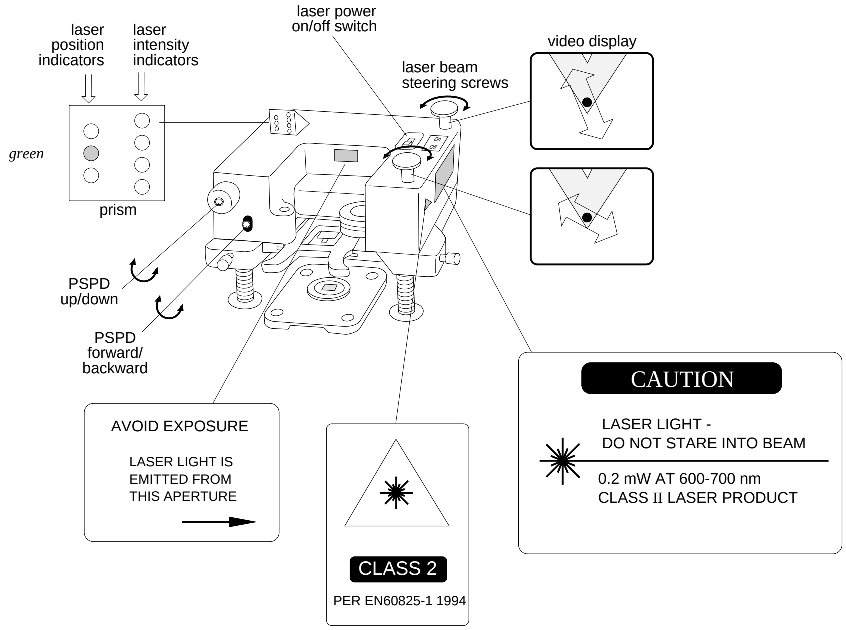


Figure 0-3. Emplacement des contrôles laser sur la tête du microscope.

Les contrôles et indicateurs montrés ci-dessus en figure 0-3 ont les fonctions suivantes :

L'interrupteur on/off du laser : active ou désactive le laser dans la tête du microscope. Une lumière rouge est allumée dans l'interrupteur lorsque le laser est enclenché.

Vis directrices du rayon laser : Les deux vis directrices du rayon laser situées sur le dessus à droite de la tête du microscope sont utilisées pour ajuster la position du rayon laser touchant le cantilever. Les vis bougent le spot du laser dans deux directions, comme montré sur la Figure 0-1, ci-dessus. Si votre système inclus l'option CP optique, vous pouvez contrôler ces ajustements en utilisant la vue optique sur votre moniteur vidéo.

Vis d'ajustement PSPD : Il y a deux vis PSPD sur la tête du microscope-haut/bas et avant/arrière. Ces vis ajustent la position du PSPD dans la tête du microscope pour centrer la lumière du laser refletée sur le photodetecteur. La vis d'ajustement avant/arrière est utile pour l'alignement PSPD sur la tête du microscope. L'ajustement haut/bas est utile principalement pour la tête du microscope AFM/LFM pour un système de configuration standard.

Indicateurs d'intensité du laser : Indique l'intensité avec laquelle la lumière reflétée du laser touche le PSPD (photodétecteur sensible à la position)

Pour une configuration standard, il y a trois têtes de microscope - AFM, AFM/NC - AFM, AFM/LFM. Il y a différents indicateurs pour les différentes têtes de microscope.

Note : La tête de microscope AFM est comprise dans la configuration standard du système. Les têtes de microscope AFM/NC-AFM et AFM/LFM peuvent être achetées séparément.

Les indicateurs de la tête AFM sont montrés dans la Figure 0-3, ci-dessus. Pour cette tête de microscope, l'intensité de la lumière du laser touchant le PSPD est maximisé lorsque la colonne de quatre Leds rouge est allumée. Les indicateurs des têtes de microscope AFM/NC-AFM et AFM/LFM sont montrés dans la Figure 0-4, ci-dessous. Pour ces têtes de microscope, lorsque la brillance du centre de la Led verte (qui a une brillance variable) est maximisée, l'intensité du laser touchant le PSPD est maximisé.

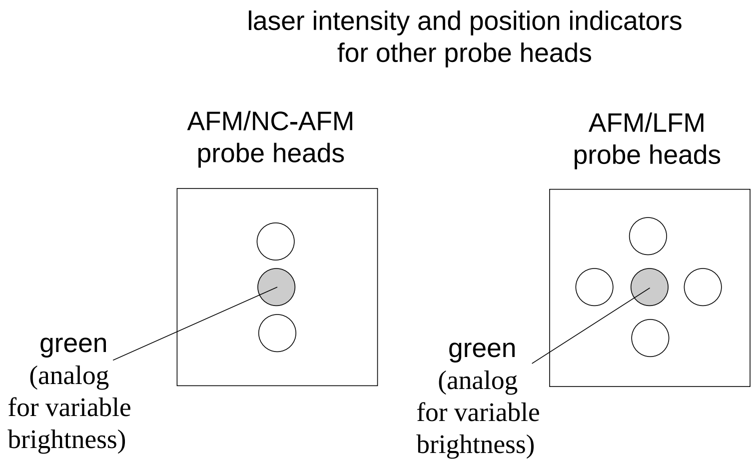


Figure 0-4. Intensité du laser et indicateurs de position de la tête de microscope AFM/NC-AFM et de la tête de microscope AFM/LFM d'une configuration de système standard.

Pour la configuration multitask, lorsque la brillance du centre de la lumière (qui a une brillance variable) est maximisée, l'intensité du laser touchant le PSPD est maximisé. Voir Figure 0-5, ci-dessous.

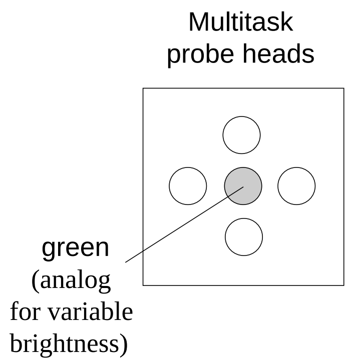


Figure 0-5. Intensité du laser et indicateurs de position pour la tête de microscope multitask.

Indicateurs de position du laser : Indique la position de la lumière du laser réflechi touchant le PSPD. Lorsque le point du laser est centré sur le photodétecteur, la led verte du centre est allumée, comme en figures 0-4 et 0-5, ci-dessus.

La Figure 0-6 ci-dessous, montre la position de l’étiquette d’avertissement du laser à l’extérieur de la coupole de l’AutoProbe CP.

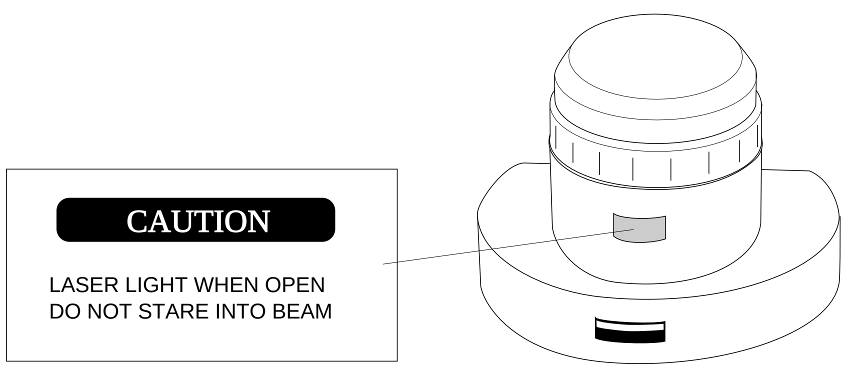


Figure 0-6. Position de l’étiquette d’avertissement du laser sur la base de L’AutoProbe CP

La Figure 0-7, ci-dessous, montre la position de l’étiquette de conformité concernant la sécurité du laser sur le panneau arrière du Module Electronic de l’AutoProbe (AEM)

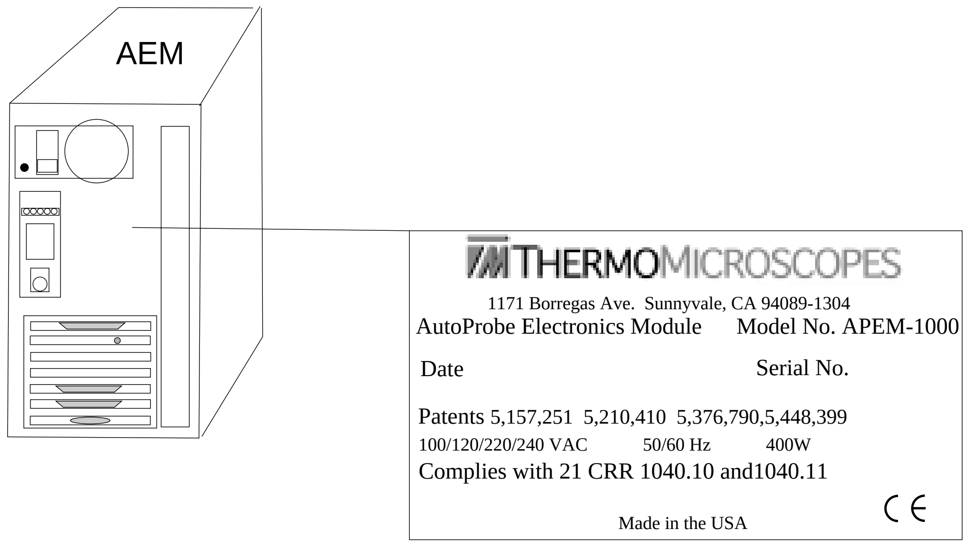


**Figure 0-7. Panneau arrière du AEM,
montrant la position de l'étiquette de conformité concernant la sécurité du laser.**

Caractéristiques et performances pour l’AutoProbe CP

Configuration du Système:

Standard	Inclus une tête de microscope pour des opérations en mode AFM. En option, la tête de microscope AFM/NC-AFM peut-être achetée pour des operations en modes AFM, non-contact, contact intermittent, et MFM. En option, la tête de microscope AFM/LFM peut-être achetée pour des opérations en modes AFM et LFM. En option, le kit d’outils STM peut-être acheté pour des opérations en mode STM.
Multitask	Inclus une tête de microscope multitask pour des opérations dans les modes suivants : AFM contact, non-contact, contact intermittent, MFM, LFM et STM.

Mesures de performance

Scanner	scanner piezoélectrique 5µm
Aire de balayage	Balayage latéral maximum : 5µm Balayage vertical maximum : 2.5µm
Résolution de contrôle	Résolution latérale maximum : 0.0013 Å. Résolution verticale maximum : 0.009 Å.
Scanner	Scanner piezoélectrique 100 µm
Aire de balayage	Balayage latéral maximum : 100µm Balayage vertical maximum : 7.5µm
Résolution de contrôle	Résolution latérale maximum : 0.25 Å. Résolution verticale maximum : 0.025 Å.

Etage du microscope :

Course de translation	8 mm x 8 mm
Taille d’échantillon	50 mm (w) x 50 mm (l) x 25 mm (h) pour une configuration standard. 50 mm (w) x 50 mm (l) x 20 mm (h) pour une configuration multitask.
Approche pointe-échantillon	Automatique avec 3 moteurs pas à pas indépendants.
Microscope optique	En option, microscope droit avec moniteur vidéo couleur pour la visualisation de la pointe et de l’échantillon.
Isolation acoustic	En option, chambre d’isolation acoustique.

Station de travail:

AEM	DAC 20-bit pour la commande des axes x, y et z.. DAC 16-bit pour le système de contrôle.
Ordinateur	Processeur Pentium 133 MHz, 256 Kbyte de mémoire cache, 16 MB RAM.
Mass storage	1 GB hard drive, 3 1/2 in. 1.4 MB floppy disk drive.
Mémoire de masse	Disque dur 1 GB, lecteur de disquette 3,5’’ 1.4 MB.
Logiciel	“Proscan Data Acquisition” et “Image Processing” fonctionnent sous Windows 95.
Graphiques	Carte graphique accélératrice Windows, moniteur couleur 17’’ à haute résolution
Alimentation	115/230 V AC, 50/60 Hz, 600 W.

Dimensions et poids :

Unité de base CP	267 mm (10.5 in) x 203 mm (8 in); 10 kg (22 lb).
AEM	432 mm (17 in) x 191 mm (7 1/2 in) x 445 mm (17 1/2 in); 20 kg (43 lb).
Ordinateur	432 mm (17 in) x 191 mm (7 1/2 in) x 445 mm (17 1/2 in); 12 kg (27 lb).

Conditions d’utilisation :

Temperature	0°C to 30°C, 32°F to 112°F.
Humidité	90%; sans condensation

Entretien :

Unité de base CP	alcool Isopropylique.
Tête de microscope	alcool Isopropylique.
AEM et ordinateur	alcool Isopropylique.

ATTENTION!

Pour éviter tout risques de choc électrique, aucun des composants du système AutoProbe CP ne doit être nettoyé lorsque le système est enclenché.

AVERTISSEMENT!

Ne pas utiliser d'acétone pour nettoyer les composants du système AutoProbe CP. L'acétone peut endommager les étiquettes d'avertissement concernant la sécurité.

Déclaration de Garantie de ThermoMicroscopes

Garantie des Systèmes neufs et des Accessoires

ThermoMicroscopes garanti au premier acquéreur que son système est exempt de tout défauts de matériel ou de fabrication et ceci pour une période d'une année à compter de la date de livraison. Pendant cette periode de garantie, ThermoMicroscopes est seul responsable du remplacement ou de la réparation, selon son propre choix, du matériel sous garantie et ceci sans charge pour l'acquéreur, autre que des frais d'envois éventuels. ThermoMicroscopes se réserve le droit d'exécuter ces services soit sur site, chez le client, soit dans ses propres locaux. Pour les réparations effectuées par ThermoMicroscopes, le client doit demander à l'avance une autorisation d'expédition de matériel à ThermoMicroscopes (RMA) et suivre la procédure ThermoMicroscopes d'expédition. Le matériel renvoyé doit être assuré par l'expéditeur.

ThermoMicroscopes fourni en prêt, dans la mesure du possible, des pièces de remplacement pour permettre au client une réparation sur site dans les meilleurs délais. Une fois le système opérationnel, les pièces défectueuses doivent être envoyées chez ThermoMicroscopes sans délai.

Sont exclus entre autre de cette garantie tout les consommables, tels que Microlevers, Ultralevers, et les pointes STM. La garantie des équipements vendus pour une utilisation, en dehors des Etats Unis, dépend des conditions de garantie spécifiées lors de la vente. Le matériel qui aurait été soumis à un mauvais traitement, emploi, à un accident, une catastrophe, à une utilisation inappropriée, qui aurait subi des dommages provoqués par un équipement non fournis avec le système, une erreur d'utilisation, une modification, une réparation ou installation non autorisée ne sont pas couverts par la garantie.

Garantie des pièces remplacées

ThermoMicroscopes (ThermoMicroscopes) garanti toutes les pièces de remplacement pendant une durée de 90 jours à partir de la date de livraison , contre les défauts de matériel ou de fabrication. ThermoMicroscopes remplacera ou réparera, selon sa décision les pièces renvoyées à ThermoMicroscopes. Le client doit demander à l'avance une autorisation d'expédition de matériel à ThermoMicroscopes (RMA) et suivre la procédure ThermoMicroscopes d'expédition

Exception faite aux conditions de garantie précitées, le vendeur ne fourni aucune garantie, de façon formelle ou implicite, et exclu, désavoue expressément toutes formes de garantie se rapportant à la marchandabilité ou l'adaptation à un usage particulier. ThermoMicroscopes ne pourra en aucun cas être designé comme responsable des pertes ou dommages, indirects, directs ou consécutifs, survenus lors d'une utilisation ou d'une immobilisation de produits, services, pièces, fournitures ou équipement. ThermoMicroscopes sera également dégagé de toutes responsabilités vis-à-vis de la loi,

incluant, mais sans s'y limiter, aux pertes de profits, retards, mauvaise volonté, dommage et toutes sortes de coûts de récupération, reprogrammation ou reproduction des programmes ou informations contenues ou utilisées avec les produits ThermoMicroscopes.

Certains états n'admettent pas de limitation, dans le temps, de garanties implicites et/ou l'exclusion ou la limitation d'incidents ou de dommages spéciaux. Dans ce cas les limitations et/ou exclusions précitées ne vous concernent pas. Ces garanties vous donnent des droits spéciaux et vous pouvez également être soumis à d'autres droits qui peuvent varier d'un état à l'autre.

Information du fabricant

Toutes les questions relatives au service devront être addressées à votre representant ThermoMicroscopes local.

ThermoMicroscopes, USA
1171 Borregas Avenue
Sunnyvale, CA 94089
T: (408) 747-1600
F: (408) 747-1601

ThermoMicroscopes, USA
6 Denny Road, No. 109
Wilmington, DE 19809
T: (302) 762-2245
F: (302) 762-2847

ThermoMicroscopes, SA
16 rue Alexandre Gavard
1227 CAROUGE
Geneva, Switzerland
T: 41-22-300-4411
F: 41-22-300-4415

ThermoMicroscopes, Korea
Suite 301, Seowon Building
395-13, Seokyo-dong, Mapo-ku
Seoul, Korea
T: 82-2-325-3212
F: 82-2-325-3214

Si le matériel que vous renvoyez au service technique a été en contact avec des substances toxiques vous devez observer certaines réglementations. Les substances toxiques sont réglementées par les pays de la Communité Européenne par "Materials and Preparations en accord avec les directives EEC du 18 Septembre 1979, Article 2." Pour le matériel qui a été en contact avec des substances toxiques, vous devez procéder comme suit :

- ♦ Decontaminate the components in accordance with the radiation protection regulations.
- ♦ Le matériel (contaminé) doit être décontaminé en accord avec les directives et réglementations de protection radioactive.
- ♦ Construct a notice that reads "free from harmful substances." The notice must be included with the components and the delivery note.
- ♦ Le materiel renvoyé doit être accompagné d'un avis "Exempt de substances toxiques". Cet avis doit également apparaître sur le bulletin de livraison.

Comment utiliser ce guide de l'utilisateur

Le guide de l'utilisateur pour l'AutoProbe CP est divisé en trois parties, faciles à utiliser, qui sont les suivantes :

- Partie I: *Apprendre à utiliser l'AutoProbe CP : Techniques d'imagerie de base.*
- Partie II: *Apprendre à utiliser l'AutoProbe CP : Techniques avancées.*
- Partie III: *Réferences du logiciel*

Le contenu des différentes parties listées ci-dessus est décrit en détails dans la section ci-dessous.

Partie I: Apprendre à utiliser l'AutoProbe CP : Techniques d'imagerie de base

La partie I de ce guide de l'utilisateur, *Apprendre à utiliser l'AutoProbe CP : "Techniques d'imagerie de base"*, contient un chapitre d'introduction, et trois formations pratiques, les chapitres 2 à 4. En travaillant sur les formations pratiques tout au long de ces chapitres, vous allez apprendre les bases dont vous aurez besoin pour faire fonctionner l'instrument et obtenir des images AFM.

Commencez par lire le Chapitre 1, "Les bases de l'AutoProbe CP," comme introduction aux configurations et composants du système AutoProbe CP. Puis travaillez sur la formation pratique du Chapitre 2, "Faire fonctionner le système pour obtenir une image," afin d'apprendre comment configurer le système logiciel et matériel en mode AFM. De façon précise, vous allez apprendre des procédures pour connecter les câbles, enlever et installer une tête de microscope et un scanner, et charger un échantillon.

Chapter 3, "Acquisition d'un image AFM," vous guide tout au long de la configuration du logiciel, durant l'approche de l'échantillon, et pour prendre une image AFM. Chapter 4, "Obtenir de meilleures images," vous apprend à optimiser les paramètres de balayages et de feedback afin de prendre des images de meilleure qualité et comment les sauvegarder et les recharger.

Partie II: Apprendre à utiliser l'AutoProbe CP : Techniques avancées

La partie II de ce Guide de l'Utilisateur, *Apprendre à utiliser l'AutoProbe CP : "Techniques avancées"*, comprend des formations pratiques pour des opérations dans les modes suivants : STM, LFM, NC-AFM, IC-AFM, and MFM. Elle comprend également des travaux pratiques qui vous introduisent aux possibilités avancées de l'AutoProbe CP, tels que les courbes force-distance, les courbes courant/tension, et la calibration du scanner.

Le chapitre 1, “Imager en mode STM”, vous guide afin de prendre une image en mode STM. Dans ce chapitre vous apprendrez des procédures pour préparer des pointes STM et utiliser des cartouches STM, pour configurer l’ordinateur et le programme afin de travailler en mode STM, et prendre une image en mode STM.

Le chapitre 2, “Imager en mode LFM”, vous guide afin de prendre simultanément des images en mode LFM et AFM. Le chapitre 2 vous donne également les informations pour obtenir des images LFM et les avantages d’avoir à disposition les 2 images LFM et AFM.

Le chapitre 3, “Imager en mode NC-AFM, IC-AFM et MFM” décrit les principes des modes d’opération NC-AFM, IC-AFM et MFM. Le chapitre 3 vous donne également les instructions, pas à pas, afin d’obtenir des images NC-AFM, IC-AFM et MFM.

Le chapitre 4, "Courbes Force-Distance," Décrit comment obtenir des courbes force-distance à une position x et y donnée sur la surface de l’échantillon en utilisant le traceur X-Y de “ProScan Data Acquisition”. Une courbe force-distance est un relevé de la force verticale que la pointe applique au levier en fonction de la distance pointe-échantillon. Les variations de la courbe fournissent des informations concernant les proprietés locales d’élasticité à la surface de l’échantillon.

Le chapitre 5, "Spectroscopie I-V," vous apprend à utiliser la fenêtre “Spectroscopie I-V” de “ProScan Data Acquisition” pour générer des courbes courant/tension (I-V) et des courbes dI/dV. Ces courbes fournissent des informations importantes concernant les propriétés électroniques de la surface.

Le chapitre 6. “calibration du scanner”, décrit comment le scanner de votre système AutoProbe CP fonctionne et comment le calibrer afin de maintenir ses performances optimales.

Partie III: Réferences du logiciel

La partie III de ce guide de l’utilisateur, *Réferences du logiciel*, est un manuel de référence pour “ProScan Data Acquisition and Image Processing” et comprend des informations pour les systèmes AutoProbe suivant : CP, LS, et M5. Les chapitres de cette partie du guide de l’utilisateur vous donnent des informations plus détaillées sur certaines caractéristiques et contrôles, les informations qui vous sont données dans les chapitres de formation pratique. Les chapitres sont conçus de telle sorte que vous puissiez allez directement aux caractéristiques et contrôle sur lesquels vous désirez apprendre quelque chose.

Le chapitre 1, "ProScan Data Acquisition," décrit en détail les caractéristiques du logiciel “ProScan Data Acquisition”. Ce chapitre traite chaque portion de l’écran, prêtant une attention spéciale à chaque possibilité de contrôle et à ses fonctions. Ce chapitre traite également des menus, avec une description de chaque article du menu et de sa fonction.

Le chapitre 2, "Traitement d’image ProScan," décrit en détail les caractéristiques du logiciel “ProScan Image Processing”. Ce chapitre explique comment obtenir des images, comment faire des mesures de surface, et comment préparer les images pour l’impression sous différents formats.

Part II
Learning to Use AutoProbe CP: Advanced Techniques

Chapter 1
NC-AFM, IC-AFM, and MFM Imaging

Introduction

This chapter describes three atomic force microscopy (AFM) modes of AutoProbe operation that use a vibrating cantilever:

- Non-Contact AFM (NC-AFM)
- Intermittent-Contact AFM (IC-AFM)
- Magnetic Force Microscopy (MFM)

The information in this chapter applies to both standard and multitask AutoProbe CP system configurations. NC-AFM and IC-AFM operating modes are standard with the multitask configuration, and they are available as options with the standard configuration. MFM requires magnetically-coated cantilevers, which are part of a separate MFM toolkit.

Following brief sections that describe vibrating cantilever AFM methods and components required for these methods, three tutorial sections take you step by step through obtaining an NC-AFM image, an IC-AFM image, and an MFM image. Then, if you are interested in learning more about how vibrating cantilever methods work, you can refer to three sections at the end of this chapter: "How Non-Contact AFM Works," "How Intermittent-Contact AFM Works," and "How Magnetic Force Microscopy Works." These sections describe the underlying principles of each imaging technique. In addition, you can refer to the section "Hardware Components for Non-Contact Imaging" at the end of the chapter for a description of the hardware components involved in image production.

Vibrating-Cantilever AFM Methods

Vibrating-cantilever AFM methods, also known as “attractive mode” and “non-contact” AFM methods, use a vibrating cantilever held tens to hundreds of angstroms above the sample surface. The cantilever tip either does not come into contact with the sample surface (NC-AFM and MFM), or it comes into contact only at the lowest point in its vibration cycle (IC-AFM).

Because there is no contact, or only limited contact, between the tip and the sample, vibrating cantilever AFM methods can be used to image samples of low moduli that can be distorted or even damaged by the tip in contact-AFM mode. In general, a combination of these methods (e.g., non-contact and intermittent-contact AFM) allows the widest possible range of samples to be analyzed.

Vibrating cantilever AFM methods also lend themselves readily to imaging surface properties other than topography, because forces between the cantilever tip and the sample can arise from other sources. For instance, magnetic domains on a surface can exert an attractive or repulsive force on a magnetized tip, making magnetic force microscopy (MFM) possible.

Non-Contact AFM (NC-AFM)

For non-contact AFM imaging, the cantilever tip is held about 50 to 100 Å above the sample surface during a scan. It is vibrated at a constant frequency near its mechanical resonant frequency (typically 50 to 400 kHz), with an amplitude of a few tens of angstroms. As the tip is scanned above the surface, the cantilever vibration amplitude changes in response to force gradients that vary with the tip-to-sample spacing. An image representing surface topography is obtained by monitoring these changes in vibration amplitude.

Since ideally the cantilever tip never touches the sample surface in non-contact mode, NC-AFM is useful for imaging samples of low moduli, such as soft polymers and biological materials, that can easily be damaged by the tip. A further advantage of NC-AFM is that samples such as silicon wafers are not contaminated by contact with the tip, and the tip is not damaged by the sample. Like contact AFM, non-contact AFM can be used to measure the topography of insulators and semiconductors as well as electrical conductors.

Intermittent-Contact AFM (IC-AFM)

Intermittent-contact AFM (IC-AFM) is similar to NC-AFM, except that in IC-AFM the vibrating cantilever tip is brought closer to the sample and its vibration amplitude is greater so that at the bottom of its travel it just barely hits the sample surface. For some samples, this is preferable to full contact AFM because it eliminates lateral forces, such as friction and drag, that might damage the tip or sample.

As for NC-AFM, for IC-AFM the cantilever vibration amplitude changes in response to force gradients that vary with tip-to-sample spacing. An image representing surface topography is obtained by monitoring these changes.

While the two methods are similar, NC-AFM tends to outperform IC-AFM for soft samples and when the maximum lateral resolution is required on samples with low-profile topography. NC-AFM does not suffer from the tip or sample degradation effects which are sometimes observed after taking numerous scans with contact or intermittent-contact AFM.

Magnetic Force Microscopy (MFM)

Magnetic force microscopy (MFM) is NC-AFM performed with a magnetized tip. Magnetic domains on a surface exert either an attractive or a repulsive force on the magnetized tip, and MFM maps the magnetic domain structure. For example, MFM can be used to image naturally occurring and deliberately written domain structures of magnetic materials.

MFM requires cantilevers that have been coated with a ferromagnetic thin film such as sputtered cobalt. The magnetic force between the tip and the sample is often stronger and has a longer range than the attractive van der Waals force which is imaged in NC-AFM. Thus it is possible to image only the magnetic domains on a sample by keeping the tip far from the surface, where van der Waals forces are negligible.

Required Components

NC-AFM and IC-AFM for AutoProbe CP require the following components:

- AFM/NC-AFM probe head (for the standard system configuration), or the multitask probe head
- Specially designed non-contact probe cartridge
- Box of NC-AFM Ultralever chip carriers for non-contact mode
- Frequency synthesizer board installed in the AutoProbe electronics module (AEM)
- BNC coaxial cable for connecting the frequency synthesizer board to the instrument
- ThermoMicroscopes ProScan Software

Note: An NC-AFM probe head and probe cartridge must be used together in order to take non-contact images using AutoProbe CP. In addition, you should use cantilevers that have been preselected for non-contact measurements.

For MFM, you need the following components in addition to those listed above for NC-AFM:

- MFM cantilevers with magnetically coated tips
- Tip magnetizer
- Non-magnetic sample holder

These components are available as part of the MFM toolkit that you receive if you order the MFM option.

Note: MFM must be ordered as a separate option. Not all AFM/NC-AFM probe heads for the standard AutoProbe CP system configuration support MFM mode. If you are not sure whether your probe head can be used for MFM mode, contact ThermoMicroscopes’s Customer Support.

Taking an NC-AFM Image

This section leads you through the process of taking and refining an NC-AFM image. Many of the procedures for taking an NC-AFM image are also followed for taking an IC-AFM or an MFM image. For this reason, it is recommended that you read this section before proceeding to “Taking an IC-AFM Image” and “Taking an MFM Image,” which give the procedures for taking IC-AFM and MFM images, respectively.

It is assumed that you are familiar with the basics of using your AutoProbe instrument, such as loading a probe head and a sample. This section does not provide the details for these procedures. Instead, it refers you to other parts of this User’s Guide where applicable.

After completing this section, you should be familiar with setting up the system to take an image, adjusting scan parameters and optimizing your images, and you should be ready to learn how to take IC-AFM and MFM images.

Summary of the Procedure

The following steps summarize the procedures for taking an NC-AFM image and can also be used as a quick reference:

Step 1: Set up the system.

1. Connect cables, including the BNC cable between the frequency synthesizer card connector on the rear panel of the AEM and the NC Clock connector on the rear panel of AutoProbe CP.

2. Install a scanner.

CAUTION

The power to the AEM must be turned OFF before you remove or install the scanner.

CAUTION

The four screws that connect the scanner to the CP base unit must be securely fastened to ensure proper grounding. When the four screws are securely fastened, maximum instrument performance is ensured since vibrations are reduced.

3. Load a sample.

4. Install the appropriate probe head and an NC-AFM probe cartridge.

   - If you have the standard AutoProbe CP system configuration: Install the AFM/NC-AFM probe head.
   - If you have the multitask AutoProbe CP system configuration: Install the multitask probe head and set the two mode switches on the probe head to the AFM and NC-AFM positions.
   - Load a non-contact chip carrier onto the NC-AFM probe cartridge.
   - Load the cartridge in the NC-AFM probe head.

5. Turn on the AEM, the computer, and the monitors and set up the system software.

6. Align the deflection sensor.

   - Focus on the cantilever using the optical view.
   - Steer the laser beam onto the back of the cantilever tip.
   - Adjust the PSPD position until the indicator lights on the probe head show that the position is optimized.

Step 2: Set NCM parameters.

1. Under the Setup menu of the Image mode window, select NCM Frequency to view the NCM (Non-Contact Mode) Frequency Set dialog box.

2. Select a drive frequency, drive amplitude (drive %), and imaging amplitude (set point) for the scan.

Step 3: Perform an auto approach.

1. In Move mode, use the z direction pad to lower the tip so that it is close to the sample.

2. Click the [Approach] button to initiate an auto approach. The auto approach stops when the cantilever's vibration amplitude matches the value represented by the set point parameter displayed on the Image mode window.

3. Enter Image mode to view a Topography signal trace.

4. Optimize the set point parameter by iteratively reducing the set point absolute value while monitoring the Topography signal trace and the Z Piezo bar. Re-approach the sample if necessary.

Step 4: Set scan parameters.

1. Set the scan rate, scan size, number of data points per image, and fast scan direction.

2. Adjust the drive %, set point, gain, and slope parameters if necessary.

Step 5: Start a scan.

1. Click the Image button to begin acquiring an image in non-contact mode.

2. While imaging, continue to monitor the scan parameters and adjust them as needed.

The sections that follow explain these steps in detail and include important hints and tips for optimal non-contact mode operation.

Setting Up the System

Setting up the instrument to operate in NC-AFM mode consists of the following general procedures:

- Connecting cables.
- Installing the scanner.
- Loading a sample.
- Installing the probe head and a probe cartridge.
- Configuring the software.
- Aligning the deflection sensor.

These procedures are described in the sections below.

Connecting Cables

1. Connect a BNC cable between the frequency synthesizer (BNC) connector on the rear panel of the AEM and the NC CLOCK connector on the rear panel of the AutoProbe CP instrument.

   At the AEM, the cable is connected to the frequency synthesizer board, which supplies the driving signal for cantilever vibration.

2. Connect all other cables as described for contact-mode operation in this User's Guide.

Installing the Scanner

1. Install the scanner as described in Part I of this User's Guide.

> ***CAUTION***
>
> The power to the AEM must be turned OFF before you remove or install the scanner.

> ***CAUTION***
>
> The four screws that connect the scanner to the CP base unit must be securely fastened to ensure proper grounding. When the four screws are securely fastened, maximum instrument performance is ensured since vibrations are reduced.

Loading a Sample

1. Secure a sample onto a sample mounting disk and load the disk onto the sample holder as described in Part I of this User's Guide.

When you are learning NC-AFM imaging, use the calibration grating supplied with your system to take your first images. The periodic spacing of the grating features allows you to determine if the signal trace is stable and makes it easier to identify true surface topography as you practice varying scan conditions. The shape of the imaged spacings also tells you if the tip you are using is sharp enough for non-contact mode. (Alternatively, you can use a sample whose topography you have already determined, perhaps from an SEM micrograph or from a contact-mode AFM image.)

Installing the Probe Head and Probe Cartridge

1. Install the appropriate probe head by sliding it onto the support arms of the XY Translation Stage, as described in Part I of this User's Guide. Make sure that the LASER ON/OFF switch is in the OFF position before you install the probe head.

   If you have the standard AutoProbe CP system configuration: Install the NC-AFM probe head, which is labeled AFM/NC-AFM to distinguish it from other probe heads you may have. A connector on the rear of the probe head plugs into a connector on the back of the translation stage.

If you have the multitask AutoProbe CP system configuration: Install the multitask probe head, and set the two mode switches on the probe head to the AFM and NC-AFM positions.

2. Once the probe head is installed, turn the LASER ON/OFF switch to the ON position.

3. Insert a non-contact chip carrier onto the non-contact cartridge. The procedure for inserting a chip carrier is the same as for contact-mode AFM. Refer to Part I of this User's Guide for detailed instructions if needed.

   Installing an NC-AFM chip carrier involves selecting a cantilever. Cantilevers best suited for NC-AFM imaging have the following properties:

   - Sharp tip
   - High stiffness
   - Well-defined resonant frequencies

   Use non-contact chip carriers, with NC-AFM Ultralevers.

4. Insert the non-contact cartridge in the probe head as described in Part I of this User's Guide.

Configuring the Software

Turn on the instrument and open ProScan Data Acquisition by completing the following steps:

1. Turn on the AEM. The on/off button is located on the rear panel of the module.

2. Turn on the color video monitor. The on/off button is located on the front of the monitor, below the screen.

3. Turn the computer and the monitor on. The computer on/off switch is located on the front panel of the computer unit. The computer monitor on/off button is located on the front of the monitor, below the screen.

   When you start the computer, you automatically enter the Windows desktop.

4. Open ProScan Data Acquisition. From Start, point to the Program folder and select ThermoMicroscopes ProScan. Then, click the Data Acquisition icon. Alternatively, double click the Data Acquisition icon in the desktop.

   The program opens to Move mode.

5. Turn off the probe head by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

6. Open the ProScan Database Configuration dialog box by selecting Configure Parts from the Setup menu. Alternatively, click the Configure Parts icon, .

7. Configure the system software for a non-contact scan. To do this, make the following selections:

   - Head type: AFMNCM.
   - Scanner: Select the file that has the scanner calibration values for the scanner that you are using.
   - Head mode: NCM.
   - Beam bounce cantilever: Select the name of the file that corresponds to the cantilever you are using.
   - Electrochemistry ON/OFF: OFF.
   - Voltage mode: HI.

   After you finish entering these selections, click the OK button to return to Move mode.

8. Reset the Z stage as described in Chapter 2, Part I of this User's Guide. This synchronizes the position of the Z stage with the coordinate system of the software.

Aligning the Deflection Sensor

This section describes the procedures for aligning the deflection sensor for an AFM/NC-AFM probe head of a standard AutoProbe CP instrument. If you are using a multitask probe head, then the procedures for aligning the deflection sensor are described in the section "Aligning the Deflection Sensor" in Chapter 2, Part I of this User's Guide.

To align the deflection sensor for an AFM/NC-AFM probe head, you must first steer the laser beam so that it reflects off of the back of the cantilever. Then, you move the position-sensitive photodetector (PSPD) so that it is aligned with the laser spot.

The procedure for aligning the PSPD for the AFM/NC-AFM probe head is similar to that for the AFM probe head (refer to Part I of this User's Guide for details). However, the laser position and intensity indicator for the PSPD of the AFM/NC-AFM probe head is different, as shown in Figure 1-1.

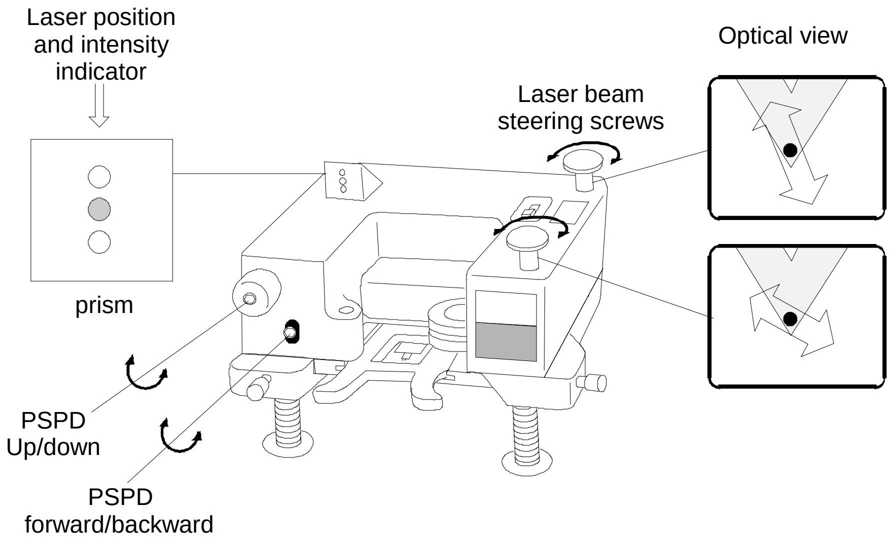


Figure 1-1. Location of the controls for aligning the deflection sensor on an AFM/NC-AFM probe head.

The position of the laser spot on the PSPD is indicated in the same way as for the AFM probe head, with a red light above and below the green light. For the AFM/NC-AFM probe head, however, the LED display of red and green lights shows the laser spot's intensity by the brightness of the center, green light, rather than with a separate column of red lights. The goal is to align the detector so that neither of the red lights is illuminated, and so that the green light is brightly illuminated.

Follow these steps to align the deflection sensor:

1. Make sure that the LASER ON/OFF switch on the probe head is set to the ON position.

2. Turn on the probe head by either selecting Head ON from the Mode menu or clicking the Head ON icon, . Always make sure that the tip is not in contact with the sample before turning the probe head on or off.

   Whenever you turn the probe head off and then back on again, a ProScan dialog box appears recommending that you re-set the NCM parameters. This recommendation is made because the phase adjustment of the cantilever vibration signal may become unsynchronized while the probe head is turned off.

   For now, since you have not yet set the NCM parameters, click the No button to close the dialog box.

3. Focus on the cantilever using the optical view as you normally do for contact-mode AFM operation.

4. If the laser beam is not reflecting off the back of the cantilever tip, then you need to adjust the position of the laser beam.

   Using the two laser beam steering screws, move the laser until you can see a red reflected spot on the back of the cantilever tip.

   Note: Don't try to maximize the brightness of the laser spot you see in the optical view. Your goal is to produce the maximum amount of reflected light hitting the PSPD. When the spot is positioned so that most of the laser beam is reflected onto the PSPD, the laser spot on the back of the cantilever is not necessarily bright.

   After this step, you may see one red LED or the green LED lit on the laser position and intensity indicator. Whether or not you see a light, continue on with the next step.

5. When the laser spot is reflecting off of the back of the cantilever tip, adjust the position of the PSPD to maximize the laser intensity incident on the PSPD.

   Note: Generally, if the deflection sensor has been previously aligned, *you only need to use the PSPD forward/backward screw*. You rarely need to use the PSPD up/down screw.

   Using the appropriately sized Allen wrench, adjust the PSPD forward/backward screw until the laser intensity hitting the PSPD is maximized. Maximum intensity is indicated when the green LED is brightly lit.

   The green LED is analog, and its brightness varies with the intensity of the laser spot hitting the PSPD. The two red LED's are digital. If either red LED is lit, then the laser is not positioned correctly. Usually, a quarter turn of the PSPD forward/backward screw switches between the two red lights. Somewhere between these two positions, the green LED lights up. When you see the green light, adjust the PSPD forward/backward screw slightly until the intensity of the green light is maximized.

   If you do not see any of the LED's light up, try adjusting the PSPD up/down screw. You may have to repeat Steps 4 and 5 until you see the green light and its brightness has been maximized.

Setting NCM Parameters

When you take a contact-AFM image, you specify values for scan parameters such as the scan rate, the scan size, and the gain. For a non-contact AFM image, you specify the following scan parameters in addition to the scan parameters that you set for contact-AFM imaging:

- Drive amplitude (drive % parameter)
- Drive frequency
- Imaging amplitude (set point parameter)

This section defines these scan parameters that are specific to NC-AFM imaging, and describes how to select their values. Sections that follow guide you in setting other scan parameters and then in taking an NC-AFM image.

The NC-AFM scan parameters are set in the NCM Frequency Set dialog box, which is displayed when you select NCM Frequency from the Setup menu. A drawing of this dialog box is shown in Figure 1-2.

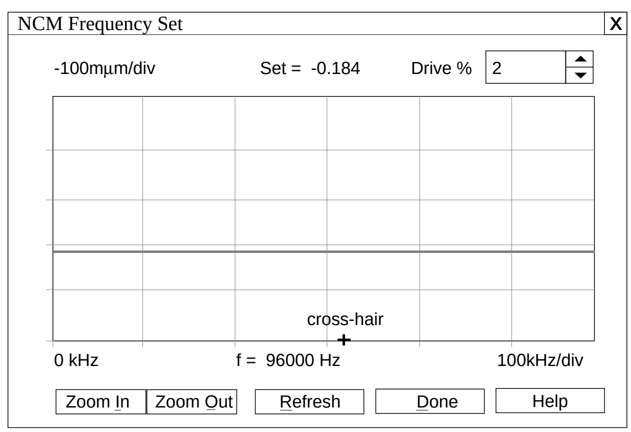


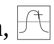
Figure 1-2. The NCM Frequency Set dialog box.

Selecting a Drive Amplitude

The **drive amplitude** is the amplitude of the AC signal from the sine wave generator that drives the cantilever to vibrate. To select the drive amplitude of the cantilever, you use the Drive % scrollbox at the top right of the NCM dialog box. The number displayed in the scrollbox is a percentage (0.1 to 100) of the allowable applied voltage to the oscillating cantilever.

The same applied voltage has different effects with each individual cantilever and cantilever mounting configuration.

If the drive amplitude is too small, then the cantilever will not be sufficiently sensitive to changes in the vibration amplitude during a scan. On the other hand, if the drive amplitude is too large, then the cantilever will be in intermittent contact with the surface. Increasing the drive amplitude too much may also cause the response curve to saturate on the NCM Frequency Set plot.

1. Open the NCM Frequency Set dialog box by selecting NCM Frequency from the Setup menu, or by clicking the NCM Frequency icon, .

2. Start with the default value of the drive % parameter, which is 25.

3. Click the Refresh button in the NCM dialog box. This prompts the system to generate a plot of the cantilever vibration amplitude as a function of drive frequency, or a frequency response curve for the cantilever. The default selected sweep range covers a large portion of the total sweep range, so that the system can locate the main cantilever resonance peak. An example is shown in Figure 1-3.

   Note: If you have already generated a frequency response curve in a given working session with the instrument software, then the frequency range covered when you click the Refresh button will match the range covered by the most recent sweep. If this range is not large enough to include the main resonance peak of your cantilever, click the Zoom Out button to sweep over a larger frequency range.

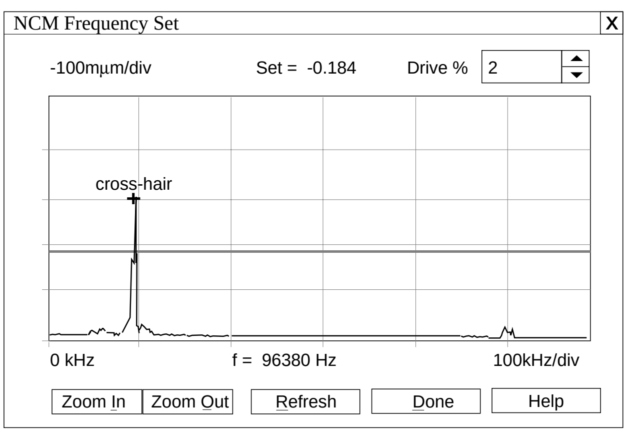


Figure 1-3. A frequency response curve for a typical NC-AFM cantilever.

The number of kHz per division for the horizontal axis is displayed at the right side of the line below the plot. The starting frequency is labeled below the lower-left corner of the plot. The units per division for the vertical axis represent cantilever oscillation amplitude, given in arbitrary units (eArbs) or units of distance if the Error signal sensitivity has been calibrated. They are displayed at the left side of the line above the plot.

Note: You may change the units of the vertical axis by selecting Servo Unit from the Setup menu, and then selecting a new unit from the Servo Set Point drop-down list.

If the frequency response curve saturates on the graph of the NCM dialog box, then you need to decrease the drive amplitude. Vary the value until the maximum peak height of the response curve is roughly one third of the full vertical scale on a zoomed-out sweep.

4. To change the drive amplitude, enter a percentage in the Drive % scrollbox of the NCM dialog box.

5. Press the `[Enter]` key so that the software recognizes the change, and click the Refresh button to see the change in the response curve.

You can also adjust the drive amplitude during a scan from within Image mode using the Drive % scrollbox.

Selecting a Drive Frequency

The **drive frequency** is the frequency of the AC signal from the sine wave generator that drives the cantilever vibration. For an NC-AFM image the drive frequency should be slightly greater than the frequency of the cantilever's main resonance peak.

When you prompt the system to generate a frequency response curve by clicking the Refresh button, it automatically determines the maximum cantilever resonance peak. The system then selects a single drive frequency lying just to the right of that peak for NC-AFM operation (within the top half of the peak, at the point with the steepest slope). This drive frequency is marked by a cross-hair.

The cantilever's main resonance peak should be at around 100 kHz, if you are using long NC-AFM Ultralevers. The cross-hair should lie just to the right side of the peak. The automatically selected drive frequency corresponding to this point is displayed at the center of the line below the plot.

You may want to make adjustments to the value of the drive frequency to optimize its position on the resonance peak. Follow these steps to select a drive frequency:

1. After the first sweep is finished, click the Zoom In button. This prompts the system to re-sweep over a smaller frequency range around the frequency marked by the cross-hair. Zoom in until the horizontal scale is divided into 5 kHz divisions, where the peak width is about one fourth of the full range on the plot. You should be able to check to see if the cross-hair at the peak is positioned near the true peak, or at a nearby, smaller peak.

   Zooming in on a peak shows much more structure, including multiple peaks and often split peaks. Since the plot has higher resolution, the optimum drive frequency (the point with the steepest slope) is reselected.

2. Vary the value of the drive % parameter until the maximum peak height of the response curve is roughly one third of the full vertical scale.

3. Examine the shape of the main resonance peak.

   The ideal peak to use should have the following properties:

   - The peak should be reasonably symmetric.
   - The peak should be narrow.
   - The peak should not have glitches or shoulders at the location of the cross hair.

   A broad peak may be due to a blunt cantilever tip and may result in a vibration amplitude that is too small (around 10 Å or less). As a result, the changes in amplitude as the tip approaches the sample will also be small and the cantilever will be less sensitive. Glitches (which are very sharp) may cause the system to select a less than optimum drive frequency. Multiple peaks may be due to vibrational modes of the cantilever in its mounted configuration.

4. If the main resonance peak is not reasonably symmetric or is broad, you should try switching to a different resonance peak. If there is another resonance peak with high amplitude near the main peak, move the cross hair just to the right side of that peak.

   To move to a different resonance peak, move the cursor, which appears as a larger cross-hair, to the new peak, and click the mouse button. The new drive frequency should be displayed in the line below the plot.

5. If you cannot find another peak with sufficient amplitude, then you should switch to a different cantilever. Remove the cartridge from the probe head and insert a new chip carrier as you normally do. Then repeat the system set-up procedures, starting from the step “Aligning the Deflection Sensor.”

6. When you have located the optimal resonance peak to use, check the location of the cross hair on the peak. For NC-AFM imaging, you can use the selected drive frequency, which lies on the right-hand side of the peak.

   The cross hair should not be located on a glitch or shoulder. If it is, then you can try re-sweeping (click the Refresh button) to see if the glitch is removed. You may also be able to move the cross hair to a slightly better location using the cursor as described before.

Figure 1-4 shows a zoomed-in version of the frequency response curve. The cross-hair positioned to the right of the main resonance peak marks the drive frequency that will be used for the scan. For this example, the selected drive frequency is 96260 Hz.

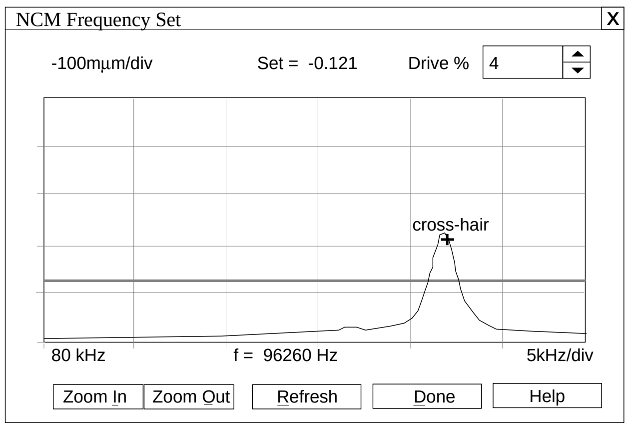


Figure 1-4. Response curve for a typical NC-AFM cantilever, with the horizontal scale expanded by the "zoom-in" operation.

Selecting an Imaging Amplitude

The **imaging amplitude** is the amplitude of cantilever vibration that is maintained by the system's feedback loop during a scan. The imaging amplitude is related to the absolute value of the set point parameter. Selecting a set point value is therefore equivalent to selecting a force gradient (or tip-to-sample spacing) that will be maintained during the scan, since the cantilever's vibration amplitude varies with the force gradient experienced by the cantilever.

For NC-AFM operation, the drive frequency lies on the right-hand side of the cantilever resonance peak. This choice of drive frequency means that the cantilever's vibration amplitude decreases with decreasing tip-to-sample spacing. (Refer to the section "How Non-Contact AFM Works" at the end of this chapter for details.) Since the absolute value of the set point parameter is related to the imaging amplitude, smaller absolute values of the set point parameter correspond to smaller tip-to-sample spacings.

The value of the set point parameter can be viewed graphically in the NCM dialog box as a horizontal red line that cuts across the response curve peak at about half of the maximum peak height. This is the default value of the set point parameter. You can adjust the value of the set point by using the mouse to drag the horizontal red line up or down on the plot. The set point parameter can be represented in units of micrometers or in arbitrary units (eArbs). When represented in arbitrary units, the value is a negative number between 0 and -2. The set point value is displayed in the top line of the NCM dialog box as, for example, Set = -0.075.

Note: You can change the units of the set point by selecting Servo Unit from the Setup menu, and then selecting a new unit from the Servo Set Point drop-down list. As mentioned in the earlier section "Selecting a Drive Frequency," changing the servo units also changes the vertical axis units for the frequency response curve in the NCM dialogue box.

1. For now, leave the set point parameter at its default value.

2. Click [Done] to close the NCM Frequency Set dialog box and return to Move mode.

You have now set all of the NCM parameters.

You can also adjust the set point parameter during a scan from the Image mode window. Since adjusting this parameter is equivalent to adjusting the tip-to-sample spacing, it is commonly used to optimize the Topography signal trace.

Again, the absolute value of the set point parameter corresponds to tip-to-sample spacing. The absolute value of the *default* set point parameter, and thus the tip-to-sample spacing corresponding to that set point value, is too large for the system to detect sample topography. In the next section, you will perform an auto approach and then incrementally decrease the absolute value of the set point parameter, bringing the tip closer to the sample until the sample topography is represented by the Topography signal trace, and that signal trace is optimized.

As a reminder, whenever you turn the probe head off and then back on again, remember to first withdraw the tip from the sample to protect the tip. When you turn the probe head back on before re-approaching the sample, a dialog box prompts you to set NCM parameters again. Re-setting NCM parameters means to re-sweep the frequency response curve while the tip is far from the sample, and re-select a drive frequency. The recommendation is made because the phase adjustment of the cantilever vibration signal may become unsynchronized while the probe head is turned off. When you re-sweep the response curve of the cantilever and then click the [Done] button, the phase is re-synchronized.

Performing an Auto Approach

1. To set up for an approach, select Approach from the Setup menu. This opens the Approach Parameters dialogue box. By default, the system is set up for an incremental approach. Select Quick, then click the Done button to register the change and close the dialogue box.

   Note: For details on setting approach parameters, refer to the section “Setup: Approach” in Part III, *Software Reference*, of this User’s Guide.

2. Perform a coarse approach by using the z direction pad to lower the probe head until the tip is within a few millimeters of the sample surface. Then, click the Approach button to initiate an auto approach.

   The first noise you hear is the system lifting the tip before the approach. Then, the system decreases the tip-to-sample spacing. The auto approach stops when the cantilever vibration amplitude matches that represented by the set point value displayed in Image mode.

   Note: If for any reason you want to re-select the drive frequency after the system has performed an auto approach, you need to lift the tip using the upper z direction pad. This positions the tip away from the sample so that its free space resonant frequency can be determined.

3. Switch to Image mode to view the Oscilloscope Display. If the Topography signal is not already selected, select it now from the Input Configuration dialogue box so that you can view the Topography signal trace on the Oscilloscope Display.

   Note: The Topography signal is named for its representation of sample topography in NC-AFM and IC-AFM modes. In all vibrating-cantilever modes (NC-AFM, IC-AFM, and MFM), the Topography signal is the signal generated by the feedback loop and applied to the scanner to maintain a constant force gradient between the tip and the sample. (Refer to the section “How Non-Contact AFM Works” for a discussion of the relationship between the force gradient and sample topography.)

4. The absolute value of the default set point parameter, and thus the tip-to-sample spacing that corresponds to the default set point value, is typically too large for the system to detect the sample topography. Begin now to incrementally decrease the absolute value of the set point parameter by clicking on the up arrow of the Set Point scrollbox.

   As you decrease the absolute value, monitor the Z Piezo bar (the green bar located below the Toolbar), which graphically represents the z position of the scanner within its total range of motion. The Z Piezo bar should show the scanner extending as you decrease the set point value, since the system is decreasing the tip-to-sample spacing as it attempts to match the lower set point value.

   If you see that the system is extending the scanner fully in its attempt to match the set point value, then you need to re-approach the sample. Re-approaching allows the system to use the motorized Z stage to decrease the tip-to-sample spacing.

5. Continue to incrementally decrease the set point value while watching both the Topography signal trace and the Z Piezo bar. Decrease the value until you see that the sample topography is represented by the signal trace and the scanner is operating roughly in the middle of its z range of motion. Re-approach, if necessary, to position the scanner optimally in the middle of its z range of motion.

   Each click of the mouse button on the Set Point scrollbox arrow changes the third decimal place of the number shown. You should find that there is a threshold set point value, above which you see no sample topography represented by the signal trace, and below which topography is represented. Stop decreasing the set point once you reach the threshold set point value.

   Note: The threshold set point value is roughly the same for the same sample and tip. So, if you take another image at a later time, you may want to start with an absolute set point value just slightly greater than the previously determined threshold set point value to save time.

In the next section, you will adjust other scan parameters, such as the gain. As you adjust these parameters, you may also want to adjust the set point value again to optimize the signal trace.

If you have trouble obtaining a signal trace that seems representative of the sample topography, try moving to a slightly different location on the sample surface, and then

repeating the approach procedure. If the approach is still unsuccessful, try the following troubleshooting tips:

- If there is an error message displayed in Message log at the bottom of the screen, read the message. There may be more than one problem that could generate a single error message. Systematically check possible causes of the error message to identify the problem.
- The auto approach may not be working because the PSPD is not properly aligned. An error message will state that either the A-B signal is too high, or the intensity of laser light on the PSPD (represented by the A+B signal) is too low. In this case, you can adjust the position of the PSPD while watching the indicator lights, as described in the earlier section “Aligning the Deflection Sensor.” Once the PSPD is properly aligned, the auto approach should work.

After trying the troubleshooting tips listed above, try again to perform an auto approach. After a successful approach, the signal trace should reflect the sample topography. If the approach is still unsuccessful, try using a different cantilever.

Setting Scan Parameters

This section describes factors to consider when setting and adjusting the scan size, scan rate, gain, and slope parameters. Adjustment of the NCM parameters was discussed in a previous section.

The purpose of adjusting the scan parameters is to obtain stable imaging conditions, which depends on obtaining a stable signal trace that is free of glitches, tip snap-ins, and saturated or truncated signals. Iterative adjustment of some of the parameters listed below is generally required in order to produce a high quality image:

- size
- rate
- set point
- gain
- slope

The design of the instrument supports adjusting all of the parameters listed above in real-time during a scan, without having to lift the tip.

Selecting a Scan Size

Choosing a scan size can be as simple as selecting a value so that the features you are interested in are represented in reasonable proportions. For example, if you are using a 1 μm calibration grating, you may choose a scan size of about 20 to 50 μm so that you can see several lines of the grating.

However, the scan size you select is also one of the factors that determines the lateral resolution of an image. Other such factors include the following:

- the effective tip radius
- the digitized step size of the scanner
- the x-y detector resolution (if ScanMaster is enabled)
- the number of data points per scan line (e.g., 256 or 512)

As a rule of thumb, *you should not select a scan size that is smaller than the lateral resolution (as limited by any of the above factors) multiplied by the number of data points per scan line.* Selecting a smaller scan size will only result in adjacent data points containing repeated information. For example, if the lateral resolution is limited by the x-y detector to be 20 nm, and a scan size is selected such that each data point covers 10 nm, then the z value for two adjacent data points may be repeated.

For more details about how the above-listed factors affect the lateral resolution of your images, refer to the section "Why You Need Low-Voltage Mode: Lateral Resolution," in Chapter 4, Part I of your User's Guide. The information in that section should help you in choosing an optimum scan size.

1. Select a scan size. Type in a value and then press the `[Enter]` key on your keyboard.

2. Select a number of data points and a fast scan direction for your image.

   You select the number of data points per image (e.g., 256x256 or 512x512) from the Input Configuration dialog box. You select the fast scan direction using the X and Y option buttons of the Image mode window.

Selecting a Scan Rate

In general, as the scan size is increased, the scanning *velocity* is also increased (a longer line is scanned at the same scan rate, so the tip travels faster over the sample). Therefore, large scan sizes may be better imaged by decreasing the scan rate, in order to decrease the scanning velocity of the tip over the sample.

If the scan rate is set too high, the feedback will not have sufficient time to respond to the surface topography. The result will be poor surface tracking, and the tip may crash into protrusions on the surface.

In non-contact mode, slower scan rates are required to give the system more time to respond to changes in surface topography. A good range of scan rates to use is from about 0.5 Hz for more difficult samples (with large variations in topography) to about 2 Hz for flat samples.

1. Select a scan rate. Type in a value and then press the `[Enter]` key on your keyboard.

Setting the Gain

The gain (the gain of the feedback loop) is a parameter that controls how much the Error signal is amplified before being used to generate the feedback signal to the scanner. Higher gain values mean that the feedback loop is more sensitive to changes in the force gradient experienced by the cantilever. Surface features can then be tracked more closely.

If the gain is too high, however, then the feedback signal will fluctuate too strongly in response to small changes, and the system will oscillate. Feedback oscillations show up on the signal trace as fringes or ripples. If the gain is set too low, on the other hand, then the z feedback will not be able to track surface topography properly. When surface tracking is poor, surface features can appear lopsided or the tip can hit features on the surface.

1. Check the signal trace for feedback oscillations.

2. If you see feedback oscillations in the signal trace on the Oscilloscope Display, try the following methods to remove them:
   - ♦ Reduce the gain parameter. (Try this first.)
   - ♦ Move the tip further away from the surface by increasing the absolute value of the set point parameter (i.e., make the set point more negative).
   - ♦ Reduce the drive amplitude (the drive % parameter).

3. Then, to improve surface tracking, try making small adjustments to increase the gain or vary the set point value incrementally until the signal trace is optimized. Reducing the scan rate can also improve surface tracking.

Adjusting the X and Y Slope

If you are taking an image and the x direction is set to be the fast scan direction, then adjusting the slope parameter in Image mode adjusts the x slope. If the y direction is set to be the fast scan direction, then adjusting the slope adjusts the y slope. You can adjust both the x and y slopes of an image by using the x and y option buttons to toggle the fast scan direction between x and y and adjusting the slope parameter for each direction.

1. While looking at the Topography signal trace on the Oscilloscope Display, adjust the slope parameter to make sure that the signal trace is level.

Starting a Scan

After you have set and/or adjusted the scan parameters listed in the previous sections so that the Topography signal trace in the Oscilloscope Display is stable and repeatable, start taking an image.

1. Click the Image button below the Oscilloscope Display to start a scan.

You may need to adjust scan parameters while a scan is being taken to obtain an optimized image.

In non-contact mode, the vibrating cantilever should be brought as close as possible to the sample surface without touching. This means operating with a small set point absolute value. The closer the cantilever tip is to the surface, the higher the lateral resolution will be.

However, if the cantilever is brought too close, the attractive force becomes strong enough to damp the cantilever vibration and even pull the tip down into the surface. In addition, if the amplitude is too small, the system will not be able to track drop-offs in sample topography, and trailing edges of topographic features may not be resolved on an image.

Avoiding Snap-ins and Glitches

The most common problem when imaging in non-contact mode is that the tip hits the surface. If the tip is too close to the surface during a scan, the strong attractive force can damp the vibrations. When the tip is either hitting the surface or is too close to it, glitches can occur in the signal trace on the Oscilloscope Display and the signal trace can become unstable. If the tip is too close to the surface, you can increase the absolute value of the set point parameter (i.e., make it more negative) to increase the tip-to-sample spacing.

If adjusting the set point value doesn't help, then adjust the drive % or the gain as described earlier in the sections "Selecting a Drive Amplitude" and "Setting the Gain," respectively. Compare the forward and reverse Topography signal traces for asymmetries. When the scan parameters are optimized, the forward and reverse signal traces should appear similar, and they should be stable and repeatable.

If adjusting scan parameters does not result in a better image, then try changing the cantilever—it may not be suitable for your purposes. A damaged tip affects the cantilever frequency response, resulting in broad, flat resonant peaks instead of sharp peaks. If the tip accumulates particles after hitting the surface, then the extra mass on the tip can also affect the cantilever frequency response.

Taking an IC-AFM Image

This section leads you step-by-step through the process of taking an IC-AFM image. Because many of the procedures for obtaining IC-AFM images are similar to those for obtaining NC-AFM images, this section refers you to “Taking an NC-AFM Image,” where applicable. It is assumed that you have read “Taking an NC-AFM Image,” and are familiar with taking NC-AFM images.

Summary of the Procedure

The following steps summarize the procedures for taking an IC-AFM image and can also be used as a quick reference:

Step 1: Set up the system.

1. Set up the instrument as for an NC-AFM scan.

Step 2: Set NCM parameters.

1. Under the Setup menu of the Image mode window, select NCM Frequency to view the NCM Frequency Set dialog box.

2. Select a drive frequency, drive amplitude (drive %), and imaging amplitude (set point) for the scan. The drive frequency you choose should be on the left side of the cantilever’s main resonance peak.

Step 3: Perform an auto approach.

1. In Move mode, use the z direction pad to lower the tip so that it is close to the sample.

2. Click the [Approach] button to initiate an auto approach. The auto approach stops when the cantilever’s vibration amplitude matches the value represented by the set point parameter displayed on the Image mode window.

3. Enter Image mode to view a Topography signal trace.

4. Optimize the set point parameter by iteratively reducing the set point while monitoring the Topography signal trace and the Z Piezo bar. Re-approach the sample if necessary.

Step 4: Set scan parameters.

1. Set the scan rate, scan size, number of data points per image, and fast scan direction.

2. Adjust the drive %, set point, gain, and slope parameters if necessary.

Step 5: Start a scan.

1. Click the Image button to begin acquiring an image.

2. While imaging, continue to monitor the scan parameters and adjust them as needed.

The sections that follow explain these steps in detail and include important hints and tips for optimal intermittent-contact mode operation.

Setting Up the System

The procedures for setting up the instrument for IC-AFM are identical to those for NC-AFM. Refer to the section “Taking an NC-AFM Image” earlier in this chapter.

Setting NCM Parameters

For an intermittent-contact AFM image, you specify the following scan parameters:

- Drive amplitude (drive % parameter)
- Drive frequency
- Imaging amplitude (set point parameter)

These scan parameters are set in the NCM dialog box, which is displayed when you select NCM Frequency from the Setup menu.

Selecting a Drive Amplitude

The drive amplitude is the amplitude of the AC signal from the sine wave generator that drives the cantilever to vibrate. To select the drive amplitude of the cantilever, you use the Drive % scrollbox at the top right of the NCM dialog box. The number displayed in the scrollbox is a percentage (0.1 to 100) of the allowable applied voltage to the oscillating cantilever.

The best IC-AFM results are usually obtained with larger oscillation amplitudes than those used in NC-AFM operation. This is because larger amplitudes (i.e., more resonant energy applied to the cantilever) are more effective at avoiding unstable operation due to erratic tip “snap-ins” caused by mesoscopic water layers and unusually large electrostatic effects.

To select a drive amplitude, do the following:

1. Open the NCM Frequency Set dialog box by selecting NCM Frequency from the Setup menu, or by clicking the NCM Frequency icon, .
2. Start with the default value of the drive % parameter, which is 25%. Generate a frequency response curve in the NCM Frequency Set dialog box as described in the section “Selecting a Drive Amplitude” for NC-AFM imaging.

If the frequency response curve saturates on the graph of the NCM dialog box, then you need to decrease the drive amplitude. Vary the value until the maximum peak height of the response curve is roughly half of the full vertical scale on the zoomed-out sweep.

3. To change the drive amplitude, enter a percentage in the Drive % scrollbox of the NCM dialog box.
4. Press the `[Enter]` key so that the software recognizes the change, and click the Refresh button to see the change in the response curve.

You can also adjust the drive amplitude during a scan from within Image mode by changing the drive % parameter.

Selecting a Drive Frequency

The drive frequency is the frequency of the AC signal from the sine wave generator that drives the cantilever vibration. For IC-AFM imaging the drive frequency should be slightly less than, or on the left side of, the frequency of the cantilever’s main resonance peak.

For drive frequencies on the left-hand side of the resonance peak, the cantilever vibration amplitude *increases* as the tip is brought closer to the sample. (For a detailed discussion of the relationship between the drive frequency and the vibration amplitude, refer to the section “How Intermittent-Contact AFM Works” at the end of this chapter.) The increasing vibration amplitude helps produce intermittent contact between the tip and the sample.

To select a drive frequency, do the following:

1. Follow the steps of the section “Selecting a Drive Frequency” for NC-AFM imaging to identify the main resonance peak of the cantilever.

2. When you have located the optimal resonance peak to use, zoom in on the frequency response curve until the horizontal scale is divided into 5 kHz divisions.

3. Vary the drive % value until the maximum peak height of the response curve is roughly one half of the full vertical scale.

4. Check the location of the cross hair on the peak. For IC-AFM imaging, move the cross-hair to the left-hand side of the peak.

   The cross hair should not be located on a glitch or shoulder. If it is, then you can try resweeping (click the Refresh button) to see if the glitch is removed. You may also be able to move the cross hair to a slightly better location using the cursor.

Figure 1-5 shows a zoomed-in version of the frequency response curve. The cross-hair positioned to the left of the main resonance peak marks the drive frequency that will be used for the scan. For this example, the selected drive frequency is 96260 Hz.

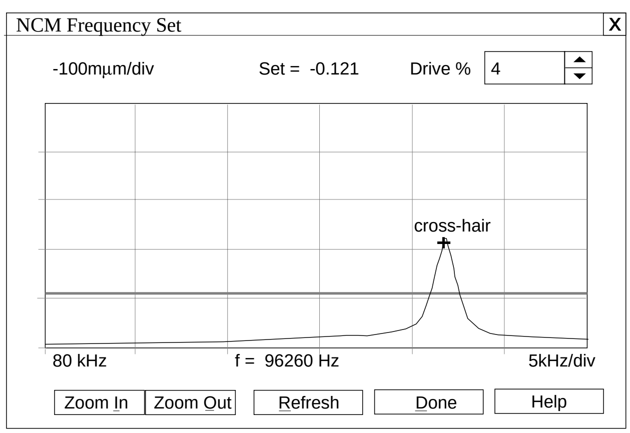


Figure 1-5. Response curve for a typical IC-AFM cantilever, with the horizontal scale expanded by the “zoom-in” operation.

Selecting an Imaging Amplitude

The imaging amplitude, represented by the set point parameter, is the amplitude of cantilever vibration that the z feedback loop tries to attain during an auto approach and to maintain during a scan.

The system's feedback loop is designed for non-contact imaging: the system expects the amplitude of cantilever vibration to *decrease* with decreasing tip-to-sample spacing, and so smaller absolute values of the set point parameter cause the scanner to extend. However, for IC-AFM, since the drive frequency lies on the left side of the resonance peak, the amplitude of cantilever vibration *increases* as the tip is brought closer to the sample. (See the section "How Intermittent-Contact AFM Works" at the end of this chapter for details.) Thus, to operate in IC-AFM mode you decrease the absolute value of the set point until intermittent contact between the tip and the sample is achieved. Because of the damping effects of contact between the tip and the sample, the amplitude of cantilever vibration decreases after intermittent contact is made, and the set point value is matched.

You can adjust the set point parameter graphically in the NCM dialog box. It is represented by a horizontal red line that cuts across the response curve peak at about half of the maximum peak height. This is the default value of the set point parameter. You can change this value by using the mouse to drag the horizontal line up or down on the plot. The set point parameter can be represented in units of micrometers or in arbitrary units (eArbs). When represented in arbitrary units, the value is a negative number between 0 and -2. The set point value is displayed in the top line of the NCM dialog box as, for example, Set = -0.121.

1. For now, leave the set point parameter at its default value.

2. Click Done to close the NCM Frequency Set dialog box and return to Move mode.

You have now set all of the NCM parameters.

You can also adjust the set point parameter during a scan from the Image mode window. Since adjusting this parameter is equivalent to adjusting the tip-to-sample spacing, it is commonly used to optimize the Topography signal trace.

The absolute value of the default set point is too large for the system to detect sample topography. In the next section, you will perform an auto approach. Then, you will incrementally decrease the absolute value of the set point parameter, bringing the tip closer to the sample until the tip and the sample come into intermittent contact and the sample topography is represented by the Topography signal trace.

Performing an Auto Approach

1. To set up for an approach, select Approach from the Setup menu. This opens the Approach Parameters dialogue box. By default, the system is set up for an incremental approach. Select Quick, then click the Done button to register the change and close the dialogue box.

   Note: For details on setting approach parameters, refer to the section "Setup: Approach" in Part III, *Software Reference*, of this User's Guide.

2. Perform a coarse approach by using the z direction pad to lower the probe head until the tip is within a few millimeters of the sample surface. Then, click the Approach button to initiate an auto approach.

   The first noise you hear is the system lifting the tip before the approach. Then, the system decreases the tip-to-sample spacing. The auto approach stops when the cantilever vibration amplitude (the probe signal) matches that represented by the set point value displayed in Image mode.

   Note: If for any reason you want to re-select the drive frequency after the system has performed an auto approach, you need to lift the tip using the upper z direction pad. This positions the tip away from the sample so that its free space resonant frequency can be determined.

3. Switch to Image mode to view the Oscilloscope Display. If the Topography signal is not already selected, select it now from the Input Configuration dialogue box so that you can view the Topography signal trace on the Oscilloscope Display.

4. The absolute value of the default set point parameter, and thus the tip-to-sample spacing that corresponds to the default set point value, is typically too large for the system to detect the sample topography. Begin now to incrementally decrease the absolute value of the set point parameter by clicking on the up arrow of the Set Point scrollbox.

   As mentioned in the previous section, decreasing the set point absolute value causes the scanner to extend. As you decrease the value, monitor the Z Piezo bar (the green bar located below the Toolbar), which graphically represents the z position of the scanner within its total range of motion. The Z Piezo bar should show the scanner extending as you decrease the set point absolute value.

5. Decrease the set point parameter and re-approach the sample if necessary until the tip and the sample are in intermittent contact, the sample topography is represented by the Topography signal trace, and the Z Piezo bar shows that the scanner is operating in the middle of its z range.

6. If you have trouble obtaining a signal trace that is representative of the sample topography, try moving to a different location on the sample surface, and then repeat the approach procedure. If you still have trouble, try the troubleshooting tips listed in the section "Performing an Auto Approach" for NC-AFM imaging.

Setting Scan Parameters

1. Select a scan size, scan rate, number of data points per image, and a fast scan direction as described for taking an NC-AFM image.

2. Adjust the gain, set point, and slope parameters, if necessary.

The purpose of adjusting the scan parameters is to obtain stable imaging conditions, which depends on obtaining a stable signal trace that is free of glitches, tip snap-ins, and saturated or truncated signals. Iterative adjustment of some of the parameters listed below is generally required in order to produce a high quality image:

- size
- rate
- set point
- gain
- slope

The design of the instrument supports adjusting all of the parameters listed above in real-time during a scan, without having to lift the tip. Adjust the parameters using the same guiding principles as described in "Taking an NC-AFM Image."

Starting a Scan

After you have set and/or adjusted the scan parameters listed in the previous section so that the Topography signal trace in the Oscilloscope Display is stable and repeatable, start taking an image.

1. Click the Image button below the Oscilloscope Display to start a scan.

You may need to adjust the drive amplitude (the drive % value) or the imaging amplitude (the set point value) while a scan is being taken. Larger drive/imaging amplitudes may work best for imaging steep features on rough samples. However, if the drive amplitude is too large, it may exceed the lock-in amplifier's input range. The lock-in amplifier detects the AC signals from the signal generator and the cantilever. If the signal trace becomes flat during imaging, this may be due to amplifier saturation.

2. If you see that the signal trace shows saturation, do the following:

- ♦ Lift the tip.
- ♦ Generate a new frequency response curve in the NCM dialog box and re-select the drive frequency.
- ♦ Reduce the drive % parameter and/or the set point parameter.

The best results in IC-AFM mode are normally obtained after some practice. On very soft or “sticky” samples, one usually has to acquire some experience with IC-AFM and the specific sample before obtaining the best possible images. If the sample does not image well after some experimentation, then NC-AFM may be required.

Taking an MFM Image

This section leads you step-by-step through the process of taking an MFM image of the hard disk sample included in your MFM toolkit. It assumes that you have read through the section “Taking an NC-AFM Image,” and are familiar with the procedures described there. This section refers to “Taking an NC-AFM Image” where applicable.

The procedures for taking an MFM image are very similar to those for taking an NC-AFM image. For MFM imaging, however, you adjust the set point parameter so that the tip-to-sample spacing is larger than that for NC-AFM imaging. In this distance regime, the gradient of the magnetic force is dominant over the gradient of the van der Waals force. (Refer to the section “How Magnetic Force Microscopy works,” at the end of this chapter, for details.) Thus, an image taken using the Topography signal represents magnetic features on the sample surface.

Once you are familiar with the basic procedures for taking an MFM image, you can move ahead to additional sections that describe using other signals to learn more about the magnetic properties of your sample. You can also find out how to take follow-up images of sample topography using either contact or non-contact AFM methods, and how to apply an electrostatic bias between the tip and the sample.

Summary of the Procedure

The following steps summarize the procedures for taking an MFM image and can also be used as a quick reference:

Step 1: Set up the system.

1. Connect cables and install a scanner, as for NC-AFM operation.

2. Mount a sample on the non-magnetic sample holder.

3. Install the sample holder on the scanner.

4. Install the appropriate probe head and an MFM probe cartridge.

   - ♦ If you have the standard AutoProbe CP system configuration: Install the AFM/NC-AFM probe head.
   - ♦ If you have the multitask AutoProbe CP system configuration: Install the multitask probe head and set the two mode switches on the probe head to the AFM and NC-AFM positions.
   - ♦ Load an MFM chip carrier onto the NC-AFM probe cartridge.
   - ♦ Load the cartridge in the probe head.

5. Turn on the AEM, the computer, and the monitors and set up the system software.

6. Align the deflection sensor.

Step 2: Set NCM parameters.

1. Under the Setup menu of the Image mode window, select NCM Frequency to view the NCM (Non-Contact Mode) Frequency Set dialog box.

2. Select a drive frequency, drive amplitude (drive %), and imaging amplitude (set point) for the scan.

Step 3: Perform an auto approach.

1. In Move mode, use the z direction pad to lower the tip so that it is close to the sample.

2. Click the Approach button to initiate an auto approach. The auto approach stops when the cantilever's vibration amplitude matches the value represented by the set point parameter displayed on the Image mode window.

3. Enter Image mode to view a Topography signal trace.

4. Reduce the absolute value of the set point parameter until you see magnetic features of the sample surface represented by the Topography signal trace.

5. Continue to reduce the set point absolute value until you see oscillations on the signal trace. Increase the set point absolute value just enough to remove the oscillations.

Step 4: Set scan parameters.

1. Set the scan rate, scan size, number of data points per image, and fast scan direction.

2. Adjust the drive %, set point, gain, and slope parameters if necessary.

Step 5: Start a scan.

1. Select additional signal channels for viewing, if desired.

2. Click the Image button to begin acquiring an MFM image.

3. While imaging, continue to monitor and adjust the scan parameters.

The sections that follow explain these steps in detail and include important hints and tips for optimal MFM operation.

Setting Up the System

The procedures for setting up your AutoProbe instrument for MFM operation are similar to those for NC-AFM operation. This section describes special instructions that relate to the magnetic sample and tip. Refer to the section “Taking an NC-AFM Image” in this chapter for the remaining set-up procedures.

Loading a Sample

The standard sample holder provided with your AutoProbe CP instrument contains a magnet that holds the sample mounting disk to the holder. Therefore, it may create problems of magnetic interference as you take MFM images, and it may also damage your magnetic samples. For the best MFM results you should replace the standard magnetic sample holder on the scanner with a non-magnetic, MFM sample holder. You may mount the sample (e.g., the piece of commercial hard disk that is included in your MFM toolkit) on the MFM sample holder either before or after installing the sample holder on the scanner.

Unlike the standard sample holder, the MFM sample holder does not use a sample mounting disk to hold the sample. Instead, the sample is mounted directly onto the holder, and you should attach the sample in such a way that it can be removed.

There are at least two ways to mount a magnetic sample to the MFM sample holder:

- Use double-sided tape.
- Use the clips provided in your MFM toolkit to clip the sample directly to the sample holder.

To install an MFM sample holder:

1. Unscrew the standard sample holder and set it aside.

2. Screw the MFM sample holder into the scanner, making sure that there is contact between the spring-loaded electrical contact in the scanner and the sample holder.

Installing the Probe Head and Probe Cartridge

1. Install the appropriate probe head by sliding it onto the support arms of the XY Translation Stage, as described in Part I of this User's Guide. Make sure that the LASER ON/OFF switch is in the OFF position before you install the probe head.

   If you have the standard AutoProbe CP system configuration: Install the NC-AFM probe head, which is labeled AFM/NC-AFM to distinguish it from other probe heads you may have. A connector on the rear of the probe head plugs into a connector on the back of the translation stage.

   If you have the multitask AutoProbe CP system configuration: Install the multitask probe head, and set the two mode switches on the probe head to the AFM and NC-AFM positions.

   Once the probe head is installed, turn the LASER ON/OFF switch to the ON position.

2. Select a cantilever. For MFM imaging, we recommend that you use MFM Microlevers. The resonant frequency for MFM Microlevers is typically around 85 kHz.

   Before loading the MFM cantilever, pass the cantilever tip between the poles of the tip magnetizer provided with your MFM toolkit. The tip magnetizer is a strong magnet that magnetizes the tip in order to maximize its interaction with the magnetic sample.

3. Insert the MFM chip carrier onto a non-contact cartridge. The procedure for inserting a chip carrier is the same as for contact-mode AFM. Refer to Part I of this User's Guide for detailed instructions if needed.

4. Insert the probe cartridge in the probe head as described in Part I of this User's Guide.

Configuring the Software

Configure the software as described in the section "Taking an NC-AFM Image" in this chapter.

Aligning the Deflection Sensor

Align the deflection sensor as described in the section "Taking an NC-AFM Image" in this chapter.

Setting NCM Parameters

The procedure for setting NCM parameters—drive frequency, drive amplitude, and imaging amplitude—for taking an MFM image are very similar to those for taking an NC-AFM image. The drive frequency and drive amplitude can be set to the same values as for NC-AFM imaging. Also, you can start by using the default value of the set point parameter, as for NC-AFM imaging.

After you approach the sample with the default value of the set point parameter, you decrease the absolute value of the set point until you see oscillations in the Topography signal trace. This process is described in more detail in the section that follows, "Performing an Auto Approach."

1. Open the NCM Frequency Set dialog box by selecting NCM Frequency from the Setup menu, or by clicking the NCM Frequency icon, .

2. Set the drive % parameter as for taking an NC-AFM image: The default value of the drive amplitude (the drive % parameter) is 25%. Vary the value until the maximum peak height of the response curve is roughly one third of the full vertical scale.

3. Select a drive frequency as for taking an NC-AFM image.

4. Leave the set point parameter at its default value.

5. Click Done to close the NCM Frequency Set dialog box and return to Move mode.

You have now set all of the NCM parameters.

Performing an Auto Approach

1. To set up for an approach, select Approach from the Setup menu. This opens the Approach Parameters dialogue box. By default, the system is set up for an incremental approach. Select Quick, then click the [Done] button to register the change and close the dialogue box.

   Note: For details on setting approach parameters, refer to the section “Setup: Approach” in Part III, *Software Reference*, of this User’s Guide.

2. Perform a coarse approach by using the z direction pad to lower the probe head until the tip is within a few millimeters of the sample surface. Then, click the [Approach] button to initiate an auto approach.

   The first noise you hear is the system lifting the tip before the approach. Then, the system decreases the tip-to-sample spacing. The auto approach stops when the cantilever vibration amplitude matches that represented by the set point value displayed in Image mode.

   Note: If for any reason you want to re-select the drive frequency after the system has performed an auto approach, you need to lift the tip using the upper z direction pad. This positions the tip away from the sample so that its free space resonant frequency can be determined.

3. Switch to Image mode to view the Oscilloscope Display. If the Topography signal is not already selected, select it now from the Input Configuration dialogue box so that you can view the Topography signal trace on the Oscilloscope Display. Also from within the Input Configuration dialogue box, select both the right and left scan directions for the Topography signal.

   Note: The Topography signal is named for its representation of sample topography in NC-AFM and IC-AFM modes. In all vibrating-cantilever modes (NC-AFM, IC-AFM, and MFM), the Topography signal is the signal that comes from the feedback electronics and controls the z position of the scanner, so that a constant force gradient between the tip and the sample is maintained. (Refer to the section “How Non-Contact AFM Works” for a discussion of the relationship between the force gradient and sample topography.) In MFM mode, magnetic samples and a magnetized tip are used. Therefore, the force gradient, and thus the Topography signal, may be dominated by magnetic rather than topographic features on the sample surface.

4. The absolute value of the default set point parameter typically sets the tip far enough away from the sample surface that neither magnetic nor topographic features appear on the Topography signal trace. At this distance, the Topography signal represents long-range, air-damping effects on the cantilever, which are not consistent between the left-to-right and right-to-left signal traces. Monitor the left-to-right and right-to-left Topography signal traces. Lack of correlation is an indication that the tip is too far away from the sample to detect magnetic features.

5. Begin now to incrementally decrease the absolute value of the set point parameter by clicking on the up arrow of the Set Point scrollbox. Continue to monitor the Topography signal traces in both directions. When the left-to-right and right-to-left signal traces overlap, the tip has entered the distance regime in which the Topography signal represents features on the sample surface. For samples that are not magnetically weak, the magnetic force gradient is dominant over the van der Waals force gradient far from the sample. Thus, the first features to appear represent magnetic properties of the sample, not topographic features. (See the section “How Magnetic Force Microscopy Works” for details.)

6. As you decrease the set point value, monitor the Z Piezo bar (the green bar located below the Toolbar), which graphically represents the z position of the scanner within its total range of motion. The Z Piezo bar should show the scanner extending as you decrease the set point value, since the system is decreasing the tip-to-sample spacing as it attempts to match the lower set point value.

   If you see that the system is extending the scanner fully in its attempt to match the set point value, then you need to re-approach the sample. Re-approaching allows the system to use the motorized Z stage to decrease the tip-to-sample spacing.

7. Continue to incrementally decrease the set point value while watching both the Topography signal trace and the Z Piezo bar. Re-approach the sample, if necessary, to position the scanner so that it is at the middle of its range of z extension when the auto approach stops.

Depending on the interaction between the tip and sample you are using and on the value of the gain parameter, you may see oscillations, spikes, or glitches appear on the Topography signal trace as you decrease the set point value. Oscillations can occur if the gain value is too high for the tip-to-sample spacing corresponding with the set point value. If this is the case, the system may overreact as it attempts to maintain a constant force gradient, causing it to oscillate. Spikes or glitches can result if the tip is pulled into contact with the sample by strong magnetic forces.

In some cases, you can use the appearance of oscillations or spikes to help you optimize the set point parameter, as it can mark the boundary between the dominance of magnetic and topographic effects. At this boundary point, the van der Waals force gradient increases abruptly. Even small changes in the tip-to-sample spacing result in large changes in the Topography signal, causing the system to oscillate or resulting in tip snap-ins.

8. As you click on the up arrow of the Set Point scrollbox to decrease the set point absolute value, note that each click of the mouse button changes the third decimal place of the number shown. You may find that there is a specific set point absolute value below which oscillations appear on the signal trace. If this is the case, stop decreasing the set point once you reach this set point value. If no oscillations or spikes appear on the signal trace, stop reducing the set point once the signal trace is stable and repeatable.

   If oscillations do appear on the signal trace, click on the down arrow of the Set Point scrollbox a few times to increase the set point absolute value. This backs the tip away from the sample. Back off until oscillations no longer appear on the signal trace.

   Note: While operating closer to the sample is generally better as it affords higher lateral resolution, for MFM mode the lateral resolution is most likely limited by the radius of the coated tip, which is typically on the order of 50 nm. Thus, operating with an average tip-to-sample spacing outside the van der Waals regime (roughly 5 to 10 nm) and up to 50 nm does not sacrifice lateral resolution of magnetic features.

The set point is now optimized. You are ready to adjust other scan parameters and take an MFM image.

Setting Scan Parameters

1. Select a scan size, scan rate, number of data points per image, and a fast scan direction as described for taking an NC-AFM image.

2. Adjust the gain, set point, and slope parameters, if necessary.

The purpose of adjusting the scan parameters is to obtain stable imaging conditions, which depends on obtaining a stable signal trace that is free of glitches, tip snap-ins, and saturated or truncated signals. Iterative adjustment of some of the parameters listed below is generally required in order to produce a high quality image:

- size
- rate
- set point
- gain
- slope

The design of the instrument supports adjusting all of the parameters listed above in real-time during a scan, without having to lift the tip. Adjust the parameters using the same guiding principles as described in “Taking an NC-AFM Image.”

At this point, you can skip ahead to the next section and take an image. Or, you can practice varying the value of the gain parameter to see its effect on the signal trace.

When you performed an auto approach, you used the default value of the gain. Now, you can try increasing to a higher gain value to make sure that the Topography signal trace represents purely magnetic, not topographic, features on the sample surface, and to make sure that the system tracks the set point value closely. To operate with a higher gain value, do the following:

3. Back the tip away from the sample by increasing the absolute value of the set point parameter.

4. Increase the gain from its default value to a higher value. For example, set the gain to 5.

5. Next, decrease the absolute value of the set point parameter incrementally, as you did before. Since the gain is set to a higher value, if oscillations appear they should be more pronounced. It should be easier to identify the regime where the van der Waals force gradient begins to dominate the magnetic force gradient.

6. Experiment with the gain parameter, checking to see if the features shown on the signal trace change depending on the gain value. Choose a gain value that generates a signal trace representing magnetic information only, with no superposition of topographic information.

   As you adjust the gain, you can also monitor the Probe Signal bar displayed underneath the Toolbar. The yellow band on the Probe Signal bar represents the probe signal as it varies about the set point value, which is represented by the red line. Higher gain values tend to tighten the excursion of the probe signal from the set point value, since the system tracks the set point more closely. This tightening of the probe signal about the set point value should be apparent as a narrowing of the yellow band about the red line.

You are now ready to start a scan.

Starting a Scan

After you have set and/or adjusted the scan parameters listed in the previous sections so that the Topography signal trace in the Oscilloscope Display is stable and repeatable, you are ready to start taking an image.

1. Click the [Image] button below the Oscilloscope Display to start a scan.

You may need to adjust some of the scan parameters while a scan is being taken. Try adjusting the set point, drive %, and gain parameters to optimize the image.

Taking Images of Other Signals

In addition to the Topography signal, there are other signals that can be useful when you are taking images of magnetic samples. These other signals include the MFM Amplitude signal, the MFM Phase signal, and the Magnetic Force signal. This section describes how to set up to take an image using each of these signals, and it explains how each type of image can be useful.

Taking an Image Using the MFM Amplitude Signal

The MFM Amplitude signal represents the amplitude of cantilever vibration. This amplitude is a function of the gradient of the force between the tip and the sample (see the later section “How Magnetic Force Microscopy Works” for details). For MFM imaging, larger tip-to-sample spacings are used than for NC-AFM imaging. In this distance regime, the force gradient is dominated by the magnetic force. The MFM Amplitude signal accentuates edges of magnetic domains on an image, and thus may help you to distinguish these domains.

The MFM Amplitude signal is the input signal to the feedback loop, analogous to the probe signal (representing cantilever deflection) in contact-AFM mode. By comparison, the Topography signal is the signal sent to the scanner to maintain a constant cantilever oscillation amplitude. The Topography signal is produced by taking the Error signal, which is the difference between the MFM Amplitude signal and the set point, and sending it through feedback electronics which include proportional and integral amplifiers.

When you take an MFM image using the Topography signal, you set the gain so that the system tracks changes in the force gradient. For vibrating cantilever methods, the Topography signal is used to take images that are analogous to constant-force mode images in contact-AFM mode.

When you take an MFM image using the MFM Amplitude signal, you set the gain to a low value so that the system's feedback electronics do not track changes in the force gradient closely. These changes in the force gradient are then reflected by changes in the MFM Amplitude signal, and an image of magnetic features on the sample surface is produced.

Taking an MFM image using the MFM Amplitude signal is analogous to constant-height mode imaging in contact-AFM mode. As such, the MFM Amplitude signal can be useful for taking images of topographically smooth samples quickly, since the gain is set to a low value and higher scan rates can be used. In addition, because the probe signal is represented more directly by the MFM Amplitude signal than by the Topography signal, MFM Amplitude images may show sharper contrast of magnetic features when these features are subtle.

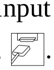
To take an MFM image using the MFM Amplitude signal, follow these steps:

1. Set up the instrument as described earlier for MFM imaging.

2. Set the NCM scan parameters—the drive frequency, drive amplitude, and imaging amplitude—as described in the earlier section “Setting NCM Parameters” for MFM imaging.

3. Perform an auto approach.

Next, you will select the input signals that you wish to view on the Oscilloscope Display. You will monitor these input signals as you adjust scan parameters for taking an image.

4. Switch to the Image mode window and select Input Config from the Setup menu to open the Input Configuration dialog box. Alternatively, click the Input Config icon, .

5. The Topography signal should be listed in the Selected listbox by default. Click on MFM Amplitude from the list of signals in the Available listbox, then click the [Add -->] button to add the MFM Amplitude signal to the list of signals in the Selected listbox. As described above, the MFM Amplitude signal represents the amplitude of cantilever vibration.

   Note: You may want to set the LP Filter to a number greater than its default setting, which is zero, but less than 1, for the MFM Amplitude signal. An LP Filter setting greater than 0 provides some averaging of high-frequency noise. For more details on the LP Filter setting, refer to the section, "Input Config: The Input Configuration Dialog Box" in Chapter 1, Part III of this User's Guide.

6. Click [OK] to return to Image mode.

   Both the Topography and the MFM Amplitude signals should be available now in the drop-down list below the Oscilloscope Display.

7. Set the gain to a relatively low value. For example, you can select a gain value in the range of 0.1 to 1.

   Note: Be careful when setting the gain to low values. You should be using a sample that is relatively smooth, since the feedback response may not be high enough to track steep features and the tip could crash into the sample surface.

8. Select a scan rate and a scan size for the image. For MFM Amplitude images, you can select a scan rate that is somewhat higher than that for Topography images. For example, you can select a scan rate in the range of 2 to 4 Hz.

9. Reduce the absolute value of the set point and re-approach the sample, if necessary, until the MFM Amplitude signal trace on the Oscilloscope Display is stable and representative of magnetic features on the sample surface.

   As discussed in the section "Performing an Auto Approach" earlier in this chapter, you may see oscillations or spike-like features on the signal trace. These features can result if the gain parameter is too high or if strong magnetic forces cause the tip to snap into the sample surface. If you see oscillations or spikes, increase the absolute value of the set point until they disappear.

10. Click the [Image] button to start a scan.

11. Adjust scan parameters if necessary, to optimize the image.

Experiment by using different values for scan parameters such as the gain, rate, and set point parameters. Adjust these parameters iteratively until you obtain the sharpest image of magnetic features on the sample surface.

With experience, you will be able to judge whether to use the MFM Amplitude signal or the Topography signal to obtain the clearest MFM images of particular samples. The next sections describe how to take images using two other signal channels of your AutoProbe CP instrument—the MFM Phase and the Magnetic Force signal channels.

Taking an Image Using the MFM Phase Signal

The MFM Phase signal represents shifts in the phase of the cantilever oscillation signal with respect to the signal to the actuator underneath the cartridge mount, which is the signal that drives cantilever to oscillate. (For details on hardware associated with non-contact image production, refer to the section “Hardware Components for Non-Contact Imaging” at the end of this chapter.) Like the amplitude of the cantilever oscillation signal, the phase of the cantilever oscillation signal is sensitive to changes in the gradient of the force between the tip and the sample. The phase, however, is even more sensitive to these changes, and can therefore produce sharper images of boundaries between magnetic regions.

Note: In order to have access to the MFM Phase signal, you must have a Materials Analysis Package™ (MAP) module connected to your AutoProbe CP system. The MAP module is an optional system component that can be used for phase detection microscopy (PDM).

Setting up to take an MFM image using the MFM Phase signal is similar to setting up to take an MFM image using the MFM Amplitude signal:

1. Set up the instrument as described earlier for MFM imaging. Make sure that a MAP module is connected to your system and turned on.

2. Set the NCM scan parameters—the drive frequency, drive amplitude, and imaging amplitude—as described in the earlier section “Setting NCM Parameters” for MFM imaging.

3. Perform an auto approach.

Next, you will select the input signals that you wish to view on the Oscilloscope Display. You will monitor these input signals as you adjust scan parameters for taking an image.

4. From the Image mode window, select Input Config from the Setup menu to open the Input Configuration dialog box. Alternatively, click the Input Config icon, .

5. The Topography signal should be listed in the Selected listbox by default. Click on MFM Phase from the list of signals in the Available listbox, then click the Add --> button to add the MFM Phase signal to the list of signals in the Selected listbox.

6. Click the OK button to return to Image mode.

Both the Topography and the MFM Phase signals should be available now in the drop-down list below the Oscilloscope Display.

You may find it useful to view an image taken using the MFM Phase signal while you are taking either a Topography signal image or an MFM Amplitude image. In either case, select the MFM Phase signal in addition to the Topography or MFM Amplitude signal.

7. Set scan parameters to values appropriate for either a Topography image or an MFM Amplitude image.

   Note: The sensitivity of the phase signal to changes in the force gradient is most pronounced at the resonant frequency of the cantilever. For this reason, you may want to open the NCM Frequency Set dialogue box and select a drive frequency that is very close to the maximum of the resonance peak. Selecting a drive frequency value that is close to the cantilever's resonant frequency may improve the sharpness of MFM Phase images. As mentioned in the earlier section "Performing an Auto Approach," you must always lift the tip before re-selecting the drive frequency if an auto approach has been performed.

To make side-by-side comparisons of images taken with the different signal channels, open two or more Active Displays:

8. Select Layout from the View menu to open the Image Layout dialog box. Alternatively, click the Image Layout, icon, . Select the Dual option button to view two Active Displays. Select the Quad option button to view up to four Active Displays.

   Once you have made your selection, click the OK button to return to Image mode.

9. Optimize scan parameters and click the Image button to start a scan.

As the images are being taken, select the image that represents magnetic features most clearly.

Taking an Image Using the Magnetic Force Signal

The Magnetic Force signal is a signal representing the magnitude of DC cantilever deflection. For many magnetic samples, the magnitude of the magnetic force between the tip and the sample is dominant over the magnitude of the van der Waals force, and it is strong enough to generate a measurable DC cantilever deflection signal.

To generate an MFM image using the Magnetic Force signal, do the following:

1. Set up the instrument as described earlier for MFM imaging.

2. Set the NCM scan parameters—the drive frequency, drive amplitude, and imaging amplitude—as described in the earlier section “Setting NCM Parameters” for MFM imaging.

3. Perform an auto approach.

Next, you will select the input signals that you wish to view on the Oscilloscope Display. You will monitor these input signals as you adjust scan parameters for taking an image.

4. From the Image mode window, select Input Config from the Setup menu to open the Input Configuration dialog box. Alternatively, click the Input Config icon, .

5. The Topography signal should be listed in the Selected listbox by default. Click on Magnetic Force from the list of signals in the Available listbox, then click the [Add -->] button to add the Magnetic Force signal to the list of signals in the Selected listbox.

6. Click [OK] to return to Image mode.

Both the Topography (NC-AFM) and Magnetic Force signals will be available now in the drop-down list below the Oscilloscope Display.

You may find it useful to view an image taken using the Magnetic Force signal while you are taking MFM images using other signals. In any case, select the Magnetic Force signal in addition to the other signal(s) you are monitoring.

7. Set scan parameters to values appropriate for the type of image you are taking (Topography, MFM Amplitude, or MFM Phase).

To make side-by-side comparisons of images taken with the different signal channels, open two or more Active Displays:

8. Select Layout from the View menu to open the Image Layout dialog box. Alternatively, click the Image Layout icon, . Select the Dual option button to view two Active Displays. Select the Quad option button to view up to four Active Displays.

   Once you have made your selection, click the OK button to return to Image mode.

9. Optimize the scan parameters and take images as described in the previous sections on MFM imaging.

As the images are being taken, select the image that represents magnetic features most clearly. Viewing the Magnetic Force signal in combination with other MFM signals may help you to identify magnetic features and therefore improve your ability to optimize scan parameters.

Taking Follow-Up Images of Sample Topography

Once you have obtained an MFM image, you can collect an image of the sample topography either by moving the tip closer to the sample to collect an NC-AFM or IC-AFM image, or by taking a contact-AFM image. Taking an NC-AFM or IC-AFM image has the advantage that both techniques minimize contact with the sample surface. For magnetically soft samples, contact between the sample surface and a magnetized tip can affect the magnetization of the sample surface.

To take a follow-up image of sample topography, do the following:

1. Start with the same parameter settings you used to take an MFM image, and select the Topography signal trace to be viewed on the Oscilloscope Display.

2. Decrease the absolute value of the set point parameter incrementally until you see oscillations or glitches on the Topography signal trace, as described earlier in the section “Performing an Auto Approach” for MFM imaging. The appearance of oscillations or glitches indicates that the force gradient is increasing sharply, or that the van der Waals force gradient is becoming dominant over the magnetic force gradient.

3. Decrease the gain parameter to stabilize the signal trace.

4. Iteratively decrease the absolute value of the set point and adjust the gain until the Topography signal trace is representative of topographic features on your sample's surface.

Obtaining an NC-AFM image that reflects topographic information may be difficult if it requires operating very close to the sample surface where the tip may be more prone to "snap-ins." For these cases, you may want to try applying an electrostatic bias to the sample, which increases the range of the topography-dependent force gradient. To learn about applying a bias to the sample, skip to the next section, "Applying an Electrostatic Bias Between the Tip and the Sample."

Another approach to collecting follow-up topographic images is to switch to contact-AFM mode and take an image. If ScanMaster is on, the scan area can be repeated accurately.

To switch to contact-AFM mode and take an image of sample topography, do the following:

5. Turn off the probe head by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

6. Select Config Parts from the Setup menu to open the Configure Parts dialogue box.

7. Under Head Mode, select AFM.

8. Click OK to return to Image mode.

9. Set scan parameters and perform an auto approach as described in Part I of this User's Guide.

   Note: You may need to realign the deflection sensor to perform an auto approach in contact-AFM mode. If you have a standard AutoProbe CP system and you have trouble realigning the deflection sensor, open a Digital Voltmeter (DVM) by clicking the DVM icon, , on the toolbar. Click the CH button on the DVM window to see a selection of channels, or signals, and select "A-B." The display of the DVM will show the value of the A-B signal, or probe signal, given in volts or millivolts depending on the value. If the DVM shows that the A-B signal is not small, then adjust the forward/backward screw to move the PSPD until the absolute value of the A-B signal is less than 300 mV. The laser spot should now be centered on the PSPD.

10. Take a contact-AFM image of surface topography.

If alteration of the magnetic properties of the sample through contact with a magnetized tip is a concern, you can switch to a non-magnetized tip before taking the contact-AFM image. Switching tips, however, makes alignment of magnetic and topographic images more difficult.

Applying an Electrostatic Bias Between the Tip and the Sample

For MFM imaging, an electrostatic bias is sometimes applied between the tip and the sample when obtaining a stable image of magnetic or topographic features is difficult. An electrostatic bias applied to the sample (the tip is grounded) creates charge on the sample surface, which superimposes a large, topography-dependent coulombic force term on top of the pre-existing van der Waals and magnetic force terms. (Refer to the section “How Magnetic Force Microscopy Works” at the end of this chapter for details.) In this section, you will learn when and how to apply an electrostatic bias to the sample to improve image quality.

When to Apply an Electrostatic Bias

Two examples of situations where image quality might be improved by the application of an electrostatic bias are the following:

1. You are having difficulty obtaining a stable follow-up NC-AFM image of sample topography.
2. The sign of the net force on the cantilever changes abruptly while you are taking an MFM image (for example, where repulsive and attractive magnetic domains are adjacent), and the tip crashes.

The first situation might occur if you are trying to take a follow-up NC-AFM image of a sample with strong magnetic features. You may find that it is difficult to determine a set point value that brings the tip close enough to the sample surface to show topography without causing feedback oscillations or tip snap-ins. These effects can be caused by the abrupt increase in the gradient of the van der Waals force and/or the strength of the magnetic forces that often characterize the close tip-to-sample range necessary for NC-AFM imaging.

By applying an electrostatic bias to the sample, you effectively broaden the tip-to-sample spacing regime over which the topography-dependent force gradient is dominant. This gives you greater flexibility in finding a set point value that produces a stable image of sample topography. You can image sample topography with the tip farther from the sample surface, in a regime where feedback oscillations and tip snap-ins are less likely.

The second situation mentioned above—tip crashes due to abrupt changes in the sign of the magnetic force—can also be addressed by the application of an electrostatic bias to the sample. In this case, the bias is used to create a net force between the tip and the sample that is constant in sign. The magnitude of the electrostatic force must be greater than that of the magnetic forces, so that changes in the sign of the magnetic forces are perturbations only, and the sign of the net force remains constant.

In general, if you have difficulty obtaining stable imaging conditions when you are taking an MFM image or a follow-up image of sample topography, try applying an electrostatic bias to the sample. The applied bias is a tool that gives you increased flexibility and can improve image quality.

How to Apply an Electrostatic Bias

If you choose to apply a bias between the tip and the sample, you must first make sure that your sample is in electrical contact with the scanner sample holder. This is especially necessary if you use double-sided tape to secure your sample to the sample holder, since the tape is nonconducting.

Note: If you have a MAP module connected to your system, be sure that the module is turned off before you attempt to apply an electrostatic bias to the sample.

To make electrical contact between the tip and the sample, do the following:

1. Paint an electrical connection between the sample and the sample holder using graphite paste or silver paint. Alternatively, you can use conductive, double-sided tape or the clips provided as part of your MFM toolkit to attach your sample to the MFM sample holder.

2. After you have mounted the sample, use a multimeter to check that the sample is electrically connected to the sample holder.

The magnitude of the bias you should apply depends on the particular tip and sample combination you are using. The system software enables you to apply a bias in the range of -10 to +10 V. Usually, applied biases are in the range of 0.5 to 2 V. As an example, if you are taking an image of the magnetic hard disk sample included in your MFM toolkit, you might start with an applied bias of 0.5 V.

The procedures for applying an electrostatic bias to the sample to improve MFM or NC-AFM images of magnetic samples are similar. In general, you iteratively vary the Sample Bias and set point parameters until the signal trace you are interested in is optimized. Following are procedures for applying a bias to the sample, assuming you are taking an NC-AFM image of a magnetic sample:

3. Set up to take a follow-up NC-AFM image as described in the previous section, “Taking Follow-Up Images of Sample Topography.”

If you are having trouble obtaining a signal trace that is stable, repeatable, and representative of sample topography, try applying a bias to the sample:

4. Use the Sample Bias scrollbox to select a non-zero value for the Sample Bias parameter. Start by entering a moderate value, for example 0.5 V. Press the `[Enter]` key so that the software recognizes the change.

5. Monitor the Topography signal trace on the Oscilloscope Display to see the effect of the sample bias. If there is no effect, use the Sample Bias scrollbox arrows or enter a new value to change the Sample Bias until you see an effect.

6. If you are able to obtain a stable Topography signal trace that begins to show topographic features, increase the bias until the Topography signal stops improving. At this point, try increasing the gain parameter and decreasing the set point parameter iteratively, while making minor adjustments to the Sample Bias if necessary. Continue iterative adjustment of the Sample Bias, set point, and gain parameters until the Topography signal trace is optimized.

If you increase the Sample Bias too much, the Topography signal may become smooth, losing resolution. Smoothing occurs because as you increase the Sample Bias the force gradient experienced by the cantilever increases, and the system increases the tip-to-sample spacing to maintain a constant vibration amplitude of the cantilever. Since the set point parameter also affects the tip-to-sample spacing, the set point and Sample Bias parameters are coupled. You must adjust them iteratively to find the set point and applied bias combination that optimizes the Topography signal trace. You should also try to optimize the gain so that the system is not oscillating, but is sensitive enough to track the set point closely.

Ideally, the Sample Bias value you set should not be too high since the bias effectively charges the sample surface and may map dielectric, rather than topographic, features. This is especially true for natural magnetic samples, whose surfaces may be less dielectrically homogeneous.

Where to Go From Here

This concludes the tutorial sections of this chapter. At this point, you can review the tutorials and practice taking images until you feel confident using vibrating cantilever techniques.

If you are interested, you may want to continue and read the next sections, which discuss underlying principles of NC-AFM, IC-AFM, and MFM imaging.

How Non-Contact AFM Works

This section describes the principles underlying NC-AFM operation. These principles are referred to in later sections, as they are applicable to IC-AFM and MFM operation as well.

Every cantilever has its own characteristic resonant frequency, which depends on its dimensions and the material used to fabricate it. A cantilever vibrates naturally at this resonant frequency. Thermal vibrations or a bump on the table, for instance, can start these oscillations. Non-contact AFM uses detection of a cantilever's resonant frequency as an indirect measure of sample topography. This section describes the correlation between cantilever resonance and sample topography, and it explains how NC-AFM images of topography are produced.

Figure 1-6 shows an interatomic force vs. distance curve, which illustrates the force between atoms on a cantilever tip and atoms on a sample surface vs. the separation distance between the tip and the sample.

Two distance regimes are labeled on the figure: 1) the "contact" regime, less than a few angstroms, which represents the tip-to-sample spacing for contact AFM; and 2) the "non-contact" regime, ranging from tens of angstroms to hundreds of angstroms, which represents the tip-to-sample spacing for NC-AFM. In the contact regime, the interatomic forces are repulsive, while in the non-contact regime they are attractive, and largely a result of long-range van der Waals interactions.

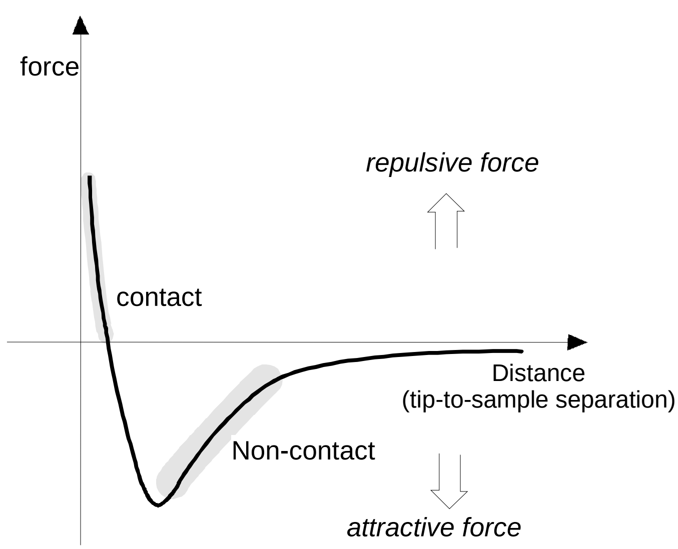


Figure 1-6. Interatomic force vs. distance curve.

NC-AFM is desirable because it provides a means for measuring sample topography with little or no contact between the tip and the sample. The total force between the tip and the sample in the non-contact regime is very low, generally about 10^{-12} N. This low force is advantageous for studying soft or elastic samples. Because the force between the tip and the sample in the non-contact regime is low, however, it is more difficult to measure than the force in the contact regime, which can be several orders of magnitude greater. In addition, cantilevers used for NC-AFM must be stiffer than those used for contact AFM because soft cantilevers can be pulled into contact with the sample surface. The small force values in the non-contact regime and the greater stiffness of the cantilevers used for NC-AFM are both factors that make the NC-AFM signal small, and therefore difficult to measure. Thus, a sensitive, AC detection scheme is used for NC-AFM operation.

In non-contact mode, the system vibrates a stiff cantilever near its resonant frequency (typically from 100 to 400 kHz) with an amplitude of a few tens to hundreds of angstroms. Then, it detects changes in the resonant frequency or vibration amplitude as the tip comes near the sample surface. The sensitivity of this detection scheme provides sub-angstrom vertical resolution in the image, as with contact AFM.

The relationship between the resonant frequency of the cantilever and variations in sample topography can be explained as follows. The resonant frequency of a cantilever is the square root of its spring constant, k, divided by its mass, m:

$$\omega = \sqrt{\frac{k_{eff}}{m}}. \qquad (1)$$

Here, the spring constant is written as k_{eff}, the effective spring constant, because the spring constant of the cantilever changes as the cantilever moves into close proximity (within a few hundred angstroms) of the sample surface and interatomic forces affect its behavior. Specifically, the spring constant changes when the force between the tip and the sample has a spatial gradient, as it does in the non-contact regime. For a force gradient f’, the effective spring constant is given by the following expression:

$$k_{eff} = k - f'. \qquad (2)$$

In Equation 2, k is the value of the cantilever’s spring constant in free space; that is, it is the value when the cantilever is far from the sample surface. The value of the cantilever’s resonant frequency far from the sample surface is likewise referred to as its free-space resonant frequency.

Equations 1 and 2 show that if the cantilever moves into a tip-to-sample spacing regime where the force gradient is positive and increasing, then the effective spring constant of the cantilever, and therefore its resonant frequency, decreases. Figure 1-6 shows that in the non-contact tip-to-sample spacing regime the force gradient is positive, and it increases as the tip-to-sample spacing decreases. Thus, when an oscillating cantilever is brought near a sample surface, the force gradient experienced by the cantilever increases, and its resonant frequency decreases as described above.

If the resonant frequency of a cantilever shifts, then the amplitude of cantilever vibration at a given frequency changes. Near a cantilever's resonant frequency, this change is large. Figure 1-7 shows a response curve (vibration amplitude vs. frequency) for a cantilever. If the curve shifts to the left, for example, then there is a change (in this case, a decrease) in the amplitude of cantilever vibration at a given frequency (f*).

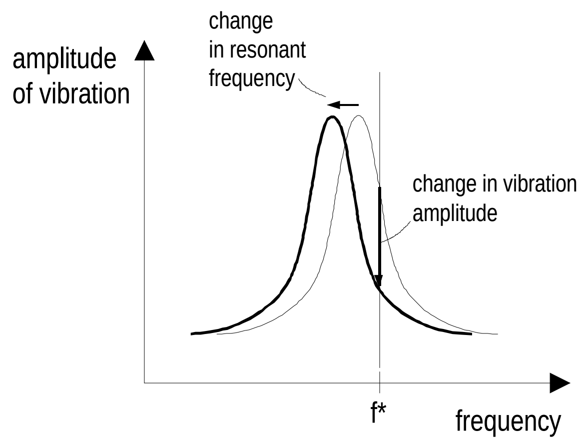


Figure 1-7. Response curves for a cantilever, showing a decrease in vibrational amplitude at f = f* for a decrease in cantilever resonant frequency.

This shift in amplitude, associated with a shift in resonant frequency, is the basis for the amplitude modulation (AM) measurement technique used by ambient AutoProbe instruments to detect changes in a cantilever's resonant frequency.

For AM detection, the cantilever is driven at a fixed frequency near resonance (e.g., f* in Figure 1-7), and changes in its vibration amplitude are detected. In non-contact AFM mode, a drive frequency close to, but *greater* than, the free-space resonant frequency of the cantilever is selected so that the vibration amplitude *decreases* significantly as the cantilever is brought closer to the sample surface (as illustrated in Figure 1-7). These amplitude changes reflect the change in the force gradient acting on the cantilever, which in turn reflects changes in the tip-to-sample spacing. A feedback mechanism operates to maintain a constant cantilever vibration amplitude by adjusting and restoring the tip-to-sample spacing during a scan. As in contact-AFM mode, the amount of scanner z movement necessary to maintain the tip-to-sample spacing (i.e., to maintain a constant force gradient, for the case of NC-AFM) is used to generate an image of topography.

How Intermittent-Contact AFM Works

The underlying principles for intermittent-contact AFM are the same as those for non-contact AFM. The difference is that for IC-AFM the cantilever is driven (forced to vibrate) at a fixed frequency close to, but *less* than, its free-space resonant frequency, as shown in Figure 1-8.

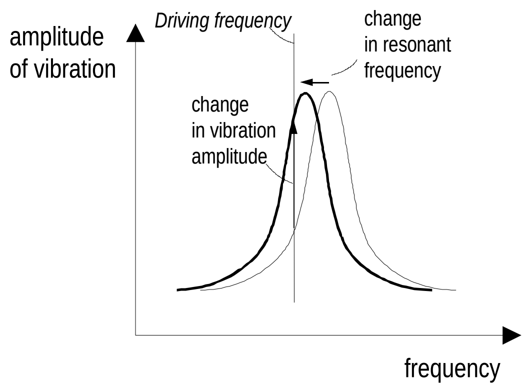


Figure 1-8. Response curve for a cantilever for IC-AFM mode, showing an increase in vibration amplitude at the drive frequency for a decrease in cantilever resonant frequency.

Because the drive frequency is just below the free-space resonant frequency, the vibration amplitude of the cantilever *increases* as the cantilever is brought closer to the sample surface, and intermittent contact is consequently achieved.

How Magnetic Force Microscopy Works

The interatomic force vs. distance curve of Figure 1-6 was central to the explanation of non-contact AFM. The figure illustrates how the force gradient changes with tip-to-sample spacing. Since the force gradient affects the cantilever's resonant frequency (as shown by Equations 1 and 2), vibrating cantilever methods can use measured changes in the cantilever's resonant frequency to maintain a constant tip-to-sample spacing, and thereby monitor and image changes in sample topography.

The underlying principles of MFM are similar to those of NC-AFM, and their explanation also benefits from a diagram of the interatomic force vs. distance relationship. For the case of MFM, a magnetized tip is used, and forces between this magnetic tip and magnetic domains on the sample surface must be included on the force vs. distance curve.

Figure 1-9 shows an interatomic force vs. distance curve for a typical sample and tip used to take an MFM image (e.g., a magnetic storage disk and a cantilever tip coated with sputtered cobalt). The figure shows that magnetic forces (F_m) are superimposed upon the van der Waals forces (F_V), which are still present.

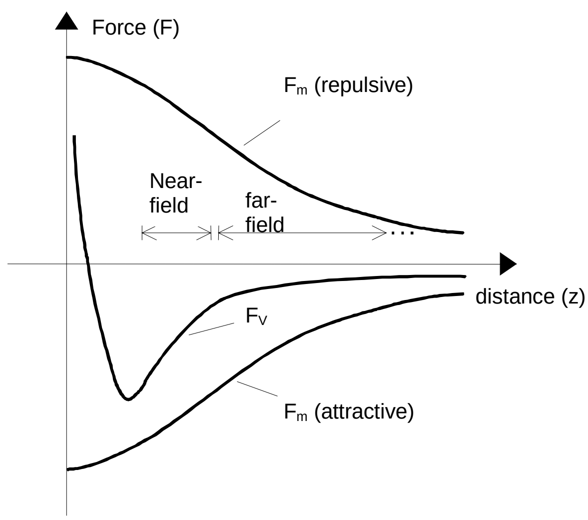


Figure 1-9. Interatomic force vs. distance curve showing both magnetic force (F_m) and van der Waals force (F_V).

There are two, symmetric magnetic force vs. distance curves: one represents forces acting when the magnetic interaction is attractive (negative F_m values), and the other represents forces acting when the magnetic interaction is repulsive (positive F_m values). Both types of forces could be present for a single sample, since they could represent different magnetic domains on the sample surface.

The net force between the atoms on the cantilever tip and atoms on the sample surface is the sum of the magnetic force (repulsive or attractive) and the van der Waals force:

$$F = F_m + F_v. \qquad (3)$$

Similarly, the net force gradient experienced by a vibrating cantilever is the sum of the gradient of the magnetic force and the gradient of the van der Waals force:

$$dF/dz = dF_m/dz + dF_v/dz, \qquad (4)$$

where z is the tip-to-sample spacing.

The key to understanding MFM methods is to identify the force or force gradient term that is dominant in a given tip-to-sample spacing regime. For MFM, the tip-to-sample spacing typically lies in the range of ten to hundreds of angstroms, or in the non-contact regime. This range of spacing for MFM operation can be further divided into far-field and near-field regimes (as indicated on Figure 1-9). The far-field and near-field regimes are defined based on whether the force gradient is dominated by the magnetic or the van der Waals force gradient term. Specific distance numbers that define the limits of these regimes depend on the specific tip and sample materials being used.

In the far-field regime, the gradient of the magnetic force is greater than the gradient of the van der Waals force. The dominance of the magnetic force gradient in the far-field regime means that the Topography signal, a signal that represents changes in the force gradient, is dominated by the magnetic properties of the sample surface. Thus, if you take an image using the Topography signal, you can set the scan parameters to position the tip far enough away from the sample that it is in the far-field regime, and the image will represent magnetic features on the sample surface.

In the near-field regime, the gradient of the van der Waals force is greater than the gradient of the magnetic force. The dominance of the van der Waals force gradient in the near-field regime means that the Topography signal that represents the force gradient is dominated by changes in the topography of the sample surface. Thus, if you take an image using the Topography signal, you can set the scan parameters to position the tip close enough to the sample that it is in the near-field regime, and the image will represent topographic features of the sample surface.

The simplest way to take an MFM image is to adjust scan parameters such that the tip is far enough away from the sample to position it in the far-field regime. In the far-field regime, the gradient of the van der Waals force is negligible and an image taken using the Topography signal represents variations in the gradient of the magnetic force.

Using an Electrostatic Bias

An electrostatic bias applied to the sample is sometimes used during MFM imaging to stabilize the signal trace and obtain images of either magnetic or topographic features on your sample's surface. This section shows how an applied electrostatic bias affects the interatomic force vs. distance curve for a magnetized tip and sample.

When you apply a non-zero bias to a sample that is dielectrically homogeneous, charge is distributed evenly over the surface. A coulombic force (F_c) is created between the tip and the sample. The absolute value of this coulombic force is much greater than that of the van der Waals force, which becomes negligible. The net force and force gradient between the tip and the sample become the following:

$$F = F_m + F_c \qquad (5)$$

$$dF/dz = dF_m/dz + dF_c/dz. \qquad (6)$$

Figure 1-10 illustrates the coulombic force term on a force vs. distance curve.

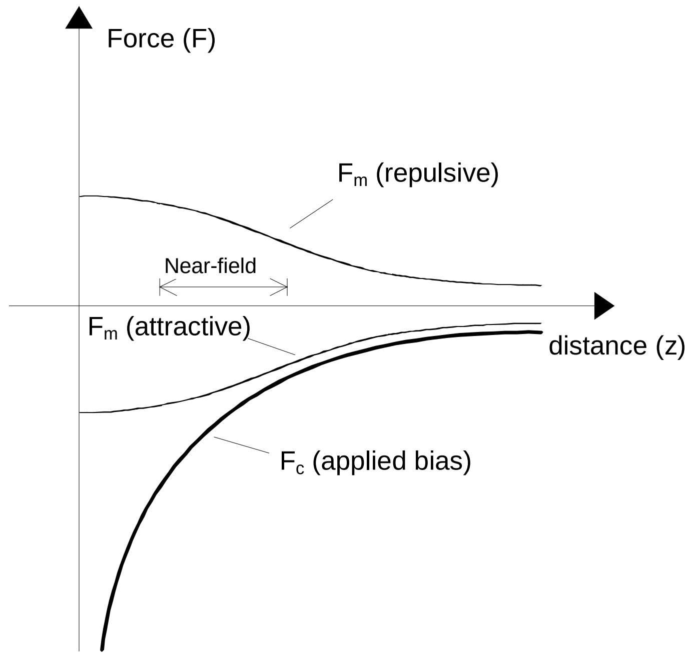


Figure 1-10. Interatomic force vs. distance curve showing magnetic (F_m) and coulombic (F_c) force terms. The magnitude of the coulombic term depends on the magnitude of the bias applied between the tip and the sample.

Applying an electrostatic bias to the sample may be useful in situations that include the following:

- Abrupt increases in the gradient of the van der Waals force and/or the strength of the magnetic forces in the near-field regime make obtaining an NC-AFM image of a magnetic sample difficult.
- The sign of the magnetic force for adjacent magnetic domains changes abruptly, causing the tip to crash into the sample surface during MFM or NC-AFM imaging.

For the first case, applying a bias to the sample extends the tip-to-sample spacing regime in which a topography-dependent force gradient term is dominant. This gives you greater flexibility in obtaining a stable image of sample topography.

For the second case, you need to apply a bias to the sample large enough to create a coulombic force term that is greater in magnitude than magnetic forces. When this is the case, the sign of the net force on the cantilever remains constant, and the tip should not crash into the sample surface.

Variations in samples are wide enough that taking MFM images becomes a somewhat subjective, iterative process. Experience and familiarity with properties of specific samples enables you to obtain the best MFM images.

Hardware Components for Non-Contact Imaging

This section outlines how hardware components are involved in image production. Brief descriptions of the function of each component are also included.

Figure 1-11 shows a simplified diagram of the non-contact system which applies to NC-AFM, IC-AFM, and MFM.

The primary components labeled in the diagram are the following:

- Cantilever and piezoelectric actuator
- Sine wave generator
- Deflection sensor (laser, mirror, and PSPD)
- Lock-in amplifier
- Comparator and z feedback loop
- Piezoelectric scanner with mounted sample

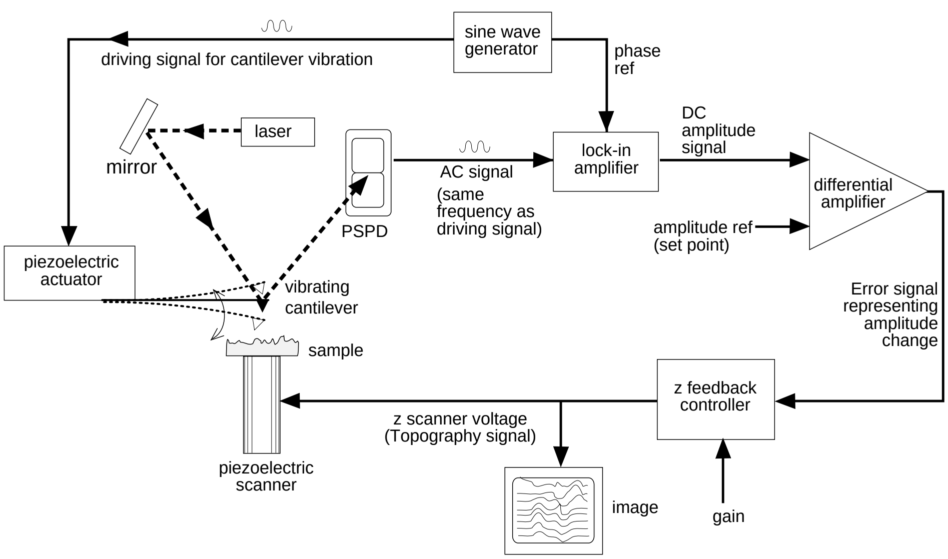


Figure 1-11. Diagram of hardware components and signal pathways for AutoProbe CP operating in NC-AFM mode.

For vibrating-cantilever AFM methods, the cantilever is mounted in a specific type of cartridge, referred to as a non-contact cartridge. The non-contact cartridge has a thin piezoelectric actuator (a piezoelectric transducer) sandwiched between the cartridge and the cartridge mount. Between the two prongs of the cartridge there is a layer of gray material directly under the cartridge mount. This layer is the actuator.

When an AC voltage signal is applied to the actuator, the actuator oscillates: it expands and contracts. The oscillations cause a cantilever mounted on the cartridge to vibrate with the same frequency as the AC signal.

On the underside of the cartridge (the side with the spring clip), there is also a small red wire. This wire delivers the AC voltage signal to the actuator. The signal is delivered via a copper contact on the top surface of the cartridge, which makes contact inside the NC-AFM probe head. Near the opposite corner of the cartridge is another contact, which grounds the cartridge when it makes contact inside the probe head.

The AC signal, or driving signal, that causes the cantilever to oscillate with a constant frequency, is generated by the sine wave generator. The sine wave generator is located on the frequency synthesizer board installed in the AEM. The drive frequency can be varied and is chosen to lie close to the cantilever's resonant frequency. The amplitude of the driving signal can also be adjusted to maximize the vibration amplitude of the cantilever far from the sample surface.

The AC signal from the sine wave generator is also input to the lock-in amplifier to provide the reference signal for lock-in detection.

Motions of the oscillating cantilever are measured by the deflection sensor, located in the NC-AFM probe head. The deflection sensor includes a laser, a mirror that reflects the laser beam onto the back of the cantilever, and a position-sensitive photodetector (PSPD). Both the frequency and the amplitude of cantilever vibration are monitored as changes in the position of the laser spot incident on the PSPD. For MFM operation, the DC component of the PSPD signal is read in addition to the AC component, and it can be used to generate an MFM image. This cantilever detection scheme is often referred to as the laser beam-bounce technique.

The AC signal from the PSPD is sent to a lock-in amplifier. The lock-in amplifier is a very narrow bandpass filter which is used to detect an AC signal at a specific frequency and output a DC signal proportional to its amplitude. The frequency "locked-in" for detection is set by the reference signal from the sine wave generator.

The DC output signal from the lock-in amplifier is sent to a comparator, or differential amplifier. The comparator compares the signal from the lock-in amplifier, which represents the vibration amplitude of the cantilever, to a reference amplitude setting. An error signal proportional to the difference between these signals is sent to the z feedback controller. The electronics for the lock-in amplifier, the comparator, and the z feedback controller are all located inside the NC-AFM head.

The z feedback controller operates to raise or lower the z position of the piezoelectric scanner in order to maintain a constant amplitude of cantilever vibration. Since changes in the amplitude are due to changes in the force gradient between the tip and the sample, the feedback loop keeps the force gradient constant during a scan.

The sample is mounted on the scanner, and it moves relative to the probe. When the z position of the scanner is raised, the tip and sample are brought closer together and the force gradient between the tip and sample increases. When the scanner is lowered, the tip and sample move further apart and the force gradient decreases. By adjusting the tip-to-sample spacing, the system controls the force gradient during a scan (keeps it constant). The z voltage applied to the scanner to maintain a constant force gradient is used to generate an image of surface topography (z voltage vs. scanner position).

Summary

This chapter presented procedures for taking NC-AFM, IC-AFM, and MFM images. For each imaging mode, you learned how to set up the system hardware and software, select scan parameters such as the drive frequency, the drive amplitude, and the imaging amplitude, and take an image. Also included was background information on how NC-AFM, IC-AFM, and MFM work. Understanding how these methods work helps you to take the highest quality images for the widest range of samples.

Chapter 2
STM Imaging

Introduction

This chapter describes STM imaging for AutoProbe CP, which is available in both standard and multitask system configurations. If you have the standard system configuration, then you should have an AFM/STM probe head, as well as an STM Upgrade kit. If you have the multitask system configuration, then your system includes the multitask probe head and STM tips that enable you to take STM images.

This chapter information on the following topics:

- how to make an STM tip
- how to insert the tip in the STM cartridge
- how to set up the system hardware and software
- how to take an STM image

The last two topics listed above are covered in the section “Taking an STM Image” at the end of this chapter. This section guides you through taking an STM image of a gold calibration grating. In addition, the section includes scan parameter values that you can use as starting points for taking an STM image of a graphite sample.

Once you configure your system software for taking an STM image, you will notice that the primary differences between STM mode and contact-AFM mode involve the Image mode window. When the software is configured for STM operation, the set point parameter represents the tunneling current value that is maintained during a scan, as opposed to the force value, as for contact-AFM imaging. Also, for STM operation, the tip must be biased relative to the sample so that a tunneling current will flow. The tip and sample biases are set using scrollboxes in the Image mode window.

Preparing and Loading STM Tips

You can prepare an STM tip using several different methods. This section describes two methods commonly used for preparing STM tips: (1) by cutting a wire and (2) by using a tip etcher. A new STM tip must be prepared when the STM is first set up and also whenever the tip being used becomes damaged or oxidized.

If you are taking STM images of a surface with high aspect ratio features (sharp or steep), you should make etched tips. Etched tips have a much higher aspect ratio than tips made using wire cutters. If you try to image a surface with tall or steep features using a relatively blunt cut wire tip, a tunneling current may occur between the side of the tip and the side of a surface feature. If this happens, you will see tip imaging effects in the STM image.

If you are taking STM images of an atomically flat surface—for instance the surface of graphite—blunt cut wire tips may be more stable over time than etched tips and result in better STM images. However, multiple tip imaging effects can also occur when blunt tips are used.

Using Wire Cutters to Make STM Tips

You can make reasonably good tips by cutting tungsten or PtIr wire at a 45° angle with a pair of sharp wire cutters. The recommended wire diameter to use is 0.020" (20 mil wire or 0.5 mm wire). (This wire diameter can also be used with the ThermoMicroscopes tip etcher to produce sharper STM tips. See the section below for instructions for using the ThermoMicroscopes tip etcher.)

You will need the following items:

- 20 mil or 0.5 mm tungsten or PtIr wire
- a strong pair of wire cutters
- a pair of needle-nose pliers

To make a tip by cutting wire:

1. First cut off a piece of wire between 1 and 1.5" long using a strong pair of wire cutters. (Ordinary wire cutters will be damaged.)

2. Grip one end of the wire tightly with a pair of needle-nose pliers.

   Orient the wire cutters at a 45° angle relative to the wire, as shown in the figure below. To cut the wire, use the wire cutters to pull and twist the end of the wire while snipping.

The resulting tip does not look sharp, but actually is. Tungsten STM tips oxidize fairly quickly and should be discarded after 1 to 2 days. Platinum iridium STM tips, on the other hand, do not readily oxidize and may be kept and used for a much longer time.

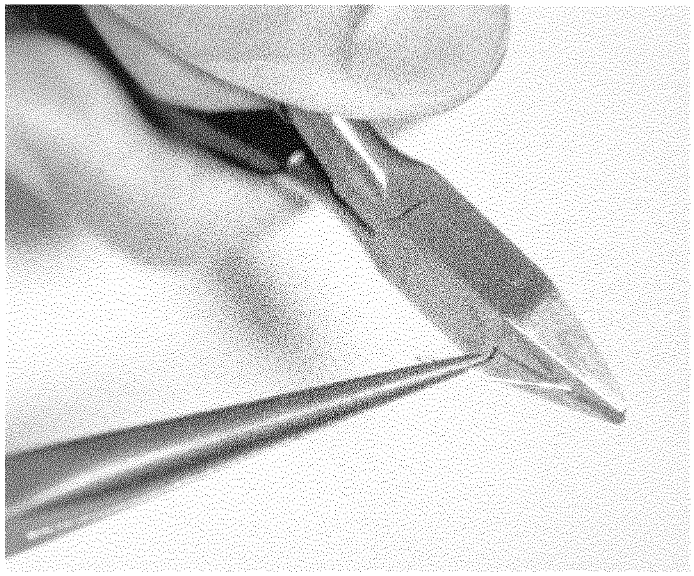


Figure 2-1. Holding wire cutters at a 45° angle to cut an STM tip.

The overall shape of tips made using wire cutters is not well-defined. STM images taken using these relatively blunt tips can show multiple tip imaging effects. Sharper, higher aspect ratio tungsten tips can be made using a tip etcher, as described below.

Using the ThermoMicroscopes Tip Etcher

The instructions in this section explain how to set up the ThermoMicroscopes tip etcher and how to use it to produce very sharp STM tips. If you wish to order a ThermoMicroscopes tip etcher, please contact your ThermoMicroscopes representative.

The components of the tip etcher are listed below:

- the TE-100 STM Tip Etcher electronics unit
- a 600 ml glass beaker
- the carbon electrode, attached to a lid which fits over the beaker
- the tip electrode, a white cylindrical tip holder which fits through the hole in the lid
- the cable and power cord

You will also need the following items:

- tungsten wire
- a strong pair of wire cutters
- a pair of needle-nose pliers
- KOH pellets
- rubber gloves and protective goggles
- a glass stirring rod
- deionized water
- isopropyl alcohol

These components are shown in Figure 2-2, below.

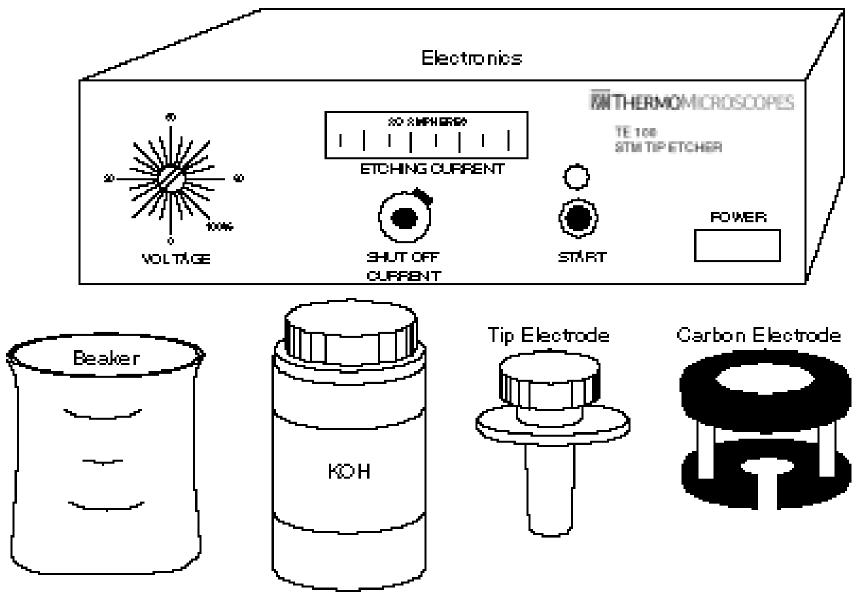


Figure 2-2. The components of the tip etcher.

Setting Up the Tip Etcher

1. Connect the power cord to the rear of the tip etcher electronics unit and plug it in. Make sure the unit is switched off. (The red POWER light should be off.)

2. Place the carbon electrode inside the beaker so that the black lid covers the top of the beaker.

3. Insert the tip electrode into the opening in the top of the lid. Push the tip electrode into the hole so that it fits snugly.

Connect the cable to the connector labeled ETCHER on the rear panel of the electronics unit. Connect the two leads on the opposite end of the cable to the carbon electrode and the tip electrode. The lead with the smaller, red lug connector attaches to the tip electrode, and the other lead attaches to the carbon electrode. Fasten the leads using the two screws in the lid.

WARNING!

Whenever you work with KOH, wear rubber gloves and protective goggles.

4. Lift up the lid and add 50 ml of KOH pellets to the beaker. Then add deionized water to make 375 ml of solution.

   Stir the solution with a glass stirring rod.

The tip etcher is now set up and ready for use.

Operating the Tip Etcher

1. Cut off a piece of wire between 1 and 1.5 inches long using a strong pair of wire cutters. (Ordinary wire cutters will be damaged.)

2. Lift out the tip electrode, holding it by the gnurled knob. The tip electrode fits into the lid snugly, so you may need to press down on the lid while you twist and pull the knob.

   Use needle-nose pliers to insert one end of the wire into the hole in the end of the tip electrode. Push the wire all the way into the hole, so that it fits snugly. Make sure the tip doesn't drop out when you hold the electrode with the tip pointing down.

3. Reinsert the tip electrode into the hole in the lid. Push the tip electrode in all the way so that it fits snugly. There should be at least 1 cm of wire showing above the solution. The length of the immersed portion of the wire affects the aspect ratio of the etched tip. Shorter wires yield etched tips with lower aspect ratios.

4. Set the VOLTAGE knob on the electronics unit to 80%. Set the SHUT-OFF CURRENT knob to 0.5. Switch on the power by pressing the POWER button.

5. To start the etching process, press the START button. The green light on the front panel will light and the etching process will begin.

You will see tiny bubbles surround the immersed portion of the wire as it is etched. The wire etches isotropically, to produce a high aspect ratio tip. After a few minutes, you will see arcing in the solution. As etching proceeds and the exposed surface area of the tip decreases, the current drops. When the current drops below the SHUT-OFF CURRENT setting, the green light on the front panel turns off. The etching process is then complete.

When the etching process is complete and the green light is off, the shortened tip will extend only about 0.5 to 1 mm below the surface of the solution.

You can experiment with different VOLTAGE and CURRENT SHUT-OFF values to find optimum settings for the best tips. Figure 2-3 below, shows the shape of a good STM tip.

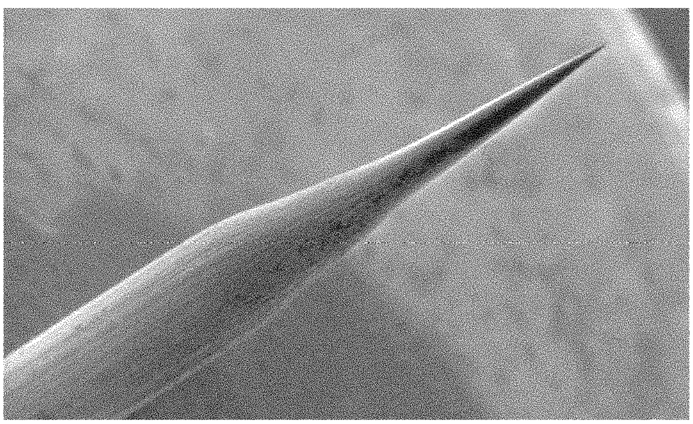


Figure 2-3. Good STM tip shape.

6. To remove the etched tip, lift out the tip electrode. The tip electrode fits snugly, so you may need to press down on the lid while you twist and pull the knob of the electrode.

   Pull the tip out of the tip electrode using needle-nosed pliers.

   CAUTION

   Be careful not to touch the etched end of the tip, or you will damage the tip.

7. Rinse the etched tip in deionized water and then in isopropyl alcohol.

Etched tungsten tips will oxidize and should not be kept longer than 1 to 2 days.

Using the STM Cartridge

For STM images, you use a cartridge specifically designed for STM. The STM cartridge contains a small hole for inserting an STM tip. Figures 2-4 and 2-5 below show a side view of the STM cartridge and a view looking down on the cartridge, respectively.

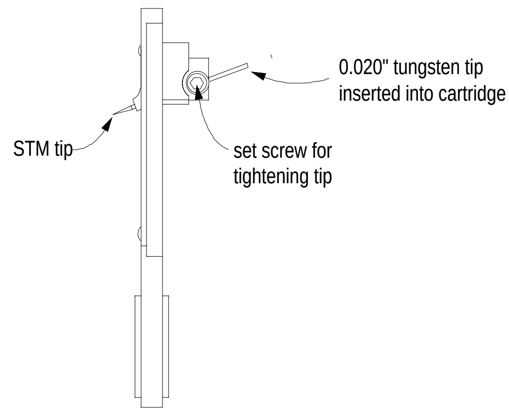


Figure 2-4. Side view of STM cartridge with tip inserted.

On the top side of the cartridge, you will see a round metal contact pad, for delivering the tunneling current signal to the control electronics.

> ***CAUTION***
>
> Try to keep the area around the metal contact pad clean.

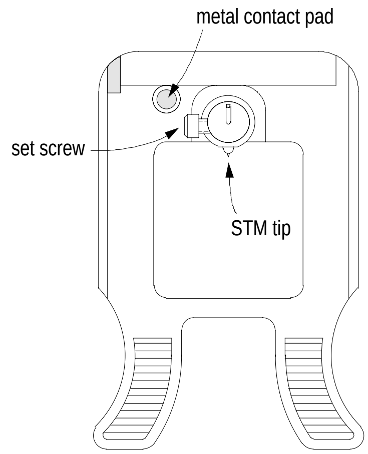


Figure 2-5. Top view of STM cartridge, with STM tip inserted.

The tip is tilted relative to the sample instead of pointing straight down. The tilt allows you to see the tip using the on-axis optical view.

The STM cartridge is installed in the probe head in the same way as the AFM cartridge, with the tip pointing down. The instructions below explain how to insert STM tips into the STM cartridge.

WARNING!

STM tips are very sharp. Be careful when handling an STM cartridge with a tip loaded. Store the STM cartridge and tip in a container with a lid.

Inserting the STM Tip into the STM Cartridge

You can use a tip that has been made using wire cutters or an etched tip. You insert the back end of the tip first.

Note: It is not necessary for you to be able to see the tip using the on-axis optical view, since you will mainly be using the side view. However, if you do want to see the tip in the on-axis view, then try to have the sharp end of the tip extend out from the STM cartridge about as far as the AFM cantilever chip on the AFM cartridge. If the tip is too long or too short, you will have difficulty locating the tip using the on-axis optical view.

1. First loosen the set screw on the top side of the STM cartridge.

2. Grip the STM tip near its middle using a pair of needle-nose pliers.

Feed the back end of the tip through the hole in the underside of the cartridge, as shown in Figure 2-6, below. The underside of the cartridge is the side with the three embedded silver balls.

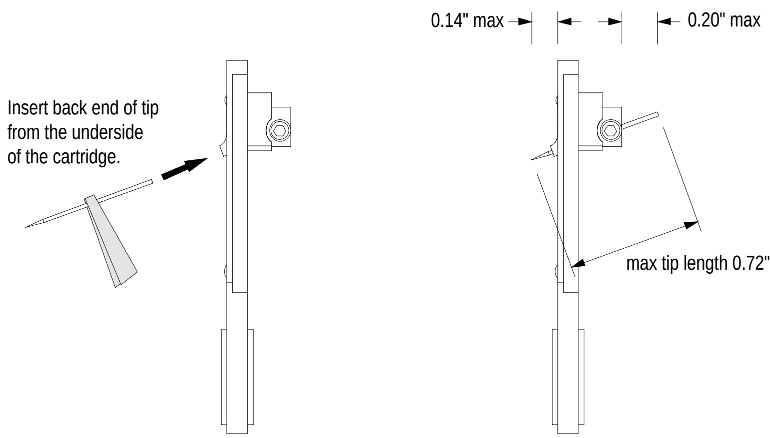


Figure 2-6. Inserting a tip into the STM cartridge.

Keep feeding the tip through the hole until only about 3 mm of the sharp end shows. Try to keep the wire reasonably straight as you feed it through the hole.

Note: Quite often, the back end of a tungsten tip splinters and becomes difficult to fit through the hole. If this happens, try trimming off the end with wire cutters to remove the splinter.

You will find it easier to see the tip in the on-axis optical view if the vertical distance between the tip and the underside of the cartridge is between 2 and 3 mm. However, since you will mainly be using the side view, this tip length is not required.

To check that the tip length is about right, compare the STM cartridge with an AFM cartridge that has a cantilever chip loaded. The STM tip should extend out about as far as the AFM cantilever chip does on the AFM cartridge.

3. Tighten the set screw on the top side of the STM cartridge using an allen wrench. The set screw is a 1/16" allen head.

4. After inserting the wire and tightening the set screw, cut the back end of the tip using a pair of wire cutters. The back end of the tip should not extend more than about 5 mm. Otherwise, the back end of the wire may scratch the objective lenses of the optical view.

> ***CAUTION***
>
> Be careful to cut the back end of the wire short enough to avoid scratching the objective lens.

To store an STM cartridge with a tip loaded: To store an STM cartridge, place the cartridge in a container with a lid with the sharp tip pointing up. Close the lid of the container.

To remove a tip from the STM cartridge: First loosen the set screw on the cartridge. Then grip either end of the tip with a pair of needle-nose pliers and pull the wire out of the hole.

> ***WARNING!***
>
> STM tips are very sharp. Be careful when handling an STM cartridge with a tip loaded. Avoid leaving the STM cartridge on a table or other work surface with the exposed tip pointing up. Store the STM cartridge and tip in a container with a lid.

Taking an STM Image

This section describes how to take an STM image using AutoProbe CP. While STM mode is often used for taking images with atomic resolution, this type of imaging can be difficult for instruments operating in air since an STM is highly sensitive to surface contaminants and water layers.

STM can be used to image metals and also semiconductors without insulating oxide layers. For example, STM images can be taken of gold, graphite, and semiconducting oxides. STM cannot be used to look at insulating samples (for instance, Al_2O_3) because no tunneling current will flow between the tip and an insulating sample. Since no tunneling current is detected, the tip will crash into the sample surface during an auto approach.

Two examples of samples that can be used to demonstrate the capabilities of an STM operating in air are a calibration grating, such as the 1 µm gold grating provided with your system, and highly oriented pyrolytic graphite (HOPG). The large, easily identifiable features of a gold calibration grating make it a good sample for taking your first image. Graphite is easily cleaved and is often used to demonstrate atomic resolution in air. Both samples provide a reflective surface that make it easier for you to perform an auto approach.

The larger size of an image of a calibration grating (5 to 100 µm compared to 50 to 100 Å for graphite) makes it more difficult to obtain because there is a greater likelihood that the tip will encounter surface contaminants. However, a gold calibration grating is a readily accessible sample, and a good image of its surface is relatively easy to identify. For these reasons, the main procedures of this chapter describe how to take an image of a gold calibration grating. Then, at the end of the chapter a special section outlines the scan parameters that you would need to change in order to take an image of graphite.

The three basic steps for taking an STM image are the following:

1. setting up the system
2. performing an auto approach
3. starting a scan

The first sections of this chapter describe these steps in detail. Following these procedural sections is a section that defines two modes of STM operation: constant-current mode and constant-height mode. The last sections of the chapter provide information that helps you to optimize your STM images, and a brief section provides you with scan parameter values to use for taking an STM image of a graphite sample.

Setting Up the System

Setting up the system for STM operation involves setting up the hardware, configuring the software, and performing some simple diagnostic checks of the system. For the best STM images, your AutoProbe CP instrument should be placed on an air table for optimal vibration isolation.

Note: In addition to the components included with your instrument, you will need a digital multimeter for performing the diagnostic checks.

Setting Up Hardware

This section includes steps for setting up the system hardware for taking an STM image.

1. Install a scanner as described in Chapter 2, Part I of this User's Guide.

> ***CAUTION***
>
> The power to the AEM must be turned OFF before you remove or install the scanner.

> ***CAUTION***
>
> The four screws that connect the scanner to the CP base unit must be securely fastened to ensure proper grounding. When the four screws are securely fastened, maximum instrument performance is ensured since vibrations are reduced.

2. Install the appropriate probe head by sliding it onto the support arms of the XY Translation Stage, as described in Chapter 2, Part I of this User's Guide. Make sure that the LASER ON/OFF switch is in the OFF position before you install the probe head.

   If you have the standard AutoProbe CP system configuration: Install the AFM/STM probe head. A connector on the rear of the probe head plugs into a connector on the back of the translation stage.

   If you have the multitask AutoProbe CP system configuration: Install the multitask probe head, and set the two mode switches on the probe head to the STM and LFM positions.

3. Once the probe head is installed, turn the LASER ON/OFF switch to the ON position.

4. Turn on all of your system components as you normally do. Refer to Part I of this User's Guide for details.

5. Load a gold calibration grating sample onto the scanner.

   Note: STM samples must be mounted so that they are in electrical contact with the sample holder, otherwise no tunneling current can flow between the tip and the sample. Do not use double- sided tape to secure a sample to a sample mounting disk. Instead, secure samples using a conductive paint or glue, such as silver epoxy or silver paint.

6. Install the STM cartridge in the probe head. Hold the STM cartridge with the sharp tip pointing down. Insert the STM cartridge into the probe head by sliding it into the two grooves, as you usually do for AFM. Wiggle the cartridge in and out a bit to make sure that all three balls on the cartridge are engaged.

   Note: If you are using a calibration grating as a sample, for instance a 1 µm gold grating, it is best to use an etched STM tip. Etched tips have a higher aspect ratio, which is better for scanning samples with high aspect ratio features.

Configuring the Software

This section includes steps for configuring the system software for taking an STM image.

1. Open ProScan Data Acquisition. From Start, point to the Program folder and select ThermoMicroscopes ProScan. Then, click the Data Acquisition icon. Alternatively, double-click the Data Acquisition icon in the desktop. The program opens to Move mode.

2. Turn off the probe head by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

3. Open the ProScan database configuration dialog box by selecting Configure Parts from the Setup menu.

4. In the ProScan Database Configuration dialog box, make the following selections to configure the system software for STM operation.:

   - Head type: AFMSTM.
   - Scanner: Select the file that has the scanner calibration values for the scanner that you are using.
   - Head mode: STM.
   - Tunneling tip: AIR.
   - Electrochemistry ON/OFF: OFF.
   - Voltage mode: HI.

After you finish making these selections, click OK to return to Move mode.

5. If you have not already done so, reset the Z stage as described in Chapter 2, Part I of this User's Guide. This synchronizes the position of the Z stage with the coordinate system of the software.

Diagnostic Checks

This section includes steps for checking electrical connections and tip-to-sample bias offsets.

1. Using a multimeter on the Ohms setting, check the electrical resistance of the path between the STM tip and the probe head. As you view the head from above, place one probe of the multimeter on the rear, left brass screw of the head, which connects to the metal contact pad of the STM cartridge. Place the other probe of the multimeter on the metal cylinder of the STM cartridge, which has a hole that holds the STM tip wire. The resistance between the probe head and the tip should be small for STM operation.

   Note: If the STM cartridge is too loose or too tight, the conducting path may be disrupted. Try adjusting the position of the probe cartridge to establish good contact. If this does not help, call ThermoMicroscopes Customer Support for help in diagnosing the problem.

Next, you will check the voltage drop between the tip and the sample. The measured voltage should correspond to the voltage difference that you set using the system software.

2. Click the Head ON icon, , to turn the power to the probe head on.

3. Switch to Image mode by clicking the Image Mode icon, .

4. Check the values of the sample bias and tip bias parameters listed in scrollboxes of Image mode. The default values of these parameters should be zero.

5. Leave the sample bias value at zero (so that the sample is grounded) and set the tip bias at 1 V.

6. Use the multimeter on the Volts setting to measure the voltage drop between the tip and the sample. Make the measurement quickly: the finite impedance of the voltmeter provides a leakage path for current flow and the voltage reading may decrease with time. The measured voltage should match the bias difference set in Image mode.

If there is an offset between the measured bias and the bias set using the system software, you can account for this offset by adjusting the value of a calibration parameter in the Manual Calibration Entry Dialog box, as follows:

7. Click the Head ON icon, , to turn the power to the probe head off.

8. Select Calibration Edit from the Setup menu to open the Manual Calibration Entry dialog box. Click the Yes button of the Warning box to indicate that you wish to proceed.

9. Select Bias Voltage from the Category listbox. Then select the TipBiasVoltsOffset parameter from the Calibration Values box so that its value appears in the textbox in the upper-right corner of the dialog box.

10. The default value of the TipBiasVoltsOffset parameter is zero. Click and drag over the existing value of the parameter to select it, then type in the offset value you measured in Step 6 above, in volts. For example, if you measured an offset of 65 mV in Step 6, then change the value of the TipBiasVoltsOffset parameter to 0.065.

    Press the [`Enter`] key on your keyboard to register the change.

11. Click the Done button to close the dialog box.

The offset in the tip-to-sample bias is now accounted for in the software. Thus, the bias you set using the Tip Bias and Sample Bias scrollboxes of the Image mode window now accurately reflects the bias between the tip and the sample. You should only need to check that this offset is valid periodically. However, you can expect the value to be different if you switch to a different probe head or scanner.

Note: If you decide not to adjust the TipBiasVoltsOffset parameter value and there is an offset between the measured tip-to-sample bias and the bias set using the

system software, then you must account for this offset when you set the sample and tip bias parameters for an STM scan. For example, if you measure an offset of - 0.065 V and you wish to apply 500 mV between the tip and the sample, then you need to enter 0.565 V for the tip bias (if the sample is grounded).

You are now ready to start the tip-to-sample approach process.

Approaching the Sample

To perform an auto approach, you will first set selected scan parameters for the approach. Then, you will bring the tip close to the sample surface using the optical view. Finally, you will tell the system to perform an auto approach, a process in which the tip and sample are brought together gradually until the set tunneling current value is detected.

Setting Up for an Auto Approach

Two of the scan parameters you must set before performing an auto approach are the tunneling current and tip-to-sample bias. The tip-to-sample bias was discussed in the previous section. The tunneling current value is displayed as the set point parameter in the Set Point scrollbox in Image mode. The set point is the reference current value that the system checks for during the approach. If you leave the set point unchanged for the scan, then it is the tunneling current value that will be maintained during the scan.

A third parameter you need to set is the gain of the feedback loop. Other parameters, such as the number of pixels per scan line, are set to default values that you do not need to change. The default number of pixels per scan line is 256. Also, the Z Servo checkbox should be enabled by default.

Note: If you have a MAP module connected to your system, be sure that the module is turned off (the gray button should be out) before you begin taking an STM image.

The procedures provided here are for taking a constant-current image, which represents a surface of constant tunneling current as the distance the scanner needs to move in order to maintain the set point (current) value. Detailed descriptions of both constant-current and constant-height mode STM images are given in a later section of this chapter.

Note: **If you have the multitask AutoProbe CP system configuration:** In order to facilitate the approach process, you may need to change the value of a calibration parameter. With the power to the probe head turned off, select Calibration Edit from the Setup menu to open the Manual Calibration Entry dialog box. Click the [Yes] button of the warning box to proceed, then choose the Error category from the Category listbox. Select the STMErrSignalMethod

parameter in the Calibration Values box so that the value of this parameter appears in the textbox in the upper-right corner of the dialog box. If the value of this parameter is not 8, select the old value and change it to 8 now. Then press the `[Enter]` key on your keyboard to register the change. Click [Done] to close the dialog box.

1. From Image mode, select a tunneling current value for the approach by entering a value for the set point parameter.

   For a gold calibration grating, start with a value of 1 to 2 nA for the set point.

2. Click the Digital VoltMeter (DVM) icon, , to open a DVM window. Click the [CH] button on the DVM window and select the Current signal so that you can view the tunneling current measured by the system.

   Viewing the tunneling current can be useful both during an auto approach and during a scan as it is an indicator of a tip crash. If the tip crashes, the current displayed on the DVM exceeds the set point value and saturates.

3. Set the tip-to-sample bias by leaving the sample bias at 0 V and entering a value of 0.1 V for the tip bias.

4. Set the gain parameter to 5. This value provides enough feedback response to prevent the tip from crashing into the sample, but not so much that the system will oscillate. Later, while you are taking an image, you can adjust the gain parameter to optimize the system's tracking of the sample surface.

CAUTION

The default value of the gain parameter, 0.01, is too low. Using this value is likely to result in the tip crashing into the sample surface.

5. Set the scan size to zero. This stops the scanner from moving the sample while you perform a coarse tip-to-sample approach.

Before you initiate an auto approach, you should move the tip as close to the sample as possible by eye. (Be careful not to touch the tip to the sample surface, however.) If the tip is close to the sample surface, then the auto approach will take less time.

If you are using an AutoProbe CP with on-axis optics, you will be relying mainly on the focus of the tip and the side view of the tip that you obtain by eye. If you are using separate optics along with your AutoProbe CP instrument, it is easiest to perform a tip-to-sample approach using the oblique view provided by the optics.

6. Enter Move mode by clicking the Move Mode icon, .

7. Find the tip in the optical view and focus on it.

   If you are using the AutoProbe CP with on-axis optics: Turn on the light source for the optical view using the Optics View ON button. Zoom out to obtain the widest field of view using the sliding zoom hardware lever. Then focus on the tip using the coarse and fine focus knobs. You may need to move the Z stage and/or the XY translation stage to bring the tip within the optics' view and range of focus.

   If you are using the separate optical microscope for AutoProbe CP: Position the fiber optic light source so that it shines directly down on the tip. Place the microscope in the front of the probe head and adjust its position and focus so that you can see the tip clearly when you look through the objective lens. You may need to move the Z stage and/or the XY stages to bring the tip within the optics' view and range of focus.

8. When the tip is in focus and centered in the optical view, use the coarse and fine focus knobs to focus on the sample surface.

9. Move the tip down towards the sample using the z direction pad. If you are using an AutoProbe CP with on-axis optics, view the tip by eye from the side as you lower the z tip. Bring the tip to within a few millimeters of the sample surface.

   If the sample surface is reflective, you should be able to look at the TV monitor and see the reflection of the tip as the tip approaches the surface. The reflection will appear to rise to meet the tip. When you see the reflection, let go of the z direction pad to stop moving. Place the cursor close to the center line of the z direction pad and slowly bring the tip toward the sample. When the tip and its reflection are almost touching, let go of the z direction pad.

   If the sample surface is non-reflective, you should be able to see the shadow of the tip. Watch the tip approach close to the sample as you lower the tip using the z direction pad and let go of the pad when the tip is within a few millimeters of the surface.

10. With the optics still focused on the sample surface, use the z direction pad to slowly lower the tip further, stopping as it starts to come into focus. This should position the tip close to, but not in contact with, the sample surface.

You are now ready to perform an auto approach.

Performing an Auto Approach

Clicking the Approach button in STM mode starts the following sequence of steps:

a. The scanner extends, moving the sample toward the tip with feedback enabled.
b. The system monitors the tunneling current, checking for the set point value as the scanner extends.
c. If the set point value is obtained, then the auto approach process stops.
d. If the set point value is not obtained with the scanner fully extended, then the system retracts the scanner and lowers the probe head one step (of the stepper motor) toward the sample.

Steps a through d are repeated until the tunneling current matches the set point value.

1. Click the Approach button in Move mode to initiate an auto approach.

The auto approach sequence is a slow process. You may see the reflection of the tip flicker up and down in the optical view with each step. Watch the Current signal displayed on the open DVM window. The Current signal should approach the set point value, and then stop.

> ***CAUTION***
>
> The tip should never touch the surface in STM mode. If the tip makes contact, both the tip and the sample will be damaged. Contact between the tip and the sample, referred to as a tip "crash," is indicated by an increased current reading on the DVM. If the tip crashes, you must change the tip before you can proceed with taking an STM image.

When the approach stops, the tip will be within 10 Å of the surface but will not actually be in contact. After a successful approach, the green Piezo bar should show that the scanner stops moving and is extended to about half of its full range.

Starting a Scan

This section presents the basic steps involved in taking an STM image. Optimizing scan parameters is discussed in a later section, along with brief explanations of what these parameters control.

1. Enter Image mode by clicking the Image mode icon, .

A signal trace representing surface topography should be displayed on the Oscilloscope Display. The name of the displayed signal appears in the drop-down list below the Oscilloscope Display. The Topography signal should appear by default.

If the scaling appears inappropriate for the signal trace, click the [A] button (auto re-scale) to re-scale the signal trace to fit the display.

2. Enter a scan size of several microns (µm). Select a scan rate of about 1 Hz. The default number of pixels per scan line is 256, and the default fast scan direction is the x direction.

3. Adjust the slope parameter as needed to level the signal trace.

4. Click the [Image] button to start taking an image.

   As the image builds up line-by-line in the Active display, watch the Topography signal trace in the Oscilloscope Display. Ideally, each signal trace should look similar to the one before.

5. Adjust scan parameters such as the gain, set point, and tip bias if necessary to improve surface tracking. Information on optimizing scan parameters is provided in the next section.

6. When the scan is finished, even if this first image is not particularly good, click the [Import] button to copy the image into the Import View. Then, you can move to a new location on the sample or vary the scan size by using the cursor box.

Optimizing STM Scan Parameters

This section describes how to optimize the current and bias parameters used for taking an STM scan. The optimal values of current and bias parameters depend on a number of factors, including what sample you are looking at, whether it is semiconducting, and what type of semiconductor it is. Optimizing these parameters is usually an experimental, trial and error process.

The set point parameter sets the tunneling current during an STM scan. The tunneling current is given in nanoamps (10^{-9} amps). The tunneling current between the tip and the sample in STM is analogous to the force interaction between the tip and the sample in AFM. With feedback enabled and the feedback setting optimized, the system operates to keep the tunneling current constant by raising or lowering the sample.

Since the tunneling current varies exponentially with tip-to-sample spacing, the set point value basically controls the tip-to-sample spacing during a scan. Raising the set point value brings the tip closer to the sample, while lowering the set point value moves the tip farther from the surface.

Ideally, the tip should never come into contact with the surface during an STM scan, because both the tip and the sample surface will be damaged. For instance, the tip can leave a small pinhole or dent in the surface if it is driven into the surface.

Typically, the set point is less than 10 nanoamps for STM.

The tip-to-sample bias during a scan is set using the sample bias and tip bias parameters. If the sample is biased negative relative to the tip, then the STM image will represent tunneling from filled electronic states on the sample surface. If the sample is biased positive relative to the tip, then the STM image will represent tunneling into empty electronic states on the sample surface. The tip and sample biases are given in volts.

The bias settings do have an indirect effect on the tip-to-sample spacing. In constant-current mode with feedback optimized, the system attempts to maintain a constant tunneling current by varying the tip-to-sample spacing. If the tip-to-sample bias is increased, the tunneling current also increases. The system therefore pulls the sample away from the tip to maintain constant tunneling current.

Typically, the bias between the tip and the sample should be lower than about 1 volt in air. If the bias is larger than about 1 volt, the STM will not be operating in the tunneling regime. The optimal bias to use depends on whether the sample is conducting or semiconducting. With conducting samples, you can use lower bias settings. With semiconducting samples, use higher bias settings, as long as they are not much above 1 volt.

A typical bias range for STM is from about 0.1 to 1 V.

Constant-Current vs. Constant-Height Mode

You can take STM images in constant-current mode or constant-height mode. These modes of STM operation are similar to the constant-force and constant-height modes for AFM images.

Constant-current mode images are taken with feedback enabled and set to a moderate value. The output signal from the feedback loop controls the z position of the scanner, which extends or retracts to control the tip-to-sample spacing and maintain a constant tunneling current. When the feedback parameters are optimized, the scanner's z motion matches the sample's surface electronic structure. The signal from the feedback loop that controls the scanner's z position, called the Topography signal, can then be used to generate an image of the sample surface. This mode of imaging is often called constant-current mode, and it is the most common method of operating an STM.

You can also monitor the tunneling current signal, which is used to generate the Error signal to the feedback loop. When feedback is enabled, the tunneling current should be constant. An image of any remaining error gives a measure of how well the feedback loop is tracking the sample topography.

When the gain is set to a low value, however, the z feedback is minimal and the tunneling current varies with the topography and surface electronic structure of the sample. Thus, the tunneling current signal, called the Error signal, can be used to generate an image of the sample surface. This mode of imaging is often called constant-height mode, because, with minimal feedback, the tip-to-sample spacing is not varied to maintain a constant tunneling current signal.

Constant-height mode images can be taken faster than constant-current mode images because feedback is minimized and the system does not have to wait for the response of the feedback loop. This is important for small-sized scans that need to be taken faster than the effects of thermal drift. However, because the z position of the scanner does not follow changes in surface topography, constant-height mode can only be used to take

images of smooth surfaces. Constant-current mode can be used to take images of irregular surfaces, but these images take longer to collect.

These characteristics of constant-current mode and constant-height mode images mean that you will typically use constant-current mode to take images of larger, more irregular regions on the sample surface, and you will use constant-height mode to take higher-resolution images of smaller, smoother regions of the sample surface. Since portions of the sample surface that you may wish to image with atomic resolution are also small, flat regions, you will typically use constant-height mode for obtaining this type of highest resolution image.

One advantage of constant-height mode for taking atomic-resolution images is that faster scan rates can be used, as mentioned above. Another advantage is the exponential relationship between the tunneling current signal used to generate these images and the tip-to-sample spacing, or sample topography. Because of this exponential relationship, small variations in topography and surface electronic structure are more prominent in constant-height mode images.

Taking a Constant-Current Mode Image

1. In Image mode, make sure that the Topography signal is available and selected in the drop-down list below the Oscilloscope Display. It should be available since it is the default signal selection.

2. If you need to add the Topography signal, open the Input Configuration dialog box by selecting Input Configuration from the Setup menu. Click on Topography in the Available list box to select the Topography signal, then click the [Add -->] button to add that signal to the list in the Selected list box.

   Click [OK] to close the Input Configuration dialog box and return to Image mode.

3. In Image mode, make sure that the Z Servo box is checked so that z feedback is enabled.

4. Click the [Image] button to start taking an image.

This mode of operation generates an image using the signal applied to the scanner in order to maintain a constant tunneling current. Constant-current mode is used for most STM images.

Taking a Constant-Height Mode Image

1. Open the Input Configuration dialog box by selecting Input Configuration under the Setup menu. Click on Error Signal in the Available list box to select the Error signal, then click the Add --> button to add that signal to the list in the Selected list box.

   Click OK to close the Input Configuration dialog box and return to Image mode.

2. In Image mode, set the gain to a low value.

   Do not lower the gain all the way to zero, however. A finite gain allows the tip to track slowly varying surface topography, for instance due to a shallow slope. Some small degree of surface tracking is important, because the tip must be within about 10 Å of the surface to obtain a measurable tunneling current.

3. Select a scan rate, for example 20 Hz.

   Scan rates used for STM are generally the same as for AFM. For atomic resolution images, however, it is best to use a faster scan rate, around 12 to 25 Hz. As mentioned earlier in this section, faster scan rates reduce the effects of thermal drift in an image.

While You Are Taking an STM Image

Ideally, for a relatively flat, featureless sample, each signal trace should look similar to the one before. If you are scanning a sample with closely spaced periodic features (for instance, a 1 µm gold grating), look for features with the same spacing in the signal trace.

A signal trace that jumps erratically or one that is jagged indicates that the scan parameters are not optimized. For instance, a saw-tooth signal trace might be an indication that the tip is tapping the surface as the sample is scanned. To increase the tip-to-sample spacing, decrease the tunneling current by lowering the set point value.

Since the STM tip is held rigidly in place on the STM cartridge, it is much easier to damage both the tip and sample surface during a scan if the tip makes contact. (The AFM tip, on the other hand, is mounted on a flexible cantilever.)

When you are trying to obtain atomic resolution images, there are several ways you can distinguish atoms on the surface from noise in an image:

1. Vary the scan size. If the corrugations you see in the signal trace represent atoms, then their size should scale with the scan size, becoming smaller for larger scan sizes.

2. Move to a slightly different location on the surface. In the next scan, the position of the corrugations in the image should shift accordingly.

3. Change the scan rate. If the corrugations represent atoms, changing the scan rate should not affect the periodicity of the image. If the spacing of the corrugations changes, then what you see in the image is due to noise.

Taking an STM Image of a Graphite Sample

This section provides the basic instructions for taking an image of a graphite sample.

1. With the probe head turned off, select Configure Parts from Setup menu to open the ProScan Database Configuration dialog box. Within this dialog box, make the following selections:

   - Head type: AFMSTM.
   - Scanner: Select the name of the file with the scanner calibration parameters appropriate for the scanner you are using.
   - Head mode: STM.
   - Tunneling Tip: AIR.
   - Electrochemistry ON/OFF: OFF.
   - Voltage mode: LO.

   Click [OK] to close the dialog box.

2. Follow the instructions of previous sections to take an image in constant-height mode, using the following values for key scan parameters:

   - set point: 1 to 5 nA
   - sample bias: 0 V.
   - tip bias: 100 to 500 mV.
   - scan rate: 20 to 40 Hz.
   - scan size: 50 to 100 Å.

Summary

This chapter provided you with instructions for taking an STM image. Some of the topics covered include the following:

- preparing and loading STM tips
- setting up the system hardware and software
- taking an STM image of a gold calibration grating
- constant-current vs. constant-height mode STM images
- optimizing scan parameters
- taking an STM image of a graphite sample

After reading this chapter, you should be able to take an STM image of a relatively straightforward sample such as the gold calibration grating provided with your system, or a graphite sample. Once you become familiar with the effects of tip quality and of varying scan parameters such as current and bias settings, you will be ready to move forward and image more complicated surfaces.

Chapter 3
LFM Imaging

Introduction

This chapter describes how to operate your AutoProbe CP instrument in lateral force microscopy (LFM) mode.

In this chapter, you will find information on the following topics:

- how LFM works
- the usefulness of having information from both AFM and LFM images available
- how to take images that reflect topographic and frictional information simultaneously

The first section of the chapter, which describes how LFM works, provides background material that prepares you for the procedural section at the end of the chapter. The procedural section is comprised of step-by-step instructions that guide you through the process of obtaining simultaneous AFM and LFM images.

How Lateral Force Microscopy (LFM) Works

Lateral force microscopy (LFM) is similar to atomic force microscopy (AFM), except that an instrument operating in LFM mode is equipped with a cantilever detection scheme that measures both vertical and lateral bending of the cantilever. This differs from AFM mode, which measures just vertical bending of the cantilever, and is thus only able to measure changes in sample topography. By measuring lateral bending (or twisting) of the cantilever, LFM mode is used to monitor motions arising from forces on the cantilever that are parallel to the plane of the sample surface. Such forces could arise from changes in the frictional coefficient of a region on the sample surface, or from onsets of changes in topography. Operating in LFM mode is therefore useful for measuring inhomogeneities in surface materials, and also for producing images with enhanced edges of topographic features.

The LFM Signal

This section describes how your system obtains the signal used to create an LFM image.

Just as for contact-AFM operation, when your system is operating in LFM mode, it measures the bending of the cantilever using a position sensitive photodetector (PSPD) to detect deflection of a laser beam off of the cantilever. For AFM mode, the PSPD is used in a bi-cell configuration, or as two halves that detect vertical deflection of the cantilever. For LFM mode, the PSPD is used in a quad-cell configuration. This means that the PSPD can detect both lateral and vertical deflection of the cantilever. Figure 3-1 shows both a quad-cell and a bi-cell PSPD.

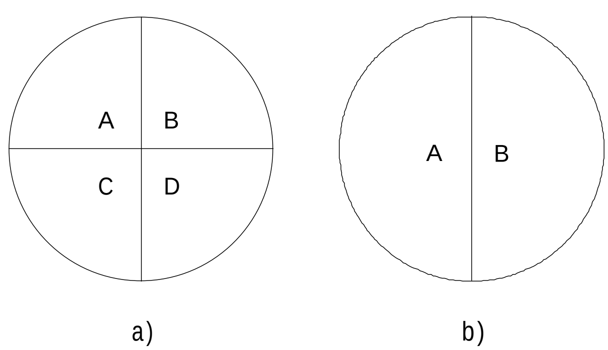


Figure 3-1. A quad-cell PSPD (a) and a bi-cell PSPD (b).

LFM mode is used mainly to collect both topographic (AFM) and frictional (LFM) information during a single scan. The topographic information is represented by vertical deflection of the cantilever, which is measured as the difference between signals from the left and right quadrants of the quad-cell PSPD. By convention with contact-AFM, this signal difference is called the "A-B" signal, referring to the two halves of a bi-cell PSPD:

A-B signal = (A+C) - (B+D).

Topographic information is also represented by the Topography signal, which is a function of the A-B signal.

Frictional information (the LFM signal) is represented by lateral deflection of the cantilever, which is measured as the difference between the upper and lower quadrants of the quad-cell PSPD:

LFM signal = (A+B) - (C+D).

Note: The PSPD is mounted facing the side of the cantilever. Therefore, lateral twisting of the cantilever is measured as vertical changes in the position of the laser beam on the PSPD. Vertical bending of the cantilever is measured as lateral changes in the position of the laser beam on the PSPD.

By acquiring both the Topography and LFM signals, an instrument operating in LFM mode can produce AFM and LFM images simultaneously.

The Tip-Sample Interaction for LFM

This section describes how LFM images correlate with changes in frictional coefficients and topography on a sample surface. This description will help you to compare and interpret the information in LFM and AFM images.

Figure 3-2 illustrates how a cantilever responds to changes in topography, and how that response correlates with the resulting LFM and AFM data. Vertical motion of the cantilever is depicted as a change in the vertical position of the cantilever. Lateral motion of the cantilever is depicted as a change in the angle of the tip with respect to the horizontal.

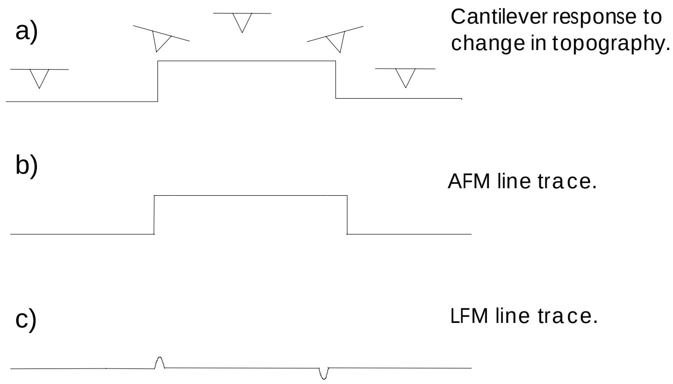


Figure 3-2. Cantilever response to change in topography, and corresponding AFM and LFM signal traces.

Figure 3-2a shows that a change in sample topography creates both vertical and lateral changes in cantilever position. The lateral component is not recorded for the AFM image, which monitors only vertical bending of the cantilever. Figure 3-2b shows the AFM signal trace that would result from the topography of Figure 3-2a.

Figure 3-2c shows the LFM signal trace that would result from the topography of Figure 3-2a. As the figure shows, the LFM data reflect only the lateral components of bending: e.g., bending to the right at the rise in topography produces a positive signal, and bending to the left at the drop in topography produces a negative signal.

Figure 3-3 illustrates how a cantilever responds to changes in frictional coefficients, and how that response correlates with the resulting LFM and AFM data.

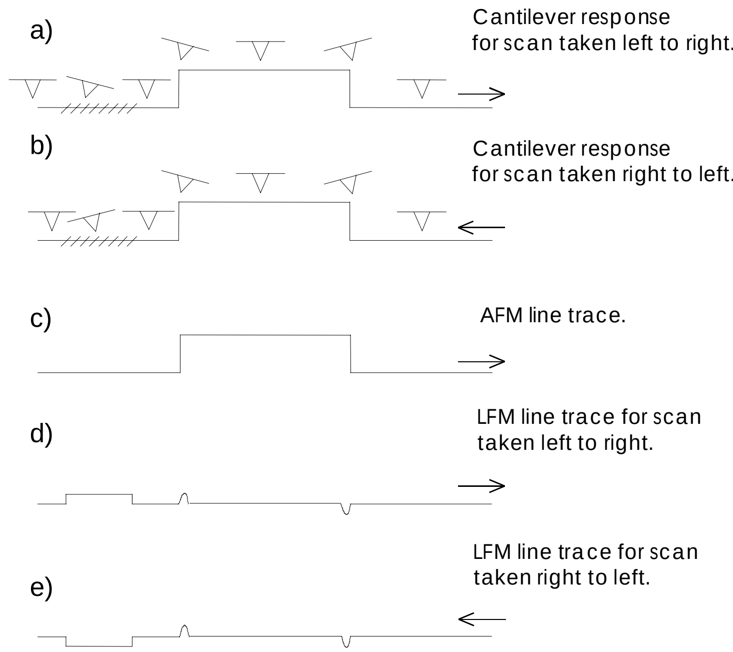


Figure 3-3. Cantilever response to change in frictional coefficient and topography, and corresponding AFM and LFM signal traces.

Figure 3-3a shows a change in frictional coefficient that causes the cantilever to bend to the right for a scan that is taken from left to right. If the scan is taken from right to left, as illustrated in Figure 3-3b, the cantilever bends to the left as it passes over the change in frictional coefficient. A change in topography causes the same type of cantilever bending as was illustrated in Figure 3-2.

Figure 3-3c shows an AFM signal trace resulting from the surface of Figure 3-3a: the data only reflect the change in sample topography. Figure 3-3d shows the LFM signal trace that would result from a scan taken from left to right. Figure 3-3e shows the LFM signal trace that would result from a scan taken from right to left. The sign of the LFM signal flips for the change in friction, but not for the change in topography. Changes in topography appear on an LFM image as adjacent dark/bright regions. By identifying these adjacent dark/bright regions, and by viewing data from two scan directions, a user looking at an LFM image can distinguish between contrast changes due to changes in frictional coefficient and those due to changes in topography.

The above description indicates the usefulness of side-by-side AFM and LFM data: they provide complementary information. By monitoring the LFM signal, you can identify the contribution of lateral cantilever bending to a AFM image. Conversely, having the AFM information available enables you to confirm contrast changes on an LFM image that are due to changes in topography, rather than frictional coefficient.

When you take a scan, you can specify whether you would like the fast scan direction to be x or y (horizontal or vertical). As an image is being taken, the scanner rasters back and forth over each scan line in the fast scan direction, and then advances to the next line in the slow scan direction. Once you have selected a fast scan direction, you can also specify whether you would like to view data collected from the forward or reverse sweep of the scanner. For example, if you choose an x scan, you can choose to view data collected from the right-to-left sweep of the scanner, or from the left-to-right sweep of the scanner, or from both sweep directions.

When you are operating in LFM mode, it is often useful to view both AFM and LFM data collected from both the forward and the reverse sweeps of the scanner. In this manner, you can distinguish between frictional and topographic information as described above.

The procedures in the following sections describe how to operate in LFM mode. You will learn how to generate and view four images simultaneously, and how to compare the information contained in those images.

Setting up the System

Setting up the instrument to operate in LFM mode consists of the following general procedures:

- installing the appropriate hardware
- configuring the system software
- aligning the deflection sensor
- performing an auto approach

This section assumes that your instrument has been installed by a ThermoMicroscopes representative and that all of the cables are properly connected.

If you have the standard AutoProbe CP system configuration: This section assumes you are using a 5 µm scanner and an AFM/LFM probe head.

If you have the multitask AutoProbe CP system configuration: This section assumes you are using a 100 µm scanner and the multitask probe head.

Installing the Scanner and the Probe Head

1. Install a scanner

> ***CAUTION***
>
> The power to the AEM must be turned OFF before you remove or install the scanner.

> ***CAUTION***
>
> The four screws that connect the scanner to the CP base unit must be securely fastened to ensure proper grounding. When the four screws are securely fastened, maximum instrument performance is ensured since vibrations are reduced.

2. Place a 1 µm gold calibration grating on the scanner sample mount.

3. Install the appropriate probe head by sliding it onto the support arms of the XY Translation Stage, as described in Chapter 2, Part I of this User’s Guide. Make sure that the LASER ON/OFF switch is in the OFF position before you install the probe head.

If you have the standard AutoProbe CP system configuration: Install the AFM/LFM probe head. A connector on the rear of the probe head plugs into a connector on the back of the translation stage.

Figure 3-4 shows the AFM/LFM probe head used with the standard system configuration

If you have the multitask AutoProbe CP system configuration: Install the multitask probe head, and set the two mode switches on the probe head to the AFM and LFM positions.

4. Once the probe head is installed, turn the LASER ON/OFF switch to the ON position.

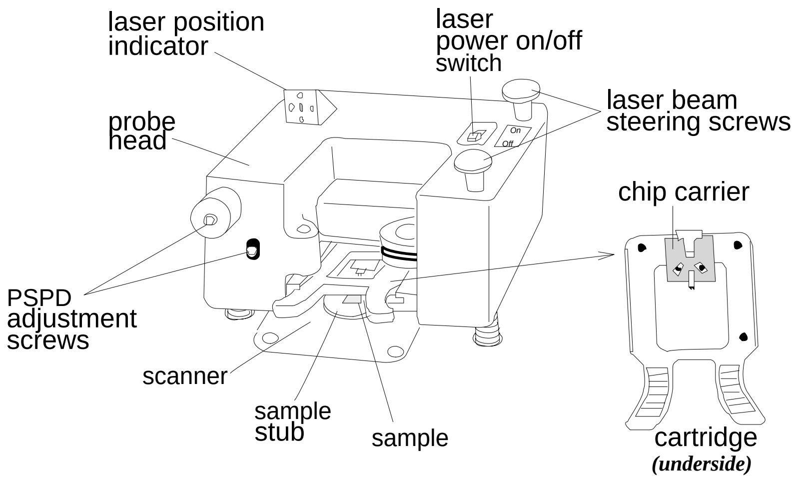


Figure 3-4. The AFM/LFM head.

5. Load a cantilever chip.

   - ♦ Place an AFM chip carrier in the probe cartridge.
   - ♦ Place the cartridge in the probe head. Make sure that you push the cartridge in so that the balls on the cartridge click into place in the probe head.

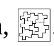
Configuring the Software

1. Turn on all of your system components as you normally do. Refer to Part I of this User's Guide for details.

2. Open ProScan Data Acquisition. From Start, point to the Program folder and select ThermoMicroscopes ProScan. Then, click the Data Acquisition icon. Alternatively, double-click the Data Acquisition icon in the desktop.

   The program opens to Move mode.

3. Turn off the probe head by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

4. Open the ProScan database configuration dialog box by selecting Configure Parts from the Setup menu. Alternatively, click the Configure Parts icon, .

5. Configure the system software for LFM mode. To do this, make the following selections:

   - Head Type: AFMLFM.
   - Scanner: Select the file that has the scanner calibration values for the scanner that you are using.
   - Head Mode: AFM.
   - Beam Bounce Cantilever: Select the name of the file that corresponds to the cantilever you are using.
   - Electrochemistry ON/OFF: OFF.
   - For Voltage Mode: HI.

   After you have finished making these selections, click the OK button, which sets the chosen system configuration items and returns you to Move mode.

6. If you have not already done so, reset the Z stage as described in Chapter 2, Part I of this User's Guide. This synchronizes the position of the Z stage with the coordinate system of the software.

Aligning the Deflection Sensor

The following steps describe how to align the deflection sensor for an AFM/LFM head. These steps apply only if you are using the standard system configuration of AutoProbe CP. If you are using the multitask system configuration, align the laser as you normally do, as described in Chapter 2, Part I of this User's Guide. Then, skip ahead to the section, "Performing an Auto Approach."

To align the deflection sensor, you must first steer the laser beam so that it reflects off of the back of the cantilever. Then, you move the position-sensitive photodetector (PSPD) so that it is aligned with the laser spot. This process can be one of the most challenging steps involved in LFM operation. At the end of this section, troubleshooting tips are included that may help you if you encounter problems while aligning the deflection sensor.

1. Bring the cantilever tip into view and turn on the laser.

   - Click the Optics View ON button to turn on the optics view light.
   - Bring the cantilever tip into view on the TV monitor.
   - Bring the tip into focus using the optics control and the Z stage pads.
   - Turn on the probe head by clicking the Head ON icon, .
   - Turn the optics view light off to see the laser spot.

2. Align the laser spot on the end of the cantilever.

   To steer the laser spot, adjust the laser beam steering screws. Figure 3-5 shows the direction the laser spot moves when you turn the laser beam steering screws. You may need to turn both screws at the same time.

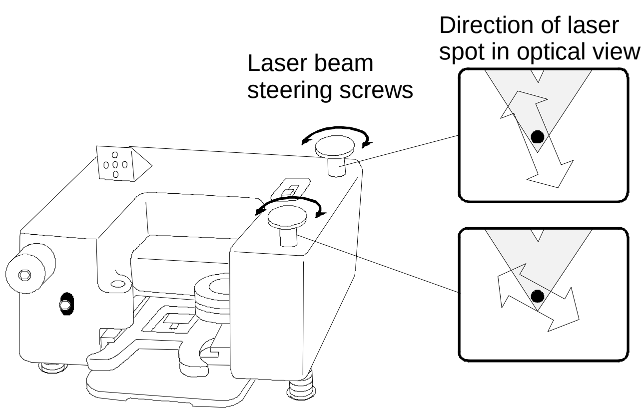


Figure 3-5. Aligning the laser spot on the end of the cantilever.

After you have aligned the laser spot on the end of the cantilever, you no longer need to move the laser beam. Now, you are ready to move the PSPD so that its center is aligned with the laser spot.

3. Adjust the position of the PSPD to align the laser spot with the center of the PSPD. As was mentioned at the beginning of this section, this step can be challenging for a quad-cell PSPD.

- When the PSPD is correctly positioned, the center green laser position indicator light is on. When the PSPD is *not* correctly positioned, one or more red lights will be on. Figure 3-6 shows how the PSPD adjustment screws move the PSPD.

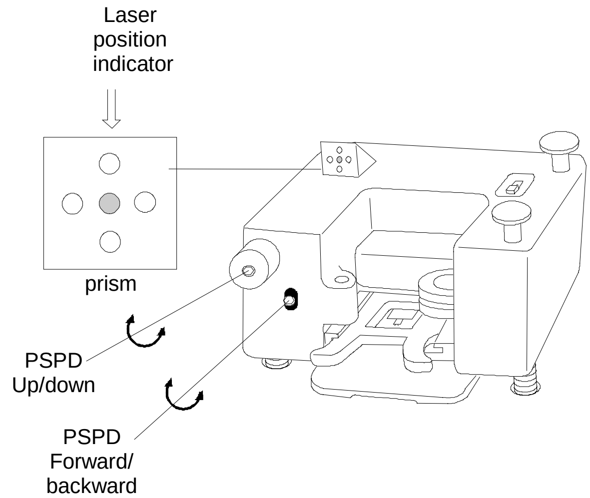


Figure 3-6. Adjusting the PSPD position up/down and forward/backward.

- Make the following adjustments:
  1) When the top or bottom red light is on, adjust the PSPD forward/backward screw.
     For the top red light, rotate the screw counterclockwise (CCW).
     For the bottom red light, rotate the screw clockwise (CW).

  2) When the left or right red light is on, adjust the PSPD up/down screw.
     For the left red light, rotate the screw clockwise (CW).
     For the right red light, rotate the screw counterclockwise (CCW).

After making adjustments to the up/down position, you may need to readjust the forward/backward position, and vice versa. Near the correct position, the red lights are very sensitive and you may find it difficult to position the PSPD so that all of the red lights stay off. As long as you are *very close* to the correct position, you can proceed with the lateral force measurements.

Troubleshooting Tips

The process of aligning the laser on the PSPD for operating in LFM mode is more difficult than it is for operating in AFM mode. This is because LFM mode uses a quad-cell PSPD while AFM mode uses a bi-cell PSPD. For a quad-cell PSPD, the laser must be aligned in the center of the detector, on all four (A through D) quadrants. For a bi-cell configuration, the laser is considered to be aligned as long as it is hitting the two halves of the detector (A and B). Figure 3-7 shows aligned laser spots for both quad-cell and bi-cell PSPD's.

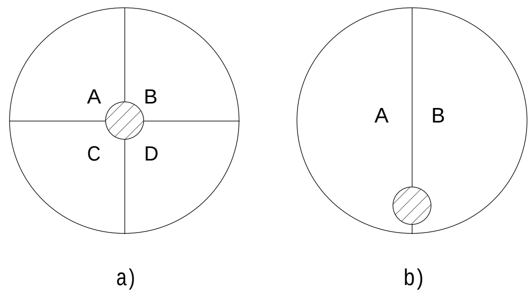


Figure 3-7. Laser spot (shaded circle) aligned on quad-cell (a) and bi-cell (b) PSPD's.

If you are having difficulty aligning the deflection sensor, you may need to try using a different cantilever. Residual strains in a cantilever may cause it to bow slightly, making laser alignment difficult. If you are using a "hand" Microlever, which has 5 tips per chip, then you have several tips to choose from without requiring changing the chip. The center tip often works well for taking LFM images.

If you cannot get the laser anywhere near the detector, try the following:

1. Try another tip on the chip.
2. Try another chip.

If you are using an unmounted chip carrier, try adjusting the position of the chip in the carrier.

Once the deflection sensor is aligned, you are ready to perform an auto approach.

Performing an Auto Approach

The auto approach process brings the cantilever into contact with the sample. The approach stops when the amount of vertical deflection of the cantilever matches that represented by the set point parameter.

1. In Move mode, use the z direction pad to lower the probe head, bringing the tip to within a few millimeters of the sample surface. Then, click the [Approach] button to initiate an approach.

   You should hear the motor in the head start, and then continue.

Troubleshooting Tips: Approach

If you hear the motor start and then stop, without proceeding further, then the approach probably did not work. Try the following troubleshooting tips:

1. Make sure that the set point is high enough.

2. The absolute value of the signal representing vertical deflection of the cantilever is usually close to, but not equal to, zero, even if the corresponding laser position indicator lights are not lit. This signal, which is the difference between the signals from the left and right halves of the PSPD, must be within a certain tolerance or range in order for the system to perform an approach. In the case that it is outside this range (even though the laser position indicator lights may not be lit), you need to check the value of the signal and adjust the position of the PSPD to minimize it.

   To check the horizontal alignment of the PSPD: Adjust the forward/backward screw to move the PSPD so that the top and bottom indicator lights are both off. This adjustment centers the laser spot between the A/C and B/D, or left and right, halves of the PSPD. When the top and bottom lights are both off, the signal representing (A+C) - (B+D), called A-B by association with a bi-cell PSPD, should be small (|A-B| < 300 mV).

   To check the value of the A-B signal, open a Digital Voltmeter (DVM) by clicking the DVM icon, . Click the [CH] button on the DVM window to see a selection of channels, or signals, and select A-B. The display of the DVM will show the value of the A-B signal, given in volts or millivolts depending on the value.

If the DVM shows that the A-B signal is not small, then adjust the forward/backward screw to move the PSPD until the absolute value of the A-B signal is less than 300 mV. The laser spot should now be centered between the A/C and B/D halves of the PSPD.

When the A-B signal is close to zero, close the DVM window and click the [Approach] button. The approach should work.

It is also desirable that the signal representing the difference between the signals from the upper and lower halves of the quad-cell PSPD—the LFM signal—is close to zero. This signal, which reflects the vertical alignment of the PSPD, is not checked as part of the auto approach process. However, if it is closer to zero then the system will be able to accommodate a greater range of lateral deflection of the cantilever during the LFM scan.

To check the vertical alignment of the PSPD: Adjust the up/down screw to move the PSPD so that the left and right indicator lights are both off. This adjustment centers the laser spot between the A/B and C/D, or upper and lower, halves of the PSPD. When the left and right lights are both off, the LFM signal = (A+B) - (C+D) should be small (|LFM| < 300 mV). This signal represents the lateral deflection of the cantilever.

To check the value of the LFM signal, open a Digital Voltmeter (DVM) by clicking the DVM icon, . Click the [CH] button on the DVM window to see a selection of channels, or signals. Click More... to see more signals, and then select LFM. The display of the DVM will show the value of the LFM signal, given in volts or millivolts depending on the value.

If the DVM shows that the absolute value of the LFM signal is greater than 300 mV, then adjust the up/down screw to move the PSPD until the absolute value of the LFM signal is less than 300 mV. The laser spot should now be centered between the A/B and C/D halves of the PSPD.

Once you have aligned the deflection sensor and successfully approached a sample, you are ready to take an image.

CAUTION

If you want to turn off the probe head after you have performed an auto approach, remember to first lift the tip (using the upper z direction pad in Move mode). Once the probe head is turned off, the z feedback loop is disabled. Lifting the tip protects the cantilever from being damaged by possible contact with the sample.

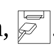
Taking an LFM Image

Taking an image of a gold grating is a useful place to start when learning how to operate your AutoProbe instrument in LFM mode. This is because a "good" image of a gold grating is relatively easy to identify. In addition, image quality is not as sensitive to scan parameter adjustment as it might be for other samples. While it might seem that a grating would only show contrast due to changes in topography, there are sometimes contaminants on the grating surface that are "sticky." These contaminants give rise to contrast in LFM images due to changes in frictional coefficients.

Taking an LFM image consists of the following general procedures:

- Selecting the data channels, or input configuration, that you would like to acquire during each scan.
- Adjusting scan parameters to optimize the AFM and LFM signal traces.
- Initiating a scan.

Selecting the LFM Signal

1. With the probe head turned on, select Input Config from the Setup menu. Alternatively, click the Input Config icon, .

2. In the Available listbox, select LFM and then click the [Add -->] button. This enables you to look at the LFM signal trace on the Oscilloscope Display and acquire LFM data.

3. The Topography signal should be selected by default. If it is not, select Topography in the Available listbox, then click the [Add -->] button. This enables you to look at the Topography signal trace on the Oscilloscope Display and acquire AFM data.

4. In the Selected listbox, click on LFM to select it. Check both the right (--≥) and the left (≤--) checkboxes. This enables you to obtain both left-to-right and right-to-left LFM data.

5. In the Selected listbox, click on Topography to select it. Check both the right (--≥) and the left (≤--) checkboxes. This enables you to obtain both left-to-right and right-to-left AFM data.

6. Click the [OK] button to close the Input Configuration dialog box and return to Image mode.

7. Set up the system so that you can view all four images, AFM and LFM right-to-left and left-to-right, simultaneously.

Select Layout from the View menu to open the Image Layout dialog box. Alternatively, click the Layout icon, . Click the Quad option button and then click the OK button. This enables you to view all four images at once.

By positioning the cursor over a Layout image in Image mode and clicking the right mouse button, you can see which image it is. The image type is displayed at the bottom of the window.

Setting Scan Parameters

1. Select the input signal you wish to view from the drop-down list below the Oscilloscope Display. You should have a choice between LFM and Topography. Check the signal traces of LFM and Topography. Adjust scan parameters to improve the signal traces where needed.

2. Set scan parameters such as the scan size, scan rate, and set point.

Starting a Scan

1. Click the Image button to take an image.

You should see all four images building up in the View display. As the images build up, note the differences between the LFM and the AFM data:

- AFM left-to-right and right-to-left images should look the same.
- LFM images may show features that are not apparent on the AFM images. These features represent something "sticky" on the sample surface.
- Sticky features should appear inverted in LFM left-to-right and right-to-left images. This is sometimes referred to as "contrast inversion." In other words, a sticky feature will appear dark for the LFM image taken in one direction and bright for the LFM image taken in the other direction.
- Topographic features on the LFM images are identifiable by their bright or dark leading edges, followed by dark or bright trailing edges. Note the difference between topographic features on the LFM vs. the AFM images.

2. Take scans of different sizes to find new features or to zoom in on features.

Troubleshooting Tips: Signal Saturation

If the LFM signal is saturating, it may be because the cantilever is twisting too much, reflecting the laser beam out of the spatial range detectable by the PSPD. If the LFM signal is saturating for data collection in one direction of scanner motion only, try adjusting the vertical position of the PSPD slightly. This alignment can be performed while the tip and sample are in contact.

If the LFM signal is saturating for data collection in both directions of scanner motion, try lowering the set point value. This reduces the force on the cantilever.

If lowering the set point value does not work, then you may need to switch to a stiffer cantilever.

Once you have successfully taken an LFM image of the gold grating sample, you can practice varying scan parameters and comparing AFM and LFM images. If you like, you can try switching to a different sample to see variations in its topography and frictional properties.

Summary

This chapter covered the following information related to operation of your AutoProbe CP instrument in LFM mode:

- how the LFM cantilever detection scheme works
- how LFM images correlate with sample surface features
- how to compare and interpret LFM and AFM images
- how to take simultaneous LFM and AFM images

Once you are familiar with the background materials and instrument setup procedures that are covered in this chapter, you should be ready to take AFM/LFM images of more complicated samples that reveal subtle features of LFM operation.

Chapter 4
Force vs. Distance

Introduction

This chapter describes how to acquire force vs. distance curves to study mechanical properties at specific x, y locations on a sample surface. A force vs. distance curve is a plot of the force between the tip and the sample as a function of the extension of the piezoelectric scanner tube. Using Spectroscopy mode of ProScan Data Acquisition software, you can acquire up to sixteen force vs. distance curves with a single AFM image.

Topics covered in this chapter include the following:

- acquiring a force vs. distance curve
- adjusting parameters and zooming in on features of a curve
- saving and exporting force vs. distance data
- retrieving previously saved force vs. distance curves
- background information about force vs. distance curves
- dimensions and physical constants of cantilevers

The first sections of this chapter are tutorials that guide you through acquiring force vs. distance data, and saving and retrieving that data. Then, optional sections at the end of the chapter provide you with background information about force vs. distance curves. These sections describe forces between a tip and a sample, and typical features of a force vs. distance curve. At the very end of the chapter you will find cantilever data sheets that include dimensions and physical constants of cantilevers.

The F vs. d Spectroscopy Window

Force vs. distance (F vs. d) curves are acquired using Spectroscopy mode of ProScan's Data Acquisition software. Spectroscopy mode is accessible as an item in the Mode menu, or as the Spectroscopy icon, , on the Toolbar.

When you enter Spectroscopy mode, the Image Gallery on the right side of the Image mode and Move mode windows is replaced by the Spectroscopy window. The Spectroscopy window includes a graph and software controls, as shown in Figure 4-1, below.

Note: The Image Gallery buffers remain accessible at the bottom right side of the window.

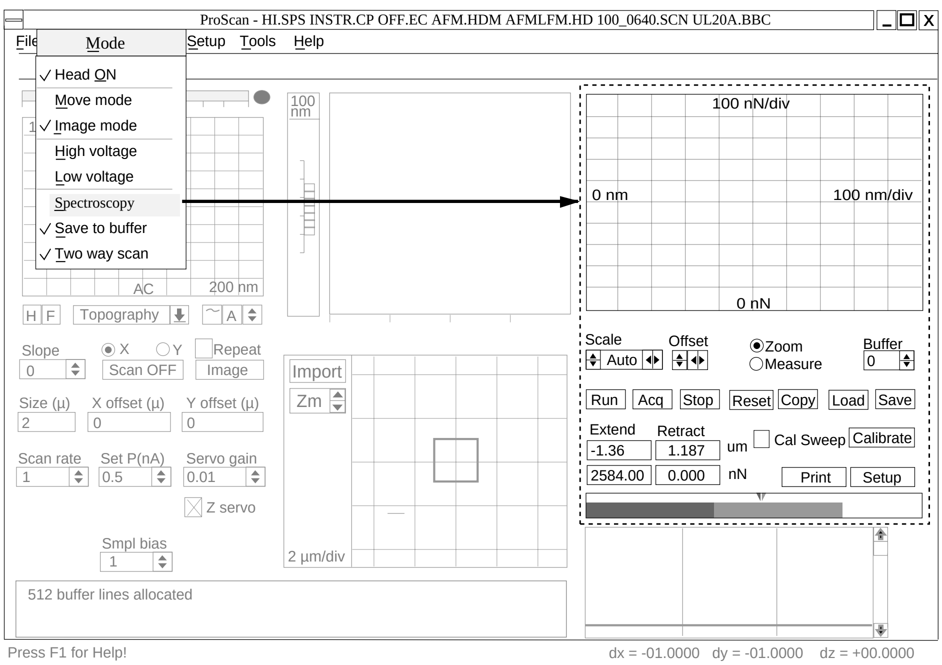


Figure 4-1. The F vs. d Spectroscopy window, shown in Image mode.

When you enter Spectroscopy mode while operating your instrument as an atomic force microscope, the software controls that appear are appropriate for acquiring force vs. distance curves. When you enter Spectroscopy mode while operating your instrument as a scanning tunneling microscope, the software controls that appear are appropriate for acquiring current vs. voltage curves.

A force vs. distance curve is generated with feedback disabled since you do not want the system to maintain a constant tip-to-sample spacing. Each curve is generated at a single x, y location on an image, which you select using the mouse. The force vs. distance curve depends only on the amount of vertical force on the cantilever as the scanner extends and retracts, and is therefore not affected by most of the scan parameter settings in Image Mode.

Variations in the shape of force vs. distance curves taken at different locations usually indicate variations in the local elastic properties of the sample surface. The shape of the curve may also be affected by surface contaminants, as well as the thin layer of water on the surface which is usually present when operating an AFM in air.

Following are sections that describe displays and controls of the Spectroscopy window. If you want to start the tutorial, you can skip these sections and return to them at a later time.

The Force vs. Distance Graph

The upper portion of the Spectroscopy window shows a graph where a force vs. distance curve is displayed. The horizontal axis of this graph represents distance, or z position of the scanner. The vertical axis of the graph represents the force exerted on the cantilever.

The default signal plotted on the horizontal axis is the Z Drive signal, which is the volts sent to the scanner to set its z position. The Z Detector signal can also be plotted on the horizontal axis and is represented as nm on the graph. The starting value and the number of units per division for the horizontal axis are displayed at the left and right sides of the graph, respectively.

The signal plotted on the vertical axis represents vertical deflection of the cantilever. You can calibrate the vertical axis with units of force by following the instructions of the section "Calibrating the Vertical Axis with Force” later in this chapter. The starting value and the number of units per division for the vertical axis are displayed at the bottom and top of the graph, respectively.

Spectroscopy Mode Controls

This section describes the controls in the F vs. d Spectroscopy window (see Figure 4-1). Table 4-1, below, lists each control in the window, along with a brief description of its function. The tutorial in the next section teaches you how to use these controls.

Table 4-1. Controls in the F vs. d Spectroscopy window.

Control	Function
Scale	Allows you to adjust the scaling of the vertical and horizontal axes of an F vs. d curve.
Auto	Resets the scaling of the vertical and horizontal axes.
Offset	Allows you to shift an F vs. d curve within the graph of the Spectroscopy window.
Zoom	Sets the function of the cursor when it is positioned within the graph. When the Zoom option button is selected, you can use the cursor to define an area that you wish to zoom in on. The Zoom option button automatically toggles off if you select the Measure option button.
Measure	Sets the function of the cursor when it is positioned within the graph. When the Measure option button is selected, the system reports the cursor's coordinates on the graph and you can use the cursor to make point-to-point measurements on an F vs. d curve. The Measure option button automatically toggles off if you select the Zoom option button.
Run	Prompts the system to disable the feedback loop and sweep the scanner, continuously updating an F vs. d curve that can be used for parameter adjustment. Clicking the Run button enables the Stop button, which you can press to stop the scanner's sweeping.
Stop	Stops F vs. d data acquisition and re-enables the feedback loop.
Acq	Initiates acquisition of one averaged F vs. d curve taken at a point or sixteen averaged curves taken along a line.
Reset	Resets the range of data read for subsequent F vs. d curves to cover the entire sweep range of the scanner, not the zoomed-in range.

Table 4-1 (continued). Controls in the F vs. d Spectroscopy window.

Control	Function
Copy	Allows you to copy raw data values of a particular F vs. d curve from the F vs. d Spectroscopy window into the Clipboard, which can then be used to export the data into any appropriate Windows application.
Load	Allows you to redisplay F vs. d curves previously saved to an image file.
Save	Saves F vs. d curves (i.e., numerical information corresponding to each F vs. d curve) to the image file associated with the curves.
Buffer	Allows you to scroll through F vs. d curves associated with the image in the Import View.
Extend and Retract: microns	Allows you to set the range of scanner extension and retraction during acquisition of an F vs. d curve. The maximum range depends on the scanner you are using.
Extend and Retract: nN	Displays the range of cantilever deflection during acquisition of an F vs. d curve.
Cal Sweep	Prompts the system to store and display subsequent curves as volts on the vertical axis vs. distance on the horizontal axis. These curves can then be used for calibrating the vertical axis units with force.
Calibrate	Prompts the system to compute and save the vertical axis calibration coefficient using points you select on a volts vs. distance curve.
Print	Prints the F vs. d curve currently displayed on the Spectroscopy graph.
Setup	Opens the Spectroscopy Setup dialog box, which includes the parameter settings described below.
Z Drive	Sets the Z Drive signal as the variable plotted along the horizontal axis of the F vs. d graph.
Z Detector	Sets the Z Detector signal as the variable plotted along the horizontal axis of the F vs. d graph.

Table 4-1(continued). Controls in the F vs. d Spectroscopy window.

Control	Function
Snap-Out	Ensures that the snap-out point is included on a zoomed-in F vs. d curve.
Snap-In	Ensures that the snap-in point is included on a zoomed-in F vs. d curve.
Average	Allows you to select the number of sweeps of the scanner that are averaged to acquire a final F vs. d curve.
Rate	Allows you to set the rate, in Hz, of each extension and retraction sweep of the scanner.
Use Database Value	Instructs the system to use the cantilever force constant (ErrSigNewtonPerMeter) value currently listed in the database for calibration of the vertical F vs. d axis with units of force.
Enter Value Manually	Allows you to manually enter the cantilever force constant value to be used for calibration of the vertical F vs. d axis with units of force.

The Piezo Adjustment Bar

The Piezo Adjustment bar is a red bar within a blue and white field. The bar is used as a graphical means of dynamically adjusting the scanner's sweep range during F vs. d set-up.

The left end of the Piezo Adjustment bar represents the limit to scanner retraction, and the right end of the bar represents the limit to scanner extension. You can use the mouse to drag the right and left ends of the red bar to change the limits of scanner extension and retraction, respectively. Clicking and dragging on the center of the red bar shifts the position of the entire bar, which is equivalent to shifting the limits of the scanner's extension and retraction simultaneously.

The white field surrounding the red bar represents the entire z throw, or range of motion, of the scanner.

Note: The z throw of a 100 µm scanner is about 7.5 µm. The z throw of a 5 µm scanner is about 2.5 µm.

The blue portion of the field represents the unused range of scanner motion between full retraction and the scanner's retracted position during F vs. d data acquisition.

The scanner's z motion is shown relative to a Set Point arrow located on top of the Piezo Adjustment bar. The red half of the Set Point arrow indicates the z position of the scanner when the set point value is matched at the x, y location where the F vs. d curve is acquired. The black half of the Set Point arrow indicates an estimate of the location of the sample surface.

The limits of the scanner's sweep range are displayed numerically in units of microns in the Extend and Retract micron textboxes. The maximum range corresponds to the z throw of the scanner you are using. The zero point of the scanner's sweep range is defined as the software's estimate of the sample surface, marked by the black half of the Set Point arrow. You can change the limits of the scanner's sweep range by typing new values into the Extend and Retract micron textboxes, which is equivalent to dragging the right and left ends of the red Piezo Adjustment bar, respectively.

Now that you are familiar with the controls of the Spectroscopy window, you are ready to set up to acquire an F vs. d curve.

Acquiring Force vs. Distance Data

This section explains in detail how to use the controls of the F vs. d Spectroscopy window.

The basic steps for generating a force vs. distance curve are the following:

1. Set up the system for contact-AFM data acquisition and perform an auto approach.
2. Take an image of your sample, and then import the image into the Import View.
3. From the Mode menu, select Spectroscopy.
4. Stop the rastering of the scanner by clicking the [Scan OFF] button.
5. Select a point on the image where you would like to generate an F vs. d curve.
6. Click the [Run] button to generate an F vs. d curve.
7. Adjust parameters.
8. Click the [Acq] button to acquire a curve that can be saved.
9. Click the [Save] button to save acquired curves to the image file.

These steps are described in detail in the sections that follow.

Setting Up to Acquire an F vs. d Curve

This section describes the procedures for setting up to take an F vs. d curve. Included is a subsection that describes how to calibrate the vertical axis of the curve with units of force. The calibration procedure must be performed any time you switch cantilevers.

Taking a Contact-AFM Image

Start by setting up the system for contact-AFM mode data acquisition. Details are described in Chapter 2, Part I of this User's Guide.

1. Install a 100 µm scanner, if you have one. The 100 µm scanner is preferable because it has the largest z range, or throw. The z range of the scanner must be large enough to include the "snap-back" point of the cantilever, which is the point where the cantilever tip snaps off the sample surface.

   Note: If you want to acquire F vs. d curves using a 5 µm scanner, use a stiff cantilever, such as an NC-AFM Ultralever. A stiffer cantilever "snaps back" sooner, so the "snap-back" point is more likely to be within the scanner's z range of motion.

> ***<u>CAUTION</u>***
>
> The power to the AEM must be turned OFF before you remove or install the scanner.

> ***CAUTION***
>
> The four screws that connect the scanner to the CP base unit must be securely fastened to ensure proper grounding. When the four screws are securely fastened, maximum instrument performance is ensured since vibrations are reduced.

2. Install a probe head, a cantilever, a probe cartridge, a chip carrier, and a sample as you normally do.

   Note: If you have not yet performed the F vs. d calibration procedure for the cantilever you are using and if you plan to do so now, be sure to use a hard sample such as the calibration grating provided with your system.

3. After opening ProScan software, turn off the probe head by clicking the Head ON icon, , on the Toolbar.

4. Select Configure Parts from the Setup menu and set up the system for taking an AFM image.

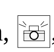
5. Reset the Z stage.

6. Align the deflection sensor.

7. From Move mode, perform an auto approach.

   When the approach is successful, the green Z Piezo bar underneath the Toolbar should indicate that the scanner is extended roughly to its mid range, and the yellow Probe Signal bar should show the Error signal to the feedback loop fluctuating regularly about the set point as the sample moves back and forth relative to the tip.

8. Switch to Image mode and click the [Image] button to start taking an image.

   Note: Make sure the Save to Buffer icon, , is ON before you begin taking an image. If the Save to Buffer icon is not ON, then the image you take cannot be saved, and therefore any F vs. d curves you take cannot be saved with the image. The Save to Buffer icon is ON by default.

After you collect an image that you wish to use as a basis for F vs. d data acquisition, import that image to the Import View by clicking the [Import] button.

The next section describes how to calibrate the vertical axis of the F vs. d graph with units of force. You can skip this section if you have already performed the calibration procedure for the cantilever you are using.

Calibrating the Vertical F vs. d Axis

This section describes how to calibrate the vertical axis of the F vs. d graph with units of force. This procedure is important: if it is not performed, then the units of the vertical axis do not correlate correctly with force.

You must perform this calibration procedure any time you switch to a different cantilever. However, the system remembers the calibration results, so you do not need to repeat the procedure even if you exit ProScan software. If you have already performed the procedure for the cantilever you are using, you can skip to the section, “Generating a Force vs. Distance Curve,” later in this chapter.

The calibration procedure involves taking an F vs. d curve using a hard sample, such as the calibration grating provided with your system. Using a hard sample ensures that the mechanical properties of the sample do not couple with those of the cantilever and affect the calibration. The procedure involves three general steps:

1. Check or enter the value of the cantilever force constant.
2. Acquire a F vs. d curve.
3. Run an automated procedure that performs the calibration.

These general steps are described in detail below.

First, you will check or enter the value of the cantilever force constant.

The cantilever force constant is a database parameter—ErrSigNewtonPerMeter—accessible in the Manual Calibration Entry dialog box. If you selected the appropriate cantilever from the Beam Bounce Cantilever listbox of the ProScan Database Configuration dialog box, then the correct force constant value may already be loaded in the software database. It is always a good idea, however, to check the value as described in the steps that follow.

Note: Values for the cantilever force constant of the cantilever you are using are listed in a section at the end of this chapter. For the most current values, check a current version of the appropriate cantilever data sheet.

If you do not wish to check the value now, you will have an opportunity later to enter a value manually from within the Spectroscopy window.

1. Select Calibration Edit from the Setup menu to open the Manual Calibration Entry dialog box. Click Yes when the Warning box asks you if you want to proceed.

2 Choose Probe from the Category listbox, and select ErrSigNewtonPerMeter from the Calibration Values listbox. If the value shown for this parameter is not the correct value for the cantilever you are using, or if the value listed is Invalid, then you need to enter the correct value.

3. To enter a new probe calibration value, select the value that appears in the textbox above the Calibration Values listbox. Type in the correct value (in units of N/m), and then press the `[Enter]` key on your keyboard. Click the Done button to register changes made and close the dialog box.

4. Open the F vs. d Spectroscopy window by either selecting Spectroscopy from the Mode menu, or by clicking the Spectroscopy icon, , on the Toolbar.

The Spectroscopy window opens on the right side of the screen.

5. Click the Scan OFF button, located next to the Image button in the Image mode window. This stops rastering of the scanner for F vs. d data acquisition. The z feedback loop is still enabled.

   Clicking the Scan OFF button enables the Run and Acq buttons of the Spectroscopy window. When you click the Scan OFF button, it changes to the Scan ON button. If you click the Scan ON button, the scanner rasters once again and the Run and Acq buttons are disabled.

6. Click the Setup button to open the F vs. d Setup dialog box. By default, the Use Database Value option button is selected in the Cantilever Force Constant portion of the dialog box. Leave the default setting unchanged if you already checked that the cantilever force constant value in the database is correct in Steps 1 through 3 above. Otherwise, click the Enter Value Manually option button to select it and enable its associated textbox. Then, manually enter the cantilever force constant value in the textbox.

7. You can leave the other F vs. d Spectroscopy Setup settings at their default values or change them, as you wish. More information on these settings is provided in the later section, "Generating a Force vs. Distance Curve."

   Click the Done button to register changes made and close the dialog box.

8. Click the Cal Sweep checkbox to select it. When the Cal Sweep checkbox is selected, all *subsequent* curves generated either in Run or Acquire mode are stored and displayed as volts on the vertical axis vs. distance on the horizontal axis.

Next, you will generate an F vs. d curve to use during the calibration procedure. The curve you generate for the purposes of the calibration procedure is displayed as volts vs. distance, not force vs. distance.

By default, the location on the image where the F vs. d curve will be taken is at the center of the image, as indicated by the presence of a cross on the image in the Active Display. You can change this location as follows:

9. Use the mouse to position the cursor on the image in the Active Display where you want the F vs. d curve to be acquired. Click the mouse button. The cross will appear at the new location.

   Note: Be careful not to drag the mouse as you click. Clicking and dragging the mouse prompts the system to generate sixteen F vs. d curves between two endpoints of a line.

10. Click the [Run] button to start sweeping the scanner and generating F vs. d curves. You can adjust parameters while the scanner is sweeping. At any time, you can click the [Stop] button to stop sweeping.

The F vs. d curve you generate for the calibration procedure should be well-behaved. That is, you should be able to view a substantial portion of the linear part of the curve, the part that represents deflection of the cantilever once contact is made with the sample. You will use the mouse to select two points on this linear portion of the curve. The system will then use these points to calculate a slope value, which is used along with the force constant to calibrate volts with units of force.

You can either use the curve you generate in Run mode for the calibration procedure, or you can use Run mode for parameter adjustment only. For example, you may need to adjust the scanner's sweep range to include a large linear portion of the curve. Once you are satisfied with parameter settings, you can generate a curve that can be saved in Acquire mode.

11. Use Run mode to generate F vs. d curves and make parameter adjustments. When you are satisfied with parameter settings, click the [Stop] button.

12. Click the [Acq] button to generate an F vs. d curve that you will use for the calibration procedure.

13. Select the Measure option button. This sets the function of the cursor for selecting points on the curve and enables the Calibrate button.

Next, you will select two points along the linear portion of the F vs. d curve. These points will be used by the system to calculate a slope value used in calibrating force with volts.

14. Using the mouse, position the cursor at one end of the linear portion of the F vs. d curve. Click the LEFT mouse button to select this first point. A cross on the graph indicates the location you selected.

15 Again using the mouse, position the cursor at the other end of the linear portion of the F vs. d curve. Try to include a long portion of the linear part of the curve that will allow the system to accurately calculate a slope value. Click the RIGHT mouse button to select the second point. A second cross, smaller than the first, appears on the graph indicating the location you selected.

16. Click the Calibrate button. This prompts the system to compute and save the calibration coefficient. The Cal Sweep box is deselected and the Calibrate button is disabled.

The calibration procedure is complete. The vertical axis is calibrated with force for all subsequent F vs. d curves you take using this cantilever.

Note: Be sure to repeat the calibration procedure any time you switch to a different cantilever.

Generating a Force vs. Distance Curve

This section describes how to acquire an F vs. d curve for general samples. It assumes you have already performed the calibration procedure described in the previous section.

1. Take a contact-AFM image as you normally do, using the sample whose mechanical properties you wish to study using F vs. d spectroscopy. Specifically, follow Steps 1 through 8 of the earlier section “Taking a Contact-AFM Image.”

2. Open the F vs. d Spectroscopy window by either selecting Spectroscopy from the Mode menu, or by clicking the Spectroscopy icon, , on the Toolbar.

The Spectroscopy window opens on the right side of the screen.

3. Click the Scan OFF button, located next to the Image button in the Image mode window. This stops rastering of the scanner for F vs. d data acquisition. The z feedback loop is still enabled.

   Clicking the Scan OFF button enables the Run and Acq buttons of the Spectroscopy window. When you click the Scan OFF button, it changes to the Scan ON button. If you click the Scan ON button, the scanner rasters once again and the Run and Acq buttons are disabled.

4. Click the Setup button to open the F vs. d Setup dialog box.

5. Click the Z Detector option button to select the Z Detector signal as the variable to be plotted along the horizontal axis.

   Note: If you are using a 5 µm scanner, do not select the Z Detector signal since 5 µm scanners are not equipped with detectors.

   The Z Drive signal, which is selected by default, represents the volts sent to the scanner to set the scanner's z position. The Z Detector signal represents the scanner's actual z position as measured by the z detectors. Because of scanner nonlinearities, plotting the Z Drive signal may result in hysteresis, or an offset of the extension and retraction paths of the scanner along the horizontal axis.

6. Set the number of sweeps that will be used to generate an averaged F vs. d curve. In the Average scrollbox, enter the number of sweeps and then press the `[Enter]` key. Or, use the scrollbox arrows to scroll through the range of values. Up to fifteen curves can be averaged. There are 1000 data points per curve.

7. Set the rate at which the system will sweep the extension and retraction of the scanner. Enter the desired rate in the Rate scrollbox and then press the `[Enter]` key. Or, use the scrollbox arrows to scroll through the range of values.

   The sweep rate is displayed in units of Hz, and the maximum rate is 10 Hz.

8. Leave the Zoom Priority at its default value, which is Snap-Out. This setting tells the system to display a zoomed-in F vs. d curve with the snap-back point positioned correctly along the horizontal axis. Details about the Zoom Priority function are given in the section "Zooming in on a Region of Interest," later in this chapter.

9. Click the Done button to register any changes made and exit the dialog box.

By default, the location on the image where the F vs. d curve will be taken is at the center of the image, as indicated by the presence of a cross on the image in the Active Display. You can change this location as follows:

10. Use the mouse to position the cursor on the image in the Active Display where you want the F vs. d curve to be acquired. Click the mouse button. The cross will appear at the new location.

    Note: Be careful not to drag the mouse as you click. Clicking and dragging the mouse prompts the system to generate sixteen F vs. d curves between two endpoints of a line. Generating multiple curves along a line is discussed in a later section, "Acquiring Curves Along a Line."

11. Drag the ends of the red Piezo Adjustment bar to be roughly symmetric about the Set Point arrow.

At this point, you are ready to generate F vs. d curves. F vs. d curves can be generated in two modes, Run and Acquire. Clicking the Run button prompts the system to continuously sweep the scanner, generating F vs. d curves that cannot be saved but that you can view as you adjust parameters. For example, you can adjust the scanner's sweep range or the sweep rate and watch the effects of these changes on curves as they are generated in Run mode. Then, once you have selected parameters to your satisfaction, you can click the Stop button to stop the scanner's sweeping.

Clicking the Acq button prompts the system to generate one F vs. d curve at a time and load that curve into a buffer where it can be saved. Each curve is the average of the number of curves you selected to be averaged in the Spectroscopy Setup dialog box. Parameter values cannot be changed while a curve is being generated in Acquire mode.

Start generating F vs. d curves for parameter adjustment now in Run mode:

12. Click the Run button to start sweeping the scanner and generating F vs. d curves. At any time, you can click the Stop button to stop sweeping.

    Note: You may need to adjust the scanner's sweep range to cover the snap-in and snap-back points of the F vs. d curve.

Figure 4-2 shows an example of an F vs. d curve displayed on the graph of the Spectroscopy mode window. The various parts of the curve in the figure that are labeled are described in the section "Understanding Force vs. Distance Curves" later in this chapter.

Note: The extension and retraction paths of the curve are offset along the horizontal axis so that labels on the curve can be shown more clearly. As mentioned earlier, if you are plotting the Z Detector signal along the horizontal axis, offset due to scanner hysteresis should be minimized.

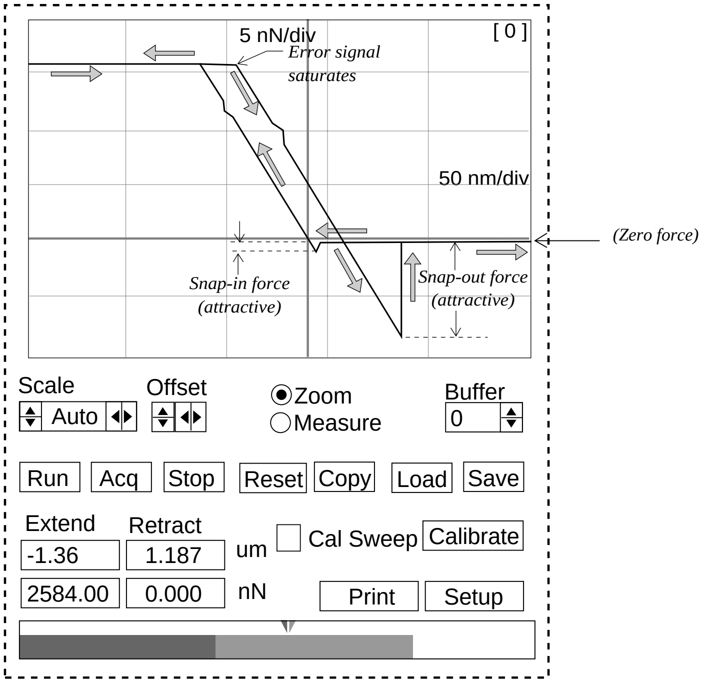


Figure 4-2. A force vs. distance curve generated using Spectroscopy mode.

You will notice a heavy horizontal line and a heavy vertical line on the graph. These lines mark the horizontal and vertical axes of the F vs. d graph.

Use the F vs. d data displayed on the Spectroscopy window graph to adjust F vs. d parameters. You can adjust parameters while the scanner is sweeping, or while it is stopped.

13. Use the Piezo Adjustment bar to graphically adjust the scanner's sweep range. Use the mouse to grab the ends of the Piezo Adjustment bar, and move the ends by dragging the mouse. Alternatively, you can use the mouse to click and drag on the center of the red bar, moving both limits simultaneously. Or, you can type in new values in the Extend and Retract micron textboxes.

    Adjust the length of the red bar so that the portion of the F vs. d curve that you are interested in is covered.

Note: At some point during scanner extension, the signal that represents cantilever bending may saturate. This means that further deflection of the cantilever cannot be measured by the PSPD. If you see the signal saturate along the vertical axis, try adjusting the alignment of the PSPD. Adjusting the alignment of the PSPD optimizes the range of cantilever deflection that the PSPD can detect.

14. Click the Setup button to open the Spectroscopy Setup dialog box.

15. Adjust the sweep rate and the number of curves to be averaged, if desired.

16. Click the Done button to register any changes made and exit the dialog box.

17. When the parameter values are set such that you are satisfied with the F vs. d curve displayed on the graph, click the Stop button to stop sweeping.

18 Now, click the Acq button to acquire an averaged F vs. d curve that can be saved.

After an F vs. d curve is generated in Acquire mode, the system stops automatically and loads the curve into the next available buffer. Buffers are filled successively from 0 to 15. If more than sixteen buffers are filled, the system begins to overwrite the contents of the first buffers. You can scroll through the buffers at any time using the Buffer scrollbox arrows. The buffer number for each curve is indicated in brackets in the upper-right corner of the graph.

Adjusting the Horizontal and Vertical Scales of an F vs. d Curve

If you have followed the steps in the previous sections, an F vs. d curve should be displayed in the F vs. d Spectroscopy window. The horizontal and vertical scales of the curve can be adjusted using the Scale scrollbox arrows. You can also adjust the starting value of the horizontal and vertical axes using the Offset scrollbox arrows.

When you expand the scales of an F vs. d curve, a reduced portion of the curve is displayed on the graph. The scanner's sweep range remains the same, and the 1000 data points per curve are still taken over the entire sweep range. The resolution of the displayed data remains the same since the 1000 points are not taken over a reduced portion of the curve.

To expand the scales incrementally using the Scale scrollbox arrows, do the following:

1. Click the [>] Scale scrollbox arrow to expand the horizontal scale. Successively clicking the [>] scrollbox arrow decreases the units per division and may also increase the starting value of the horizontal scale.

   The units per division for the horizontal scale are displayed at the right side of the graph.

   Note: You can prompt the system to re-scale the axes automatically at any time by clicking the [Auto] button.

2. If you expand the horizontal scale too much, you can reduce it again by clicking the [<] Scale scrollbox arrow.

3. Click the [∧] Scale scrollbox arrow to expand the vertical scale. Successively clicking the [∧] scrollbox arrow decreases the units per division.

   The units per division of the vertical scale are displayed at the top of the graph.

4. If you expand the vertical scale too much, you can reduce it again by clicking the [∨] Scale scrollbox arrow.

You can also shift the position of the F vs. d curve on the graph without changing the scale using the Offset scrollbox arrows:

5. Shift the curve to the left by clicking the [<] Offset scrollbox arrow. Successively clicking the [<] Offset scrollbox arrow increases the starting value of the horizontal axis, shifting the curve to the left on the graph.

6. Shift the curve to the right by clicking the [>] Offset scrollbox arrow. Successively clicking the [>] Offset scrollbox arrow decreases the starting value of the horizontal axis, shifting the curve to the right on the graph.

7. Shift the curve up by clicking the [∧] Offset scrollbox arrow. Successively clicking the [∧] Offset scrollbox arrow decreases the starting value of the horizontal axis, shifting the curve up on the graph.

8. Shift the curve down by clicking the [∨] Offset scrollbox arrow. Successively clicking the [∨] Offset scrollbox arrow increases the starting value of the horizontal axis, shifting the curve down on the graph.

Zooming in on a Region of Interest

Often times you will want to zoom in on a particular portion of an F vs. d curve you have generated. You can do this graphically by defining a region of interest on the curve. Or, you can zoom in by changing the limits of the scanner's sweep range to cover a smaller portion of a curve. Details of zooming in on an F vs. d curve are described in two sections that follow.

Zooming in Graphically Using the Cursor

To zoom in on a portion of an F vs. d curve, you can use the cursor to define a region of interest on the graph. You define a region while the scanner is stopped. The portion of the curve displayed on the graph changes immediately to reflect the area you define. The resolution of the zoomed-in area does not increase, however, until you resume sweeping of the scanner by clicking the Run or Acq button. At that point, the same number of data points (1000 per curve) are read over a smaller portion of the scanner's sweep range. Therefore, the resolution of the resulting F vs. d curve increases.

1. Click the Run button to generate an F vs. d curve to zoom in on. Adjust parameters if necessary, and then click the Stop button.

2. Click the Zoom option button to set the cursor function as a zoom box tool.

3. Select a portion of the F vs. d curve by dragging a box around it with the cursor.

The F vs. d curve displayed on the graph changes immediately to reflect the zoomed-in area. As mentioned above, the resolution of the data remains the same. When you resume data acquisition by either clicking Run or Acq, the scanner's sweep range remains the same, but the portion of that range over which data are collected (or read) is re-selected to match the zoomed-in area, and the resolution of the data increases accordingly.

Note: If you are plotting the Z Detector signal along the horizontal axis, you may notice on the zoomed-in curve that the portion of either the extension or the retraction path of the F vs. d curve differs from the portion you selected. This phenomenon is a result of scanner hysteresis. If you choose to plot the Z Detector signal, you can use the Zoom Priority feature of the Spectroscopy Setup dialog box to ensure that the portion of either the extension or the retraction path of subsequent, zoomed-in curves is consistent with the portion you select on the original curve. Selecting Snap-In ensures that the extension path is consistent. Selecting Snap-Out ensures that the retraction path is consistent.

4. Click the [Run] or [Acq] button again to start sweeping the scanner once again. The limits of the scanner's sweep range over which data are collected will be those defined by the cursor's zoom box.

   Note: Sometimes a smaller portion of the scanner's sweep range is not large enough to accommodate drift and the portion of the F vs. d curve that you are interested in moves off scale. If this happens, click the [Reset] button. This resets the range of data collection to once again match the full scanner sweep range. You can then adjust the range of data collection again, incrementally, until you are satisfied with the curve.

Zooming in by Changing the Scanner's Sweep Range

You can also zoom in on a portion of an F vs. d curve by reducing the sweep range of the scanner. This method of zooming in can be performed while the scanner is sweeping in Run mode. The resolution of the data increases as the scanner's sweep range decreases.

To zoom in by decreasing the sweep range of the scanner, follow these steps:

1. Click the [Run] button to generate continuous F vs. d curves that you can observe as you zoom in.

2. Using the mouse, grab an edge of the red Piezo Adjustment bar and drag the edge to shorten the bar. Grab and drag each edge as necessary so that the sweep range of the scanner is reduced to cover only the portion of the F vs. d curve that you are interested in.

Now try changing the sweep range of the scanner by typing new values in the Extend and Retract microns textboxes:

3. Type a value that is larger (i.e., less negative) in the Extend textbox. You should see the right end of the red Piezo Adjustment bar move to the left.

4. Type a value that is smaller in the Retract textbox. You should see the left end of the red Piezo Adjustment bar move to the right.

Making Point-to-Point Measurements on an F vs. d Curve

When the Measure option button is enabled, you can measure horizontal and vertical distances between two points on an F vs. d curve. The measurements are shown by coordinates —**x, y, dx, dy**—below the curve. The values of **x** and **y** are relative to the origin defined by the heavy horizontal and vertical lines on the graph. The values of **dx** and **dy** are relative to the position of an anchor point, which you set as described below. Before you set an anchor point, the values of **dx** and **dy** are relative to a default anchor point located at the upper left corner of the graph.

Try the following for practice:

1. Select the Measure option button. This sets the function of the cursor so that its coordinates on the graph are displayed below the graph.

2. Use the mouse to place the cursor on the F vs. d graph. The cursor should change to a black crosshair.

3. Use the mouse to move the crosshair to a position on the graph where you would like an anchor point. To define this point as the anchor point, click the mouse. The crosshair will remain at the position where you clicked, and the cursor will change to a second black crosshair.

   As you move the mouse, the coordinates of the second crosshair (**x**, **y**) as well as its position relative to the anchor point (**dx**, **dy**) are reported below the graph.

Generating an F vs. d Curve at a Different X, Y Location

You may want to generate an F vs. d curve at an x, y location on your sample that is different from the first location you selected. If the desired location is visible on the image you used to select the first location, you can move to the new location by changing the position of the crosshair on the image shown in the Active Display. If the desired location lies outside of the region shown in the image, you must take a new image.

To generate an F vs. d curve at a new location, do the following:

1. Using the mouse, move the cursor to the x, y location on the image where you want to acquire F vs. d data, and click. The cross will appear at the new x, y location on the image.

2. If desired, change the sweep range of the scanner, the sweep rate, and the number of sweeps, as described in the section "Generating an F vs. d Curve," earlier in this chapter.

3. Click the [Run] button if you would like to adjust parameters as F vs. d curves are generated.

4. Once you are satisfied with your parameter selections, click the [Stop] button.

5. Click the [Acq] button to acquire an averaged F vs. d curve.

Up to sixteen force vs. distance curves can be generated at different x, y locations on a single image. The Buffer scrollbox arrows allow you to scroll through the stored F vs. d curves.

Acquiring F vs. d Curves Along a Line

Spectroscopy mode enables you to acquire sixteen equally spaced F vs. d curves along a line that you select using the mouse. This feature is useful for studying changes in characteristics of F vs. d curves across an interface.

To acquire sixteen equally spaced F vs. d curves along a line, do the following:

1. Take an image as you normally would for F vs. d data acquisition. The image should include the line where you want the F vs. d curves to be taken.

   Note: Be sure that the Save to Buffer icon, , is ON before you take the image. Otherwise, the image will not be saved, and therefore you will not be able to save the F vs. d curves associated with the image.

2. Click and drag the mouse on the image in the Active Display to define one endpoint of the line and the extent of the line. Release the mouse to define the second endpoint. The line you draw will appear on the image.

3. Adjust parameters as described in the section “Generating an F vs. d Curve,“ earlier in this chapter. The parameter settings apply for all of the sixteen F vs. d curves taken along the line.

4. Click [Acq] when you are ready to begin acquiring curves that can be saved with the image.

5. Click the [Save] button when you are satisfied with the curves and wish to save them to disk along with their associated image.

Saving, Exporting, and Printing Data

The Save button saves up to sixteen curves with the image file corresponding to the image displayed in the Import View. Saved curves can be redisplayed later in the F vs. d Spectroscopy window.

The Copy button places numerical force values as a function of distance into the Clipboard. The numerical information can then be pasted into other software applications such as Excel, which enable you to perform in-depth analyses on your data.

To save F vs. d curves, do the following:

1. Click the Save button. Curves currently in buffers associated with an image are saved to the image file. You can save up to sixteen curves with any image.

To export F vs. d data to the Notepad or another Windows application, do the following:

2. Scroll through the buffers to the F vs. d curve whose data you want to export.

3. Click the Copy button. This places the data for the currently displayed F vs. d curve in the Clipboard.

4. Open the Notepad. From the Edit menu, select Paste. The numerical values of force as a function of distance should appear on the Notepad.

   Alternatively, you can open any software application where you want to paste the numerical information. From the Edit menu select Paste. The numerical information associated with the curve should appear in the application.

To print an F vs. d curve, do the following:

5. Scroll through the buffers to the F vs. d curve that you want to print.

6. Click the Print button.

The F vs. d curve will be printed, along with its associated image and the x,y location of the curve on the image.

Redisplaying Curves in F vs. d Spectroscopy

F vs. d curves that were saved to an image file can be redisplayed during a later Spectroscopy mode working session. To redisplay previously saved curves, do the following:

1. If the F vs. d Spectroscopy window is not open, open it now by either selecting Spectroscopy from the Mode menu or clicking the Spectroscopy icon, , on the Toolbar.

2. Open the Load to Buffer dialog box by selecting Load from the File menu.

3. In the Load to Buffer dialog box, select the file name of the image you want to load to the Image Gallery and then click the OK button to close the dialog box. The selected image should appear in the Image Gallery.

4. Select the image in the Image Gallery (a green box will enclose the selected image) and then click the Import button to import the image into the Import View.

   Note: Sometimes an image displayed in the Import View appears very small in the center of the display. Click the Zm button of the Import View to expand the image in the display.

5. Click the Load button in the F vs. d Spectroscopy window.

   The F vs. d curve in the first of the sixteen buffers associated with the selected image appears on the graph of the Spectroscopy window.

6. Use the Buffer scrollbox arrows to scroll through the stored curves. The x, y location on the image where each curve was taken is marked on the image in the Import View.

Where to Go From Here

This concludes the tutorial portion of this chapter. At this point, you can review the tutorial and practice taking F vs. d curves until you feel confident with the techniques described here.

If you are interested, you may want to continue and read the next sections, which discuss underlying principles of F vs. d data acquisition.

Forces Acting on the Cantilever

Vertical deflection of the cantilever originates from several sources. Attractive van der Waals forces between the tip and the sample pull the cantilever toward the surface. Capillary forces exerted on the tip by liquid layers on the sample surface also pull the cantilever toward the surface. In addition, repulsive van der Waals forces (essentially due to electrostatic repulsion) between the tip and the sample deflect the cantilever away from the surface.

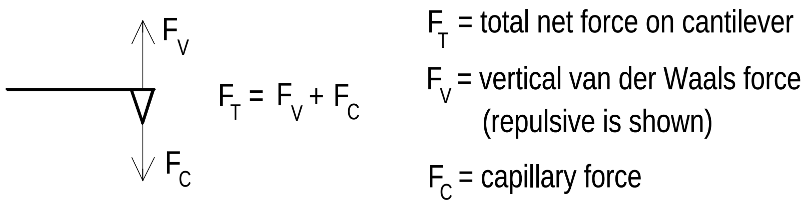


Figure 4-3. Forces acting on the cantilever tip.

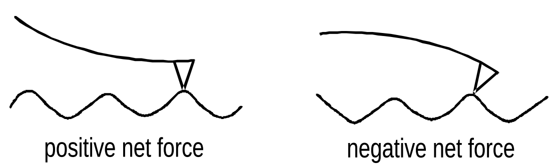


Figure 4-4. The effects of positive and negative net forces on cantilever bending.

Figure 4-3 shows the forces acting on the cantilever. Cantilever deflection *away from* the surface is the result of a net positive force on the cantilever ($F_V > F_C$). Cantilever deflection *toward* the surface is the result of a net negative force on the cantilever ($F_V < F_C$). Figure 4-4 shows the effects of positive and negative net forces on cantilever bending.

Figure 4-5 shows an interatomic force vs. distance curve, which is a plot of the force acting between the tip and the sample as a function of tip-to-sample spacing. The interatomic force vs. distance curve is similar to the Lennard-Jones curve of the potential energy between atoms as a function of distance. Looking at the curve, you can see two regimes where an atomic force microscope is operated: the non-contact and contact regimes.

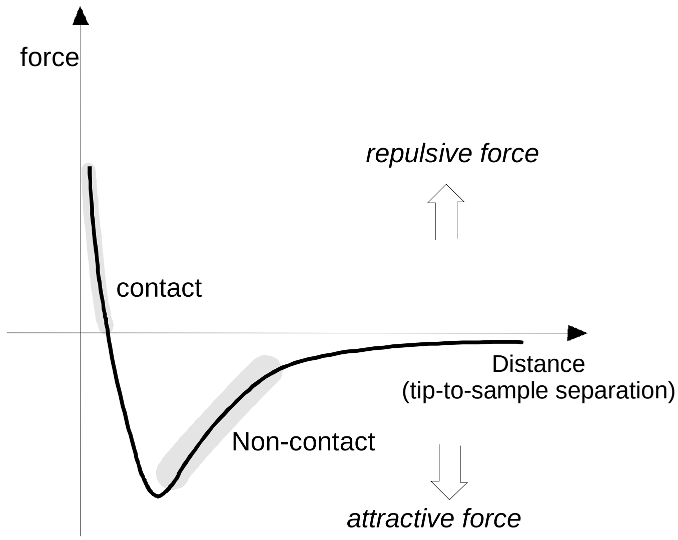


Figure 4-5. Interatomic force vs. distance curve.

Figure 4-5 shows that when the tip-to-sample spacing is large, the force between the tip and the sample is attractive. A non-contact atomic force microscope (NC-AFM) is operated within this range of forces, where the total net force on the cantilever is negative. As the tip approaches the sample, the force between atoms on the tip and atoms on the sample eventually becomes repulsive. When the cantilever tip is "in contact" with the sample (in the absence of liquid layers on the sample surface), the repulsive force dominates, exerting a positive net force on the cantilever. An atomic force microscope in contact mode is operated within this range of forces, where the total net force on the cantilever is positive.

Understanding Force vs. Distance Curves

A force vs. distance curve is a graph of the vertical force on the cantilever tip as a function of the extension of the piezoelectric scanner tube. The vertical force on the cantilever tip is proportional to the cantilever bending, which is measured using a position-sensitive photodetector (PSPD).

A force vs. distance curve is generated at a single location on a sample surface by measuring how much the cantilever bends during one or more "sweeps" (up and down movements) of the scanner. Variations in the shape of force vs. distance curves taken at different locations indicate variations in the local elastic properties of the sample surface. The shape of the curve is also affected by contaminants and surface lubricants, as well as a thin layer of water on the surface which is usually present when operating an AFM in air.

A generalized force vs. distance curve is shown in Figure 4-6 for the case of an AFM operating in air. It is generated at a specific location on the sample surface by extending and then retracting the scanner while measuring cantilever bending. In the figure, the vertical axis ("force") represents the measured cantilever deflection. The horizontal axis ("distance") represents the z position of the scanner.

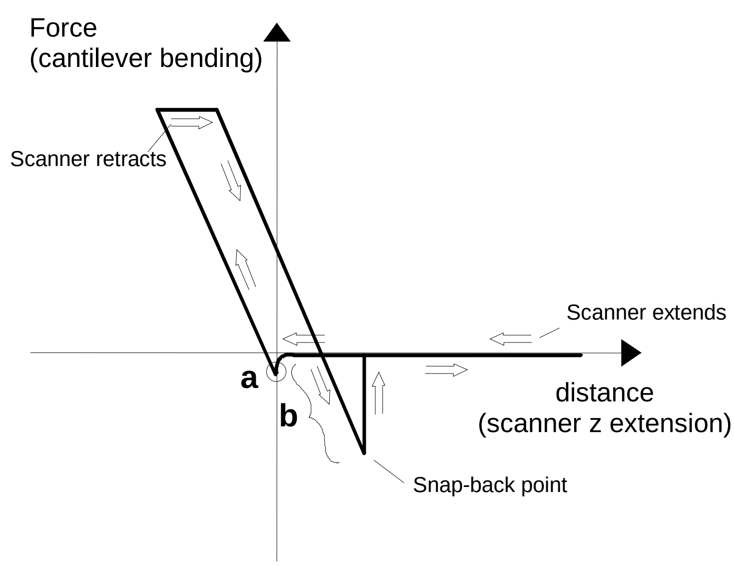


Figure 4-6. A generalized force vs. distance curve for an AFM in air. The curve represents force experienced by the cantilever vs. z position of the scanner.

The far right side of the curve is defined to be where the scanner tube is fully retracted, which is the starting point before a curve is taken. The net force on the cantilever at this point should be zero. The tip is not in contact with the sample, and the cantilever is undeflected. As the scanner tube is extended (moving to the left in Figure 4-6), the cantilever remains undeflected until the tip is close enough to the sample to experience the attractive interatomic force. At the "snap-in" point (point **a** in Figure 4-6), the tip snaps into the surface, causing the cantilever to bend *toward* the surface. The net force on the cantilever is negative (attractive).

The scanner continues to extend, until the cantilever is bent *away from the surface*. The net force on the cantilever is positive (repulsive).

After the scanner tube is fully extended, it begins to retract (moving to the right in Figure 4-6). The force on the cantilever follows a different path. The horizontal offset between the initial and the return paths of Figure 4-6 is due to scanner hysteresis. The additional portion of the curve that shows a negative (attractive) force on the cantilever is attributable to a thin layer of water that is usually present on the sample surface when the surface is exposed to air. This water layer exerts a capillary force on the cantilever tip which is strong and attractive. The water layer holds the tip in contact with the surface, pulling the cantilever strongly toward the surface. This deflection of the cantilever is shown on Figure 4-6 as region **b**, where the net force on the cantilever is strongly negative.

The scanner tube eventually retracts far enough for the cantilever tip to spring free of the water layer. This point is called the "snap-back," or “snap-out,” point. Multiple snap-back points can occur when the force vs. distance curve is averaged over more than one sweep of the scanner tube. Beyond the snap-back point, the cantilever remains undeflected, and the net force on the cantilever should be zero.

The next section includes cantilever data sheets that contain information about Microlevers and Ultralevers. This information includes force constant values that you need in order to calibrate the vertical axis of an F vs. d curve with force.

Cantilever Data Sheets

This section contains information about Microlevers™ and Ultralevers™. You can enter the spring constant (force constant) for your cantilever in the Calibration Values textbox of the Manual Calibration Entry dialog box, as described in an earlier section.

This section also gives the dimensions of available cantilevers, as well as their theoretical resonance frequencies.

Microlevers

Microlevers™, microfabricated from low-stress silicon nitride, are highly resilient with a wide range of force constants, from 0.5 to 0.01 N/m. Microlevers are available with standard or sharpened integrated pyramidal tips, with nominal radii of less than 500 Å and 200 Å, respectively. Each Microlever chip has five V-shaped cantilevers and one rectangular cantilever. A top view and a close-up view of a Microlever chip are shown below.

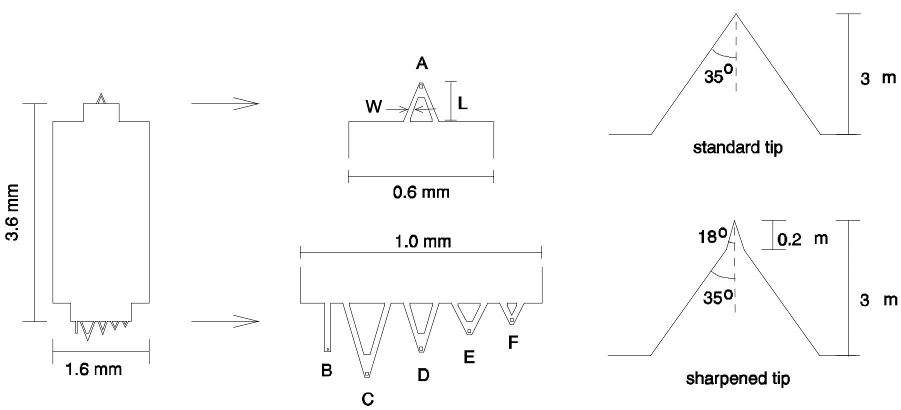


Figure 4-7. Microlever chips hold six cantilevers. Typical radius of curvature is 500 Å for standard tips and 200 Å for sharpened tips.

Type	L (µm)	W (µm)	Thickness (µm)	Force constant (N/m)	Resonance frequency (kHz)
A	180	18	0.6	0.05	22
B	200	20	0.6	0.02	15
C	320	22	0.6	0.01	7
D	220	22	0.6	0.03	15
E	140	18	0.6	0.10	38
F	85	18	0.6	0.50	120

Ultralevers

Ultralevers™ are gold-coated, all-silicon cantilevers with integrated high aspect ratio conical tips. The typical radius of curvature for Ultralever tips is 100 Å, a more than fourfold improvement over the radius of standard Microlever tips. On many samples, improved tip sharpness translates directly into improved resolution.

The aspect ratio, which is the ratio of tip length to width, fundamentally limits the ability of an AFM to measure steep sidewall features and deep trenches that can be characteristic of patterned semiconductor devices and reticles. The tip geometry of Si_3N_4 pyramidal tips gives an aspect ratio on the order of 1:1. Ultralever tips are conical in shape and their aspect ratio can be controlled in the manufacturing process. Ultralevers have an aspect ratio of about 3:1.

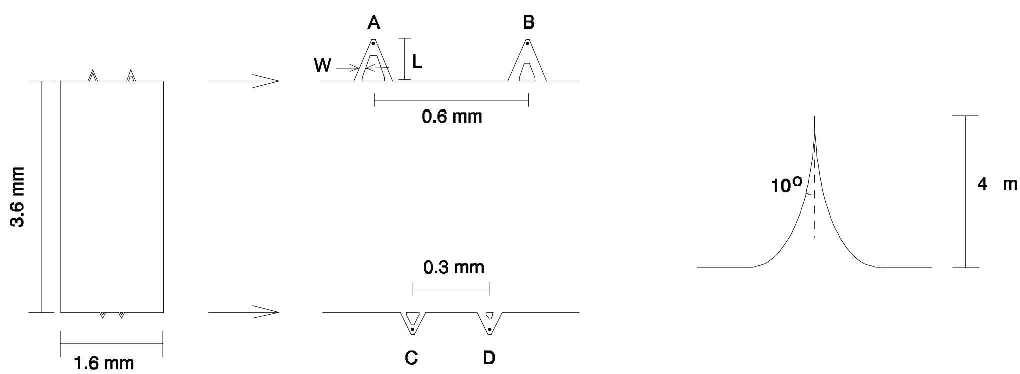


Figure 4-8. Ultralever chips hold four cantilevers.
Typical radius of curvature is 100 Å.

Type	L (µm)	W (µm)	Thickness (µm)	Force constant (N/m)	Resonance frequency (kHz)
A	180	25	1.0	0.26	40
B	180	38	1.0	0.40	45
C	85	18	1.0	1.6	140
D	85	28	1.0	2.1	160
A	180	25	2.0	2.1	80
B	180	38	2.0	3.2	90
C	85	18	2.0	13	280
D	85	28	2.0	17	320

Summary

This chapter explained how to acquire force vs. distance curves using Spectroscopy mode of ProScan Data Acquisition software. You learned how to acquire, save, and re-load F vs. d curves. In addition, sections at the end of the chapter explained the principles underlying force vs. distance data acquisition.

Chapter 5
I-V Spectroscopy

Introduction

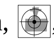
This chapter describes how to generate current vs. voltage (I-V) curves to study electronic properties at specific x, y locations on a sample surface. A current vs. voltage curve is a plot of the tunneling current as a function of the bias voltage that is applied to the sample. Up to sixteen current vs. voltage curves can be generated for each STM image you acquire using the I-V Spectroscopy feature of Data Acquisition.

In this chapter, you will find information on the following topics:

- understanding the controls in I-V Spectroscopy
- generating a current vs. voltage curve and a dI/dV curve
- adjusting parameters and zooming in on features of a curve
- adjusting the horizontal and vertical scales of a current vs. voltage (or, dI/dV) curve
- making point-to-point measurements on a current vs. voltage (or, dI/dV) curve
- saving and exporting current vs. voltage data
- retrieving previously saved current vs. voltages (or, dI/dV) curves

This tutorial will give you the basic knowledge you need to generate current vs. voltage curves. The curves provide important information about the local electronic properties of your sample.

The I-V Spectroscopy Window

Current vs. voltage (I-V) curves are acquired using Spectroscopy mode of ProScan's Data Acquisition software. You can open the I-V Spectroscopy window by selecting Spectroscopy from the Mode menu, or by clicking the Spectroscopy icon, , on the Toolbar.

When you enter Spectroscopy mode, the Image Gallery on the right side of the Image mode and Move mode windows is replaced by the Spectroscopy window. The Spectroscopy window includes a graph and software controls, as shown in Figure 5-1, below.

Note: The Image Gallery buffers remain accessible at the bottom right side of the window.

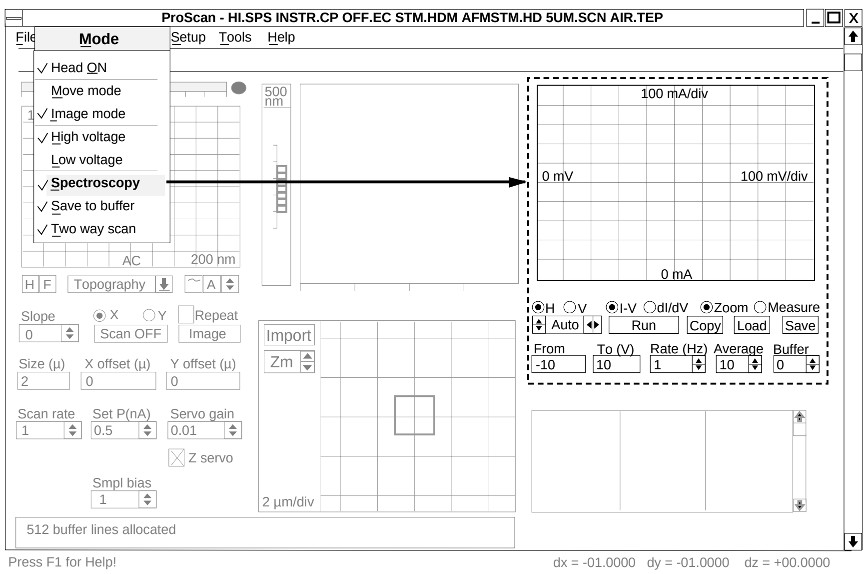


Figure 5-1. The I-V Spectroscopy window, shown in Image mode.

When you enter Spectroscopy mode while operating your instrument as a scanning tunneling microscope, the software controls that appear are appropriate for acquiring current vs. voltage curves. When you enter Spectroscopy mode while operating your instrument as an atomic force microscope, the software controls that appear are appropriate for acquiring force vs. distance curves.

A current vs. voltage (I-V) curve is generated using the most recently acquired STM image. The STM image is typically acquired using the Topography signal, as this signal is representative of the surface electronic structure.

A current vs. voltage curve is generated at a single x, y location in an image. The scanner remains fixed in x, y, and z during acquisition of a current vs. voltage curve to maintain a constant tip-to-sample spacing. The system sweeps over a specified bias voltage range and measures the tunneling current.

The next section describes controls of the I-V Spectroscopy window. If you want to start the tutorial, you can skip this section and return to it at a later time.

I-V Spectroscopy Controls

This section describes the controls in the I-V Spectroscopy window (see Figure 5-1). The table below lists each control in the window, along with a brief description of its function. The tutorial in the next section teaches you how to use these controls.

Table 5-1. Controls in the I-V Spectroscopy window.

Control	Function
I-V	Selects an I-V curve to be generated at a selected x, y location on the sample surface.
From and To	Allow you to set the range of bias voltage that is applied to the sample during acquisition of an I-V curve. The From textbox allows you to set the lower limit of the bias voltage range. The To textbox allows you to set the upper limit of the bias voltage range.
Rate	Allows you to set the rate at which the system sweeps the bias voltage range during I-V data acquisition.
Average	Allows you to select the number of sweeps that are averaged to generate an I-V curve.
Run	Disables the feedback loop and starts ramping the bias voltage to generate an I-V curve. Once the I-V curve has been acquired, the feedback loop is enabled again.
dI/dV	Differentiates an I-V curve. This operation can be performed only once for a given I-V curve.
H (Horizontal)	Sets the horizontal scale of an I-V (or, dI/dV) curve for adjustment.
V (Vertical)	Sets the vertical scale of an I-V (or, dI/dV) curve for adjustment.
Auto	Depending on the option button that is selected (H or V), allows you to adjust either the horizontal or vertical scale of an I-V (or, dI/dV) curve.
Zoom	Allows you to zoom in on an area of an I-V (or, dI/dV) curve.

Table 5-1 (continued). Controls in the I-V Spectroscopy window.

Control	Function
Measure	Allows you to make point-to-point measurements on an I-V (or, dI/dV) curve.
Buffer	Allows you to scroll through current vs. voltage and dI/dV curves.
Copy	Allows you to place numerical values of current as a function of voltage from the I-V Spectroscopy window to the Clipboard. From there, data can be pasted into any appropriate Windows application for analysis.
Save	Saves I-V curves (i.e., numerical information corresponding to each I-V curve) and dI/dV curves to the image file.
Load	Allows you to redisplay I-V and dI/dV curves previously saved to an image file.

Acquiring Current vs. Voltage Data

This section explains in detail how to use the controls of the I-V Spectroscopy window.

The basic steps for current vs. voltage data acquisition are the following:

1. Take an STM image as you normally do, and then import the image into the Import View.
2. Open the Spectroscopy window by either selecting Spectroscopy from the Mode menu or clicking the Spectroscopy icon, , on the Toolbar.
3. Click the Scan OFF button in Image mode to stop the rastering of the probe.
4. Select the I-V option button to select a current vs. voltage curve to be generated.
5. Select the location on the image where you want to generate the current vs. voltage curve.
6. In the From and To textboxes, set the range of the bias voltage that will be applied to the sample during current vs. voltage data acquisition.
7. In the Rate scrollbox, enter the rate at which the system will sweep through the bias voltage range.
8. In the Average scrollbox, set the number of times that the system will sweep through the bias voltage range to generate an averaged current vs. voltage curve.
9. Click the Run button to begin generating a current vs. voltage curve.
10. Click the Save button to save the current vs. voltage curve (the numerical values of current as a function of voltage) to the image file.

Generating a Current vs. Voltage Curve

This section describes how to acquire a current vs. voltage curve in I-V Spectroscopy mode. Instructions for generating a dI/dV curve are included.

1. Take an STM image using the Topography signal as you normally do.

2. Open the I-V Spectroscopy window by either selecting I-V Spectroscopy from the Mode menu, or clicking the Spectroscopy icon, , on the Toolbar.

3. Click the Scan OFF button in Image mode. This stops the rastering of the probe in the fast scan direction—x or y.

4. By default, the I-V option button is selected. This selects a current vs. voltage curve to be generated. If the I-V option button is not selected, select it now.

5. Select the x, y location in the image where you wish to generate an I-V curve. The green crosshair that appears in the image represents the x, y location where the I-V curve will be generated. By default, the green crosshair is at the center of the image. To change the location of the crosshair, move the cursor to the desired x, y location and click the mouse.

6. Set the range of the bias voltage that will be applied to the sample during current vs. voltage data acquisition. The From and To textboxes list the lower and upper limits, respectively, of the bias voltage range.

   The maximum bias voltage range is from -10 to +10 volts. This range is selected by default. The values you choose depend on the sample you are using. For example, if your sample is graphite, you may choose a range that is roughly -1 to +1 volts.

7. Set the rate at which the system will sweep the selected bias voltage range. To enter a rate, type the value in the Rate scrollbox and then press the `[Enter]` key. Or, use the scrollbox arrows to scroll through the range of values.

   The ramp rate is displayed in units of Hz, and can have a value between 0.01 and 10 Hz. For now, leave the rate at its default value, which is 1 Hz.

8. Set the number of sweeps that will be used to generate an averaged current vs. voltage curve. In the Average scrollbox, enter the number of sweeps and then press the `[Enter]` key. Or, use the scrollbox arrows to scroll through the range of values.

   For now, type in a value of 5 curves to be averaged. As you generate I-V data, you can monitor whether to increase or decrease the number of curves that are averaged.

9. Click the Run button to disable the feedback loop and begin generating a current vs. voltage curve.

   When you click the Run button, it changes to a Stop button, which remains enabled for as long as it takes the system to generate the I-V curve. When the system is finished generating the I-V curve, the Run button is enabled, and the I-V curve is displayed in the I-V Spectroscopy window.

The horizontal scale (voltage) is displayed on the x axis. The starting value of the horizontal scale is shown on the left side of the curve, and the units per grid division are shown on the right side of the curve.

The vertical scale (current) is displayed on the y axis. The starting value of the vertical scale is shown at the bottom of the curve, and the units per grid division are shown at the top of the curve.

10. Select the dI/dV option button to differentiate the current vs. voltage curve.

    The horizontal scale (i.e., the x axis) displays voltage. The vertical scale (i.e., the y axis) should now display current/voltage.

11. Toggle between the current vs. voltage curve and the dI/dV curve by clicking the I-V and dI/dV option buttons, respectively.

Generating an I-V Curve at a Different X, Y Location

You can generate a current vs. voltage curve at a different x, y location in the image by changing the position of the green crosshair. If the desired location is visible in the image you used to select the first location, you can move to the new location by clicking and dragging the crosshair. If the desired location lies outside of the region shown in the image, you must take a new image.

To generate more than one I-V curve, do the following:

1. Make sure that the I-V option button is selected.

2. Position the cursor at the new x, y location on the image, and click the mouse.

3. If desired, change the bias voltage range, the sweep rate, and the number of sweeps as described in the previous section, "Generating a Current vs. Voltage Curve."

4. Click the [Run] button to start generating a current vs. voltage curve.

Up to sixteen current vs. voltage curves can be generated at different x, y locations in the image. The Buffer scrollbox arrows allow you to scroll through the stored I-V curves.

Adjusting the Horizontal and Vertical Scales of an I-V Curve

If you have followed the steps in the previous sections, a current vs. voltage curve should be displayed in the I-V Spectroscopy window. The horizontal and vertical scales of the curve can be adjusted using the H (Horizontal) and V (Vertical) option buttons along with the [Auto] button. You can expand or shrink the units per grid division and adjust the starting value of the horizontal and vertical axes.

Note: The procedures described in this section also apply to dI/dV curves.

To adjust the horizontal scale:

1. Select the H (Horizontal) option button. This selects the horizontal scale to be adjusted.

2. Adjust the starting value of the horizontal scale. This value is displayed on the left side of the current vs. voltage curve.

   To increase the starting value successively click the [<] scrollbox arrow of the [Auto] button. To decrease the starting value successively click the [>] scrollbox arrow of the [Auto] button.

3. Adjust the units per grid division of the horizontal scale. This value is displayed on the right side of the current vs. voltage curve.

   To increase the number of units per grid division successively click the [∨] scrollbox arrow of the [Auto] button. To decrease the number of units per grid division successively click the [∧] scrollbox arrow of the [Auto] button.

To adjust the vertical scale:

1. Select the V (Vertical) option button. This selects the vertical scale to be adjusted.

2. Adjust the starting value of the vertical scale. This value is displayed at the bottom of the current vs. voltage curve.

   To increase the starting value successively click the [<] scrollbox arrow of the [Auto] button. To decrease the starting value successively click the [>] scrollbox arrow of the [Auto] button.

3. Adjust the units per grid division of the vertical scale. This value is displayed at the top of the current vs. voltage curve.

   To increase the number of units per grid division successively click the [∨] scrollbox arrow of the [Auto] button. To decrease the number of units per grid division successively click the [∧] scrollbox arrow of the [Auto] button.

Zooming in on a Region of Interest

Often times you will want to zoom in on a particular portion of an I-V curve you have generated. You can do this graphically by defining a region of interest on the curve. Or, you can zoom in by reducing the limits of the voltage sweep range. Details of zooming in on an I-V curve are described in two sections that follow.

Zooming in Graphically Using the Cursor

To zoom in on a portion of an I-V curve, you can use the cursor to define a region of interest on the graph, as follows:

1. Click the Run button to generate an I-V curve to zoom in on.

2. Click the Zoom option button to set the cursor function as a zoom box tool.

3. Select a portion of the I-V curve by dragging a box around it with the cursor. A black box shows up on the graph.

4. To prompt the software to zoom in on the region inside the box, click the Auto button.

   The I-V curve displayed on the graph changes to reflect the zoom-in area. The resolution of the data remains the same. When you resume data acquisition by clicking the Run button again, the range of data acquisition is re-selected to match the zoom-in region. Since the same number of data points (1000 per curve) are taken over a smaller range, the resolution of the resulting I-V curve increases.

5. Click the Run button again to start sweeping the voltage range once again. The voltage limits over which data are acquired will be those defined by the cursor's zoom box.

Zooming in by Changing the Voltage Sweep Range

To zoom in by decreasing the voltage sweep range, follow these steps:

1. Click the Run button to generate an I-V curve that you can observe as you zoom in.

2. Type new voltage sweep range limits in the From and To textboxes. Change the voltage sweep limits so that the range is reduced to cover only the portion of the I-V curve that you are interested in.

Making Point-to-Point Measurements on an I-V Curve

When the Measure option button is selected, you can measure the horizontal and vertical distances between two points on a current vs. voltage curve. The measurements are shown by coordinates —**x, y, dx, dy**—below the current vs. voltage curve.

Note: The procedures described in this section also apply to dI/dV curves.

Try the following for practice:

1. Select the Measure option button. This enables you to make measurements on the current vs. voltage curve.

2. Use the mouse to place the cursor over the current vs. voltage curve. The cursor should change to a black crosshair.

3. Use the mouse to move the crosshair to a position on the curve where you would like an anchor point. To define this point as the anchor point, click the mouse. The crosshair will remain at the position where you clicked, and the cursor will change to a second black crosshair.

   As you move the mouse, the coordinates of the second crosshair (**x**, **y**) as well as its position relative to the anchor point (**dx**, **dy**) are reported below the graph.

Saving and Exporting Data

The [Save] button saves current vs. voltage and dI/dV curves to the image file. Later you can open I-V Spectroscopy to redisplay the saved curves.

The [Copy] button exports numerical current values as a function of voltage to the Clipboard. The numerical information can then be pasted into other software applications such as Excel, which enable you to perform in-depth analyses on your data.

To save current vs. voltage and dI/dV curves:

1. Click the [Save] button. Any curves you generate will be saved to the image file.

To export current vs. voltage data, do the following:

2. Scroll through the buffers to the I-V curve whose data you want to export.

3. Click the [Copy] button. This places the data for the currently displayed I-V curve in the Clipboard.

4. Open the software application where you want to paste the numerical information. From the Edit menu select Paste. The numerical information associated with the curve should appear in the application.

Redisplaying Curves in I-V Spectroscopy

Current vs. voltage curves that were saved to an image file can be redisplayed in I-V Spectroscopy. dI/dV curves can also be redisplayed.

To redisplay curves, follow these steps:

1. If the I-V Spectroscopy window is not open, open it now by either selecting I-V Spectroscopy from the Mode menu or clicking the Spectroscopy icon, ,on the Toolbar.

2. Open the Load to Buffer dialog box by selecting Load from the File menu.

3. In the Load to Buffer dialog box, select the file name of the image you want to load to the Image Gallery and then click the OK button to close the dialog box. The selected image should appear in the Image Gallery.

4. Select the image in the Image Gallery (a green box will enclose the selected image) and then click the Import button to import the image into the Import View.

5. Click the Load button in the I-V Spectroscopy window.

6. Use the Buffer scrollbox arrows to scroll through the stored curves. The x, y location on the image where the curve was taken is marked on the image in the Import View.

7. To display the dI/dV curve associated with the displayed I-V curve, click the dI/dV option button.

Summary

In this chapter you learned how to generate a current vs. voltage curve using controls in of the I-V Spectroscopy window. You also learned how to adjust the horizontal and vertical scales used to display the curve, make point-to-point measurements on the curve, save curves to the image file, and redisplay curves.

Practice the techniques described in this chapter to become more familiar with generating current vs. voltage and dI/dV curves, and to learn about the local surface electronic properties of your samples.

Chapter 6
Scanner Calibration

Introduction

This chapter describes how the scanner of your AutoProbe CP instrument works, and how to calibrate the scanner to maintain its optimal performance.

The scanner is a crucial component of your AutoProbe system. The precision of the scanner motion is largely responsible for the quality and reliability of your data. Understanding both the scanner's role in producing images as well as how to calibrate the scanner is therefore an important part of operating your instrument.

AutoProbe CP comes in two system configurations: standard and multitask. The standard configuration comes with a 5 µm scanner, and the multitask configuration comes with a 100 µm scanner. The procedures for calibrating the two scanners are different. This chapter is therefore divided into two sections: "Calibrating a 5 Micron Scanner," and "Calibrating a 100 Micron scanner." *You only need to read the section that pertains to the scanner you are using.*

Note: Additional scanners can be purchased for either system. Contact your ThermoMicroscopes representative for details.

Within each section, the following topics are covered:

- what it means to calibrate the scanner
- how to calibrate the scanner

The first topic provides useful background material that prepares you for performing the scanner calibration procedures for the scanner you are using. The second topic is covered in a procedural section comprised of step-by-step instructions that guide you through the scanner calibration process. Background material common to both types of scanners is included in the sections "How the Scanner Works" and "When to Calibrate the Scanner," which follow.

How the Scanner Works

The scanner is a tube made of a piezoelectric material, which is a material that expands or contracts with applied voltage. The scanner is a core component of a scanning probe microscope, as it is used to move either a probe or a sample with extremely fine precision. The line and pixel spacing of an image, as well as the interaction between the tip and the sample, are functions of the instrument's control over motion of the scanner.

Control of the scanner position depends on the predictability of the scanner's response to an applied voltage. To first approximation, this response is linear. On the scale that applies for scanning probe microscope applications, however, the response exhibits nonlinearities. These nonlinearities include hysteresis, creep, and aging. If you have not already done so, read Chapter 2 of *A Practical Guide to Scanning Probe Microscopy*, a publication available through ThermoMicroscopes. This will familiarize you with different types of scanner nonlinearities and their effects on images produced by a scanning probe microscope.

There are two approaches to improving the accuracy of scanner positioning. One approach, termed software correction, uses software algorithms to predict a scanner's response to applied voltage. The system calculates the voltages that should be sent to the scanner to achieve a desired scan size. A second approach is called hardware correction, in which detectors and feedback loops are used to measure and correct the position of a scanner to achieve a desired raster pattern as well as scan size.

If you are using a 5 µm scanner with your AutoProbe CP instrument, then your system is equipped with software correction. You need to calibrate the response of the scanner tube with applied voltage.

If you are using a 100 µm scanner with your AutoProbe CP instrument, then your system is equipped with both software and hardware correction. the ThermoMicroscopes's hardware correction system, called ScanMaster, includes detectors that you must calibrate first. Then, your system uses the calibrated detectors to automatically calibrate the response of the scanner tube to applied voltages.

The next section explains when you should perform scanner calibration procedures.

When to Calibrate the Scanner

When you purchase an AutoProbe instrument, the scanner(s) you receive arrives pre-calibrated. In other words, the system software contains calibration parameter files for all of the scanners, and those files contain default values for the scanner calibration parameters. The default values reflect the characteristics of each scanner for standard testing conditions.

There are, however, three main reasons why you should know how to calibrate the scanner:

1. The scanner calibration procedure is a method for checking that the scanner is in good condition (i.e., to confirm that the scanner has not been damaged from handling).
2. Scanner tube calibration values vary somewhat depending on scan conditions (e.g., xy scan size, and z range of topography). Therefore, you should calibrate the scanner tube whenever these scan conditions change.
3. The properties of scanner tubes change over time, so you should calibrate the detector offsets periodically (e.g., once a week). Performing this calibration frequently is relatively straightforward since it is automated.

In general, you should calibrate the scanner any time you think calibration could improve its performance.

Following are two sections: The first includes background information and calibration procedures for instruments equipped with a 5 µm scanner. Next is a section that includes background information and calibration procedures for instruments equipped with a 100 µm scanner. *Read the section that applies for the scanner you are using.*

Calibrating a 5 Micron Scanner

This section includes background information and calibration procedures for a 5 µm scanner. As mentioned in the introduction of this chapter, standard AutoProbe CP instruments come with a 5 µm scanner, while AutoProbe CP multitask instruments come with a 100 µm scanner. Therefore, this section applies if you have a standard AutoProbe CP, or if you have purchased a 5 µm scanner for a multitask AutoProbe CP.

This section is divided into two subsections. The first section provides background information that may be useful to you as you perform the scanner calibration procedures. If you would like, however, you may skip directly to the section that describes how to calibrate a 5 µm scanner.

What it Means to Calibrate a 5 Micron Scanner

As mentioned in the earlier section, “How the Scanner Works,” software correction is used to improve the accuracy of scan sizes for a 5 µm scanner. Equations are used to more accurately calculate the voltages that are applied to the scanner to produce a desired scan size. The parameters used in the equations are called scanner calibration parameters. Calibrating a 5 µm scanner means to check and, if necessary, to change the values of scanner calibration parameters. Since these parameters describe the scanner’s response to applied voltage, the procedure is also referred to as calibrating the scanner sensitivity.

For small scan sizes (below about 1 µm), scanner nonlinearities are not significant. The relationship between the scanner's position and the voltage applied to the scanner is approximately linear, but the slope of the line can vary depending upon the particular scanner being used, the scan rate, or the scan direction. The parameters used to describe the scanner's behavior in this range of scan sizes are termed first order scanner calibration parameters since the behavior of the scanner is roughly linear.

The first step in calibrating the scanner is to determine values for the first order calibration parameters for the two scan directions, x and y. Two values need to be determined for each scan direction: one for each direction when it is the fast scan direction, and one for each direction when it is the slow scan direction. There are thus four first order scanner calibration parameters. Once you determine and enter values for the four first order scanner calibration parameters, the accuracy of small scan sizes improves.

For larger scan sizes (greater than roughly 1 µm), the relationship between the scanner's position and the voltage applied to the scanner becomes nonlinear. The software adds second order terms to the description of the scanner's response to applied voltage that is used to produce the desired scan size. There are four second order calibration parameters: one for each direction when it is the fast scan direction, and one for each direction when it is the slow scan direction. Once you determine and enter non-zero values for the second order calibration parameters, the accuracy of scan sizes for larger images improves.

Note: While calibrating a 5 µm scanner improves the accuracy of scan sizes, you may still see the spacing of features on an image vary with distance for large scan sizes.

Values for all of the calibration parameters are determined manually. The procedure involves making measurements on an image of a calibration sample to determine new values for the calibration parameters. The parameters are stored in calibration parameter files in ProScan's calibration database. They are accessible to the user from within the ProScan Data Acquisition program.

The next section, "Scanner Calibration Procedures," takes you step-by-step through the scanner calibration procedures.

Scanner Calibration Procedures

The procedures of this section describe calibration of a 5 µm scanner. The sequence of the procedures is as follows:

- setting up the system for scanner calibration
- first-order calibration of scanner sensitivity in x and y
- second-order calibration of scanner sensitivity in x and y
- calibration of scanner sensitivity in z

After you have determined values for each set of parameters, you will learn about how to access scanner calibration parameters in the software, and how to change their values.

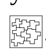
Setting Up the System

This section assumes that your instrument has been installed by a ThermoMicroscopes representative, all of the cables are properly connected, and you have completed the tutorial chapters in Part I of this User's Guide. It also assumes you are using a 5 µm scanner.

In addition, to calibrate a 5 µm scanner you will need a calibration sample. A calibration sample has periodic features of known spacing. *The calibration sample you choose depends on the image size you expect to use most frequently.* You should be able to take an image of that size and see several periods of the features on the sample.

This tutorial uses a 1 µm gold calibration grating as an example, since this sample is provided with standard AutoProbe CP systems. Ideally, however, you should use a sample that has features with a spacing similar to features on samples you plan to use regularly, since a maximum of only five periods on the 1 µm grating can be measured using the 5 µm scanner. The general procedures outlined here can be applied to whatever calibration sample you use.

Once you have installed the appropriate hardware, you can configure the system software. Values for all of the scanner calibration parameters are contained in a calibration parameter file. Each scanner in your system has a working scanner calibration parameter file.

To direct the system to use a particular scanner calibration parameter file, select that file when you configure the system software in the ProScan Database Configuration dialog box. This can be done at any point during a working session by selecting Configure Parts from the Setup menu, or by clicking the Configure Parts icon, .

The names of available files are under the drop-down list in the CP/LS Scanner category of the ProScan Database Configuration dialog box.

Note: The files can also be found in the **c:\psi\cal** directory.

A file name for a working file typically includes the size and the serial number of the scanner. For example, a file for a 5 µm scanner with the serial number 0123 would have the file name **5_123.scn**.

You may also have default scanner calibration parameter files under the drop-down list in the CP/LS Scanner category of the ProScan Database Configuration dialog box. These default files contain typical calibration parameters for a particular model of scanner or scan head. These default files cannot be used as working files unless scanner calibration is performed. The default value for many of the parameters is listed as "Invalid," which

means that a value has not yet been determined. However, the default files can be used after calibration has been performed.

The default scanner calibration files should be left in the **c:\psi\cal** directory as a backup, in case the files for specific scanners become corrupted. The file name for a default file will typically include the size of the scanner. For example, a default file for a 5 µm scanner would have the file name **5um.scn**.

If for some reason you need to perform the scanner calibration procedure using a default file, you should make a copy of the default file and work with the copy. By doing this you will retain an uncorrupted default file as a backup.

To copy a default scanner calibration parameter file: Open the Explorer, and then open the directory **c:\psi\cal**. Make a copy of the default scanner calibration parameter file for the appropriate scanner size. For example, if you have two 5 µm scanners and you wish to create a different scanner calibration parameter file for each scanner, make two copies of the file **5um.scn** and name each copy **5_XXXX.scn** where XXXX is the serial number of that particular scanner, or some other descriptive label.

Follow these rules when creating a file name:

- Use only letters, digits, and the underscore symbol in the file name. The system is not case sensitive.
- Use a maximum of eight characters.
- Do not change the file extension, scn.
- Do not create a calibration parameter file for a scanner of one size from the calibration parameter file for a scanner of a different size. For example, do not create a file for a 5 µm scanner from the file for a 100 µm scanner. This may cause confusion later if the file is changed during a system upgrade, due to coding within the file.

When you perform the calibration procedures described in this section, you will be writing over the calibration parameter values in the working scanner calibration parameter file. ThermoMicroscopes recommends that you keep a backup copy of the scanner calibration parameter file in a separate directory, in case the working copy becomes corrupted. You may also wish to keep a backup copy of the scanner calibration parameter file on a floppy disk. After you complete the scanner calibration procedures of this section, you will be instructed on how to create a backup copy of the scanner calibration file.

If you need to reinstall your software for some reason, be aware that only the default scanner calibration parameter files will be installed in the **c:\psi\cal** directory: the working scanner calibration parameter files will not be installed. You will have to copy the

working scanner calibration parameter files from the backup copies you have in a different directory. By reinstalling the backup copies you will not have to perform a complete scanner calibration again.

Now, install the appropriate hardware and set up for taking a contact-AFM image:

1. Install a 5 µm scanner, as described in Chapter 2, Part I of this User’s Guide.

> ***CAUTION***
>
> The power to the AEM must be turned OFF before you remove or install the scanner.

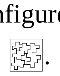
> ***CAUTION***
>
> The four screws that connect the scanner to the CP base unit must be securely fastened to ensure proper grounding. When the four screws are securely fastened, maximum instrument performance is ensured since vibrations are reduced.

2. Place the 1 µm gold grating sample on the sample holder. If the grating is roughly square, rotate the sample so that the edges of the grating are parallel with the x and y scan directions. Later, you will take an image and make adjustments to the position of the grating.

3. Open ProScan Data Acquisition. From Start, point to the Program folder and select ThermoMicroscopes ProScan. Then, click the Data Acquisition icon. Alternatively, double-click the Data Acquisition icon in the desktop.

   The program opens to Move mode.

4. Turn off the probe head by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

5. Select Configure Parts from the Setup menu. Alternatively, click the Configure Parts icon, . The ProScan Database Configuration dialog box will open.

   Note: The Configure Parts option is only enabled when the probe head is turned off. When the probe head is turned back on, the system is prompted to load files pertaining to the installed hardware and mode of

operation. This procedure ensures that files are updated before an image is taken.

6. Configure the system software for taking an AFM image by making the following selections:

   - ♦ Head Type: Select the type of probe head—AFMSTM, AFMNCM, or AFMLFM—that you are using. If you are using a multitask probe head, select AFMLFM.
   - ♦ CP/LS Scanner: Select the file that has the scanner calibration values for the scanner you are using.
   - ♦ Head Mode: AFM.
   - ♦ Beam Bounce Cantilever: Select the file that corresponds to the cantilever you are using.
   - ♦ Electrochemistry ON/OFF: OFF.
   - ♦ Voltage mode: HI.

   After you finish entering these selections, click OK to return to the Move mode window.

7. If you have not already done so, reset the Z stage as described in Chapter 2, Part I of this User's Guide. This synchronizes the position of the Z stage with the coordinate system of the software.

8. Make sure that the power to the probe head is on. If the power to the probe head is turned off, turn it on by clicking the Head ON icon, . If the LASER ON/OFF switch is in the OFF position, turn it to the ON position.

   Note: If you are using a multitask probe head, set the AFM/STM switch to the AFM position, and the LFM/NC-AFM switch to the LFM position.

9. Align the deflection sensor (as described in Chapter 2, Part I of this User's Guide).

You are ready to begin calibrating the scanner sensitivity.

First-Order Calibration of Scanner Sensitivity in X and Y

The calibration parameters you will determine in this section are termed first order calibration parameters because they are used to describe the linear behavior of the scanner position with applied voltage appropriate for small scan sizes. There are four first order calibration parameters, listed below:

- ♦ **MicronPerDac_FastSX**: Calibrates scanner movement with voltage in x for small scans when x is the fast scan direction.

- **MicronPerDac_SlowSX**: Calibrates scanner movement with voltage in x for small scans when x is the slow scan direction.
- **MicronPerDac_FastSY**: Calibrates scanner movement with voltage in y for small scans when y is the fast scan direction.
- **MicronPerDac_SlowSY**: Calibrates scanner movement with voltage in y for small scans when y is the slow scan direction.

Note that there are two calibration parameters associated with each scan direction, x and y. One parameter is for when the direction is the fast scan direction, and the other parameter is for when the direction is the slow scan direction. There are different calibration parameters for the fast and slow scan directions because the scanner's response to applied voltage varies depending on the speed of scanner motion.

When you calibrate the scanner, you will take one image using x as the fast scan direction to determine values for the **MicronPerDac_FastSX** and **MicronPerDac_SlowSY** parameters. Then, you will take a separate image using y as the fast scan direction to determine values for the **MicronPerDac_FastSY** and **MicronPerDac_SlowSX** parameters.

Before you perform the scanner calibration procedures, two default calibration parameters are used for describing the scanner's response to applied voltage in the x and y directions. The values of these default first order calibration parameters provide only an approximate description of the scanner's behavior, and just one calibration parameter value is used for each direction, x and y.

The default first order calibration parameters for the x and y directions are named **MicronPerDac_SX** and **MicronPerDac_SY**, respectively. The system software uses these parameters when the value of any of the four first order calibration parameters or four second order calibration parameters is set as Invalid. Once all eight of the calibration parameters have numerical values, the values of the four first order parameters are used by the system software and the two default first order calibration parameters are disabled.

Next, you will take an AFM image of your calibration sample. (For details on taking an AFM image, refer to Part I, Chapters 2 through 4 of this User's Guide.) You will use measurements on this image to determine values for the first order calibration parameters.

Taking an Image and Determining Calibration Parameter Values:

This tutorial uses the 1 µm gold calibration grating provided as part of your system as an example. If you are using a different calibration standard, simply substitute the known spacing value for your sample where that for the gold grating is referred to here.

Note: If you will be taking atomic-scale images frequently, then you should use a calibration sample that has atomic-scale features of known spacing, such as

HOPG (highly oriented pyrolytic graphite). Since values of the calibration parameters depend on scan size, values obtained using a 1 µm grating as a calibration standard can lead to inaccurate reporting of scan sizes for atomic-scale images.

1. Turn on the probe head by selecting Head ON from the Mode menu or clicking the Head ON icon, .

2. Perform a coarse approach by using the z direction pad to lower the probe head until the tip is within a few millimeters of the sample surface. Then, click the [Approach] button to initiate an auto approach.

3. Switch to Image mode by clicking the Image Mode icon, .

4. Make sure that the x direction is set to be the fast scan direction, and that High Voltage is selected in the Mode menu.

5. Select a scan size. The scan size should be representative of typical small scans you will take, since the first order calibration parameters are used to correct small scan sizes.

   Choose a scan size that will enable you to see at least a few periods of the features on your sample. For the 1 µm grating, the smallest scan size you can take that enables you to see at least two periods is about 2 µm. Ideally, if you commonly take 2 µm images, for example, you should use a calibration sample that has features spaced on the order of 0.1 µm. In that case, you would be able to select a scan size of 2 µm and see roughly 20 periods.

6. Select a scan rate appropriate for the scan size you are using. For example, for a 2 µm image of the gold grating, try a scan rate of 2 Hz.

   Note: Since the response of the scanner varies depending on the speed of scanner motion, it is important that you select an appropriate scan rate for the scanner calibration procedures.

7. Adjust the set point, gain, and slope parameters until the signal trace on the Oscilloscope Display is level and representative of the sample topography.

8. Click the [Image] button to take an image.

9. Note the orientation of the features on the sample with respect to the x and y scan directions. Earlier, it was mentioned that you should try to mount the sample such that the grating lines (sometimes parallel to the sample's edges) are

aligned with the x and y axes of the image. Now, check to make sure that this is the case.

For example, if you are using the 1 µm gold grating sample, make sure that each successive row of maxima on the image lines up with the row directly above it, not with the row two rows above it. The sample can be rotated 45 degrees from its correct orientation and still appear to be lined up with the x and y scan direction, so be sure that features of *successive* rows line up.

If you are using a sample other than the gold calibration grating, make sure that features of known spacing line up along the x and y axes.

If the sample needs to be rotated, lift the tip, rotate the sample, re-approach the sample, and take another image. Continue this process until the sample is aligned properly. Once it is aligned, you may want to make a mark on the sample mount for future reference.

10. Once you have an image you are satisfied with, use the Line Analysis software tools (described in the Image Processing chapter of Part III of this User's Guide) to measure the spacing between the largest number of maxima for a given direction on the image. For example, if you can see three maxima on a cross section of the image in the x direction, measure the spacing between all three maxima. For the gold grating, the spacing between three maxima should be 2 µm.

11. Compare the measured distance value to the known distance value. If the distance produced by the software measurement tools is incorrect, then the first order scanner calibration value for the x direction of a fast-x scan, **MicronPerDac_FastSX**, needs to be changed.

At this point, it is recommended that you create a table listing the names of all calibration parameters that you will be checking. Make a row for each of the four first order and four second order calibration parameters, and an additional row for the z direction calibration parameter, **MicronPerDac_SZ**, which you will be determining in a later section. Make two columns for each row, labeled High-Voltage Mode and Low-Voltage Mode, so that you can enter two separate values for each parameter, depending on whether you are operating in high or low-voltage mode.

Keep this table for future reference. As mentioned earlier, *if you ever need to reinstall the software, the default values of all calibration parameters will be restored.*

12. Calculate a new value for a first order scanner calibration parameter using the following formula:

$$\text{correct cal. value} = \text{existing cal. value} \times \frac{\text{correct distance}}{\text{measured distance}} \qquad (1)$$

For example, if you ask the software to measure the distance between three maxima along the x axis and it produces a value of 1.5 µm, and the existing **MicronPerDac_FastSX** value is 2.5, then the correct value of the calibration parameter is calculated as follows:

$$\text{MicronPerDac\_FastSX} = 2.5 \times \frac{2}{1.5} = 3.33$$

Record the correct value in the high-voltage column of your table of calibration values.

13. Repeat Steps 10 through 12, measuring the spacing between maxima along the y axis of the fast-x image. Record a value for the **MicronPerDac_SlowSY** parameter.

14. Next, switch the fast scan direction to be the y direction. Again, correct the slope parameter so that the signal trace on the Oscilloscope Display is level. The scan rate and scan size should be left the same.

15. Click the [Image] button to take an image with the y direction as the fast scan direction.

16. Repeat steps 10 through 12, measuring the distance between maxima in the y direction of the fast-y image to calculate a value for the **MicronPerDac_FastSY** parameter.

17. Repeat steps 10 through 12, measuring the distance between maxima in the x direction of the fast-y image to calculate a value for the **MicronPerDac_SlowSX** parameter.

You should now have values recorded in your table for all four of the first order scanner calibration parameters for high-voltage mode. Next, you will enter the corrected values of the first order scanner calibration parameters into the scanner calibration file.

Editing the Scanner Calibration File:

1. Switch to Move mode and use the z direction pad to raise the probe head so that the tip is a safe distance from the sample.

2. Turn off the probe head by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

3. Select Calibration Edit from the Setup menu. Click Yes in the Warning box to indicate that you want to proceed.

4. Select the Scanner category in the left listbox.

5. Select a first order calibration parameter whose value you would like to change. For example, select **MicronPerDac_FastSX**.

6. Change the value of the parameter by typing the new value into the textbox above the Calibration Values listbox. Be sure to press the `[Enter]` key after entering the new value so that the correction is recognized by the software.

7. Repeat Steps 5 and 6 for all of the first order scanner calibration values that you wish to change.

8. Now set the values of all four of the second order calibration parameters to zero. The names of the second order calibration parameters are as follows: **MicronPerDacSq_FastSX**, **MicronPerDacSq_SlowSX**, **MicronPerDacSq_FastSY**, and **MicronPerDacSq_SlowSY**. Note that the names are identical to their first-order counterparts, except for the inclusion of "Sq."

   If the value of any of these parameters is listed as Invalid, then the system will not disable the default first order calibration parameters and the calibrated first order values you determined will not be used.

9. Click Done to register the changes and close the dialog box.

10. As a check, repeat the steps of the earlier section "Taking an Image and Determining Calibration Parameters," making sure that distances reported by the software now match their correct values.

After the corrections are made, you should see an improvement in the accuracy of scan sizes for small scans when you are operating in high-voltage mode.

First-Order Calibration in Low-Voltage Mode:

The system software uses separate sets of scanner calibration parameter values for high and low-voltage modes. Therefore, if you will be operating frequently in low-voltage mode, you need to repeat the first-order scanner calibration procedures while operating in low-voltage mode.

1. Select Low Voltage from the Mode menu.

2. Follow Steps 1 through 17 of the earlier section "Taking an Image and Determining Calibration Parameter Values." In low-voltage mode, however, the maximum scan size is roughly 1 to 1.5 µm, depending on the scanner. Therefore, you need to select a calibration sample other than the 1 µm gold calibration grating. In addition, as you calculate corrected values of first order calibration parameters for low-voltage mode, be sure to enter the values in the Low-Voltage column of your table of calibration parameters.

3. Follow Steps 1 through 10 of the previous section "Editing the Scanner Calibration File" to edit the values of first order scanner calibration parameters for low-voltage mode.

First-order calibration of the scanner sensitivity is now completed for high and low-voltage modes. You are ready to continue and perform the procedures for second-order calibration of the scanner sensitivity.

Second-Order Calibration of Scanner Sensitivity in X and Y

In this section, you will determine the values of second order calibration parameters. Second order terms account for nonlinear behavior of the scanner for large scan sizes. The addition of these terms improves the accuracy of scan sizes for large scans.

The procedure is similar to that for determining the first order parameters. A larger scan size is used and the formula for calculating the correct parameter values is different. Again, the software keeps track of two sets of second order calibration parameter values, one for high-voltage mode, and another for low-voltage mode. However, since the maximum scan size in low-voltage mode is between 1 and 1.5 µm (depending on the scanner), determining second order scanner calibration parameter values for low-voltage mode is not necessary.

The names and descriptions of the second order parameters are the following:

- **MicronPerDacSq_FastSX**: Calibrates additional scanner movement with voltage in x for large scans when x is the fast scan direction.
- **MicronPerDacSq_SlowSX**: Calibrates additional scanner movement with voltage in x for large scans when x is the slow scan direction.
- **MicronPerDacSq_FastSY**: Calibrates additional scanner movement with voltage in y for large scans when y is the fast scan direction.
- **MicronPerDacSq_SlowSY**: Calibrates additional scanner movement with voltage in y for large scans when y is the slow scan direction.

Note: Pay careful attention to the name of the calibration parameter you are selecting when you are changing a parameter's value. The only difference between the

names of the first and second order calibration parameters is that the second order parameters include "Sq" in their names.

To determine values for the second order terms, you must take another, larger image of your calibration standard sample.

Taking an Image and Determining Calibration Parameter Values:

1. If the probe head is not turned off, turn it off now by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

2. Select High Voltage from the Mode menu.

3. Turn on the probe head by selecting Head ON from the Mode menu or clicking the Head ON icon, .

4. From the Move mode window, perform a coarse approach by using the z direction pad to lower the probe head until the tip is within a few millimeters of the sample surface. Then, click the Approach button to initiate an auto approach.

5. Switch to Image mode by clicking the Image Mode icon, .

6. Select a scan size that is as large as possible by typing a value larger than 5 µm in the Size textbox. The system will then default to the largest scan size possible, which varies somewhat from scanner to scanner.

7. Set the x direction as the fast scan direction.

8. Use a scan rate that is representative of the scan rate you will be most likely to use when you take large scans. For a 5 µm scan of a gold calibration grating, select a scan rate of 1 Hz.

9. Adjust the set point, gain, and slope parameters until the signal trace on the Oscilloscope Display is level and representative of the sample topography.

10. Click the Image button to take an image.

11. Once the image is complete, use the Line Analysis software tools (described in the Image Processing chapter of Part III of this User's Guide) to measure the spacing between the largest number of maxima for a given direction on the image. For example, for the gold calibration grating, measure the spacing between 5 maxima along the x axis. The spacing between 5 maxima should be 4 µm.

12. Compare the measured distance value to the known distance value. If the distance produced by the software measurement tools is incorrect, then the second order scanner calibration value for the x direction of a fast-x scan, **MicronPerDacSq_FastSX**, needs to be changed.

At this point, refer to the table of calibration parameters that you made when calibrating the first order parameters. You can enter the corrected values of the second order calibration parameters into this table as well.

13. Calculate a new value for a scanner calibration parameter using the following formula:

$$\text{2nd O. cal. value} = \frac{\text{correct distance - measured distance}}{(\text{measured distance / 1st O. cal. value})^2} \qquad (2)$$

For example, if you ask the software to measure the distance between 5 maxima along the x axis of a fast-x scan and it produces a value of 3.5 µm, and the value of the **MicronPerDac_FastSX** parameter is 3.33, then the value of the **MicronPerDacSq_FastSX** calibration parameter is calculated as follows:

$$\text{MicronPerDacSq\_FastSX} = \frac{4 - 3.5}{(3.5/3.33)^2} = 0.45$$

14. Record the value in the High-Voltage column of your table of calibration parameter values.

15. Repeat Steps 11 through 14 measuring the spacing between grating lines along the y axis of the fast-x image to calculate a value for the **MicronPerDacSq_SlowSY** parameter.

16. Next, switch the fast scan direction to be the y direction. Again, correct the slope parameter so that the signal trace on the Oscilloscope Display is level. The scan rate and scan size should be left the same.

17. Click the [Image] button to take an image with the y direction as the fast scan direction.

18. Repeat steps 11 through 14, measuring the distance between grating lines in the y direction of the fast-y image to calculate a value for the **MicronPerDacSq_FastSY** parameter.

19. Repeat Steps 11 through 14, measuring the distance between grating lines in the x direction of the fast-y image to calculate a value for the **MicronPerDacSq_SlowSX** parameter.

You should now have values recorded in your table for all four of the second order scanner calibration parameters for high-voltage mode. Next, you will enter these values into the scanner calibration parameter file.

Editing the Scanner Calibration File:

1. From the Move mode window, use the z direction pad to withdraw the tip from the sample.

2. Turn off the probe head by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

3. Select Calibration Edit from the Setup menu. Click Yes to indicate that you want to proceed.

4. Select the Scanner category in the left listbox.

5. Select the appropriate second order calibration parameter. For example, select **MicronPerDacSq_FastSX**.

6. Change the value of the parameter by typing the new value into the textbox above the Calibration Values listbox.

   Press the `[Enter]` key after entering the new value so that the correction is recognized by the software.

7. Repeat Steps 5 and 6 for all of the second order scanner calibration values that you wish to change.

8. Click Done to register the changes and close the dialog box.

After the second order parameter values are changed in the scanner calibration parameter file, you should see an improvement in the scan size as reported by the software for scan sizes up to the full range of the scanner when you are operating in high-voltage mode. If you would like, you can continue and perform the procedures for calibrating the scanner sensitivity in z.

Calibration of Scanner Sensitivity in Z

Calibrating the scanner sensitivity in the z direction means calibrating the voltages sent to the scanner with motion of the scanner in the z direction. The procedure is similar to that for calibrating the scanner sensitivity in the x and y directions, except that you need to use a sample with a z step height of a known distance (a step-height standard). The z range of scanner motion for a 5 µm scanner in high-voltage mode is roughly 2.5 µm, and in low-voltage mode it is roughly 0.8 µm. Choose a step height standard that is appropriate for these ranges.

Software correction for scanner movement in the z direction includes only one first order parameter, the **MicronPerDac_SZ** parameter. Second order correction is not necessary since scanner motion in the z direction is usually small.

The value of the **MicronPerDac_SZ** parameter varies depending upon whether you are operating high or low-voltage mode. Therefore, you need to perform the first order calibration procedure in both high and low-voltage modes if you expect to be operating in both modes frequently.

Taking an Image and Determining a Calibration Parameter Value:

1. Install a step-height standard in place of the 1 µm gold grating sample.

2. Make sure that you are in high-voltage mode by selecting High Voltage from the Mode menu.

3. Approach the sample, set scan parameters, and take a contact-AFM image as you normally do. Be sure that the step of known height on your sample is included in the image. In addition, scan across the step in the fast scan direction.

4. Use the Line Analysis software tools (described in the Image Processing chapter of Part III of this User's Guide) to measure the known step height in the z direction on the image.

5. Compare the measured distance value to the known distance value. If the distance produced by the software measurement tools is incorrect, then the calibration parameter for the scanner sensitivity in the z direction, **MicronPerDac_SZ**, needs to be changed.

   The correct z scanner calibration value is the existing value multiplied by the ratio of correct to measured distances:

$$\text{correct cal. value} = \text{existing cal. value} \times \frac{\text{correct distance}}{\text{measured distance}} \qquad (1)$$

For example, if you ask the software to measure a distance that you know is 0.2 µm and it produces a value of 0.16 µm, and the existing **MicronPerDac_SZ** value is 0.6, then you should change the value as follows:

$$\text{MicronPerDac\_SZ} = 0.6 \times \frac{0.2}{0.16} = 0.75$$

6. Enter the correct value for the **MicronPerDac_SZ** parameter in the table you created earlier for the first and second order scanner calibration parameters.

Next, you will enter the corrected **MicronPerDac_SZ** parameter value into the scanner calibration parameter file.

Editing the Scanner Calibration File:

1. From the Move mode window, use the z direction pad to withdraw the tip from the sample.

2. Turn off the probe head by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

3. Select Calibration Edit from the Setup menu. Click Yes in the Warning box to indicate that you want to proceed.

4. Select the Scanner category in the left listbox.

5. Select **MicronPerDac_SZ** from the list of calibration parameter values.

6. Change the value of the parameter by typing the new value into the textbox above the Calibration Values listbox.

   Press the `[Enter]` key after entering the new value so that the correction is recognized by the software.

7. Click Done to register the change and close the dialog box.

The scanner sensitivity is now calibrated in the z direction for high-voltage mode. After the correction is made, the software should measure the step height correctly.

Z Calibration in Low-Voltage Mode:

If you plan to operate frequently in low-voltage mode, you should repeat the procedures to calibrate the scanner sensitivity in z for low-voltage mode.

1. Switch to low-voltage mode by selecting Low Voltage from the Mode menu.

2. Follow Steps 3 through 6 of the earlier section "Taking an Image and Determining a Calibration Parameter Value" for the scanner sensitivity in z. This time, enter the value in the Low-Voltage column of your table of calibration parameters.

3. Follow Steps 1 through 7 of the previous section "Editing the Scanner Calibration File" to edit the value of the **MicronPerDac_SZ** calibration parameter for low-voltage mode.

The scanner sensitivity calibration parameter for the z direction is now calibrated for both high and low-voltage modes.

Creating a Backup Scanner Calibration File

If you have completed the instructions of this section, then you have calibrated your 5 μm scanner and thus created a new calibration parameter file. Saving a backup copy of this file involves the following general procedures:

1. Create a special directory, **c:\scancal**, for backup files.
2. Create backup copies of the current scanner calibration parameter files and store them in **c:\scancal**.

Each time you perform a scanner calibration you automatically update the working scanner calibration parameter file. You should update the backup copy of this file in the **c:\scancal** directory at the same time in case the working file becomes corrupted.

The above-listed general procedures for file management are broken into detailed steps below. The directions assume you are using Windows 95.

1. Create the **c:\scancal** directory:

    a. From the Start menu, point to Programs and select Explorer. Open the **c:** drive.
    b. From the File menu, click New, then click Folder. This creates a new folder in **c:**. The label of the folder icon will be highlighted to indicate that it can be altered.
    c. Type **scancal** in the new folder icon label and press the `[Enter]` key.

2. Select the scanner calibration parameter file be copied: Using Windows Explorer, go to the folder **c:\psi\cal**. Identify the scanner calibration parameter file(s) you wish to copy. For example, you will most likely wish to copy the file for the scanner you most recently calibrated.

3. With the cursor on that file, click the *right* mouse button to open the right mouse button menu.

4. Copy the scanner calibration parameter file from **c:\psi\cal** to **c:\scancal**:

   a. Select Copy from the right mouse button menu.
   b. Move the cursor to the **c:/scancal** folder. Click the right mouse button again, and click Paste from the right mouse button menu.
   c. A copy of the selected scanner calibration parameter file will appear in the **c:/scancal** folder.

You have now created a backup copy of the scanner calibration parameter file.

Calibrating a 100 Micron Scanner

This section describes the scanner calibration procedures for AutoProbe CP instruments equipped with a 100 μm scanner. As mentioned in the introduction of this chapter, AutoProbe CP multitask instruments come with a 100 μm scanner, while standard AutoProbe CP instruments come with a 5 μm scanner. Therefore, this section applies if you have an AutoProbe CP multitask instrument, or if you have purchased a 100 μm scanner for a standard AutoProbe CP instrument.

This section is divided into three subsections, which cover the following topics:

- how ScanMaster works
- what it means to calibrate the scanner
- scanner calibration procedures

The first two sections provide background information that may be useful to you as you perform the scanner calibration procedures. If you would like, however, you may skip directly to the section that describes how to calibrate a 100 μm scanner.

How ScanMaster Works

If you are using a 100 μm scanner, then your system is equipped with ScanMaster. ScanMaster is a hardware solution that addresses the problems of nonlinearity intrinsic to a piezoelectric scanner. Position-sensitive photodetectors (PSPD's) and light-emitting diodes (LED's) are used to monitor the position of the scanner tube in the x, y, and z directions. Both the response of the detectors and the response of the scanner tube to applied voltage must be calibrated for systems that are equipped with ScanMaster.

The detectors are mounted on the scanner tube and therefore move with the tube. The LED's are located inside the scanner housing and remain stationary. An LED is aimed at each detector. Changes in the scanner's position are monitored as changes in the position of each LED light spot on its detector.

One detector, located on one end of the scanner tube, is for monitoring the xy position of the scanner. This detector is connected to a feedback loop that is enabled if ScanMaster is turned on. The xy position is read, and the information is compared to a reference value representing the intended xy position. A voltage is then sent to the scanner to correct its position. You can turn ScanMaster on or off using software controls. If ScanMaster is off, then the xy feedback loop is disabled and no correction is applied to the scanner's xy position.

Z detection differs from xy detection in that it is not connected to a feedback loop. This is because there is no "intended" z position (as there is for the xy position of a raster pattern), since the z position reflects sample topography. AutoProbe systems that have the sample mounted on the scanner (i.e., scanning-sample systems) are equipped with two z detectors. These detectors are located on the left and right sides of the scanner tube and measure both the extension and the tilt of the scanner. The signals from these two detectors are averaged to produce a single Z Detector signal, which reflects the z position of the scanner.

AutoProbe systems that have the probe mounted on the scanner (i.e., scanning-probe systems) are equipped with a single z detector. The signal from this detector is used to produce the Z Detector signal.

For some applications, the Z Detector signal is a more reliable measure of the scanner's z position than the Topography signal, which represents the voltage applied to the scanner. This is because the correlation between voltage applied to the scanner and scanner position is subject to the nonlinearities mentioned earlier.

For small variations in topography, a smaller z range of the scanner is typically used (i.e., low-voltage mode). At these reduced z ranges of scanner motion, scanner non-linearities are not a significant problem. The signal-to-noise ratio of the z detector, however, decreases. For this type of application, the Topography signal is therefore preferable over the Z Detector signal as a measure of sample topography. The Topography signal is often used in high-voltage mode as well.

This description of how the scanner works and how its position is controlled and corrected will be useful to you as you perform the scanner calibration procedures. Additional background information is provided in the next section, which describes what it means to calibrate the scanner.

What it Means to Calibrate a 100 Micron Scanner

Calibrating a 100 μm scanner means calibrating both the ScanMaster detectors and the scanner sensitivity. Voltage readings from the detectors must be calibrated with the distances those voltages represent (measured in microns); and, voltages applied to the scanner tube must be calibrated with the distance that the scanner tube moves (again, measured in microns).

An additional calibration that should be performed for a 100 μm scanner is the calibration of detector offsets. When the scanner tube is in its "relaxed" or "home" position with no voltages applied to it, the detectors should all read positions of zero. Thermal effects and changes in the properties of scanner tubes over time, however, may cause shifts such that the detectors measure non-zero home positions. These shifts are accounted for by the detector offset calibration parameters, which are the measured outputs from the detectors when there are no voltages applied to the scanner tube.

When you calibrate a 100 μm scanner, you will manually calibrate the output of the xy and z detectors with distance (in microns). Then, once the detectors are calibrated, the system can use them to calibrate the detector offsets and the scanner sensitivity automatically.

You only need to become familiar with the names of scanner calibration parameters that you change manually. For a 100 μm scanner, the scanner calibration parameters you will change manually are the following three detector calibration parameters:

- **DetMicronPerAdc_SX:** This parameter calibrates the xy detector’s x output signal with position.
- **DetMicronPerAdc_SY**: This parameter calibrates the xy detector’s y output signal with position.
- **DetMicronPerAdc_SZ**: This parameter calibrates the z detector’s output signal with position.

Values for the three parameters listed above are contained in a calibration parameter file. Every scanner has its own file. You direct the system to use a particular scanner calibration parameter file by selecting its filename when you configure the system software.

Specifically, at any point during a working session you can select Configure Parts from the Setup menu to view or change the scanner calibration parameter file that the system is set to use. The names of available files are included in the drop-down list labeled CP/LS Scanner. Typically, the filenames refer to the scanner’s size. For example, the file containing the calibration parameter values for a 100 μm scanner might be called 100UM.

The values of scanner calibration parameters are accessible in a dialog box called Manual Calibration Entry, which opens when you select Calibration Edit from the Setup menu. The three calibration parameters listed above are grouped in the Scanner Det category of the Manual Calibration Entry dialog box.

In the tutorial section that follows, you will learn how to manually calibrate the detectors. You will also learn how to prompt the system to calibrate the detector offsets and the scanner sensitivity automatically.

Scanner Calibration Procedures

This section of the chapter provides step-by-step instructions for calibrating a 100 µm scanner for an AutoProbe CP instrument. For the calibrations in the x and y directions, you can use a 1 µm gold calibration grating (provided with standard AutoProbe CP systems) or a 9.9 µm grid (provided with multitask AutoProbe CP systems). For the calibrations in the z direction, you will need a z height calibration standard.

This section includes instruction for the following procedures:

- setting up the system for scanner calibration
- calibrating the xy detector
- calibrating the z detector
- running the scanner calibration routine to calibrate the detector offsets and scanner sensitivity in x, y, and z

Setting up the system for calibrating the scanner consists of installing the appropriate system hardware, configuring the system software, and performing an auto approach. These procedures are described in detail in the following sections.

Installing the System Hardware

This section assumes that your instrument has been installed by a ThermoMicroscopes representative and that all of the cables are properly connected. It also assumes that you are using the 9.9 µm grid provided with multitask AutoProbe CP systems as a calibration sample.

1. Install a 100 µm scanner.

> ***CAUTION***
>
> The power to the AEM must be turned OFF before you remove or install the scanner.

> ***CAUTION***
>
> The four screws that connect the scanner to the CP base unit must be securely fastened to ensure proper grounding. When the four screws are securely fastened, maximum instrument performance is ensured since vibrations are reduced.

2. Place the 9.9 µm grid sample on the sample holder. Try to rotate the sample so that the grid lines are parallel with the x and y scan directions.

3. Install the probe head. Make sure that the LASER ON/OFF switch on the probe head is in the OFF position before you install the probe head.

   If you are using a multitask probe head, set the AFM/STM switch to the AFM position, and the LFM/NC-AFM switch to the LFM position.

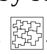
4. Once the probe head is installed, set the LASER ON/OFF switch on the probe head to the ON position.

5. Place an AFM chip carrier in the probe cartridge.

6. Place the cartridge in the probe head.

Configuring the System Software

Once you have installed the appropriate hardware, you can configure the system software. Values for all of the scanner calibration parameters are contained in a calibration parameter file. Each scanner in your system has a working scanner calibration parameter file.

To direct the system to use a particular scanner calibration parameter file, select that file when you configure the system software in the ProScan Database Configuration dialog box. This can be done at any point during a working session by selecting Configure Parts from the Setup menu, or by clicking the Configure Parts icon, .

The names of available files are under the drop-down list in the CP/LS Scanner category of the ProScan Database Configuration dialog box.

Note: The files can also be found in the **c:\psi\cal** directory.

A file name for a working file will typically include the size and the serial number of the scanner. For example, a file for a 100 µm scanner with the serial number 0123 would have the file name **100_0123.scn**.

You may also have default scanner calibration parameter files under the drop-down list in the CP/LS Scanner category of the ProScan Database Configuration dialog box. These default files contain typical calibration parameters for a particular model of scanner or scan head. These default files cannot be used as working files unless scanner calibration is performed. The default value for many of the parameters is listed as "Invalid," which means that a value has not yet been determined. However, the default files can be used after scanner calibration has been performed.

The default scanner calibration files should be left in the **c:\psi\cal** directory as a backup, in case the files for specific scanners become corrupted. The file name for a default file will typically include the size of the scanner. For example, a default file for a 100 µm scanner would have the file name **100um.scn**.

If for some reason you need to perform the scanner calibration procedure using a default file, you should make a copy of the default file and work with the copy. By doing this you will retain an uncorrupted default file as a backup.

To copy a default scanner calibration parameter file: Open the Explorer, and then open the directory **c:\psi\cal**. Make a copy of the default scanner calibration parameter file for the appropriate scanner size. For example, if you have two 100 µm scanners and you wish to create a different scanner calibration parameter file for each scanner, make two copies of the file **100um.scn** and name each copy **100_XXXX.scn** where XXXX is the serial number of that particular scanner, or some other descriptive label.

Follow these rules when creating a file name:

- Use only letters, digits, and the underscore symbol in the file name. The system is not case-sensitive
- Use a maximum of eight characters.
- Do not change the file extension, scn.
- Do not create a calibration parameter file for a scanner of one size from the calibration parameter file for a scanner of a different size. For example, do not create a file for a 5 µm scanner from the file for a 100 µm scanner. This may cause confusion later if the file is changed during a system upgrade, due to coding within the file.

When you perform the calibration procedures described in this section, you will be writing over the calibration parameter values in the working scanner calibration parameter file. ThermoMicroscopes recommends that you keep a backup copy of the scanner calibration parameter file in a separate directory, in case the working copy becomes corrupted. You may also wish to keep a backup copy of the scanner calibration parameter file on a floppy disk. After you complete the scanner calibration procedures of

this section, you will be instructed on how to create a backup copy of the scanner calibration file.

If you need to reinstall your software for some reason, be aware that only the default scanner calibration parameter files will be installed in the **c:\psi\cal** directory: the working scanner calibration parameter files will not be installed. You will have to copy the working scanner calibration parameter files from the backup copies you have in a different directory. By reinstalling the backup copies you will not have to perform a complete scanner calibration again.

Now, open ProScan and set up for taking a contact-AFM image:

1. Turn on the AEM, the computer, and the monitors.

2. Open ProScan Data Acquisition. From Start, point to the Program folder and select ThermoMicroscopes ProScan. Then, click the Data Acquisition icon. Alternatively, double-click the Data Acquisition icon in the desktop. The program opens to Move mode.

3. Turn off the probe head by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

4. Select Configure Parts from the Setup menu. Alternatively, click the Configure Parts icon, . The ProScan Database Configuration dialog box will open.

   Note: The Configure Parts option is only enabled when the probe head is turned off. When the probe head is turned back on, the system is prompted to load files pertaining to the installed hardware and mode of operation. This procedure ensures that files are updated before an image is taken.

5. Configure the system software for taking an AFM image by making the following selections:

   - Head Type: Select the type of probe head—AFMSTM, AFMNCM, or AFMLFM—that you are using. If you are using a multitask probe head, select AFMLFM.
   - CP/LS Scanner: Select the file that has the scanner calibration values for the scanner you are using.
   - Head Mode: AFM.
   - Beam Bounce Cantilever: Select the file that corresponds to the type of cantilever you are using (e.g., select UL06B if you are using the B cantilever of a contact-AFM Ultralever).

- Electrochemistry ON/OFF: OFF.
- Voltage mode: HI.

After you finish entering these selections, click OK to return to the Move mode window.

6. If you have not already done so, reset the Z stage as described in Chapter 2, Part I of this User's Guide. This synchronizes the position of the Z stage with the coordinate system of the software.

7. Make sure that the power to the probe head is on. If the power to the probe head is turned off, turn it on by clicking the Head ON icon, . If the LASER ON/OFF switch is in the OFF position, turn it to the ON position.

   Note: If you are using a multitask probe head, set the AFM/STM switch to the AFM position, and the LFM/NC-AFM switch to the LFM position.

8. Align the deflection sensor as described in Chapter 2, Part I of this User's Guide.

9. Perform a coarse approach by using the z direction pad to move the tip to within a few millimeters of the sample surface. Then, click the Approach button to initiate an auto approach.

Once the auto approach is complete, you are ready to begin calibrating the detectors.

Calibrating the XY Detector

Manual calibration of the ScanMaster detectors is an important step of the scanner calibration procedures, since the auto calibration procedures that calibrate the detector offsets and the scanner sensitivity use positions reported by the ScanMaster detectors. This section describes the procedures for calibrating the xy detector.

Since the detectors are not affected by the range of volts to the scanner, this calibration procedure only needs to be performed in high-voltage mode.

The XY Detector Calibration Parameters:

The detector calibration values for the x and y directions are labeled **DetMicronPerAdc_SX** and **DetMicronPerAdc_SY**, respectively. The values are given in units of microns per Adc, where Adc units are defined as follows:

Each detector produces an analog voltage value that represents scanner position. An analog-to-digital converter (adc) then converts this analog voltage to a digital number. Thus, the signal from a detector is the digital output from an adc.

The full voltage range from the adc is -10 V to +10 V. One adc unit represents half of the adc range, or 10 V. Each detector calibration value represents the distance (in microns) along a given axis that the software associates with a change in the output from the detector of one adc unit, or 10 V. For example, a value of 140 for the **DetMicronPerAdc_SX** parameter means that the software associates a change in position of 140 µm along the x direction with a 10 V output from the detector.

Taking an Image and Determining Calibration Parameter Values:

To calibrate the xy detector, you must take an image of your calibration sample, with ScanMaster ON:

1. Switch to Image mode by clicking the Image Mode icon, .

2. Select ScanMaster from the Setup menu. This opens the ScanMaster Setup dialog box. Make sure that ScanMaster is on by selecting the ON option buttons for both the x and y directions.

   Click [Done] to register any changes and close the dialog box.

3. Select Scan Config from the Setup menu. Select the 512x512 option button from the Image Pixel Size section of the Scan Config dialog box. Then, click [OK] to close the dialog box.

   Note: Selecting 512 data points per scan line increases the resolution of your image. This is especially important since you will be taking a large image to calibrate the xy detector.

4. Select a large scan size, e.g., 90 µm, so that you will be able to see several lines of the 9.9 µm grid sample.

5. Adjust the set point, rate, gain, and slope parameters as you normally do to optimize the Topography signal trace for a contact-AFM image.

6. Click the [Image] button to take a contact-AFM image. Make sure that the grid lines of the calibration sample are aligned with the x and y scan directions. If they are not aligned, lift the tip, rotate the sample, re-approach the sample, and take another image. Repeat this process until the grid lines are aligned with the x and y scan directions.

7. Once you have obtained a satisfactory image, use the Line Analysis software tools (described in the Image Processing chapter of Part III of this User's Guide) to flatten the image and measure a known distance along the x axis. For

example, measure the distance between 10 grid lines, which corresponds to 89.1 μm.

8. Compare the measured distance value to the known distance value. If the distance produced by the software measurement tools is incorrect, then the detector calibration value along the x axis, **DetMicronPerAdc_SX**, needs to be changed.

At this point, it is recommended that you create a table listing the names of the three calibration parameters that you will be calibrating manually. Include spaces for the values of the calibration parameters. Keep this table for future reference. After you have completed the scanner calibration procedure, you will save a copy of the scanner calibration parameter file. As mentioned earlier, if you need to reinstall the software, the default values of all calibration parameters will be restored.

9. Calculate a new value for the **DetMicronPerAdc_SX** calibration parameter using the following formula:

$$\text{correct cal. value} = \text{existing cal. value} \times \frac{\text{correct distance}}{\text{measured distance}} \qquad (1)$$

For example, if you ask the software to measure the distance between 10 grid lines along the x axis and it produces a value of 80 μm, and the existing **DetMicronPerAdc_SX** value is 140, then you should change the value as follows:

$$\text{DetMicronPerAdc\_SX} = 140 \times \frac{89.1}{80} = 155.9$$

10. Enter the correct value for the **DetMicronPerAdc_SX** parameter in your table.

11. Repeat Steps 7 through 9 for the y axis. This time, if you ask the software to measure the distance between 10 grid lines along the y axis and it produces an incorrect measurement, then you need to use Equation 1 to calculate a new value for the **DetMicronPerAdc_SY** parameter.

12. Enter the correct value for the **DetMicronPerAdc_SY** parameter in your table.

You should now have values recorded in your table for both of the xy detector calibration parameters—**DetMicronPerAdc_SX** and **DetMicronPerAdc_SY**. Next, you will enter these values into the scanner calibration parameter file.

Editing the Scanner Calibration File:

1. From the Move mode window, use the z direction pad to withdraw the tip from the sample.

2. Turn off the probe head by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

3. Select Calibration Edit from the Setup menu. Click [Yes] in the Warning box to indicate that you want to proceed.

4. Select the Scanner Det category in the left listbox.

5. Select the calibration parameter whose value you would like to change. For example, select **DetMicronPerAdc_SX**.

6. Change the value of the parameter by typing the new value into the textbox above the Calibration Values listbox. Be sure to press the `[Enter]` key after entering the new value so that the correction is recognized by the software.

7. Repeat Steps 5 and 6 for the **DetMicronPerAdc_SY** parameter.

8. Click [Done] to register the changes and close the dialog box.

You have completed calibration of the xy detector.

If you have a z height calibration sample, proceed with the next section and calibrate the z detector. If you do not want to calibrate the z detector, you can skip to the section “Auto Calibration of Detector Offsets and Scanner Sensitivity” and calibrate the detector offsets and the scanner sensitivity. Be aware, however, that the scanner sensitivity is calibrated using the ScanMaster detectors. If you do not calibrate the z detector, then calibration of the scanner sensitivity in the z direction will be limited to the accuracy of the default value of the z detector calibration parameter.

Calibrating the Z Detector

Calibrating the z detector means calibrating the z detector output signal with distance. The procedure is similar to that for calibrating the xy detector, except that you need to use a sample with a z step height of a known distance (a step-height standard) in place of the 9.9 µm grid sample.

Since the detectors are not affected by the range of volts to the scanner, this calibration procedure only needs to be performed in high-voltage mode.

1. Install a step-height standard in place of the 9.9 µm grid sample.

2. Select Input Configuration from the Setup menu, and add the Z Detector signal to the list of Selected signals in the box on the right side of the dialog box.

   Click OK to close the dialog box.

3. From the Image mode window, select the Z Detector signal from the drop-down list below the Oscilloscope Display.

4. Approach the sample, set scan parameters, and take a contact-AFM image as you normally do. Be sure that the step of known height on your sample is included in the image. In addition, scan across the step in the fast scan direction.

5. Once the image is complete, use the Line Analysis software tools (described in the Image Processing chapter of Part III of this User's Guide) to measure a known distance in the z direction on the image generated from the Z Detector signal.

6. Compare the measured distance value to the known distance value. If the distance produced by the software measurement tools is incorrect, then the z detector calibration value, **DetMicronPerAdc_SZ**, needs to be changed.

   The correct z detector calibration value is the existing value multiplied by the ratio of correct to measured distances:

$$\text{correct cal. value} = \text{existing cal. value} \times \frac{\text{correct distance}}{\text{measured distance}} \qquad (1)$$

   For example, if you ask the software to measure a distance that you know is 0.2 µm and it produces a value of 0.16 µm, and the existing **DetMicronPerAdc_SZ** value is -20, then you should change the value as follows:

$$\text{DetMicronPerAdc\_SZ} = -20 \times \frac{0.2}{0.16} = -25.0$$

7. Enter the correct value for the **DetMicronPerAdc_SZ** parameter in the table you created earlier for the three detector calibration parameters.

   Note: When the existing **DetMicronPerAdc_SZ** value is negative, be sure to retain the negative sign in entering any corrections.

Next, you will enter the corrected **DetMicronPerAdc_SZ** parameter value into the scanner calibration parameter file.

Editing the Scanner Calibration File:

1. From the Move mode window, use the z direction pad to withdraw the tip from the sample.

2. Turn off the probe head by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

3. Select Calibration Edit from the Setup menu. Click Yes in the Warning box to indicate that you want to proceed.

4. Select the Scanner Det. category in the left listbox.

5. Select **DetMicronPerAdc_SZ** from the list of calibration parameter values.

6. Change the value of the parameter by typing the new value into the textbox above the Calibration Values listbox. Again, be sure to retain a negative sign if the value is a negative number.

   Press the `[Enter]` key after entering the new value so that the correction is recognized by the software.

7. Click Done to register the change and close the dialog box.

You have completed calibration of the z detector. After the correction is made, the software should measure the step height correctly.

You are now ready to proceed with the auto calibration procedures.

Auto Calibration of Detector Offsets and Scanner Sensitivity

This section describes the auto calibration procedures for calibrating the detector offset and scanner sensitivity calibration parameters. Any sample, or no sample, can be used for the auto calibration procedure, as the procedure does not involve a sample.

Calibrating the detector offsets means measuring the voltage outputs from each detector when no voltage is applied to the scanner tube. If these values are non-zero, then the finite value read is entered as the detector offset value for a given direction. That value is used to correct all subsequent detector readings for that direction.

Calibrating the scanner sensitivity means calibrating the volts applied to the scanner tube with the distances that the scanner tube moves.

If the scanner has not been used much recently, you may want to exercise it for an extended period of time before initiating the scanner calibration routine. For example,

scan at full range for one or more hours. This “shakes out” residual strains in the scanner. Alternatively, you may choose to repeat the calibration procedure later after more extensive use of the scanner.

To initiate the software routine that calibrates the detector offsets and the scanner sensitivity, follow these steps:

1. From Move mode, lift the probe using the z direction pad. Contact between the probe and the sample should be avoided because the scanner will jerk and oscillate during the calibration procedure.

2. Turn off the probe head, if it is on, by either deselecting Head ON from the Mode menu or clicking the Head ON icon, .

3. Make sure you are in high-voltage mode by selecting High Voltage from the Mode menu.

4. Select Scanner Calibration from the Setup menu. This opens the Scanner Calibration dialog box.

   The top option button, “Calibrate detector offset only,” is selected by default. Click the middle option button to calibrate both the detector offset and the scanner sensitivity.

   Note: At some point you may wish to calibrate the detector offset parameters only. Select the top option button when this is the case.

5. Click the [GO] button.

   Note: If you wish to stop the procedure at any time, click the [Stop] button.

Calibrating both the detector offset and the scanner sensitivity calibration parameters takes about 20 minutes. When the procedure is complete, the calibration parameter values are written to the appropriate file, and the [Done] button is enabled.

6. Click the [Done] button to return to Move mode.

The above scanner calibration procedure, when performed in high-voltage mode, determines values for the detector offset and scanner sensitivity calibration parameters in high-voltage mode. Now, the procedure must be repeated to determine the values for these parameters in low-voltage mode:

7. Switch to low-voltage mode by selecting Low Voltage from the Mode menu.

8. Repeat Steps 4 through 6 above.

The detector offset and scanner sensitivity calibration parameters are now calibrated for both high and low-voltage modes.

Creating a Backup Scanner Calibration File

If you have completed the instructions of this section, then you have calibrated your 100 µm scanner and thus created a new calibration parameter file. Saving a backup copy of this file involves the following general procedures:

1. Create a special directory, **c:\scancal**, for backup files.
2. Create backup copies of the current scanner calibration parameter files and store them in **c:\scancal**.

Each time you perform a scanner calibration you automatically update the working scanner calibration parameter file. You should update the backup copy of this file in the **c:\scancal** directory at the same time in case the working file becomes corrupted.

The above-listed general procedures for file management are broken into detailed steps below. The directions assume you are using Windows 95.

1. Create the **c:\scancal** directory:
   a. From the Start menu, point to Programs and select Explorer. Open the **c:** drive.
   b. From the File menu, click New, then click Folder. This creates a new folder in **c:**. The label of the folder icon will be highlighted to indicate that it can be altered.
   c. Type **scancal** in the new folder icon label and press the `[Enter]` key.
2. Select the scanner calibration parameter file be copied: Using Windows Explorer, go to the folder **c:\psi\cal**. Identify the scanner calibration parameter file(s) you wish to copy. For example, you will most likely wish to copy the file for the scanner you most recently calibrated.

3. With the cursor on that file, click the *right* mouse button to open the right mouse button menu.

4. Copy the scanner calibration parameter file from **c:\psi\cal** to **c:\scancal**:
   a. Select Copy from the right mouse button menu.
   b. Move the cursor to the **c:/scancal** folder. Click the right mouse button again, and click Paste from the right mouse button menu.
   c. A copy of the selected scanner calibration parameter file will appear in the **c:/scancal** folder.

You have now created a backup copy of the scanner calibration parameter file.

Summary

This chapter described the procedures for calibrating both 5 µm and 100 µm scanners. The topics covered include the following:

- how the scanner works
- when to calibrate the scanner
- identification and definition of scanner calibration parameters that are involved in the scanner calibration process
- scanner calibration procedures

The scanner is an important part of your AutoProbe CP instrument. Understanding how it works and how it is calibrated helps to ensure that you are optimizing the performance of your instrument.