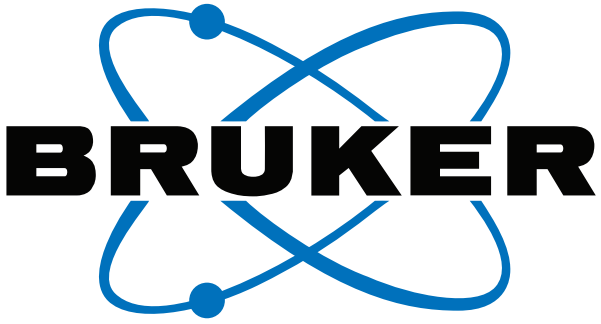

NanoScope Software 8.10

User Guide

004-1025-000

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Document Revision History: NanoScope 8.10 Manual

Revision	Date	Section(s) Affected	Ref. DCR	Approval
D	13-Jan.-2011	Rebranding		M. Wright
C	6-Jan.-2010	8.10 Updates		Vinson Kelley
B	19-May-2009	Dual monitor updates		Vinson Kelley
A	3-Mar.-2009	Initial release		Vinson Kelley
1	4-Feb.-2009	Pre-release draft		Vinson Kelley

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PeakForce™ QNM™
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Hardware Options:
TipX®
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Extender™
TipView™
Interleave™
LookAhead™
Quadrex™

Software Options:
NanoScript™
Navigator™
FeatureFind™

Miscellaneous:
NanoProbe®

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Chapter 1 New Features in NanoScope Software

1.1 New Features in NanoScope v8.10 Software

- MultiMode microscope support. See the *MultiMode V Instruction Manual NanoScope Software v 8*, Bruker p/n 004-1033-000 for details.
- ScanAsyst™ mode. Refer to your BioScope Catalyst, Dimension Icon or MultiMode 8 *Instruction Manual* for details.
- PeakForce™ QNM™ mode. Refer to the *PeakForce QNM User Guide*, Bruker p/n 004-1036-000, for details.
- Peak Force Tapping™ mode.
- NanoScope Data Analysis package.
- Adaptive XY scanning.
- Revised GUI.
- AutoScale function. See Page 108.

1.2 New Features in NanoScope v8.00 Software

- New workflow-oriented GUI.
- Dimension Icon and Dimension Icon-PI microscope support.
- BioScope Catalyst microscope support.
- NanoScope V-PI Controller support.
- Crash protection.
- Workspaces created before NanoScope version 8.00 can not be opened in NanoScope version 8.00. See **Older Workspaces Unsupported in NanoScope v7.30 and later:** Section 2.4.2.

1.3 New Features in NanoScope v7.30 Software

- Harmonic Force Microscopy (HarmoniX)—optional. See the *HarmoniX User Guide*, Bruker p/n 004-1024-000 for details.
- Offline Modify command Clean Image function. See **Clean Image:** Section 7.2.
- Offline Modify command Guassian function. See **Gaussian:** Section 7.6.
- Dimension Heater/Cooler Support. See Support Note 441, *Dimension Heater/Cooler*.
- Closed Loop Force Volume. See Page 146.
- 5K x 5K image is available on all 8 channels.
- Starting with NanoScope 7.30, older workspaces are not supported. See **Older Workspaces Unsupported in NanoScope v7.30 and later:** Section 2.4.2.
- Dark Lift. See *Application Modules NanoScope Software Version 7*, Rev. B or later, Bruker p/n 004-1020-000.

1.4 New Features in NanoScope v7.20r1sr1 Software

- EnviroScope STM and Electrochemistry support. See the *EnviroScope Using a NanoScope V Controller Instruction Manual*, Bruker part number 004-1008-000 and the *Electrochemical SPM NanoScope Software v7* manual, Bruker part number 004-1016-000.
- TR TUNA. See the *Applications Modules NanoScope Software v7* manual, Bruker part number 004-1020-000.
- Piezo Response improvements. See *Piezoresponse Atomic Force Microscopy Using a NanoScope V Controller User Guide*, Bruker part number 013-444-000 and the *NanoScope V Controller Manual*, Bruker part number 004-992-000, Revision E or later.
- MultiMode Closed Loop XYZ. See *MultiMode Closed Loop Scanner*, Bruker Support Note 013-431-000.
- Many other smaller features and bugs fixed. See the *Research 7.20 Release Notes*.

1.5 New Features in NanoScope v7.20r1 Software

1.5.1 Newly Supported Hardware

NanoScope v7.20r1 supports additional hardware. This includes:

- EnviroScope using a NanoScope V Controller.
- BioScope (SZ) using a NanoScope V Controller.
- MS10 dedicated STM.
- Serial communication for the Universal Bipotentiostat

See the appropriate manuals, *EnviroScope Manual, BioScope SZ Instruction Manual*, *Scanning Tunneling Microscope Operation Manual* and *Universal Bipotentiostat* for details.

1.5.2 Additional New Features

Additional new features, described in the NanoScope v7.20 release notes. These include:

- Pulse Counting
- Improved Width Offline function
- Spectrum 2D
- Nanoindentation
- Piezo response imaging. See the *NanoScope V Controller Manual* for information about this mode.
- Torsion TUNA (Tunneling Atomic Force Microscopy) imaging. See the *Applications Modules NanoScope Software v7* Manual and *Support Note 416*, *Revision H* or later, *TRmode NanoScope Version 7* for information about this mode.
- Offline feature **ROUGHNESS** revised.

1.6 New Features in NanoScope v7.10 Software

1.6.1 Newly Supported Hardware

NanoScope v7.10 supports additional hardware. This includes:

- Dimension 5000 microscope.

See the appropriate manual, *Dimension 5000 using a NanoScope V Controller Instruction Manual* for details.

1.6.2 Additional New Features

Additional new features, described in the NanoScope v7.10 release notes. These include:

- Recipes
- **CROP AND SPLIT** Offline View replaces **ZOOM**
- XY to Z Coupling with Ramp mode
- TIFF Export

1.7 New Features in NanoScope v7.00 Software

1.7.1 Newly Supported Hardware

NanoScope v7.0 supports new hardware. This includes:

- NanoScope V Controller.
- BioScope II.

See the appropriate manuals, *NanoScope V Controller Manual,* and *BioScope II User Manual* for details.

1.7.2 Windows XP Support

NanoScope v7.0 runs on Windows XP.

1.7.3 Additional New Features

Additional new features, described in the NanoScope v7.0 release notes and the *NanoScope V Controller Manual*, are included in this manual. These include:

- Eight channel support.
- High resolution imaging.
- Signal Access Software.
- Surface Potential Detection
- Generic Lock-In
- High Speed Data Capture
- Force Volume.

Chapter 2 Getting Started with NanoScope v8.10 Software

The focus of this manual is the NanoScope software version 8. It is a reference to the tasks related to your NanoScope system. The material provides an overview (i.e., theory and applications), procedures, interface definitions and optimization tips.

Refer to the following sections to begin to understand the NanoScope software:

- **Conventions and Definitions:** Section 2.1
- **Installing the NanoScope Software:** Section 2.2
- **Getting to Know NanoScope Software:** Section 2.3
- **NanoScope Version 8 Workspaces** Section 2.4
- **Quick Guide to an Image:** Section 2.5
- **Technical Support at Bruker:** Section 2.6

2.1 Conventions and Definitions

- In the interest of clarity, certain nomenclature is preferred. An SPM *probe* is comprised of a *tip* affixed to a *cantilever* mounted on a *substrate*, which is inserted in a *probe holder*.
- Three font styles distinguish among contexts. For example:
  Window or Menu Item / **BUTTON OR PARAMETER NAME** is set to **VALUE**.
- NSV is used to refer to a NanoScope V Controller. NSV-PI is used to refer to a NanoScope V-PI Controller.

2.2 Installing the NanoScope Software

2.2.1 System Requirements

CAUTION: Contact Bruker Technical Support (see **Contact Information** Section 2.6.2) before attempting to increase the RAM of your system. Failure to do so could cause irreparable damage to your system.

The 8.0 version of NanoScope software requires the following:

- A minimum computer configuration of a Quad Core 2.4GHz CPU or a Dual Core 2.0GHz CPU (NanoScope V-PI Controller)
- 4GB RAM
- GeForce 8600GT or 9400GT 512MB video card

2.2.2 Before You Install

CAUTION: Ensure you have backed up all critical data onto external media before installing the NanoScope 8.00 software.

1. If you are upgrading from a previous version of NanoScope, ensure you are starting with a working version. The settings from the working version will be used for the new version.
2. Note that some of the installation screen views may not appear, or may appear slightly different, depending on your particular system configuration.
3. Ensure you are logged in as Administrator on the local workstation.

2.2.3 NanoScope 8.00 Installation

Note: Most systems are configured on the microscopes prior to delivery.

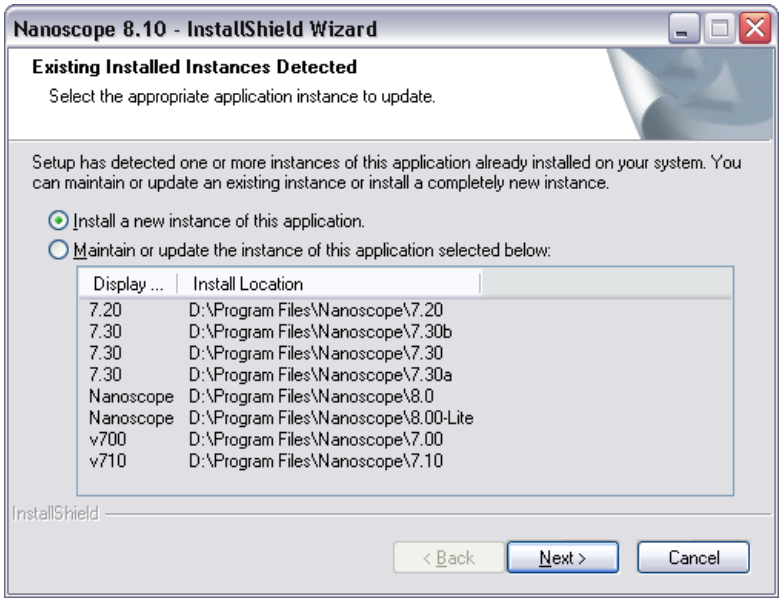
1. Insert the NanoScope 8.00 CD-ROM in your CD drive, open the CD-ROM files, open the v8.00 folder, and select the **Setup.exe** icon. NanoScope V-PI users will need to append the argument "- InstallNSVLite" to the install command.

If you do not have Administrator privileges on your workstation, a WARNING will appear on the screen and installation will discontinue (see Figure 2.2a).

Figure 2.2a Administrator Warning

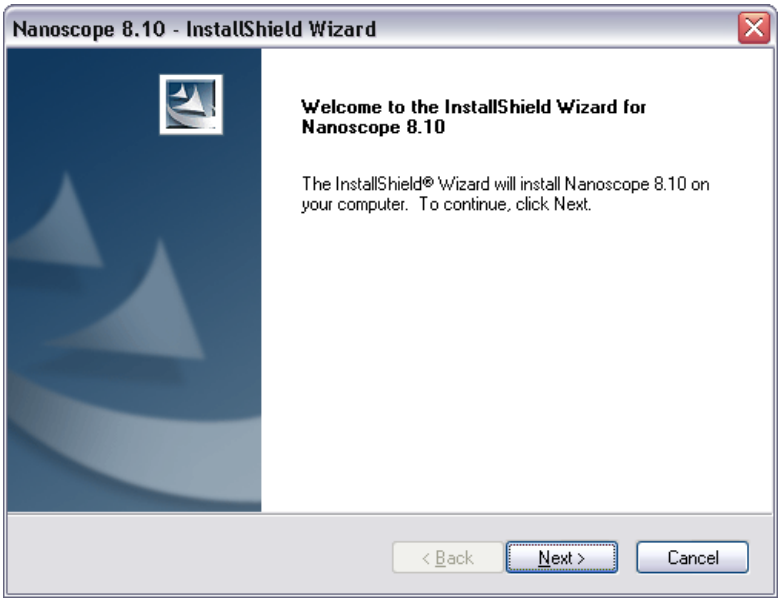
2. If you have an existing instance of NanoScope software, the message shown in Figure 2.2b will appear. Check the appropriate radio button and click **NEXT**.

Figure 2.2b Welcome to NanoScope 8 Dialog Box



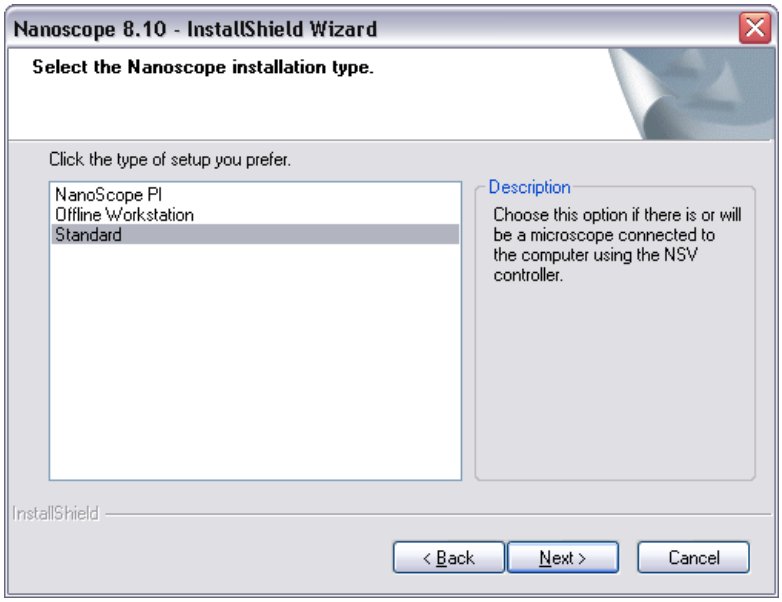
3. The **Welcome to the InstallShield Wizard for NanoScope 8.10** dialog box will open (see Figure 2.2c). Click **NEXT**.

Figure 2.2c Welcome to NanoScope 8 Dialog Box



4. After accepting the license agreement, the **Installation Type** dialog box will open (see Figure 2.2d). Click **NEXT**.

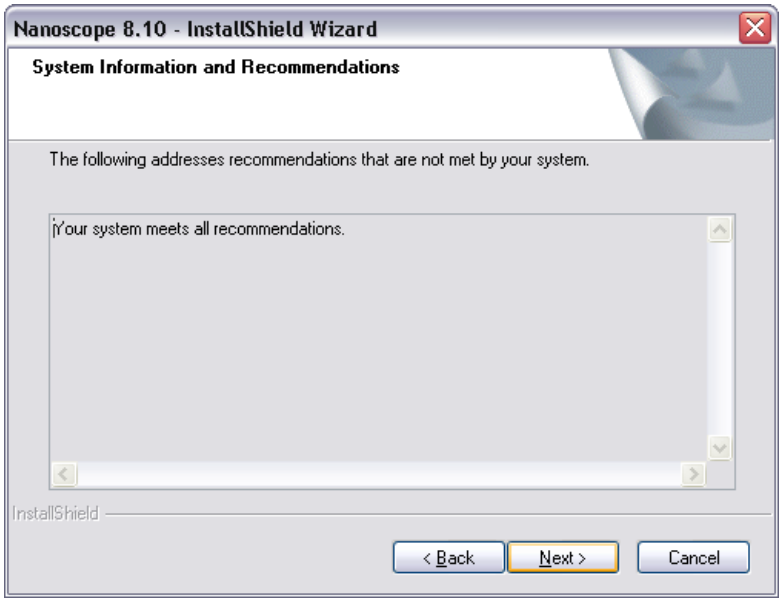
Figure 2.2d Installation Type Dialog Box



5. Select **STANDARD** and click **NEXT**.

6. Install Shield then checks your system and, if needed, makes recommendations. See Figure 2.2e.

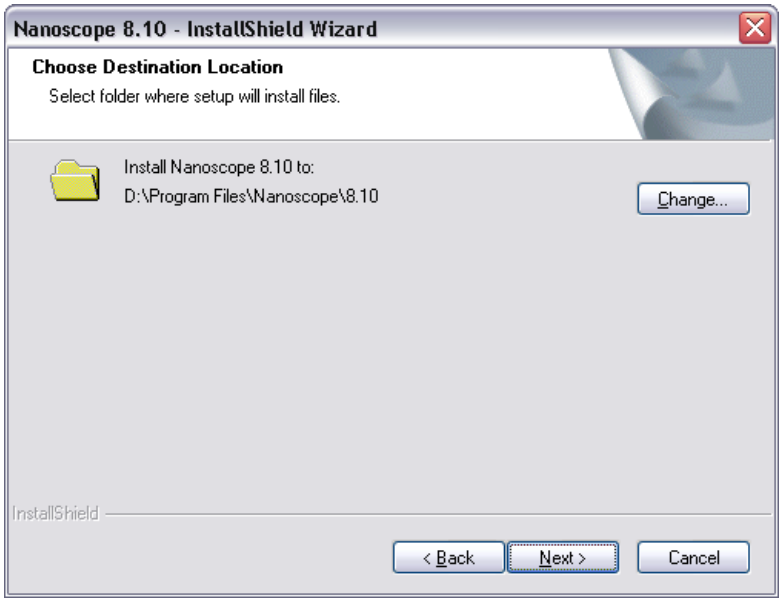
Figure 2.2e System Information and Recommendations Dialog Box



7. Click **NEXT**.

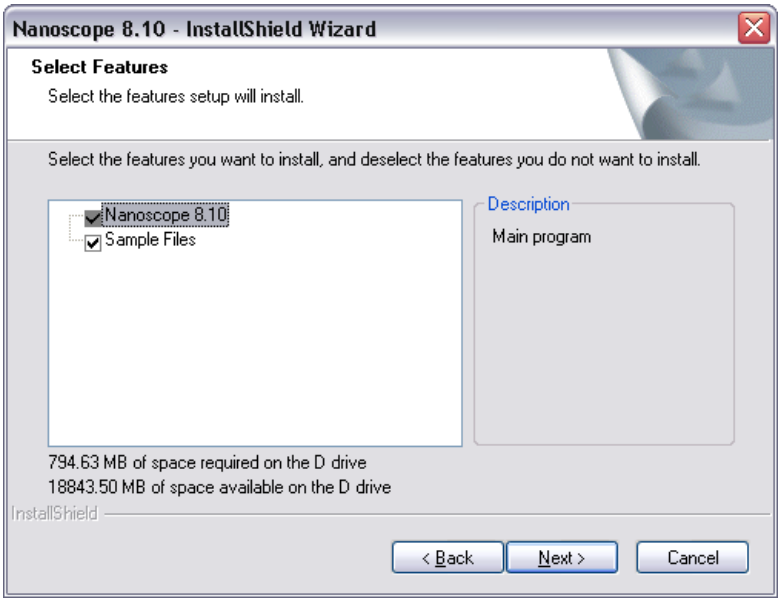
8. After choosing a destination location (see Figure 2.2f), click **NEXT**.

Figure 2.2f Destination Location Dialog Box



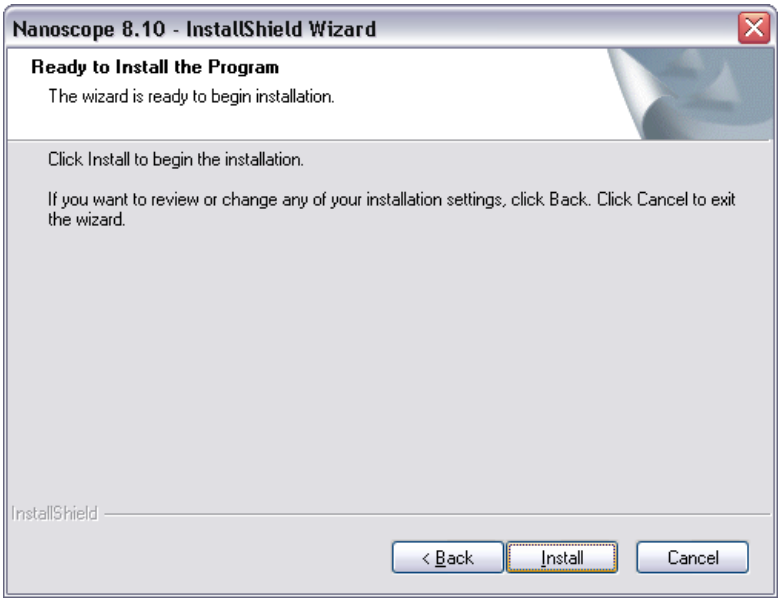
9. Select the features you wish to install (see Figure 2.2g) and click **NEXT**.

Figure 2.2g Select Features Dialog Box



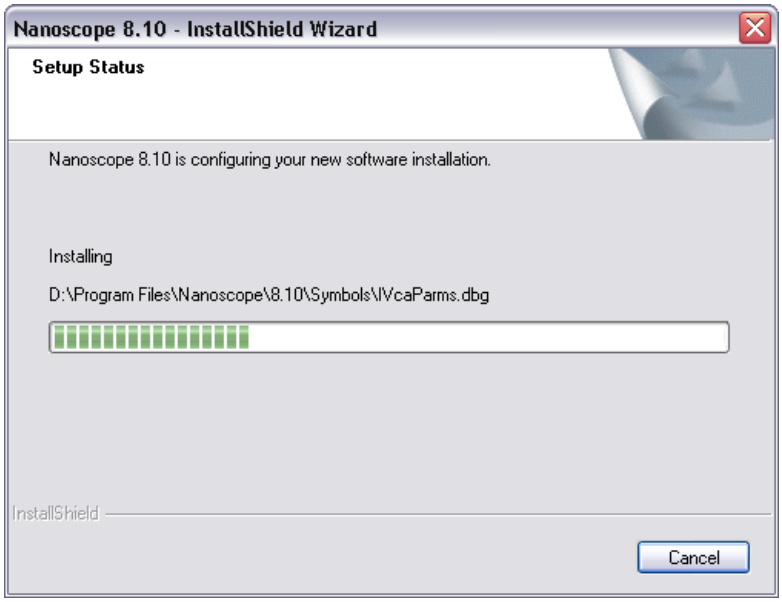
10. The **Ready to Install** dialog box will display:

Figure 2.2h Ready to Install Dialog Box



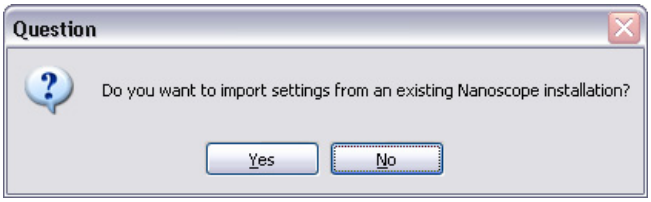
11. Click **INSTALL**. Installation of the NanoScope V8.00 software will then continue. A progress box, shown in Figure 2.2i, appears:

Figure 2.2i Progress Dialog Box



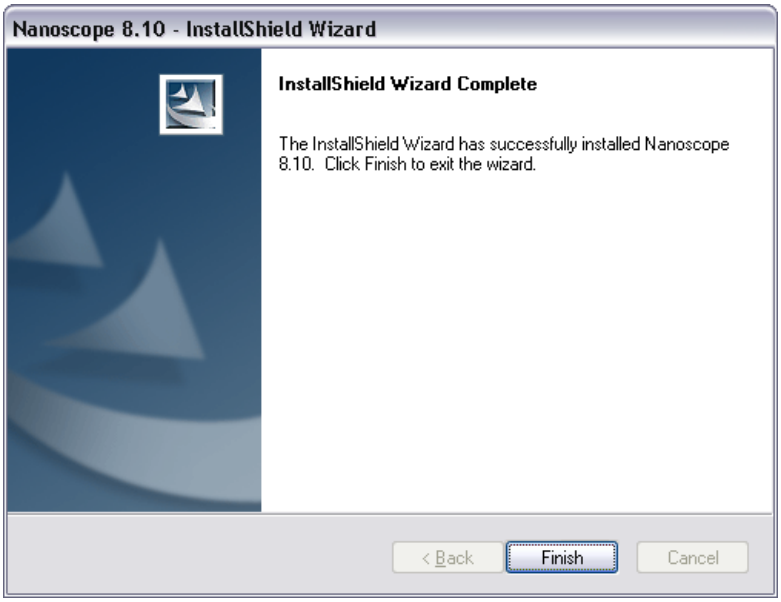
12. Click Yes to import setting, including calibration files from an existing NanoScope software installation. See Figure 2.2j.

Figure 2.2j Import settings dialog box



13. When the NanoScope V8.10 installation is complete, the dialog box shown in Figure 2.2k will appear.

Figure 2.2k Installation Complete Dialog Box



14. Click **FINISH** to complete the installation.

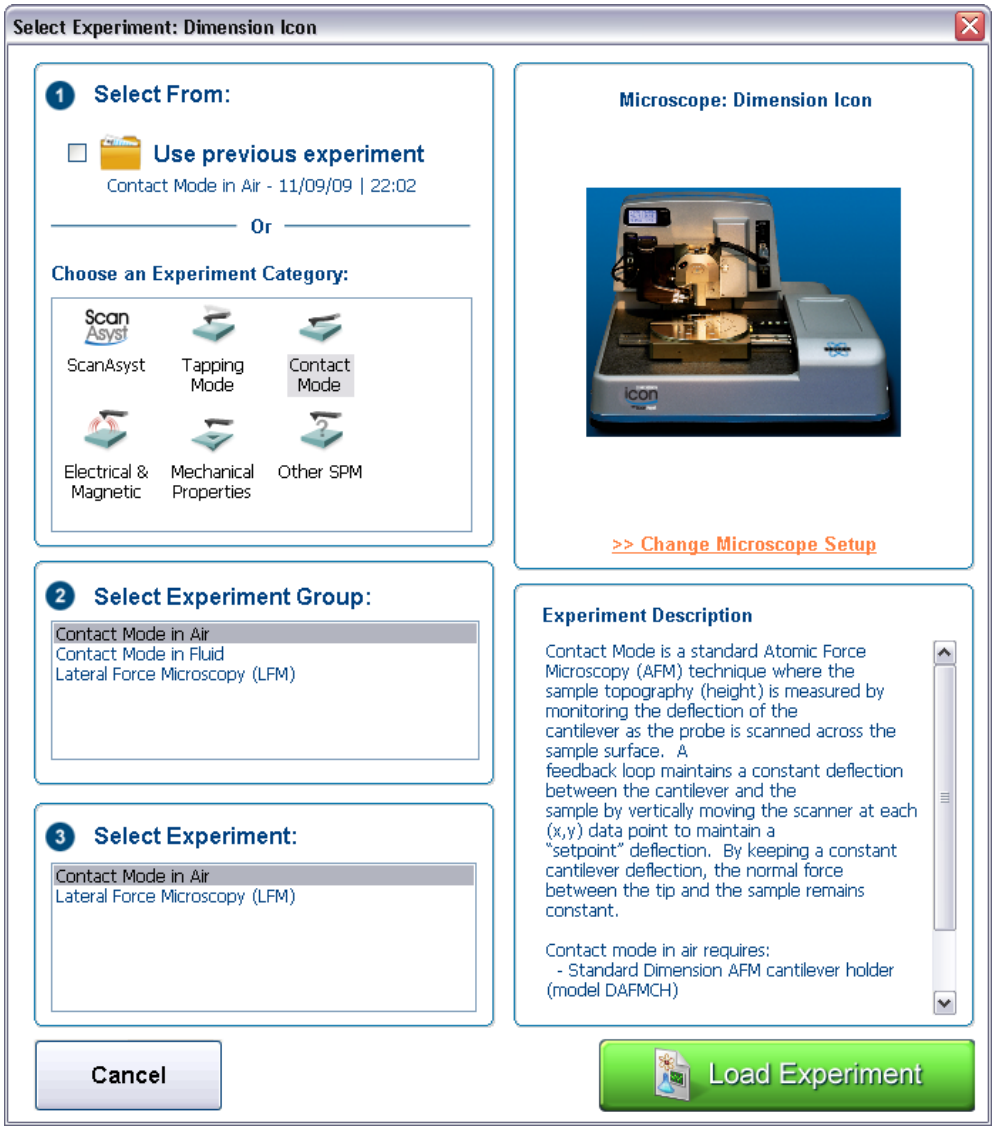
2.3 Getting to Know NanoScope Software

Start the NanoScope software by double-clicking on the desktop shortcut labeled **NanoScope 8.10**.

2.3.1 Software Interface

NanoScope version 8 software is organized by experiment type. Click **EXPERIMENT** > **SELECT EXPERIMENT** or the **SELECT EXPERIMENT** icon in the top left of the NanoScope software window. This opens the **Select Experiment** window, shown in Figure 2.3a.

Figure 2.3a The **Select Experiment**, Contact Mode, window



The **Select Experiment** window forms the basis of the NanoScope version 8 user experience. Your experiment choice configures the **Scan Parameters** and, if necessary, the **Ramp Parameters** needed to run that experiment. This was done to simplify and make NanoScope software more intuitive and easier to use. That said, all functions from versions 6 and 7 remain accessible.

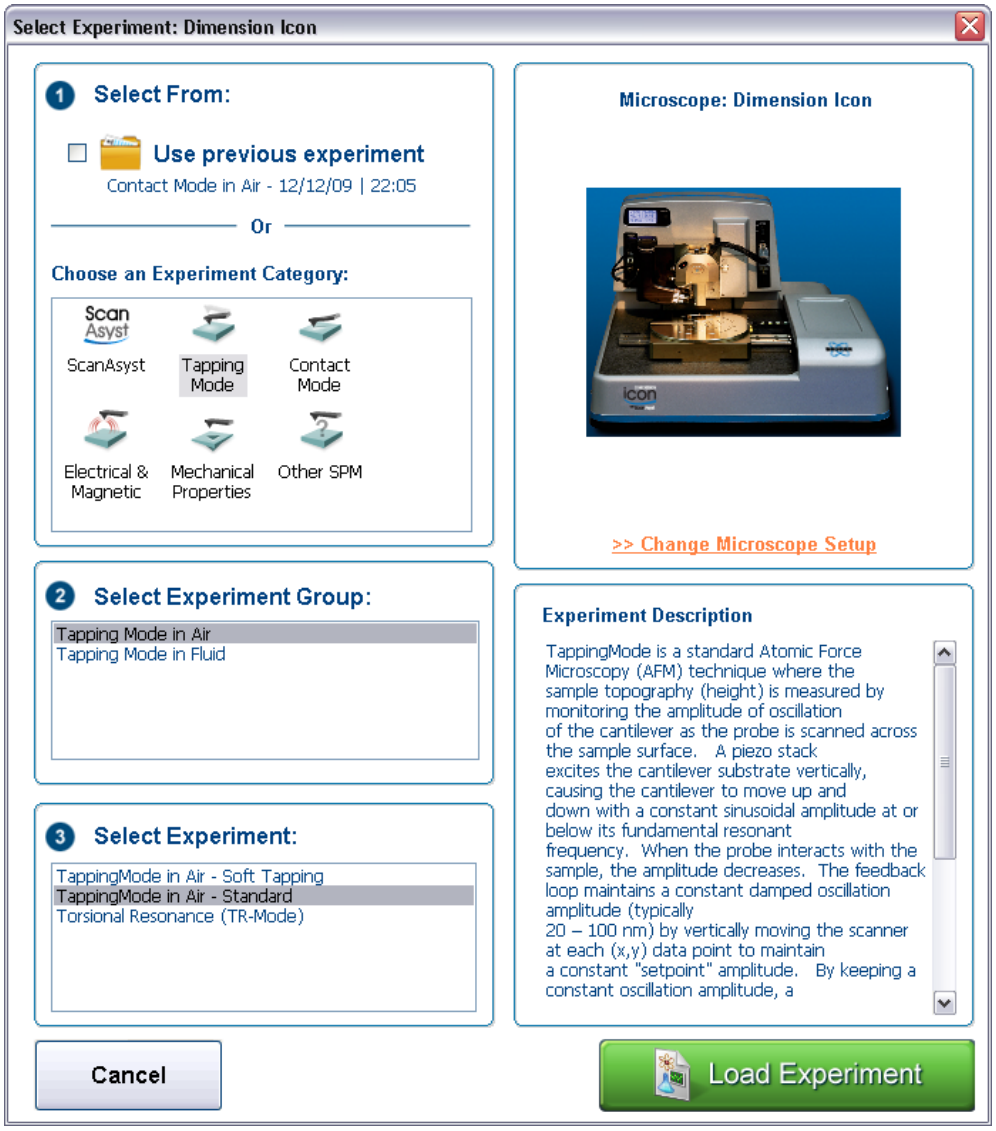
In addition to the **Scan Parameters List** and the **Ramp Parameters List**, **Select Experiment** also configures the **Workflow Toolbar**. The workflow toolbar, shown in Figure 2.3f, guides you through the experiment.

NanoScope software contains two modes of operation: **Realtime** (i.e., all operations related to controlling the microscope) and **Image Processing** or **Offline** (i.e., analysis and manipulation of captured images). In previous versions of NanoScope software, these modes were separate work environments. With versions 6, 7 and 8, both work environments have been combined.

2.3.2 The Select Experiment Window

Use of the **Select Experiment** window, shown in Figure 2.3b, is described below.

Figure 2.3b The **Select Experiment**, TappingMode, window



The Experiment Category Window

Highlight the **Experiment Category** that you wish to select in this window.

The Experiment Group Window

Highlight the **Experiment Group** that you wish to select in this window.

The Experiment Window

Highlight the **Experiment** that you wish to select in this window.

Description

A brief experiment **Description** is shown in this window.

Load Experiment

Click **LOAD EXPERIMENT** to begin real-time microscope operation.

Open Previous

Your previous experiment is saved in the **Previous Experiment** window. Click **OPEN** to start that experiment.

Change Microscope

Click **CHANGE MICROSCOPE** to open the **Microscope Select** window, discussed in Section 2.5.1, that allows you to select a new microscope or new microscope features.

Cancel

Click **CANCEL** to close the **Select Experiment** window and continue to use the existing **Scan** and **Ramp Parameters**.

2.3.3 Single Monitor and Dual Monitor GUIs

NanoScope version 8 software supports, depending on the microscope, one large (30 in., 2560 x 1600 pixels) single monitor (Dimension Icon and BioScope Catalyst) or two smaller (19 in., 1280 x 1024 pixels) dual monitors (Dimension Icon-PI). The larger area of the single monitor allows for a fixed window configuration, shown in Figure 2.3c. Because of reduced screen area, the image window in the dual monitor GUI, shown in Figure 2.3d, is smaller and displays at most two channels simultaneously. All windows in the dual monitor GUI may be resized or closed using standard Windows icons.

2.3.4 The Main Screen Elements

Workflow Toolbar	The left pane in the NanoScope window. The Workflow Toolbar sequentially organizes the steps (work) needed to perform your experiment.
Client Window	A central window for viewing all Realtime and offline graphical displays, input parameters, results parameters and graphs.
Menu Bar	A group of items for executing commands or viewing files.
Toolbar	A group of icons for executing commands or viewing dialog boxes to configure input parameters.
Scan Parameter List	A list of the available scan parameters.
Status Bar	A read only list that displays the stage X, Y, Z coordinates and enabled functions (e.g., Capture: On).
RealTime Status Window	A dockable window in the client window displaying information about the Z piezo position.
Browse Window	A dockable window in the client window for browsing files. Available in list or thumbnail format.
Image Window	Windows that graphically display the 2D scan results.
Image Thumbnails	Highlight a thumbnail to view that channel in the selected image window.
Scope Window	Windows that display a real-time plot of the channel signal.
Video Window	Displays the video camera image.
Engage Status Window	Window that prominently displays the engage status

Figure 2.3c NanoScope Version 8 Screen Elements—single monitor

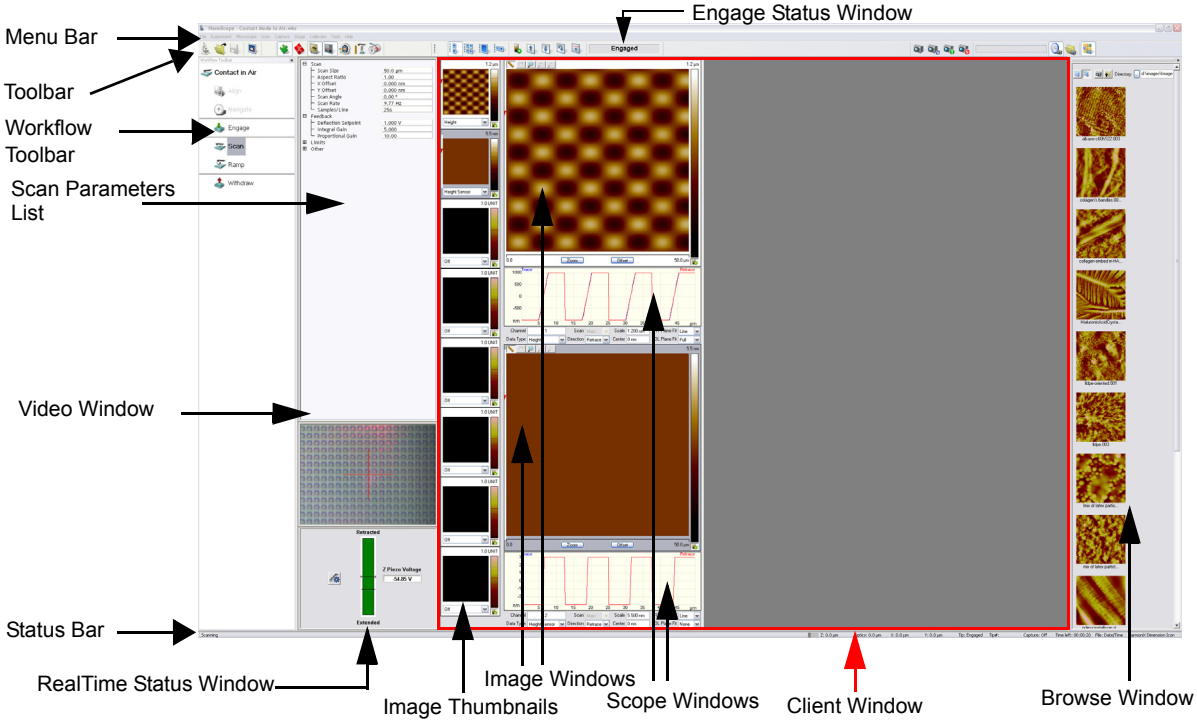
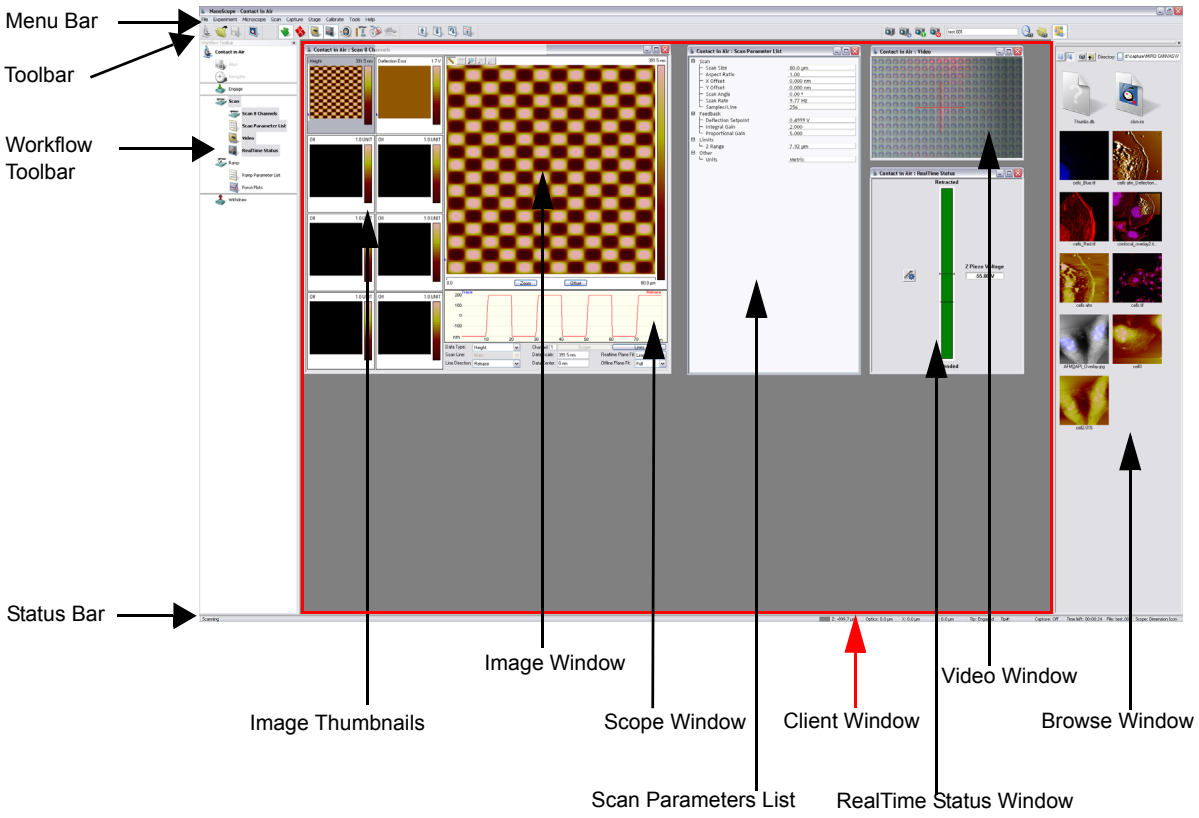


Figure 2.3d NanoScope Version 8 Screen Elements—dual monitor



2.3.5 Menu Bar Items

The initial menu bar includes: **File**, **Experiment** and **Help** to begin the process of initializing and opening files in the client window. Once an experiment (workspace) is open, an expanded toolbar exists for running and configuring the microscope to scan or process images.

The menu items include:

- **File**—Accesses menu selections for opening, saving and printing files and documents.
- **Experiment**—Accesses menu selections allowing you to select and save experiments.
- **Microscope**—Accesses menu selections to administer commands during data collection.
- **Scan**—Re-starts the scan from the chosen location.
- **Capture**—Accesses menu selections that allow you to capture (save) images.
- **Stage**—Accesses menu selections that control stage movement.
- **Calibrate**—Accesses menu items for calibrating various settings.
- **Tools**—Accesses menu items for selecting various settings.
- **Help**—Accesses menu items for initializing and displaying the help screen, Technical Support contact information, probe purchase information and NanoScope information about your system.

2.3.6 Toolbar Items

The NanoScope version 8 toolbar, shown in Figure 2.3e, is described in Table 2.3a, Table 2.3b, Table 2.3c Table 2.3d, Table 2.3f and Table 2.3g.

Figure 2.3e The NanoScope 8 Toolbar—single monitor

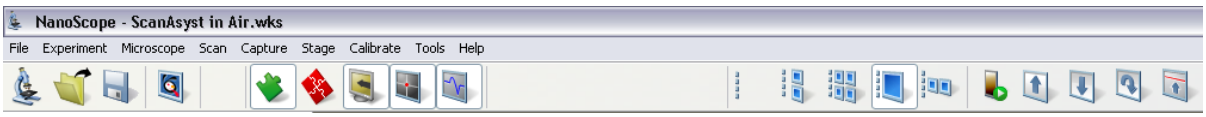


Table 2.3a NanoScope version 8.00 Toolbar menu

 **Select Experiment**	**SELECT EXPERIMENT** configures the **Scan** and **Ramp Parameters** needed to run an experiment. **SELECT EXPERIMENT** also configures the **Workflow Toolbar**.
 **Open**	Opens NanoScope files.
 **Save Experiment**	Saves the NanoScope Workspace.
 **MIRO**	Opens the (optional) MIRO (Microscope Image Registration and Overlay) package. See the *MIRO User Guide*, Bruker p/n 004-1027-000 for more information.
 **Simple Mode**	Makes only essential scan or ramp parameters visible, making operation simpler for Dimension SPM users.
 **Expanded Mode**	Increases the number of visible scan, ramp and channel parameters for more advanced applications.
 **Video**	Turns the video (camera) window on and off.
 **Real Time Status**	Turns the real time status window on and off.
 **Point and Shoot**	Opens the **Point and Shoot** window. See Section 3.1.4 and Section 3.8.4 for more information.
 **High Speed Data Capture**	Opens the High Speed Data Capture window. See Section 3.8 for more information.
 **Thermal Tune**	Opens the **Thermal Tune** window. See the *NanoScope V Controller Manual*, Bruker p/n 004-992-000.
 **HarmoniX**	Opens the HarmoniX window. See the *HarmoniX User Guide*, Bruker p/n 004-1024-000 for more information.

Note: The availability of some functions depends on the microscope model. E.g. High Speed Data Capture, ScanAsyst and HarmoniX are not available on the Dimension Icon-PI. MIRO, is available on only the BioScope V and BioScope Catalyst.

Table 2.3b NanoScope version 8 single monitor scan layout toolbar icons

 **Thumbnails Only**	Shows 8 thumbnails only.
 **Two Channels Down**	Displays 8 thumbnails and two channels, arranged vertically.
 **Four Channels**	Displays 8 thumbnails and four channels.
 **One Channel**	Displays 8 thumbnails and one, large, channel.
 **Two Channels Across**	Displays 8 thumbnails and two channels, arranged horizontally.

Table 2.3c NanoScope version 8 scan controls toolbar icons

 **AutoScale**	Automatically scales the vertical axis. Refer to **AutoScale,** page 108 for details.
 **Frame Up**	The **Frame Up** command restarts the Realtime scan at the bottom of the frame. It is an easy way to begin to view an entire Realtime frame from the bottom. By clicking on this button, the Realtime scan restarts and moves up at the bottom of the frame. This allows you to go directly to the start of the frame and not have to wait for the previous frame to end.
 **Frame Down**	The **Frame Down** command restarts the Realtime scan at the top of the frame. This allows you to go directly to the start of the frame and not have to wait for the previous frame to end.
 **Frame Reverse**	Reverses the vertical scan direction from the existing location.
 **Skip to Line**	Restarts the scan at a user-specified line.

Table 2.3d NanoScope version 8.00 single monitor ramp display toolbar menu

 **Plots Only**	Displays the ramp plots.
 **Plots and Controls**	Displays the ramp plots and ramp controls tabs.

Table 2.3e NanoScope version 8.00 ramp controls toolbar menu

 **Ramp Single**	Lowers and raises the probe tip *once* by a distance equal to the Z scan size, the halts.
 **Ramp Continuous**	The tip is continuously lowered and raised by a distance equal to the Z scan size. This is the normal, default motion during Force Calibrate.
 **Stop**	Halts all tip movement.
 **Single Approach**	The tip is lowered to the surface and raised in a single, controlled step. This process is halted if the surface is encountered by the tip, causing deflection exceeding the Step threshold amount. The resulting force curve is displayed.
 **Continuous Approach**	The tip lowers to the surface and raises in a controlled series of steps, then indexed by the Z step size (see Scan Mode panel) distance. This process continues downward until the tip encounters the surface. When tip deflection exceeds the Threshold Step amount, Continuous Approach halts and the resulting force curve displays.
 **Auto Ramp**	Begins auto ramping as defined by the parameters specified in the **Auto Panel**.
 **Update Sensitivity**	Updates the cantilever **Deflection Sensitivity**.

Note: For both **Continuous Approach** and **Single Approach**, if **Start mode** = **MOTOR STEP**, the motor is stepped towards the surface, not the Z piezo.

See **Force Curves** Section 3.3 for more information about ramp functions.

Table 2.3f NanoScope version 8.00 Capture Toolbar menu

 **Capture**	The **CAPTURE** command directs the software to save the next complete,uninterrupted frame to a file. A second click will force the software to save the next interrupted frame (i.e. - parameter changed).
 **Continuous Capture**	Continuously saves every fram until **WITHDRAW** or **ABORT CAPTURE** is selected.
 **Capture Now**	Immediately saves the current uninterrupted image before the frame is complete.
 **Abort Capture**	The **ABORT CAPTURE** command stops the capture process.
 **Capture Last**	Saves the last complete frame prior to the current frame.
 **Date and Time Stamp**	Sets the capture filename automatically using a date and time format.
 **Select Capture Directory**	Specifies the capture directory.

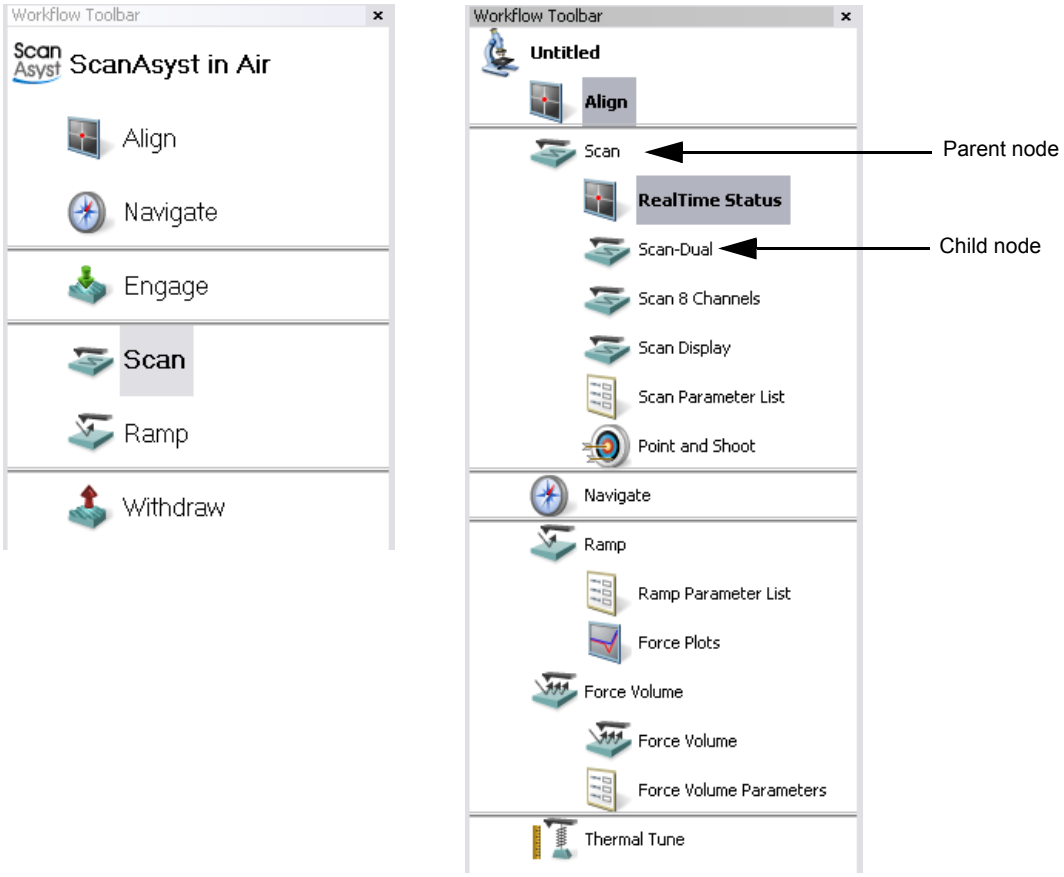
Table 2.3g NanoScope version 8.00 Browse Toolbar menu

 **Show/Hide Browse**	Displays the **Browse** window, shown in Figure 2.3c. See Chapter 4 for more information.

2.3.7 The Workflow Toolbar

The **Workflow Toolbar**, shown in Figure 2.3f, provides you with the steps, sequentially ordered, to run your experiment.

Figure 2.3f The **Workflow Toolbar**. Single monitor (left) and dual monitor (right)



Workflow Toolbar items are briefly described in Table 2.3h. Active function names are highlighted in the **Workflow Toolbar**.

Table 2.3h NanoScope **Workflow Toolbar** menu

 **Experiment**	The name of the type of experiment that you have selected. The icon displayed is a function of the experiment chosen.
 **Align**	Opens the **Align** window, described in Section 2.5.2.
 **Navigate**	Opens the **Navigate** window, described in Section 3.1.2.
 **Tune**	Opens the **Tune** window, described in Section 3.1.5.
 **Engage**	The **Engage** command brings the tip into contact with the sample surface and starts the Realtime imaging process.
 **Scan**	Scans the probe tip over the sample, producing an image. Additional information can be found in Section 3.1.
 **Ramp**	Opens the Ramp Parameter List, the ramp plots window and, if requested, the ramp controls window. Additional information can be found in **Ramp Panel** Section 3.3.3.
 **Force Volume**	Opens the **Force Volume Parameter List** and the Force Volume GUI. Additional information can be found in **Force Volume** Section 3.4.
 **Withdraw**	The **Withdraw** command stops the scanning process and withdraws the tip from the surface.
 **Generic Sweep**	Opens the **Generic Sweep** window, described in Section 3.7.2.

Nodes

The NanoScope dual monitor GUI retains the concept of nodes introduced in NanoScope 6. A top level node is known as the *parent node* and each node underneath is known as a *child node* (see Figure 2.3f). Parent nodes are usually the name for the microscope mode (e.g., Scan) or a file name of an image within the workspace. Parent nodes are the higher level nodes for auto programs. Child nodes, also known as "views," are typically associated with a window that is used to carry out an analysis, image processing, or Realtime control function of the software.

Each node may be renamed, deleted and grouped. Node names may be preceded by an icon and/or lines indicating the relative positions of nodes in the hierarchy. Table 2.3i lists the available NanoScope dual monitor child nodes.

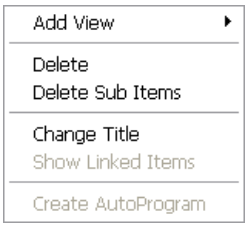
Table 2.3i NanoScope dual monitor **Workflow Toolbar** child nodes

Scan Dual	Scans the probe tip over the sample and displays images of 2 channels. Additional information can be found in Section 3.1.
Scan 8 Channels	Scans the probe tip over the sample and displays an image of one channel and 8 thumbnails. Additional information can be found in Section 3.1.
Scan Parameter List	Opens the **Scan Parameter List**. Additional information can be found in **Scan and Ramp Parameter Lists:** Section 2.3.8 and **Scan Panel Interface:** Section 3.1.9.
Ramp Parameter List	Opens the Ramp Parameter List. Additional information can be found in **Scan and Ramp Parameter Lists:** Section 2.3.8 and **Ramp Panel** Section 3.3.3.
Force Plots	Opens the **Force Plots** window and starts Force mode. Additional information can be found in **Ramp Panel** Section 3.3.3.
Force Volume Parameters	Opens the **Force Volume Parameter List**. Additional information can be found in **Force Volume** Section 3.4.

Functions Menu

The **Functions** menu, shown in Figure 2.3g, is accessed by right-clicking on a parent node (i.e., Scan, Ramp or a filename). It includes specific elements for viewing multiple windows, renaming views, grouping views, and adding and deleting views. This menu also includes the command for running an Auto Program (i.e., **Run AutoProgram**) where the image processing commands may be run in a series on multiple images and results may be saved in a data file.

Figure 2.3g Functions Menu



Menu Items

Add View Accesses a submenu of Realtime or offline commands.

Delete Deletes the currently selected node in the workspace. If changes were made, a prompt appears to save the view.

Delete Sub Items Deletes the items listed under the currently selected node in the workspace. If changes were made, a prompt appears to save the view.

Change Title Allows for the selected view title to be changed.

Show Linked Items

Create Auto Program Allows you to create a new Auto Program based on analysis done on a node.

Edit AP Attributes If the currently selected node is in Auto Program, this parameter allows you to edit the Auto Program properties.

Run Auto Program Accesses the Auto Program Results view to run the selected image processing commands.

Functions Submenu

The **Functions** submenu allows for adding new views to the workspace in the **Add View** command (see Figure 2.3h).

Figure 2.3h Functions Submenu

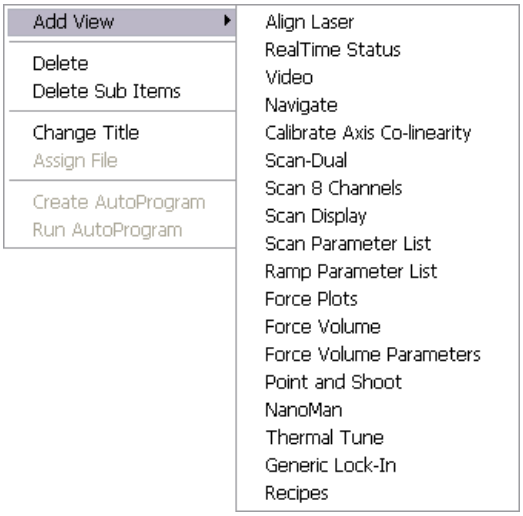
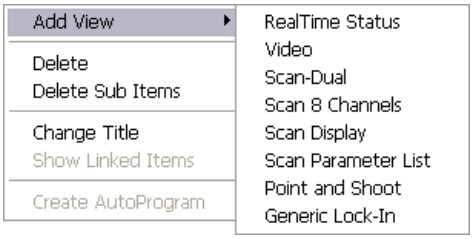


Figure 2.3i Scan Workspace Functions Submenu



Functions Submenu Items

The **Add View** submenu includes commands for running the microscope, analyzing and reporting. Selecting a command adds the item name and icon as a new child node to the workspace window. Click on a node to invoke the view in the client window.

Depending upon the microscope type and mode (i.e., Realtime and Image Processing), each workspace has unique commands in the **Add View** submenu. For the Realtime functions **Add View** submenu, see Figure 2.3i. For more detailed descriptions about the views, see Chapter 3.

2.3.8 Scan and Ramp Parameter Lists

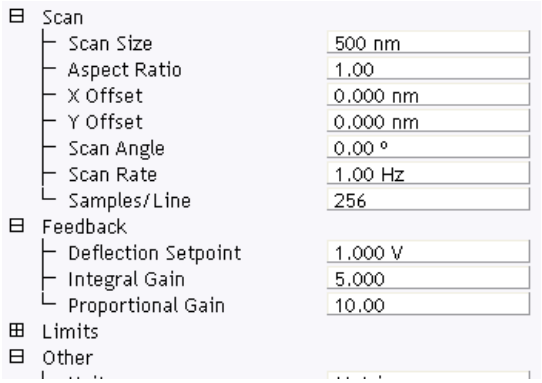
The Scan and Ramp Parameter Lists display the user-configurable (depending on options) scan and ramp parameters relevant to your experiment type.

Simple Mode

You can adjust the number of parameters shown in the **Scan Parameter List** using several methods.

1. The default **SIMPLE MODE**, shown in Figure 2.3j, displays the essential parameters needed to make an image.

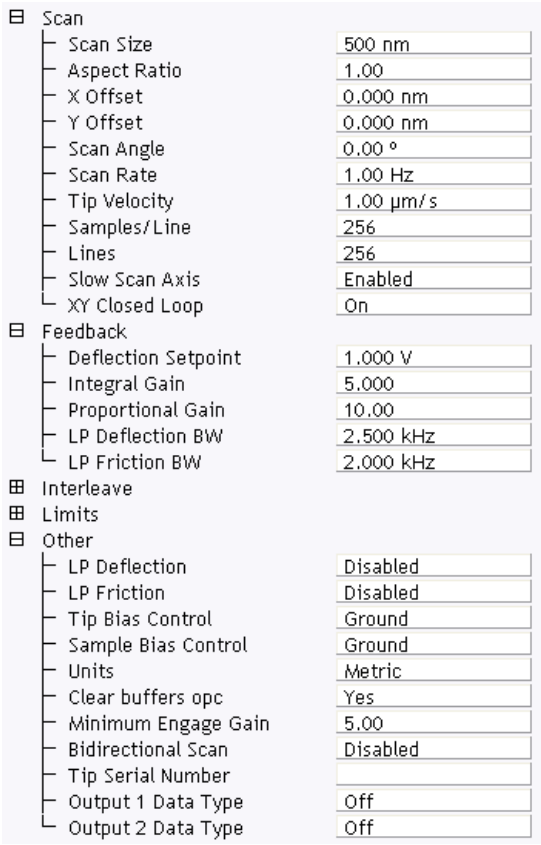
Figure 2.3j The **SIMPLE MODE** view of the **Scan Parameter List** in **Contact Mode**



Expanded Mode

1. The **EXPANDED MODE** view, shown in Figure 2.3k, increases the number of displayed parameters, providing access to more advanced options.

Figure 2.3k The **EXPANDED MODE** view of the **Scan Parameter List** in **Contact Mode**

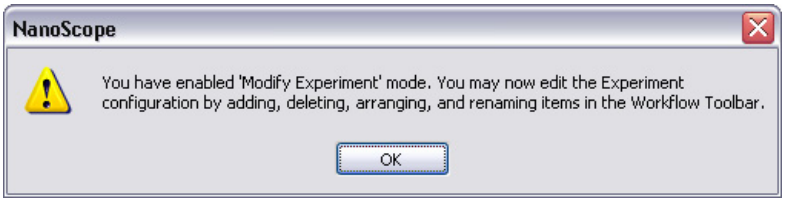


More advanced **Scan Parameter List** views are discussed below.

Show All

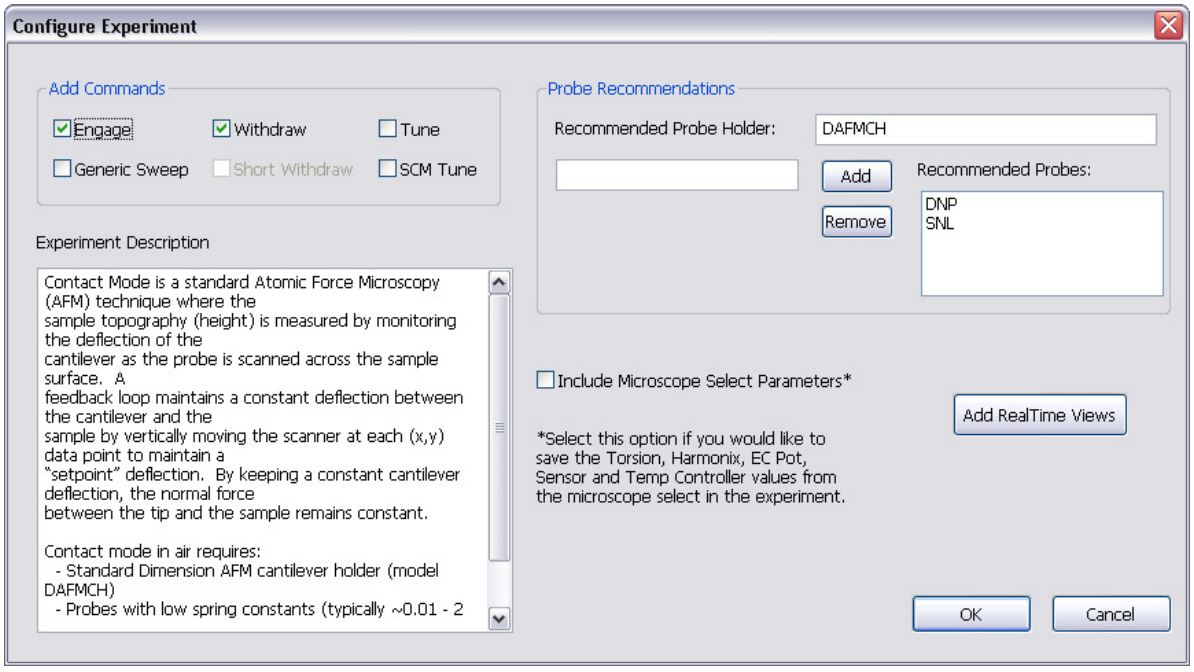
1. From the Menu bar, click **EXPERIMENT** > **CONFIGURE EXPERIMENT**. This opens an information window, shown in Figure 2.3l.

Figure 2.3l The Configure Experiment information window



2. Click **OK** to open the **Configure Experiment** window, shown in Figure 2.3m.

Figure 2.3m The **Configure Experiment** Window

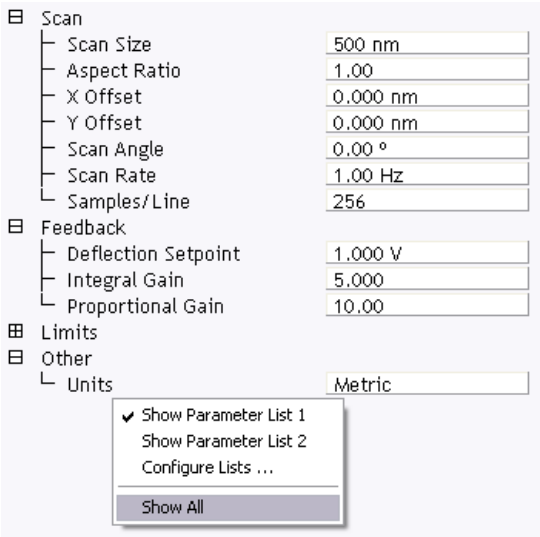


3. Check a box in the **Add Commands** panel to add that command to the **Workflow Toolbar**.

4. Click **OK** to accept your choices and close the **Configure Experiment** window.

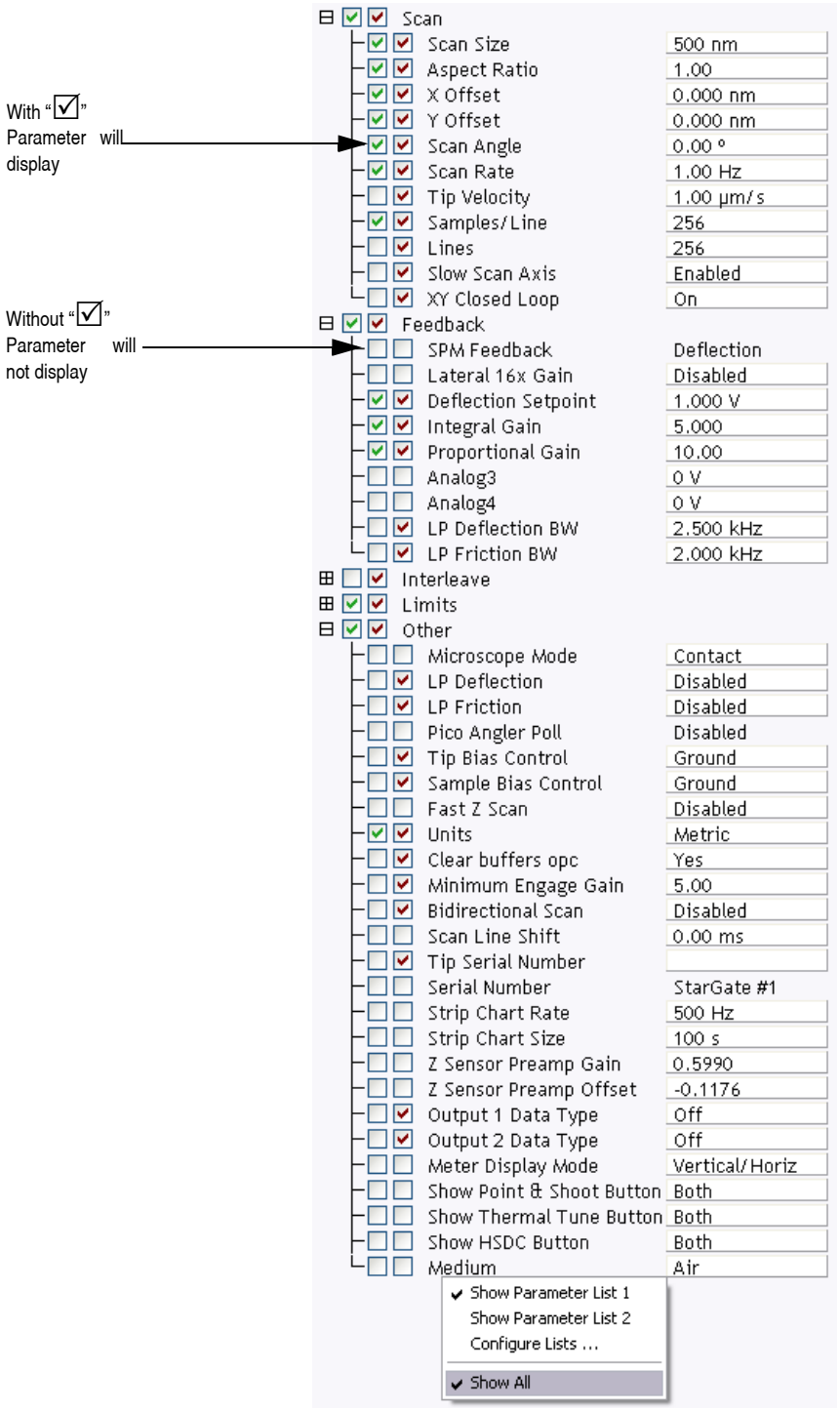
5. Right-click in the **Scan Parameter List** and select **SHOW ALL**, shown in Figure 2.3n.

Figure 2.3n Select **SHOW ALL** items



This makes all **Scan Parameters** visible along with two check boxes, the left, green, check box for the **SIMPLE MODE** and the right, red, check box for the **EXPANDED MODE**. See Figure 2.3o.

Figure 2.3o Enable Parameters



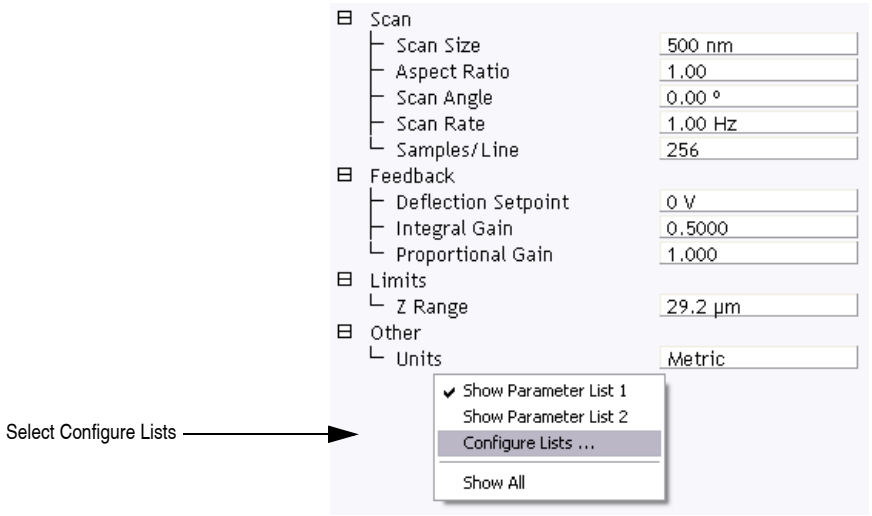
The checked ☑ parameters display in normal Real-time mode while those parameters without a ☑ will not display in normal Real-time mode.

Check the parameters that you want displayed and right-click in the **Scan Parameter List** and select **SHOW ALL** items to hide the unchecked parameters. The panel will once again appear in normal Real-time mode.

Configure Lists

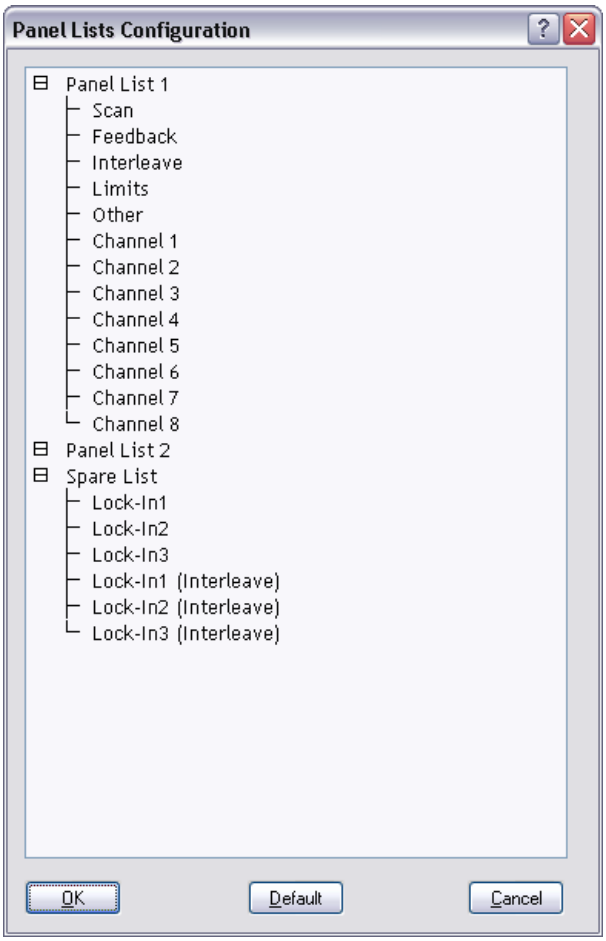
1. Right-click in the **Scan Parameter List** and select **CONFIGURE LISTS**, shown in Figure 2.3p.

Figure 2.3p Select **SHOW ALL** items



This opens the **Panel Lists Configuration** window, shown in Figure 2.3q.

Figure 2.3q The **Panel Lists Configuration** window



2. Drag an item from the **Spare List** to either **Panel List 1** or **Panel List 2** and click **OK**.

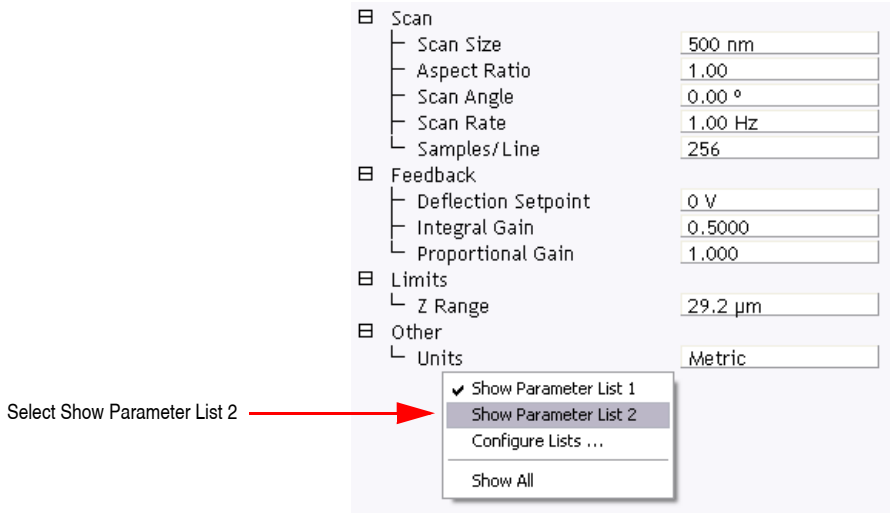
This adds selected items to the **Scan Parameter List**.

The **SHOW ALL** function works in the **Panel Lists Configuration** window the same way that it works in the **Scan Parameter List** window.

Show Parameter List 2

A second Scan **Parameter List** can be made visible by right-clicking in the Scan **Parameter List** window and selecting **SHOW PARAMETER LIST 2**.

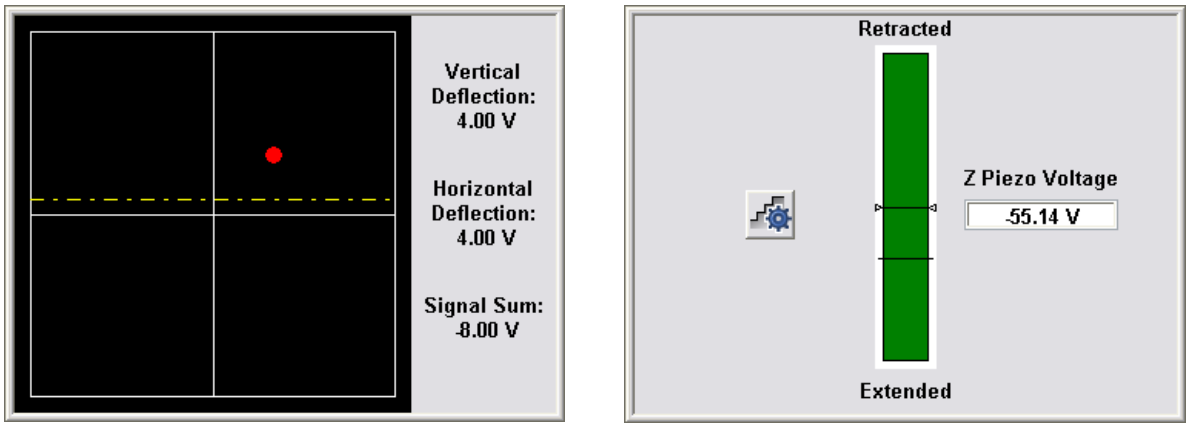
Figure 2.3r SHOW PARAMETER LIST 2



2.3.9 The RealTime Status Window

The Real Time Status window, show in Figure 2.3s, displays either the photo detector quadrant voltages or the Z piezo voltage.

Figure 2.3s Meter View (left) and Z position indicator (right) in the RealTime Status window.



2.3.10 Image Windows

Figure 2.3t A NanoScope Image Window

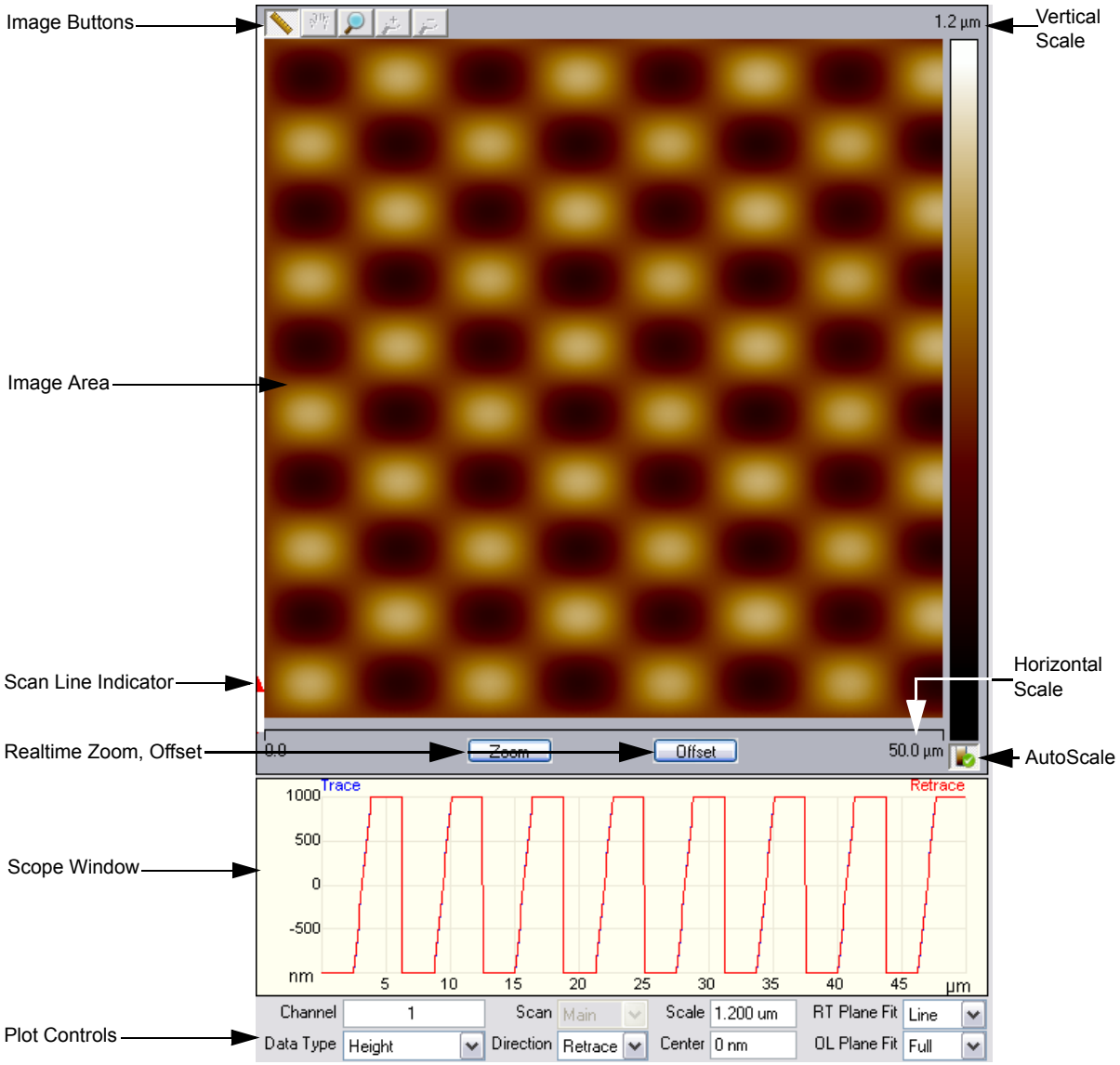


Image Area	The SPM image is displayed here.
Image Buttons	The image buttons, described below, allow pan, zoom and measurement functions.
Scan Line Indicator	An arrow showing the current scan line.
Vertical Scale	The vertical scale of the image.
Horizontal Scale	The horizontal scale of the image.
Realtime Zoom, Offset	Zooms and Offsets the scan. To Unzoom, you must change the **Scan Size**
Scope Window	Displays a real-time plot of the channel signal.
AutoScale	Automatically scales the data. Refer to **AutoScale,** page 108 for details
Plot Controls	Provides control of what is plotted in the image area.

The NanoScope image buttons, shown in Figure 2.3u, are described in Table 2.3j. These buttons operate on the scanned data and do not affect the real-time scanning. Realtime scaning can be controled with the real-time Zoom and offset buttons, shown in Figure 2.3v.

Figure 2.3u NanoScope image buttons

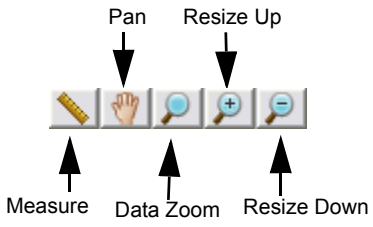


Table 2.3j NanoScope image buttons

Measure	Allows you to draw a box to make measurements, translate the image or offset and resize the image.
Pan	From a zoomed image, you can pan around to other areas of the original image.
Zoom	Allows you to draw a box to zoom in on an image.
Resize Up	Resizes the image up to the previous zoom level.
Resize Down	Resizes the image down to the previous zoom level.

Figure 2.3v Realtime Zoom and Offset buttons

2.3.11 Cursor Types

Within captured images, it may be necessary to do analysis or modification on a selected area or exclude this area from the analysis. Cursors allow for specifying this information.

The cursor types are as follows:

- **Lines**—Selecting specific data (e.g., lengths of features or sectioning features) along the line.
- **Boxes**—Selecting specific areas on the display for including or excluding data.
- **Grid Markers**—Horizontal or vertical line cursors within histograms and spectrum graphs for choosing data ranges or making measurements.

Using a Slider Cursor

In a graph or histogram, position the mouse within the blank area between the axis and the edge of the graph and drag the slider along the graph to position the cursor. The mouse cursor will change to ↔.

Positioning a Line or Box Cursor

- Click and drag the image to draw a line or box cursor.
- To resize an existing line or box cursor, click and drag on a corner edge or end of the object. Cursor will change to ↔ or ↕.
- To move an existing object, click and drag the center of the object to the desired location. The cursor will change to ✥.

2.4 NanoScope Version 8 Workspaces

A NanoScope workspace is a collection of views and parameters in NanoScope software. A NanoScope experiment is sometimes referred to as a workspace.

2.4.1 Multiple Users using NanoScope

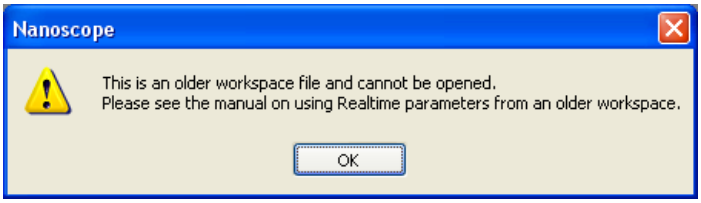
The NanoScope computer can save multiple user preferences/settings in the computer registry. Once a user sets up an account on the computer, several settings are automatically saved for the user. These settings include:

- Previous image file type
- Previous directories
- Browse window settings
- Option to disable video while scanning
- Section View results to display
- Location of Abort dialog box
- Review curve settings
- Force Filter settings
- Help settings
- Script directory
- Track ball on
- Default Parameter dialog box location
- Point and Shoot View settings
- Sweep dialog box settings
- Workspace settings
- Image control settings
- Grid control settings
- Meter View control settings
- Color control settings
- Z center control settings

2.4.2 Older Workspaces Unsupported in NanoScope v7.30 and later

Starting with V7.30 older workspaces will not be supported. See Figure 2.4a.

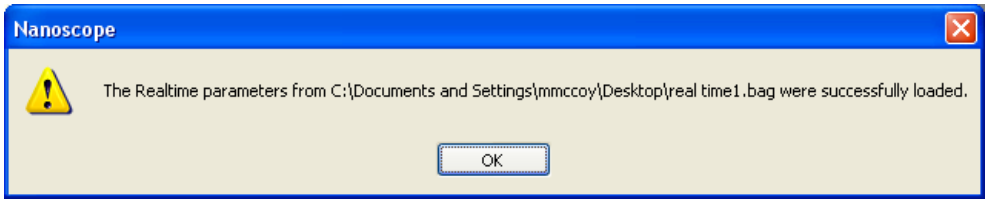
Figure 2.4a Older workspaces are not be supported



To import an older NanoScope workspace:

1. Open the older version of Nanoscope.
2. Open the workspace you would like to get parameter values from.
3. Ensure that you are in RealTime Mode.
4. Go to **FILE** > **SAVE AS**...
5. You will be prompted to save to a (settings) .bag file.
6. Open the newer version of Nanoscope.
7. Go to Realtime mode.
8. Go to Open...
9. Select settings type, (settings)*.bag files.
10. Select the bag file saved from the older version.
11. You should get the confirmation message shown in Figure 2.4b.

Figure 2.4b Import confirmed



2.5 Quick Guide to an Image

The following procedures provide quick steps for using NanoScope 8 software. Follow these steps to quickly scan a sample and then capture and analyze an image. Along the way, you'll see how NanoScope 8 software works, learn some useful tricks, and find out how to learn more later.

This section is not intended to teach a new user how to run an AFM, but only to introduce experienced users to NanoScope version 8.

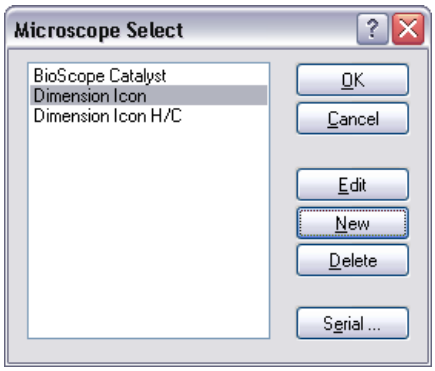
2.5.1 Starting the NanoScope Software

After the software installation is complete, you are ready to start the NanoScope software.

1. Start the NanoScope software by double-clicking on the desktop shortcut labeled **NanoScope 8.10**.

2. Select **Tools** > **Select Microscope** to open the **Microscope Select** dialog box, shown in Figure 2.5a.

Figure 2.5a Microscope Select Dialog Box



In the **Microscope Select** dialog box:

a. You can add a new set of hardware configuration parameters by clicking **NEW**, or edit the parameters of the selected microscope by clicking **EDIT**. The parameters include things such as the controller and vision system.

b. In the **Equipment** dialog box, choose the microscope you are using (see Figure 2.5b). If you are using a MultiMode AFM, select the scanner you plan to use (**SCANNER** button).

Note: Select the **ADVANCED** button to view all equipment parameters.

Figure 2.5b Select the appropriate microscope from the **Equipment** window

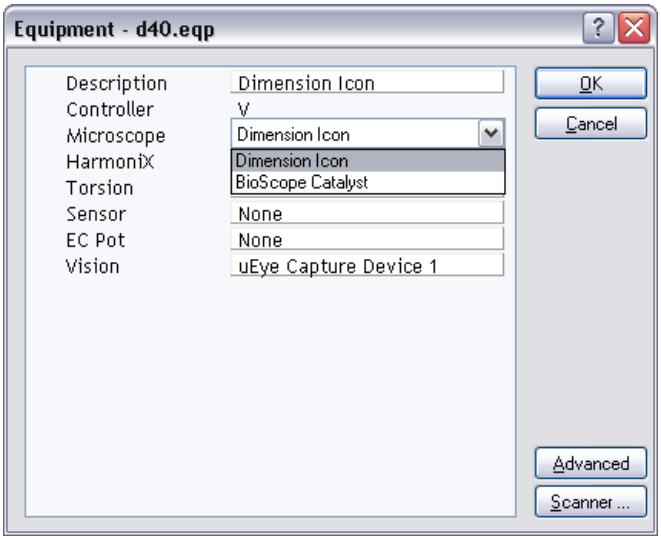
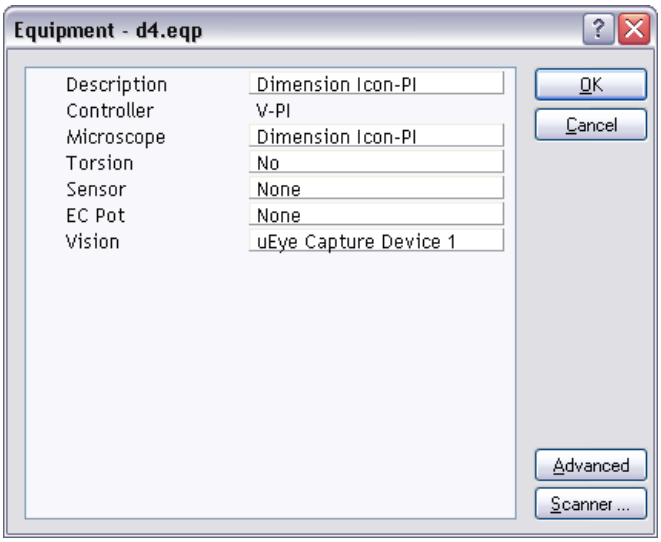
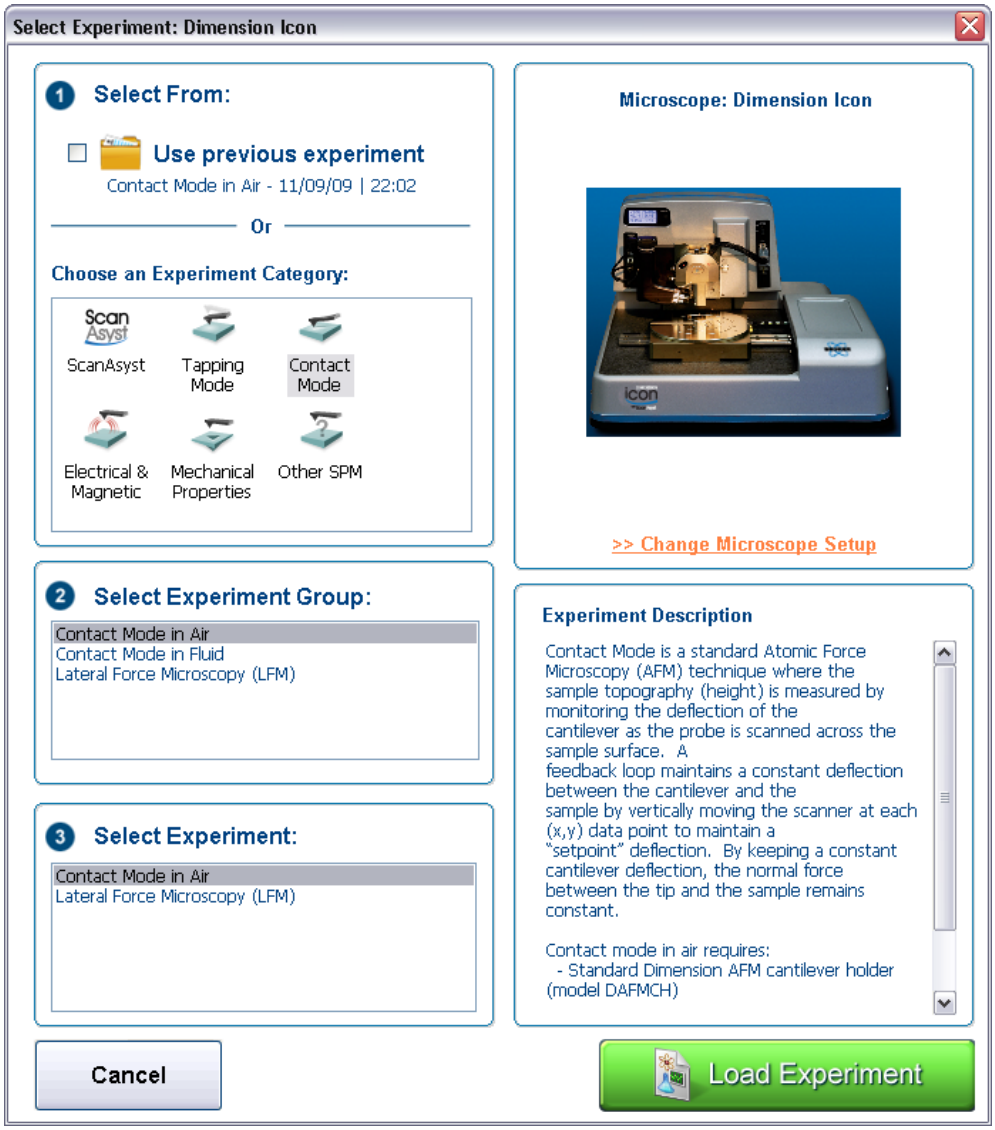


Figure 2.5c Select the **DIMENSION ICON-PI** from the **Equipment** window



3. Click **EXPERIMENT** > **SELECT EXPERIMENT** or the **SELECT EXPERIMENT** icon in the top left of the NanoScope software window. This opens the **Select Experiment** window, shown in Figure 2.5d.

Figure 2.5d The **Select Experiment**, Contact Mode, window



4. Select the **Experiment Category**, **Experiment Group** and **Experiment**.

5. Click **LOAD EXPERIMENT**.

6. If you are using a Dimension Series AFM, continue with the steps in **Preparing a Dimension Series AFM for a Realtime Scan** Section 2.5.2.

2.5.2 Preparing a Dimension Series AFM for a Realtime Scan

Once you've created the workflow and scan parameters, prepare the system to scan. This includes aligning the laser, adjusting the photo detector, locating the cantilever tip with the optical microscope, and focusing the optical microscope on the surface. If you have not yet learned these procedures, refer to your **Dimension Microscope Manual** and/or **SPM Training Notebook**.

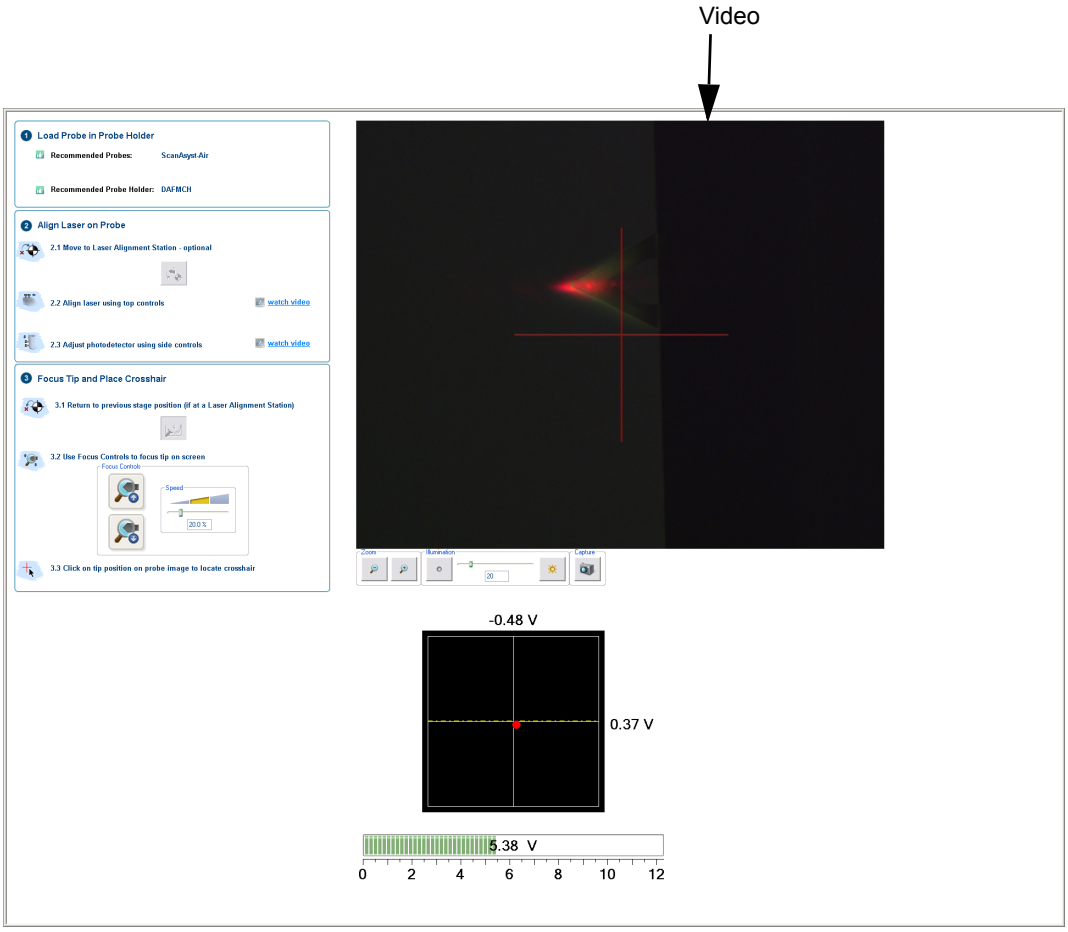
For details on using the Realtime **Scan Views**, see Chapter 3.

1. Mount the probe into the cantilever holder

2. Mount the cantilever holder onto the end of the scanner head.

3. Click the **ALIGN** icon in the **Workflow Toolbar**. This opens the **Align** window, shown in Figure 2.5e.

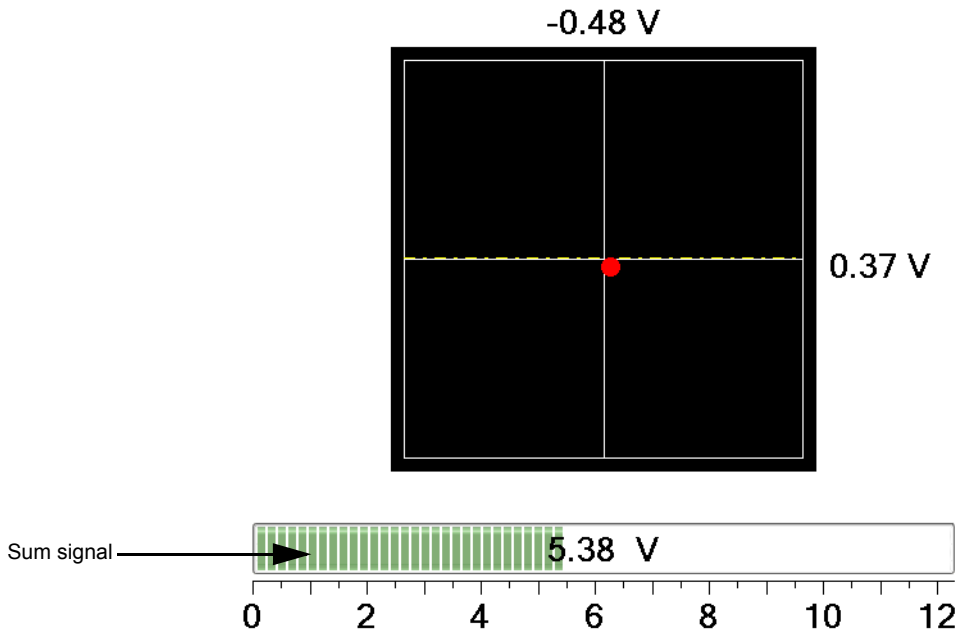
Figure 2.5e The **Align** Window



Several panels in the **Align** window help you through the process:

- The **Video** panel, shown in Figure 2.5e, displays an image of the area around the cantilever.
- The **Meter** panel, shown in Figure 2.5f, displays the signals on the quad photo detector and the laser sum signal.

Figure 2.5f The Meter panel in the **Align** window



- The align instruction video, accessable through the Align panel (Fig Figure 2.5g) and shown in Figure 2.5h, plays a short instructional movie showing the effects of moving the laser and photo detector alignment knobs.

Figure 2.5g Watch Video Commands in the Align Panel

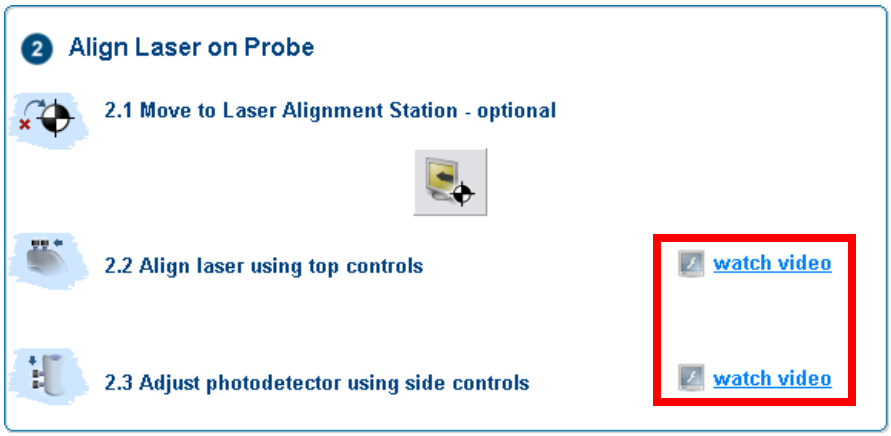
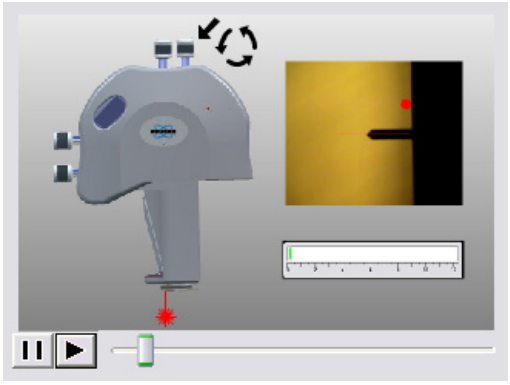
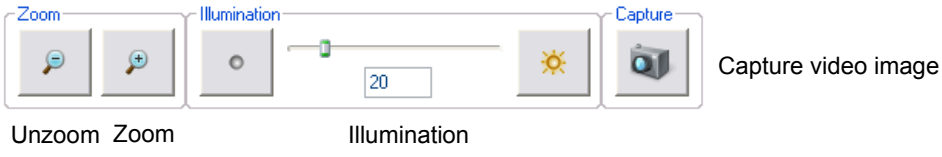


Figure 2.5h The align instruction movie window



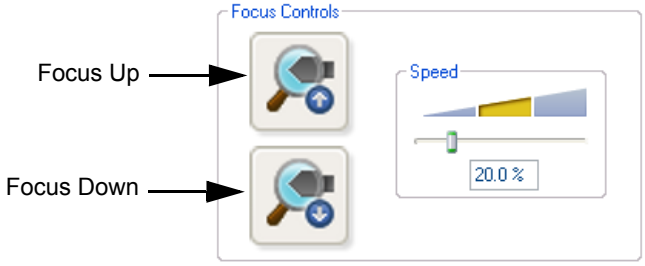
- The **optics** panel, shown in Figure 2.5i, has buttons to zoom or unzoom the camera and buttons to adjust the sample illumination LED. Zooming out may aid in locating the tip.

Figure 2.5i The optics panel



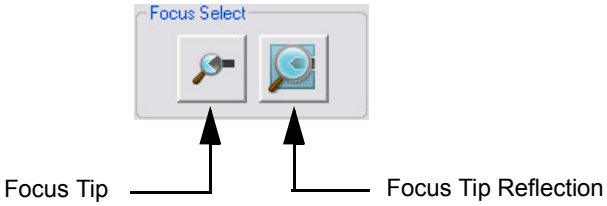
- The **video** panel, shown in Figure 2.5e, displays an image of the area around the cantilever.
- The **Focus Controls** panel, shown in Figure 2.5j focuses the optics on the probe tip and thus knows the Z position of the probe tip. This knowledge is needed to successfully engage the probe tip onto your sample.

Figure 2.5j The **Focus** panel



- The **Focus Select** panel, shown in Figure 2.5k, tells the system if you are focusing on the **TIP** or the **TIP REFLECTION**.

Figure 2.5k The **Focus Select** panel in the **Align** window



4. Using the video image as a guide, adjust the laser control knobs on the top of the Dimension head to place the laser spot near the probe tip.
5. Adjust the laser control knobs on the side of the Dimension head to center the laser diode on the quad photo detector and maximize the sum signal.

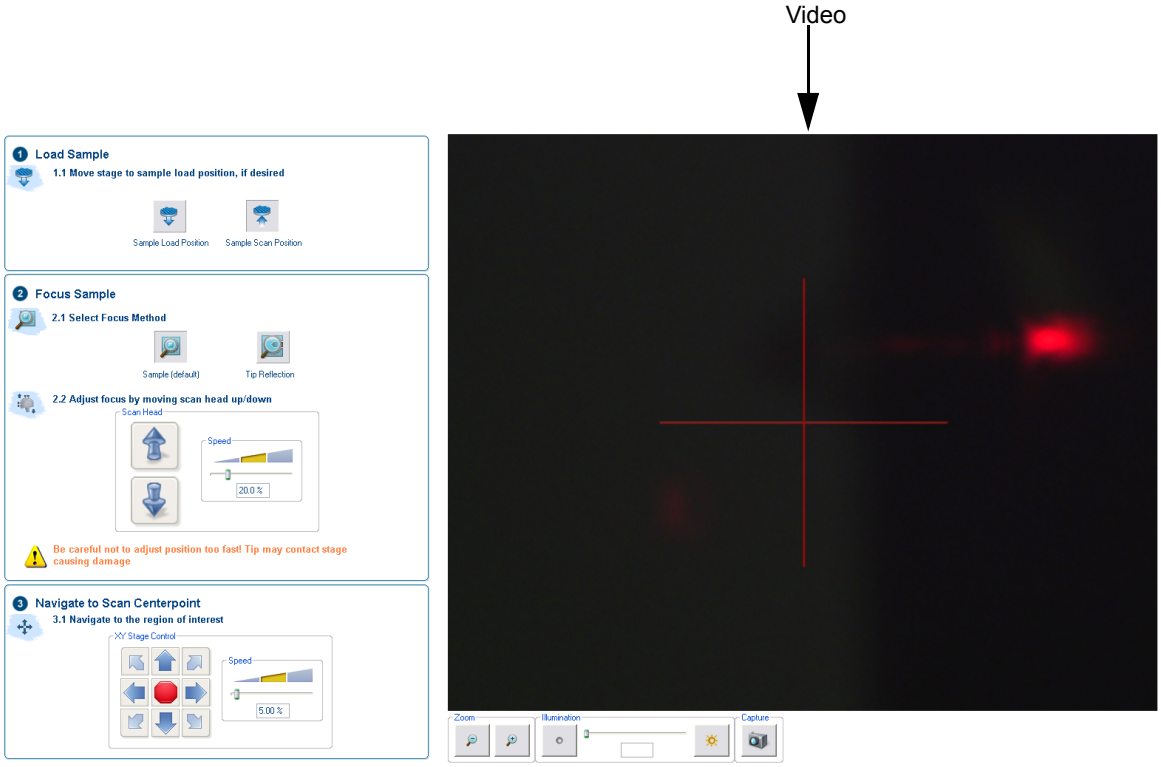
6. Click the **TIP** button in the **Focus Select** panel and, using either the trackball while holding down the bottom-left button or the **FOCUS UP** and **FOCUS DOWN** buttons in the **Focus Optics** panel, shown in Figure 2.5j, move the focus up or down. The focus **Speed** is controlled by the sliding bar or by typing a value from 0 to 100.

7. Select the Tip Reflection button to focus on the tip reflection. This is particularly useful when scanning reflective samples.
8. Dimension Icon users may prefer to use the Alignment Station. See the *Dimension icon Instruction Manual*, Bruker p/n 004-1023-000, for details.

When you leave **Locate Tip** mode, the optics move to a focus position, typically 1mm below the tip. To set this distance, select **Microscope** > **Engage Settings** > **General** > **Sample clearance**.

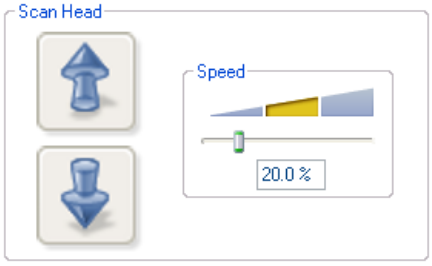
9. Click the **NAVIGATE** icon in the **Workflow Toolbar**. This opens the **Navigate** window, shown in Figure 2.5l.

Figure 2.5l The **Navigate** Window



10. Focus the optics on the sample surface using either the trackball or the **Scan Head** arrows, shown in Figure 2.5m, in the **Navigate View**. If you have used the Alignment station, the stage will prompt you before moving back to the sample position.

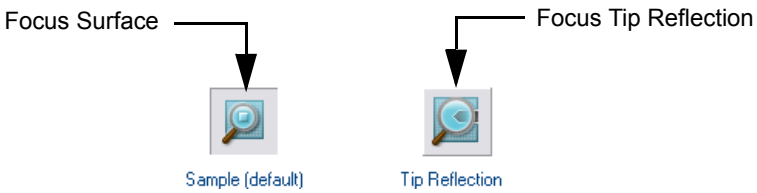
Figure 2.5m Focus: Z Motor Controls



11. To use the track ball, roll the trackball up or down while holding down the bottom-left button. To use the **Z Motor** arrows, click and hold them down. You can use the speed controls in the **Z Motor** area to adjust the speed. This adjustment raises or lowers the Z stage on which the SPM and optics are mounted.

12. To focus on the sample **SURFACE** (normal operation) or the **TIP REFLECTION** (for extremely clean samples), change the **Focus Select** parameter accordingly.

Figure 2.5n The **Navigate Focus Select** Panel



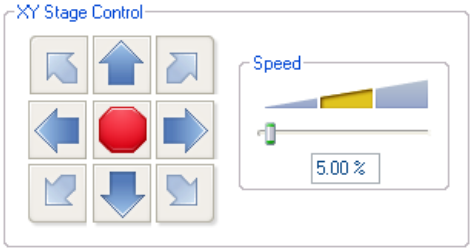
Note: For reflective or semi-reflective samples, the tip reflection is easier to bring into focus than the surface, especially if the sample is very flat or clean.

CAUTION: When moving the SPM stage up and down, it is possible to crash the tip into the surface. To prevent a crash while focusing on the surface, watch the optical image **and** tip-to-sample proximity. The sample should be in focus when the tip is 1mm (1000µm) above the surface.

13. For samples which are difficult to bring into focus, move to an edge of the sample, which is easy to find in the optical image, and bring the top of the edge into focus.

14. Move the X-Y stage to align the desired location on the sample under the crosshairs either by using the trackball without holding down any buttons or by using the **XY Stage Control** arrows, shown in Figure 2.5o, in the **Navigate View**.

Figure 2.5o XY Stage Controls



15. If you are using TappingMode, click the **TUNE** icon. Check your parameters in the **Auto Tune** list.

16. Click the **Auto Tune** button. Notice that the status bar at the bottom of the NanoScope software window says “Cantilever Tuning” during automatic tuning. When tuning is complete, click **Exit** in the **Cantilever Tune** dialog box. Proceed to Section 2.5.3, "Scanning and Scan Parameters".

2.5.3 Scanning and Scan Parameters

Next, you set scan parameters and scan the sample.

1. In the **Scan Parameters** window, use the following initial parameter settings in the **Scan** tab. These values may already be set; they are handy starting values.

Scan size:	1μm
Aspect Ratio:	1.00
Scan Angle:	0.00 °
Scan Rate:	1Hz

2. To collect 5K points of data per line, set the following parameters in the **Scan** panel:

Aspect Ratio:	8.00 (4.00 if Lines is 1024; 1.00 if Lines is 5120) and you want square pixels
Samples/Line:	5120
Lines:	640, 1280 or 5120

> **Note:** You can use the mouse to adjust the value in many parameter fields. Click on the value and drag the mouse left to decrease the value or right to increase the value.

The **Aspect Ratio** controls the X:Y ratio of the pixels in the displayed image. Because there is an 8:1 ratio between 5120 samples/line and 640 lines, using an **Aspect Ratio** of 8 causes the pixels displayed in the image to be square.

> **Note:** Some microscopes, e.g. Dimension Icon-PI, are limited to 1K (1024) lines and 1K points per line.

3. For TappingMode, use the following initial parameter settings in the **Feedback** panel:

SPM feedback:	Amplitude
Integral gain:	0.5
Proportional gain:	5.0

4. For Contact mode, use the following initial parameter settings in the **Feedback** panel:

Integral Gain:	2.0
Proportional Gain:	5.0
Deflection Setpoint:	0V (vertical deflection = -2V (before engage)

5. Click the **ENGAGE** icon in the **Workflow Toolbar**. Scan lines appear in the **Image Windows** once the tip engages and scanning begins.

6. Check to see whether the trace and retrace lines in the **Scope** window are tracking each other well. They should have a similar shape, but they may not overlap each other horizontally or

vertically. Adjust the **Scan Rate**, **Integral Gain**, **Proportional Gain**, and/or **Setpoint** (that is, **Amplitude Setpoint** for TappingMode and **Deflection Setpoint** for Contact Mode) parameters. Once the trace and retrace are tracking well, your tip is scanning the sample surface.

7. At this point, you may want to adjust the **Scan Size**, **X offset**, **Y offset**, and **Scan Angle** parameters to locate the scan over features of interest. If you increase the **Scan Size**, remember that the **Scan Rate** should be lowered.

Note: You can zoom in on the scan image by selecting the **Zoom** button below the image. Then, use your mouse to drag a box outline over the area you want to zoom in on. Click **Offset** to offset the center position of your scan.

8. With a large image, it may be useful to zoom in on the scan without changing the **Scan Size**. Select the data **ZOOM** button above the image. Use your mouse to drag a box outline on the image (begin by clicking where you want the center of the box to be). When you release the left button, you will be zoomed in (scan size of image display will change) but the scanner will remain scanning the original scan size. At this point you can choose to “pan” over to other areas of the total scan. Select the **PAN** button and click and hold the left mouse button as you move the mouse. The minus zoom (right) button above the image allows you to go back to the original scan and the plus zoom button allows you to go to more zoomed in scans (if you have done multiple zooms). You may also choose to physically change the scan size or X/Y offsets by using the **Zoom** or **Offset** buttons below the image.

2.5.4 Capturing an Image

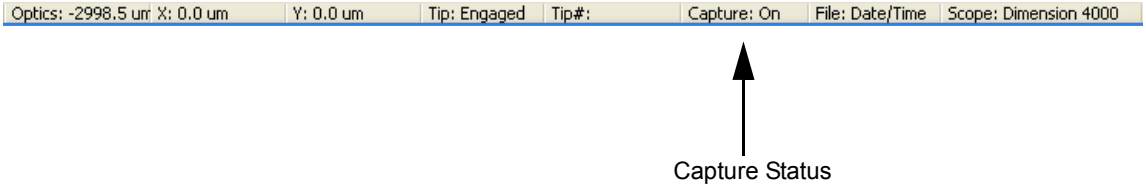
Once you have adjusted the scan parameters, you can capture a scanned image. Perform these steps once a scan you want to capture is in progress.


1. You can capture a scan in any one of four ways:

   - Click the **CAPTURE** icon in the toolbar.
   - Click the **CAPTURE NOW** icon in the toolbar.
   - From the menu bar, select **Capture** > **Capture**.
   - From the menu bar, select **Capture** > **Capture Now**.

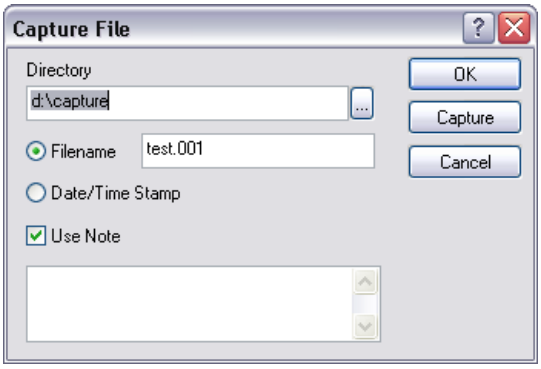
   The scan will continue. Notice that the status bar at the bottom of the NanoScope window (see Figure 2.5p) says "Capture: On." When the current scan is complete, the image will be stored automatically in the Capture Directory with the file name indicated in the status bar.

Figure 2.5p Status Bar



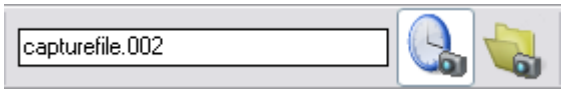
The file name and directory can be changed by selecting **Capture** > **Capture Filename** from the menu bar (see Figure 2.5q).

Figure 2.5q Change Filename



You may also select the capture filename by clicking the **SELECT CAPTURE DIRECTORY** icon and/or the **DATE/TIME STAMP**, shown in Figure 2.5r, icons on the menu bar.

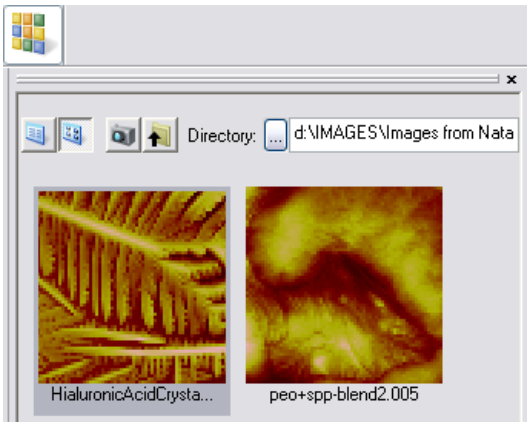
Figure 2.5r Date/Time Stamp menu bar menu



Capture Now, and **Capture Last** save as much of the image buffer as possible including parts of it that were generated with different parameters such as gains, setpoints, etc., so some of the information in the header may be incorrect for some parts of the saved image.

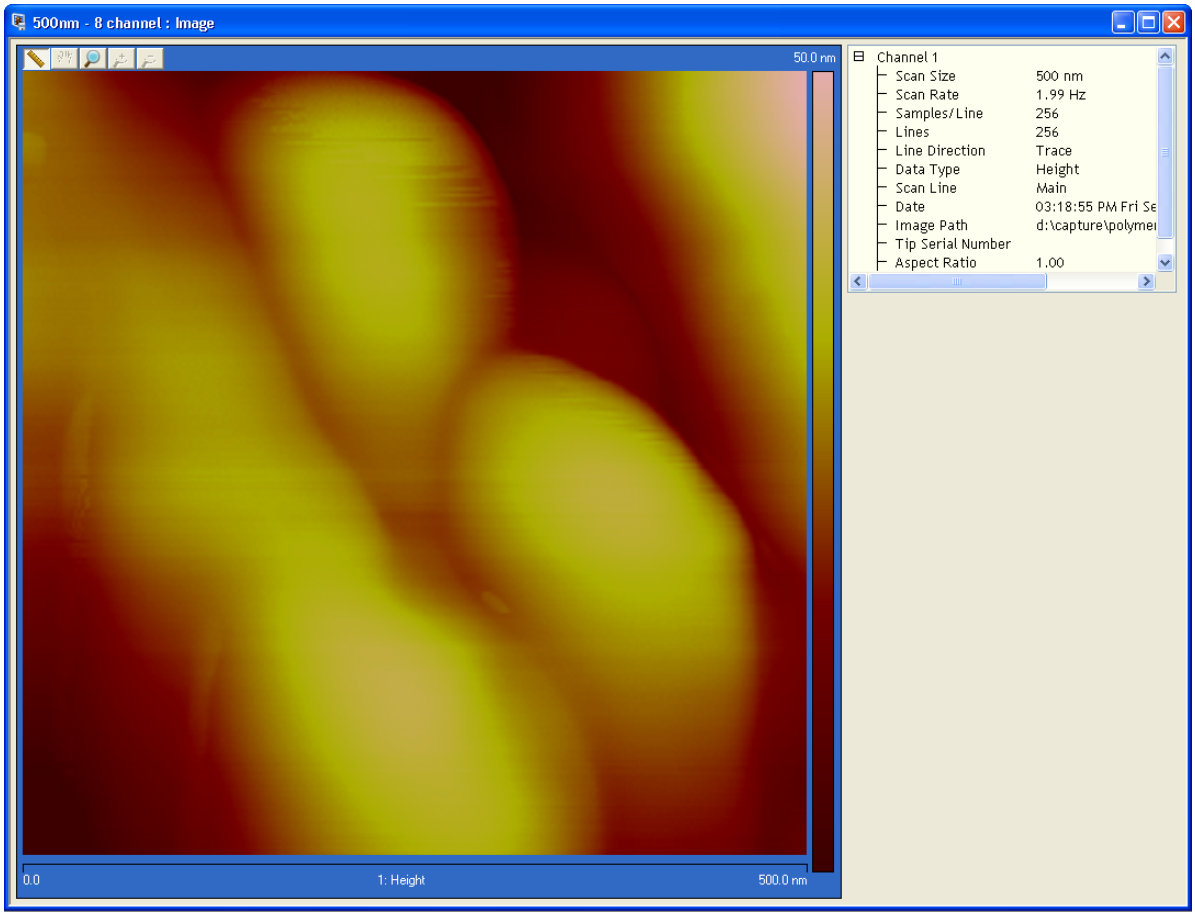
2. In the Image Browser area (see Figure 2.5s), check to see if you are looking at the Capture Directory. If not, select the **Capture Directory** icon, shown at left, (or click the "**...**" button and select the Capture Directory, which is usually **d:\capture**). If you don't see the Image Browser, click the **SHOW/HIDE BROWSE** icon on the toolbar.

Figure 2.5s NanoScope Image Browse Window



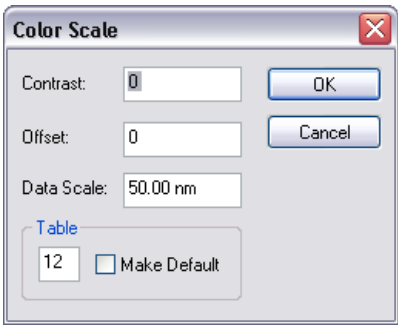
3. Double-click the image you just captured. The image opens in the **Image** window, shown in Figure 2.5t. Notice that the image filename and an image view are added to your workspace.

Figure 2.5t NanoScope Image View Window



4. If you need to change the **Contrast**, **Offset** or **Color Table**, right-click on the color scale of the **Image** window, and change the appropriate values in the **Color Scale** popup window, shown in Figure 2.5u. The **Color Table** may also be changed by clicking and holding the color bar, then dragging the mouse left or right. The **Color Table** may also be changed by using th left/right arrows when the cursor is inside the **Table** window. See Appendix B for a list of color tables.

Figure 2.5u Color Scale



Note: To rename image files, you can use **File > Save As**, use Explorer to rename the file, or right-click on the image in the image browser and select **Move**.

2.5.5 Analyzing an Image with Section Analysis

After opening the captured image, you can analyze the image. In this example, the **Flatten** filter and **Section** analysis views are used.

1. Right-click on the name of the image in your workspace. Choose **ADD VIEW** > **FLATTEN** from the pop-up menu, select **MODIFY** > **FLATTEN** from the menu bar, or click the **FLATTEN** icon on the toolbar.

   The **Flatten** filter can be used to remove image artifacts due to vertical (Z) scanner drift, image bow, skips, and anything else that may have resulted in a vertical offset between scan lines. Refer to Flatten on page 333 for a detailed description of **Flatten**.

2. Set the input parameters for the filter. For example, you can choose the order of the polynomial to use to fit scan lines.

3. Click **EXECUTE**.

4. To restore to the original data, click **RELOAD**. Then change the parameters and click **EXECUTE** again.

5. Right-click on the name of the image in your workspace again. Choose **ADD VIEW** > **SECTION** from the pop-up menu, select **ANALYSIS** > Section from the menu bar, or click the **SECTION** icon on the toolbar. **Section** analysis allows you to easily make depth, height, width, and angular measurements.

Section analysis allows you to easily make depth, height, width, and angular measurements. Refer to Section on page 268 for a detailed description of **Section**.

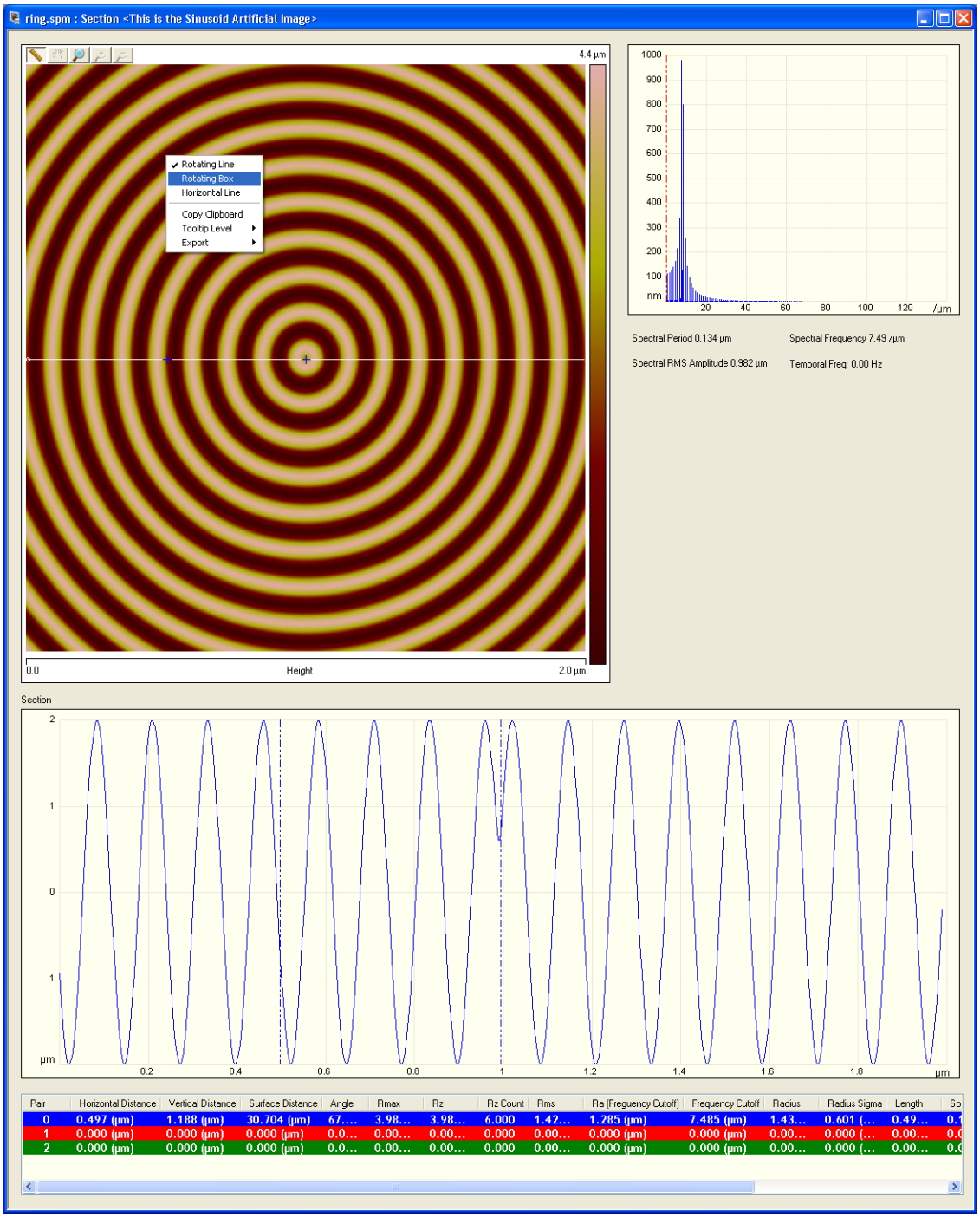
6. Drag a line across the image. A vertical cross section along that line is shown in the upper graph area, shown in Figure 2.5v. The right graph, also shown in Figure 2.5v, shows the power spectrum (Fourier Transform) of the cross section.

7. In the lower (Section) graph, drag the two cursors around to make measurements. You can grab two or more measurement cursors from the outside of the grid. You will see the cursor change to a ↔, at which point you can grab the measurement cursors. The results area at the bottom of the view shows various measurements at the marker position.

   Note: **Section** can have three horizontal lines or 3 rotating lines or one rotating box. It can have three sets of grid markers on one image cursor or one set of grid markers on each image cursor.

8. If you would like to make an Average Section, right-click on the image, select **ROTATING BOX**. After drawing the box, you can make it rotate by holding down the shift key while grabbing anywhere in the box.

Figure 2.5v Section Analysis

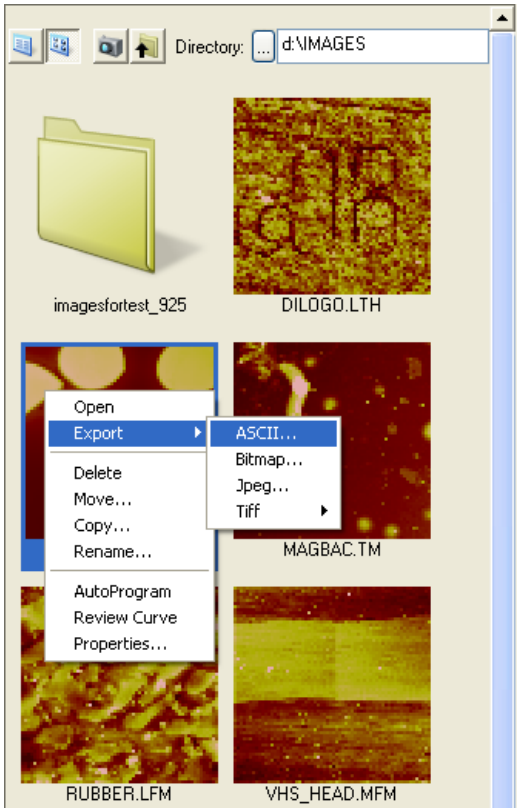


2.5.6 ASCII Export

When transporting the results of using NanoScope software to another computing platform, the most generic format is an ASCII text file. The **File** > **Export** > **ASCII** command builds such a file.

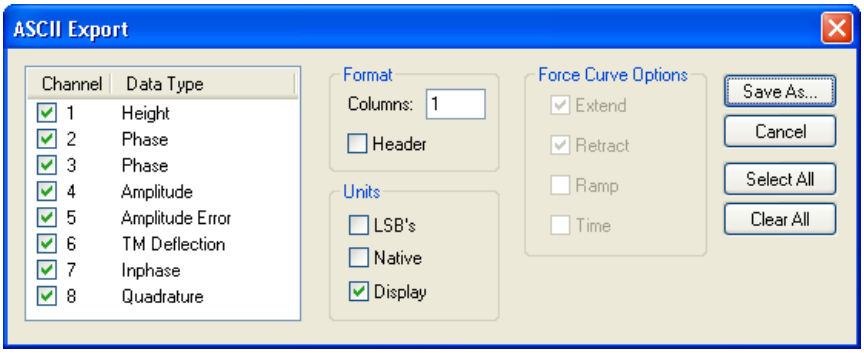
1. Select a directory, then an image file within it, from the file browsing window at the right of the **NanoScope** main window. Right-click in the thumbnail image to open the menu shown in Figure 2.5w.

Figure 2.5w The ASCII Export Command



2. Click **Export** > **ASCII** to open the **ASCII Export** dialog box, shown in Figure 2.5x.

Figure 2.5x The **ASCII Export** Dialog Box



3. Select the **Units** in which to record the data in the new file by checking the appropriate boxes. **DISPLAY** exports the image data in the displayed units, e.g. Height is exported in metric (nm), Phase in degrees, Frequency in Hz... **NATIVE** exports the data in raw (unscaled) Volts. **LSB** exports the data in bits.

4. You can also export image **HEADER**, **RAMP**, or **TIME** information by selecting those check boxes.

5. Click **Save As...**, designate a directory path and filename, and click **SAVE**.

Figure 2.5y shows the start of an exported ASCII image file saved without a header.

Figure 2.5y Sample ASCII Image File

File Edit Format View Help

Height()	Height(Lsb)
1.931886e+003	2.877500e+004
1.984790e+003	2.956300e+004
1.999628e+003	2.978400e+004
1.976264e+003	2.943600e+004
1.915370e+003	2.852900e+004
1.818356e+003	2.708400e+004
1.687303e+003	2.513200e+004
1.524830e+003	2.271200e+004
1.334159e+003	1.987200e+004
1.119050e+003	1.666800e+004

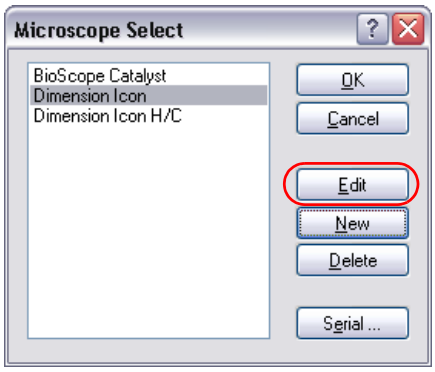
2.5.7 High Resolution Imaging

Your controller can collect data at a maximum resolution of 5120 x 5120 points per image for all 8 simultaneous channels. This increase makes re-imaging at higher resolution unnecessary in most situations.[1]

> **Note:** Images with more than 1 million data points require that the **SCAN DATA LIMITS** parameter in the **Equipment** panel be set to **SYSTEM MAXIMUMS**:

1. Click the **TOOLS** drop-down menu, then **SELECT MICROSCOPE**, shown in Figure 2.5z, to specify your SPM.

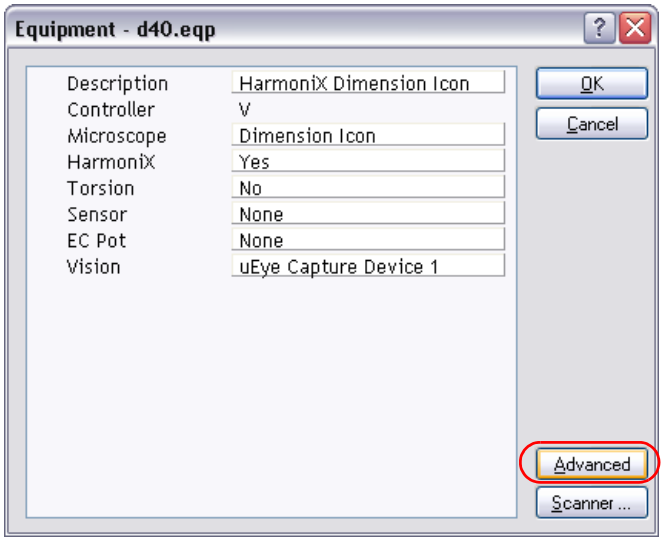
Figure 2.5z Microscope Select



1.This feature is not available on the NanoScope V-PI.

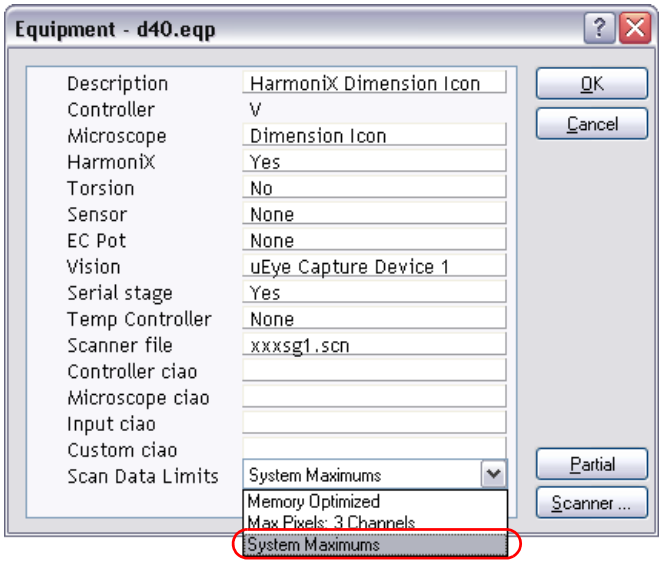
2. Click **EDIT** in the **Microscope Select** panel to open the **Equipment** panel, shown in Figure 2.5aa.

Figure 2.5aa System Component Designation



3. Click **ADVANCED** and set the **SCAN DATA LIMITS** parameter to **SYSTEM MAXIMUMS**. See Figure 2.5ab.

Figure 2.5ab Set the **SCAN DATA LIMITS** to **SYSTEM MAXIMUMS** for images with more than 1 M data points.



4. Click **OK** to close the **Equipment** panel. Click **OK** to close the **Microscope Select** panel. The NanoScope software will close all open RealTime and Offline panels before re-entering RealTime.

2.6 Technical Support at Bruker

Your satisfaction and productivity regarding Bruker products and documentation are absolutely essential.

2.6.1 Technical Support

Click **Help** > **TECHNICAL SUPPORT** for Bruker SPM technical support contact information.

Phone: 1-800-873-9750 (or 805-967-1400), Option 4, then Option 5.

e-mail: spmhelp@bruker.com.

2.6.2 Contact Information

Mailing Address

Technical Documents, Technical Support or Bug Reports at Bruker
Bruker Corporation
112 Robin Hill Rd.
Santa Barbara, CA 93117

E-mail: help@bruker.com

Voice Phone

(805) 967-1400, (800) 873-9750

Fax

(805) 967-7717

World Wide Web

http://www.bruker.com

Chapter 3 Realtime Views

The RealTime Views control the Real time collection of data. Each part of the screen is an integral part of the scanning process. For more information on controlling views and the workspace, refer to Chapter 2.

For general procedures in setting the parameters and data definitions, refer to the following sections:

- **Views for Scanning** Section 3.1
- **Tips on Using Realtime** Section 3.2
- **Force Curves** Section 3.3
- **Force Volume** Section 3.4
- **Piezoresponse Force Microscopy** Section 3.5
- **Surface Potential Detection** Section 3.6
- **NanoScope V Controller Lock-In** Section 3.7
- **High Speed Data Capture** Section 3.8
- **Pulse Counting** Section 3.9

Note: If you have never used an AFM before, refer to your microscope manual or contact Bruker for training.

3.1 Views for Scanning

The general interface views associated with configuring parameters for scanning include:

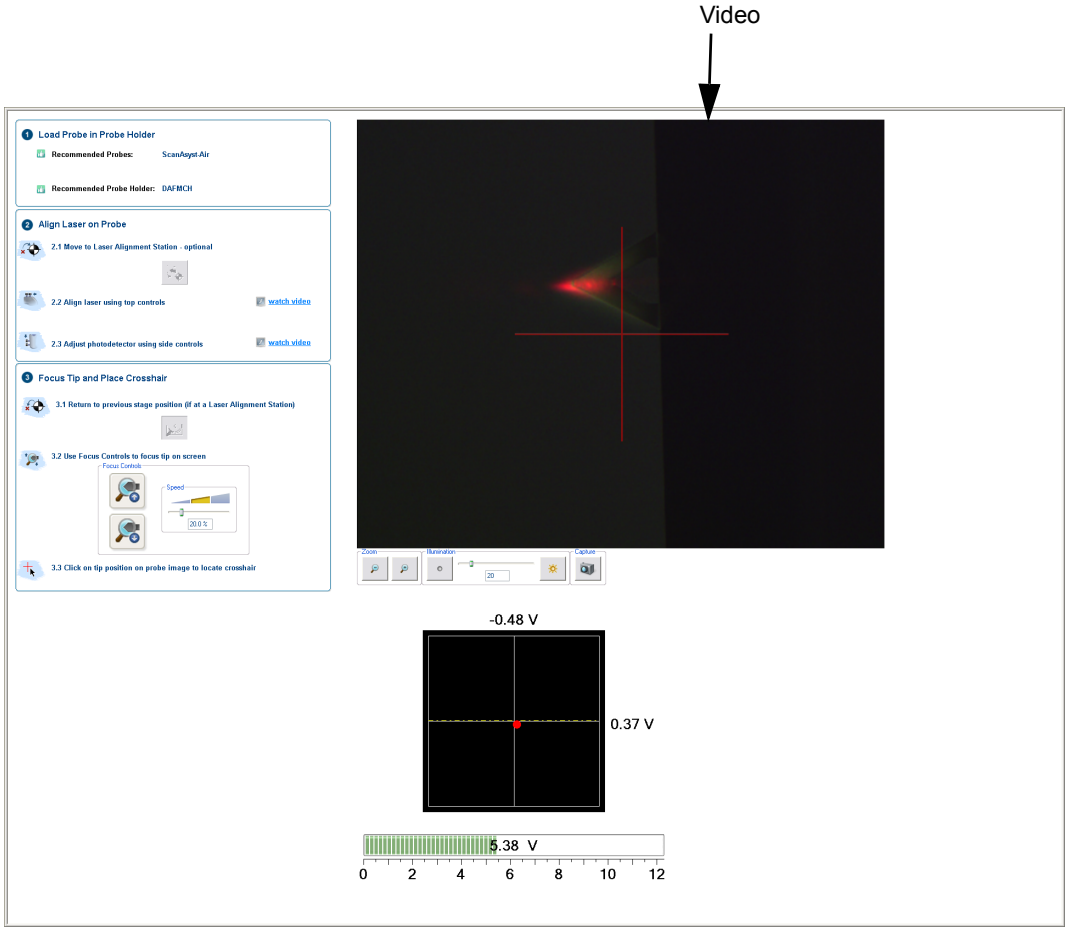
- **Align View** Section 3.1.1
- **Navigate View** Section 3.1.2
- **Real Time Status** Section 3.1.3
- **Point and Shoot View** Section 3.1.4
- **Cantilever Tune** Section 3.1.5
- **Electric Tune** Section 3.1.6
- **Scan Interface** Section 3.1.7
- **Scope Trace Plot** Section 3.1.8
- **Scan Panel Interface** Section 3.1.9
- **Channels Interface** Section 3.1.10
- **Feedback Interface** Section 3.1.11
- **Interleave Mode** Section 3.1.12
- **Other Panel** Section 3.1.14

3.1.1 Align View

Use the **Align** commands to align the laser and photodetector on the cantilever probe of your Dimension or other scanning probe microscope equipped with a vision system. To access the **Align** view, click the **ALIGN** icon the **Workflow Toolbar**.

The **Align** window, shown in Figure 3.1a, has several panels described below.

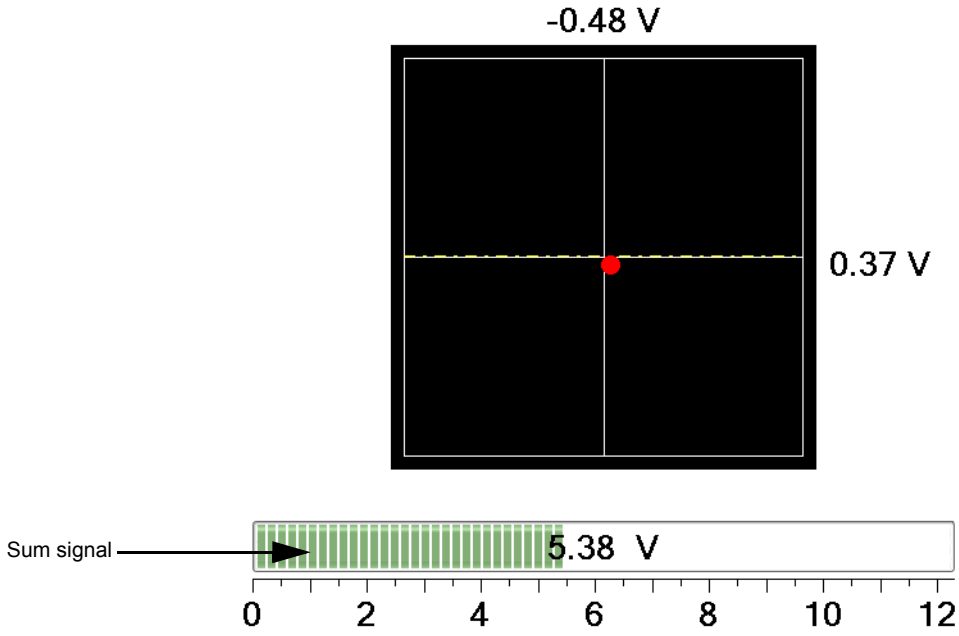
Figure 3.1a The **Align** Window



1. The **Video** panel, shown in Figure 3.1a, displays an image of the area around the cantilever.

2. The **Meter** panel, shown in Figure 3.1b, displays the signals on the quad photo detector and the laser sum signal.

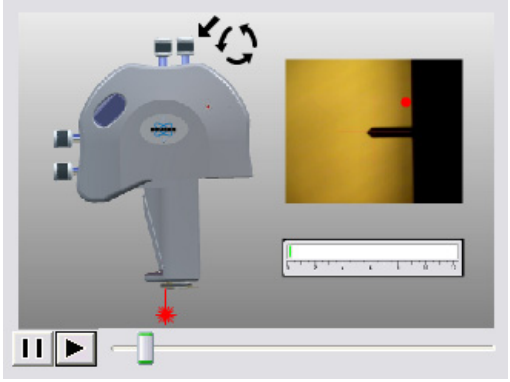
Figure 3.1b The Meter panel in the **Align** window



3. The align instruction video, shown in Figure 3.1c, plays a short instructional movie showing the effects of moving the laser and photo detector alignment knobs.

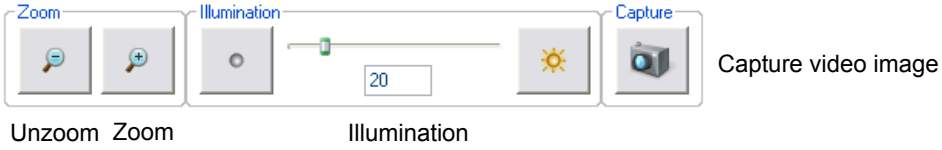
Refer to your microscope instruction manual for details regarding adjustment of the laser spot and photodetector.

Figure 3.1c The align instruction movie window



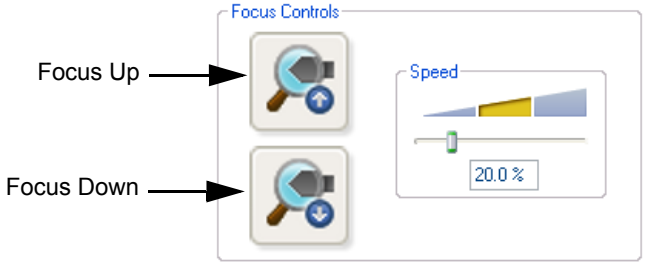
- The **optics** panel, shown in Figure 3.1d, has buttons to zoom or unzoom the camera and buttons to adjust the sample illumination LED. Zooming out may aid in locating the tip.

Figure 3.1d The optics panel



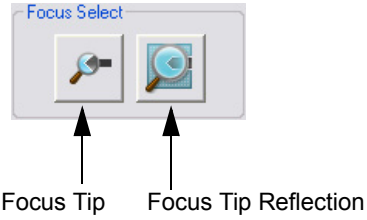
- The **Focus Controls** panel, shown in Figure 3.1e focuses the optics on the probe tip and thus knows the Z position of the probe tip. This knowledge is needed to successfully engage the probe tip onto your sample.

Figure 3.1e The **Focus** panel



4. The **Focus Select** panel, shown in Figure 3.1f, tells the system if you are focusing on the tip or the tip reflection.

Figure 3.1f The **Focus Select** panel



5. The **Alignment Station** panel, shown in Figure 3.1g, moves the stage to position the head over a mirrored surface mounted to the *Dimension Icon* stage. In many cases finding the laser reflection is easier if a mirrored surface replaces the sample.

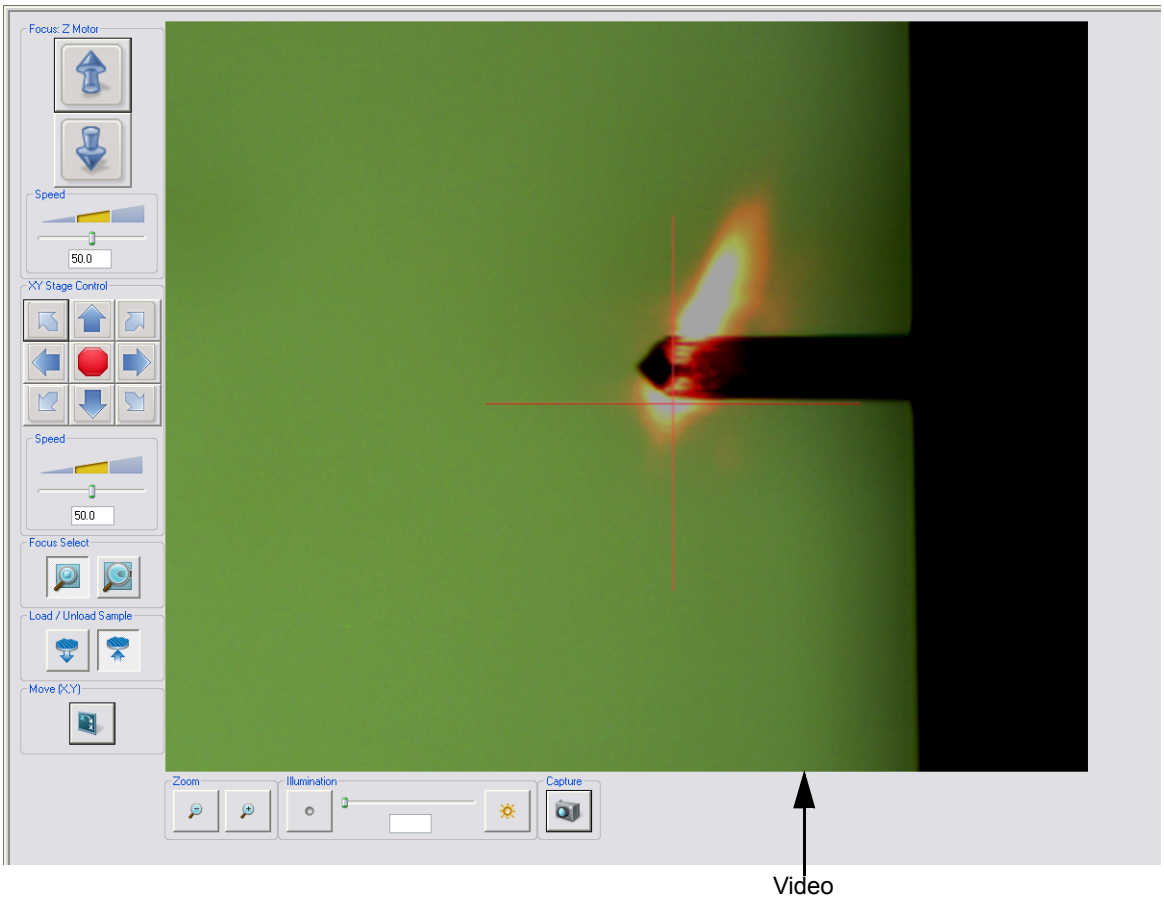
Figure 3.1g The **Alignment Station** panel

3.1.2 Navigate View

Use the **Navigate View** to position the tip, locate a surface position for referencing Z height and move the stage for scanning the sample surface. To access the **Navigate** view, click the **NAVIGATE** icon the **Workflow Toolbar**.

The **Navigate** window, shown in Figure 3.1h, has several panels described below.

Figure 3.1h The **Navigate** Window



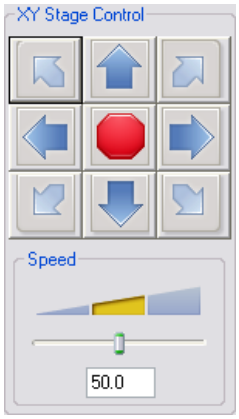
1. The **Video** panel, shown in Figure 3.1h, displays an image of the area around the cantilever.

2. The **Focus Z Motor** panel, shown in Figure 3.1i, moves the head vertically while you focus the optics on the sample surface. You may also use the trackball to accomplish this task. Refer to the your microscope *Instruction Guide* for details. To use the **Z Motor** arrows, click and hold them down. Use the **Speed** controls in the **Z Motor** area to adjust the speed of the head movement. Slider, numeric and min/max controls are available.

Figure 3.1i Focus: Z Motor Controls

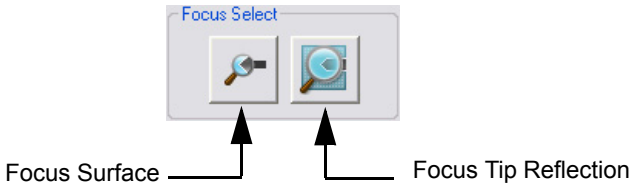
3. The **X-Y Stage Control** panel, shown in Figure 3.1j, moves the stage to align the desired location on the sample under the crosshairs by using the **XY Stage** arrows. Adjust the stage movement speed with the **Speed** controls. Slider, numeric and min/max controls are available.

Figure 3.1j XY Stage Controls



4. The **Focus Select** panel, shown in Figure 3.1k, tells the NanoScope software what you focus on, the sample **SURFACE** (normal operation) or the **TIP REFLECTION** (for extremely clean samples). Change the **Focus Select** parameter accordingly.

Figure 3.1k The **Navigate Focus Select** Panel



5. The **Load Sample** function first lifts the SPM head then indexes the stage to a preprogramming location (usually front-center) where samples may be rapidly reloaded.

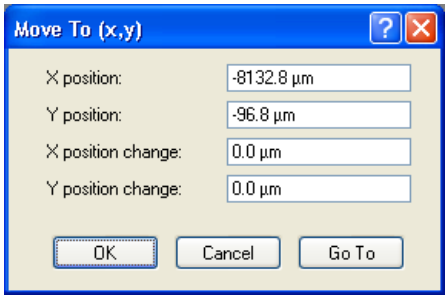
6. This raises the head to the **Load/Unload** height (see **SPM Parameters**, page 74) and the stage indexes to the front-center position.

7. The **Unload Sample** function moves the sample back to the analysis position

8. The **Move To X/Y** function enables you to move quickly to a defined X-Y coordinate. If the origin has not been preset using the **Stage** > **Set References** panel, the stage automatically defaults to the last origin that was previously used. All subsequent X-Y moves are done from the origin. Select the **Move To (X, Y)**... panel under the **Stage** pop-down menu. The screen presents a panel with four fields (see Figure 3.1l). Enter the X and Y coordinates of the desired move to position, then click **OK**.

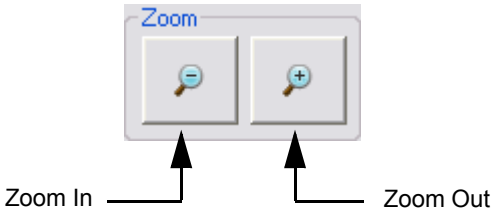
Note: The first two fields define absolute moves relative to the currently set origin (0,0). The third and fourth fields define relative moves from the *current position*.

Figure 3.1l Move To Prompt



9. The **Zoom** panel, shown in Figure 3.1m, digitally zooms (i.e. crops) in on the image.

Figure 3.1m The **Zoom** panel



10. The **Illumination** panel, shown in Figure 3.1n, adjusts the brightness of the sample illumination LED. Slider, numeric and min/max controls are available.

Figure 3.1n The **Illumination** panel

11. The **Video Capture** function, shown in Figure 3.1o, saves the current video image to a bmp file.

Figure 3.1o The **Video Capture** panel

Using the Navigate View

CAUTION: If **Locate Tip** is not accomplished before **Focus Surface**, there is a danger of crashing the tip during **Engage**.

Access the **Navigate View** at any time when the stage movement or focus surface and locate tip settings are necessary.

Note: Some microscope options, such as **Engage** and **Withdraw**, are unavailable when the **Navigate View** is active. You must select another view, such as the **Scan View**, to enable these options.

SPM Parameters

To access the stage parameters panel, select **MICROSCOPE > ENGAGE SETTINGS > GENERAL** to open the **Engage Stage-Motor Settings** window, shown in Figure 3.1p.

Figure 3.1p Default SPM Parameters

- Sample Clearance
- SPM Safety
- SPM Engage Step
- Load/Unload Height
- SPM exclusion limit
- Sew tip
- Trigger safety

3.1.3 Real Time Status

Meter View

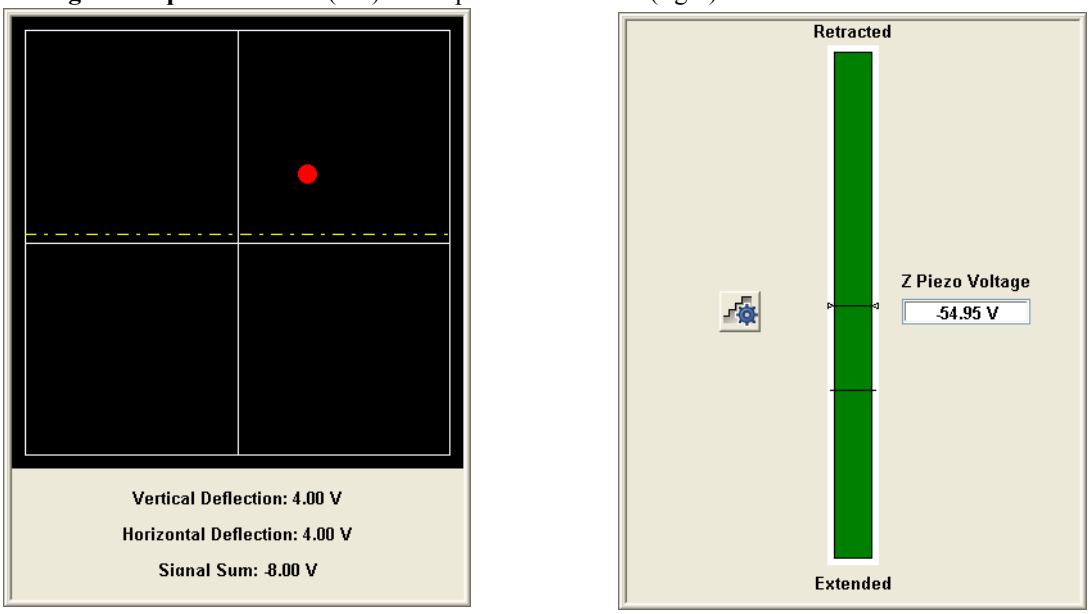
The **Meter View** shown in Figure 3.1q, is activated by clicking the **REALTIME STATUS** icon in the NanoScope toolbar. This displays the photodetector signal, RMS amplitude, horizontal and vertical deflection signals, and the signal sum when you are not engaged.

- **Photodetector Signal**—Red dot that corresponds to the positioning of the laser on the photodetector.
- **Signal Sum**—Horizontal meter that displays the sum of the voltage response from the laser in all 4 sections of the photodetector.
- **Vertical Deflection**—Corresponds to the voltage for vertical displacement of the laser signal. Should be “0” for centering.
- **Horizontal Deflection**—Corresponds to the voltage for the horizontal displacement of the laser signal. Should be “0” for centering.
- **RMS Amplitude**—Root mean square (RMS) signal measured at the detector (TappingMode only).

Z position indicator

The Z position indicator and the step motor control, shown on the right in Figure 3.1q, are displayed when the probe is engaged.

Figure 3.1q Meter View (left) and Z position indicator (right) in the RealTime Status window.

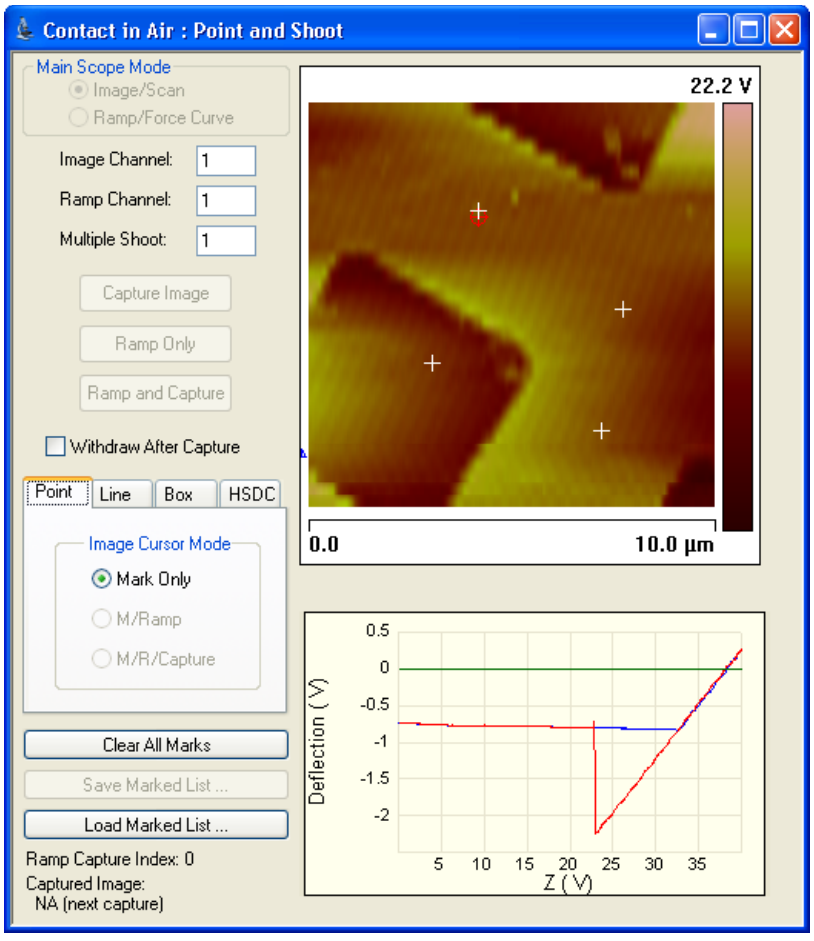


3.1.4 Point and Shoot View

The **Point and Shoot View** allows you to select specific points on an image (see Figure 3.1r). Use **Point and Shoot** to capture an image and/or collect a force curve for every point you designate.

When you click a point on an image, a crosshair (+) marks the location. You can designate individual points, or use the tools in the **Point and Shoot View** to assign multiple points simultaneously.

Figure 3.1r Point and Shoot View



Controls and Parameters

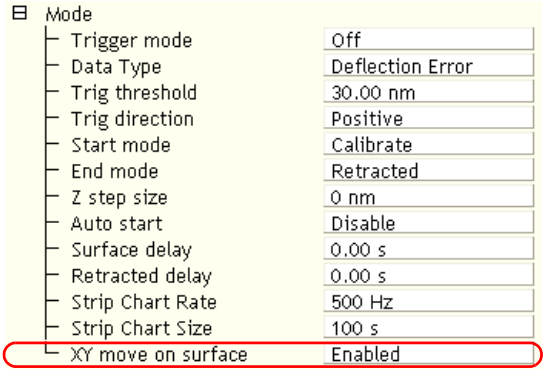
Image/Scan	Allows you to switch to Image/Scan mode. Use Image/Scan mode to adjust scan parameters in any scan view.
Ramp/Force Curve	Allows you to switch to Ramp/Force Curve mode. Use Ramp/Force Curve mode to adjust the ramp settings. You can select points on an image, ramp each point, and create a force curve for each point.
Image Channel	Select the channel to use for the image.
Ramp Channel	Select the channel to use for the ramp display.
Multiple Shoot	Number of force curves collected at each point, 100 max.
Capture Image	Click this button to capture an image and save it in the Capture Directory. After the capture the software switches to Ramp/Force Curve mode.
Ramp Only	Click this button to ramp a variable determined from the force curve menu at each point.
Ramp and Capture	Click this button to ramp each point, capture the ramp/force curve, and save it in the Capture Directory.
Point Parameters	Image Cursor Mode Settings: **Mark Only**—Select points of interest on the image. **M/Ramp**—Select points of interest. Software will automatically ramp each point. **M/R/Capture**—Select points of interest. Software will automatically ramp each point and capture a ramp/force curve.
Line Parameters	Draw a line to select specific points on an image. **Point Number**—Number of points in the line. **Spacing**—The distance in nm between each point. All points are equidistant. **Clear Path**—This button clears the current line and associated points. **Convert to Points**—Places a + in the location of each point in the line. The line disappears.

Box Parameters	Draw a box in the area you want to place a group of points. You can use the parameters below to create a grid of points. **Row Number**—Designates the number of rows of points in the grid. **Column Number**—Designates the number of columns of points in the grid. **Row Space (nm)**—Designates the distance in nm between each row of the box. **Col Space (nm)**—Designates the distance in nm between each column of the box. **Clear Path**—This button clears the current box and associated points. **Convert to Points**—Places a + in the location of each point in the grid. The box disappears.
Clear All Marks	Removes all user-defined marks from the Point and Shoot image.
Save Marked List...	Save the marks on the image as Path Files (*.psm).
Load Marked List...	Opens and loads a previously saved Path File (*.psm) which contains marks on a Point and Shoot image. **Note**: If there are points on the image prior to selecting this option, when this button is selected the saved marks will appear *in addition* to the previous marks.

Two options are available for moving, in XY, from one point to another:

1. **XY move on surface**: **OFF** - Move with tip at home (lift) height.
2. **XY move on surface**: **ENABLED** - Move on surface with Z feedback on See Figure 3.1s.

Figure 3.1s Ramp Parameters > Mode > XY move on surface



3.1.5 Cantilever Tune

The **Cantilever Tune** command allows determination of the cantilever resonant frequency and the setting of the operating point for TappingMode feedback (see Figure 3.1t). **Cantilever Tune** sweeps the cantilever drive frequency over a selectable range, then displays plots of the cantilever amplitude and phase versus drive frequency. This command is enabled *only* when the **Microscope mode** parameter in the **Other** panel of the **Scan Parameter List** is set to **TAPPING**. On Small Sample MultiMode SPMs, verify that the switch located on the base is toggled to **TM AFM** before selecting the **Cantilever Tune** command.

Note: The sweep channel is determined by the data selection in the **Channel 1**, **Channel 2**, or **Channel 3** control panels.

Figure 3.1t shows how the maximum amplitude is attained in air at the cantilever natural resonance. Figure 3.1u shows the amplitude is reduced when it is in contact with the sample surface.

Figure 3.1t Tapping Cantilever in Mid-air

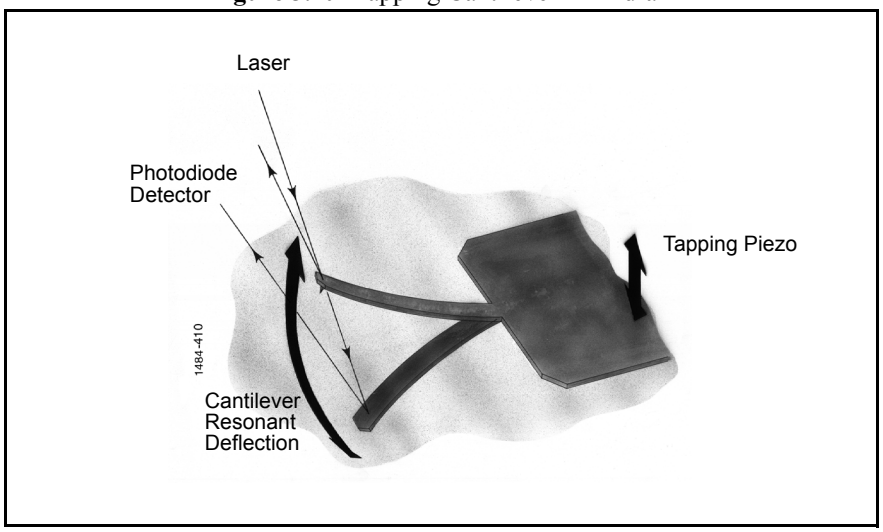
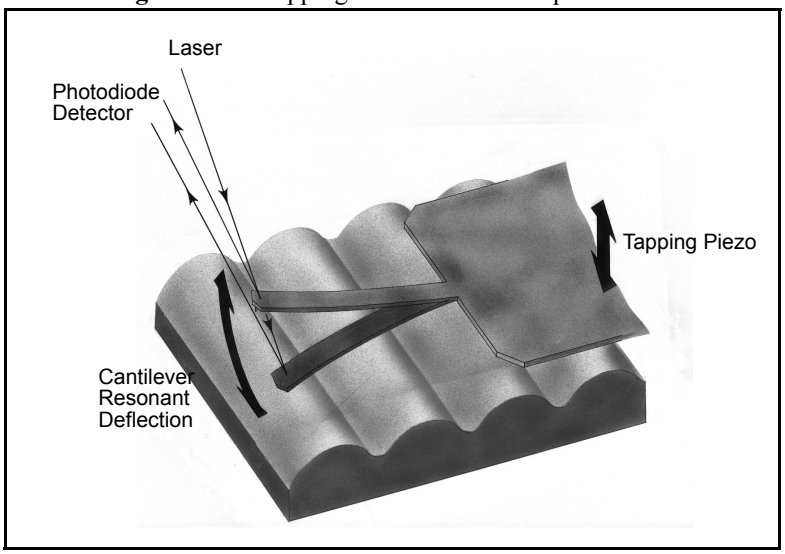


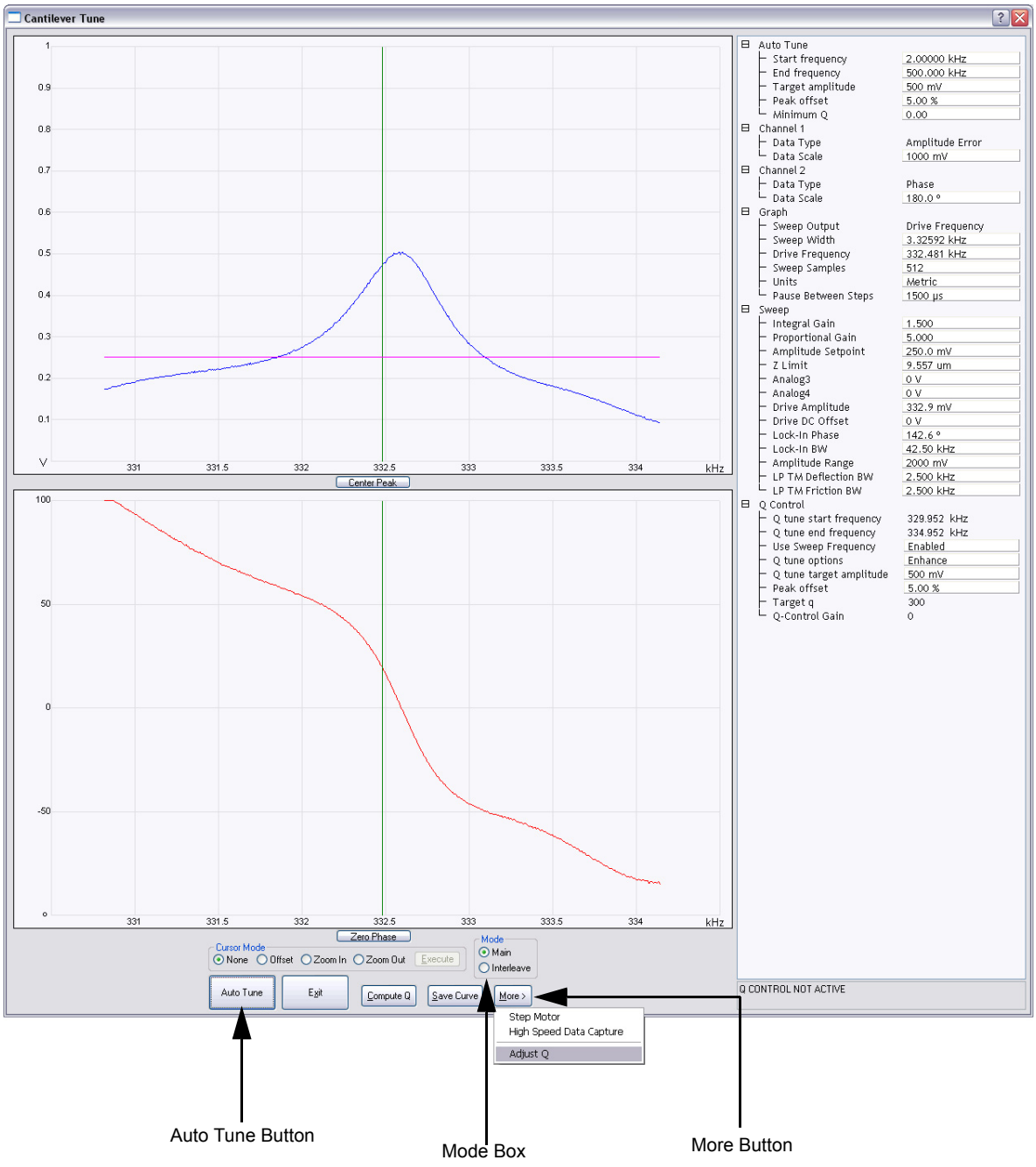
Figure 3.1u Tapping Cantilever on Sample Surface



In TappingMode, the optical lever technique reflects a laser beam off the back of the oscillating cantilever, thence to a segmented photodiode. The differential signal between the top and bottom photodiode segments provides a sensitive measure of cantilever deflection. As the sample is scanned, analog circuitry determines the RMS value of the rapidly changing cantilever deflection signal. The RMS value of the cantilever deflection signal corresponds to the amplitude of the cantilever oscillation. Changes in amplitude of the cantilever oscillation are controlled by the feedback system to track the sample surface.

Access the **Cantilever Tune** dialogue box, shown in Figure 3.1v, by selecting the **Tune** icon or by selecting **Cantilever Tune** from the **Microscope** menu.

Figure 3.1v Cantilever Tune Dialog Box



Select Cantilever Tune Dialog Box Definitions:

Mode box	Toggles the Auto Tune signal from the main to interleave signals. *Settings*: **Main**— Displays the set of parameters applied to the main scan (see Section 3.1.7). **Interleave**—Displays a duplicate set of parameters applied only to the interleaved portions of the scan.
Auto Tune Button	Executes the automatic tuning procedure: the cantilever is excited through a range of frequencies beginning at the Start frequency and ending at the End frequency.

Auto Tune Parameters:

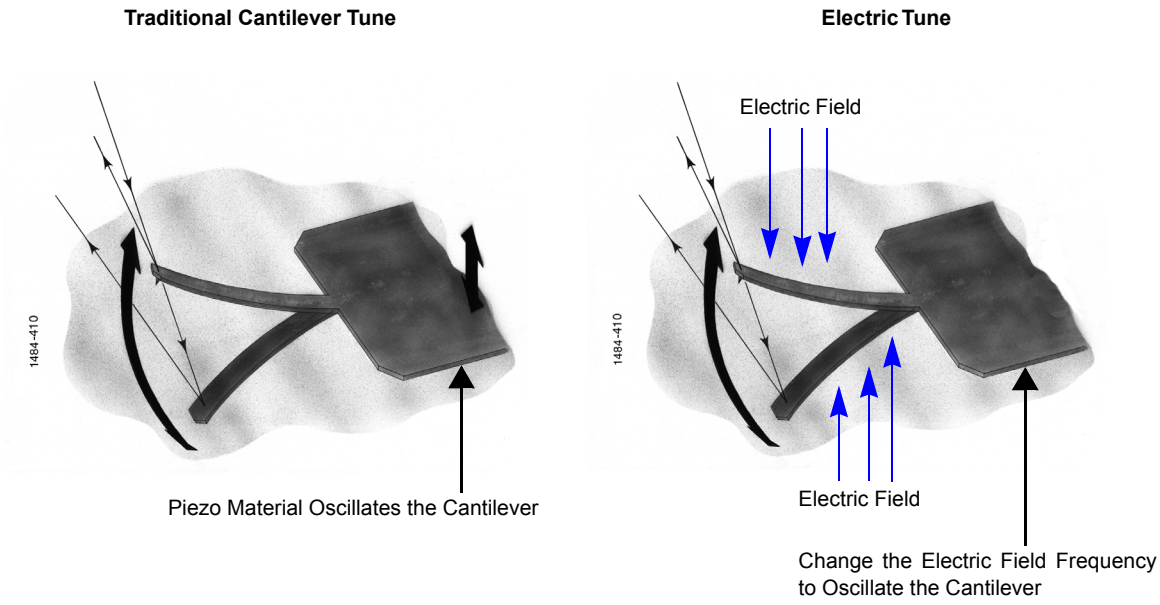
Start frequency	Starting point of the **Auto Tune** frequency sweep.
End frequency	Ending point of the **Auto Tune** frequency sweep.
Target amplitude	Targeted output signal amplitude *at the photodiode detector.* This value should *not* be confused with Drive amplitude, which is the amplitude applied directly to the cantilever itself (see Drive amplitude). *Range and Settings*: **0.00** to **8.00 V** Note: Dimension Series SPMs, nominal = 500mV Small Sample MultiMode SPMs, nominal = 500mV
Peak offset	Percentage of cantilever's free-air resonant frequency to be automatically offset. Peak offset is used to compensate for changes in resonance before engagement due to the tip's interaction with the surface after engagement. *Range and Settings*: **0** to **50%**; typical value = **5%**
Minimum Q	Q is the value defined by the amount of oscillation it takes for a wave to drop to 1/e (e = 2.718) of its amplitude value (i.e. a wave with an amplitude of ten would have a Q of 10/e, or 3.6788). Minimum Q establishes a minimum "width of peak" value allowed by the AutoTune function. Peaks not meeting the Minimum Q may be ignored by setting the Smash width factor.
Smash width factor	The width of the area beneath the wave *smashed* (set to zero) when a peak not meeting the Minimum Q requirement is found. **Note**: This parameter does not appear if Minimum Q is 0.

3.1.6 Electric Tune

Theory

When evaluating Surface Potential, you can now tune the cantilever electrically. Traditional cantilever tune oscillates the cantilever via tapping piezo material (see Figure 3.1w). Electric Tune sweeps the frequency of the electric field surrounding the cantilever. The force of the electric field moves the cantilever. The cantilever amplitude is then plotted in the **Generic Sweep** dialogue box.

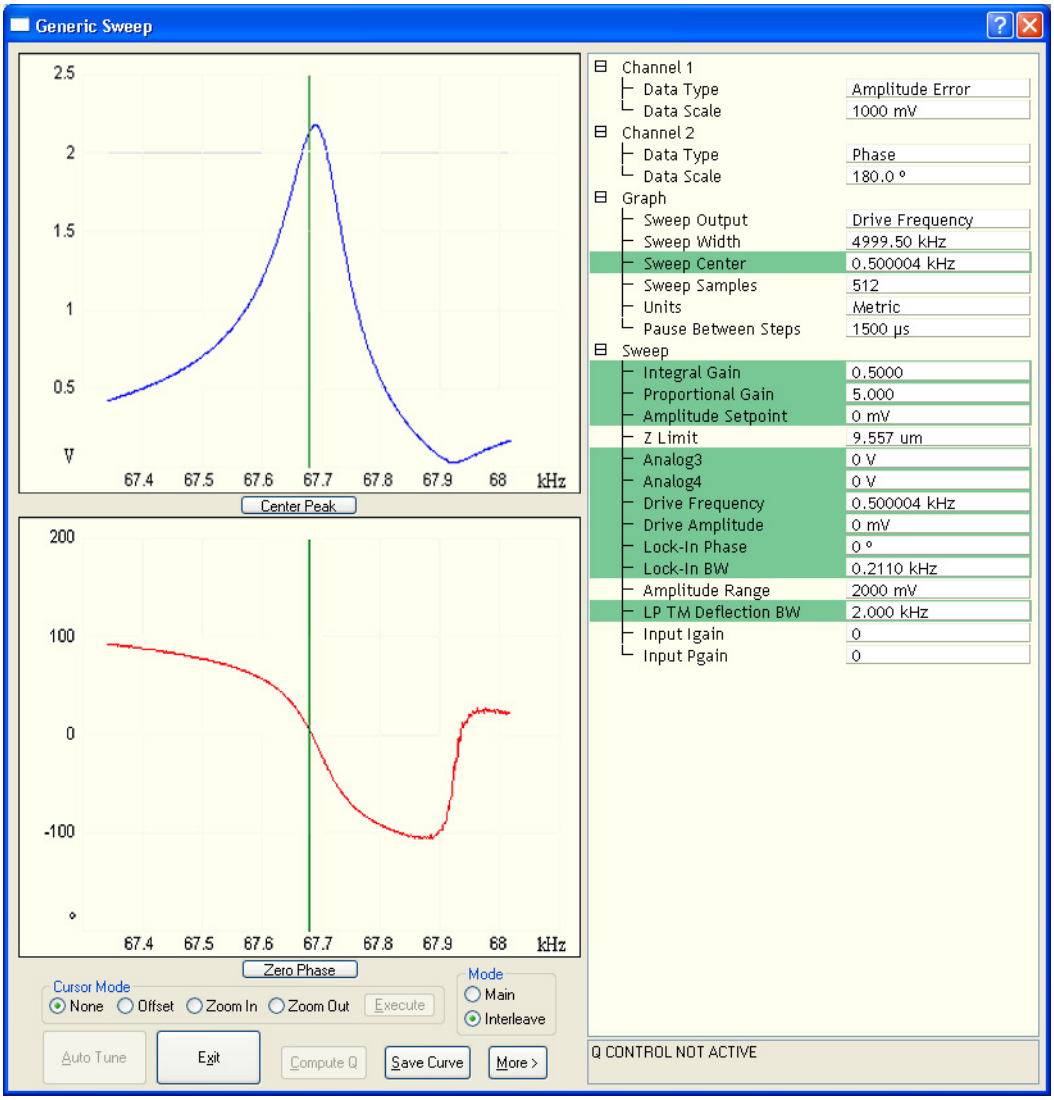
Figure 3.1w Cantilever Tune Method Comparison



Procedure

1. While evaluating Surface Potential in Realtime mode, select **Microscope** > **Generic Sweep**. The **Generic Sweep** dialogue box, shown in Figure 3.1x, will display.

Figure 3.1x Typical Generic Sweep



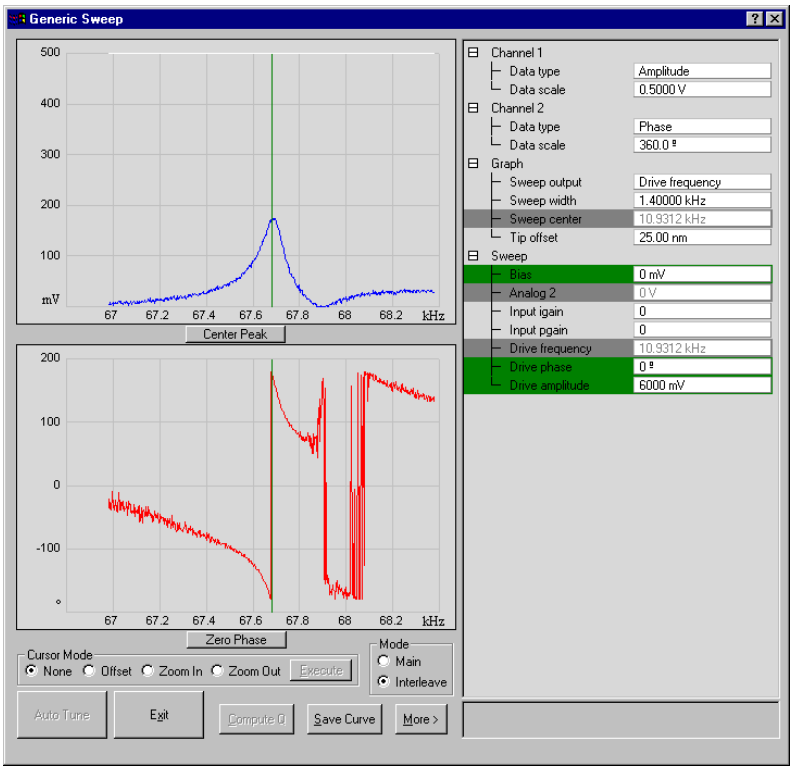
2. Select **Interleave** as the **Mode** (see Figure 3.1x).

3. In the **Generic Sweep** dialog box, set the **Sweep** parameters **Input igain** and **Input pgain** to **0**. This disables the Surface Potential feedback loop, which works to keep the cantilever's amplitude at zero.

4. You can adjust several parameters to acquire interesting data:

   - Try changing the **Data Scale**, **Drive Phase** and **Drive Amplitude** (see Figure 3.1y).
   - Try changing the channel. For example, the **Data Type** can be changed to **Potential Input**.
   - Try sweeping another channel. For example, set the **Graph** parameter **Sweep Output** to **Bias** (see Figure 3.1y).

Figure 3.1y Electric Tune **Generic Sweep** while adjusting the Drive Amplitude and Drive Phase



Note: Remember to re-enable the **Input gains** before collecting further Surface Potential data.

3.1.7 Scan Interface

The **Scan** display includes an image viewer, color bar, scope viewer, vision control viewer (for systems configured with vision controls), and numerous parameters to configure Scan data collection. Most SPM operators use only a few of these parameters to obtain images. The parameters within each panel are also microscope-specific or level-access dependent and may be greyed out or hidden, depending on microscope configuration.

Scan Interface:

Image Window	During scanning, the Realtime image of the sample appears along with a small blue cursor on the left. The cursor moves along the image vertically to show the engaged tip position on the surface. The **Measure** button at the top of the scan allows you to make line measurements. the **Zoom** and **Offset** buttons below the scan change the scan size and location while the **Magnify** button above allows you to "zoom in" to a smaller view, but doesn't change the scan size. The **Pan** button allows you to pan over to other areas of the total scan if you are zoomed in.
Color Bar	Sets the color table for viewing height data in the image window. Left-click on the color bar and drag the mouse left or right. Right-click to open the **Color Adjustment** dialog box.
Image Parameters	Configure options below the image window to select the channel and image display values, (e.g. **Data type**, **Line direction**, **Data scale**, and so on).
Vision Window	The **Vision** window displays the video image.

User-Defined Parameters in the Scan View

Clicking on a parameter and then dragging the mouse back and forth increases or decreases a parameter value much like an old analog slider. The significance, range of acceptable values, and specific information about control panel parameters are discussed in this section.

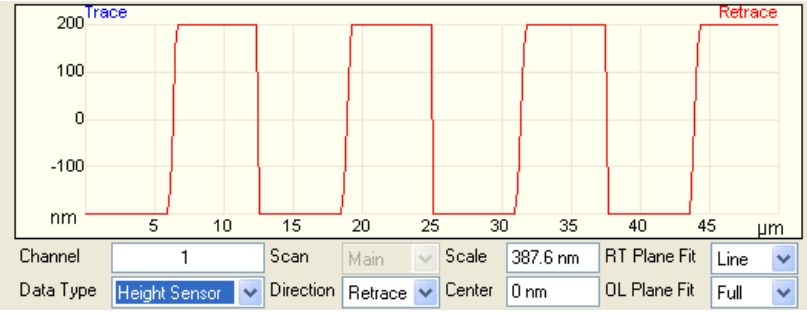
Parameters listed in the **Scan Parameter List** depend on the microscope selected, the **Experiment** type and the experiment **Mode**. Parameters necessary for one style of microscope are not applicable to another. For example, the **Drive frequency** and **Drive Amplitude** parameters are enabled on the **Feedback** tab only when the mode is set to TappingMode.

Some users find operating an SPM less confusing if the number of parameters is limited to only the most essential ones. For this reason, the **Simple Mode** contains the minimum number of user specified parameters.

3.1.8 Scope Trace Plot

The **Scope** window, shown in Figure 3.1z, displays a plot of the probe position versus channel data in an oscilloscope-type format.

Figure 3.1z Scope Grid



Scope Trace Interface

By right-clicking the **Scope** grid**,** you will get a menu of different options, shown in Figure 3.1aa.

Figure 3.1aa Scope Grid Parameters

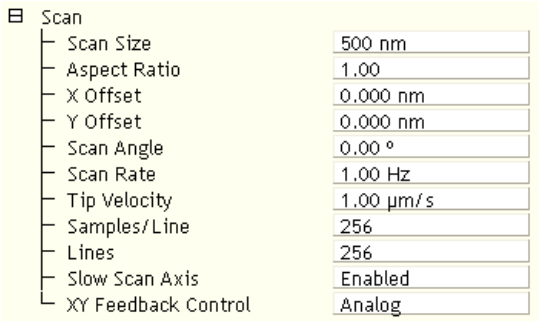
These menu options allow you to make the following changes:

Color	Allows operator to change color of: • Curve (data) • Text • Background • Grid • Minor Grid • Markers
Filter	Typically used for a Profiler Scan. • **Type**—Allows the user to plot the mean, maximum or minimum y-value per x-value. • **Points**—Allows user to plot multiple vertical axis (y) values at each horizontal axis (x) value. Select 4K, 8K, 16K or 32K Points to limit the display to 4, 8, 16 or 32 times 1024 points.
Minor Grid	Places a minor grid in the background of the **Vision** Window.
Scale	Allows user to auto scale, set a curve mean, or set their own data range.
X Translate	Offsets the curve by placement of vertical cursor on the grid. Grab vertical cursor in the space above the grid and pull down onto grid.
Y Translate	Offsets the curve by placement of horizontal cursor on the grid. Grab horizontal cursor in the space next to the grid and pull onto grid.
Line Style	For each curve, operator can choose, connect, fill down, or point.
User Preferences	**Restore**—Reverts to initial software settings **Save**—Saves all changes operator has made during this session. This becomes the new default settings.
Copy Clipboard	Copies the grid image to the Microsoft Clipboard.
Print	Prints out the current screen view to a physical printer.
Export	Exports data in bitmap, JPEG or XZ data format.
Active Curve	Determines which curve you are analyzing.

3.1.9 Scan Panel Interface

The **Scan** panel, shown in Figure 3.1ab, includes parameters influencing piezo movement and data acquisition, as well as the ability to execute non-square scans. This panel is probably the most frequently used panel, as it controls what type of scan to run, how large the scan is, its angle, scan rate, and number of samples per scan line.

Figure 3.1ab Scan Panel Parameters, Contact in Expanded Mode



Scan Panel Parameters

Scan size

Determines the size of the scan by controlling the voltage applied to the X and Y piezos.

Range or Settings:

- **0** to **440V**
- **0** to **XXµm** (scanner-dependent)

The units of this parameter are volts if the **Units** parameter (**Other** panel) is set to **Volts**. The units are linear distance (nm or μm) if the **Units** parameter is set to **Metric**.

See also, Optimizing the Scan Size Parameter on page 123.

Aspect ratio

Controls the width-to-height size ratio of scans. Set the **Aspect ratio** to 1.00 for square scans. An **Aspect ratio** of 2.00 yields scanned images having width equal to twice the height.

Range or Settings: (depends upon the number of scan lines) **1** to **256**.

Figure 3.1ac Aspect Ratio Example

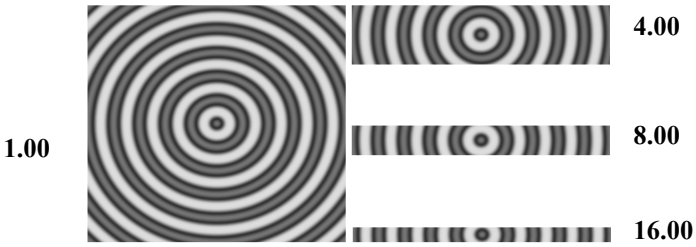
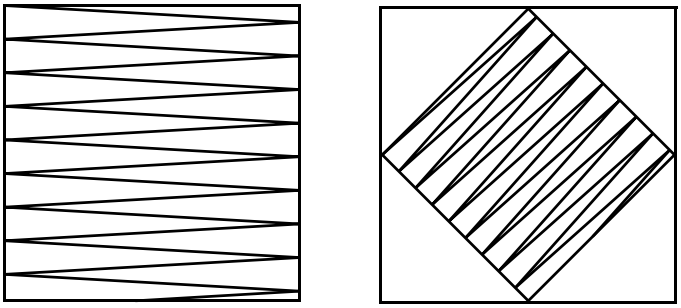


Figure 3.1ad Scan Angle Rotated Example.



X offset, Y offset

Controls the center position of the scan in the X and Y directions, respectively.

Range or Settings: **±220V**; **± XXµm** (dependent on **Scan size** and scanner).

See also, Optimizing the X Offset, Y Offset Parameter on page 124.

Scan angle

Controls the angle of the X (fast) scan relative to the sample.

Range or Settings: **0** to **359°** (Any angular value can be entered with the keyboard)

Changing this parameter can dramatically affect the quality of images due to tip effects (tip side wall angle).

Setting this parameter to a setting besides 0 or 90° may reduce the maximum allowable **Scan size** 10-20 percent due to corner constraints (see Figure 3.1ad).

Scan rate

The **Scan rate** sets the number of fast scan lines performed per second. When the Scan rates are low, it can take a fairly long time to scan an entire frame. For example, with the **Scan rate** set to **0.5Hz** and the **Number of samples** set to **512**, it can take over 17 minutes to capture a single image.

Range or Settings: **0.1-237Hz**, depending on the number of **Samples/line**.

See also, Optimizing the Scan Size and Scan Rate Parameters on page 124.

Lines

Selects the number of lines to scan in a frame. The **Lines** parameter reduces resolution along the Y axis. It also speeds imaging (or frame rate) and reduces the size of the resulting image file.

Range or Settings: **2** to **1024**. The maximum number of lines may be limited by the value for **Samples/line**.

Tip velocity

Velocity of the tip (in µm/s) as it scans over the surface.

When **Tip Velocity** is changed, the **Scan Rate** adjusts automatically.

Samples/line

Selects the number of sample data points per scan line.

When this parameter is changes, the number of scan lines per image (**Lines**) are automatically adjusted to maintain the same ratio between the samples/line and lines per image.

Range or Settings: **128** to **16384**. This setting influences the memory size of captured files and image resolution (see Table 3.1a).

Table 3.1a File Size/Samples per line

Samples/line value	File size (for square scans, including 8K header)
128	40Kb
256	136Kb
512	520Kb

Note: **Samples/line** should be kept at 512 or higher for high resolution scans. To increase the frame rate (rate at which complete images are generated), the **Lines** parameter should be reduced. When the **Lines** parameter is reduced, file sizes in Table 3.1a are reduced accordingly.

Slow scan axis

Allows the slow scan to be disabled, causing the fast scan to be repeated continuously at the same position. This means that the image displays the same line continuously. Images may be presented either as "true" X-Y renderings of the sample surface (Enabled), or as "stretched" single-line scans of length equal to the **Scan size** (Disabled).

Range or Settings:

- **ENABLED**—Sample is scanned in the slow scan direction. (This is the normal setting of this parameter.)
- **DISABLED**—No scanning of the sample in the slow direction is performed. The fast scan is repeated at the same position.

Note: Disabling the **Slow scan axis** and viewing the **Scope** display is a convenient way of setting the **Feedback Gain** parameters.

The advantage of using the **Slow Scan Axis** > **DISABLED** parameter is to emphasize one area (line) to adjust the SPM parameters. For example, an area of the image that appears fuzzy (suggesting SPM parameters are not optimized for the sample). **DISABLE** the **Slow Scan Axis**, view the **Scope** trace, and reconfigure scan parameters to optimize the scan.

Note: Setting the **Slow scan axis** parameter to **DISABLED** stops the slow scanning of the piezo, but does not stop the movement of the Realtime display in Y. Lines are replicated in the Y direction.

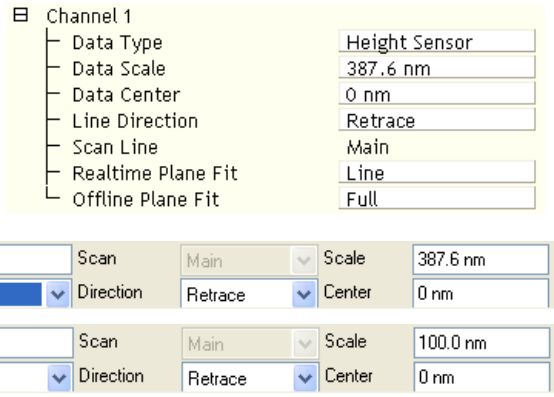
3.1.10 Channels Interface

The Channels interface (see Figure 3.1ae) consists of parameters for eight channels. Each channel represents a unique scanning image. Up to eight data **Channels** may be opened by selecting each channel and choosing a data type to view simultaneously. Channels are numbered **1**, **2**, **3**... and feature their own control panels. When a Data type is selected on a Channel, its image appears. It is possible to have up to eight separate images from each scan. For example, a TappingMode scan might simultaneously present a **Height Sensor** image on **Channel 1**, a **TM Deflection** image on **Channel 2**, and a **Phase** image on **Channel 3**.

Parameters shown on each **Channel** control panel vary slightly, depending upon the type of microscope selected and operating mode.

You may access the Channel controls through either the panel below the scope trace of each channel or the Channel panels in the **Scan Parameter List** in the **EXPANDED MODE**. See Figure 3.1ae.

Figure 3.1ae The Channels Interfaces: Scan Parameter List, Expanded Mode (top); Scan Interface (below)



Channel Parameters

Data Type — Settings vary, depending upon the microscope selected and operating mode as shown in the field descriptions below. The **Data Type** parameter may receive: no data (**OFF**); sample-height data (**HEIGHT**); cantilever oscillation amplitude data for TappingMode (**AMPLITUDE**); cantilever deflection data (**DEFLECTION**); STM current data (**CURRENT**); phase data (**PHASE**).

See also, Optimizing the Data Type Parameters on page 125.

Data Type Range or Settings

Amplitude (TappingMode and Force Mode only) — The RMS of the cantilever amplitude signal is displayed and captured.

Current (STM only) — Data displayed and captured is the tunneling current generated by the preamplifier. (When set to **Current**, the units of the data are **nA**.)

TM Deflection — Cantilever deflection signal data is displayed and captured. (When set to **TM Deflection**, the units of the data are in distance or volts.)

Height — The Z piezo voltage set by the feedback calculation in the Digital Signal Processor (DSP) is displayed. (The displayed data comes from the voltage output to the Z piezo.) Units are distance (e.g., **nm**, **µm**, etc.). Standard imaging of topography.

Height Sensor — Displays the signal from the Z position sensor in the closed loop head.

Off — Channel is turned off.

Phase (MFM, EFM) — Phase data from oscillating TappingMode tips, generally used with Magnetic Force Microscopy (MFM) and Electrical Force Microscopy (EFM), is displayed and captured. This setting appears when the microscope is configured with an Extender™ Electronics Module.

Potential (EFM) — Surface potential data is displayed. (For detailed information on Surface Potential or EFM features, see Support Note 231, *Electric Force Microscopy on the MultiMode Systems*.)

Deflection — Cantilever deflection signal data is displayed

Friction — Torsional deflection signal data is displayed

Data scale

The Data Scale controls the Z scale corresponding to the full height of the display and color bar.

Range or Settings:

- **0.0067** to **440V** (**Data type** set to *height*, **Units** are set to *volts*).
- **XX** to **XXX µm** (Scanner dependent; where **Data type** is set to *height*, **Units** set to *metric*).
- **XX** to **XXX µm** (Sensitivity dependent; where the **Data type** is set to *deflection* or *amplitude*; **Units** are set to *metric*).
- **0.00003815** to **2.5V** or **20V** (**Data type** set to *amplitude*; **Units** set to *volts or deflection*)
- **0.0031** to **200nA** (**Data type** set to *current*; **Units** are set to *metric*).
- **0.0003052V** to **20V** (**Data type** set to *current*; **Units** are set to *volts*).

See also, Optimizing the Data Scale Parameters on page 125.

Data center

Offsets centerline on the color scale by the amount entered.

The **Data Center** offset does *not* become a permanent part of the data.

Range or Settings:

- **± 220V**

Line direction

Selects the direction of the fast scan data collection that is displayed in the image.

The feedback calculation is always performed regardless of the scan direction. This parameter simply selects whether the data is collected on the trace or the retrace. This parameter selects the relative motion of the tip to the sample.

Range or Settings:

- **TRACE**—Data is collected when the relative motion of the tip is left to right as viewed from the front of the microscope.
- **RETRACE**—Data is collected when the relative tip motion is right to left as viewed from the front of the microscope.

Scan line

The scan line controls whether data from the **MAIN** or **INTERLEAVE** scan line is displayed and captured.

Range or Settings: **MAIN** or **INTERLEAVE**

This parameter is not selectable when the **Interleave mode** parameter is set to **DISABLED**. The system is locked on the **Main** scan lines whenever the interleaved mode is turned off.

Realtime Planefit — Applies a software *leveling plane* to each Realtime image, removing up to first-order tilt. Three types of planefit are available to each Realtime image.

Range or Settings:

- **NONE**—Only raw, unprocessed data is displayed.
- **OFFSET**—Takes the Z-axis average of each scan line, then subtracts it from every data point in that scan line.
- **LINE**—Takes the slope and Z-axis average of each scan line and subtracts it from each data point in that scan line. This is the default mode of operation, and should be used unless there is a specific reason to do otherwise.

Offline Planefit — Applies a software "leveling plane" to each captured image for removing up to first-order tilt. Three types of planefit are available to each Offline image.

Range or Settings:

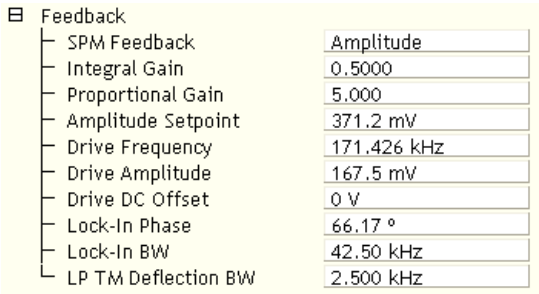
- **NONE**—Only raw, unprocessed data is displayed.
- **OFFSET**—Captured images have a DC offset removed, but they are not fitted to a plane.
- **FULL**—A best-fit plane which is derived from the data file subtracted from the captured image.

See also, Optimizing the Offline Planefit Parameter on page 125.

3.1.11 Feedback Interface

The **Feedback** parameters allow for monitoring the signals between the NanoScope Controller and the cantilever. These signals adjust the setpoint, oscillation frequency, drive voltage, Z response for surface tracking, and output voltages. The purpose of the **Feedback** controls is to maintain a constant setpoint (deflection, amplitude, or current) in the **Feedback Loop** for tip/sample control and tracking optimization. Parameters listed in the **Feedback** tab depend on the microscope selected and the **Mode**.

Figure 3.1af Feedback Controls Tab in **EXPANDED** TappingMode



Feedback Control Parameters

Z Modulation (Fluid TappingMode only)

Allows the user to add the drive oscillation signal to the Z piezo voltage. This parameter is used to set up fluid cell oscillation in any Dimension system for Fluid TappingMode.

Range or Settings:

- **ENABLED—**Enables Z modulation. Drive oscillation signal (Drive Frequency) is added to Z piezo voltage. **When enabled, the Z limit must be set ≤ 420V**.
- **0—**Disables the Z modulation (i.e., no additional signal is added to Z piezo voltage).

The desired **Drive Amplitude** and **Drive Frequency** voltages (**Cantilever Tune**) need to be set for Fluid **TappingMode** operation.

SPM Feedback

Selects the signal to be used for tip feedback according to the selected **Microscope Mode** parameter (**Other** panel). For Contact AFM, the choice defaults to **Deflection**; however, for TappingMode, you may select either the **TM Deflection** or the **Amplitude**. STM offers two choices of feedback: Linear and Log.

Range or Settings:

- **TappingMode—Amplitude**, **TM Deflection-Phase** (Forcemod only)
- **Contact Mode—Deflection** only
- **STM—Linear**, **Log**

Linear—*The linear difference between the instantaneous tunneling current and the* ***Setpoint*** *current is used in the feedback calculation.*

Log—*The difference between the log of the instantaneous tunneling current and the log of the* ***Setpoint*** *current is used in the feedback calculation.*

See also, Optimizing the STM Feedback Parameters on page 126.

Input Feedback

Controls Frequency Modulation (MFM or EFM) and Surface Potential.

Integral Gain

Controls the amount of integrated error signal used in the feedback calculation.

Range or Settings: ***0*** to ***1024***

See also, Optimizing the Integral and Proportional Gain on page 126.

Gain settings vary, depending upon the scanner used, the sample and scanner sensitivity. See Table 3.1b for approximate, nominal values (assumes a **Scan rate** of ≈ **2.5Hz**).

Table 3.1b Typical Integral Gain Ranges:

Scanner	Contact AFM and Forcemod	TappingMode	STM
A[a]	4.0 - 20.0	0.4 - 2.0	0.3 - 5.0

a. For atomic-scale images, scan rate must be increased to approximately 60 Hz.

Proportional Gain

Controls the amount of the proportional error signal used in the feedback calculation. The **Proportional gain** term in the feedback calculation has equal gain at all frequencies; therefore, it has a dominating effect over the **Integral gain** for high frequencies (scan rates).

Range or Settings: **0** to **1024**

(Typical settings for the **Proportional gain** parameter are 35-100% more than **Integral gain** values).

Setpoint

The meaning of this parameter depends on the operating mode of the microscope as follows:

Amplitude Setpoint (TappingMode)—defines the amplitude of the cantilever oscillation signal to be maintained by the feedback loop. (Range: **0.00** to **10.00V**)

Deflection Setpoint (Contact Mode)—Controls the deflection-signal level used as the constant desired voltage in the feedback loop. (Range: **-12.00** to **12.00 V**)

Current Setpoint (STM)—Controls the constant current maintained by the feedback loop. (*Range*: **0.0** to **100.0nA)**

Drive Frequency (TappingMode and Force Mode only)

Selects the oscillation frequency applied to the piezoelectric crystal that vibrates the cantilever.

Range or Settings: **0.00** to **250MHz**

The **Center Frequency** is adjusted with the **Cantilever Tune** command to find the resonance frequency of the cantilever. The maximum cantilever oscillation amplitude occurs at its resonant frequency. The software sets the **Drive Frequency** equal to the current **Center frequency** value when the **OK** button in the Cantilever Tune control panel is pressed.

Drive Phase (TappingMode and Force Mode only)

Selects the phase of the drive voltage applied to the piezoelectric crystal that vibrates the cantilever.

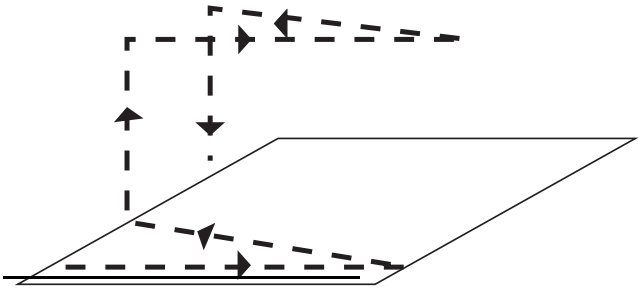
Drive amplitude (TappingMode and Force Mode only)	Selects the amplitude of the drive voltage applied to the piezoelectric crystal that vibrates the cantilever. *Range or Settings*: **0.00** to **20.00V** The **Drive Amplitude** is also adjusted with the **Cantilever Tune** command. Increasing the **Drive Amplitude** increases the cantilever-oscillation amplitude. The cantilever-oscillation amplitude is increased to an appropriate level with the **Cantilever Tune** command. In **AutoTune**, the **Drive Amplitude** automatically adjusts to get a cantilever oscillation (rms amplitude) equivalent to the user's **Target amplitude**.
Bias	Controls the sign and magnitude of the bias voltage applied to the sample. *Range or Settings*: **-10.00** to **10.00V** When used with STM, typical settings for the **Bias** voltage parameter are **20** to **100mV** for conductive samples and up to several volts with poorly conducting samples. Positive settings of the **Bias** voltage item correspond to negative current (electrons) tunneling from the tip into the sample on heads with the **Bias** applied to the **Sample** or **Tip**.
Analog 1, 3, 4	This voltage has no effect on the operation of the standard microscope, but is useful in custom applications. *Range or Settings*: **-10.00** to **10.00V**.
Aux Lockin	Directs an external input signal through the auxiliary lock-in amplifier.
Drive Phase	The phase of the AC bias signal applied to stimulate piezoresponse.
Lockin BW	The bandwidth of the effective bandpass filter centered on the TTL level reference frequency (i.e., the cantilever drive frequency in the NanoScope Controller) used by the main lock-in amplifier.
Lateral 16x Gain	Increases the lateral gain 16 times. This should be set to **Disabled** for most applications. *Range or Settings*: **DISABLED**, **ENABLED**

3.1.12 Interleave Mode

- **Interleave—**Adds a second, interleaved set of lines to the scan, which can be accessed from the Channel panel and captured as data. Invoking Interleave reduces the slow axis speed by one-half and doubles the capture time.

- **Lift—**A variant of Interleave, the Lift option uses the first set of scan lines to detect the surface, then lifts the probe above the sample surface on the interleaved set of scan lines according to the Lift start height and Lift scan height parameter settings. During the Interleaved scan, the tip mimics the surface topography from the previous surface scan line (see Figure 3.1ag).

Figure 3.1ag Interleave Lift Mode



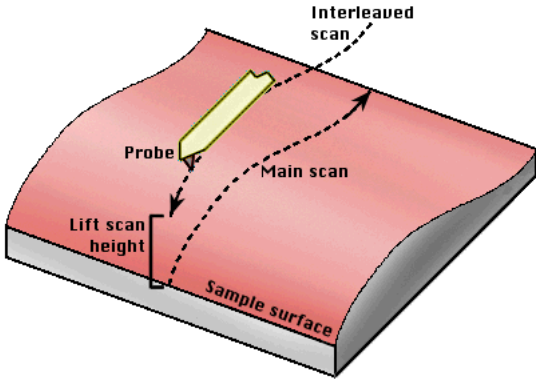
- **Disabled—**Turns off the interleave scanning.

Lift scan height Specifies the tip's height above the sample surface during interleaved scans. This parameter is in effect ONLY when the Interleave mode parameter is set to **Lift** (see Figure 3.1ah).

Range or Settings: XXµm (Scanner dependent)

The maximum meaningful value of the parameter depends on the Z voltages applied in the **Main** scan line and the maximum voltage that the system can output. The maximum voltage that can be applied to the piezo is ±220V. It will be lower if the Z voltage is restricted by the **Z limit** parameter.

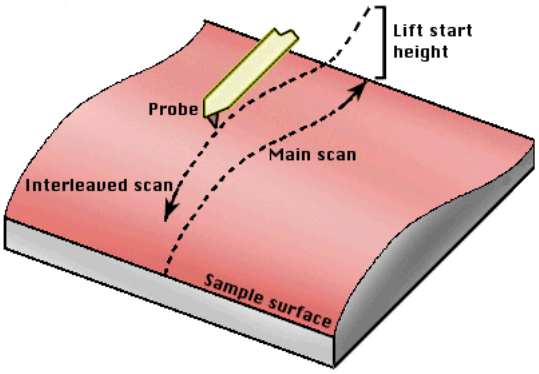
Figure 3.1ah Lift Scan Height Illustrated



Lift start height Specifies the height that the tip is to be lifted above the sample surface at the start of each interleaved scan. Generally, this parameter serves to lift the tip clear of any contamination layers present on the sample before assuming its Lift scan height during interleaved scans. This parameter is in effect ONLY when the **Interleaved mode** parameter is set to **Lift**. This parameter defines an offset from the Z voltage, or height, applied to the piezo on the **Main** scan line.

Range or Settings: XXµm (Scanner dependent)

Figure 3.1ai Lift Start Height Illustrated



Tips for Using the Lift Start Height Parameter

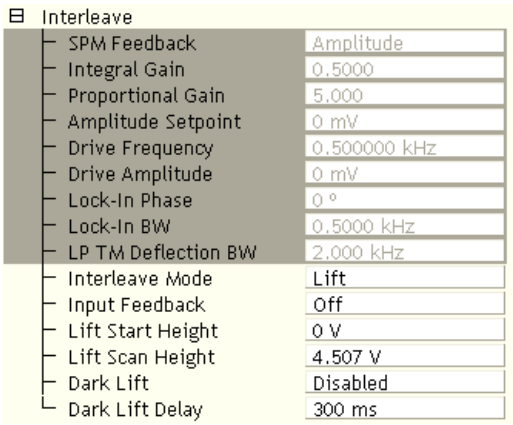
- This value can be left at zero for TappingMode and STM. It is generally only used for Contact AFM to break the tip free of the adhesive force produced by the water layer before settling to the final tip height.

The tip will go through this height at the start of every lifted scan line, then proceeds to the lift scan height for the rest of the scan line.

Linked Parameters Range or Settings

Several parameters (e.g. Z modulation, SPM Feedback, etc.) are highlighted by dark gray or green background. Dark grey indicates that the parameters are coupled with the equivalent values in the Feedback panel. By selecting (left-click) the Interleave parameters, the grey field turns green, indicating that the Feedback and Interleave parameters are decoupled and the value in those parameters will be used as feedback during the interleave scan line.

Figure 3.1aj The Interleave Panel



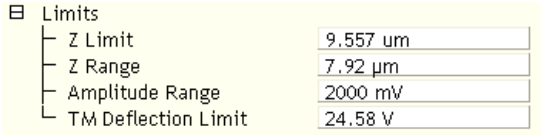
Input Igain Integral gain for Frequency modulation. Controls the feedback loop that uses phase electronics.

Input Pgain Proportional gain for Frequency modulation. Controls the feedback loop that uses phase electronics.

3.1.13 Limits Panel

The Limits panel, shown in Figure 3.1ak, sets the Z tracking limits.

Figure 3.1ak The **Limits** Panel



Z limit

Permits attenuation of maximum allowable Z voltage and vertical scan range for achieving higher resolution (smaller quantization) in the Z direction.

Range or Settings:

11 to **440V** (with Units set to Volts) for the XY Closed loop head
11 to **330V** (with Units set to Volts) for the XYZ and Dimension Icon Closed loop head

Note: In previous software versions, engaging with **Z LIMIT** ≠ Z max could result in a tip crash and the operator was warned by a message on the screen. Engage in versions 7.0 and later is always done with **Z LIMIT** = **Z MAX**. Therefore the warning is no longer needed.

Deflection Limit

Use this parameter for attenuating the input voltage signal (appears only when performing Contact AFM). Appears as **TM Deflection Limit** in Tapping mode.

Range or Settings:

- 2.500V to 20.0V for regular imaging
- 24.58V in **Force Mode** *only*

Amplitude Range

Use this parameter for attenuating the input voltage signal (appears only for TappingMode or STM).

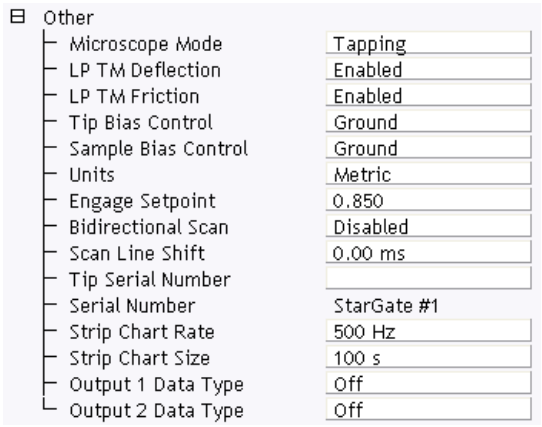
Range or Settings:

- 1000, 2000, 3000 or 4000mV for regular imaging

3.1.14 Other Panel

The **Other** controls parameters set the type of microscopy, units to use in measuring and other parameters specific the to microscope mode (i.e., the parameters that appear in the **Other** panel will vary from one microscope to another).

Figure 3.1al Other Panel



Parameters in the Other Controls Tab:

Microscope Mode — Selects the type of microscopy to be employed. Switching this parameter enables/disables other parameters. Also, on **MultiMode SPMs**, any change to the **Microscope mode** must be accompanied by use of the mode selector switch on the microscope's base.

Range or Settings:

Contact, **Tapping** or **STM**

Units — Selects whether the units of certain scan parameters are in Volts or in units of Metric distance (nm, etc.). Parameters affected include Scan size, X Offset, Lift start height and Lift scan height, Y Offset, Data Scale, Z Limit, Z Scan Start, Ramp Size, Column Step and Row Step.

Range or Settings:

- **Volts—**Parameters are in Volts.
- **Metric—**Parameters are in units of distance (nm, µm, etc.)

Engage Setpoint (TappingMode only)

Allows the user to correct for loss of tracking on engage due to sample differences. The automatic **Engage** procedure establishes the setpoint voltage at the smallest possible value that detects the sample surface, resulting in a value that protects both the sample surface and the cantilever tip. However, this value may not be sufficient for optimal surface tracking on all samples. The setpoint voltage determined by the automatic **Engage** procedure will be multiplied by the **Engage Setpoint** value, increasing or decreasing tapping force.

Range or Settings:

0.5 through **2.0**. A value of **1.0** results in no change to the tapping force. Values less than **1.0** increase the tapping force and values greater than **1.0** decrease the tapping force. A value of **0.9** is nominal for most samples.

Example of Engage Setpoint

The **Engage Setpoint** for a particular sample may be empirically determined. Procedures are as follows:

1. Set the **Engage Setpoint** to **1.0** and engage on the sample.
2. After engagement, make note of the **Setpoin**t parameter.
3. While watching the scan, adjust the **Setpoint** value until the tip tracks the surface correctly. Calculate the following:

   (Setpoint value/Starting Setpoint value) = Engage Setpoint
   (For optimal value, take the average of several engages on a selection of samples or different areas of the same sample).

Bidirectional Scan

When the Bidirectional scan parameter is **Enabled**, data from both Trace and Retrace scans are used to capture frames in half the normal time. Images have alternately shifted lines, which cause features to lose some of their lateral definition; however, data may be used for metrological analysis. Use to save time while capturing images.

Range or Settings:

Enabled or **Disabled**

When **Enabled**, features shown in images lose some lateral definition, making point-to-point measurements inadvisable. Vertical data, however, is unaffected.

Use the **Scan line shift** parameter to readjust images with the **Bidirectional scan** parameter **Enabled.** This will shift scan lines relative to one another to restore some lateral definition in features.

Scan Line Shift

Use the **Scan Line Shift** parameter to shift trace and retrace lines relative to one another by up to 5 pixels in either direction. Units are in pixels and range from -5 to +5. Scan line shift is used for readjusting images captured when the **Bidirectional** scan parameter is **Enabled**.

Range or Settings: **-5** to **+5**

This parameter is generally only for images that have been captured with the **Bidirectional scan** parameter set to **Enabled**.

Tip Serial Number

Saves input in the image header (Ciao Scan List) for users who keep a tip filing system. This is to keep track of the tips used for certain images.

Serial Number

Scanner Calibration file.

Min. Engage Gain (STM only)	Allows user to engage tip in *constant height* mode. In constant height mode, the gains (feedback) is disabled. However, the **Min**. **Engage Gain** parameter provides for gain during engagement.
Strip Chart Rate	Frequency of (Z-position, deflection) data point acquisition. *Range*: **1kHz** *Typical value*: **100Hz**
Strip Chart Size	Time interval over which (Z-position, deflection) data points are displayed. *Typical value*: Tens of seconds. Note: Although the strip chart collects and displays data over the time interval defined by clicking **Start**, then later, **Stop**, this data is not saved for subsequent use until the **Capture** icon is clicked. If **Capture** is clicked while strip chart data is being taken, what is saved begins at the start of the chart (sooner than the icon is clicked).

3.2 Tips on Using Realtime

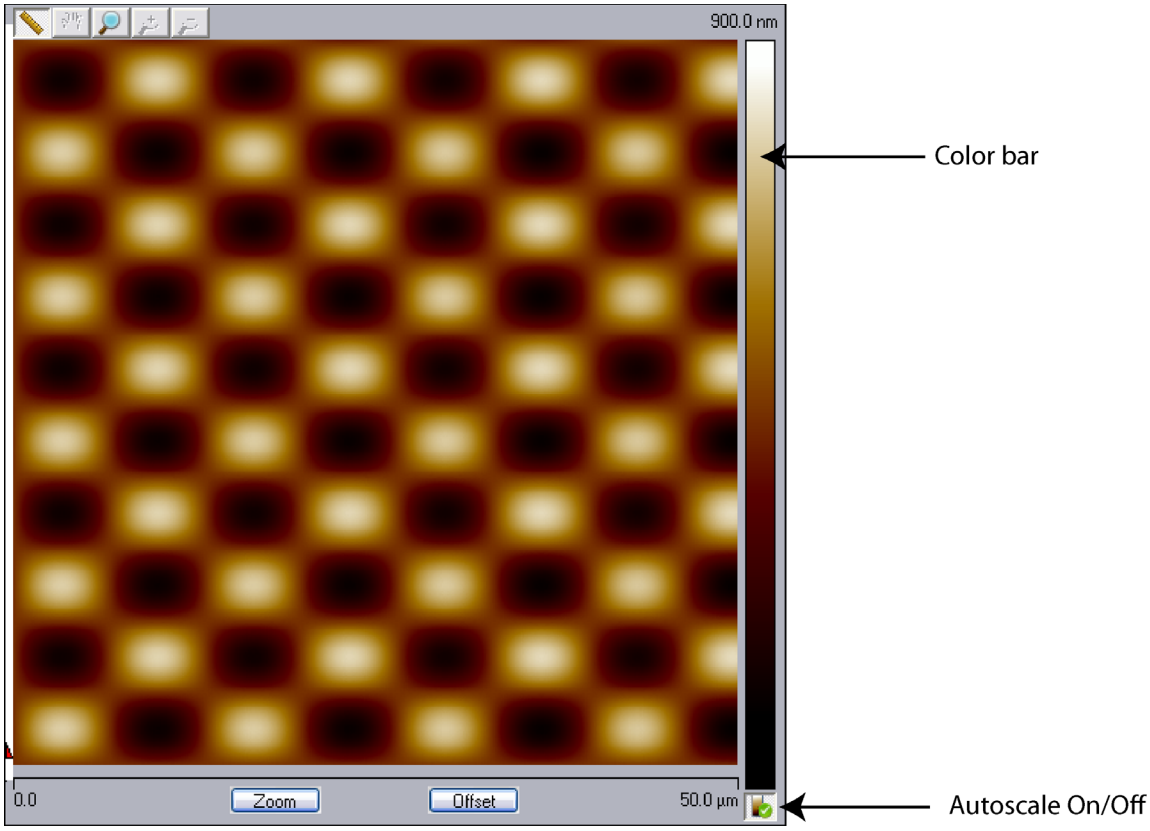
Refer to the following Realtime commands available on the NanoScope software:

- **Using the Image Interface** Section 3.2.1
- **Multiple Channels** Section 3.2.2
- **Hints to Optimize the Engage Button** Section 3.2.3
- **Tapping Engage** Section 3.2.4
- **Scan View Parameters Tips** Section 3.2.5
- **Channels Parameters Tips** Section 3.2.6
- **Feedback Parameters Tips** Section 3.2.7
- **Signal Access Software** Section 3.2.8

3.2.1 Using the Image Interface

There are various commands available for use during a Realtime scan. A description of these commands follows.

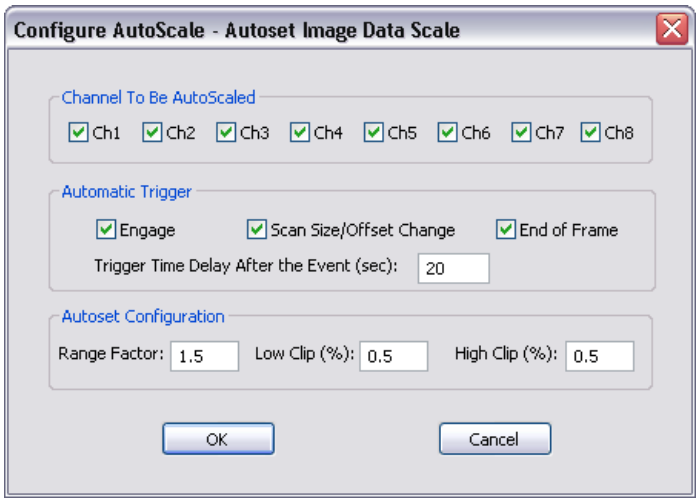
Figure 3.2a A NanoScope Realtime Scan Window



AutoScale

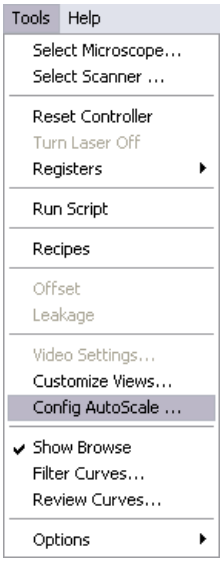
The **AUTOSCALE ON/OFF** button, shown in Figure 3.2a, appears below the color bar in both the image and thumbnail windows. Auto scaling is performed in selected windows according to user-defined auto scaling rules. These rules are defined in the **Configure AutoScale** window, shown in Figure 3.2b.

Figure 3.2b Configure AutoScale



Open the **Configure AutoScale** window either by clicking **TOOLS** > **CONFIG AUTOSCALE**, shown in Figure 3.2c, or by right-clicking an **AUTOSCALE ON/OFF** icon.

Figure 3.2c Click **TOOLS** > **CONFIG AUTOSCALE**

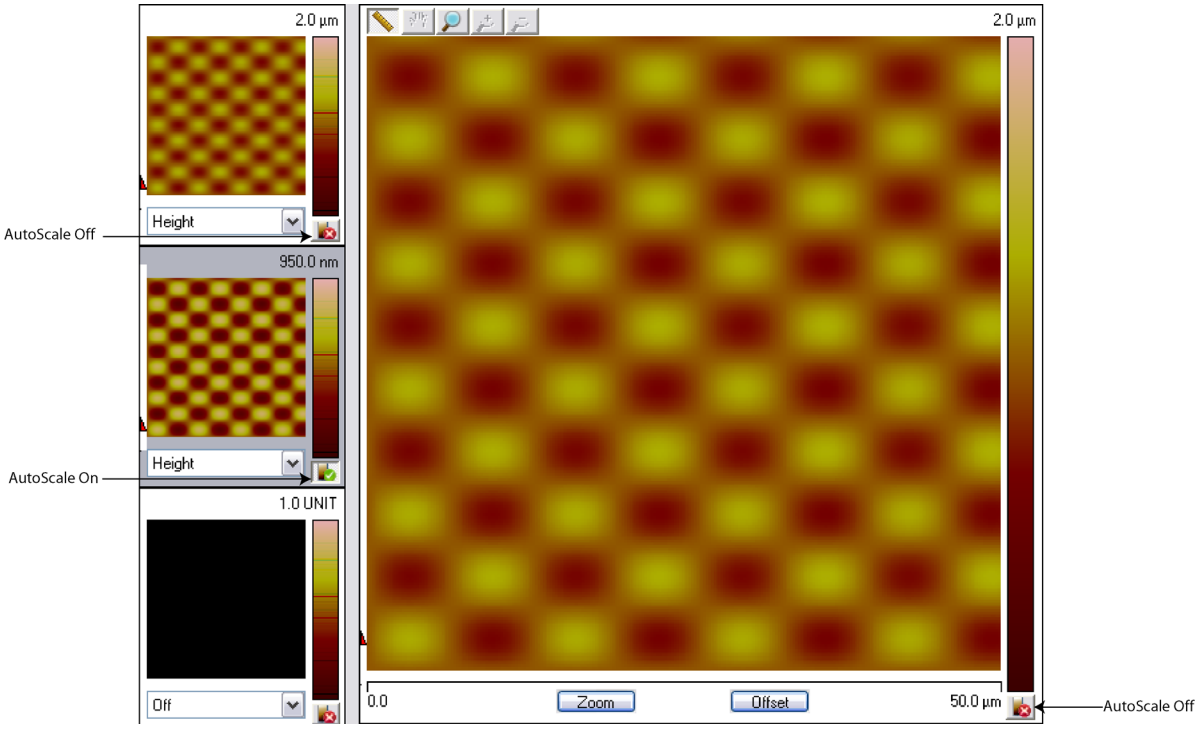


Channel to Be AutoScaled Panel

Ch1 ...	Check the channels that you wish to AutoScale.

Click the **AUTOSCALE ON/OFF** icon, shown in Figure 3.2d, at the bottom of the color scale to turn AutoScaling **ON** (green checkmark) or **OFF** (red X).

Figure 3.2d AutoScale On/Off



Automatic Trigger Panel

Engage	AutoScales the selected channels after engaging.
Scan Size/Offset Change	AutoScales the selected channels after a change in Scan Size or Offset.
End of Frame	AutoScales the selected channels at the end of a frame.
Trigger Time Delay After the Event (sec)	The delay after a trigger event before AutoScaling is applied.

Autoset Configuration Panel

Range Factor	Sets the vertical scale to be Range Factor * (range of data after clipping).
Low Clip (%)	The Low Clip function clips a small, user-adjustable, number of pixels to accommodate long tails in the bottom of the distribution. See Figure 3.2f.
High Clip (%)	The High Clip function clips a small, user-adjustable, number of pixels to accommodate long tails in the top of the distribution. See Figure 3.2f.

Figure 3.2e Height image of Hyaluronic Acid

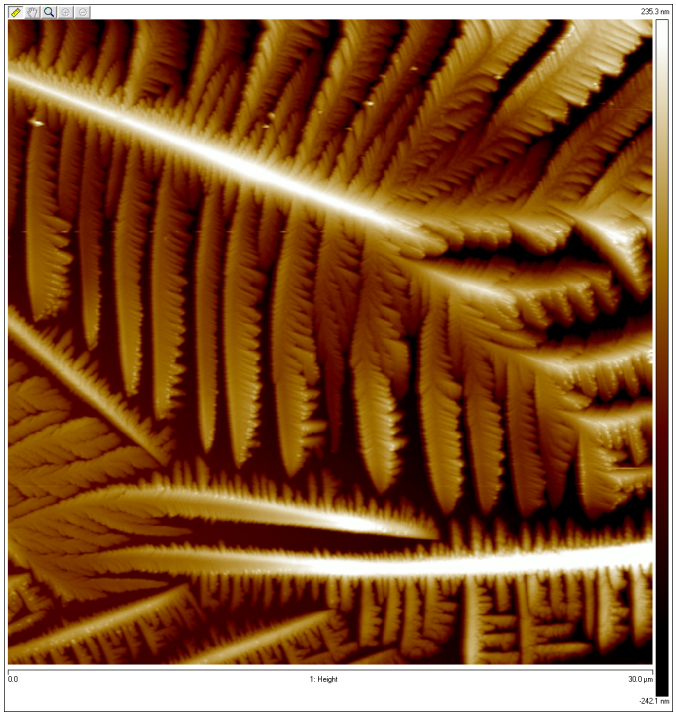
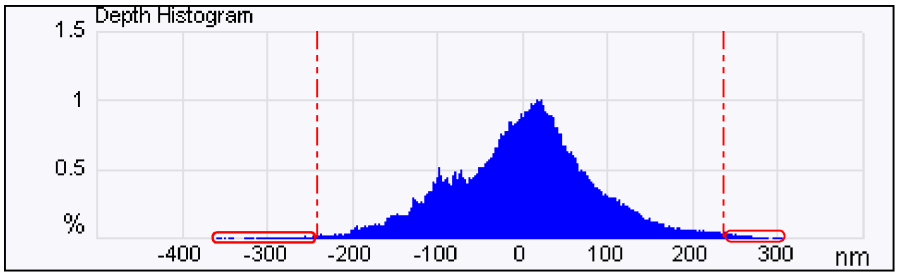


Figure 3.2f Histogram of image in Figure 3.2e with the **Low Clip** and **High Clip** portions circled.



You may force AutoScaling on all selected channels at any time by clicking the **AUTOSCALE IMAGE DATA SCALE** icon, in the NanoScope toolbar.

Image Buttons

The NanoScope image buttons, shown in Figure 3.2g, are located above the scan window and are described in Table 3.2a.

Figure 3.2g NanoScope image buttons

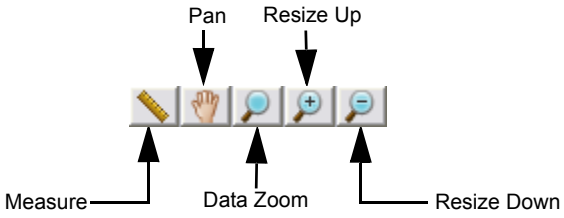
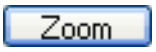


Table 3.2a NanoScope image buttons

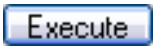
Measure	Allows you to draw a box to make measurements, translate the image or offset and resize the image.
Pan	From a zoomed image, you can pan around to other areas of the original image.
Data Zoom	Left-click, hold, and drag out a box. Release the mouse button and the image will automatically zoom in to the area of the box. The original scan size remains the same.
Resize Up	Resizes the image up to the previous zoom level.
Resize Down	Resizes the image down to the previous zoom level.

Zoom and Offset Buttons

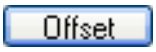
Three scan control button are below the **Scan** window:



- **Zoom**: Allows you to zoom in on a region of interest.
  - When you select **Zoom** a bounding box appears on the image display. Left-click on the outer edge of the box to resize.
  - Left-click in the center to reposition.
  - Click the **Execute** button to zoom in. This updates the **Scan size** and **X** and **Y Offset** parameters.



- **Execute**: Executes the **Zoom** and **Offset** commands. You must select the **Zoom** or **Offset** button for the **Execute** button to appear.



- **Offset**: Allows you to center the scan at the region of interest.
  - When you select **Offset** a crosshair displays at the center of the image.
  - Left-click and hold the crosshair to reposition it.
  - Click the **Execute** button to center the scan. This updates the **X** and **Y Offset** parameters.

Right-Clicking on the Image

By right-clicking on the image, you will get a menu that allows you to perform the following tasks:

- **Box:**
  - Draws a box when in **Measure** mode
- **Rotating Line**
  - Draws a line when in **Measure** mode
- **Copy Clipboard**: Copies the image to the Microsoft™ clipboard.
- **Tooltip Info Level**:
  - Basic
  - Medium
  - Advanced
  - None

Right-Clicking on the Color Bar

Right-clicking on the color bar along the right side of the image (see Figure 3.2a) will produce a **Color Scale** button (see Figure 3.2h). Clicking on this **Color Scale** button will open the **Color Adjust** menu, shown in Figure 3.2i, where you can perform the following image adjustments:

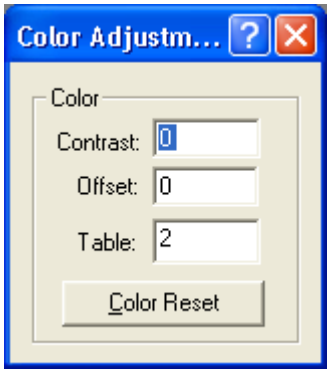
Figure 3.2h Color Button

a. You can adjust the color by changing the **Contrast** or **Offset** settings.

- **Contrast**—Number (-10 to +10) designates contrast of colors in displayed image (e.g., 0 shows little change, while 10 shows highest contrast).
- **Offset**—Number (-128 to +128) designates offset of colors in displayed image (e.g., 120 shows illuminated background on image).
- **Table**—Number (0 to 24) designates which color table will be used.

b. Clicking the **Color Reset** button will change all the current readings to the default settings.

Figure 3.2i Color Adjust Menu



c. To change the color table, position the mouse over the color bar on the right side of the image. Click and hold the left mouse button, then drag the mouse from left to right to scroll through the different color tables or set the table number in the **Color Adjust** window.

Using the Mouse Within a Captured Image in Measure Mode

Left-click anywhere in image window, drag line out, and release	Creates a line of X length, at X^o of angle in the image window.
Place cursor on line	Displays length and angle values of line in the image window.
Place cursor on line, click and hold left button, and drag	Allows you to drag the line anywhere in the image window.
Click and hold on either end of line and drag	Changes length and/or the angle of the line.
Right-click	Clicking the right mouse button when the cursor is on the line accesses the **Image Cursor** menu (see Figure 3.2j). • **Delete**—Deletes the line. • **Flip Direction**—Switches the line end to end. • **Show Direction**—Adds small arrowhead to the line to indicate its direction. • **Set Color**— Allows you to change the color of the line. • **Clear All**—Deletes the line.

Figure 3.2j Image Cursor Menu

Using the Grid Display

Measurement cursors for the **Scope** window are provided to the left and right of the Grid Display. You can bring the cursors into the grid by placing the mouse cursor outside of the grid, clicking and holding the left mouse button, and dragging them onto the grid. When you place the mouse cursor onto a measurement cursor, the cursor will change from a plus sign to a horizontal or vertical arrowhead cursor, which indicates you can grab and drag this cursor.

Right-clicking on the grid will bring up the **Grid Parameters** menu, shown in Figure 3.2k, and allow you to make the following changes:

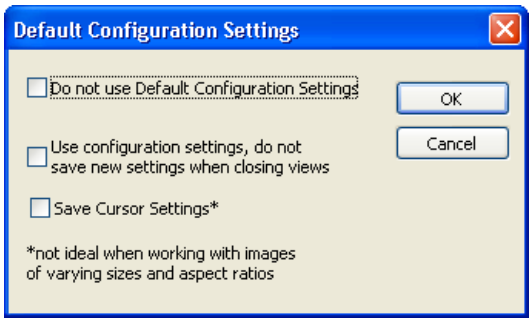
Color	Allows operator to change the color of the: • Curve (data) • Text • Background • Grid • Minor Grid • Markers
Filter	Typically used for a Profiler Scan. • **Type**—Allows the user to plot the mean, maximum or minimum y-value per x-value. • **Points** —Allows user to plot multiple vertical axis (y-)values at each horizontal axis (x-)value. Select 4K, 8K, 16K or 32K Points to limit the display to 4, 8, 16 or 32 times 1024 points.
Minor Grid	Places a minor grid in the background of the Vision Window.
Scale	Allows user to auto scale, set a curve mean, or set their own data range
Translate	Offsets the curve by the placement of a horizontal cursor on the grid
Line Style	For each curve, the operator can choose a connect, fill down, or point line.
User Preferences	**Restore**—Reverts to initial software settings **Save**—Saves all changes operator has made during this session. This becomes the new default settings.
Copy Clipboard	Copies the grid image to the Microsoft Clipboard
Print	Prints out the current screen view to a physical printer
Export	Exports data in bitmap, JPEG or XZ data format
Active Curve	Determines which curve you are analyzing

Figure 3.2k Grid Parameters

Default Configuration Settings

NanoScope software, starting with version 7.10, remembers your customized configurations, both **RealTime** and **Offline**. You may customize your use of this feature by selecting **Tools** > **Options** > **Default Configuration Settings**.This will open the **Default Configuration Settings** window shown in Figure 3.2l.

Figure 3.2l Default Configuration Settings Window



Default Configuration Settings Buttons

- **Do not use Default Configuration Settings**—Turns off the **Default Configuration Settings** feature and opens views using factory settings.
- **Use configuration settings, do not save new settings when closing views**—Uses your customized settings but does not save the current settings for future use.
- **Save Cursor Settings**—Saves the cursor locations. Cursors will appear when you open the same view at a later time. This only works well if you open a view with the same horizontal and vertical resolution.

3.2.2 Multiple Channels

It is often helpful to view more than one channel of data simultaneously. The Scan View Layout buttons, shown in Figure 3.2m, in the NanoScope toolbar allow you to display one, two or four channels simultaneously. The **SCAN DUAL** and **SCAN 8 CHANNELS** perform similar functions in the dual 19" monitor configuration. See Figure 2.3i.

Figure 3.2m Single monitor scan layout icons

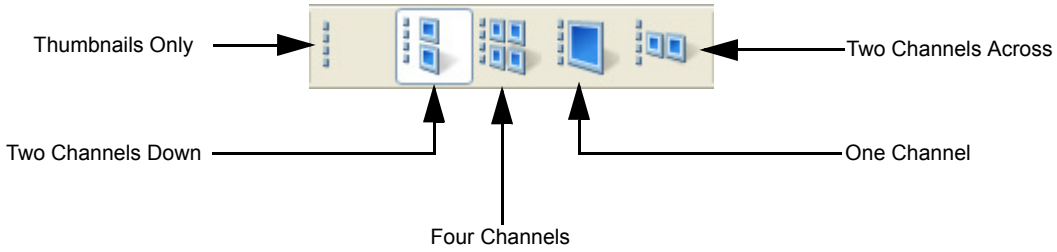


Image controls are displayed beneath each image.

The currently displayed channel is highlighted. The image parameters may be set independently for all channels including data type and scale, plane fitting and color table. Settings common to all channels can be set through the **Scan Parameter List**.

Typical examples of the use of multiple channels:

- To simultaneously monitor both a TappingMode height image and a phase image of the same region.
- To simultaneously collect a topography and MFM image.

3.2.3 Hints to Optimize the Engage Button

- When used with stepper-motor-engagement microscopes, the tip is lowered under program control. While the tip is being engaged, the tip travel distance is shown in the status bar. When the surface is detected, the workstation beeps, starts the RealTime imaging process, and displays **Engaged** in the status bar.
- During automatic engagement, the tip will travel a preset distance (200µm for Dimension AFMs, 125µm for MultiMode AFMs). If the sample surface is not detected in this distance, an error message will be displayed.
- If the tip is on the surface and the Z center voltage indicates that the piezo is near full extension or retraction, the tip may be withdrawn and re-engaged to center the Z center voltage. Alternatively, the *Tip Up* and *Tip Down* subcommands of the **Motor** command can be used to center the Z voltage. If the Z center position indicates that the scanner is retracted, click the Tip Up button until Z center is near 0V (0.50V).
- Pressing **Ctrl-F** will cause a false engage to occur after the SPM safety height is recycled for Dimension, causing the Realtime software to start scanning independently of whether the surface has been detected or not.

3.2.4 Tapping Engage

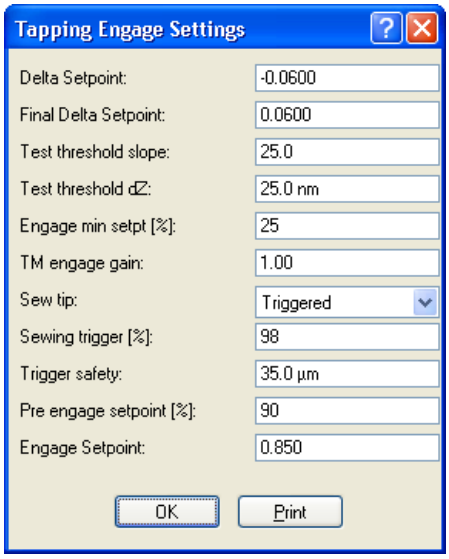
The **Microscope** > **Engage Settings** > **Tapping** window is designed to assist users in controlling key parameters associated with surface engagement during TappingMode. By using the **Tapping Engage** panel, however, users may minimize engagement times or tapping forces for specific conditions (e.g., TappingMode in fluids, etc.).

CAUTION: Adjustment of the **Tapping Engage** parameters can decrease engagement times during **TappingMode** by speeding the tip's travel to the surface and decreasing the number of test probes. Although this may save time, it also endangers the tip. You should always default to more conservative settings when in doubt; otherwise, you risk breaking tips.

Tapping Engage Panel

The Tapping Engage panel shown in Figure 3.2n illustrates recommended parameter values for most conditions. These settings yield an engagement time of 20 - 40 seconds.

Figure 3.2n Tapping Engage Window



Setpoint values represent percentages of a setpoint established internally by the software for engagement purposes (generally, about 90 percent of the tip's free-air amplitude). These values should *not* be confused with the **Setpoint** value indicated on the **Feedback** panel.

Parameters in the Tapping Engage Panel

Delta setpoint

Amount the setpoint is adjusted during each false engage test.

> **Note:** While in **TappingMode**, this tests for false engagement and assists in engaging the tip on the sample surface. Tests for false engagement help to avoid artifacts produced by light scatter, fluid film damping, etc. Therefore, a setting of **0.00** (no test for false engagement) is not recommended.

Range and Settings:

- **± 0—0.25** (default: **0.02**) A value of 0.25 (corresponds to ±25%) is the recommended maximum. If set to 0.00, the system will not test for false engagement.

Final delta setpoint

Percentage of setpoint value (internally set) to be used *after* tests for false engagement are concluded. This is the amount of temporary "overdrive" used by the system to verify whether the sample is, in fact, engaged by the tip. If this test is passed, the setpoint is restored to the last value used during false engagement tests.

Range and Settings:

- **0.00—0.50** (corresponding to 0 to 50 percent)

  Note: This value is usually set equal to the **Delta setpoint**. It represents a cumulative value which is eventually reached in a series of **Delta setpoint** increments (rather than one, single test). For example, with an engage delta setpoint of 0.02 and a final delta of 0.10, five extra tests will be run after "engagement" to verify that the tip is actually on the surface (0.10 ÷ 0.02 = 5).

  Note: If problems persist with false engagement, set the **Final delta setpoint** to a value that is 2-3 times the engage delta setpoint.

Test threshold slope

Slope value obtained by dividing the change in Z piezo voltage by the change in setpoint, which ultimately represents an envelope within which engagement is detected.

Range and Settings:

- **0.11—1000** (default: **100**)

  Note: Because changes in Z piezo voltage units occur approximately 200 times per unit change of setpoint, slope values tend to be between **5—1000**.

  Note: The higher the slope value, the greater the chance of "false engagement." Lower values are recommended for most applications. Using much lower values may reduce tip life.

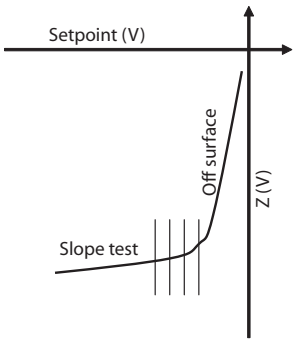
Test threshold dZ

Similar to **Test threshold slope**, above. Engage occurs when either **Test threshold slope** > dZ/dA (change in Z with respect to Amplitude - shown as Slope test in Figure 3.2o) or **Test threshold dZ** > dZ. The probe tip tapping amplitude drops markedly when the tip contacts the surface.

Range and Settings:

- **0.0—2000nm** (typical value: **25nm**)

Figure 3.2o Tip Amplitude While Approaching the Sample Surface



Engage min setpoint [%]

Lowest allowable percentage of setpoint value (internally set) used during engagement, representing the "last word" in tip-sample force. This value overrides other parameters determining setpoint during engagement.

Range and Settings:

- **10—90.** (typical value: **25**).

  Note: Lower values may endanger the tip and/or sample, as higher tip-sample forces will be employed.

  Note: Higher values represent lower, more conservative tip-sample forces; however, very high values will increase false engagements.

TM engage gain

Integral gain value used during TappingMode engagement. Once the surface is engaged, gain values revert to those displayed on the **Feedback** panel.

Range and Settings:

- **0.0100—10.00** (typical values: **0.5-2**)

Hints for optimizing the TM Engage Gain

- As **TM engage gain** is increased, the tip's vertical velocity downward increases. This parameter may be used to speed the engagement process and save time; however, if set too high, the tip and sample may be damaged.
- During engagement, gain values (**Integral** and **Proportional**) displayed on the **Feedback** panel are *not* utilized. Instead, the software sets its own integral gain based on this parameter.
- With normal (non-fluid) samples, higher values tend to accelerate engagement speed at the cost of endangering tips and samples. Use of a higher gain may be recommended for TappingMode scanning of hard samples in fluid; however, gain should be increased cautiously.
- Use of lower gain values will tend to increase engagement times; however, lower values are recommended for soft, delicate samples where impact is to be minimized.

Sew tip

Controls use of sewing during the engagement process to detect the surface. Sewing consists of moving the tip vertically with the Z piezo while lowering it toward the surface. If the surface position is well known, sewing may be triggered to save time.

Range and Settings:

- **Yes**—Turns sewing on. This is the normal, default mode.
- **No**—Turns sewing off.

  Note: Only used for testing purposes; typically results in a damaged tip.
- **Triggered**—Turns sewing on when the RMS amplitude reaches the specified Sewing trigger value. The Triggered switch is used to protect tips and samples and to decrease engagement time.

Sewing trigger [%]

Percentage of oscillation amplitude required to trigger sewing. This parameter is enabled *only* when the Sew tip parameter has been set to Triggered. Default setting is 98; not recommended at values less than 90.

Range and Settings:

- **1—100**; default setting = **98**.

  Note: Regardless of setting, this parameter may be overridden by the **Trigger safety** parameter.

Trigger safety [for Dimension series microscopes only]

Minimum height above sample surface at which sewing is turned on. This parameter overrides the **SEWING TRIGGER** parameter.

Range and Settings:

0—100 μm; typical setting = **20 μm**

CAUTION: To avoid damaging the tip or sample, the **Trigger safety** should be set to a value greater than the height of the tip, or the maximum peak-to-valley distance of surface features, whichever is greater. This parameter consists of a height above the surface as determined during the **TOOLS/STAGE** > **FOCUS SURFACE...** command.

Pre engage setpoint [%]

Used to set the setpoint of the tip prior to engagement by reducing the setpoint relative to the RMS amplitude.

Range and Settings

- **30—100**; default = **90**.

  Note: The usable range of this parameter is generally from **85** to **95**. This represents the starting value for the engagement cycle (see beginning of this section).

3.2.5 Scan View Parameters Tips

Optimizing the Scan Size Parameter

- The **Scan Size** and offsets can be set by using the **Zoom** and **Offset** subcommands in the **Scan View**.
- Non-zero **X** and **Y offsets** reduce the maximum **Scan size**. Each volt of **X** or **Y offset** reduces the maximum scan size by 2V.
- Having a non-zero **Scan Angle** will reduce the maximum allowable **Scan Size**.
- The maximum **Scan Size** will also decrease as the **Scan Rate** increases.

Optimizing the X Offset, Y Offset Parameter

- These parameters use the sample as the position reference. Therefore, a more negative **X Offset** value will move a feature in the current image to the *left* on the Image display Similarly, a more negative **Y Offset** moves a feature in the current image *down* on the Image display.

- Using the left-arrow and right-arrow keys when the cursor is in these parameters will decrement and increment these parameters by 10% of the **Scan Size**.

- Using the **Zoom** or **Offset** subcommands automatically changes the value of **X** and **Y offsets**.

Optimizing the Scan Size and Scan Rate Parameters

- The **Scan Size** and height of features on the sample will affect the maximum **Scan Rate** that should be used on a given sample. Scan rate should be set to a rate that allows the tip to closely track the sample surface in both trace and retrace. In general, larger scans and taller features require slower scan rates.

3.2.6 Channels Parameters Tips

Optimizing the Data Type Parameters

- The system can display up to four simultaneous Realtime images.
- The **Data Type** parameter does *not* switch the operating mode of the instrument, it simply changes the source of the data displayed.

Optimizing the Data Scale Parameters

- Data beyond the setting of the **Data Scale** is clipped for the RealTime display. Captured data, however, is not clipped. Independent of the settings of this parameter, the captured data will be correct unless it exceeds the maximum vertical range of the scanner.
- Each **Data Type** retains separate settings for **Data Scale**.
- **Data Center** is used to manually offset the trace data when Realtime Planefit is set to none.

The conversion of volts to **nm** or **nA**, is dependent on the value **Sensitivity Detector** parameters in the **Calibrate** > **Detector** panel.

For example, nanometers of cantilever deflection are calculated using the **Sensitivity** parameter in the **Force Calibrate** panel.

Optimizing Realtime Planefit Parameters

The setting of **Realtime Planefit** only affects the displayed data. It does not affect the captured data The parameters are described below.

- **None** displays the raw data in the scope window.
- **Offset** applies a zero order correction to each line of data so that the average height of the line is centered in the scope display.
- **Line** applies a 1st order correction, removing both tilt and offset from each line of data.

  Note: If features are not evenly spaced along the scan line, using **Realtime Planefit Line** can result in artificial tilting of the scan line.

Optimizing the Offline Planefit Parameter

- The **None** option should only be used in special cases. The **Offset** and **Full** options provide greater dynamic range in the data to reduce round-off and other errors in subsequent calculations.
- The **Modify** > **Flatten** and **Plane Fit** commands can also be used to level the data after it has been captured.

3.2.7 Feedback Parameters Tips

Optimizing the STM Feedback Parameters

- **Log** mode is preferable for most STM samples, because the tip responds in a more symmetric manner (i.e., the same going up and coming down). **Log** mode tends to linearize the entire feedback loop since $Z \approx \ln(i)$. The asymmetric response of the **Linear** setting distorts data.

Optimizing the Integral and Proportional Gain

- The **Integral Gain** is usually the major contributor to the performance of the feedback loop due to its “long term” influence. For this reason, it is usually adjusted before proportional gain.
- The integral term in the feedback calculation has the highest gain at low frequencies, and its effects diminish with increasing frequency.
- A nominal **Integral Gain** value may be obtained by slowly increasing the value until the piezo begins to oscillate, then decreasing the value until oscillation ceases. Oscillation effects are best viewed in the **Scope** window and show up first in error signal (i.e deflection or amplitude).
- The **Proportional Gain** parameter is typically set to 35 to 100% more than the **Integral Gain** value.

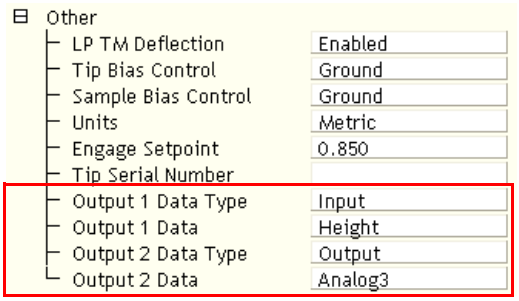
3.2.8 Signal Access Software

Signal Access Software[1] allows selected signals to be copied, at 10 micro-second intervals, to the Output 1/2 connectors on the front of the NanoScope V Controller. To use this feature:

1. Select the **Output 1** and/or **Output 2 Data Type** in the **Other** panel of the **Scan Parameter List** in **EXPANDED MODE**. See Figure 3.2p. **INPUT** allows selected input signals to be copied to the Output 1/2 connectors. **OUTPUT** allows selected output signals to be copied to the Output 1/2 connectors.

2. Select, using the **OUTPUT 1/2 DATA** field, the signal that you wish to be copied.

Figure 3.2p Select **OUTPUT 1 DATA TYPE**



1.This feature is optional on the NanoScope V-PI.

3.3 Force Curves

Force Curves ramp tip-sample separation while holding the X, Y position constant in the center of the previous scan. The scanner's vertical position is plotted versus either the cantilever deflection (Contact AFM), or the amplitude of the cantilever oscillation (TappingMode). Alternatively, the cantilever deflection or oscillation amplitude can be plotted relative to a user-designated input signal.

3.3.1 Force Curves Procedure

Ramp Settings

To obtain force curves, it is necessary to first engage in Scan Mode using one of the **Scan Views** (see **Preparing a Dimension Series AFM for a Realtime Scan** Section 2.5.2), then switch to **RAMP** mode. If you want to calibrate deflection sensitivity, use a hard sample in the following procedure.

1. Activate **RAMP**, mode by clicking the **RAMP** icon in the **Workflow Toolbar**. This causes the system to stop scanning, and the probe to position above the center of the previous image.

   Note: See **Ramp Parameter List** Section 3.3.2 - **Feedback Panel** Section 3.3.7 for a discussion of the **Ramp Parameter List** Parameters. When in **Ramp** mode, a ramp- specific menu also displays, the **Ramp** menu. See **Ramp Menu** Section 3.3.8 for more information.

2. Enter the following parameter settings in the designated panels of the **Ramp Parameter List**:

   a. In the **Ramp** panel select:

Parameter	Setting
Ramp output	Z
Ramp size	1.00µm
Z scan start	0nm
Scan Rate	1.00Hz
Number of samples	512

b. In the **Channel 1** panel select:

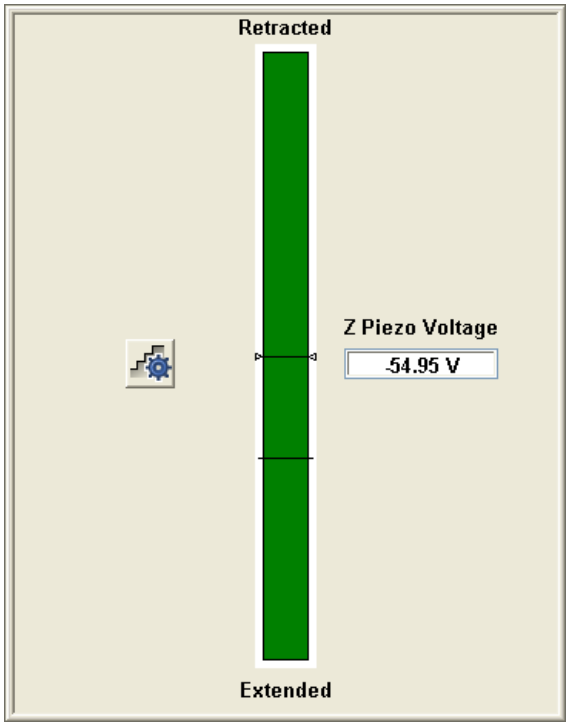
Parameter	Setting
Data Type	Deflection Error
X Data Type	Z
Display Mode	Deflection Error vs. Z

Gather Force Curves

1. Click the **RAMP CONTINUOUS** icon on the NanoScope toolbar or select **Ramp** > **Ramp Continuous**, from the menu bar.

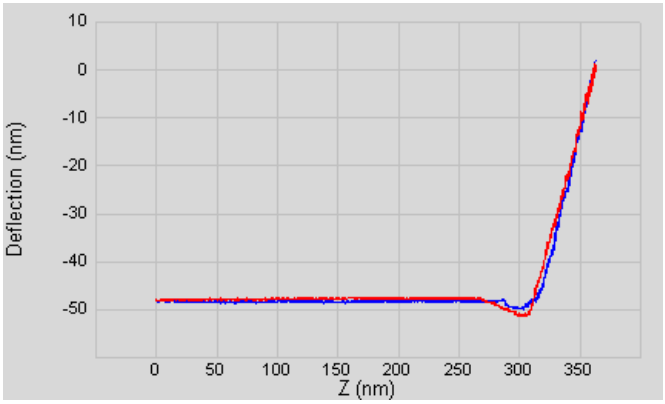
2. While watching the **Ramp Plot** and the **Real Time Status** bar graph (see Figure 3.3a), increase the **Z Scan Start** parameter to move the tip closer to the sample.

Figure 3.3a Bar Graph



3. When the force curve suddenly rises, the tip has reached the surface (see Figure 3.3b).

Figure 3.3b Force Curve



4. Click the **Capture** icon to save the force curve. Make note of the file name shown in the status bar (lower right corner of the window).

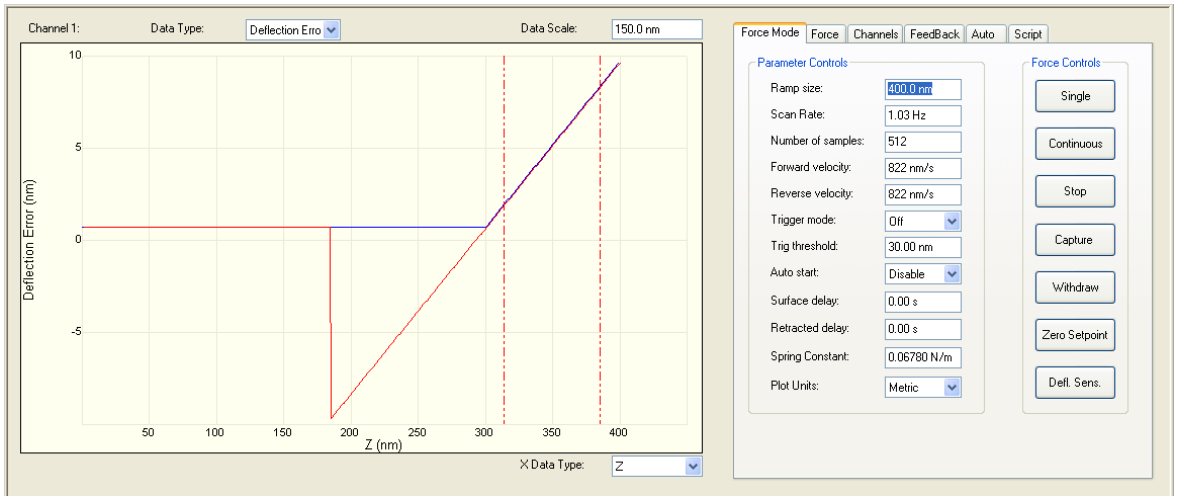
Calibrate Deflection Sensitivity

It is often necessary to calibrate the deflection sensitivity of a force curve. The deflection sensitivity depends upon several factors, such as the position of the laser spot on the cantilever, so it needs to be calibrated each time you change the probe. Use the following procedure to determine the deflection sensitivity:

1. Move two cursors onto the Deflection vs. Z plot (see Figure 3.3c).

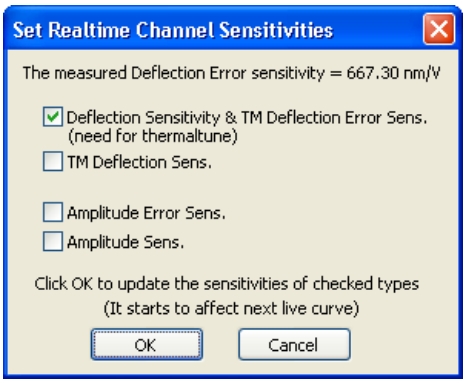
2. Arrange the cursors so that they surround the contact (steepest) portion of the graph (see Figure 3.3c).

Figure 3.3c Force Curve Cursors



3. Click the **UPDATE SENSITIVITY** icon in the NanoScope toolbar or select **Ramp** > **Update Sensitivity**. The software will automatically calculate the deflection sensitivity and open the Set Realtime Channel Sensitivities window (see Figure 3.3d).

Figure 3.3d Deflection Sensitivity Dialog Box



4. Click **OK** to accept this deflection sensitivity in the dialogue box that displays, and it will automatically be entered into the **Deflection Sensitivity** parameter in the **Channels** panel to the right of the plot (see Figure 3.3c).

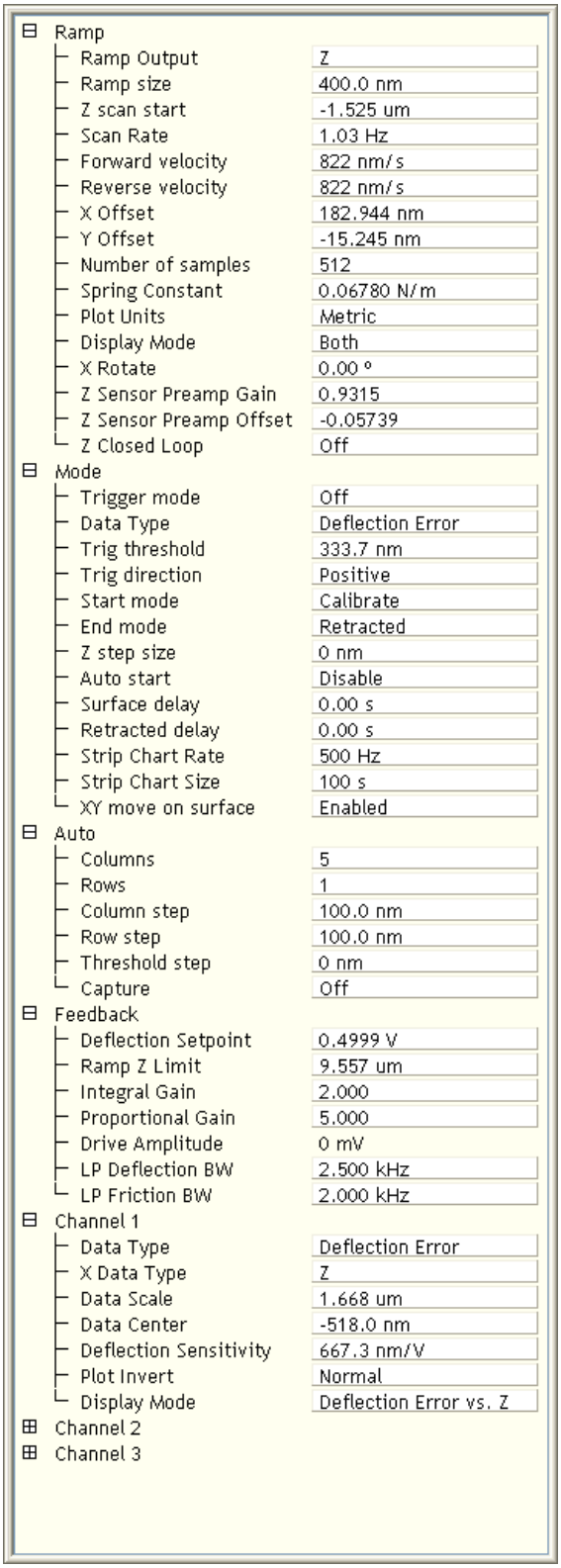
5. Replace the hard sample with the sample you wish to analyze. The deflection sensitivity will remain applicable as long as the position of the laser spot on the cantilever does not change.

3.3.2 Ramp Parameter List

When you open **Ramp** function, the **Ramp Parameter List** box displays (see Figure 3.3e). All force curve parameters can be set in the **Ramp Parameter List**. The **Ramp Parameter List** is sectioned into seven panels. The parameters in each panel are defined in the following sections:

- Ramp Panel on page 133
- Mode Panel on page 135
- Auto Panel on page 137
- Channel (1, 2 or 3) Panels on page 137
- Feedback Panel on page 138

Figure 3.3e Ramp Parameter List



3.3.3 Ramp Panel

Ramp Output: Specifies the **Ramp Channel**.

Ramp size: Specifies the range of the **Ramp Channe**l. Visible only if the Ramp Channel parameter is set to Z. Settings depend on the specified units.

Z scan start: Visible only if the **Ramp Channel** parameter is set to **Z** and **TRIGGER MODE** is **OFF**. **Z scan start** is the bottom position of the Z-axis scan as represented on the Real Time status bar. When the **Ramp** node is first accessed during imaging, this value is automatically set to the **Z Center Position**.

- *Range and Setting*s: The range of this parameter depends on the scanner. The units of this parameter are volts or nanometers, depending on the setting of the **Units** parameter.

  Note: The value of this parameter will need to be increased to move the sample closer to the cantilever in the case where there is no deflection of the cantilever for a displacement of the sample.

  Note: While the user is ramping Z in **Ramp Mode**, some feedback parameters are inactive.

Scan Rate: The **Scan Rate** sets the ramping rate. Changing this value effects the **Forward** and **Reverse Velocities**.

Forward Velocity: **Forward Velocity** of the tip (in µm/s) as it approaches the surface. Increasing this value increases the **Scan Rate**.

Reverse Velocity: **Reverse Velocity** of the tip (in µm/s) as it retracts from the surface.

X Offset: Controls the position of the range in the X direction.

Y Offset: Controls the position of the range in the Y direction.

Number of samples: Number of data points collected during each upward (retraction) and downward (extension) travel cycle of the piezo. The **Number of samples** parameter sets the pixel density of the force curve. This parameter does not change the Z scan size.

- *Range or Settings*: **16** to **19,968** data points displayed per extension and retraction cycle.

Spring Constant: Records the spring constant of the cantilever that is currently being used. This parameter is input by the user and is recorded along with each force plot captured. It is used for Offline analysis of the force plot. It is not critical to set the **Spring constant** in Realtime, since it can be altered in the Offline analysis of the captured force plot. The Spring constant is necessary to display a graph of force vs. separation if **UNITS** is set to **FORCE**.

Plot Units: Switches parameters in the control panels between units of Volts (V), Metric (nm or μm), or Force (nN). Changing this parameter also changes the setting of the **Units** parameter on the **Scan Parameter** panel.

- *Range or Settings*: **Volts** (V), **Metric** (nm) or **Force** (nN)

Display Mode: The portion of a tip's vertical motion to be plotted on the force graph.

- *Range or Settings*:
  - **Extend**—Plots only the extension portion of the tip's vertical travel.
  - **Retract**—Plots only the retraction portion of the tip's vertical travel.
  - **Both**—Plots both the extension and retraction portions of the tip's vertical travel.
  - If a channel other than Z is chosen, **Display mode** will not be available in Offline view.

X Rotate: Allows the user to move the tip laterally, in the X direction, during indentation. This is useful since the cantilever is at an angle relative to the surface. One purpose of **X Rotate** is to prevent the cantilever from plowing the surface laterally, typically along the X direction, while it indents in the sample surface in the Z direction. Plowing can occur due to cantilever bending during indentation or due to X movement caused by coupling of the Z and X axes of the piezo scanner. When indenting in the Z direction, the **X Rotate** parameter allows the user to add movement to scanner in the X direction. X Rotate causes movement of the scanner opposite to the direction in which the cantilever points. Without **X Rotate** control, the tip may be prone to pitch forward during indentation. Normally, it is set to about 22.0º.

- *Range or Settings*: **0** to **50º**; most effective values are between 15 and 25º.

3.3.4 Mode Panel

Trigger Mode: Limits the amount of force exerted by the tip upon the sample. It is possible to operate the trigger independent of drift (Relative) or at some arbitrarily fixed point (Absolute) depending on the trigger settings.

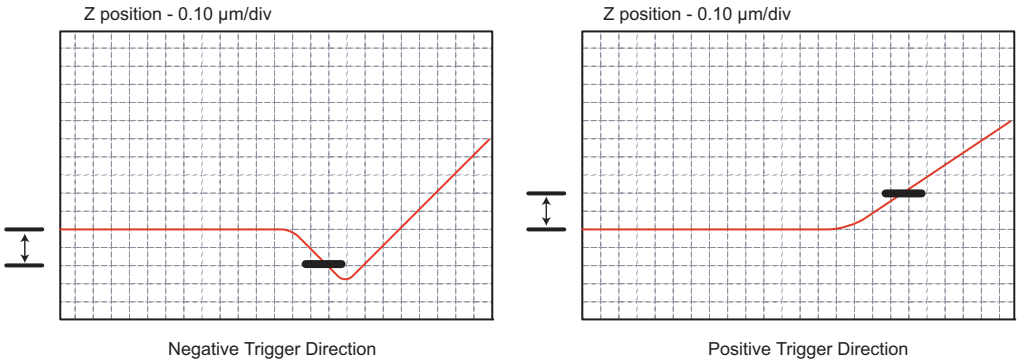
Data Type: Channels may be assigned for triggering to any input signal available including: **Deflection**, **Amplitude**, **Phase** or **Friction** data.

Trig threshold: The value of the cantilever deflection, as measured by the photodetector, desired for the indentation or scratch. The **Trigger threshold** defines the maximum force applied to the sample corresponding to the upper right-most point on the force plot.

- *Range or Settings*: **-10V** to **+10V**, depending on the **Deflection Limit**. Try 0.5V to 1.0V.

Trig direction: Determines the direction of the trigger and allows for a Positive, Negative, or Absolute trigger slope. In this way, the trigger may be configured to activate on either the positive or negative direction of the force curve.

Figure 3.3f Trigger Direction



Start Mode: Start mode allows you to switch between the various force modes without returning to image mode.

- *Range or Settings*:
  - **CALIBRATE**—Produces standard force plots. Includes the ability to continuously cycle the tip up and down.
  - **STEP**—Produces standard force plots, with added control to step the tip towards the surface.
  - **MOTOR STEP**—Tip is stepped towards surface using the motor.
  - **INDENT**—Starts optional nanoindentation mode. Available only in TappingMode.

End Mode: Determines the location of the tip when the microscope is returned to Image mode. Choices include **Extended**, **Retracted**, or **Surface**.

Z Step Size: The change in tip height per step when using force step.

Auto Start: When enabled, autostarts ramping when entering from **Image mode**. If off, you must start ramping by clicking the **Continuous** or **Single** icon, or by selecting the proper menu selection under the **Ramp** menu.

Surface Delay: Specifies a delay when the tip reaches the point closest to the sample.

- *Range or Settings*: **0** to **200 seconds**

Retracted Delay: Similar to **Surface delay**, this value specifies the duration of the delay when the piezo is at the top of the cycle (farthest away from the sample).

- *Range or Settings:* **0** to **200 seconds**

Strip Chart Rate: Frequency of (Z-position, deflection) data point acquisition for strip chart (only available for Picoforce and NanoMan).

- *Range*: **0.01Hz** to **1kHz**. Typical value: **100Hz**.

Strip Chart Size: Time interval over which (Z-position, deflection) data points are displayed in the strip chart.

- *Range*: **10** to **360,000,000 sec**. Typical value: **100 sec**.

  Note: Although the strip chart collects and displays data over the time interval defined by clicking **Start**, then later, **Stop**, this data is not saved for subsequent use until the **Capture** icon (shown) is clicked. If **Capture** is clicked while strip chart data is being taken, what is saved begins at the start of the chart (sooner than the icon is clicked).

3.3.5 Auto Panel

The Auto Panel parameters are only applicable when Autoramping.

Columns: Number of points in the Y axis.

Rows: Number of points in the X axis.

Column step: Offset distance between points in the X direction.

Row step: Offset distance between points in the Y direction.

Threshold step: The trigger point at which the deflection or the current activates the position change.

Capture: State is either **ENABLED** or **OFF**. When **ENABLED**, the software records and stores the ramp data for each data point in the matrix of rows and columns.

3.3.6 Channel (1, 2 or 3) Panels

Data Type: Channels may be assigned to any input signal available including: **DEFLECTION ERROR**, **AMPLITUDE**, **PHASE**, **FRICTION** and so on. Any channel may be switched to **OFF**, however, *at least one channel* is always on.

X Data Type: Type of data that the channel data is being compared to. This data displays on the X-axis of the scope grid.

Data Scale: Voltage range for the vertical axis of the force curve plot.

> **Note:** This can be overridden by selecting **AutoScale ON** for the plot.

Data Center: Offsets centerline of scan by the amount entered.

> **Note:** The Data center offset does *not* become a permanent part of the data.

- *Range or Settings*: Depends upon the input signal, generally ± one-half of **data scale** maximum.

Deflection Sensitivity: Defines the conversion factor from cantilever deflection signal voltage to nanometers of cantilever displacement (in nm/V) using data in the contact region of a force plot.

Plot Invert: Inverts data along the Y-axis, effectively turning valleys into mounds and vice versa.

Average Points: Averages multiple points to smooth the curve.

Effective BW: A display (you cannot input a value to it) representing the sampling frequency with display averaging taken into account:

Effective BW = (force plot sampling rate)/(**Ave. Points**)

Phase Offset: Shift horizontal position of plot to compensate for averaging of endpoint data.

Note: The numerical values of the two **Phase Offset** parameters can be ignored; set them to whatever values minimize the apparent hysteresis. Particularly when **Forward Velocity** and **Reverse Velocity** are unequal, the same numerical value for each **Phase Offset** may not correspond to an identical displacement on each axis.

Display Mode: The data types to be plotted on the force graph. E.g. Amplitude vs. Z.

3.3.7 Feedback Panel

Only the Force Curve-applicable menu parameters are described below:

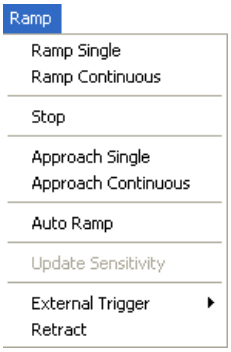
Deflection Setpoint: Defines the deflection signal, and therefore the tip-sample force, maintained by the feedback loop.

- *Range or Settings*: ± **12.0V** maximum

3.3.8 Ramp Menu

While the microscope is engaged and in Realtime mode, opening the **Ramp** parameters will display the **Ramp** Menu, shown in Figure 3.3g.

Figure 3.3g Ramp Menu



Ramp Menu Definitions

Ramp Continuous: The tip is continuously lowered and raised by a distance equal to the **Ramp size**. This is the normal, default motion during **Ramp Calibrate**. “Raising” and “lowering” are relative to your system (e.g., On Dimension Series SPMs, the tip is raised and lowered to the surface; however, other SPMs raise and lower the sample beneath the tip).

Ramp Single: Lowers and raises tip *once* by a distance equal to the Z scan size, then halts.

External Trigger: (Not available)

Stop: Halts all tip movement.

Retract: The Z-axis piezo retracts to its limit in preparation for **Approach Continuous**. This command does *not* initiate motor movements.

Continuous Approach: The tip lowers to the surface and raises in a controlled series of steps, then indexed by the Z step size (see Scan Mode panel) distance. This process continues downward until the tip encounters the surface. When tip deflection exceeds the **Threshold Step** amount, **Continuous Approach** halts and the resulting force curve displays.

Approach Single: The tip is lowered to the surface and raised in a single, controlled step. This process is halted if the surface is encountered by the tip, causing deflection exceeding the Step threshold amount. The resulting force curve is displayed.

> **Note:** For both **Approach Continuous** and **Approach Single**, if **Start mode** = **MOTOR STEP**, the motor is stepped towards the surface, not the Z piezo.

Auto ramp: Begins auto ramping as defined by the parameters specified in the **Auto Panel**.

3.4 Force Volume

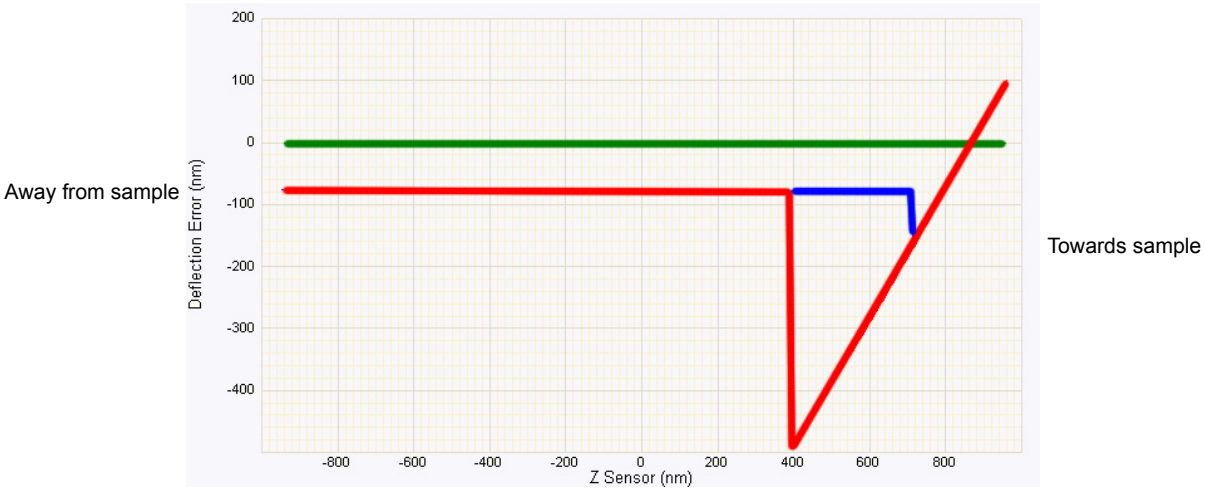
3.4.1 Introduction

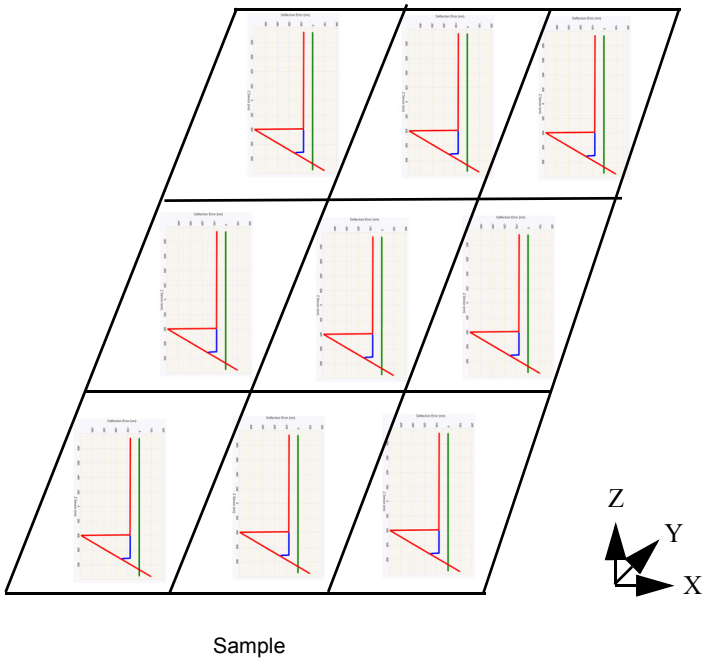
NanoScope Force Volume (FV) imaging with the atomic force microscope (AFM) combines force measurement with topographic imaging. Typical AFM images depict the topography of a surface by measuring the action of a feedback loop to maintain a constant tip/sample interaction as the tip is scanned across the surface. The force volume data set combines nearly simultaneously measured topographic and force information into a single data set allowing the microscopist to test for correlations between forces and surface features.

A single force curve records the force imposed on the tip as it approaches and retracts from a point on the sample surface (see Figure 3.4a, top). Force volume imaging associates each (X,Y) position with a force curve in Z for some selected range. By plotting these values along X and Y coordinates, you may view stratified layers of force at various Z-axis heights above the sample surface. The value at a point (X,Y,Z) in the volume is the deflection (force) of the cantilever at that position in space (see Figure 3.4a, bottom).

A force volume data set can be used to map in two or three dimensions the interaction forces between a sample and the AFM probe tip. Possible applications include studies of elasticity, adhesion, electrostatics and magnetics. Force volume imaging enables the measurement of forces at various Z-positions and at thousands of (X,Y) positions during a single image scan.

Figure 3.4a Force Curve with Both Extending and Retracting Traces (top)





Force Volume Array of (Identical in this Case) Force Curves (bottom)

3.4.2 Varieties of Force Volume Imaging

The matrix below summarizes each of the major imaging types.

Signal Type	Contact AFM	TappingMode
Amplitude		☑
Deflection	☑	☑
Friction	☑	
Phase		☑

The type of force image captured from a surface depends on how the SPM is set up. For example:

- If an magnetic force microscopy (MFM) image is being captured, force volume imaging (phase) allows the detection of long-range magnetic forces otherwise difficult to detect.
- For ordinary contact AFM, the use of force volume imaging (deflection) allows the user to see otherwise invisible electrostatic forces.

CAUTION: It is the responsibility of the microscopist to carefully define all force volume experiments. There are at least ten types of force volume imaging, including numerous combinations of triggers, drive frequency and amplitude, Z-axis direction, offset, etc. The utility of each image is subject to the interpretations and controls of the experimenter. This document does not cover all possible force volume types; therefore, discussion is limited to a general description of controls and an example in contact AFM. Experimentation is encouraged.

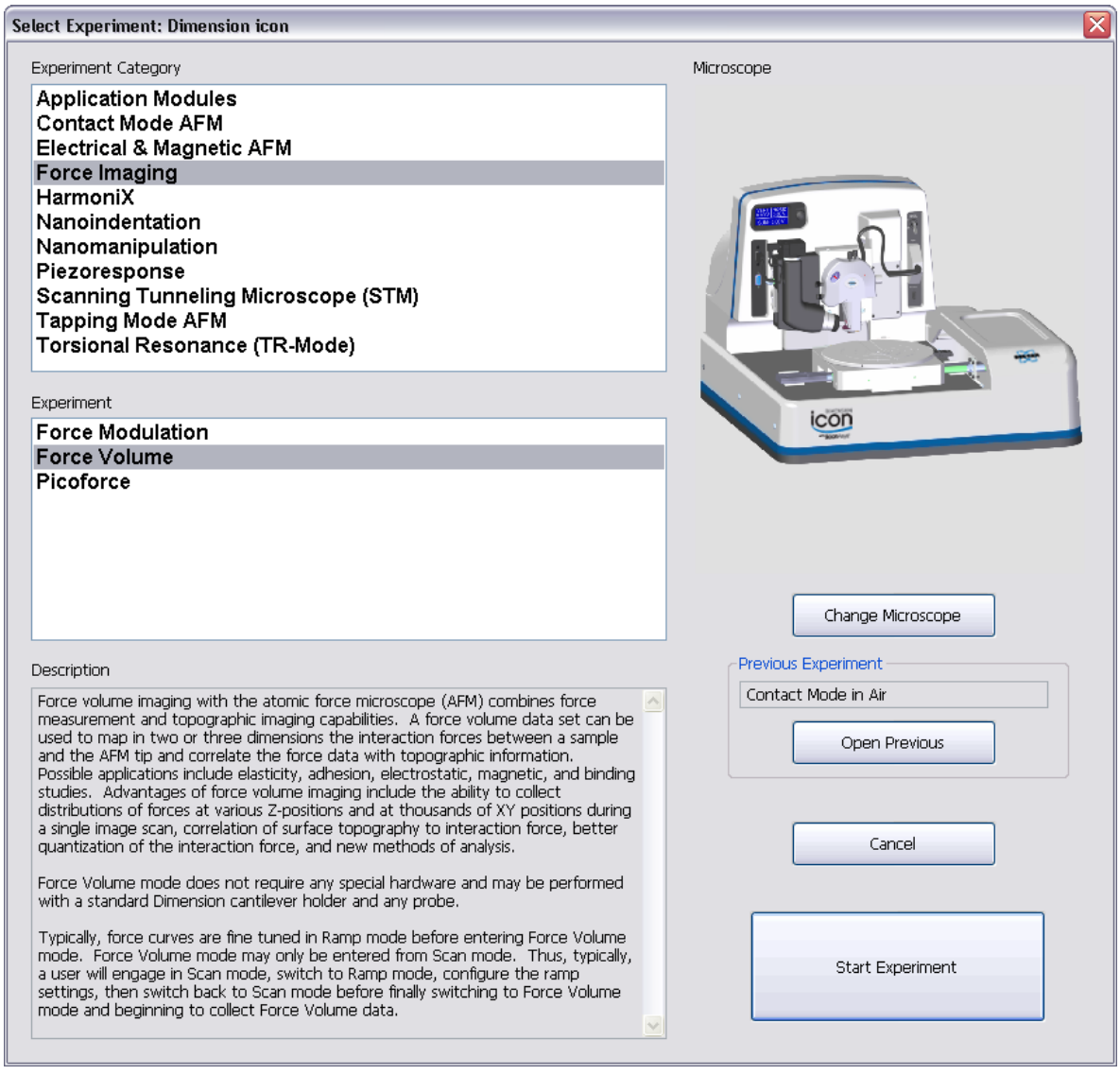
3.4.3 A Force Volume Imaging “Jump Start”

This section provides an overview of force volume imaging for the casual reader or the experienced experimenter eager to get started. Force volume images require preliminary use of the Force Measurement function.

The basic procedure for generating a force volume image follows.

1. Click the **SELECT EXPERIMENT** icon. This opens the **Select Experiment** window, shown in Figure 3.5a.

Figure 3.4b The **FORCE VOLUME Select Experiment** window



2. Select **Force Imaging** in the **Experiment Category** panel.

3. Select **Force Volume** in the **Experiment** panel and click **START EXPERIMENT**.

4. Create a height image of the surface of interest. This assigns values to image parameters, including image size.

5. Switch to **RAMP** mode and generate a standard force curve featuring both contact and non-contact tip/sample interactions. Set **SENSITIVITY** as described in your *SPM Instruction Manual* and set the **Deflection Limit** to `24.58V`. Set **Z scan rate**, **Z scan size**, and a **RELATIVE Trigger** with a **Trig threshold** of approximately 40 nm. Ensure that triggering is functioning properly before proceeding.

6. Switch back to Scan mode by clicking on the **SCAN** icon in the **Workflow Toolbar**.

7. Switch to **Force Volume** mode by clicking the **Force Volume** icon in the **Workflow Toolbar**. This opens the **Force Volume** window, shown in Figure 3.4c, and the **Scan** and **Force Volume Parameter Lists**, shown in Figure 3.4e.

8. Verify the force plot parameters are still in effect in all control panels. Set the number of **Samples per line** to `16`, the number of samples per force plot (**Number of samples** = `512`), and the number of force plots (**Force per line** = `16`) and start collecting data. Don't forget to capture the image.

Force volume mode displays the data in three separate, but interdependent, regions (see Figure 3.4c and Figure 3.4d). The top image displays height. The large middle image displays the force volume image. It is a horizontal (parallel to the sample surface) slice through the volume at a distance **Z display** above the piezo position at the deflection trigger. The girded region in the lower right corner of the screen displays force curves as they are collected. The position of the cross hairs determines the slice presented in the force volume region. The position of the horizontal cursor on the deflection axis of the force curves determines the offset of the scale bar in the force volume image. The position of the vertical cursor sets **Z Display**.

Figure 3.4c The Single Monitor **Force Volume** Interface

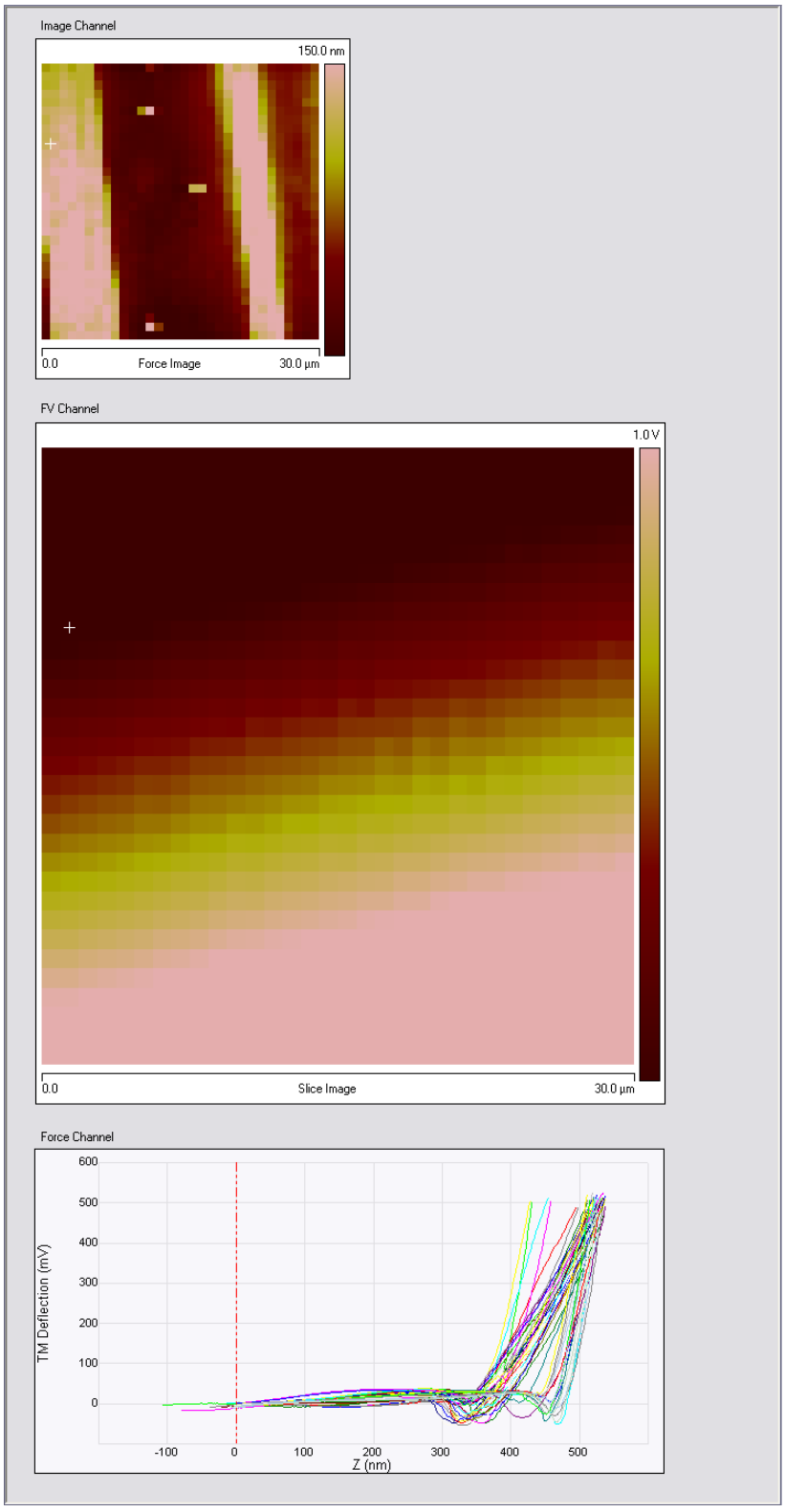


Figure 3.4d The Dual Monitor **Force Volume** Interface

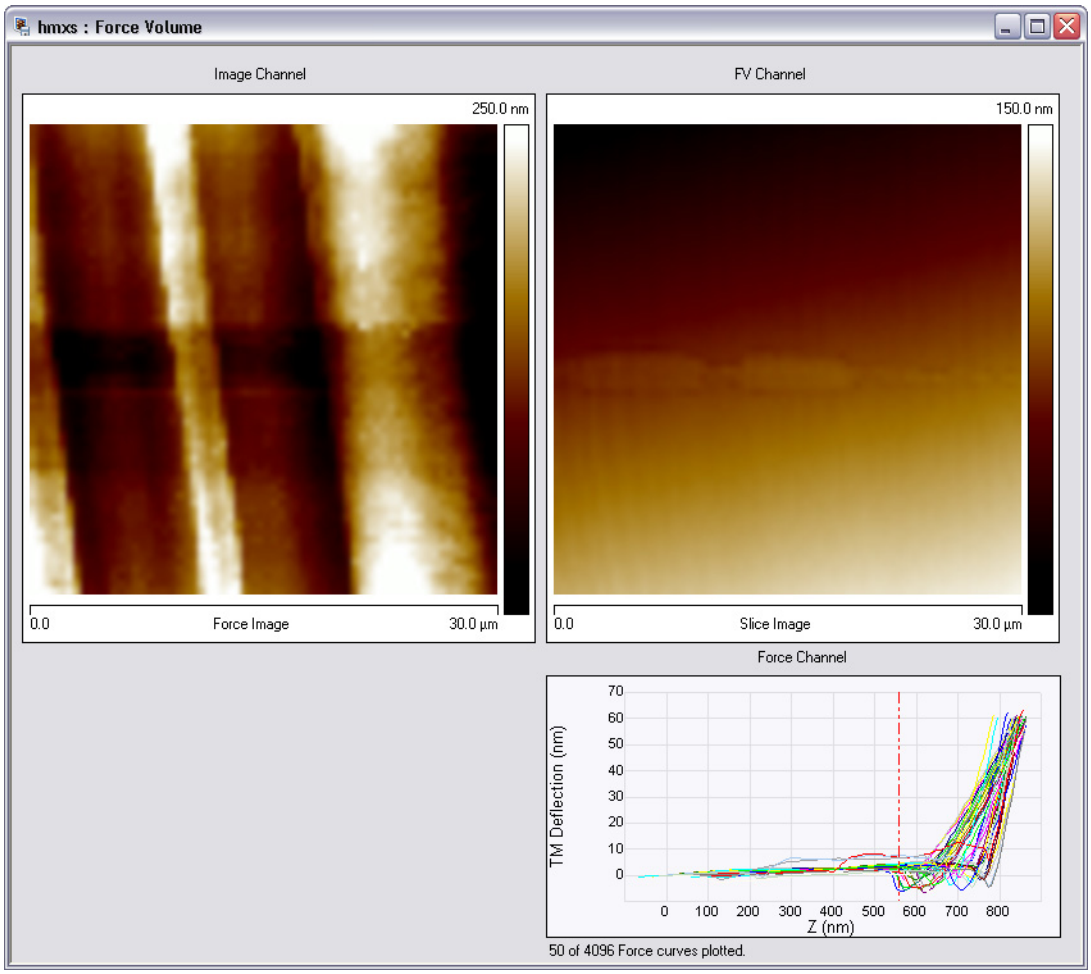
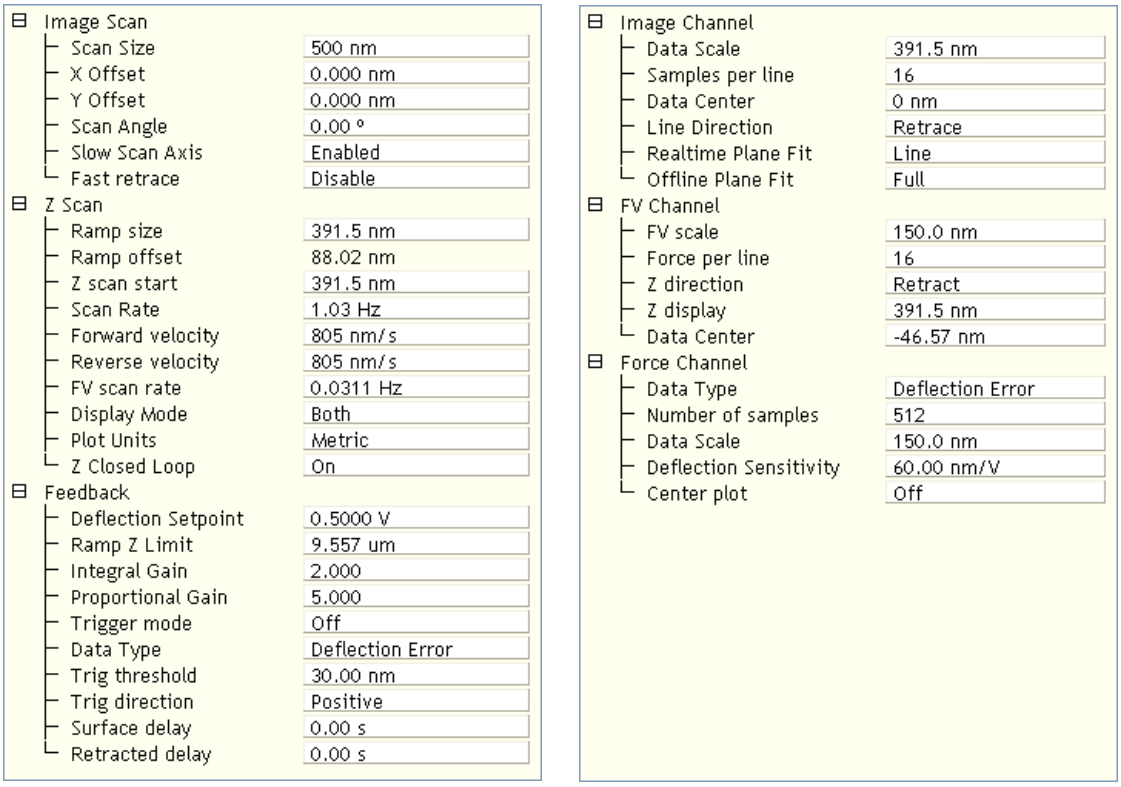


Figure 3.4e Force Volume Parameter Windows



While collecting data in this mode, it is possible to change the slice displayed and its offset without affecting the raw data. This is helpful in determining whether or not the parameters have been set correctly. Only data collected after the cursors are moved is displayed with the new **Data Center** and **Z Display**.

With NanoScope 7.30 and later software, you can turn **Z Closed Loop ON** and **OFF** without withdrawing the probe from the sample. With this change, **Z Limit** and **Z Range** are no longer coupled.

Force volume data can be evaluated offline like other images, and, additionally, with specialized analysis options. Different slices can be chosen by sliding the vertical red line along the Z axis of the force plot region, clicking on and dragging the line with the mouse. Force curves can be displayed by clicking on appropriate pixels in either the image or volume region. See **Force Volume Display and Interpretation,** page 164 for more detail.

3.4.4 Sample Preparation

Samples intended for force volume imaging require no special preparation. Force volume imaging can be done in both air and fluid environments.

CAUTION: Be careful not to allow liquid to leak onto the (expensive) piezoelectric actuating scanner tube; it can be damaged in a high voltage short circuit and require replacement.

Refer to Support Note 290, *Fluid Operation: Overview for Contact and TappingMode with a MultiMode Microscope* or *Electrochemical SPM* (part number 004-125-000), Support Note 410, *Direct Drive Fluid Cantilever Holder*, the *Dimension* or *MultiMode V Instruction Manuals* for fluid cell preparation details.

Interpretable force volume images depend on an appropriate probe selection. A stiff cantilever may provide better control when measuring strong forces and is less prone to entrapment by surface tension; however, a stiff cantilever does not respond to small forces. A flexible cantilever is more sensitive to small forces and is less harmful to delicate samples. Too pliant a probe, in responding to myriad small forces, generates noise, and may jump to contact if large attractive forces act. Refer to the Bruker website, http://www.bruker.com, for an illustrated survey of probe options.

3.4.5 Force Volume Procedures

Tip Movement

The force volume data set height image is collected in a slightly different manner than one taken in Image Mode. In Image Mode, the tip is scanned along a line in the XY plane, deflecting to and from the surface as it encounters features. The heights of features are determined by the piezoelectric actuator moving the probe to minimize the error between the setpoint and tip deflection. In Force Volume Mode, the piezoelectric actuator closes the distance between sample and tip until a (trigger) threshold tip deflection is reached. The piezo position at the deflection trigger is recorded as the height of the feature. Tip deflection or another signal type during this approach is recorded as the extending portion of a force curve. Once the height measurement has been made, the piezoelectric actuator retracts one **Z SCAN SIZE** and the AFM records the retracting portion of the force curve. The forces measured reflect the Z component of the sum of forces acting on the tip at that location. This process is then repeated at the next XY position in the area.

Force volume imaging always includes executing tip motions as follows:

- The tip is lowered and pressed against the sample surface until the cantilever is deflected to the **Trig**[ger] **threshold** value. If the surface is not contacted within one **Z scan size** distance, the tip is extended one additional **Z scan size** (for a total distance of two times the **Z scan size)**, then retracted one **Z scan size**. This means that the tip is incrementally lowered (or "ratcheted") one **Z scan size** for each extension-retraction cycle until the surface is contacted, or the Z piezoelectric actuator reaches its maximum extension at 220 volts.

- Once the tip contacts the surface and deflection attains the **Trig[ger] threshold** value, sample height is recorded for that Z-axis threshold. A force curve is recorded for the (X,Y) coordinates after the piezoelectric actuator retracts. The tip is lifted clear of the surface and translated to the next sample (X,Y) coordinates. The entire process is then repeated.

  Note: In NanoScope version 7 and later, the ramp data is collected in the trace direction and the system then moves the tip rapidly back to the start of the line.

  Note: In NanoScope version 5.xx and earlier, the time required to add one scan line to the height image is twice that calculated by multiplying **Z SCAN RATE** for the force curves by the number of pixels in the image. This is because the microscope collects both trace and retrace curves along each line in the XY plane. Only data from one or the other scan direction can be saved.

General Force Volume Procedure

The general sequence for obtaining a force volume image consists of the following:

1. Obtain a height, deflection, amplitude or phase image of the sample in **Image Mode**. On the **Channel** panel, select the same **Data type** intended for force calibrating and for triggering.

   Note: A trigger is required to obtain a height image during force volume imaging.

2. Obtain a **Force Plot** of the sample surface (any portion of the surface suffices). Using the force plot, determine the sample's general force characteristics and set the following parameters: **Setpoint**, **Z range**, **Z scan size**, **Z scan start**, and **Trigger mode**.

   Note: While not required, using Image and Force Plot Modes to set parameters can quicken the set-up process. Making parameter adjustments in Force Volume Mode can take longer since the SPM responds to the new settings only when it begins scanning a new line.

3. Return to **Image Mode**.

4. Obtain a **Force Volume** image by clicking the **Force Volume** icon in the **Workflow Toolbar**. Set the following parameters in the **Force Volume Parameters** panel: **Z scan rate**, **FV scan rate**, **Number of samples**, **Force per line**, **Samples per line**, **Display mode**, **Sample period**.

5. Fine tune **Image Channel** parameters to obtain a height image. Based upon the experimental design, set parameters in the **FV** (**Force Volume**) **Channel** and **Force Channel** panels.

6. **Capture** the **Force Volume** image.

   Note: This takes longer than a normal image capture—the force volume image may consist of up to 512 samples taken 512 times per line at the **Z scan rate**.

7. Interpret the **Force Volume** image using Offline commands.

Detailed Force Volume Procedure

Contact AFM Mode produces the best understood force volume images. The forces encountered, both attractive and repulsive, include electrostatic, van der Waals, surface tension, capillary, ligand/receptor, and magnetic interactions. Alternative modes of force volume imaging (tapping, phase, etc.) are harder to interpret and are not discussed here.

Refer to Support Note 228, *Force Measurements,* for detail on generating force curves. A force volume procedure follows.

1. Select a sample and mount it on the AFM. Initially, the sample should be familiar enough to obtain a recognizable image easily (e.g. a silicon calibration reference).

2. Click the **SELECT EXPERIMENT** icon. This opens the **Select Experiment** window, shown in Figure 3.5a.

3. Select **Force Imaging** in the **Experiment Category** panel.

4. Select **Force Volume** in the **Experiment** panel and click **START EXPERIMENT**. This will set the **Microscope Mode** to **CONTACT**.

After engaging the surface, adjust the **Setpoint** so the tip exerts minimal force on the sample. Reduce the **Setpoint** until the tip retracts, then raise it slowly until there is just enough tip-sample contact to obtain an image. Optimize the **Channel 1** parameters for a good image: set **Data Type** to **HEIGHT** and **Realtime Planefit** to **LINE**. The image collected by Channel 1 is displayed as the height image in the force volume display.

If the sample is weakly adsorbed to the substrate or there is some other reason for minimal tip-sample contact before collecting the volume (i.e.: to avoid contamination of or damage to the tip), it is possible to collect force volume data skipping the contact image step. First, before engaging, set **Image** > **Scan Size** to `0`. Then engage normally, or false engage if it is absolutely necessary not to contact the surface. Once engaged, lower the Setpoint until the tip is retracted from the surface. The rest of the procedure is essentially the same.

5. Create a force plot of the surface.

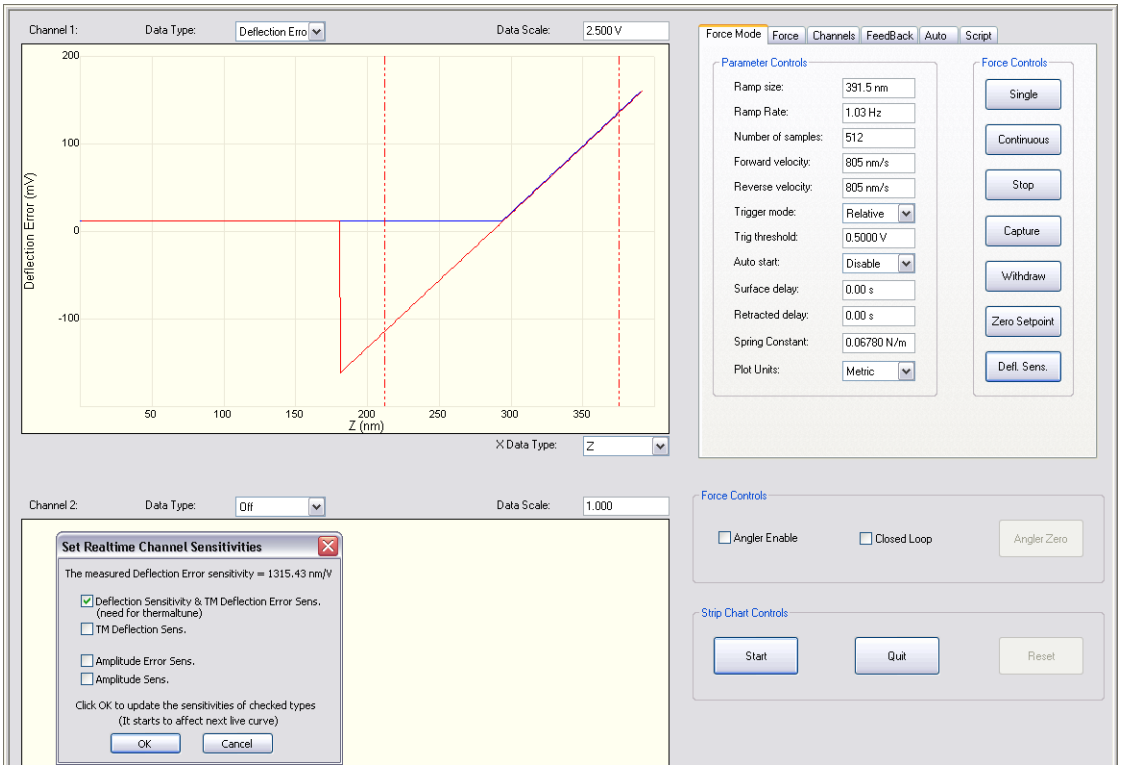
To obtain a force plot of the surface, click the **RAMP** icon. Set the **(Ramp) Scan Rate** to the recommended default of **`4 Hz`**. (In fluid, higher rates can induce hydrodynamic forces on the tip.)

Using the data scale from your image, set the **RAMP SIZE** to a number larger than the roughness of your sample.

Click the **SINGLE RAMP** icon on the NanoScope task bar.

Set the **SENSITIVITY** parameter using the mouse to draw a line on the force curve parallel to its slope in the contact region (see Figure 3.4f). This parameter must be well-determined for quantitative force readings.

Figure 3.4f Calibrating Deflection as Displacement- single monitor view shown. Dual monitor view is similar.



- Click and hold on either side of the plot area to get a cursor line.
- Drag this cursor line onto the plot to mark one part of the contact portion of the force curve.
- Get and drag a second cursor onto another part of the contact portion of the force curve.
- Right click to choose the trace or retrace curve (Active curve 1 or 2).
- Then under the **FORCE** tab, select **DEFL. SENS**.

6. Adjust the **Z Scan** parameters until a good force curve is obtained, that is, one such that a significant portion of the curve contains the transition from noncontact to contact. For example, if measuring an interaction force with a decay length of 10 nm, have a **Z scan size** on the order of **50 NM**.

Make sure the piezoelectric actuator is centered in the Z direction. This gives it ample room to move in response to surface features.

7. Return to Image Mode by clicking on the **SCAN** icon in the **Workflow Toolbar**. (You cannot switch directly from **RAMP** to **FORCE VOLUME**.)

Once a good force curve is obtained, return to Scan Mode.

8. Obtain a force volume image of the surface.

To obtain a force volume image, click the **FORCE VOLUME** icon in the **Workflow Toolbar**.

Note: The screen appears similar to the one shown in Figure 3.4g, except that most of the image regions are blank at first. (A minimum of several minutes are required to obtain complete images.)

Figure 3.4g A Force Volume Image - single monitor view shown. Dual monitor view is similar to Figure 3.4d.

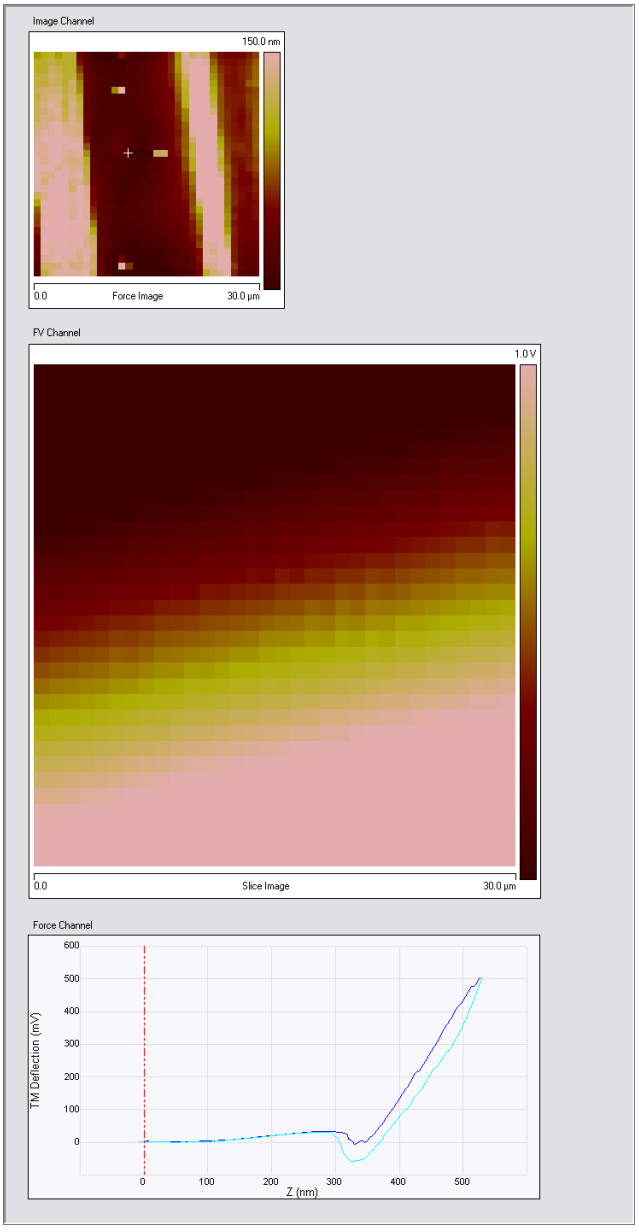


Figure 3.4g shows the following:

- **Top Image**: The image at the top of the screen is a height image similar to the one shown in **Real-time**/**Image mode**; however, it may appear more pixelated.
- **FV Image**: The large image in the middle plots force as a function of Z distance.

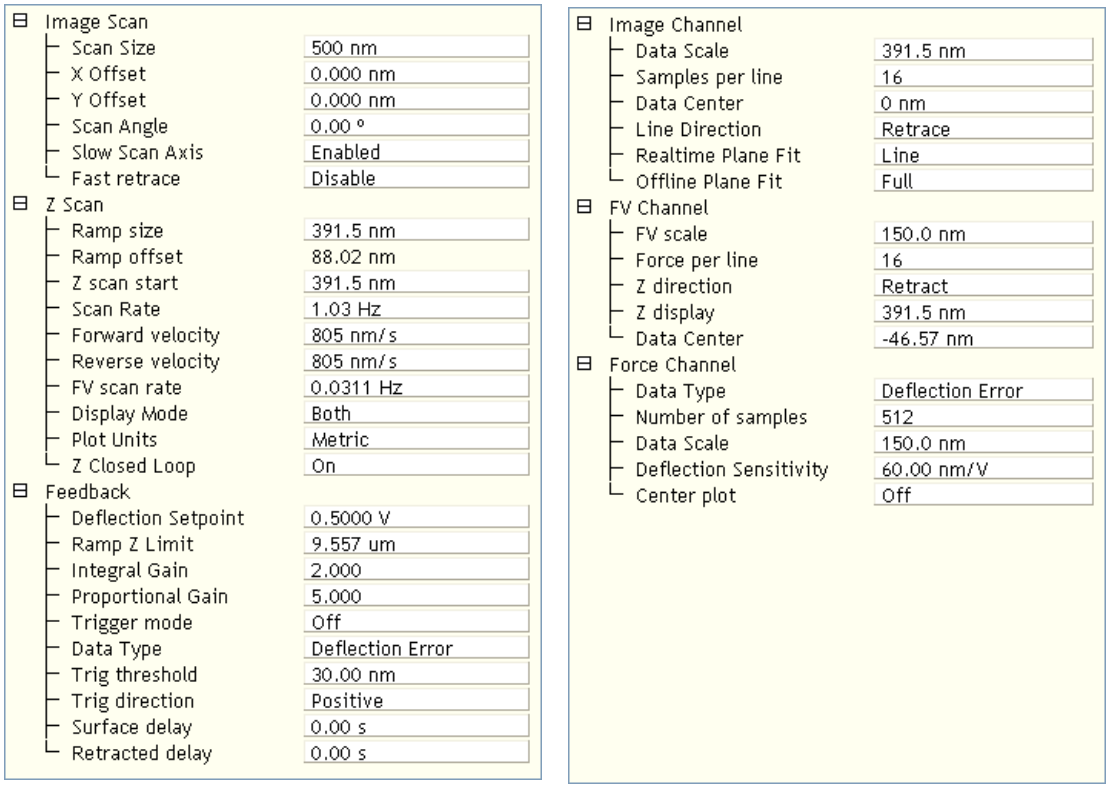
  Note: The resolution of the force plot varies depending upon various parameter settings.

- The force plot at the bottom of the panel displays a series of superimposed force plots for each scan line.

There are six **Force Volume** panels in the **Force Volume Parameters** window, shown in Figure 3.4h, which control sampling and scanning for the force volume image and force curve. They are organized by function:

- **Image Scan** - Real-time parameters for the height image shown in the **Image Scan** (top) panel of the **Force Volume Parameters** window, such as **Scan Size**, **X-** and **Y Offset**, **Scan Angle**, and **Scan Rate**.
- **Image Channel** - more Real-time parameters affecting the height image.
- **Z Scan** - parameters affecting vertical movement of the probe, including **Z scan start**, **-size** and **-rate**.
- **Feedback** - parameters controlling **Setpoint**, and where probe travel is to be reversed (triggered): **Trigger mode**, **-threshold** and **-channel**.
- **FV Channel** - force volume channel controls affecting the force volume image in the upper-right corner of the window, including **FV scale**, **Force per line**, **Z direction** and **-display**, and **Data Center**.
- **Force Channel** - parameters affecting the force plots.

Figure 3.4h Force Volume Parameters Window



9. Set **Z Scan** parameters.

The **Z Scan** panel groups basic sampling and scanning parameters for the force volume image and force curve.

The following parameters are often carried over from the force plot settings: **Z scan start**, **Ramp size** and **Scan Rate**.

The **Display Mode** parameter in the **Z Scan** panel can be set to display in the force plots region the **EXTEND** portion of the force curves, the **RETRACT** portion, or **BOTH**.

10. Set the resolution of the height, FV, and force plot images.

Remember that you are constructing a “map” of many separate force plots across the sample surface; therefore, there is a lot of data to sort. Depending upon settings, capturing a detailed force volume image can require hours.

Note: While the size of the area imaged by the AFM is ultimately limited by the characteristics of the piezoelectric actuator, the resolution of the data is limited by the computer hardware and software. The total amount of data for any given force volume image file is limited to a maximum of 128 megabytes (MB). This places restrictions on the resolution of the force curves, and the force volume image.

There are three parameters in three distinct control panels in Force Volume Mode which affect the resolution of the data: **Number of samples**, **Force per line** and **Samples per line**.

The **Number of samples** parameter in the **Force Channel** control panel sets the number of points collected in each force curve. This is the number of slices in the force volume image, that is, the Z resolution of the force volume image. This parameter does not affect the speed of the scan but does affect file size. A good default setting is **32**.

The **Force per line** parameter in the **FV Channel** control panel sets the number of force curves collected and stored along each scan line of the sample and significantly affects the scan speed. This parameter is, effectively, the XY resolution of the force volume image. A setting that sufficiently resolves force-defined features, yet minimizes collection time, is desirable. A good default value is **64**.

These two parameters are interdependent, due to the 128 MB limit:

$$(\text{FORCE PER LINE})^2 \times (4 \times \text{NUMBER OF SAMPLES}) < 128 \text{ MB}$$

The above requirements restrict the maximum number of force curves per line in the volume to 64.

The **Samples per line** parameter in the **Image Channel** control panel sets the number of pixels in each scan line of the height image.

> **Note:** For each pixel in the height image, a force curve is collected. Increasing the value of **Samples per line**, therefore, increases the scanning time needed to collect the entire volume. This parameter directly affects the XY resolution of the height image only. A setting of **128** provides sufficient detail to resolve many small features while helping to reduce capture time.

When **Samples per line** is greater than **Force per line**, at each XY position in the height image, the NanoScope moves the probe toward the sample until the **Trig Threshold** is reached and then retracts - the same motion as a force curve. However only one force curve, the first one taken in a pixel's area of the force volume image, is displayed in the force volume image. For example, with 512 **Samples per line** and **Force per line** set at 64, then there are 16 pixels (4×4) in the height image that correspond to one pixel in the force volume image. While the piezoelectric actuator and the tip go through the motions of a force curve at each of those sixteen pixels, only the first force curve is used in the force volume pixel.

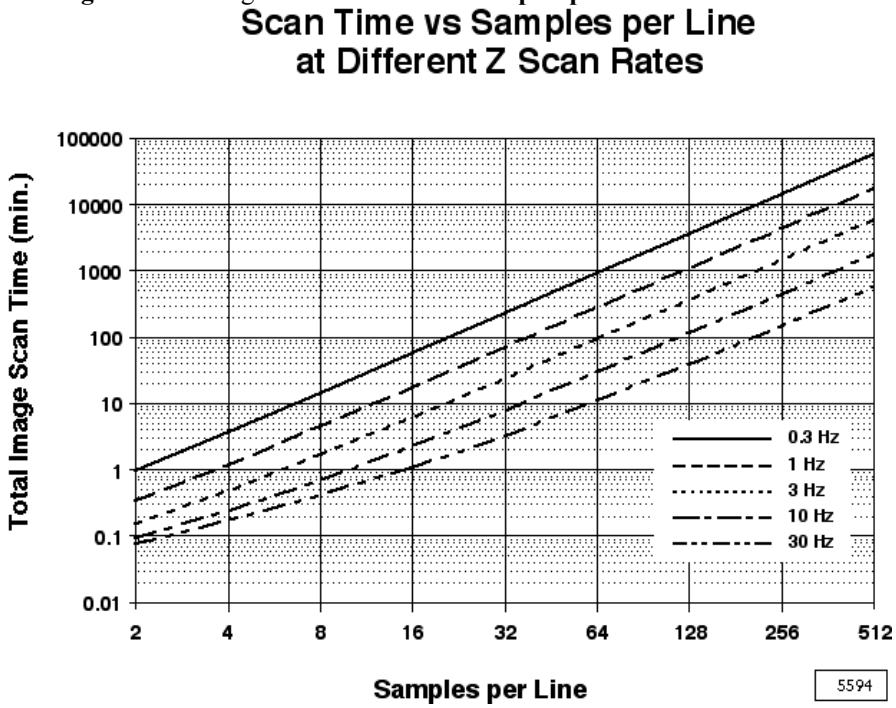
The size limit on the data file enforces a trade-off between XY resolution and Z resolution. To know whether a tip sticks to the surface at different locations, low Z resolution (**Number of samples**) in favor of high XY resolution (**Samples per line** and **Force per line**) is sufficient. If a detailed examination of the interaction forces between tip and sample is desired, then high Z resolution is needed. Saving the Scan Mode height image (step 1) can compensate for low XY resolution in the force volume image.

Setting **Number of samples**, **Force per line**, and **Samples per line** to `16`, `16`, `512`, respectively, are good starting values.

Resolution and scan speed are the major determinants of the time required to collect a complete force volume image. Figure 3.4i illustrates the effect that **Samples per line** and **Z scan rate**

parameters have on imaging time. The times were calculated assuming the maximum number of force curves per line (**Force per line**) for each **Samples per line**.

Figure 3.4i Image Scan Time versus **Samples per line** and **Z scan rate.**



Doubling the lateral resolution roughly quadruples the capture time, while doubling the scan rate halves the capture time.

11. Adjust **Feedback** parameters.

Feedback panel parameters carry over from the force plot settings; however, changes may be required to protect the tip and optimize the force volume image.

For silicon nitride tips, the **Setpoint** may be adjusted to within plus or minus several volts of the microscope noncontact free-deflection signal value. For crystalline silicon TappingMode tips, the **Setpoint** should normally be increased no more than 1-3 volts below the RMS amplitude voltage; this helps protect the tip.

In Force Volume imaging, triggers are used to set the direction reversal point of the Z-axis piezoelectric actuator during both height and force measurements. The **Data Type** parameter registers which data channel acts as the trigger. Usually, this is the same as the **Data Type** located on the **Force Channel** panel. The **Trigger Mode** determines the type of trigger to be employed, **RELATIVE**, or **ABSOLUTE**. The trigger may also be turned **OFF**.

A relative trigger measures the trigger threshold relative to the non-contact voltage deflection value and compensates for drift. An absolute trigger measures the trigger threshold relative to the Setpoint. In most cases, a relative trigger is preferable, as it offers better protection to the tip and sample by limiting the total force on the surface independent of setpoint and drift.

The **Trig threshold** parameter limits forces on the sample and the tip by "clipping" the **Ramp size**. For example, when using a relative trigger of **25 nm** and a **Ramp size** of **500 nm**, if the tip were to come into contact with the surface after extending only 300 nm of the scan size, the tip would halt its movement after 25 nm more extension (for a total of 325 nm) before retracting. Thus, tip-sample forces are constrained, and the force curve is defined for a controlled interval of tip-sample interaction.

During the execution of a force curve with a trigger on, the piezoelectric actuator extends continuously, bringing the surface towards the tip until the tip is deflected to the **Trig threshold** value. Once deflecting to the **Trig threshold** value, the piezoelectric actuator retracts one **Z scan size** distance - it does not retract to the position defined by **Z scan start**. Thus, the collection of the next force curve begins at a piezo position one **Z scan size** value lower than the piezo position at the **Trig threshold** value. Keep this in mind when setting the **Z scan start** and **Z scan size** parameters if a relative trigger is used.

> **Note:** This discussion assumes that **Sensitivity** has been properly set and that the detector range has not been exceeded. Otherwise, the **Trig threshold** value does not correspond to the true deflection value.

In **Force Volume** imaging, triggers are used to set the turnaround point of the Z-axis piezoelectric actuator. The **Trigger mode** determines the type of trigger to be employed. Two types are offered: **Relative** and **Absolute**, or the trigger may be turned **Off**.

> **Note:** If the **Trigger mode** is turned **Off**, no height image is displayed.

The **Data type** determines which data channel is to act as the trigger. (Normally, this is the same as **Force Channel/Data type**.)

A relative trigger measures the trigger threshold with respect to the free-air deflection voltage value and compensates for drift. An absolute trigger sets the threshold with respect to the **Setpoint**. Normally, a relative trigger is the preferable default, as it offers better protection to the tip and sample, limiting the total force on the surface independent of setpoint.

> **Note:** When using a relative trigger threshold, be certain **Ramp size** (in the **Z Scan** panel) is sufficiently large to deflect the cantilever to the **Trig**[ger] **threshold** value *and* lift the tip clear of the surface. This ensures the tip is not ratcheted into the surface and dragged laterally through surface material during XY indexing.

To limit forces on the sample and tip, **Ramp size** may be clipped to within some **Trig threshold** value. For example, a tip which is being oscillated along the Z-axis with a **Z scan size** of **500 nm** may have its **Trig threshold** set to **-25.0 nm**. When using a **Relative** type **Trigger mode**, if the tip encounters the sample surface after extending 300 nm, it halts its Z-axis extension at 325 nm, then reverses (retracts). Thus, tip-sample forces are limited and the force curve is defined for a controlled interval of tip-sample interaction.

> **Note:** This example assumes the **Sensitivity** parameter has been properly set (see step #2 above) and that the detector's range has not been exceeded.

12. Adjust **Force Channel** parameters.

The **Force Channel** panel features parameters for the force plots region at the bottom right of the Force Volume display window. In most ways the force plots region is exactly like a Force Plot graph.

The available settings for the **Data Type** parameter depend on the type of imaging being done. Also available are **Amplitude**, **Deflection**, **Potential**, and **Thermal**. Set the **Data type** accordingly. For Contact Mode force volume imaging, select **DEFLECTION ERROR**, for instance.

When beginning a force volume scan, set **Z display** to its maximum to locate the force plots. (The force curves resemble a thin line.) **Z display** is the range of deflection values plotted in the force curves region. Slowly decrease **Z display** until the force plot fills most of the graph area.

The **Center plot** parameter determines where the force plots are graphed relative to the current **Setpoint**. When **Center plot** is **OFF**, the center horizontal line of the graph is positioned at the probe **SETPOINT** value and deflection is measured from there. When **Center plot** is **ENABLED**, the central horizontal line is positioned at the tip noncontact voltage (i.e., the voltage when the tip is just clear of the surface - in the noncontact portion of the curve) from which the deflection is measured.

13. Adjust **FV Channel** parameters.

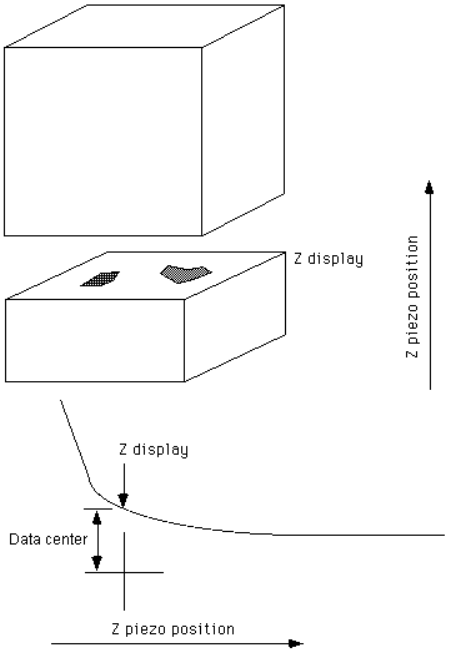
Parameters in the **FV Channel** panel control the type and range of forces viewed in the force volume image. In addition, the **FV scale** parameter also affects the viewable range of data captured during force volume imaging. These parameters affect the real-time display of the force volume image only. The deflection at (X,Y), and Z-position data of each force curve (extending and retracting) are saved to disk.

The **Z direction** parameter determines which portion of the Real-time force curve cycle, **EXTEND** or **RETRACT**, is shown in the force volume image. For example, if the force of interest is material elasticity, the Extend portion of the curve is selected. If adhesion forces are probed, then the Retract portion is usually used.

The **FV scale** parameter sets the range of values represented by the force volume image. Because the force volume image is generated line by line and the effects of changing **FV scale** are not displayed until the next line of data is taken, several adjustments of this parameter may be needed before it is optimized.

The **Data Center** parameter adds (or subtracts) a constant value to (or from) the data signal (**DEFLECTION ERROR** in the case of Contact Mode force volume imaging). This is used to center the force volume data within the FV scale bar. For most applications, the value should coincide with a value on one of the force curves. This is most easily accomplished by positioning the cursor on a force curve. This centers the force volume image within the color bar of the specified **Z display**. **Data Center** can be set in two ways. The first is to simply enter the desired value in the control panel. The second is to use the cursors. Drag a vertical cursor from the left or right side of the plot region. Drag a horizontal cursor from the top or bottom of the plot region. Position the cursor vertically at the desired offset and click the left mouse button (see Figure 3.4j). In a slice, the pixels are colored based on their distribution within the range defined by **FV scale** and the **Data Center**. Modifying these parameters during data collection affects the display only. The raw deflection and piezoelectric actuator position data are saved.

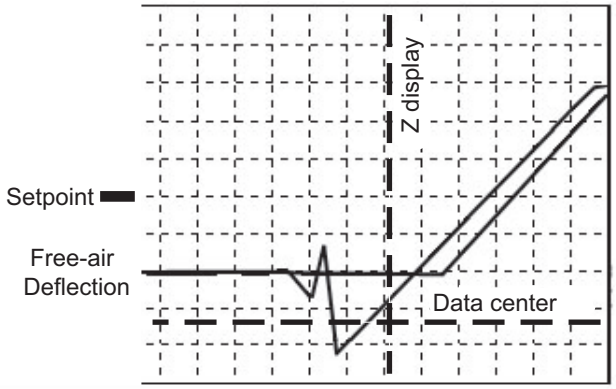
Figure 3.4j **Data center** and **Z display** are Controlled by Cross-hairs



The **Z display** parameter determines which slice of the force volume is displayed in the force volume image region. Like **Data Center**, the **Z display** can be set in two ways. The first is to enter the desired Z value of the slice in the control panel. The second is to use the mouse to change the horizontal position (that is, the Z position) of the cursor in the force plot region. For example, a **Z display** of **30 nm** causes the force volume image region to depict forces on the tip when it is at a Z position of 30 nm above the piezoelectric actuator position at the **Trig threshold**. The **Z display** parameter may be thought of as defining bands of force at fixed distances from the sample surface.

The **Z display** and **Data Center** parameters work in unison to define which portion of the superimposed force curves is plotted in the **Force Curves** panel of the force volume image. These parameters are also simultaneously represented as a green cursor on the force plot graph. Both **Z display** and **Data Center** may be changed by positioning the cursor with the mouse, or vice versa (i.e., the cursor is repositioned automatically whenever these parameters are changed.) The relationship of each parameter to the cursor is shown in Figure 3.4k.

Figure 3.4k Z Display and Data center in Relation to Cursor



14. Collect the force volume data set.

Once all parameters have been properly set, begin collecting force volume data by clicking the **CONTINUOUS RAMPING** icon (shown). Use the **FRAME UP (DOWN)** to start the scan at the bottom (top) of the image and force volume image regions.

15. Capture the force volume data set.

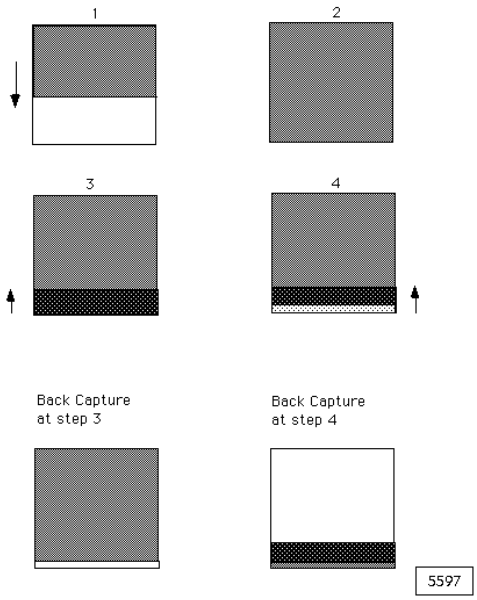
Completed images are saved to disk by clicking the **CAPTURE** icon (shown).

Note: If parameters are changed during a scan, the capture is interrupted. To force the capture, click the **CAPTURE** icon a second time. The more recent parameter value entries are saved with the image.

If you forgot to capture an image, and the next image is not yet complete, click **CTRL-B** to Back Capture the image. You can also select **CAPTURE** > **CAPTURE LAST**. Back capturing in Force Volume Mode captures whatever image was collected before the last change of frame direction, that is, in the slow-scan direction.

Use of **CAPTURE LAST** can reduce the time required to gather data when only a non-square, rectangular subarea of the image is relevant (see Figure 3.4l; panels 1-4 show a scan in progress). Begin scanning an image from the top, for example, of the image region. In panel one, a new frame (dark) is scanned from top to bottom. When the strip of interest has been scanned, click on the **FRAME DOWN** icon (the scan is finished in panel 2). When the new image is beginning, enter **CTRL-B** to capture the strip. The slow-scan direction reverses in panel 3 and a new frame is begun (dark speckled). In panel four, the upward scan from panel 3 is interrupted and a new upward scan (light speckled) begins. The lower panels show what part of the scan is saved if the back capture is pressed in step 3 versus in step 4, after the new upward scan begins.

Figure 3.4l CAPTURE LAST Assists Collecting Non-Square Force Volume Data (see text for discussion)



Another trick to imaging only strips of interest is to set **Trig threshold** to zero and the **Z scan rate** to a high value (i.e.: `20 Hz`) and begin a scan. When the tip is positioned near the beginning of the strip of interest, reset **Trig threshold** and **Z scan rate** to their appropriate values and capture the image.

3.4.6 Force Volume Troubleshooting

Mechanical complications or poor choices of settings for both operational and display parameters can frustrate force volume data acquisition. Some common situations and their resolution follow.

A Force Volume Image is Uniform

If a force volume image is uniform at all Z display values (that is, all slices), check the various display parameters first. The settings may be too high or too low. For example, if **FV scale** is much smaller (or larger) than the actual range of cantilever deflections at any Z position, then all the pixels at the Z position will be to the low (or high) end of the scale. The same effect occurs if **Data Center** fails to bring the measured forces into the **VOLUME SCALE** range. Adjust **FV scale** and **Data Center** until the variation in forces is displayed.

If **FV Channel**/**Z display** is set too high, force curves appear as flat lines; if it is too low, the majority of force curves display flattened against one or the other extreme of Z position.

Check the color bar. If the contrast is too high, only the extremes of deflection show up in the force volume image. Changing the Color Table in Image Mode can reduce contrast (different color tables have different default contrast levels).

If **Sensitivity** was not set properly in Force Plot Mode, then force plot scaling is inaccurate.

If a trigger is being used, make sure it is enabled, and vary **Trig threshold** to assure that the threshold deflection is large enough. If it is too low, only the noncontact portion of the curve is measured. For example, a 320 µm cantilever with a spring constant of 0.01N/m oscillates with an amplitude of roughly 3 nm at room temperature. These oscillations and a 2 nm **Trig threshold** initiate the trigger almost immediately after beginning a scan.

All the interesting forces may be mapped to a single pixel of Z data; that is, the Z resolution is too low for the forces of interest. Trade off XY resolution (i.e., **Force per line** or **Samples per line** or both) for Z resolution (**Number of samples**) to alleviate the problem.

If no adjustment to display parameters creates a nonuniform image, perhaps there is no force variability in the scan area. Adjust **Z scan start** and **Ramp size** in the **Z Scan** panel to scan the regions of interest within the force curves. It may be necessary to return to Force Plot Mode to do this. If the probe cantilever is too stiff to respond to the forces present, replace it with a more pliant cantilever or use a higher **Trig threshold**.

Drift

Although drift is a symptom that has a number of causes, it appears in Force Volume in two characteristic ways. The force curves, over time, can drift vertically or horizontally in the force plots region. The shades of the force volume image drift to one end of the color bar, as do the pixel values in the height image. *Horizontal*, or *substrate*, *drift* is due to the substrate or Z piezoelectric actuator drifting. *Vertical*, or *cantilever*, *drift* can result from DC electrical drift in the probe, thermal fluctuations, bubbles attached to the cantilever in fluid or slipping of the O-ring in a fluid cell - to name a few sources. Even small rates of drift can distort a force volume image during the hours needed to collect such a data set.

If the drift rate is low, it can be ignored during data collection and subtracted out offline by a horizontal or vertical cursor and selecting **X** or **Y TRANSLATE**. A relative trigger keeps the magnitude of probe deflections within a fixed range.

If the drift is slow to moderate (relative to the time scale of the entire collection process), adjust **FV Channel/Z display** upwards to keep the curves from drifting out of view. Reset the **SETPOINT** and collect the image. Set **Force Channel/Center Plot** to **ENABLE** to zero the force curves as they are taken.

If the drift is fast, check the hardware for mechanical causes. Ensure that the probe is secure in its holder. Thermal fluctuations near and within a probe can cause fast drift. Flexible cantilevers make good thermometers and respond to the slight temperature increases due to laser heating. To minimize thermal drift, bring sample, fluid (if any), probe and probe holder into thermal equilibrium (i.e., the same temperature) at the start of imaging.

> **Note:** NanoScope AFMs take 90 minutes from when the machine is turned on to achieve thermal equilibrium.

If the force curves appear nonsensical, the extending and retracting portions reading maximum force along their entire length, **FV scan rate** may be set too low for the NanoScope DSP board. A **FV scan rate** of **6 Hz** ensures smooth signal averaging. Too low a **FV scan rate** and the force curves will appear discretized.

If imaging in fluid, bubbles in the fluid cell or adsorbed to the cantilever can result in fast drift rates. Bubbles can be removed by injecting more solution into the fluid cell and forcing the bubbles out of the cell through a tube. If the O-ring was subjected to torque in making a seal, it can relax and slide across the sample surface. This is remedied by minimizing lateral movement of the O-ring during set-up, or by not using an O-ring at all (though, then the probe is more sensitive to air currents and thermal variation).

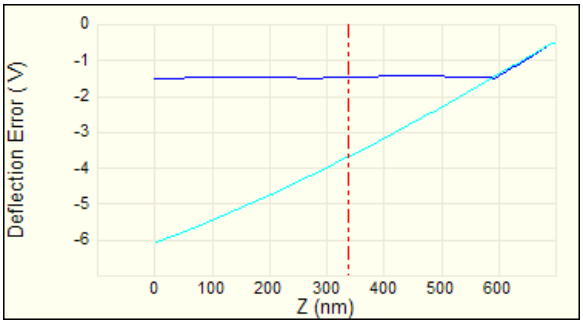
CAUTION: Not using an O-ring is *not* recommended by Bruker. Leaks are hard to avoid and can quickly lead to expensive damage to the high voltage piezoelectric scanner tube.

As a last resort, if fast drift cannot be removed from the system, reset the setpoint (**Feedback > Setpoint**) during data collection to keep the force curves "in bounds". Capture must be forced (click on the Capture icon twice in quick succession) to save the image. Another way to compensate for fast drift during imaging is to track the drift with the photodetector adjustment screws during the retrace portion of a line scan. The banding in the resulting height and force volume images can be removed offline by setting **Center plot** to **Enabled**.

Excessive Adhesion

Excessive adhesion of the tip to the sample results in the absence of the noncontact portion of the force curves as well as, in some cases, a downward curvature in the extending portion of the curve towards and meeting the retracting curve at the end of the noncontact region (see Figure 3.4m). This is caused by the inability of the tip to leave the surface as it is retracted. This can damage the sample during the repositioning of the tip to the next XY location. Adjust **Z scan start** and **Z scan size** in the **Z Scan Controls** panel to ensure that the tip is lifted clear of the surface during retraction. Check that most piezoelectric actuator motion occurs near its center position. Adjust **Trig threshold** if the tip is being pushed so far into the sample that adhesive forces on the tip are unnecessarily large.

Figure 3.4m Example of Excessive Adhesion



Hydrodynamic Drag

Occurring only in fluid cells, hydrodynamic drag appears as a vertical separation between the noncontact portions of the extending and retracting curves on the force plot. The magnitude of the separation is dependent on the rate of the scan; reduce **Z Scan**/**Scan Rate** until the curves are co-linear in the noncontact region.

3.4.7 Force Volume Display and Interpretation

Display Options During Imaging

Perform analysis in real-time by adjusting display parameters during imaging. For instance, **Z display** chooses the slice of the volume to be displayed in the force volume image region. Lines scanned after changing **Z display** correspond to the new slice. Lines scanned before the change correspond to the previous slice.

Adjusting **FV scale** and **Data center** allow the user to zoom in on particular features of a force volume image. Set these parameters to mask all but the range of forces of interest. See **Detailed Force Volume Procedure,** page 149, step 13.

Adjust the **Image Controls**/**Z range** scale to modify the height image. **Z direction** determines whether the trace or retrace scan line are collected.

If any of these parameters are modified while scanning, force image capture (by double-clicking the Capture icon) to save the data, including the final parameter set.

Post-Data Collection Image Analysis

NanoScope Offline analysis software processes force volume images in much the same way as it handles topographical images and force plots. There are also tools specific to the interpretation of force volume images.

When a force volume image is selected from the Offline directory, it is displayed much as it appears during data collection. The three regions - height image, force volume image, and force plots - are in their respective corners. Both the topographic and the force volume images appear as they did during collection.

Scales and Offsets

Scaling and offset options for each data type are available in the offline parameter list in the lower left of the Force Volume view.

The first **Data scale** parameter sets the scale of the height image. The **Z scale** sets the deflection scale for the force curve.

FV scale defines the range of deflection values to be displayed in the force volume image.

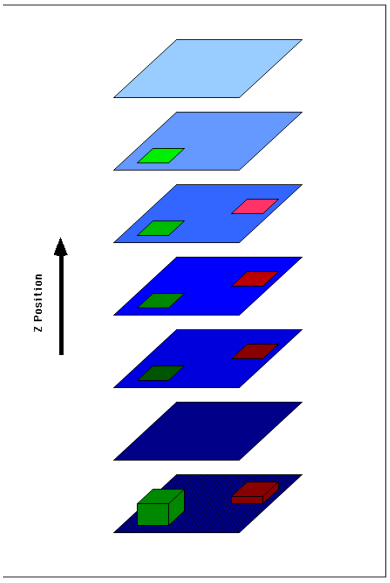
Setting **Center plot** to **ENABLE** centers all the retracting force curves noncontact portions to the center horizontal line in the force plots region, effectively subtracting out any DC drift from the data. (The extending curves also are shifted, but they maintain their position relative to the retracting curve.) All deflection values are then measured relative to the center horizontal line. This allows for clear comparisons to be made among force curves in the data set and is recommended before further analysis.

Z direction toggles the force volume image between displays of the **EXTEND** (e.g., to study elasticity) or **RETRACT** (e.g., to study adhesion) portions of force curves.

Viewing Slices

You may inspect each slice in a volume (see Figure 3.4n).

Figure 3.4n Force Volume Slices - Block Height Represents Deflection.



To display a force volume slice at a particular Z position, drag a cursor from the left or eight edge of the force plot region. Clicking on consecutive pixels in the force plots region (with the **MULTIPLE** radio button selected) displays consecutive slices in sequence (see Figure 3.4n, Figure 3.4q). Note that multiple force curves, measured at points A, B, and C in the height image, can be displayed simultaneously offline.

Figure 3.4o Force Volume: multi-layered polyethylene. Single monitor view shown.

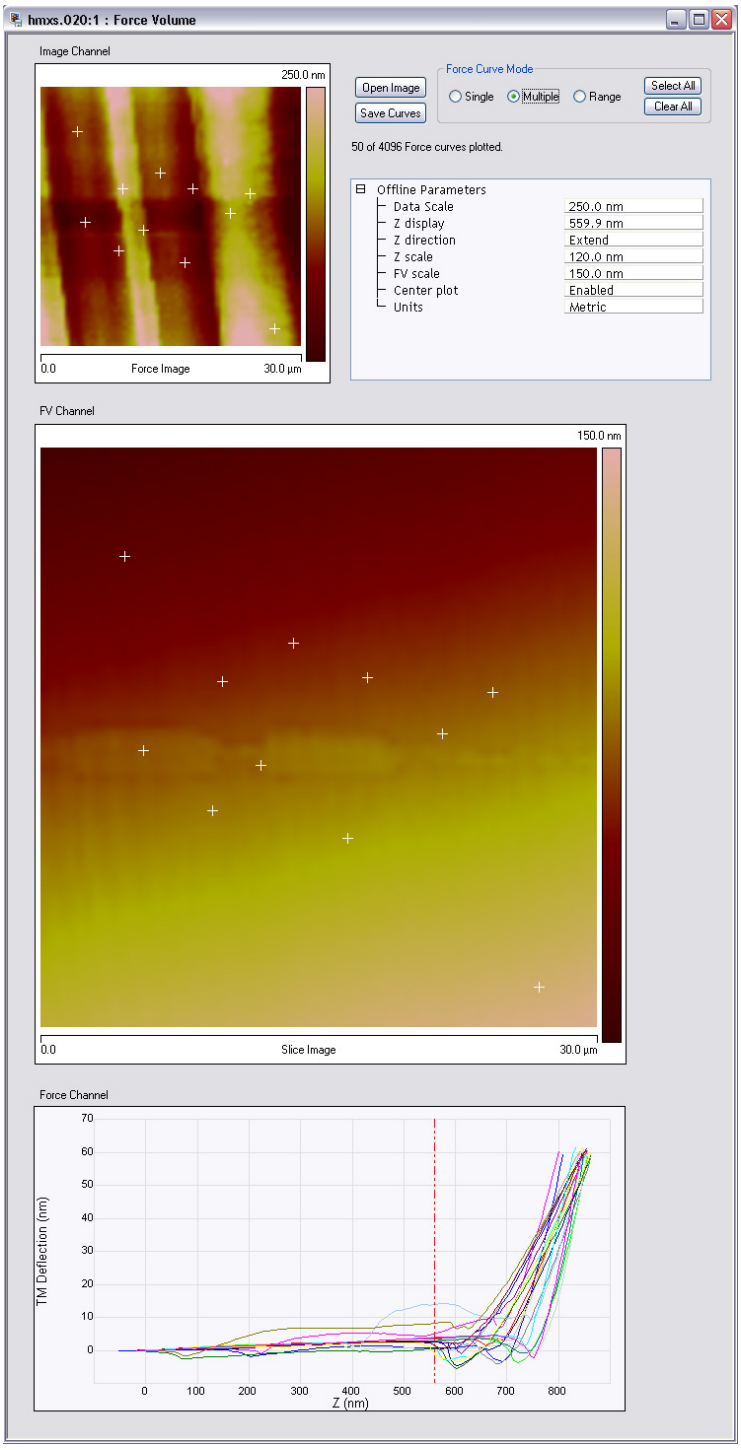
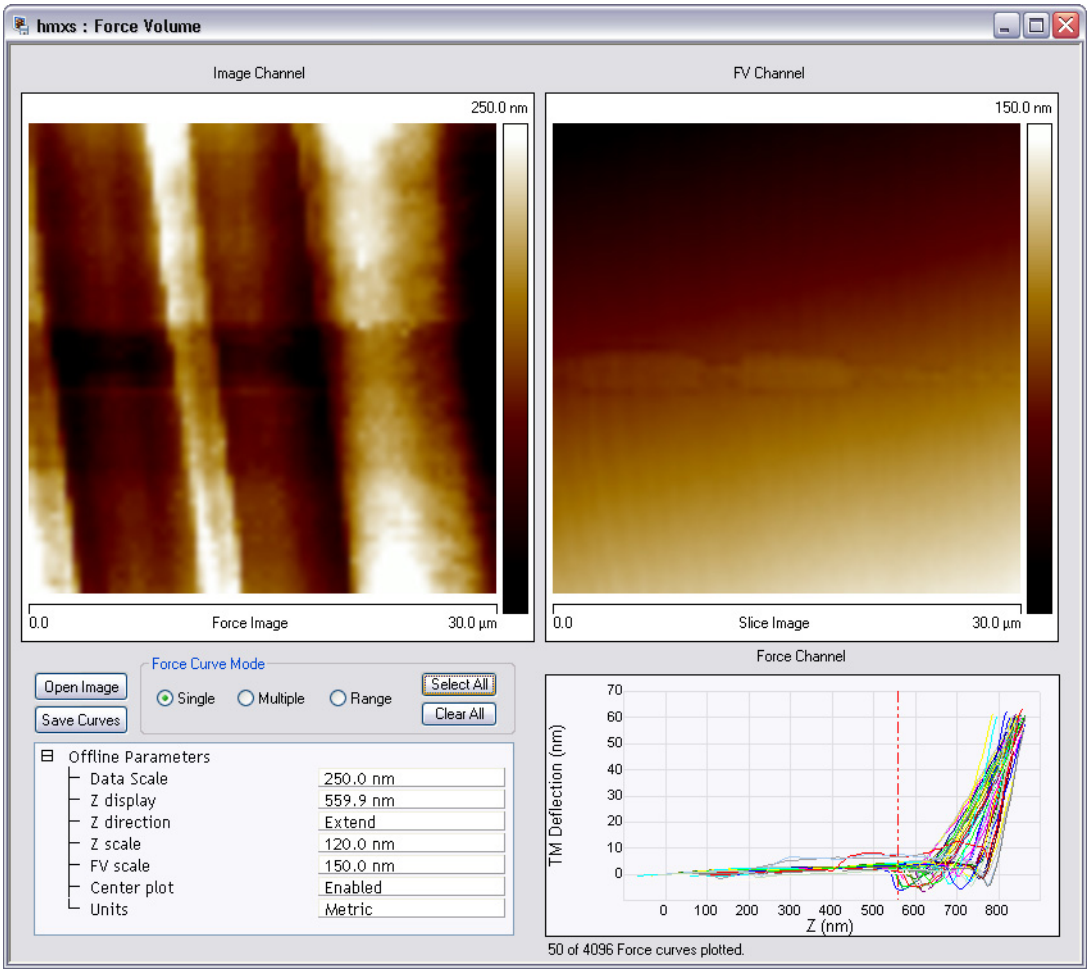
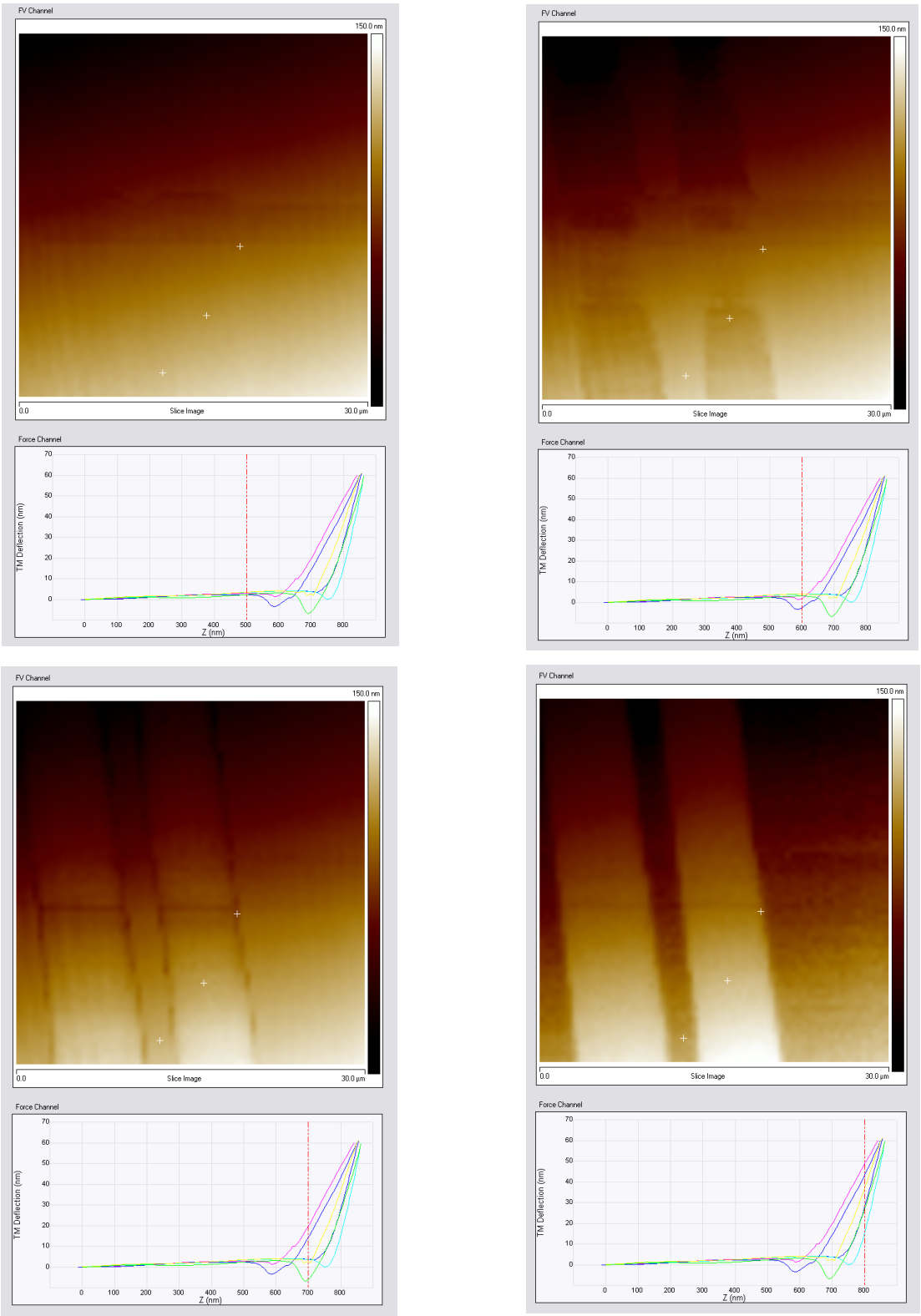


Figure 3.4p Force Volume: multi-layered polyethylene. Dual monitor view shown.



Save images of slices for later use through the **EXPORT** menu. The images can be modified in third party graphics software (e.g., IDL, NIH image, Canvas, etc.). For example, slices selected in Figure 3.4o or Figure 3.4p are displayed as a montage in Figure 3.4q.

Figure 3.4q Figure 3.4o Retracting Slices: Adhesion vs. Z Position



Viewing Force Curves

Display individual force curves by first opening the file from the appropriate capture directory and then selecting **Force Curve Mode > SINGLE**. Click the left mouse button on a specific pixel in either the height image or the force volume image to display the associated force curve in the force plots region (see Figure 3.4o). Note that the pixels in the height image and the force volume image are marked with white crosses. The Z value of the slice is displayed in the force volume image as a vertical cursor at that particular Z value.

Individual force curves can be analyzed separately from the height and volume data; select **SAVE CURVES** and the standard force curve analysis view is saved and can be opened from the **Browse** window. Once modified and analyzed, select **File**/**SAVE** to save the image and modified force curve.

Selecting **Force Curve Mode > MULTIPLE** to display several force curves in the force plots region. Click either the topography or the force volume image to display the associated force curve in the force plots region. A white cross labels the (X,Y) position of the force curve in both the topographic and force volume images. Superimpose multiple force curves by selecting many pixels (see Figure 3.4o). Select **Force Curve Mode > CLEAR ALL** to erase the force plots region.

If multiple force curves are displayed, clicking **SAVE CURVES** saves each curve as its own standard force curve file.

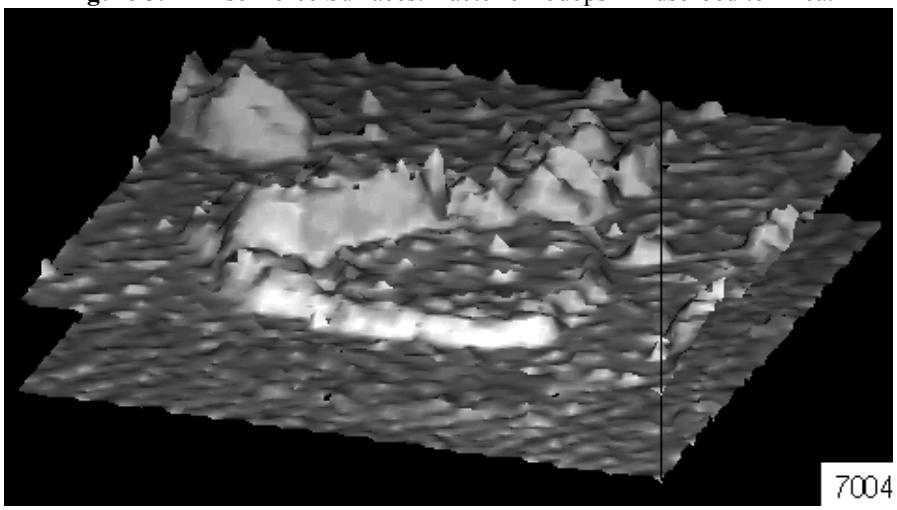
Selecting Images to Analyze

A height image can be analyzed independently of force data by selecting **OPEN IMAGE** from the **Force Volume** window. The standard image analysis software loads. Once modified and analyzed, select **File** > **SAVE** to save the image and modified force curve.

Constant Force Surfaces

NanoScope software displays force volume data as a distribution of forces at a given Z position. It is also possible to consider the force volume data as a stack of constant force surfaces. Importing the force volume image file into a third party software package with array processing and three-dimensional graphical display capabilities, like IDL, can produce images of these iso-force surfaces. Constant force surfaces can be measured directly with the AFM, but force volume data facilitates generating many iso-force surfaces. For the bacteriorhodopsin (BR) membrane adsorbed to mica shown in Figure 3.4r, the flat lower surface corresponds to a **Trig threshold** of **20 NM**. All the Z positions are zero since they are measured relative to the piezo position at **Trig threshold**. The upper surface is a lower force just before tip contact with the membrane; it is effectively a topographic image. The iso-force surfaces were calculated and displayed using IDL.

Figure 3.4r Iso-Force Surfaces: Bacteriorhodopsin Adsorbed to Mica.



Interpretation

A two dimensional image is specific to a particular Z position of the base of the probe and is a mapping from an area of the XY sample plane to the deflection values obtained at each sampled point in the area. A three dimensional volume is a collection of images over the same XY area, each at a different Z value in a range of probe/sample separations.

To convert deflection data to values of force, the spring constant of the cantilever must be determined.

Tip charge density and shape, charge density of the sample, adsorbents on both tip and sample, and the elasticity of the sample are among the contributors to tip/sample force. Where possible, include reference control samples in your experiment to minimize unexplained variability in your interpretation of force volume data.

3.4.8 Force Volume Glossary

Data type: occurs in Image and Force Volume Modes. In Image Mode, **Data type** identifies the type of signal displayed in the image window. In Force Volume Mode, **Data type** identifies force volume imaging type (in the **Force Channel** panel); the choices depend on SPM (e.g., a MultiMode AFM has more options than a standard AFM). This note discusses force volume imaging based on the deflection signal. Under the **Feedback** panel, the **Data Type** of the FV trigger is selectable.

Display Mode: in the **Z Scan** control panel is set to display in the force plots region the **EXTEND** portion of the force curves, the **RETRACT** portion, or **BOTH**.

Force per line: in the **FV Channel** panel determines the number of force curves collected and stored along each scan line and significantly affects the scan speed. This parameter is, effectively, the XY resolution of the force volume image.

Number of samples: in the **Force Channel** panel sets the number of points collected in each force curve. This is also the number of slices in the force volume image, that is, the Z resolution of the force volume image. This parameter does not affect the speed of the scan but does affect the file size.

Center plot: in the **Force Channel** control panel determines where the force plots are graphed relative to the current setpoint. When **Center plot** is **OFF**, the center horizontal line of the graph is positioned at the **Setpoint** value and cantilever deflection is measured from this value. When **Center plot** is **Enabled**, the central horizontal line is positioned at the tip noncontact voltage (i.e., voltage when the tip is clear of the surface - the noncontact portion of the curve) from which the deflection is measured.

Samples per line: in the **Image Channel** control panel sets the number of pixels in each scan line of the height image. Total force volume data acquisition time is proportional to **Samples per line**. This parameter directly affects the XY resolution of the height image only.

Deflection Sensitivity: in the **Force Channel** control panel relates cantilever deflection as measured in photodetector output voltage to topographic height.

Data Type: in the **Feedback** panel determines the data channel to act as the trigger. Usually, this has the same value as **Force Channel/DATA TYPE**.

Trig threshold: in the **Feedback** control panel is set to the tip deflection magnitude which causes the piezoelectric actuator to begin retracting if a trigger is in use. **Trig threshold** limits forces on the sample and tip.

Trigger mode: in the **Feedback** panel determines the type of trigger to be employed: **RELATIVE**, or **ABSOLUTE**. A relative trigger measures the trigger threshold relative to the noncontact deflection voltage value, so compensates for drift. An absolute trigger measures the trigger threshold with respect to **Setpoint**.

Data Center: in the **FV Channe**l control panel adds/subtracts a constant value to/from the data signal (deflection in the case of contact mode force volume imaging). This is used to center the force volume data within the FV scale bar.

FV scale: in the **FV Channel** control panel sets the range of values displayed by the force volume image in RealTime. For offline viewing, use **FV scale** in the **Offline Parameters** panel in the Force Volume view.

Z direction: in the **FV Channel** control panel determines which portion of the Real-time force curve cycle, **EXTEND** or **RETRACT**, is shown in the force volume image region. **Z direction** is also found in the **Offline Parameters** list of a captured force volume.

Z display: in the **FV Channel** control panel determines which slice of the force volume is displayed in the force volume image region. **Z display** is also found in the **Offline Parameters** list of a captured force volume.

Data Scale: in the **Force Channel** control panel sets the range of cantilever deflection values plotted in the force curves region.

Scan Rate: in the **Z Scan** panel sets the rate at which the AFM collects a force curve, both extending and retracting portions. **Scan Rate** and **Samples per line** determine the time to collect a force volume data set.

Ramp size: in the **Z Scan** panel sets the excursion size for the probe during the extend and retract portions of a force curve. When the cantilever deflects an amount equal to **Trig threshold**, the piezoelectric actuator retracts one **Ramp size** before beginning the next curve.

Z scan start: in the **Z Scan** panel sets the starting position of the piezoelectric actuator for the first force curve only.

3.4.9 Force Volume Sample Parameter Settings

For imaging a relatively smooth (features less than 100 nm tall) surface:

Image Scan Controls:

Scan size:	2 µm
Scan angle:	90 deg.
Scan rate:	20 Hz
Slow scan:	Enabled
Z limit:	440 V

Z Scan Controls:

Ramp size:	100 nm
Scan rate:	4 Hz
FV scan rate:	6 Hz

Feedback Controls:

Trigger mode:	Relative
Trig threshold:	10 nm
Data type:	Deflection

Image Channel:

Samples per line:	64, 32 or 16
Realtime Planefit:	Line
Offline planefit:	None

Force Channel:

Number of samples: 64, 256 or 512
Data type: Deflection

FV Channel:

Force per line: 64, 32 or 16

3.4.10 Fluid Cell Preparation for Force Volume

If making force volume measurements in fluid, ensure that the fluid cell is clean. Wash the cell with a mild detergent, rinse in de-ionized water, and blow dry with a few blasts of compressed air.

Place the cantilever (preferably UV cleaned) in the holder and gently seat the O-ring in its place in the cell. Ultraviolet (UV) cleaning is achieved by irradiating the probe at 3-5mm distance from a UV lamp.

Place a thin film of fluid/buffer (20-30µL) on the sample before placing it into the microscope.

Adjust the positioning screws so that, when the fluid cell is placed in the head of the microscope, neither the O-ring nor the tip are in contact with the fluid.

Place the holder into the microscope and aim the laser at the tip of the cantilever and adjust the photodetector so that the deflection is approximately zero.

Using the screws, slowly lower the tip towards the sample until the fluid meets the O-ring. Then, watching the A+B (sum) signal for a large deflection, lower the tip until it is pulled by surface tension into the fluid. Lower the stage carefully a little more to ensure that the entire fluid cell is full of fluid.

If there are no air bubbles in the cell or on the cantilever, simply adjusting the mirror should bring the laser spot back onto the photodetector.

If the laser spot cannot be found, gently inject (by syringe and/or through a tube) more fluid into the cell to flush bubbles out (also through a tube).

CAUTION: Be careful; if the O-ring is not well-seated or the fluid cell otherwise leaks, the piezoelectric actuating scanner tube may suffer a high voltage short circuit and require replacement.

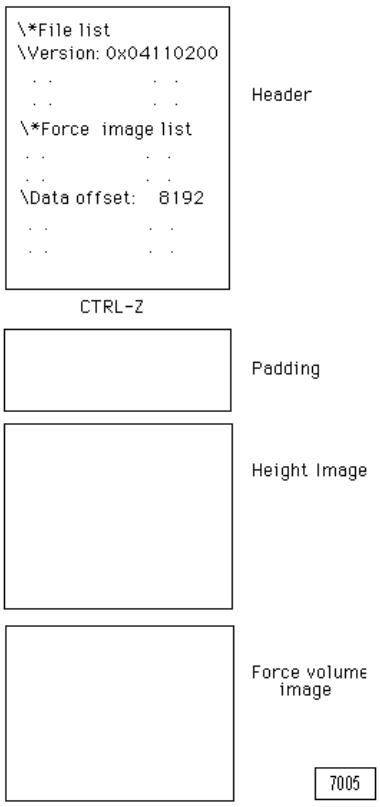
Once the signal is regained, lower the tip to the surface and begin imaging.

3.4.11 Force Volume Image File Format

While the NanoScope analysis software includes many useful routines, sometimes one might wish to import a force volume image into third party software - a spreadsheet program or an image processing system. The following discussion explains how to extract data from a saved (captured) force volume image.

Like all NanoScope image files, the force volume image file has two parts: a header, and one or more images (see Figure 3.4s). The header contains a series of lists, each of which contains a number of parameters. There is a list for the microscope, for the piezoelectric actuator, for the images, and for the force curves. Basically, every parameter under operator control is written to some line in a list in the header. This information, when combined with the data stored in the images, can be used to reconstruct the original images.

Figure 3.4s Force Volume Data File Structure.



The end of the header is flagged with a **CTRL-Z** character (ASCII 26). Different types of files have different length headers, but they all end with the **CTRL-Z**. There is a block of padding (random) data between the header and the actual images. The height image (Channel 1) is first, followed by the force volume image. All the image data is saved by the NanoScope with 16 bits per pixel, (i.e., in 2's complement notation for negative numbers with the least significant byte (LSB) in "little endian" form).

The height image data begins at byte 8192. It is a two dimensional array of data. The NanoScope *Manual* explains how to reconstruct the image from information in the header.

The force volume data is stored as a series of force curves. Depending on the resolution of the height image, the starting byte will vary. The start position of the force volume data can be found in the Data offset line of the Ciao Force List, designated as:

*Ciao Force List

. .

. .

\Data offset:

Regardless of which is displayed during data collection, both the retract and extend portions of the force curve are written to disk. The force curve data set is a linear array of deflection values. The first half of the array is the retracting portion of the curve; the second half is the extending portion. Both Z position and deflection values need to be scaled based on header values.

The force curves which make up the force volume image are saved in column major format. For example, if **Number of samples** is **256** and **Force per line** is **32**, then there are 32 x 32 = 1024 force curves, each with 512 (retract and extend) deflection values. The force curves are ordered such that the first 32 form the first row of the image, the second 32 the next row, etcetera.

Only the deflection values of the force curves are saved to the file. The corresponding Z-position values are calculated from information in the header:

z = index *440.0 * zsens * zscansize / (65536.0 * samples)

where index = the index in the Z direction, 0-511, of a deflection value

zsens = \Z sensitivity

zscansize = *Force image list\Scan Size

samples = *Force image list\Samps/line

Deflection values are scaled according to the following formula:

deflscaled = deflraw* (20.0 /dsens) / 65536.0

where deflraw = the raw, integer values from the file.

dsens = \Detect sens.

Once the force volume data has been extracted from the file, it can be processed and analyzed by third party software such as RSI's IDL, NIH Image, or Adobe Photoshop.

Third party graphics software is needed to construct a composite figure of several slices or representative force curves pictured along with the height image, for example. The images (heights or slices) and force curves need to be saved/exported individually and then loaded into the third party software.

3.5 Piezoresponse Force Microscopy[1]

Piezoresponse force microscopy is a Contact Mode technique to measure sample displacement out of the sample plane in response to an applied AC bias. The method is most directly applicable to piezoelectric samples such as lead zirconia titanate, but can also work for electrostrictive samples such as lead magnesium niobate, and has been used on ferroelectric materials such as barium titanium oxide.

With the SPM in Piezoresponse Mode, the tip is engaged with the sample and an AC voltage is applied between tip and sample during scanning. A responsive sample expands and contracts in synchronization with the applied voltage. By feeding the photodetected cantilever deflection signal into a lock-in amplifier whose reference signal is the applied AC bias frequency, background topography is suppressed from the resulting image which features only the sample surface height changes induced by the applied field.

Piezoresponse imaging does not require any dedicated hardware and works with both fixed tip/rastered sample (MultiMode) and fixed sample/rastered tip (Dimension) SPMs. There are several consequences of the need to form a circuit to bias the sample:

- The sample must be electrically connected to the sample platform (e.g., with silver paint; see Figure 3.6j).
- Though a light imaging force best preserves samples, the tip must stay in contact with the sample to maintain the applied tip/sample voltage. A particularly rough sample may require a higher load force, higher gains or slower scan speeds to ensure a continuous electrical connection.

  Note: Internal current limiting protects the NSV Controller and the probe tip when using the NanoScope V Controller to apply the bias voltage.

- A conductive cantilever (such as MESP [Magnetic, Etched Silicon Probe], NPG [silicon Nitride Probe, Gold-coated], PIC [Platinum Iridium, Contact], or PIT [Platinum Iridium, Tapping]) is required.

  Note: Active tip cantilevers are not conductive, so PR is not operable with FastScan or dual scan, but only by normal scan using the tube scanner exclusively.

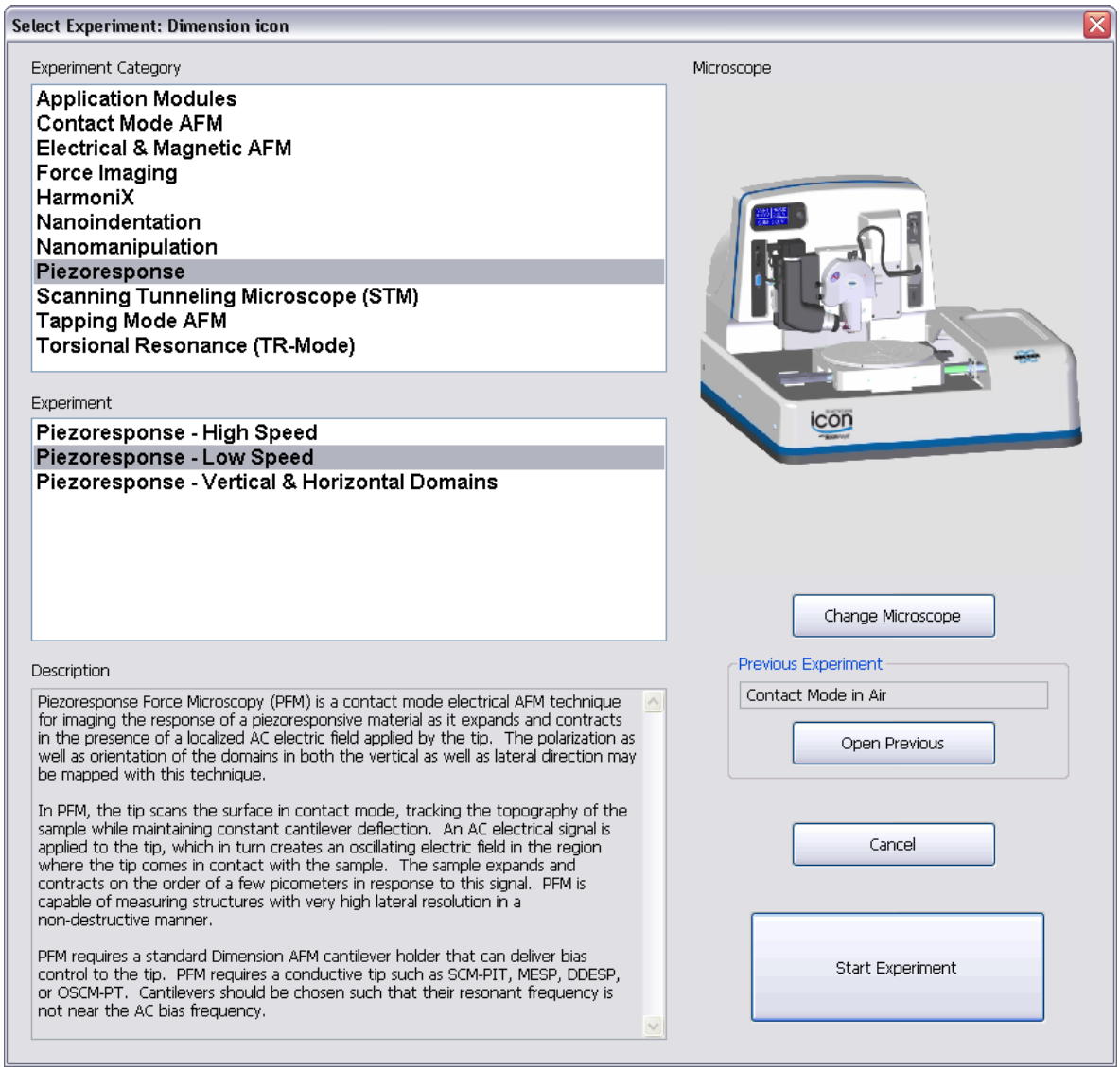
- Piezoresponse imaging may be performed in a nonconducting fluid. In a conductive fluid, a conductive cantilever must be insulated from the fluid, except at the tip; this is difficult to accomplish.

1.This feature is optional on some microscopes such as the Dimension Icon-PI.

Piezoresponse imaging is set up in the following procedure:

1. Click the **SELECT EXPERIMENT** icon. This opens the **Select Experiment** window, shown in Figure 3.5a.

Figure 3.5a The Piezoresponse **Select Experiment** window



2. Select **Piezoresponse** in the **Experiment Category** panel.

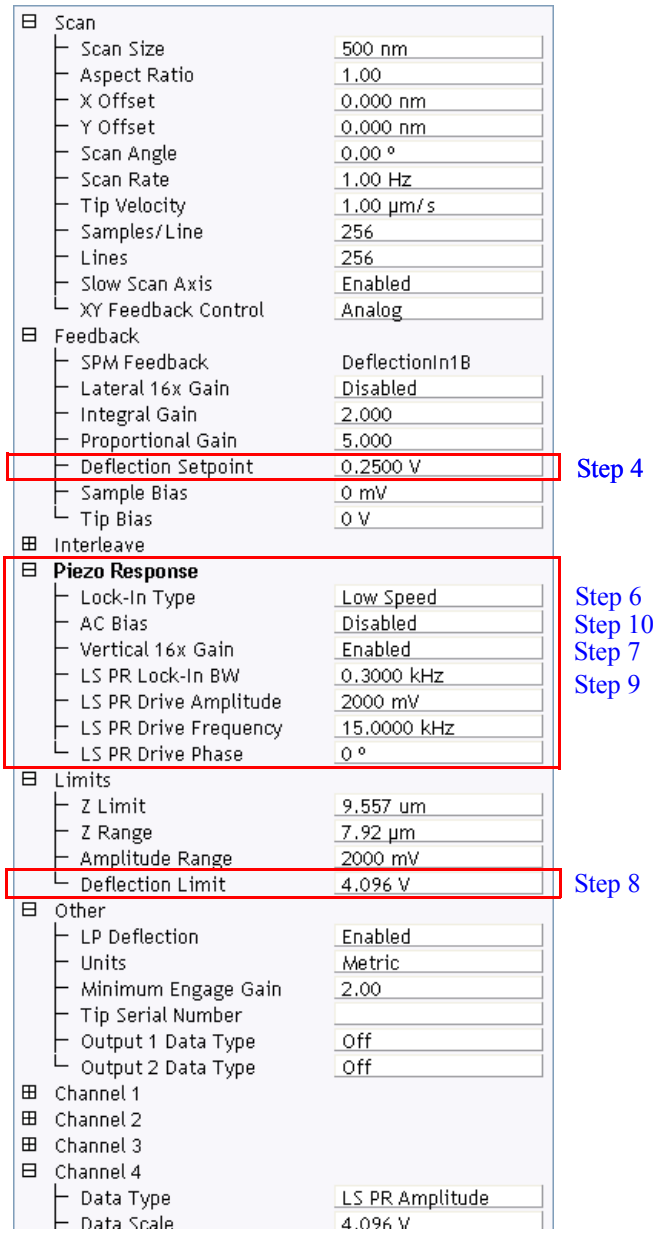
3. Select the type of piezoresponse measurement that you wish to perform in the **Experiment** panel and click **START EXPERIMENT**.

4. To reduce tip wear and increase resolution, set the **DEFLECTION SETPOINT** (in the **Feedback** panel, Figure 3.5b) to a low value, **`0.25V`** initially. Decrease this later while looking at an image to lower the force applied to the sample, or increase it to ensure contact on a rough, but robust sample. This low value, **`0.25V`**, assumes a stiff cantilever (such as MESP, PIC or PIT).

   Note: For an NPG probe, set **DEFLECTION SETPOINT** to **`2.0V`** instead.

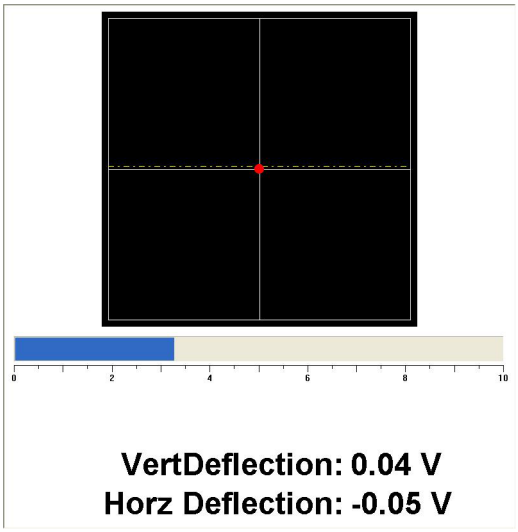
   Note: Most Piezo Response control parameters can be found in the **Piezo Response** panel and have PR for Piezo Response in the parameter name. See Figure 3.5b.

Figure 3.5b EXPANDED MODE Scan Parameter List including Piezoresponse variables



5. Click the **Meter** workspace, shown in Figure 3.5c, and zero-out the photodetector. Note the low **DEFLECTION SETPOINT** (dashed line).

Figure 3.5c Zero the photodetector



6. Set the **Piezo Response LOCK-IN TYPE**. See Figure 3.5b.

   Note: This selection is done for you when you select **LOW** or **HIGH SPEED** in the **Experiment** panel of the **Select Experiment** window.

7. To increase vertical sensitivity, set the **Piezo Response VERTICAL 16X GAIN** to **ENABLED** (default for this workspace). See Figure 3.5b.

8. To further increase vertical sensitivity (by 6x), reduce the **DEFLECTION LIMIT** in the **Limits** panel to **4.096V**. See Figure 3.5b.

   Note: Reducing the **DEFLECTION LIMIT** only provides additional bit resolution but does not multiply the deflection by a factor as the vertical **16X GAIN** does.

9. Set the **PR DRIVE AMPLITUDE** to **2000mV** and the **PR LOCK-IN BW** to **0.3kHz**. See Figure 3.5b.

10. To prevent ESD, set the **AC Bias** to **DISABLED** before Engaging the sample. See Figure 3.5b.

11. Engage the tip on the sample and optimize scan parameters while watching the displayed image with **Channel 1/Data Type** set to **HEIGHT SENSOR**.

The following steps provide initial settings for the Piezo Response control parameters.

12. Select **SAMPLE** in the **AC Bias** drop-down menu.

13. Adjust the **PR DRIVE AMPLITUDE** to optimize contrast in your PR image.

14. Set the **PR DRIVE FREQUENCY**.

CAUTION: AC bias frequency is set to excite piezoresponse in the chosen sample. Typical values are between **2** and **5kHz**, though **60kHz** PR imaging has also been successful. The bias frequency should be well above the scan rate so at least one full bias cycle is performed at each pixel in a piezoresponse image. Check TappingMode Cantilever Tune (see the Q Control chapter in the NanoScope V Controller Manual) to determine the cantilever resonant frequency if there is a possibility it is close to the AC bias frequency desired. PIC cantilevers have resonant frequencies of approximately 10kHz; PIT probes resonate between 60 and 90kHz. Do not set **PR DRIVE FREQUENCY** near the cantilever resonant frequency because the probe could begin mechanically oscillating, compromise tip/sample contact and confound cantilever deflection due to energy absorbed at resonance from the desired deflection due only to piezoresponse of the sample. A 2nm cantilever deflection amplitude is typical both of a piezoresponsive material and of a cantilever being driven in TappingMode.

15. Set **PR DRIVE PHASE** to **0°** initially. This may be adjusted to shift the location of high contrast regions in the piezoresponse image.

16. Select **PR AMPLITUDE** in **Channel 4** and **PR PHASE** for **Data type** in **Channel 5**.

    Note: These are the Piezoresponse workspace default channels.

Write an area in the piezoelectric sample

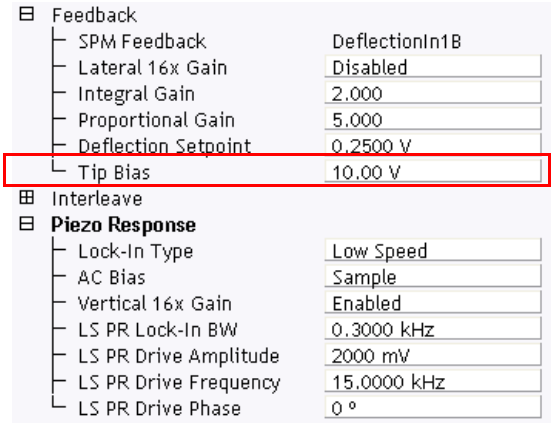
Using the ferroelectric properties of piezoelectric materials, we will now write an area.

Set the following **Scan** Parameters:

- **SCAN SIZE**: 2 µm
- **SCAN RATE**: 1Hz
- **SAMPLES/LINE**: 512

1. Change the **ASPECT RATIO** to 64 to write a small strip.
2. View the **LS PR Phase** channel.
3. Set the **REALTME PLANE FIT** to **NONE**.
4. Set the **TIP BIAS** to **10V** to write the area. See Figure 3.5d.

Figure 3.5d Set the **TIP BIAS** to 10V to write the area.



5. After writing the area, turn off the **TIP BIAS** by setting it to **0V**.

Image the written area

1. Increase the scan size to see the area that was written:

   - Increase the Scan Size to 3µm. See Figure 3.5e. Note the written area between 0.5µm and 2.5µm.

   - Increase the **ASPECT RATIO** to 4. The images are shown in Figure 3.5f.

Figure 3.5e Written strip

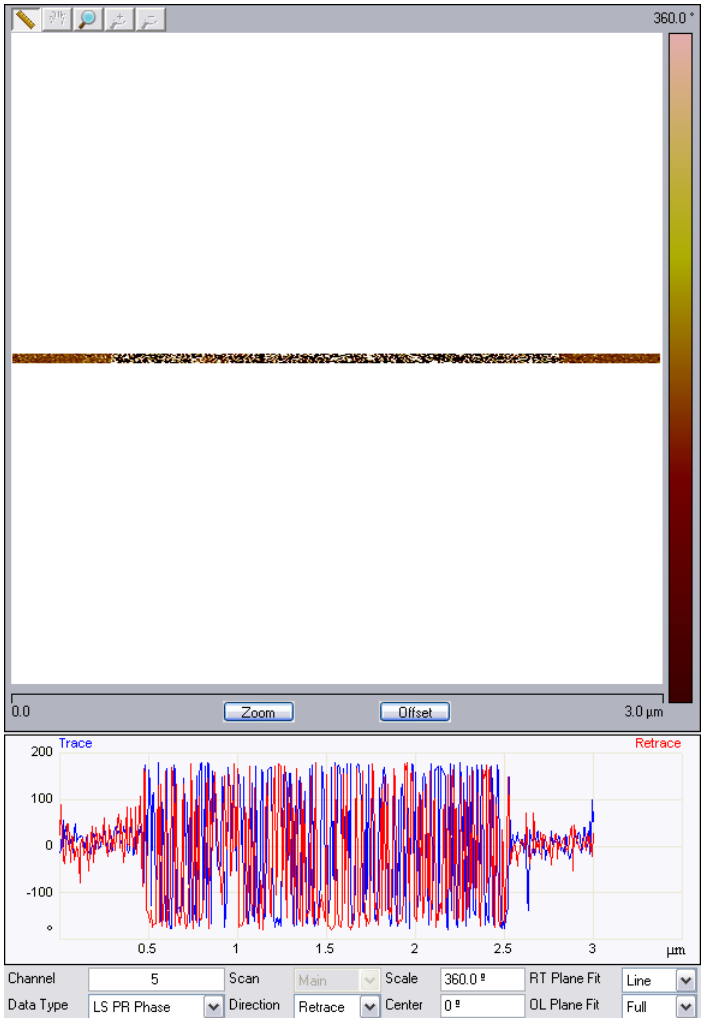
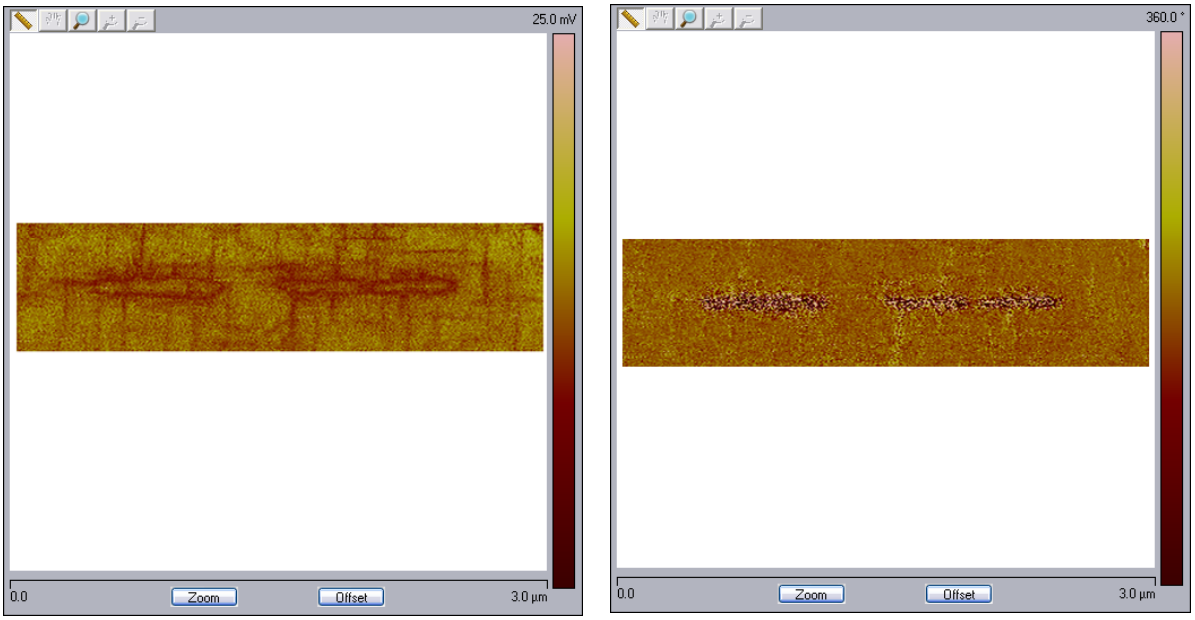


Figure 3.5f Piezo Response images of written strip

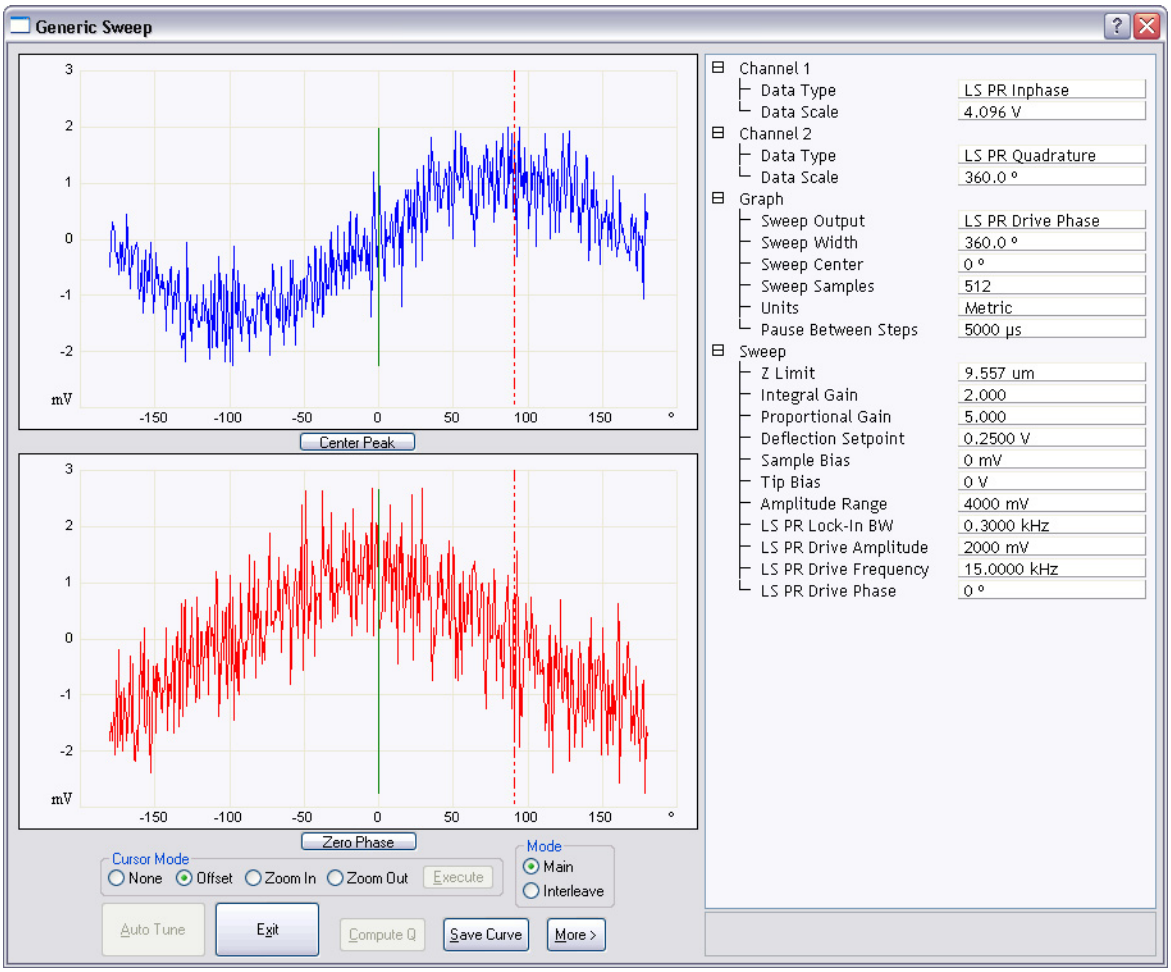


Optimize the image

Piezo response image contrast my be improved by using the **Generic Sweep** feature of the NanoScope V Controller to optimize the drive frequency or phase.

1. Start the **Generic Sweep** by clicking the **SWEEP** icon in the **Workflow Toolbar** to open the Generic Sweep window, shown in Figure 3.5g.

Figure 3.5g Generic Sweep Window



2. Set the **CHANNEL 1 DATA TYPE** to `LS PR INPHASE` and the **CHANNEL 2 DATA TYPE** to `LS PR QUADRATURE`.

3. Set the **SWEEP OUTPUT** to `PR DRIVE PHASE`.

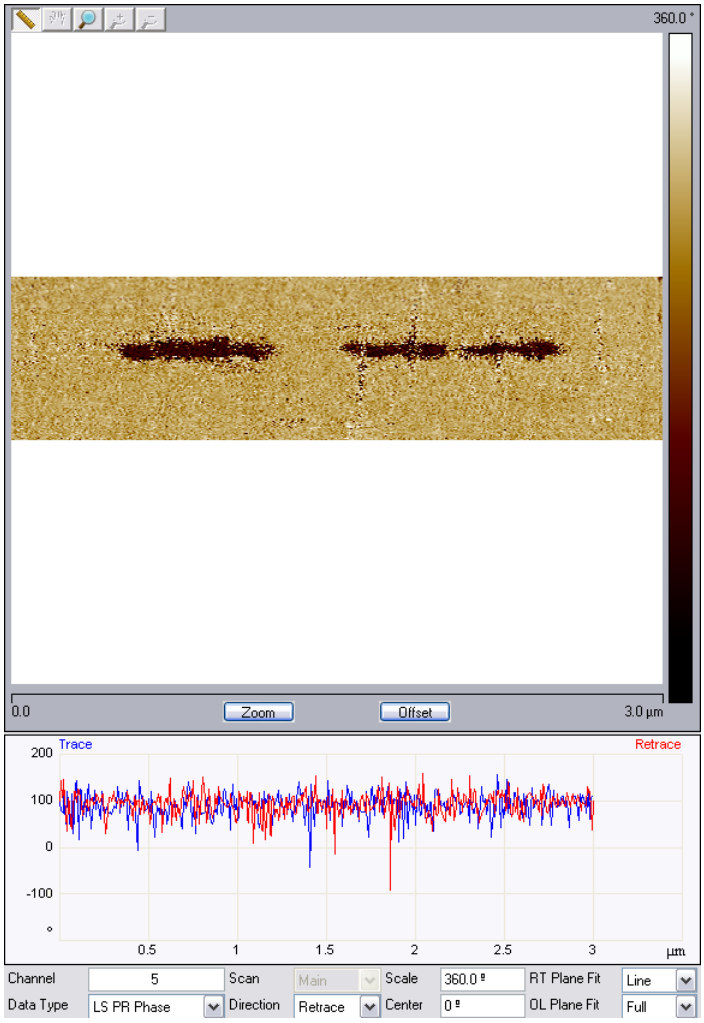
4. Click the **OFFSET Cursor Mode** radio button.

5. Drag the dashed red cursor to the point of maximum response and click **EXECUTE** to set the **PR DRIVE PHASE**.

6. Click **EXIT** to exit the **Generic Sweep** function.

This will change the **PR DRIVE PHASE** to maximize the PR In Phase signal and minimize the PR Quadrature signal. See Figure 3.5h.

Figure 3.5h LS PR In Phase optimized



7. Similarly, one may also optimize LS PR Quadrature.

Additional information about the piezoresponse mode can be found in *Piezoresponse Atomic Force Microscopy Using a NanoScope V Controller*, Bruker p/n 013-444-000.

3.6 Surface Potential Detection

3.6.1 Surface Potential Detection Overview

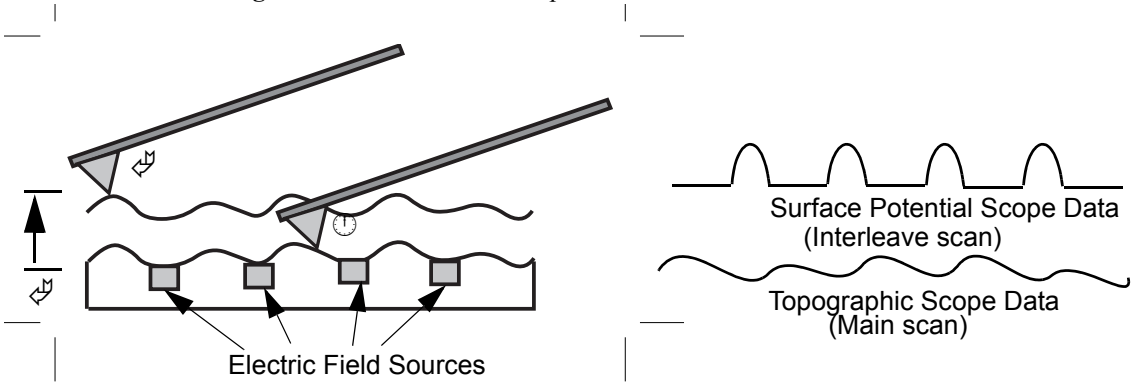
Surface potential detection measures the effective surface voltage of the sample by adjusting the voltage on the tip to match that of the surface, thereby minimizing the electric force from the sample. Samples for surface potential measurements must have a surface voltage in the range [-10,+10 volts], and operation is easiest for voltages in the range of [-5,+5V]. The noise level with this technique is typically 10mV. Samples may include both conducting and nonconducting regions. Samples with regions of different metals will also show contrast due to contact potential differences. Quantitative voltage measurements are made of the relative voltages within a single image.

3.6.2 Surface Potential Detection—Theory

Theory Overview

Surface potential detection is a two-pass procedure where the surface topography is obtained by standard TappingMode in the first pass and the surface potential is measured on the second pass (see Figure 3.6a). The two measurements are interleaved: that is, they are each measured one line at a time with both images displayed on the screen simultaneously. A block diagram of the Surface Potential measurement system is shown in Figure 3.6b. On the first pass, in TappingMode, the cantilever is mechanically vibrated near its resonant frequency by a small piezoelectric element. On the second pass, the tapping drive piezo is turned off and an oscillating voltage $V_{AC} \sin\omega t$ is applied directly to the probe tip. If there is a DC voltage difference between the tip and sample, then there will be an oscillating electric force on the cantilever at the frequency ω. This causes the cantilever to vibrate, and an amplitude can be detected.

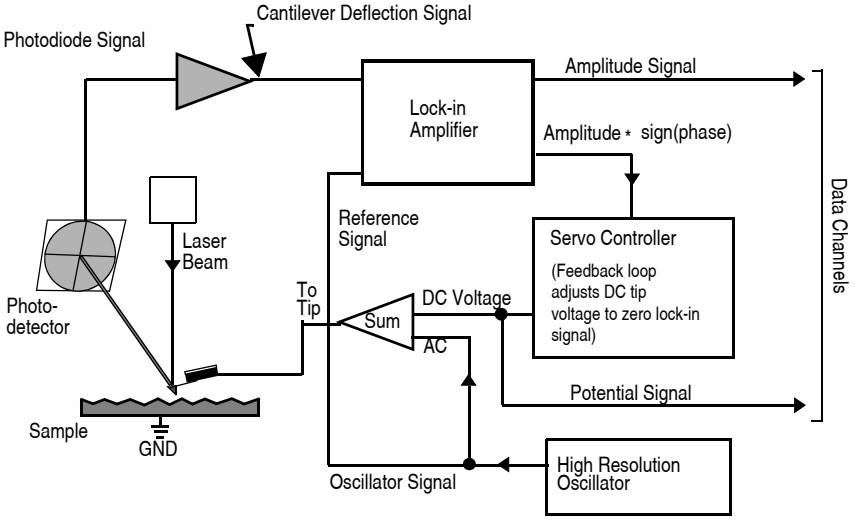
Figure 3.6a LiftMode Principles Used in Surface Potential Detection



1. Cantilever measures surface topography on the first (main) scan.
2. Cantilever ascends to lift scan height.
3. Cantilever follows stored surface topography at the lift height above sample while responding to electric field influences on the second (interleave) scan.

If the tip and sample are at the same DC voltage, there is no force on the cantilever at ω and the cantilever amplitude will go to zero. Local surface potential is determined by adjusting the DC voltage on the tip, V_{tip}, until the oscillation amplitude becomes zero and the tip voltage is the same as the surface potential. The voltage applied to the probe tip is recorded by the NanoScope Controller to construct a voltage map of the surface.

Figure 3.6b Simplified Block Diagram of Surface Potential Detection

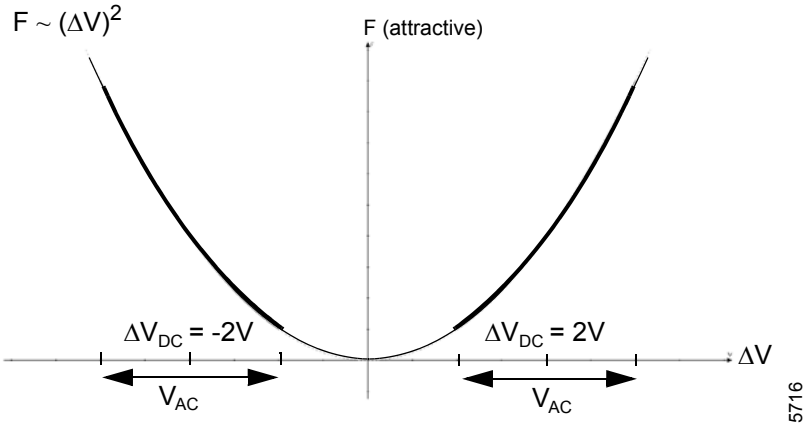


Theory Details

A good way to understand the response of the cantilever during Surface Potential operation is to start with the energy in a parallel plate capacitor, $U = \frac{1}{2}C(\Delta V)^2$, where C is the local capacitance between the AFM tip and the sample and ΔV is the voltage difference between the two. The force on the tip and sample is the rate of change of the energy with separation distance:

$$F = -\frac{dU}{dZ} = -\frac{1}{2}\frac{dC}{dZ}(\Delta V)^2$$

Figure 3.6c Force as a Function of Voltage



The voltage difference, ΔV, in Surface Potential operation consists of both a DC and an AC component. The AC component is applied from the oscillator, $V_{AC}\sin\omega t$, where ω is the resonant frequency of the cantilever.

$$\Delta V = \Delta V_{DC} + V_{AC}\sin\omega t$$

ΔV_{DC} includes applied DC voltages (from the feedback loop), work function differences, surface charge effects, etc. Squaring ΔV and using the relation $2\sin^2 x = 1 - \cos(2x)$ produces:

$$F = \underbrace{-\frac{1}{2}\frac{dC}{dZ}(\Delta V_{DC}^2 + \frac{1}{2}V_{AC}^2)}_{\text{DC term}} \underbrace{-\frac{dC}{dZ}\Delta V_{DC}\,V_{AC}\sin\omega t}_{\omega\text{ term}} + \underbrace{\frac{1}{4}\frac{dC}{dZ}V_{AC}^2\cos(2\omega t)}_{2\omega\text{ term}}$$

The oscillating electric force at ω acts as a sinusoidal driving force that can excite motion in the cantilever. The cantilever responds only to forces at or very near its resonance, so the DC and 2ω terms do not cause any significant oscillation of the cantilever. In regular TappingMode, the cantilever response (RMS amplitude) is directly proportional to the drive amplitude of the tapping piezo. Here the response is directly proportional to the amplitude of the F_ω drive term:

$$\textit{amplitude of}\ F_\omega = \frac{dC}{dZ}\Delta V_{DC}V_{AC}$$

The goal of the Surface Potential feedback loop is to adjust the voltage on the tip until it equals the voltage of the sample (ΔV_{DC}=0), at which point the cantilever amplitude should be zero (F_{ω}=0).

The larger the DC voltage difference between the tip and sample, the larger the driving force and resulting amplitude will be. But the F_{ω} amplitude alone is not enough information to adjust the voltage on the tip. The driving force generated from a 2V difference between the tip and sample is the same as from a -2V difference (see Figure 3.6c).

What differentiates these states is the phase. The phase relationship between the AC voltage and the force it generates is different for positive and negative DC voltages (see Figure 3.6d through Figure 3.6g).

In the case where ΔV_{DC} = 2V, the force is in phase with V_{AC}. When ΔV_{DC} = -2V, the force is out of phase with V_{AC}. Thus, the cantilever oscillation will have a different phase, relative to the reference signal V_{AC}, depending on whether the tip voltage is larger or smaller than the sample voltage. Both the cantilever amplitude and phase are needed for the feedback loop to correctly adjust the tip voltage. The input signal to the Surface Potential feedback loop is the cantilever amplitude multiplied by the sign of its phase (i.e., amplitude for phase ≥0 degrees, -amplitude for phase <0 degrees). This signal can be accessed in the software by selecting **POTENTIAL INPUT** (interleave scan line) in one of the channel panels.

If ΔV_{DC} = 0, the electric drive force is at the frequency 2ω. The component of the force at ω is zero so the cantilever does not oscillate (see Figure 3.6h and Figure 3.6i). The Surface Potential feedback loop adjusts the applied DC potential on the tip, V_{tip}, until the cantilever's response is zero. V_{tip} is the Potential data that is used to generate a voltage map of the surface.

Figure 3.6d V_{AC} at ω, ΔV_{DC} = 2V

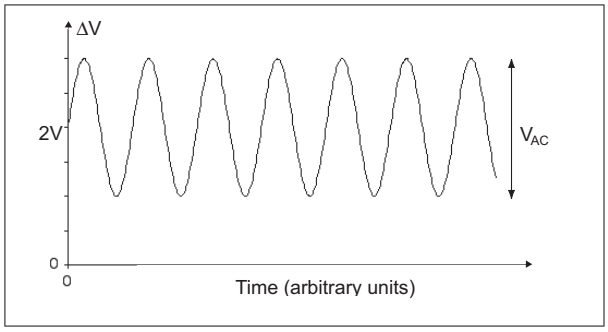


Figure 3.6e Major Force Component in Phase with V_{AC} at Frequency ω, $\Delta V_{DC} = 2V$

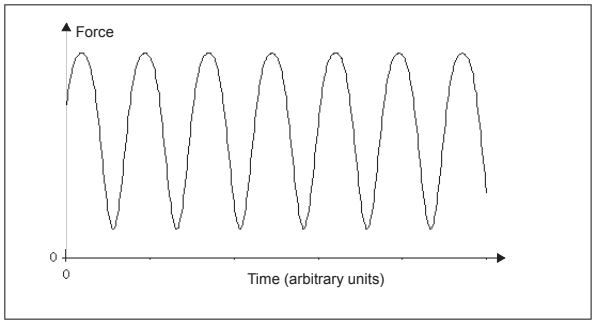


Figure 3.6f V_{AC} at ω, $\Delta V_{DC} = -2V$

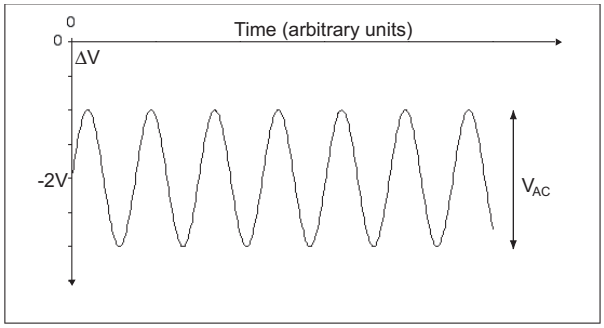


Figure 3.6g Major Force Component 180° Out of Phase with V_{AC} at Frequency ω, $\Delta V_{DC} = -2V$

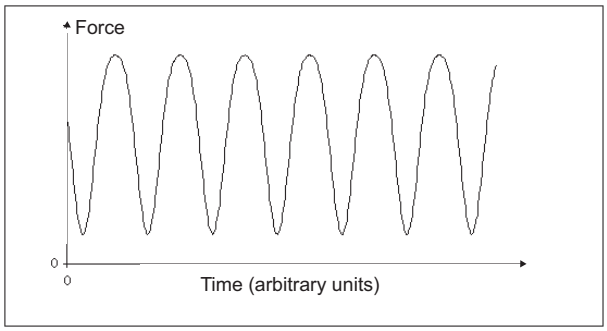


Figure 3.6h V_{AC} at ω, $\Delta V_{DC} = 0V$

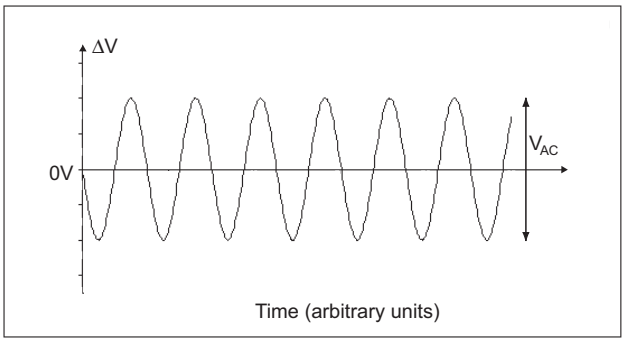
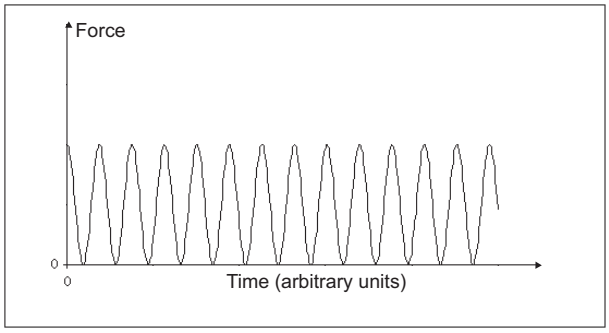


Figure 3.6i Force at frequency of 2ω, $\Delta V_{DC} = 0V$



3.6.3 Surface Potential Detection — Voltage Application

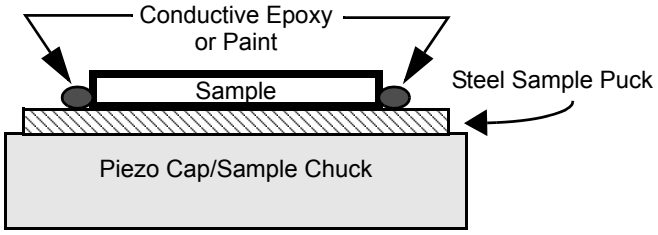
If the sample does not require voltage to be applied (as in measuring work function difference on a sample made up of several metals), skip to **Surface Potential Detection — Procedure:** Section 3.6.4.

It is often desirable to apply a voltage to the probe tip and/or to the sample. The NSV Controller provides a dedicated programmable power supply for each option through parameters **Tip Bias Control** and **Sample Bias Control**, respectively.

To bias the sample using an NSV Controller, ensure the sample is electrically connected to a standard steel sample puck using conductive epoxy or silver paint, as shown in Figure 3.6j.

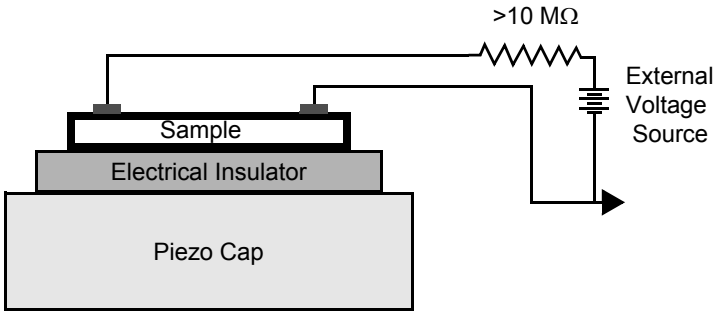
Note: Painted samples are easier to remove from the puck than epoxied samples.

Figure 3.6j Electrically Connecting a Sample to the Piezo Cap (MultiMode) or Chuck (Dimension)



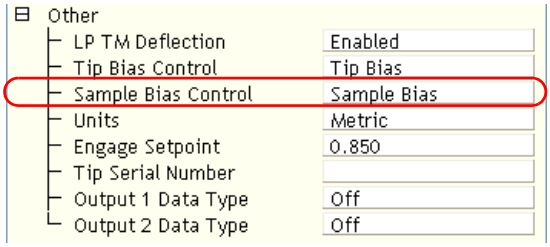
Note: With an NSV Controller, it is often unnecessary to insulate a sample from the conductive sample platform (the MultiMode piezo cap or the Dimension sample chuck) to bias the sample using an external power supply. Instead, electrically connect the sample to its platform (see Figure 3.6j) and bias the platform. To apply a custom waveform or a voltage >|12V| directly to the sample, isolate (insulate) the sample from the platform (with Kapton tape, see Figure 3.6k).

Figure 3.6k Electrically Isolating a Sample from the Piezo Cap (MultiMode) or Chuck (Dimension)



To electrically bias the tip during scanning, set **Other** tab/**TIP BIAS CONTROL** to **TIP BIAS**. Similarly, to electrically bias the sample platform, set **Other**/**Sample Bias Control** to **SAMPLE BIAS** as shown in Figure 3.6l. With the NSV Controller, the **Tip Bias** signal is dedicated to applying a voltage to the tip, while the **Sample Bias** signal is dedicated to sample biasing. The **Tip Bias** power supply may be set anywhere in the range [-12, +12V] while the **Sample Bias** power supply range is [-10, +10V]. Therefore, the tip/sample voltage difference may be made as large as 22V.

Figure 3.6l Sample Bias



Note: **Tip Bias** and **Sample Bias** parameter names do not appear in the **Feedback** and **Interleave** panels until selected for either **Tip Bias Control** or **Sample Bias Control**.

In the **Feedback** panel, set the desired voltage levels for the two parameters for the main scan lines (for Surface Potential, setting to zero or ground is recommended). In the **Interleave** panel set **Sample Bias** separately for the interleave scan lines.

Alternatively, each of these two parameters may be assigned the value **GROUND** instead. The **GROUND** setting is used to force the tip or sample to ground. Selecting **GROUND** for **Tip Bias Control** overrides the current value of **TIP BIAS** in setting the voltage of the tip. Similarly, selecting **GROUND** for **Sample Bias Control** overrides the current value of **Sample Bias** in setting the voltage of the sample platform.

Note: Tip and sample biasing as just described are not limited to Surface Potential Detection, but work as well with other SPM applications using the NSV Controller.

Note: Bruker recommends biasing the tip for Surface Potential detection.

3.6.4 Surface Potential Detection — Procedure

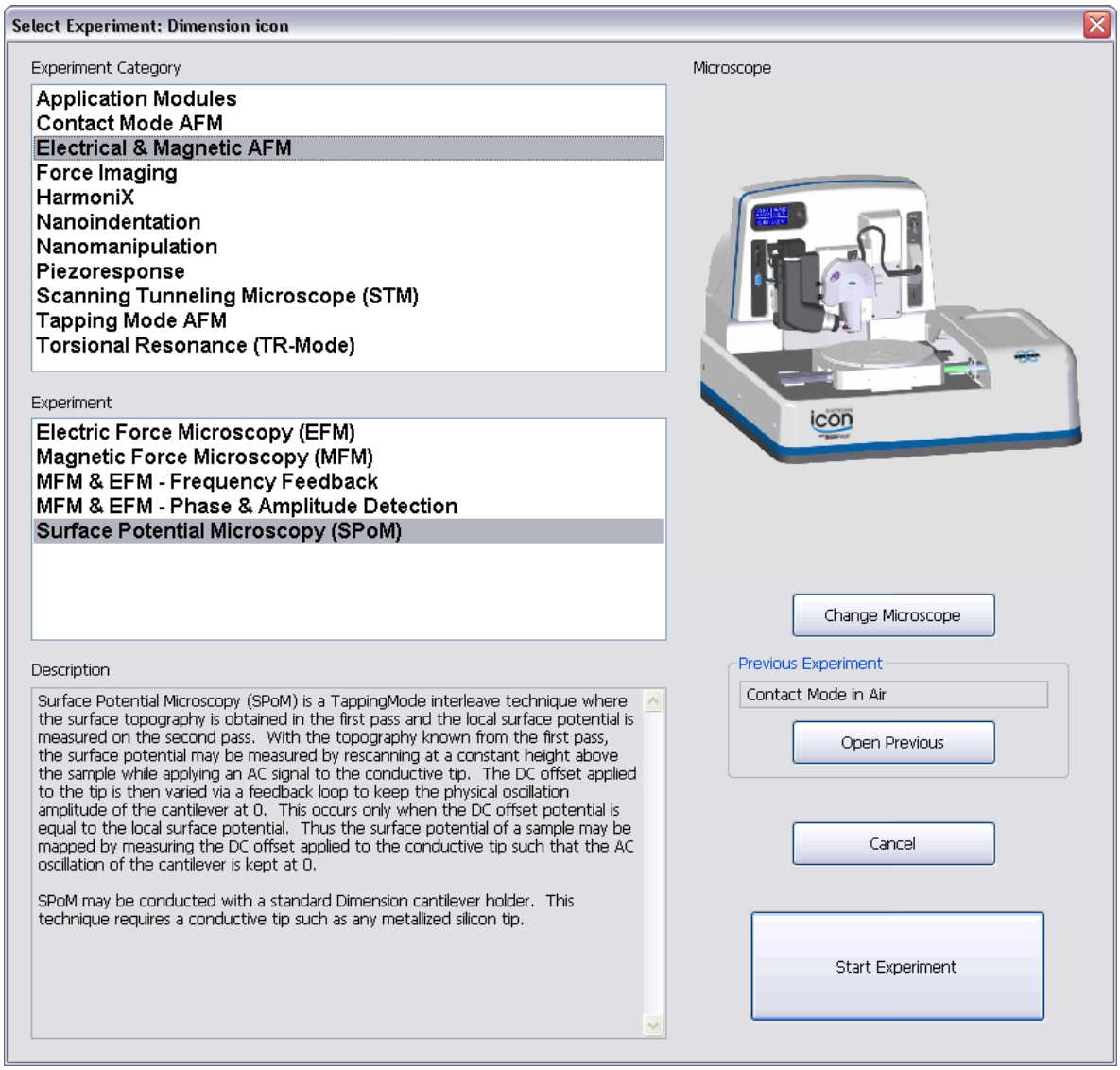
1. Mount a sample onto the sample platform. Ensure electrical connectivity between sample and platform if bias will be applied to the sample (see Figure 3.6j).

2. Mount a metal-coated cantilever into the probe holder (i.e., an MMEFCH probe holder for MultiMode SPMs). MESP- or SCM-PIT model cantilevers (metal coated, 225 µm long, with resonant frequencies around 70 kHz) usually work well.

   Note: The MMEFCH probe holder for MultiMode SPMs is a special probe holder used for both EFM and Surface Potential that can be recognized by the white Teflon washer beneath the screw at the base of the cantilever clip.

3. Click the **SELECT EXPERIMENT** icon. This opens the **Select Experiment** window, shown in Figure 3.6m.

Figure 3.6m The Surface Potential **Select Experiment** window



4. Select **ELECTRICAL AND MAGNETIC AFM** in the **Experiment Category** panel.

5. Select **SURFACE POTENTIAL MICROSCOPY (SPOM)** in the **Experiment** panel and click **START EXPERIMENT**.

6. After you have aligned the laser and photodetector, click the **CANTILEVER TUNE** icon (shown) in the **Workflow Toolbar**. Set **Start frequency**, **End frequency** and **Target amplitude** appropriately then click **AUTOTUNE** to locate the cantilever resonant peak.

7. Engage the AFM and make the necessary adjustments for a good TappingMode image while displaying **HEIGHT SENSOR** (or **HEIGHT**, depending on your SPM) data in **Channel 1**.

8. Set the **Interleave**/**Drive Frequency** (and any other unmentioned interleave parameters) to the main feedback values (i.e., set parameters gray).

   Note: When an **Interleave** parameter is green, the value shown is used during the interleave scan. To fix any parameter so that it is the same on the main and interleave scans, click on that parameter. The parameter changes color to gray ("off") and the main **Feedback** value for that parameter is used.

9. The **Interleave**/**Drive Amplitude** is the AC voltage that is applied to the AFM tip, V_{AC}. To start, choose a **Drive Amplitude** of **6V** and set the corresponding button green.

10. Set **Interleave**/**Lock-In phase**. For MESP, SCM-PIT, or FESP cantilevers (resonant frequency ~60-80khz) enter a **LOCK-IN PHASE** of **-90 DEGREES**. Ensure that the corresponding button is green.

    Note: The NSV Controller records phase in standard degrees with the convention that cantilever phase is zero at resonance.

11. Choose a **LIFT START HEIGHT** of **0NM** (i.e., the parameter is ignored because there is no need for additional initial retraction to break free of the surface in TappingMode) and a **Lift Scan Height** of **100NM**. The **Lift Scan Height** can be readjusted later (i.e., in step 12).

12. In the **Interleave** panel set **Input Feedback** to **POTENTIAL**. Set **Interleave Mode** to **LIFT**.

13. Set the **Channel 3 Scan line** to **INTERLEAVE** and **DATA TYPE** to **Potential**. For both data channels (height and potential) set the **SCAN LINE** direction to **Retrace**. The retrace direction should be chosen because the lift step occurs on the trace scan.

14. Set **Sample Bias Control** and **Tip Bias** as appropriate.

15. Adjust the input gains. Set the **Input Igain** to **10** and **Input Pgain** to **10** as a starting point. As with the topography gains, the scan can be optimized by increasing the gains to maximize feedback response, but not so high that oscillation sets in. More information on tuning the feedback loop is given in Section 3.6.5.

16. Optimize the **LIFT SCAN HEIGHT**. The best resolution is achieved with **LIFT SCAN HEIGHT** at the smallest value possible that does not make the tip crash into the sample surface (see **Optimizing LIFT SCAN HEIGHT**, page 197).

3.6.5 Surface Potential Detection Pointers

Troubleshooting

Potential signal is oscillating

1. Observe the **POTENTIAL** signal in the **Scope** window. If oscillation noise is evident in the signal, reduce the input gains. If oscillations persist even at very low input gains, try increasing the **Lift Scan Height** and/or reducing the **Interleave**/**Drive Amplitude** until oscillation stops. If the tip crashes into the surface during the Potential measurement, dark or light streaks or dots appear in the Potential image, and the signal becomes unstable and can cause the feedback loop to malfunction. Increasing the **Lift Scan Height** and reducing the **Drive Amplitude** can prevent this problem.

   Note: An electrically "floating" sample is a common cause of oscillation. Ensure that there is a low impedance ground connection.

2. Lower **INPUT IGAIN** and **INPUT PGAIN**.

Potential signal is stuck at an extreme (i.e., railed), at either +12V or -12V

1. If the Potential signal is perfectly flat and shows no noise even with a small data scale, the feedback loop is probably railed at ±12V. Verify this by changing the value of **RT Plane Fit** to **NONE** in the **Channel 3** (**POTENTIAL**) panel and increasing the **Data Scale** to the maximum value, **20V**. Check if the data is railed at one of the limits in the **Scope** window. Common reasons for this include:

   - A regular probe holder is being used instead of the EFM probe holder.
   - An inappropriate **Drive Phase** is being used. For MESP or SCM-PIT probes ensure that the Interleave **Lock-In Phase** is set near **-90 DEGREES**. For more details on optimizing drive phase, see **Lock-In Phase**, page 198 .
   - An incorrect electrical connection is being made. Verify that the sample is connected properly to the sample platform. Verify that the jumpers in the base of the MultiMode or on the backplane of the Dimension are in their factory configuration.

Signal contrast is poor, but the Potential signal is not railed

1. Verify there is an electric field at the sample surface. If applying bias voltage to the sample to generate an electric field, set the potential channel **Realtime Plane Fit** to **NONE**. While observing the **Scope** trace, vary the interleave **Bias** value and verify that the potential signal shifts accordingly.

Optimizing Lift Scan Height

1. Fine tune **Lift Scan Height** to as small a value as possible without hitting the surface. Lateral resolution of surface potential detection improves with decreased tip/sample separation. The minimum **Lift Scan Height** depends on the roughness of the sample, the difference between the **Amplitude Setpoint** and free air amplitude, and the quality of the height image. Hitting the surface usually produces phase data with extremely high contrast (i.e., either black or white pixels).

   Because the tip is not oscillating during the Potential measurement (the feedback loop works to keep the amplitude zero), the **Lift Scan Height** is generally smaller than with other LiftMode techniques. **Lift Scan Height**s down to **−5nm** are possible on smooth samples. This lower limit to the **Lift Scan Height** is affected by sample roughness, scan speed, and target amplitude used during tuning, etc. Once oscillation stops, you can increase the input gains for improved performance.

Tip Choices

It is possible to deposit custom coatings on model FESP silicon TappingMode cantilevers. Verify that all deposited metal adheres strongly to the silicon cantilever.

It is also possible in some cases to use uncoated tips. The metallic coating and low spring constant/resonance frequency of MESP and SCM-PIT tips make them well suited for sensitive electrical measurements. However, the coating increases the tip radius, and wear of the coating can cause significant changes in the detection of the electric field in the immediate vicinity of the tip. It has been suggested (Jacobs, H.O., Knapp, H.F., Stemmer, A., “Practical Aspects of Kelvin Probe Force Microscopy,” Rev. Sci. Instrum. 70 (1999) 1756.) that these changes in tip shape account for many of the DC shifts observed in Surface Potential images. Standard TappingMode probes (Models TESP) and the Force Modulation probes (Model FESP) are highly n-doped silicon that are often conductive enough for surface potential detection. The advantage to using uncoated silicon tips is the small tip radius improves lateral resolution in topographic imaging and the absence of changes in the metallic coating during surface potential detection. FESP tips have a lower spring constant and should be more sensitive to smaller forces than TESP tips. However, there is a reduction in sensitivity to small electric fields with the decreased conductivity of an uncoated tip.

If tips with higher resonant frequency are used, such as TESP (~300kHz), a different drive phase must be used, see **Lock-In Phase**, page 198 .

Tuning

Two curves should appear in the Cantilever Tune box—the amplitude curve in blue and the lock-in curve in red. In Surface Potential it is more important than usual that the resonant peak is symmetric. If the peak is unsatisfactory, its shape can often be changed by readjusting the position of the probe in the probe holder. The laser and photodiode usually require readjustment after the probe is moved.

Drive Amplitude

Higher **Interleave Drive Amplitude**s produce larger electric forces on the cantilever, and this makes for more sensitive potential measurements. Conversely, the maximum total voltage (AC + DC) that may be applied to the tip is ±12V. So a large **Drive Amplitude** reduces the range of the DC voltage that can be applied to the tip (**POTENTIAL** signal). If the potentials to be measured are very large, it is necessary to choose a small **Drive Amplitude** (it is not recommended to use less than **2V**), while small surface potentials can be imaged more successfully with large **Drive Amplitude**s. To start, choose a **Drive Amplitude** of **6V**.

Lock-In Phase

Lock-In Phase adjusts the phase of the reference signal to the lock-in amplifier. As discussed in **Surface Potential Detection—Theory** Section 3.6.2, the correct phase relationship must exist between the reference and the input signals to the lock-in for the potential feedback loop to perform correctly. **Lock-In Phase** depends on the mechanical properties of the cantilever. For cantilevers with resonant frequencies from 60-80kHz (such as MESP, SCM-PIT, and FESP), use an interleave **Lock-In Phase** of **170 DEGREES**. For cantilevers with higher resonant frequencies, increased electronics phase lag must be compensated. For cantilevers with resonant frequencies around 300kHz (such as TESP, RTESP) an interleave **Lock-In Phase** near **130 DEGREES** often works well.

Open Loop Operation

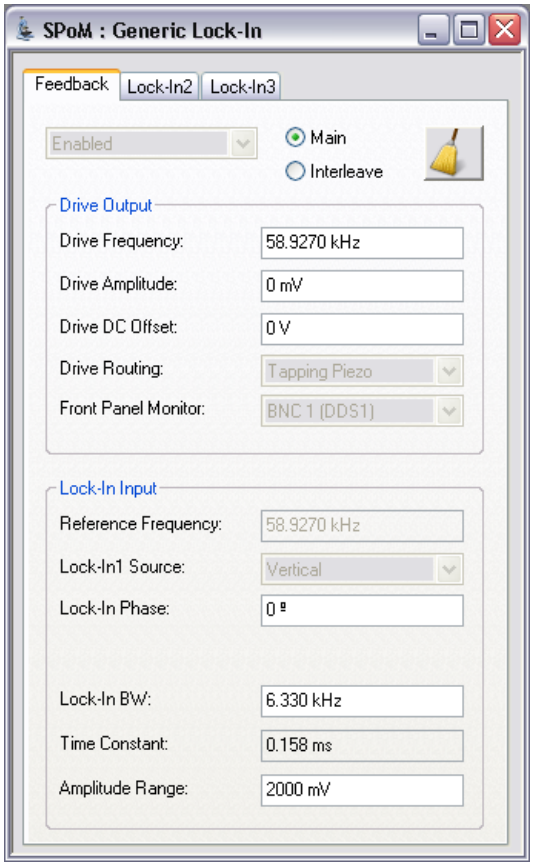
Sometimes it is useful to run Surface Potential in the “open-loop” configuration. This means that the Potential feedback loop is disabled and the data is only qualitative. The AC voltage is applied to the tip as in the standard Potential operation; the tapping piezo used for mechanical driving of the cantilever is disabled. Because the feedback is disabled, there is no adjustment of the DC voltage on the tip, so the oscillating electrical force drives the cantilever into motion. This motion can be monitored by observing the amplitude signal (the input to the potential feedback loop), called “potential input.” Set up the system as described above with the following changes: Set the **Input Igain** and **Input Pgain** to zero. Select **AMPLITUDE** or **POTENTIAL** as the **Data Type**.

> **Note:** Turning the input gains to zero stops further changes to the DC voltage on the tip but does not set the tip voltage back to zero.

3.7 NanoScope V Controller Lock-In

The **Generic Lock-In** GUI, brings together all of the controls associated with the use of the three internal lock-in amplifiers of the NanoScope V Controller into a single panel, shown in Figure 3.7a. The tabs along the top of the main panel are used to access the interface for individual lock-ins.

Figure 3.7a The Generic Lock-In, shown configured for TappingMode imaging. The DDS 1 output is routed to the Tapping Piezo and the lock-in input is set to monitor the vertical photodetector signal.



Note: The **Generic Lock-In** function is not available on all microscopes, e.g. the Dimension Icon-PI, supported by NanoScope version 8 software.

3.7.1 Mode-specific behavior

TappingMode

When calling the lock-in panel with the microscope set to **TAPPING**Mode, the primary lock-in selection tab is labelled **Feedback**. In addition the parameters **DRIVE ROUTING**, **LOCK-IN1 SOURCE** and Lock-in **ENABLE/DISABLE** are disabled and greyed out. This prevents the user from inadvertently mode switching while scanning and using the primary lock-in for feedback.

Contact Mode

When calling the lock-in panel with the microscope set to **CONTACT** mode the primary lock-in selection tab is labelled **Lock-In 1**. All of the lock-in parameters including those disabled for tapping mode are enabled for user selection. Lock-in changes are unable to change the microscope mode while scanning in Contact mode.

Other Modes

STM, Tapping/TR, TR/Tapping, Dynamic Friction and Piezo Response modes are not yet supported by the Generic Lock-In.

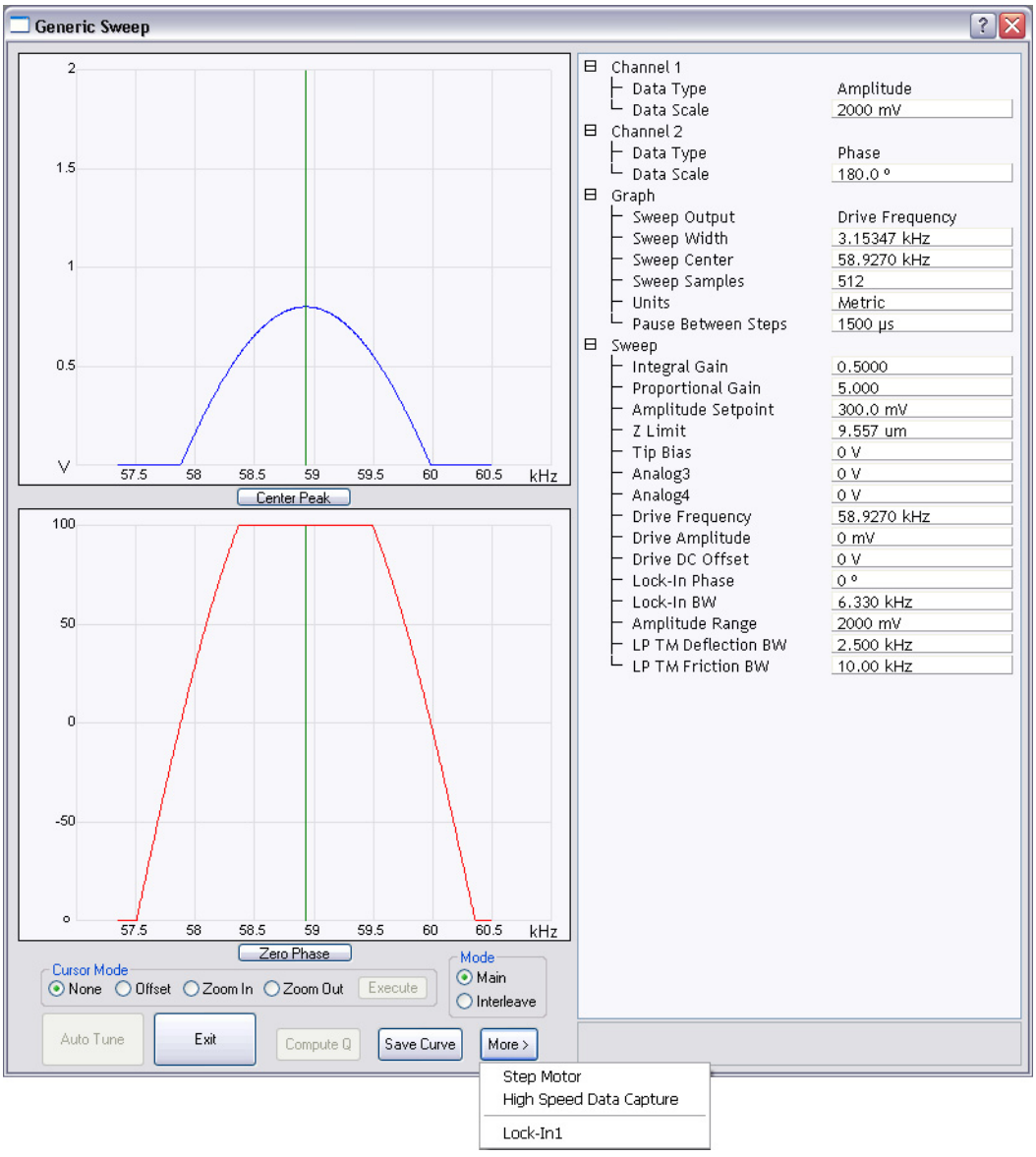
3.7.2 Generic Sweep Window

Below the lock-in selection tabs are controls, shown in Figure 3.7b, that enable the lock-in enable setting parameters for both main and interleave modes. Each of the three lock-in panels has all of the controls necessary to use that lock-in independent of the state of the other lock-ins. Each panel also has a button that allows the user to rapidly access the NanoScope **Generic Sweep** function, shown in Figure 3.7c.

Figure 3.7b Buttons to enable/disable the lock-in and to set parameters for main and interleave modes.

The **GENERIC SWEEP** button takes the user to the **Generic Sweep** window and populates fields based on values in the calling lock-in panel. Clicking the **MORE** button of the **Generic Sweep** window allows the user to toggle between the enabled lock-ins without leaving the **Generic Sweep** window.

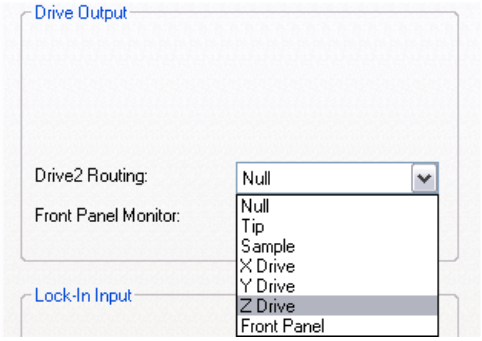
Figure 3.7c The **Generic Sweep** window may be accessed from the lock-in panel.



3.7.3 Drive Output Panel

The **Drive Output** panel, shown in Figure 3.7d, contains all of the controls to configure the output waveform of the DDS including frequency, amplitude, DC offset and the signal routing.

Figure 3.7d The **Drive Output** panel



Harmonic

The **HARMONIC Drive Output** option, available for **Lock-In 2**, locks in on a user-selected harmonic (1-25) of the drive (DDS 1) signal. This enables you to lock in on higher (than the fundamental) frequency modes of the cantilever. You must set **Lock-In 1** (**Feedback**) to ENABLED and select set **Lock-In 2** to HARMONIC.

Drive Frequency

Sets the frequency of the corresponding DDS output and the reference for the lock-in input.

Drive Amplitude

Sets the zero-to-peak amplitude of the DDS output.

Drive DC Offset

Applies a DC shift to the AC bias.

Note: The maximum output voltage of the DAC is +/-10 Volts. Ensure that the DC offset plus the AC **DRIVE AMPLITUDE** is less than 10V to avoid clipping the output waveform.

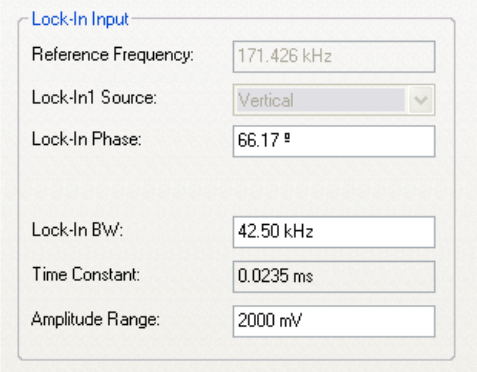
Drive Routing

Sets the output destination for the drive signal. Options are **TAPPING PIEZO**, **TIP**, **SAMPLE**, **X DRIVE**, **Y DRIVE**, **Z DRIVE**, **FRONT PANEL** (Lock-In 2) and **NULL**. When the output is selected as **FRONT PANEL**, the output is routed to the DDS 2 BNC on the front panel of the NanoScope V Controller. When the output is selected as **NULL**, the output is not routed but allows a reference signal to be generated and the lock-in used for inputs.

3.7.4 Lock-Input Panel

The **Lock-In Input** panel, shown in Figure 3.7e, contains all of the controls to configure the inputs to the lock-in.

Figure 3.7e The **Lock-In Input** panel.



Reference Frequency

Duplicates the frequency from the **Drive Output** panel.

Lock-In Source

Selects the input source to the lock-in amplifier. Options are **VERTICAL** Photo-detector, **HORIZONTAL** Photo-detector, **APPLICATION MODULE** and **FRONT PANEL**.

Lock-In Phase

Sets the phase offset between the detected signal and the reference. Three buttons below the parameter display add/subtract 90° or Zero the current phase.

Lock-In BW

Sets the lock-in bandwidth for the lock-in input.

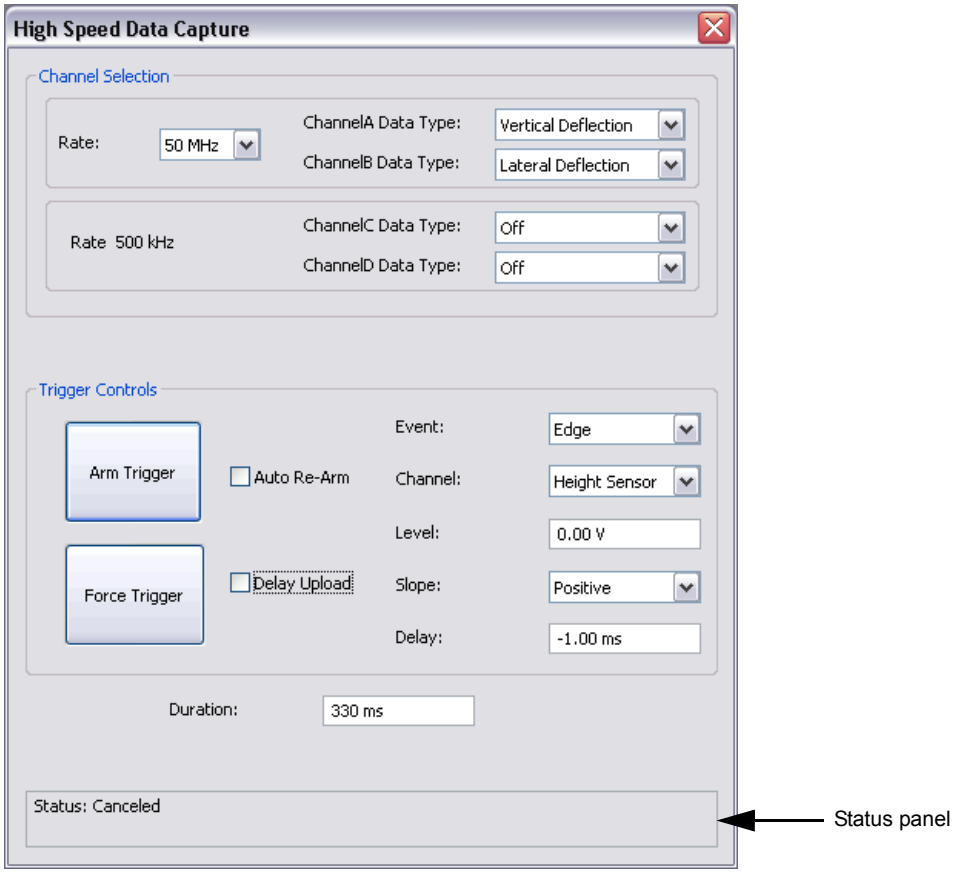
Time Constant

Calculated from the lock-in bandwidth as (1/lock-in BW).

3.8 High Speed Data Capture

The **High Speed Data Capture** window, shown in Figure 3.8a, allows you to capture and store many signals. To open the **High Speed Data Capture** window, click **CAPTURE** > **HIGH SPEED DATA CAPTURE**.

Figure 3.8a High Speed Data Capture window



Note: The **High Speed Data Capture** function is not available on all microscopes, e.g. the Dimension Icon-PI, supported by NanoScope version 8 software.

3.8.1 Channel Selection Panel

Channels A and B can capture data at 6.25MHz and 50MHz while channels C and D capture data at 500kHz. Channels A and B capture **VERTICAL** and **LATERAL DEFLECTION** respectively. Data capture of those channels may also be turned **OFF**.

The following data types are available for capture at 500kHz by the C and D channels:

- Height
- Signal Sum
- X sensor
- Y sensor
- Z sensor
- Amplitude
- Phase
- TM Deflection
- Deflection Error
- Friction
- Z Feedback Output
- Input 1
- Input 2
- Input 3
- X Scan
- Y scan

3.8.2 Trigger Controls Panel

The following trigger controls are available:

Arm Trigger

ARM TRIGGER begins monitoring for the trigger conditions to be met and starts data acquisition into the FIFO buffer. This button toggles to **DISARM TRIGGER** when the trigger is armed.

Disarm Trigger

DISARM TRIGGER stops data acquisition and stops monitoring for a trigger event.

Auto Re-Arm

The **AUTO RE-ARM** check box causes the trigger to be re-armed after the data acquisition is completed. If **AUTO RE-ARM** is not checked, the trigger will be disarmed after the data acquisition has been completed.

Force Trigger

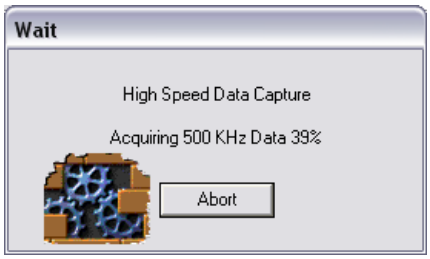
The **FORCE TRIGGER** button triggers data collection.

Event

The trigger **EVENT** drop-box allows you to trigger on an **EDGE**, **EOL** (End of Line), **EOF** (End of Frame) or **NONE**. When the trigger is armed and a trigger **Event** occurs (or, if the trigger is forced), an **ABORT** box, shown in Figure 3.8b, giving you the ability to abort the data acquisition appears.

Note: If **Event** = **NONE**, you must **FORCE TRIGGER** to begin data acquisition.

Figure 3.8b Abort box



Channel

The Channel drop-box allows the following data types to be used as a trigger:

- Signal Sum
- X sensor
- Y sensor
- Z sensor
- Deflection Error
- Friction
- Z Feedback Output
- Input 1
- Input 2
- Input 3
- X Scan
- Y Scan

Level

Select the trigger **LEVEL** at which you wish to begin acquiring data.

Slope

You may trigger on either a **POSITIVE** or **NEGATIVE SLOPE**.

Delay

Trigger **DELAY**, if **POSITIVE**, specifies the amount of time between when the trigger conditions are met and when data capture begins. If **NEGATIVE**, **DELAY** specifies the amount before the trigger conditions are met that data capture begins.

Duration

The time **DURATION** of data that is saved.

3.8.3 Status Panel

The high speed data capture status is displayed in the status panel at the bottom of the HSDC window. Captured file names have a suffix of .hsdc

3.8.4 Point And Shoot

The High Speed Data Capture (HSDC) function in the Point and Shoot view, shown in Figure 3.8c, allows you to mark a spot for data collection. This can be operated in two modes:

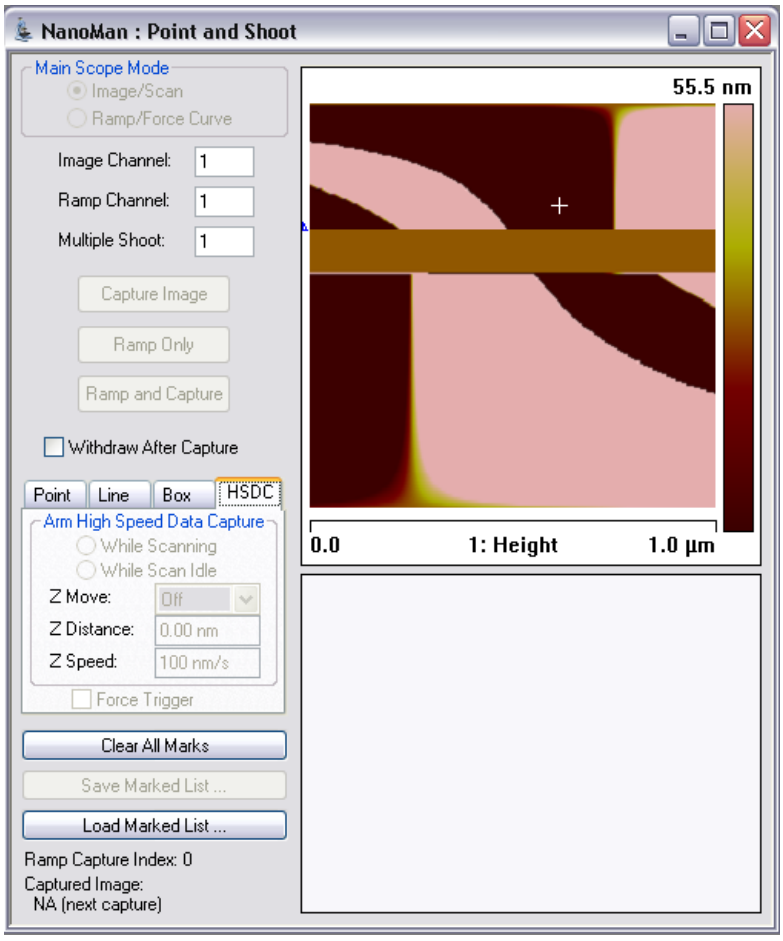
1. **WHILE SCANNING**: triggers a capture when the tip passes the marker point.

2. **WHILE SCAN IDLE**: stops the scan, moves to the marked point and captures data there.

In either mode, you must set the capture conditions in the **High Speed Data Capture** window before acquiring data.

FORCE TRIGGER: forces a trigger at the marked point regardless of the preset trigger conditions.

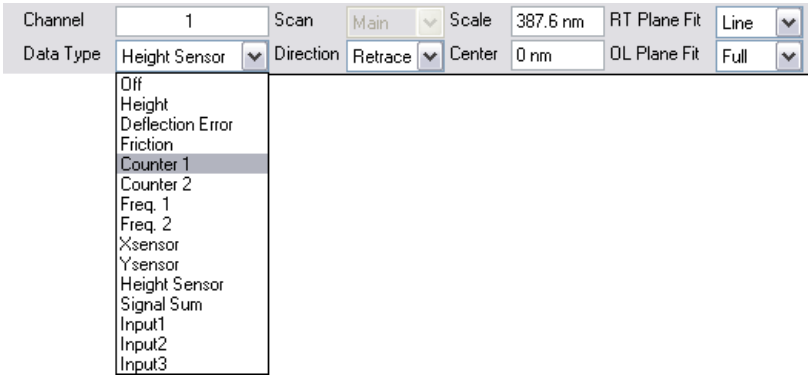
Figure 3.8c Point and Shoot - High Speed Data Capture



3.9 Pulse Counting

Counting of TTL-compatible pulses input through the **DIGITAL 1 IN 1** and **DIGITAL 2 IN 2** inputs is enabled by setting the **Channel Data Type** to either **COUNTER 1**, **COUNTER 2**, **FREQ.1** or **FREQ.2**, shown in Figure 3.9a. **COUNTER 1/2 Data Types** display results in counts/pixel while **FREQ.1/2 DATA TYPES** display results in counts/second (Hz). I.e. each pixel represents a frequency. This result is a function of **Scan Rate** and number of **Samples/Line**.

Figure 3.9a Pulse Counter Enabled



Set **Offline Plane Fit** to **NONE**. If **Offline Plane Fit** is not set to **NONE**, the frequency data will be offset. **REALTIME PLANE FIT** applies only to image view mode, not data, but typically should be set to **LINE** to enable visibility of data over all ranges.

The counter range is 0 to 32767 counts/pixel.

The sensitivity of pulse counter is user-adjustable but should generally be left unchanged at 1.0.

> **Note:** The **Pulse Counting** function is not available on all microscopes, e.g. the Dimension Icon-PI.

Chapter 4 File Navigation and Browsing

The Browse and File Navigation commands allow you to select, display and export NanoScope images.

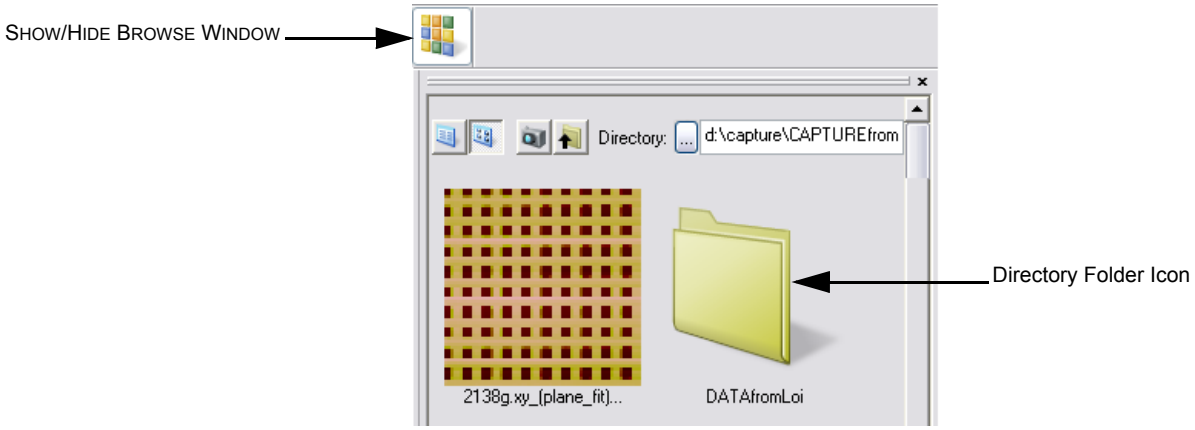
Refer to the following commands available in the NanoScope software:

- **The Browse Window:** Section 4.1
  - **Image Display:** Section 4.1.1
  - **Exporting Images:** Section 4.1.2
  - **Add View:** Section 4.2.1
- **Workflow Toolbar Commands:** Section 4.2
  - **Add View:** Section 4.2.1
  - **Remove File on Close:** Section 4.2.2

4.1 The Browse Window

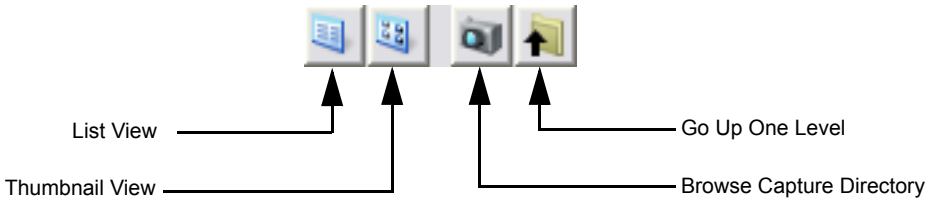
Open the Browse window by clicking the **SHOW/HIDE BROWSE** icon on the toolbar. Directory icons appear in the browse window. Double-click a folder icon to browse that directory (see Figure 4.1a).

Figure 4.1a Browse Window



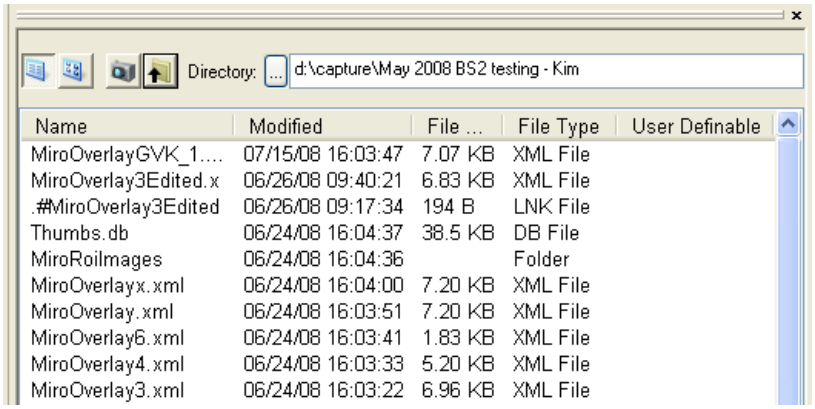
Browse window icons are shown in Figure 4.1b.

Figure 4.1b Browse Window Icons



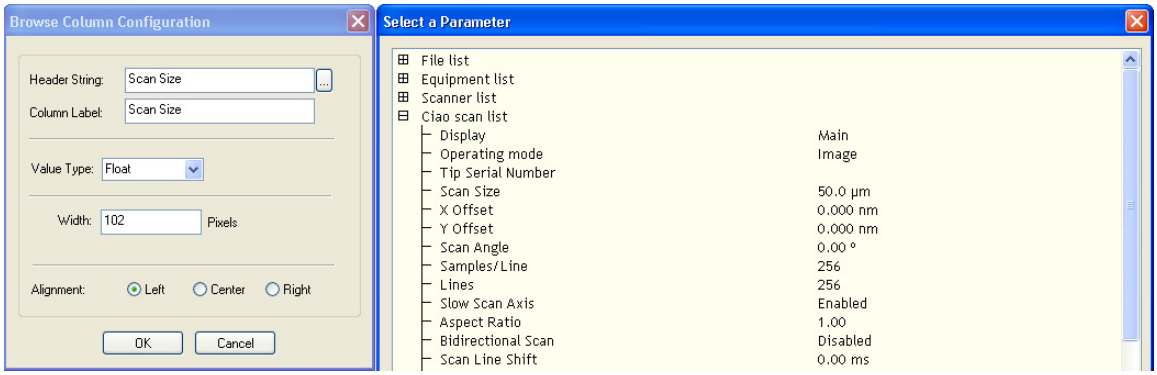
Selecting the first icon of the file browsing window initiates a List View of file information, shown in Figure 4.1c.

Figure 4.1c Browse List View



Right-clicking the **USER DEFINABLE** button allows you to view and sort for many SPM parameters. See Figure 4.1d.

Figure 4.1d Browse Column Configuration



Clicking the second icon in the upper left of the file browsing window causes thumbnail presentation of image files, illustrated in Figure 4.1e.

If no images are selected, right-clicking in the image browse window (but not on an image icon) allows you to sort the image icons in the browse window. See Figure 4.1f. Double- click on a thumbnail to open the image for further analysis.

Clicking the **CAPTURE DIRECTORY** icon in the upper left of the file browsing window displays file information, in either text or thumbnail presentations, of the capture directory (default is D:\capture).

Figure 4.1e Thumbnail Images in the Browse Window

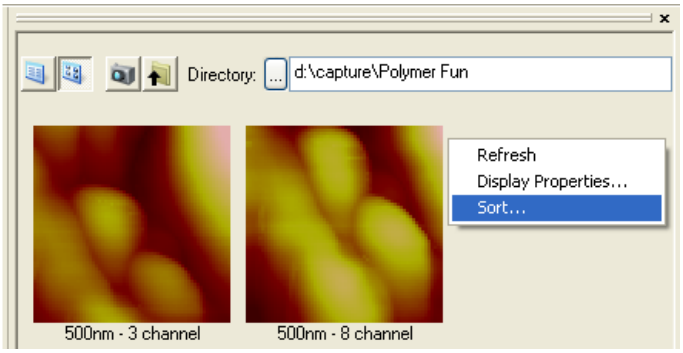
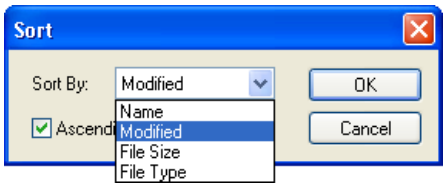
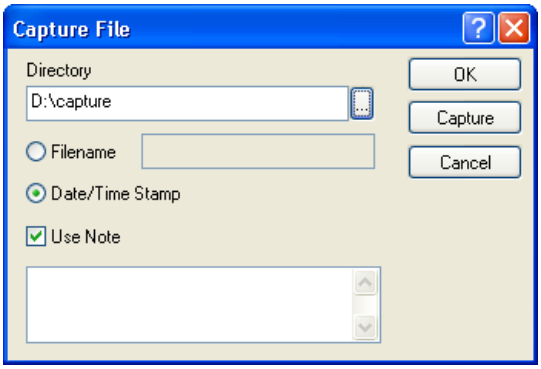


Figure 4.1f Sorting Thumbnails



You can change the current capture directory in the **Capture File** dialog box by selecting **CAPTURE** > **CAPTURE FILENAME...** from the menu bar, shown in Figure 4.1g.

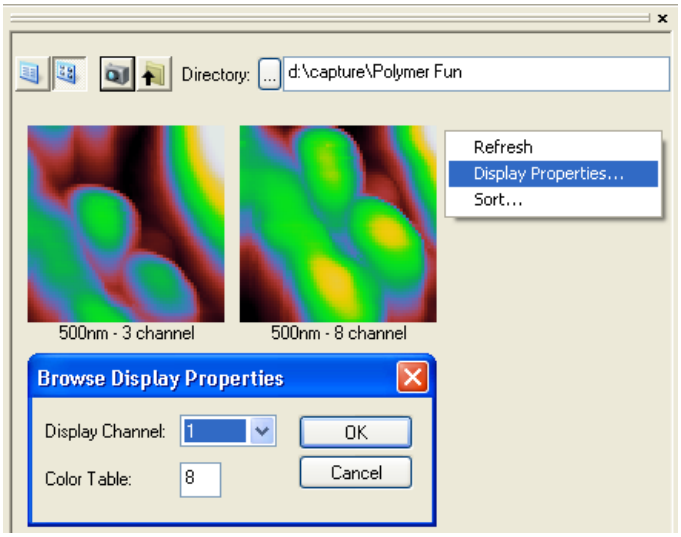
Figure 4.1g Capture File Dialog Box



4.1.1 Image Display

If no images are selected, right-clicking in the image browse window (but not on an image icon) allows you to select a display channel and a color table for the image icons in the browse window. See Figure 4.1h.

Figure 4.1h Selecting the Display Channel and Color Table for the Icons

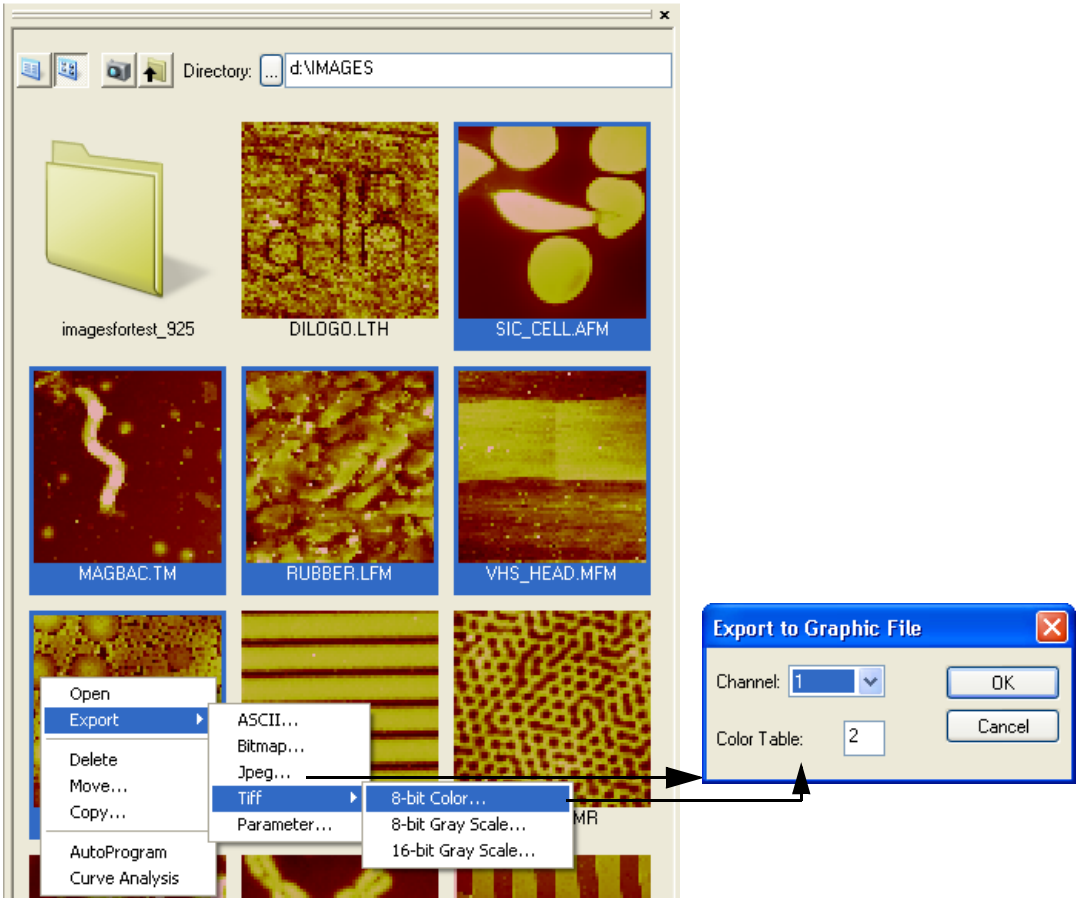


See Appendix B for a list of color tables.

4.1.2 Exporting Images

You may export images, in either bitmap, JPEG or tiff formats from the image browse window by right-clicking single or multiple images (shift right-click), shown in Figure 4.1i. You may then select the channel and a color table.

Figure 4.1i Exporting Multiple Images from the Image Browse Window

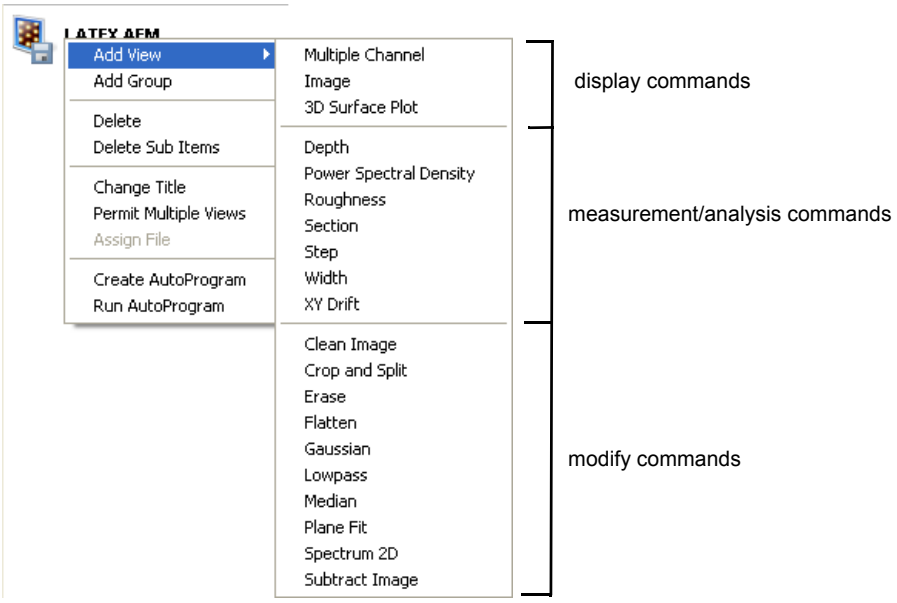


4.2 Workflow Toolbar Commands

4.2.1 Add View

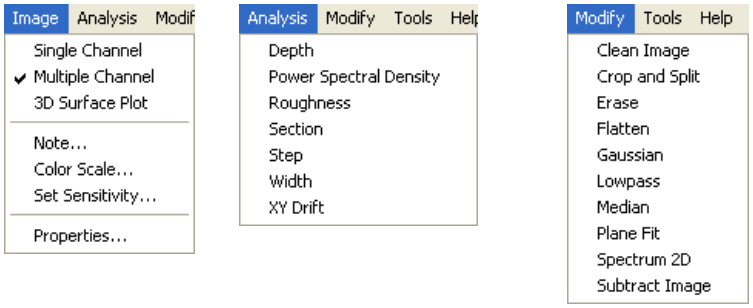
Right-click the offline icon of an image in the workspace window to display the Offline **Add View** menu. The commands include display, measurement, analysis and modification commands, shown in Figure 4.2a.

Figure 4.2a Image Processing Functions Menu



You can also add Offline views by clicking **IMAGE**, **ANALYSIS** or **MODIFY** in the NanoScope toolbar and selecting the desired function (see Figure 4.2b).

Figure 4.2b Adding Offline Functions



4.2.2 Remove File on Close

Select **TOOLS > OPTIONS > REMOVE FILE ON CLOSE** menu item (see Figure 4.2c). You can also right-click the workspace and select **REMOVE FILE ON CLOSE**, shown in Figure 4.2d. When selected, this option removes the workspace item of the offline file when all views on that file are closed.

Figure 4.2c Select **TOOLS** > **OPTIONS** > **REMOVE FILE ON CLOSE**

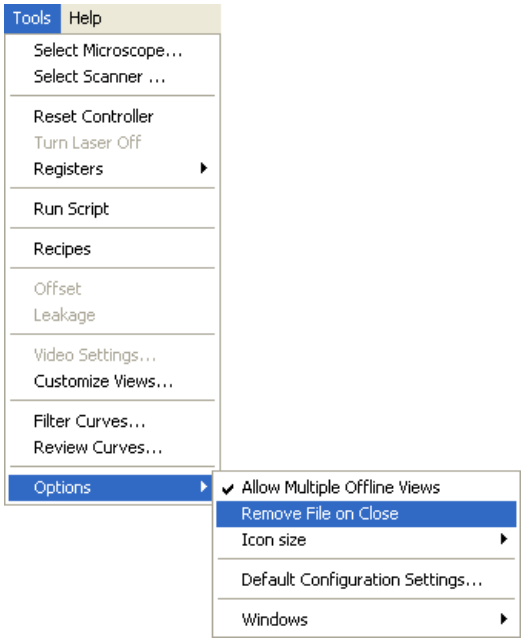
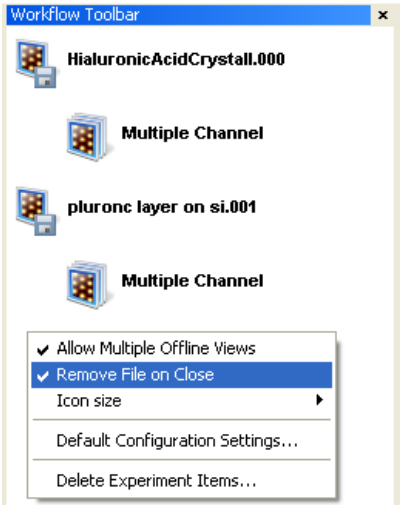


Figure 4.2d Select **REMOVE FILE ON CLOSE** from the **Workflow Toolbar**



Note: The entire **Tools** > **Options** menu, with the exception of **Set Help File...**, is available when you right click in the workspace (not on a node).

Chapter 5 Display Commands

The **Display** commands relate to the display of images captured in Realtime mode. These commands are known as image processing.

Refer to the following analysis commands available in **Offline** menu of the NanoScope software:

- **Image:** Section 5.1
- **Multiple Channel Analysis:** Section 5.1.2
- **3D Surface Plot:** Section 5.2
- **Zoom:** Section 5.3
- **High Speed Data Capture Display:** Section 5.4

5.1 Image

The term **Image** refers to the data captured in RealTime mode. The current image processing capabilities include data analysis, modification, presentation and storage of the images. The source of the image includes:

- Data captured in RealTime scanning mode
- New image files created using modify or analysis commands

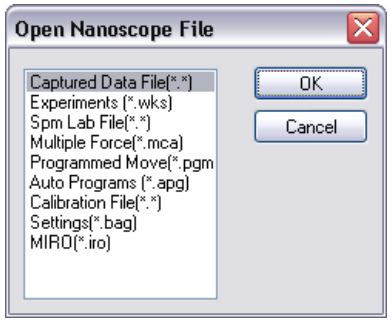
For general information on the interface and basic functions in image processing, see **Using the Image Interface:** Section 5.1.1.

5.1.1 Using the Image Interface

To process an image, you must open an image file. This can be done by:

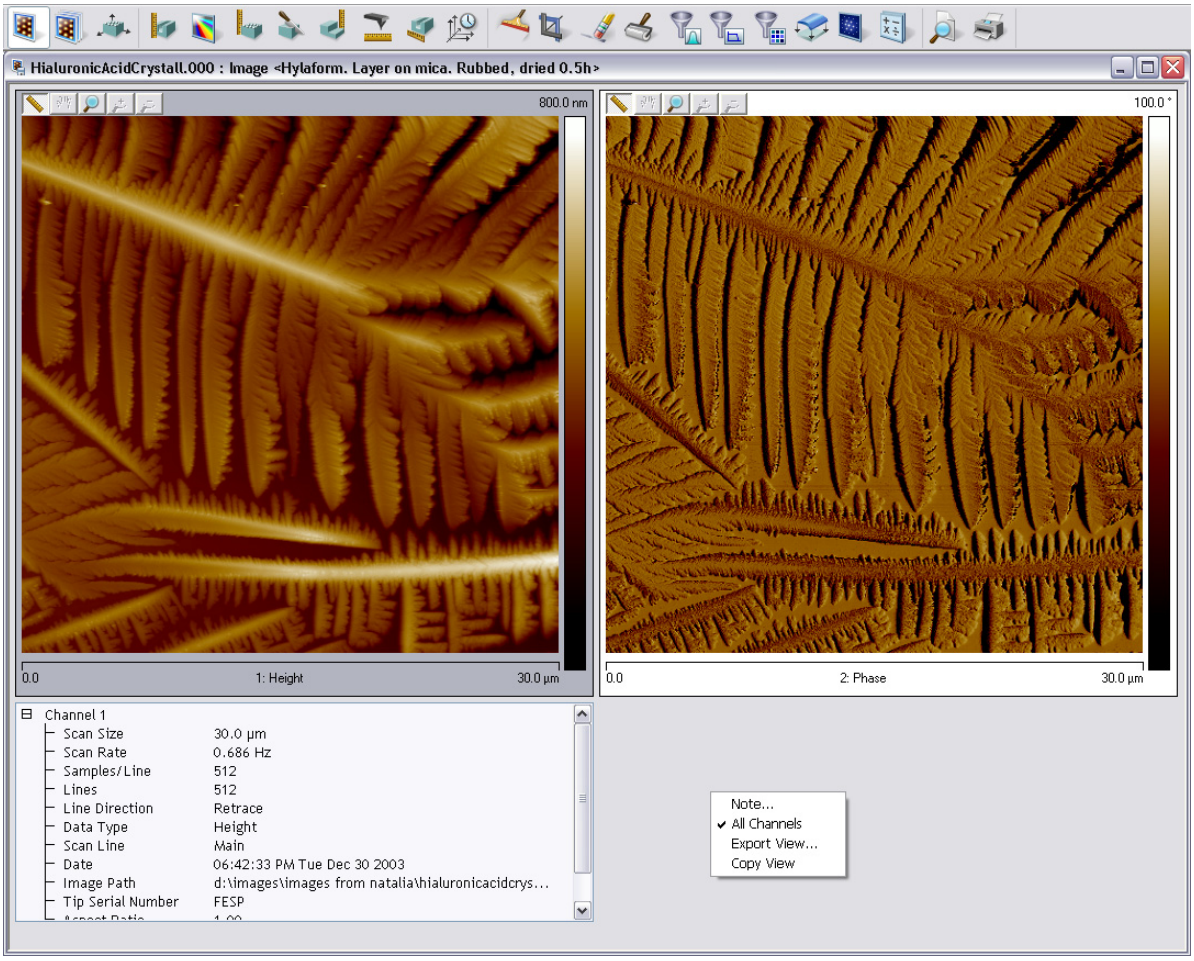
1. Clicking **File** > **Open**. When the **Open Nanoscope File** dialog box opens (see Figure 5.1a), select **Captured Data File (*.*)** and click the **Ok** button.

Figure 5.1a Open NanoScope File Dialog Box



2. Double-clicking an image in the **Browse** window. The new image appears in the client window (see Figure 5.1b).

Figure 5.1b Image for Processing



Right-Clicking in the Image Window

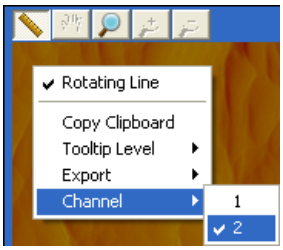
By right-clicking in the **Image** window, but not on the image (see Right-Clicking on the Image on page 226), shown in Figure 5.1b, that allows you to perform the following tasks:

- **Note**—Adds notes to an image file.
- **All Channels**—When checked, the All Channels button displays all captured data channels.
- **Export View**—Exports the current view as a jpeg image.
- **Copy View**—Copies the current view to the clipboard.

Right-Clicking on the Image

By right-clicking on the image, you will get a menu, shown in Figure 5.1c, that allows you to perform the following tasks:

Figure 5.1c Image Click



- **Rotating Line**—Left-click, hold, and drag out a line. Release the mouse button to end the line.
- **Box** (for some analyses)—Left-click, hold, and drag out a box and release the mouse button.

  Note: Left-clicking in the center of the box allows you to translate. Left-clicking on edges allows you to change the box size.
- **Copy Clipboard**—Copies the image to the Microsoft clipboard.
- **Tooltip Info Level**:
  - Basic
  - Medium
  - Advanced
  - None
- **Export**—Exports the image as a bitmap.
- **Channel**—Selects which channel is displayed.

Image Buttons

Clicking the **Image** buttons, shown in Figure 5.1d, above the captured image (see Figure 5.1e) performs the following functions:

Figure 5.1d NanoScope Image buttons

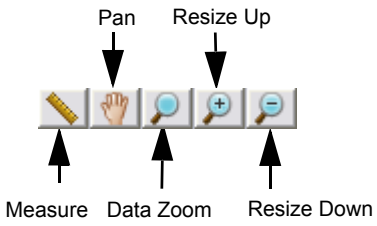


Table 5.1a NanoScope image buttons

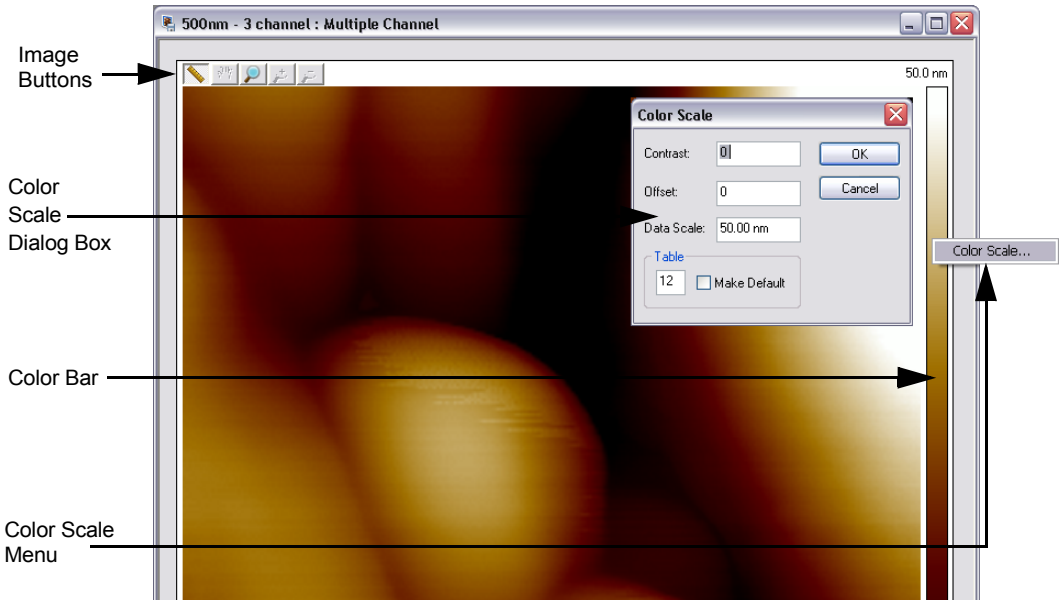
Measure	Left-click, hold, and drag out a line. Length of line appears in a box near the line any time cursor is on the line.
Pan	From a zoomed image, you can pan around to other areas of the original image.
Data Zoom	Left-click, hold, and drag out a box. Release the mouse button and the image will automatically zoom in to the area of the box. The zoomed region will be centered about the point originally selected.
Resize Up	Resizes the image up to the previous zoom level.
Resize Down	Resizes the image down to the previous zoom level.

Right-Clicking on the Color Bar

Right-clicking on the color bar along the right side of the image (see Figure 5.1e) will produce a **COLOR SCALE** button. Clicking on this **COLOR SCALE** button will open the **Color Scale** dialog box, where you can perform the following image adjustments:

- **Contrast**—Number (-10 to +10) designates contrast of colors in displayed image (e.g., -10 shows little change, while 10 shows highest contrast).
- **Offset**—Number (-128 to +128) designates offset of colors in displayed image (e.g., 120 shows illuminated background on image). **Offset** effectively changes the color value around which the color scale is mapped.
- **Data Scale**—Designates the vertical range of the displayed data, corresponding to the full extent of the color table.
- **Table**—Designates the **Color Table** number. There are 25 available color scales. For instance color **Table** 0 is grayscale, color **Table** 1 features blue... See Appendix B for a list of color tables.

Figure 5.1e Image Adjustment Controls



Using the Mouse Within a Captured Image

Left-Click anywhere in image window, drag line out, and release	Creates a line of X length, at θ^{o} angle in the image window
Place cursor on line	Displays length and angle values of line in the image window
Place cursor on line, click and hold left button, and drag	Allows you to drag the line anywhere in the image window
Click and hold on either end of line and drag	Changes length and/or the angle of the line
Right-Click	Clicking the right mouse button when the cursor is on the line accesses the Image Cursor menu (see Figure 5.1f) • **Delete**—deletes the line. • **Flip Direction**—switches the line end to end. • **Show Direction**—Adds small arrowhead to the line to indicate direction. • **Set Color**—Allows you to change the color of the line. • **Clear All**—Deletes all lines.

Figure 5.1f Image Cursor Menu

5.1.2 Multiple Channel Analysis

It is often advantageous to analyze more than one channel of data from the same scan simultaneously. The Multiple Channel Analysis feature allows you to view up to eight channels of data simultaneously with one channel enlarged. Multiple Channel is the default initial view for all offline image analysis.

Eight Channel Image

Open the Multiple Channel offline view by double-clicking an image file in the image browse window. See Figure 5.1g and Figure 5.1h. Change the displayed channel by clicking either a thumbnail on the bottom or the previous/next buttons below the image window.

Figure 5.1g Multi-Channel offline view—single monitor

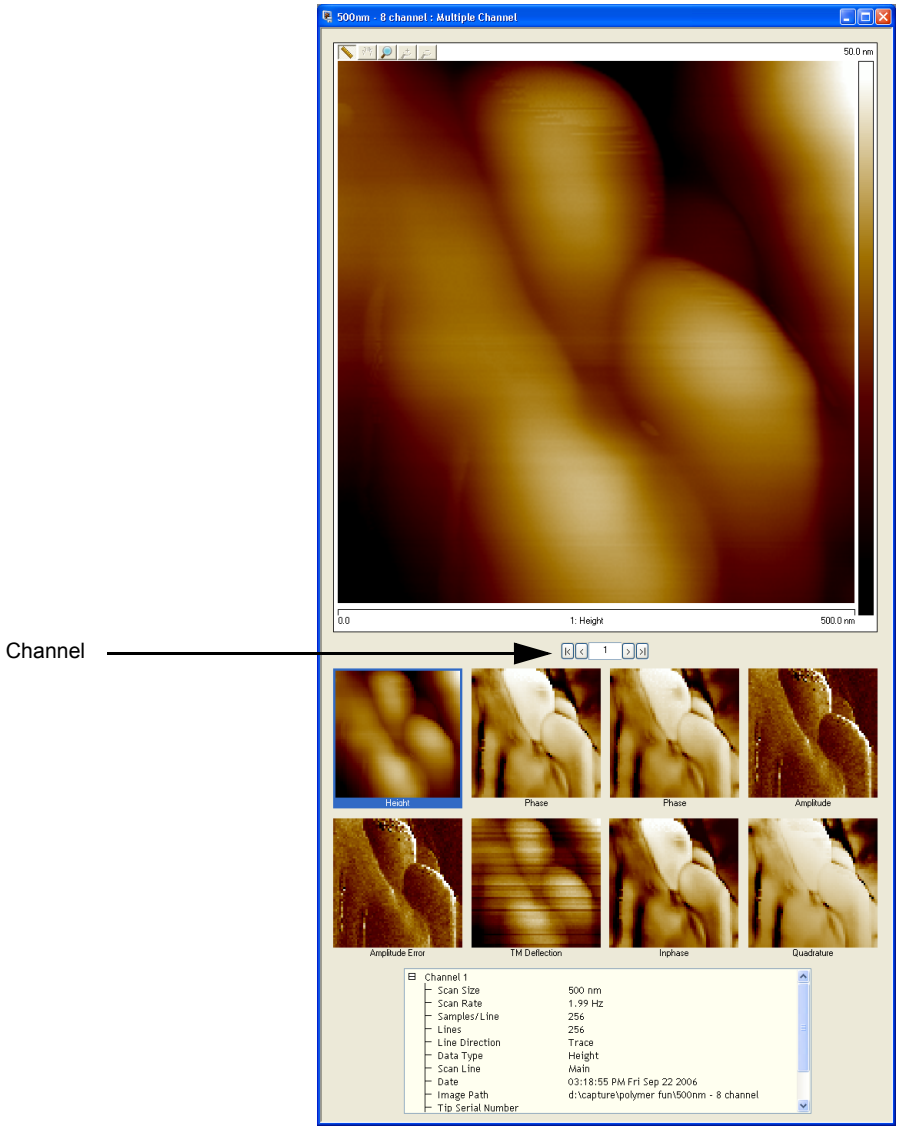
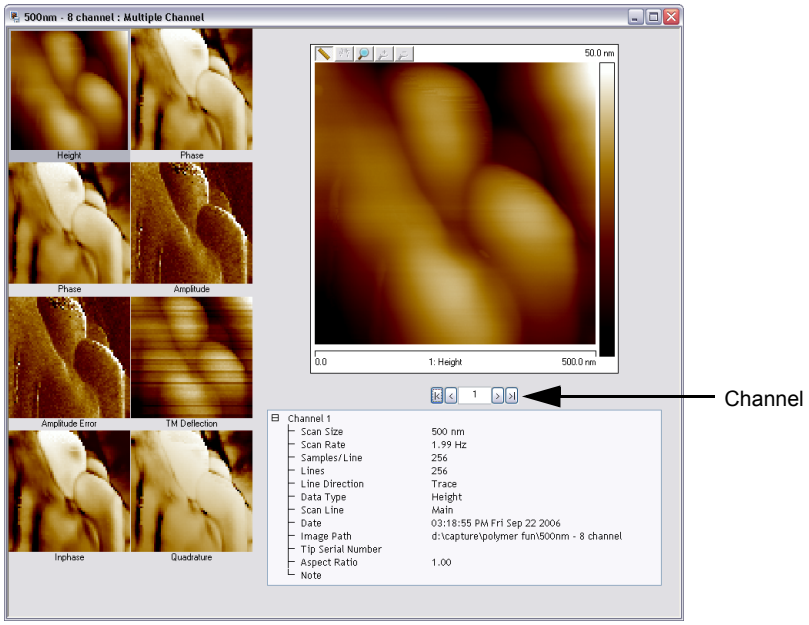


Figure 5.1h Multi-Channel offline view—dual monitor



Analyzing Captured Multichannel Images

When performing any analysis of a multichannel scan, you may only analyze one channel at a time. Highlight the appropriate channel image by clicking on it, then select the desired **Analysis View** by any one of the following:

- Right-clicking on the image file name in the **Workspace**, selecting **Add View**, and clicking on the desired view.
- Selecting **Analysis** or **Modify** from the menu bar and clicking on the desired view.
- Clicking on the appropriate button in the toolbar bar.
- Right-clicking on a thumbnail in the Multiple Channel window.

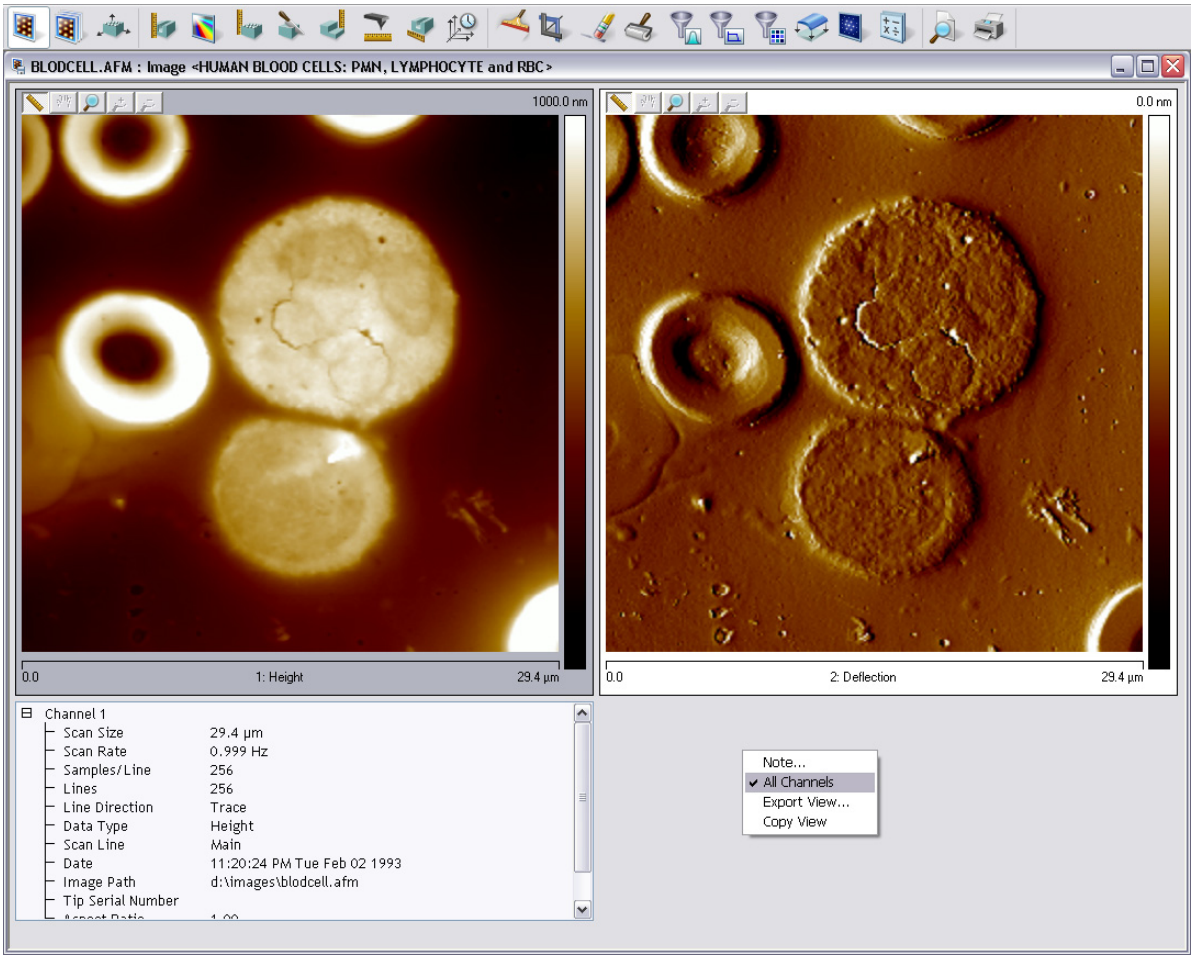
Once you select the desired channel, and the appropriate view, a new window will open with only the image of the selected channel and you may start your analysis. If the image display in the view is not the desired channel, you can right-click on the image, go to **Channel**, and select the appropriate channel from the pop-up menu.

5.1.3 Dual and Triple-Scan Images

Clicking the Image icon on the toolbar will display a single channel image. Right-click in the **Image** window, but not on the image and select **ALL CHANNELS** to display up to three channels simultaneously. Click on the desired image to select the channel and the corresponding channel data will appear (see Figure 5.1i).

Note: The location of the Channel data may vary depending on window proportions.

Figure 5.1i Captured Dual-Scan Image



5.2 3D Surface Plot

The **3D Surface Plot View** displays the selected image with color-coded height information in a three-dimensional, oblique perspective. You can select the viewing angle and illumination angle for a modeled light source.

You can view the **3D Surface Plot** view using *one* of the following methods:

- Right-click on the image name in the **Workspace** and select **Add View** > **3D Surface Plot** from the popup menu.

  Or

- Right-click on a thumbnail in the Multiple Channel window and select **3D SURFACE PLOT**.

  Or

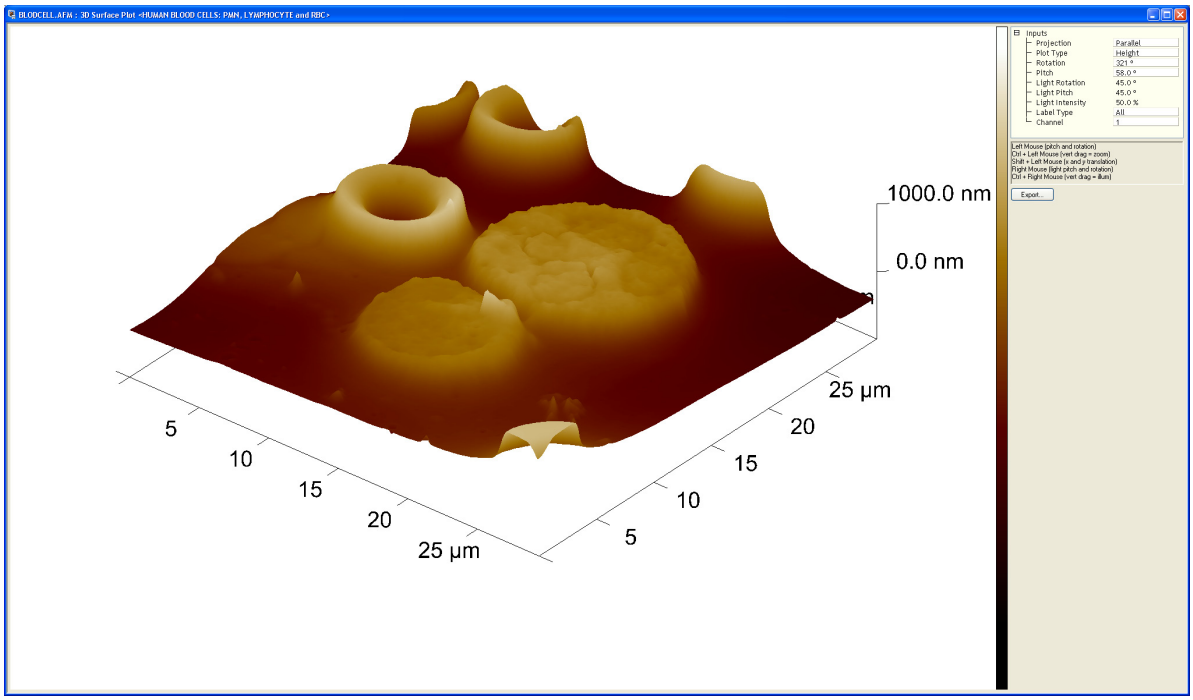
- Select **IMAGE** > **3D SURFACE PLOT** from the menu bar.

  Or

- Click the **3D Surface Plot** icon in the toolbar.

The **3D Surface Plot** panel, shown in Figure 5.2a, appears and allows formatting of image data.

Figure 5.2a 3D Surface Plot Window



5.2.1 Parameters in the 3D Surface Plot Inputs

The **Projection**, **Plot Type**, and **Label Type** parameters can be changed by clicking in the related window and selecting from the drop-down menus. The remaining parameters may be changed by typing the desired information in the related window or by use of the keyboard and mouse keys.

- To zoom in or out on the image, hold the control key down and slide the mouse up and down on the image while holding the left mouse button.
- To pan, hold the shift key down and move the mouse up, down, left, or right on the image while holding the left mouse button.
- Clicking and holding the right mouse button down while moving the mouse left and right changes the light rotation on the image. This is only available when **Plot Type** is set to **MIXED**.
- Clicking and holding the right button while moving the mouse up down changes the light pitch. This is only available when **Plot Type** is set to **Mixed**.

The function of the **Input** parameters are:

Projection	Select either **Parallel** or **Perspective** • In **Parallel** mode, the viewing volume does not change, which has the effect keeping objects the same size as they are projected. This is useful for maintaining the size and angle of objects between the front and back of the view. • In **Perspective** mode, objects appear to get smaller the further away they are from the eye. This is how the objects are perceived in the real world.
Plot Type	Select **Height**, **Wire**, or **Mixed** • **Height** displays the image with height values encoded according to the color table. • **Wire** displays the image as a line representation of the scanned data. • **Mixed** displays a combination of height and illumination encoding.
Rotation	The **Rotation** parameter in the **Surface Plot Inputs** changes as the viewing angle is changed by rotating the displayed image about the Z axis relative to its captured orientation.
Pitch	The **Pitch** parameter in the **Surface Plot Inputs** changes as the viewing angle by manually changing the pitch of the Y axis in the three-dimensional Surface Plot image.
Light Rotation	The **Light Rotation** parameter in the **Surface Plot Inputs** rotates the light source in the horizontal plane (xy plane). This is only available when the **Plot Type** is set to **Mixed**.

Light Pitch	The **Light Pitch** parameter in the **Surface Plot Inputs** changes the viewing angle by selecting the pitch of the Z axis in the three-dimensional Surface Plot image. This is only available when the **Plot Type** is set to **Mixed**.
Light Intensity	Selects the percentage of the imaginary light source mixed with the color-encoded height information when the **Plot Type** is set to **Mixed**.
Label Type	The **Label Type** parameter in the **Surface Plot Inputs** selects whether labels and/or axes are displayed with the image. • **All** displays the axes with labels. • **Axis** displays the axes without labels. • **None** displays the image without labels.
Channel	Displays the current channel of multichannel scan displays.

The **Export** button allows the operator to export the image in the window to either JPEG or bitmap (bmp) format.

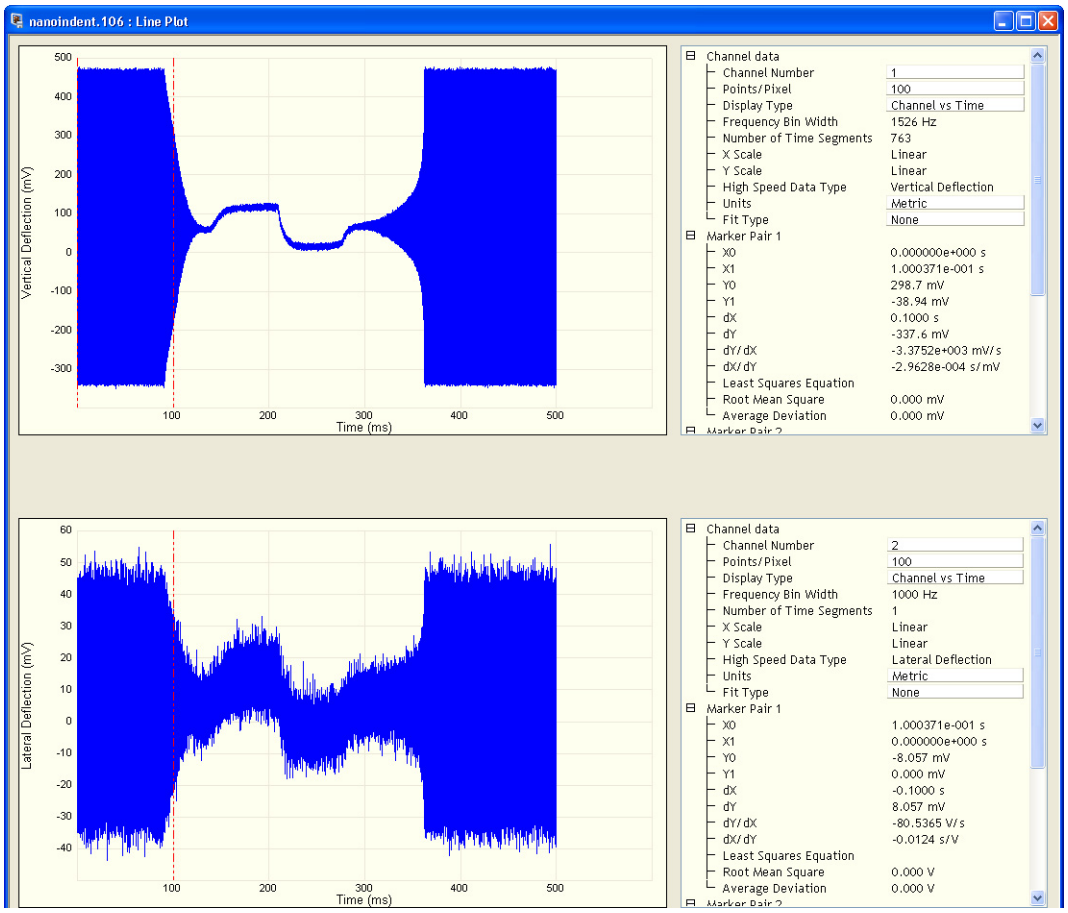
5.3 Zoom

The **Zoom** function has been replaced by the **Crop and Split** function. See **Crop and Split:** Section 7.3.

5.4 High Speed Data Capture Display

Files created using the High Speed Data Capture on page 205 feature can be displayed by double-clicking the file icon (.hsdc file type) in the NanoScope browse window. This opens a window, shown in Figure 5.4a, that displays the captured data for multiple channels.

Figure 5.4a HSDC Offline Display Window



You may zoom in on the plotted data by using **CTRL** plus the left mouse button. Revert to the original plot scale by clicking the magnifying glass in the lower left corner of the plot area.

In addition to displaying the captured data plotted vs. time, you may also perform a Fast Fourier Transform of the data by changing the **DISPLAY TYPE** to **AMPLITUDE VS FREQUENCY**.

The function of the **Channel data** parameters are:

Channel Number	Selects the **CHANNEL** (**1-4**) to display
Points/Pixel	This parameter is used to speed plotting of large data files in a small (~355 pixels horizontally) display area. If your file has 100,000 data points and you select 100 points/pixel (the default) ~35,500 data points will be plotted—every third point. As you zoom in, the number of skipped points will decrease. Aliasing may occur if there are many skipped points. The total number of points in the file and plot increment is shown in the status bar at the lower left of the NanoScope window.
Display Type	Determines the type of plot: • **CHANNEL VS TIME** • **AMPLITUDE VS FREQUENCY** computes and displays a FFT of the data between the markers. If you do not have markers, the FFT will be performed on all the input data. The plot is updated only when the **DISPLAY TYPE** is changed.
Frequency Bin Width	The approximate width of the histogram bin used in for the FFT calculation. Because a FFT algorithm is employed, this user input is updated so that 2^n points are used.
Number of Time Segments	(sample data time)/(1./frequency bin width). [1] A portion of the last segment may be truncated to accommodate the FFT 2^n points requirement. You may wish to increase the **FREQUENCY BIN WIDTH** if the **NUMBER OF TIME SEGMENTS** is small.
X Scale	Determines the scaling of the X Axis: • **LINEAR** • **LOG** base 10
Y Scale	Determines the scaling of the Y Axis: • **LINEAR** • **LOG** base 10
High Speed Data Type	Displays the **DATA TYPE** of the selected channel.
Units	Determines the Y axis units: • **VOLTS** • **METRIC**
Fit Type	Determines the type of fit between the markers: • **NONE** • **LINE**

Chapter 6 Analysis Commands

The **Analysis** commands relate to analyzing the surface behavior of materials on images captured in Realtime mode. These commands are known as image processing or analysis commands. The commands contain views, options and configurations for analysis, modification, and storage of the collected data. The analysis may be automated (i.e., in autoprograms) or completed manually. In general, the analysis commands provide methods for quantifying the surface properties of samples.

Refer to the following analysis commands available in **Analysis** menu of the NanoScope software:

- **Depth:** Section 6.1
- **Power Spectral Density:** Section 6.2
- **Roughness:** Section 6.3
- **Section:** Section 6.4
- **Step:** Section 6.5
- **Tip Qualification:** Section 6.6
- **Width:** Section 6.7
- **XY Drift:** Section 6.8

6.1 Depth

To analyze the depth of features you have numerous choices which measure the height difference between two dominant features that occur at distinct heights. **Depth** was primarily designed for automatically *comparing* feature depths at two similar sample sites (e.g., when analyzing etch depths on large numbers of identical silicon wafers).

Refer to the following sections on **Depth** analysis:

- **Depth Theory:** Section 6.1.1
- **Depth Procedures:** Section 6.1.2
- **Depth Interface:** Section 6.1.3

6.1.1 Depth Theory

The **Depth** command accumulates depth data within a specified area, applies a Gaussian low-pass filter to the data to remove noise, then obtains depth comparisons between two dominant features. Although this method of depth analysis does not substitute for direct, cross-sectioning of the sample, it affords a means for comparing feature depth between two similar sites in a consistent, statistical manner.

The **Depth** window includes a top view image and a histogram; depth data is displayed in the **Results** window and in the histogram. The mouse is used to resize and position the box cursor over the area to be analyzed. The histogram displays both the raw and an overlaid, Gaussian-filtered version of the data, distributed proportional to its occurrence within the defined bounding box.

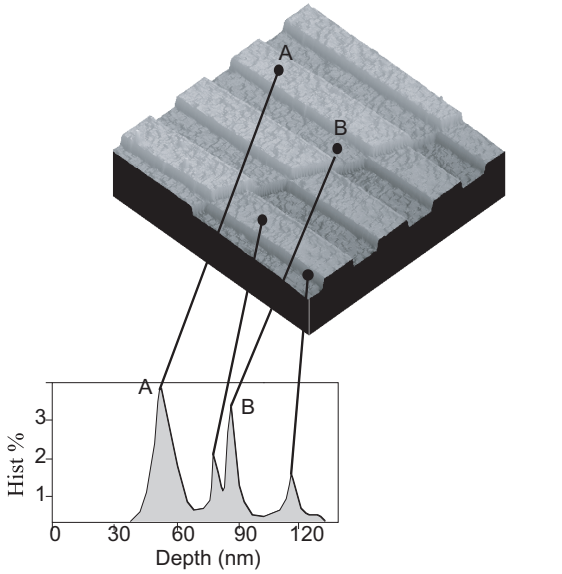
Histogram

Raw Data

Figure 6.1a (bottom graph) displays a histogram from raw depth data. Data points A and B are the two most dominant features, and therefore would be compared in Depth analysis. Depending upon the range and size of depth data, the curve may appear jagged in profile, with noticeable levels of noise.

Note: Color of cursor, data, and grid may change if user has changed the settings. Right-click on the graph and go to **Color** if you want to change the default settings.

Figure 6.1a Depth Histogram



Correlation Curve

The **Correlation Curve** is a filtered version of the **Raw Data Histogram** and is located on the **Raw Data Histogram** represented by a red line. Filtering is done using the **Histogram Filter Cutoff** parameter in the **Inputs** parameters box.The larger the filter cutoff, the more data is filtered into a Gaussian (bell-shaped) curve. Large filter cutoffs average so much of the data curve that peaks corresponding to specific features become unrecognizable. On the other hand, if the filter cutoff is too small, the filtered curve may appear noisy.

The **Correlation Curve** portion of the histogram presents a lowpass, Gaussian-filtered version of the raw data. The low-pass Gaussian filter removes noise from the data curve and averages the curve's profile. Peaks which are visible in the curve correspond to features in the image at differing depths.

Peaks do not show on the correlation curve as discrete, isolated spikes; instead, peaks are contiguous with lower and higher regions of the sample, and with other peaks. This reflects the reality that features do not all start and end at discrete depths.

When using the **Depth** view for analysis, each peak on the filtered histogram is measured from its statistical centroid (i.e., its statistical center of mass).

6.1.2 Depth Procedures

1. You can open the **Depth** view, shown in Figure 6.1c and Figure 6.1d, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Depth** from the popup menu. See Figure 6.1b.

Figure 6.1b Select Depth from the workspace

Or

   - Right-click on a thumbnail in the Multiple Channel window and select **DEPTH**.

Or

   - Select **ANALYSIS** > **DEPTH** from the menu bar.

Or

   - Click the **Depth** icon in the toolbar.

2. Using the mouse, left-click and drag a box on the area of the image to analyze. The Histogram displays the depth correlation on this specified area.

   Note: If no box is drawn, by default, the entire image is selected.

3. Adjust the **Minimum Peak to Peak** to exclude non relevant depths.

4. Adjust the **Histogram Filter Cutoff** parameter to filter noise in the histogram as desired.

5. Note the results.

Note: To save or print the data, run the analysis in an **Auto Program** (see Chapter 8).

Figure 6.1c Depth Window—single monitor

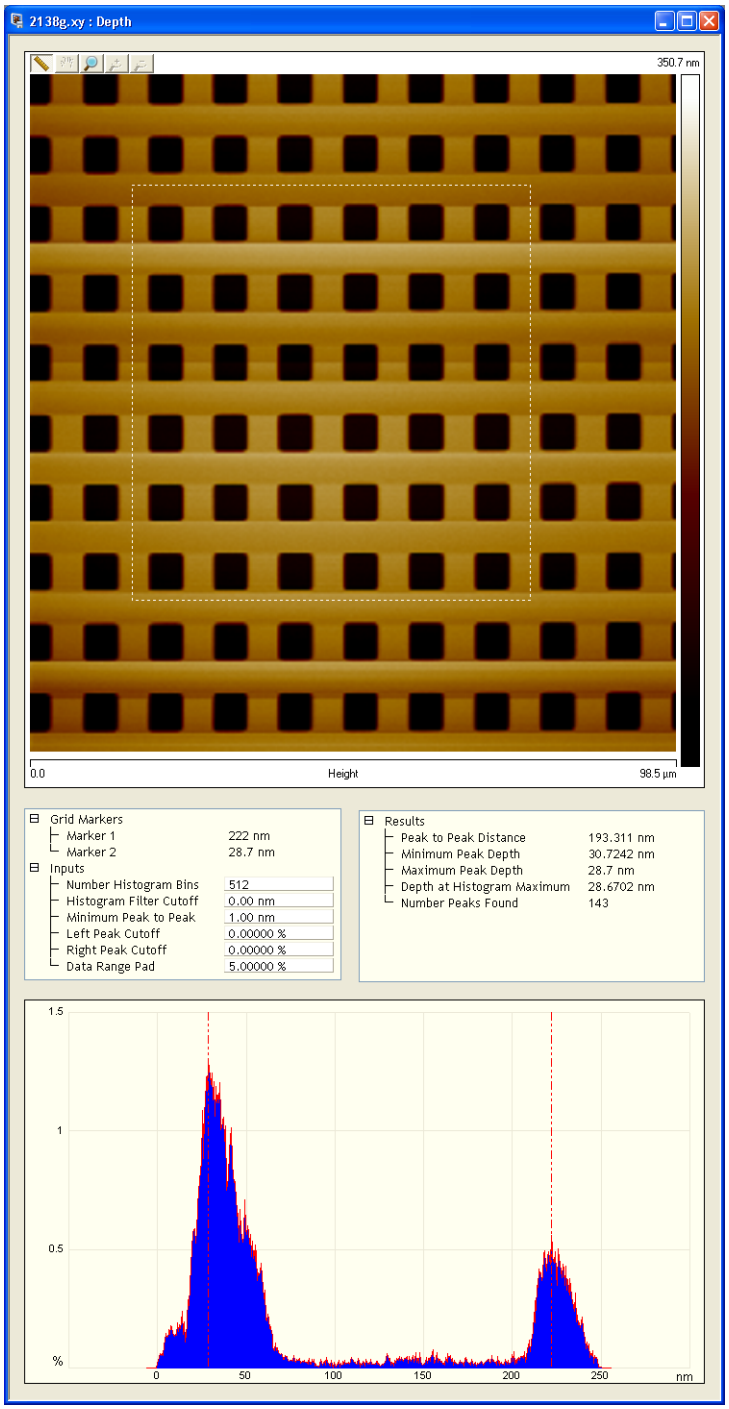
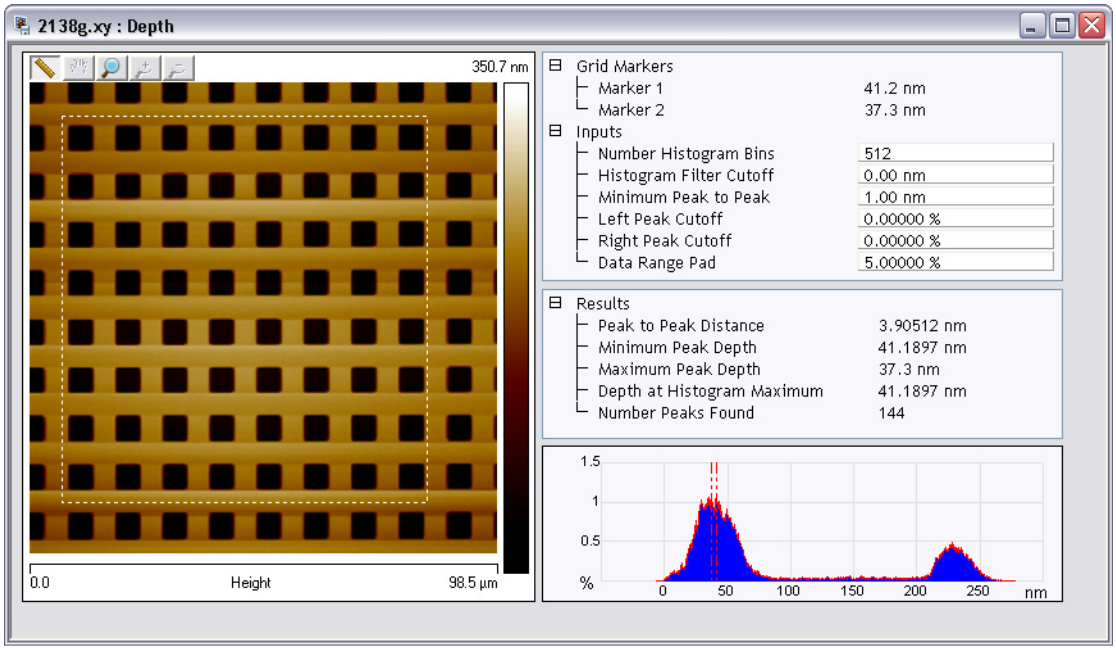


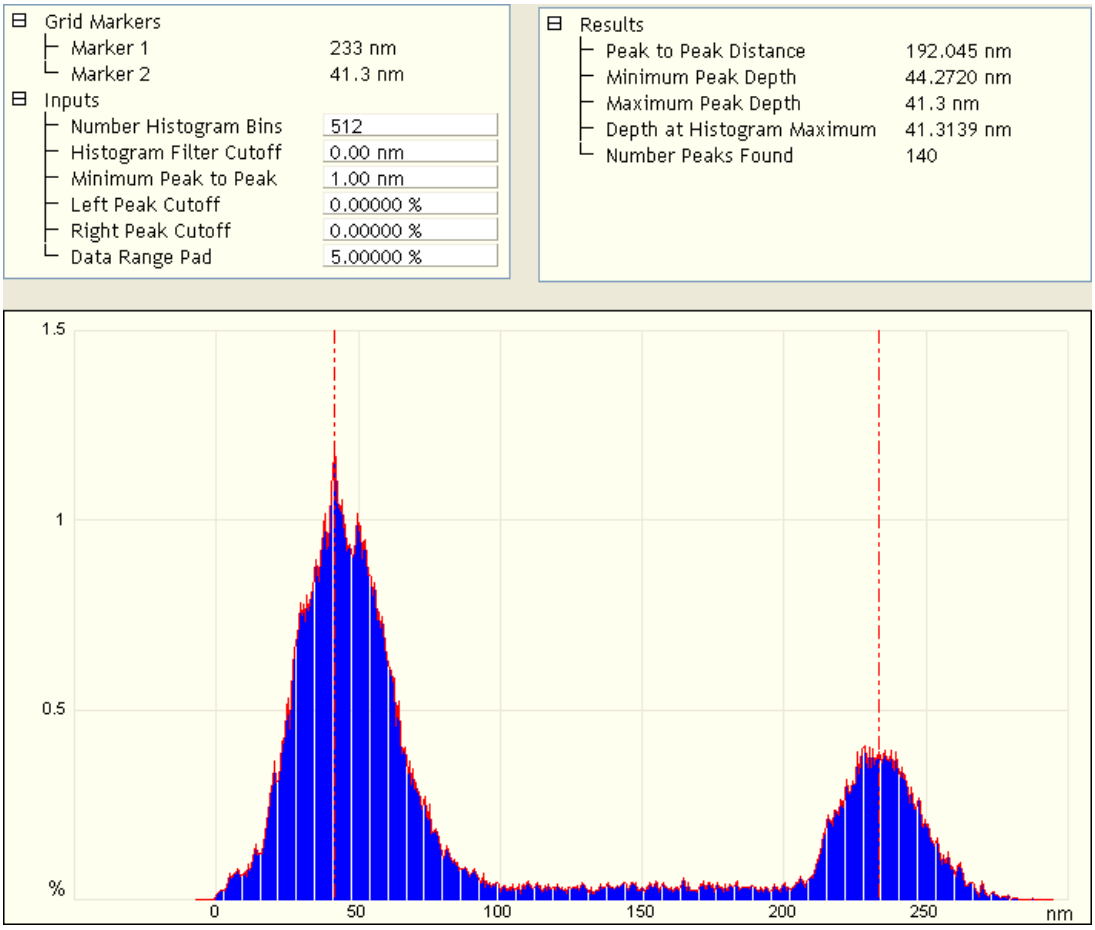
Figure 6.1d Depth Window—dual monitor



6.1.3 Depth Interface

The **Depth** interface includes a captured image, **Input** parameters, **Results** parameters and a correlation histogram (see Figure 6.1e).

Figure 6.1e Depth Interface



Depth Input Parameters

The depth input parameters below define the slider cursor placement for determining the exact depth of a feature.

Number of Histogram Bins	The number of data points which result from the filtering calculation. Note: Having more histogram bins than pixels is unnecessary.
Histogram Filter Cutoff	Lowpass filter which smooths out the data by removing wavelength components below the cutoff. Use to reduce noise in the Correlation histogram.
Minimum Peak To Peak	Sets the minimum distance between the maximum peak and the second peak marked by a cursor. The second peak is the next largest peak to meet this distance criteria.
Left Peak Cutoff	The left (smaller in depth value) of the two peaks chosen by the cursors. Value used to define how much of the left peak is included when calculating the centroid. At 0 percent, only the maximum point on the curve is included. At 25 percent, only the maximum 25 percent of the peak is included in the calculation of the centroid.
Right Peak Cutoff	The right (larger in depth value) of the two peaks marked by the cursors. Value used to define how much of the right peak is included when calculating the centroid. At 0 percent, only the maximum point on the curve is included. At 25 percent, only the maximum 25 percent of the peak is included in the calculation of the centroid.
Data Range Pad	Creates a buffer region at either end of the histogram.

Results Parameters:

Peak to Peak Distance	Depth between the two data peak centroids as selected using the line cursors.
Minimum Peak Depth	The depth of the deeper of the two features.
Maximum Peak Depth	The depth of the shallower of the two features.
Depth at Histogram Maximum	Depth at the maximum peak on the histogram.
Number of Peaks Found	Total number of peaks included within the data histogram.

Using the Grid Display

Measurement cursors for the histogram are automatically positioned based on the numerical values selected in the **Input** fields. Slide the markers into the grid from the left or right side by clicking and holding the left mouse button. The location of the two markers is displayed in the **Grid Markers** window.

Right-clicking on the grid will bring up the **Grid Parameters** menu (see Figure 6.1f) and allow you to make the following changes:

Color	Allows operator to change the color of the: • Curve (data) • Text • Background • Grid • Minor Grid • Markers
Filter	Typically used for a Profiler Scan. • Type—Select None, Mean (default), Maximum, or Minimum • Points—Select 4k, 8k (default), 16k, or 32k
Minor Grid	Places a minor grid in the background of the **Graph** window.
Scale	Allows user to auto scale, set a curve mean, or set their own data range
Line Style	For each curve, the operator can choose a connect, fill down, or point line.
User Preferences	Restore—Reverts to initial software settings Save—Saves all changes operator has made during this session. This becomes the new default settings.
Copy Clipboard	Copies the grid image to the Microsoft Clipboard
Print	Prints out the current screen view to a printer
Export	Exports data in bitmap, JPEG or XZ data format
Active Curve	Determines which curve you are analyzing

Figure 6.1f Grid Parameters Menu

6.2 Power Spectral Density

The **Power Spectral Density** (PSD) function is useful in analyzing surface roughness. This function provides a representation of the amplitude of a surface's roughness as a function of the spatial frequency of the roughness. Spatial frequency is the inverse of the wavelength of the roughness features.

The **PSD** function reveals periodic surface features that might otherwise appear random and provides a graphic representation of how such features are distributed. On turned surfaces, this is helpful in determining speed and feed data, sources of noise, etc. On ground surfaces, this may reveal some inherent characteristic of the material itself such as grain or fibrousness. At higher magnifications, **PSD** is also useful for determining atomic periodicity or lattice.

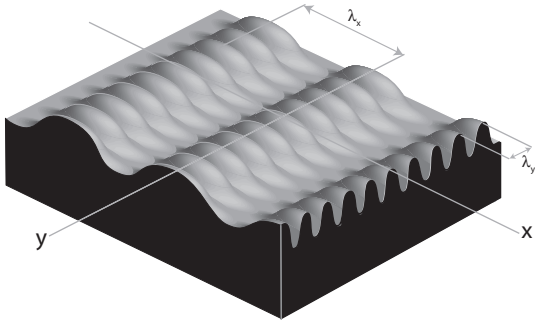
Refer to the following **Power Spectral Density** sections:

- **PSD and Surface Features:** Section 6.2.1
- **PSD and Flatness:** Section 6.2.2
- **Performing a Spectral Density Analysis:** Section 6.2.3
- **Changing Parameters of the Spectrum Plot:** Section 6.2.4

6.2.1 PSD and Surface Features

Consider the image in Figure 6.2a.

Figure 6.2a Waveform Surfaces



2D Spectrum

This synthetic surface consists of essentially two dominant wave forms: a long period waveform along the X-axis, and a shorter period waveform along the Y-axis. A 2 dimensional power spectral density plot consists of two dominant spikes (one for each dominant wavelength), plus some number of extra wavelengths inherent within the image. (These extra wavelengths may appear due to fine surface features and/or side bands of the dominant wave forms.) Because of the sinusoidal

nature of the composite wave form, a relatively small set of spectral frequencies suffices to describe the entire surface. By contrast, an image comprised of angular (saw-toothed or square) waveform contains more spatial frequency components.

Over a given range of spatial frequencies the total power of the surface equals the RMS roughness of the sample squared.

The frequency distribution for a digitized profile of length L, consisting of N points sampled at intervals of d_o is approximated by:

$$PSD(f) = \frac{2d_o}{N}\left|\sum_{n=1}^{N} e^{\frac{i2\pi}{N}(n-1)(m-1)} z(n)\right|^2 \qquad \text{for } f = \frac{m-1}{Nd_o}$$

Where $i = \sqrt{-1}$, and frequencies, **f**, range from $\frac{1}{L}$ to $\frac{N/2}{L}$. Practically speaking, the algorithm used to obtain the PSD depends upon squaring the FFT of the image to derive the power. Once the power, *P*, is obtained, it may be used to derive various PSD-like values as follows:

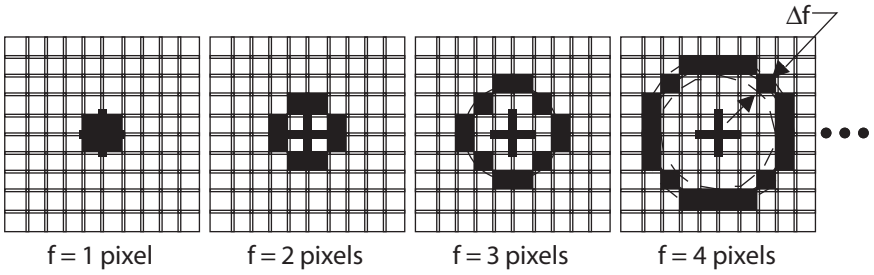
$$\text{1D PSD} = \frac{P}{\Delta f}$$

$$\text{1D isotropic PSD} = \frac{P}{2\pi f}$$

$$\text{2D isotropic PSD} = \frac{P}{2\pi f(\Delta f)}$$

The terms used in the denominators above are derived by progressively sampling data from the image's two-dimensional FFT center (see Figure 6.2b).

Figure 6.2b Progressive Data Sampling



Each sampling swings a "data bucket" of given frequency *f*. Since samples are taken from the image center, the sampling frequency, *f*, is limited to $\frac{N/2}{L}$, where *N* is the scan size in pixels. This forms the upper bandwidth limit (i.e., the highest frequency or Nyquist frequency) of the PSD plot. The lower bandwidth limit is defined at 1/L.

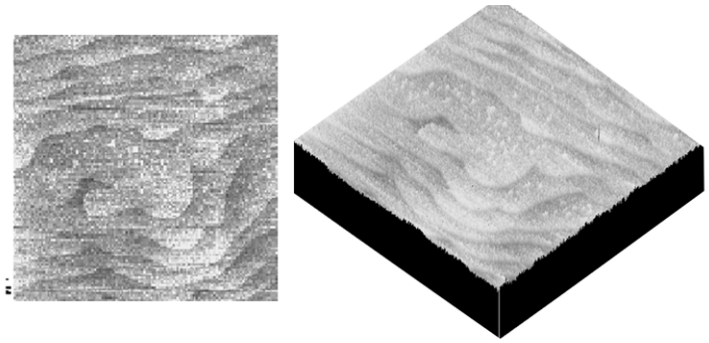
6.2.2 PSD and Flatness

PSD is used increasingly as a metrology tool for evaluating extremely flat surfaces, such as polished or epitaxial silicon. Generally, the desired surface is expected to adhere to certain **PSD** thresholds, signifying it meets a specified flatness criterion.

The main advantage gained over traditional RMS specifications is that **PSD flatness** is qualified through the full spectral range of interest. For example, one may specify spectral thresholds at frequencies measured on the atomic scale, thus ensuring surfaces consist largely of uniform lattices. Setting the precise thresholds for various materials remains a matter of debate.

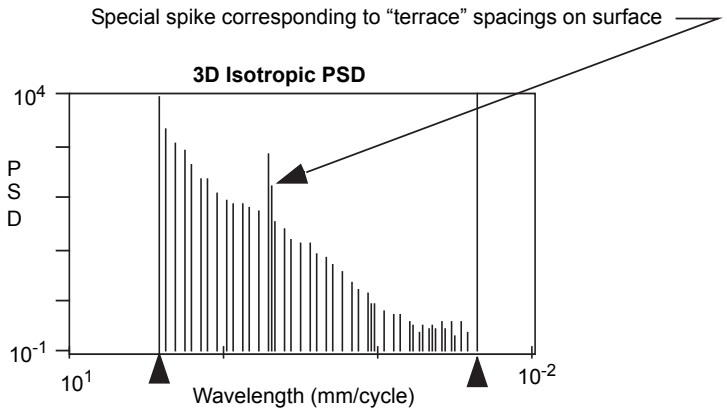
Consider the image of epitaxial gallium arsenide in Figure 6.2c.

Figure 6.2c Epitaxial Gallium Arsenide Image



This surface is comprised of "terraces" formed from the material's natural lattice structure; each terrace is one atomic monolayer thick and is spaced at fairly regular intervals. This degree of flatness is handily evaluated with PSD, as the terraces produces a spectral spike corresponding to their spacing wavelength. A PSD plot for this type of surface generally takes the form shown in Figure 6.2d.

Figure 6.2d PSD Plot for Terraced Sample



This tapered PSD plot is characteristic of flat, isotropic surfaces. Longer wavelengths are present up to the scan width, and are accompanied by uniformly decreasing powers of shorter wavelengths down to 2 pixels. On the plot shown above a spike stands out, corresponding to the wavelength spacing of the terraced features. Depending upon the qualitative standards of the person evaluating such a plot, this spike may exceed a threshold standard of flatness.

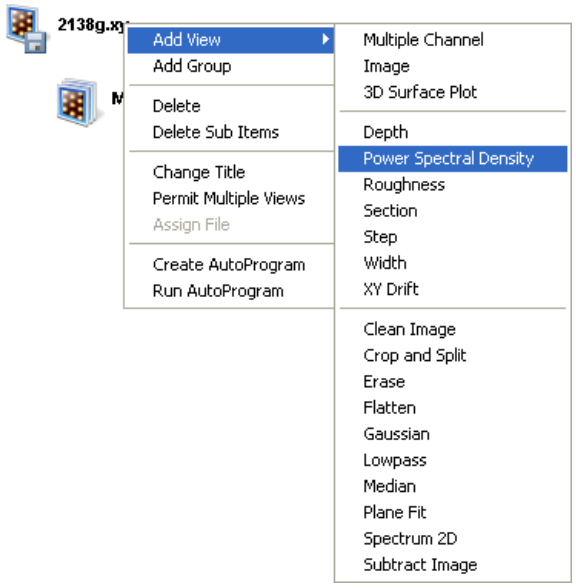
6.2.3 Performing a Spectral Density Analysis

To use the **PSD Analysis** function, perform the following procedures:

1. You can open the **Power Spectral Density** view, shown in Figure 6.2f, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Power Spectral Density** from the popup menu. See Figure 6.2e.

Figure 6.2e Select Power Spectral Density from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **POWER SPECTRAL DENSITY**.

Or

   - Select **ANALYSIS** > **POWER SPECTRAL DENSITY** from the menu bar.

Or

   - Click the **Power Spectral Density** icon in the NanoScope toolbar.

The **PSD** window opens to allow spectral density plotting (see Figure 6.2f and Figure 6.2g).

Figure 6.2f The Initial PSD Analysis Window

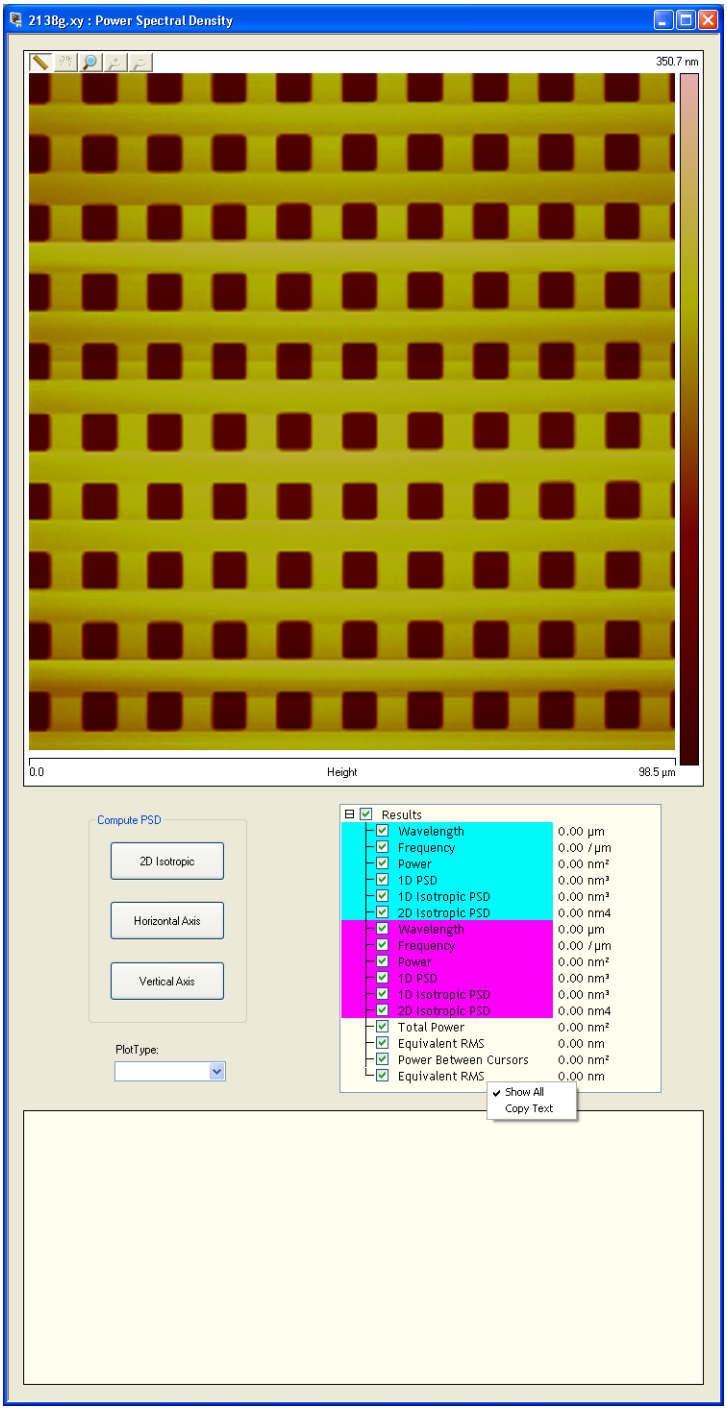
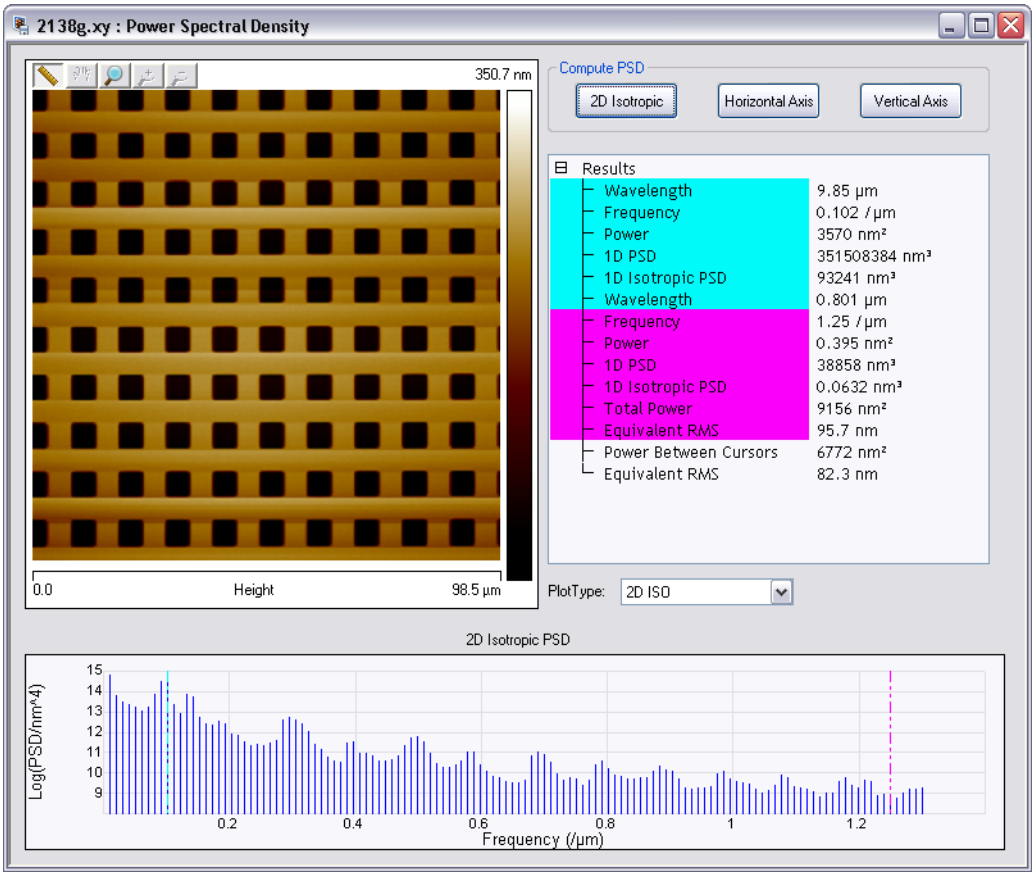


Figure 6.2g The PSD analysis window—dual monitor



Compute PSD Buttons

Once the **PSD analysis** window is opened, select the type of spectral density analysis you wish to perform by clicking the appropriate button in the **Compute PSD** window.

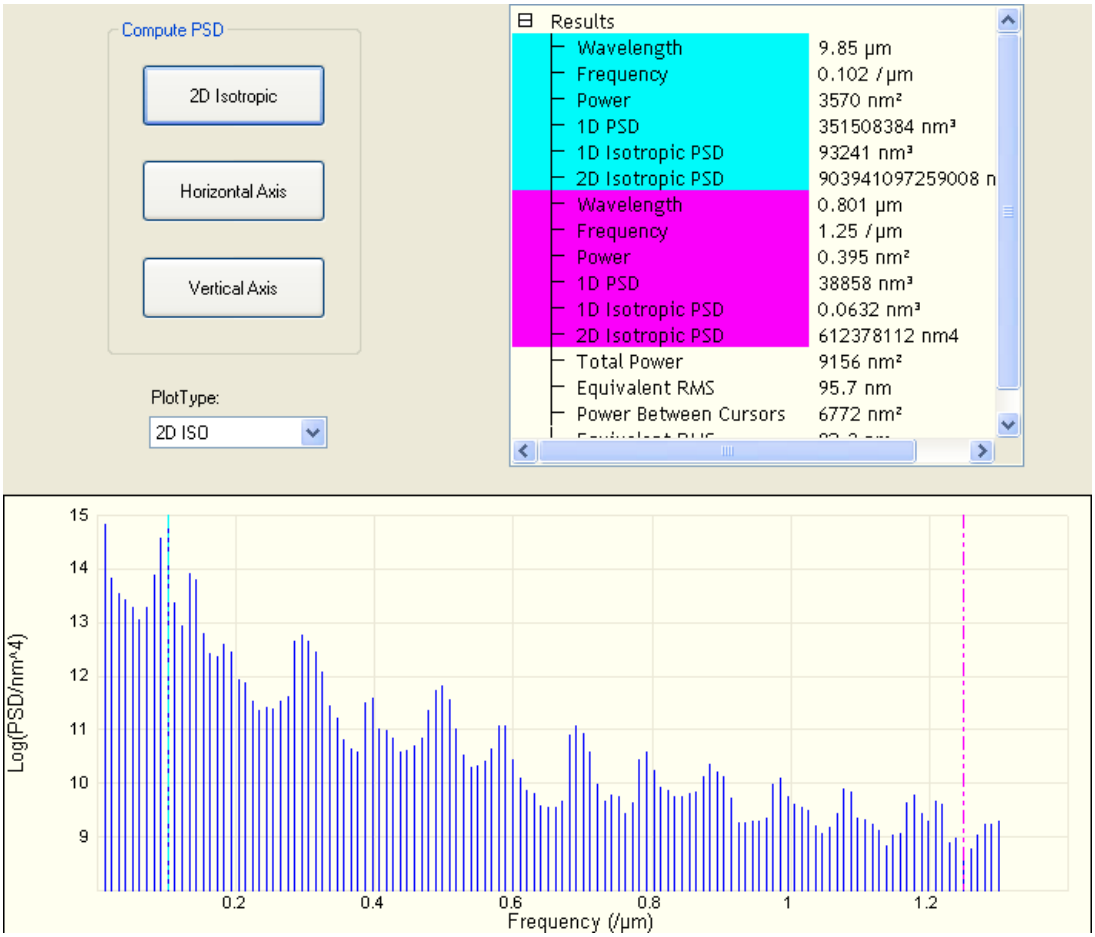
2D Isotropic—Executes a two-dimensional **Power Spectral Density** analysis.

Horizontal Axis—Executes a one-dimensional **Power Spectral Density** analysis along the X-axis.

Vertical Axis—Executes a one-dimensional **Power Spectral Density** analysis along the Y-axis.

The calculation begins as soon as one of these buttons is selected. The **PSD** and a table of values from the graph are shown in the **Results** window. Completion of the analysis will also result in a topographical histogram in the spectrum plot window, shown in Figure 6.2h.

Figure 6.2h Power Spectral Density Histogram



Results Parameters:

Wavelength	The wavelength, λ, in µm/cycle units at current cursor positions. See Figure 6.2a.
Frequency	The spatial frequency (1/λ) at current cursor positions.
Power	Power measured in nm^2 at current cursor positions.
1D PSD	One-dimensional power spectral density. Power measured in nm^3 at current cursor positions. See Page 247 for a mathematical definition.
1D Isotropic PSD	One-dimensional isotropic power spectral density. Power measured in nm^3 at current cursor positions. See Page 247 for a mathematical definition.
2D Isotropic PSD	One-dimensional isotropic power spectral density. Power measured in nm^4 at current cursor positions. See Page 247 for a mathematical definition.
Total Power	The sum of the power contained in the entire spectrum.
Equivalent RMS	The root-mean-square (RMS) roughness of the sample. It is calculated as the square root of the total power.
Power Between Cursors	The sum of the power contained in the portion of the spectrum between the cursors.
Equivalent RMS	The root-mean-square (RMS) roughness of the sample contributed by the frequencies between the cursors. It is calculated as the square root of the integral of the **Power Between Cursors** (above).

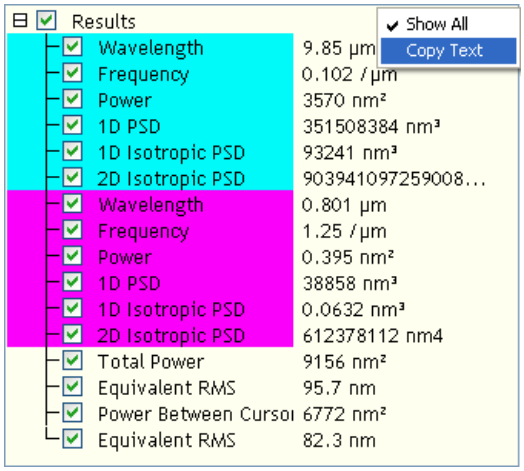
Results Display

The **Results** window displays the **Name** and **Value** of the procedures performed during a **PSD** analysis. The teal shaded area in the display window corresponds to the area designated by the teal cursor on the **Power Spectral Density** histogram, and the magenta shaded area corresponds to the magenta cursor. You can generate a report by right-clicking in the **Results** window, selecting **COPY TEXT** and pasting the clipboard into another application (e.g. Notepad, Word...).

Select Displayed Parameters

The operator can select which **Results** will or will not be displayed in the **Results** window by Right-clicking in the **Results** window, selecting **SHOW ALL** from the popup menu, and checking or unchecking the appropriate boxes (see Figure 6.2i).

Figure 6.2i Select Show All On/Off Check Boxes



Exporting Text

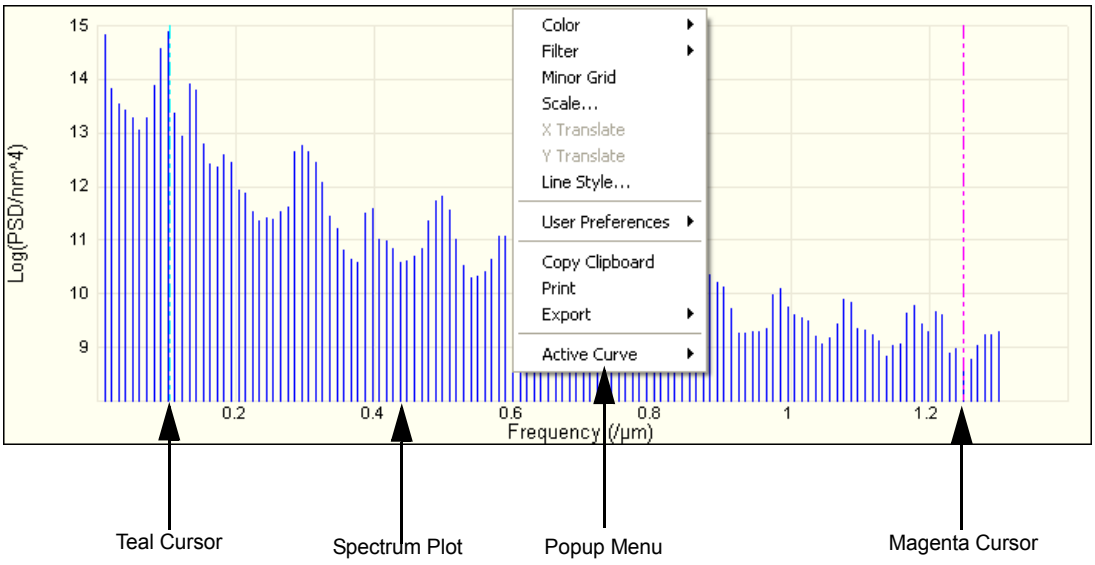
Selecting **COPY TEXT** from the popup menu will copy the text from the **Results** window, in tab-delimited text format, to the Windows clipboard. You may then paste it into a text or word processing program.

6.2.4 Changing Parameters of the Spectrum Plot

The **Spectrum Plot** window displays results of the **PSD** analysis (see Figure 6.2j). The window has two cursors whose color corresponds to the shaded areas in the **Results** window. You can move either of these cursors within the **Spectrum Plot** window by placing the cross hair cursor directly over the cursor, clicking and holding the left mouse button, and dragging the mouse to the left or right. You can also move both cursors simultaneously by left-clicking the mouse with the cross hair cursor anywhere between the two cursors and dragging to the left or right.

To change the parameters of the **Spectrum Plot**, right-click in the **Spectrum Plot** window at the bottom of the display and choose from the popup menu.

Figure 6.2j Spectrum Plot Parameter Menu



Spectrum Plot Popup Menu Items

Color—Changes the colors of the curves, text, background, grid lines, minor grid lines (if selected), and the marker pairs (see Figure 6.2k).

Filter—Selects Filter type and points (see Figure 6.2l).

Minor Grid—Shows/hides minor grid lines

Figure 6.2k Color Menu Items

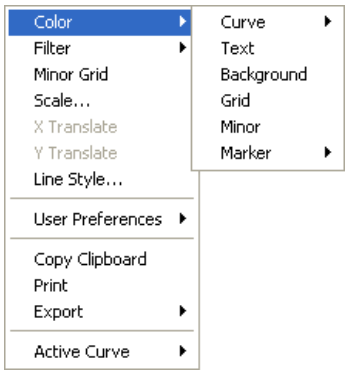
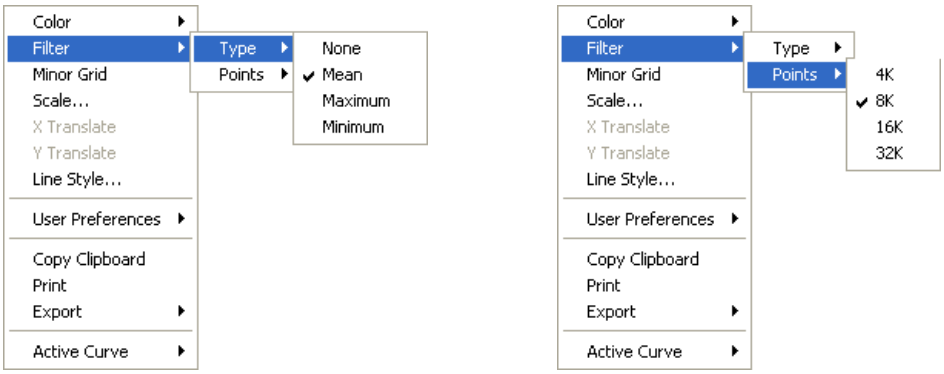


Figure 6.2l Filter Menu Items



Scale—Sets the vertical axis range, the center of the range, or allow the software to autoscale (see Figure 6.2m).

Line Style—Changes the line style of the Spectrum Plot graphical display (see Figure 6.2n).

User Preferences—You can either save all changes made to the graphical display, or restore previously saved settings (see Figure 6.2o). **Save** will result in all graphical displays maintaining any design changes made to this display.

Copy Clipboard—Copies the graphical display only to the Windows clipboard, allowing it to be pasted into any compatible Windows program.

Print—Prints the graphical display only to a printer.

Export—Saves the graphical display as a JPEG graphic, a Bitmap graphic, or as an XZ Data file text, which can be read in a database program (e.g. Excel).

Active Curve—Changes the curve displayed when more than one curve has been plotted. (Does not occur in PSD).

Figure 6.2m Scale Settings Dialog Box

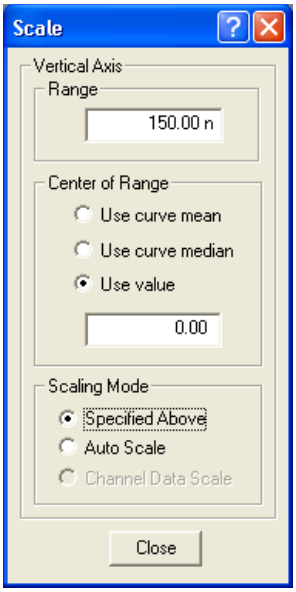


Figure 6.2n Line Style Display

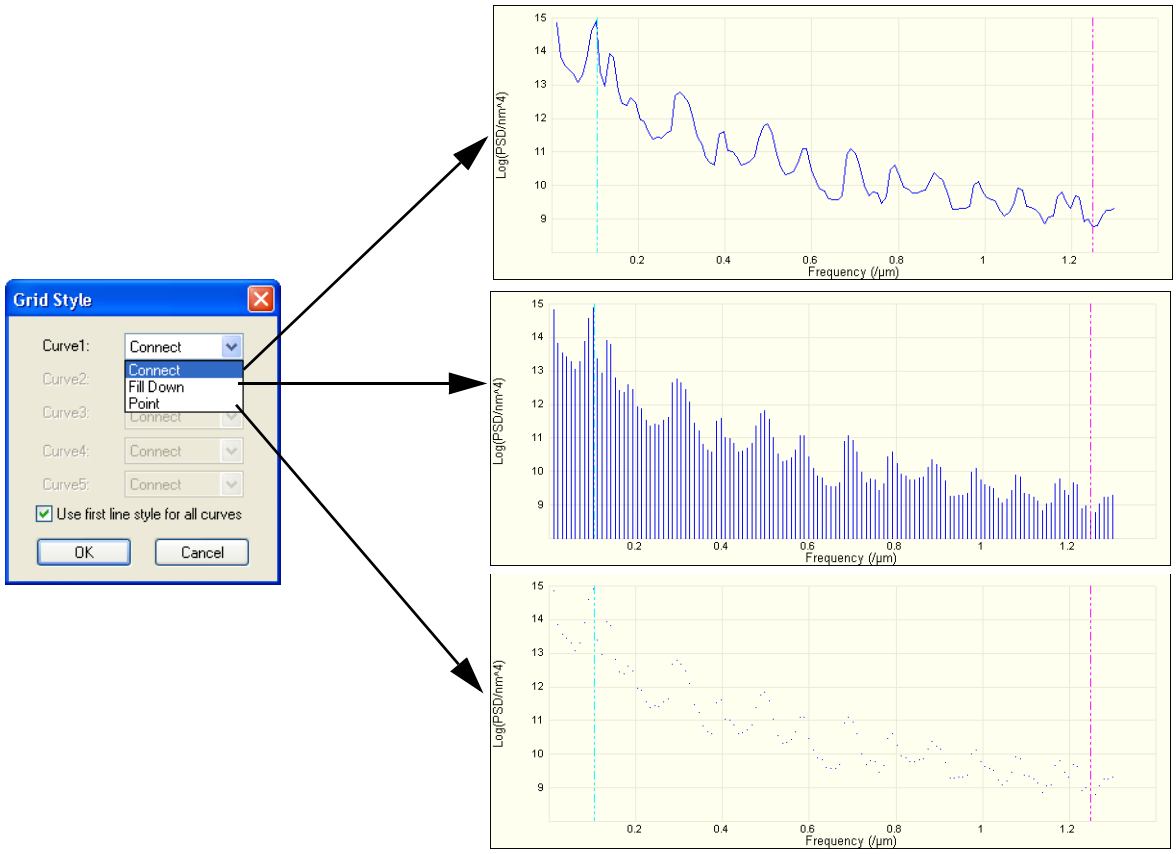
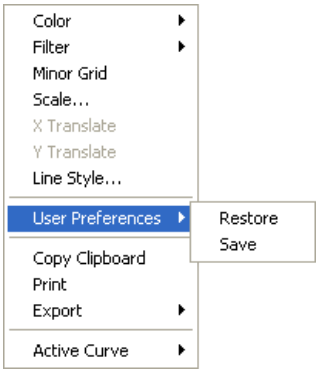


Figure 6.2o User Preferences Menu



6.3 Roughness

The **Roughness** command generates a variety of statistics on surfaces, including classical roughness values and peak and zero crossing data. “Image” statistics are reported for the entire image. “Box” statistics are reported only for the region you define within a cursor box. In addition, the data can be augmented with *stopbands*, (excluding features) to isolate desired analysis.

Refer to the following sections on **Roughness**:

- **Roughness Theory:** Section 6.3.1
- **Roughness Procedures:** Section 6.3.2
- **Roughness Interface:** Section 6.3.3

Most industrial standards for roughness measurement call for planefitting data *before* calculating values. Planefitting applies a temporary first-order planefit before calculating statistics. On many surfaces, especially those which are tilted, this yields different values from those seen in raw (unplanefitted) data. Moreover, peripheral features included within the analyzed region may produce cumulative results uncharacteristic of the feature(s) of interest. To ensure the best results, you should observe the following rules when using **Roughness** analysis:

- If the image shows signs of second- or third-order distortion (e.g., bow due to large scans on large scanners), apply a second- or third-order **Flatten** and **Planefit** to the image *before* using **Roughness** analysis.
- Isolate your analysis to specific areas of the image. This may be accomplished by using the box cursor in **Roughness** to analyze only select portions of the image.

6.3.1 Roughness Theory

Regarding the effects of **Planefitting** on **Roughness** statistics—When **Roughness** analysis is applied to an image, statistical values are calculated according to the relative heights of each pixel in the image. **Planefitting** (used to correct images for tilt and bow) reorients these pixels in a manner which can affect roughness statistics dramatically on some surfaces. This is especially true of surfaces having broad, coplanar features. Planefitting can be applied at the time of file capture using **OL Plane Fit** from a **Channel** panel, or via the **Modify** > **Plane Fit** function.

When **Roughness** analysis is applied to an image, the image data is automatically planefit beforehand. This is done to accord with ASME and ISO metrological standards. (Only the **Raw mean** parameter is exempt from this operation, being calculated from raw data only.) To avoid unexpected results due to planefitting, be certain to apply **Roughness** analysis only to the surface(s) of interest by utilizing a cursor box, or by scanning just the specific site of interest. Including peripheral features within an analyzed area may produce cumulative results uncharacteristic of the feature(s) of interest.

The relationship between the zero plane and the data also changes according to the setting of the **OL Plane Fit** parameter. If the **OL Plane Fit** parameter is set to **None**, the offset is not removed from the data and it is very possible that the zero plane does not intersect the data. The other

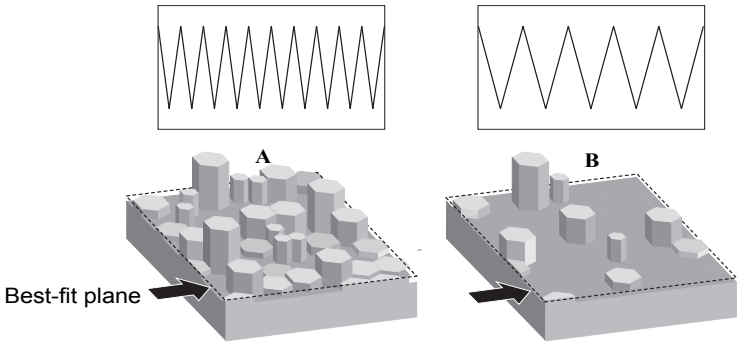
settings (see Data Type Range or Settings on page 93) of the parameter subtract the average Z value from every point in the image so the data varies around the zero plane.

Regarding Basic Roughness Measurements—Average roughness (R_a) is one of the most commonly used roughness statistics. Figure 6.3a represents two surfaces having the same average roughness.

Similarly, a number of other roughness values are based upon least-squares calculations (e.g., RMS roughness, or R_q), and their algorithms are more concerned with a best fit of all height points than with the spatial frequency of features.

The surface of image **A** is represented as having a high frequency profile of features. Image **B** represents a separate surface having the same average feature height, but distributed at wider (lower-frequency) intervals. In terms of average and RMS roughness, both surfaces are equally rough. If you are interested in differentiating between the two, you must rely upon other statistical parameters such as Power Spectral Density.

Figure 6.3a Basic Roughness Measurements



6.3.2 Roughness Procedures

Example of Using Roughness Analysis

For general **Roughness Analysis**, complete the following procedures:

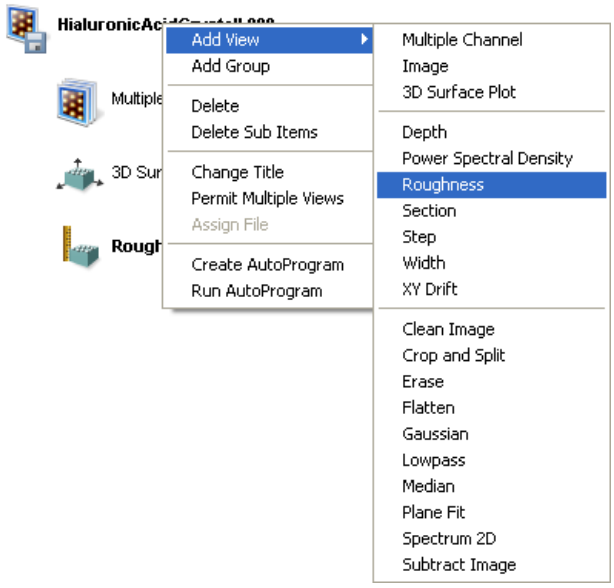
1. Select an image file from the file browsing window at the right of the main window. Double click the thumbnail image to select and open the image.

To use the **Roughness Analysis** function, perform the following procedures:

2. You can open the **Roughness** view, shown in Figure 6.3c, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Roughness** from the popup menu. See Figure 6.3b.

Figure 6.3b Select Roughness from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **ROUGHNESS**.

Or

   - Select **ANALYSIS** > **ROUGHNESS** from the menu bar.

Or

3. Click the **Roughness** icon in the NanoScope toolbar.

4. The **Roughness View** appears showing results for the entire image.

5. To perform **Roughness** measurements within an area, left-click and move the mouse to draw a measurement box. Click on the **Execute** button to calculate the **Roughness** inside the box.

6. To exclude an area, right-click in the image to access a pop-up menu and select **Stop Band**. Using the mouse, draw a box around the area to be excluded by the stop band command. Click on the **Execute** button to calculate the **Roughness** outside the box.

6.3.3 Roughness Interface

The **Roughness View** shows the image along with **Input** parameters and a **Results** window.

Figure 6.3c Roughness Display—single monitor

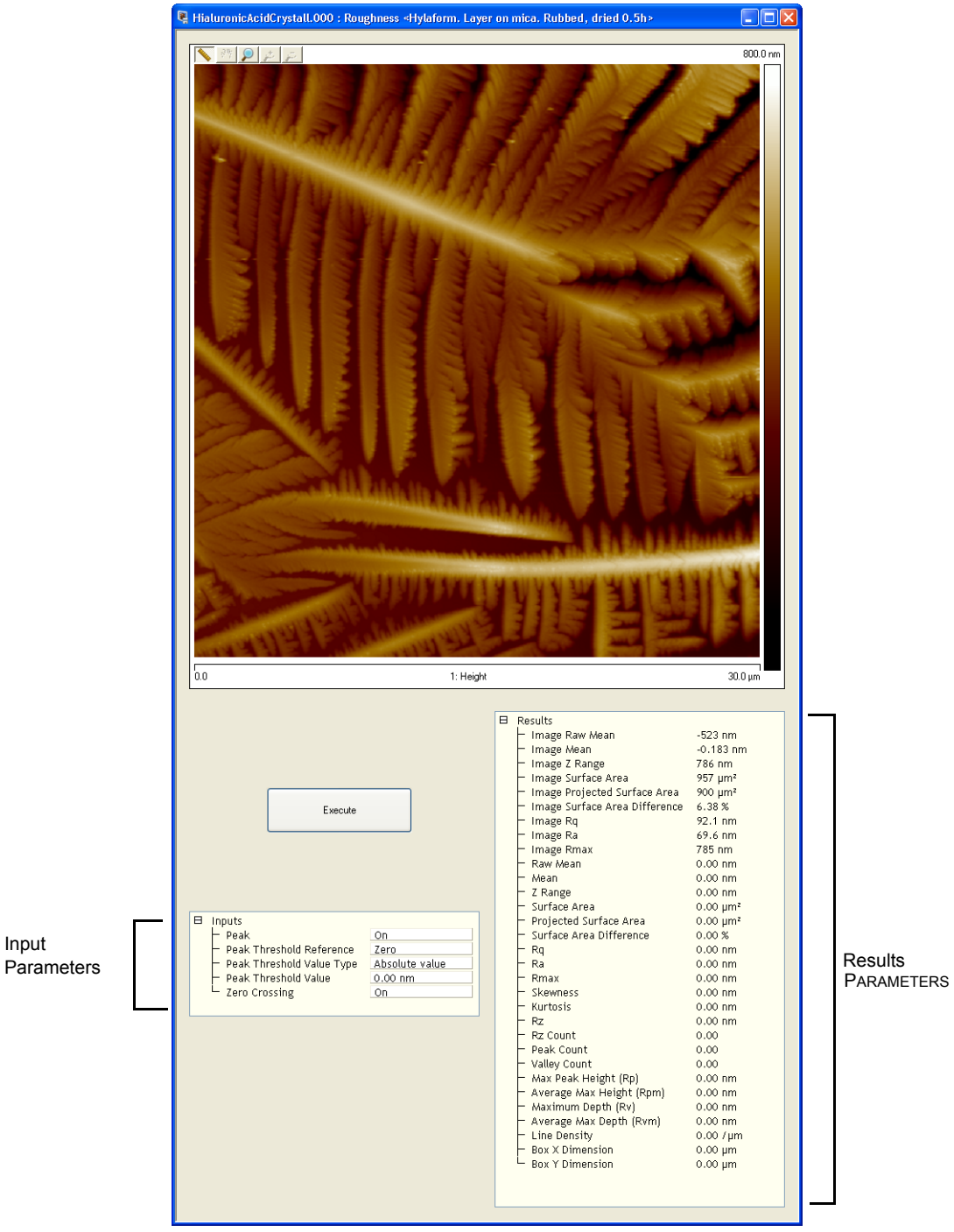
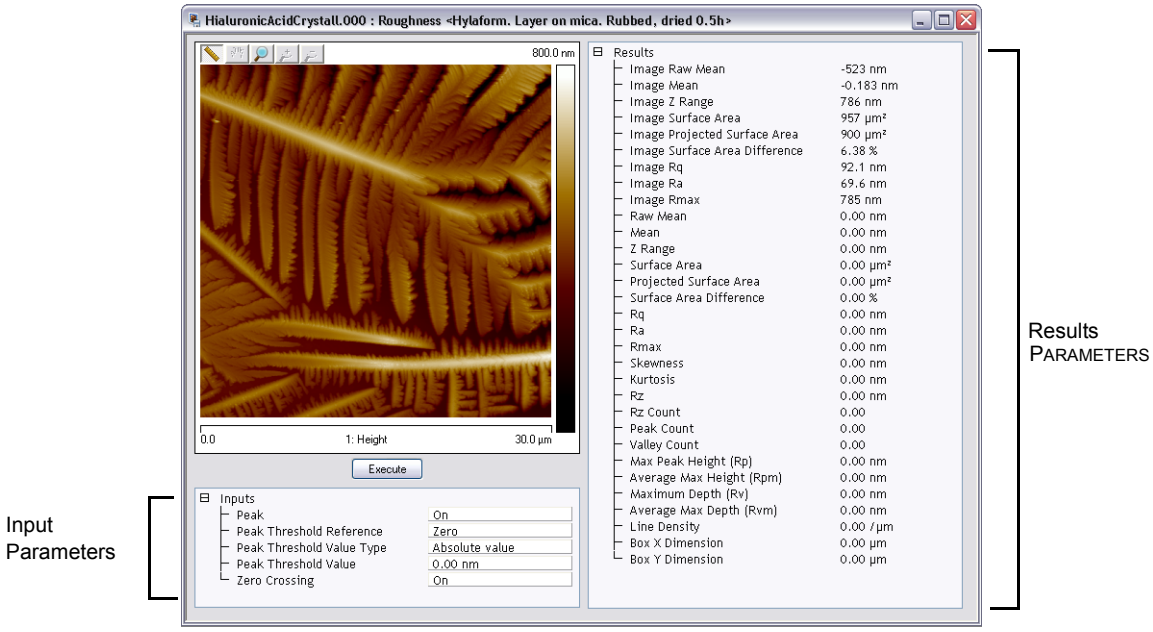


Figure 6.3d Roughness Display—dual monitor



Note: Some parameters are reported only when certain subroutines are turned on.

Input Parameters

Peak

The **Peak** feature, when switched **On**, isolates specified height portions of the image (peaks) from background data. Peaks are specified using the **Peak Threshold** parameters, either in terms of their absolute height or their deviation from the RMS value of all surface data, and relative to either the highest data point (Peak) or the mean (Zero). When **Peak** is turned **On**, portions of the image contained within the box cursor and falling within the specified boundaries are retained; all other data is removed.

Range or Settings—When **Peak** is turned **On**, the following subcommands are activated (see Figure 6.3e):

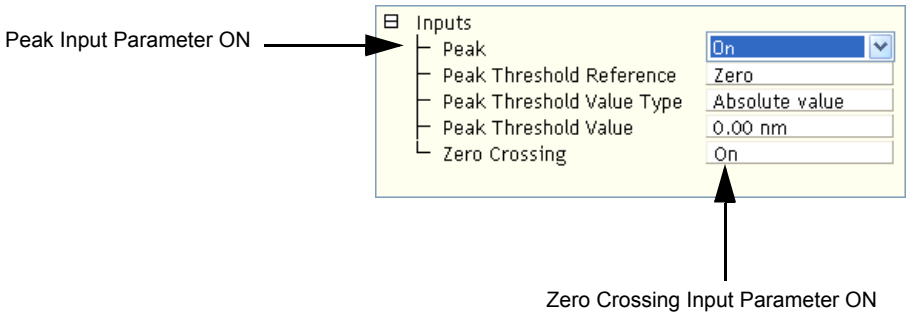
Peak Threshold Reference	The **Reference** buttons select whether the threshold is defined relative to the **Zero** (lowest) value, or the tallest **Peak** in the selected region.
Peak Threshold Value Type	The **Value Type** determines whether the threshold is defined as an absolute distance from the reference point in nanometers (**Absolute value**) or a percentage of the root-mean-square (**Rms %**) of the Z values.
Peak Threshold Value	The **Value** is an absolute distance from the reference point in nanometers (Absolute value) or a percentage of the root-mean-square (Rms %) of the Z values.

When **Peak** is turned **On**, the following statistical parameters are turned on. All **Peak** parameters are calculated from the thresholds you define with the **Peak** subcommands.

- **Rz**
- **Rz count**
- **Peak Count**
- **Valley Count**
- **Max peak ht (Rp)**
- **Av. Max ht (Rpm)**
- **Max depth (Rv)**
- **Av. max depth (Rvm)**

When **Peak** is turned **Off**, statistics are not calculated.

Figure 6.3e Input On Parameters



Zero Crossing

A zero crossing is a point where the Z values go through zero regardless of slope. This value is the total number of zero crossings along both the X and Y center lines divided by the sum of the box dimensions.

Range or Settings—When **Zero crossing** is turned **ON** and you click the **EXECUTE** button, the number of zero crossings along the X and Y center lines of the box cursor is determined (see Figure 6.3e). The number of zero crossings is divided by the sum of the lengths of the X and Y center lines and reported as the **Line density**.

When **Zero crossing** is turned **OFF**, the zero crossing determination is not performed.

Results Parameters

Statistics used by the Roughness routine are defined in this section. The terms are listed alphabetically. Most are derived from ASME B46.12 ("Surface Texture: Surface Roughness, Waviness and Lay") available from the American Society of Mechanical Engineers.

Av max Depth (R_{vm}) — Average distance between the (**VALLEY COUNT** value) lowest profile points and the mean data plane.

Av max ht (R_{pm}) — Average distance between the (**PEAK COUNT** value) highest profile points and the mean data plane.

Box x Dimension — The width of the $\mathbf{L_X}$ box cursor you define.

Box y Dimension — The length of the $\mathbf{L_Y}$ box cursor you define.

Image Mean — Mean value of data contained within the image.

Image Projected surface area — Area of the image rectangle (X x Y).

Image R_a — Arithmetic average of the absolute values of the surface height deviations measured from the mean plane.

$$R_a = \frac{1}{N}\sum_{j=1}^{N}|Z_j|$$

Image Raw mean — Mean value of image data without application of plane fitting.

Image R_{max} — Maximum vertical distance between the highest and lowest data points in the image following the planefit.

Image R_q — Root mean square average of height deviations taken from the mean image data plane, expressed as:

$$\sqrt{\frac{\sum Z_i^2}{N}}$$

Image Surface area — The three-dimensional area of the entire image. This value is the sum of the area of all of the triangles formed by three adjacent data points.

Image Surface Area Difference — Difference between the image's three-dimensional **Surface area** and two-dimensional projected surface area.

Image Z range — Maximum vertical distance between the highest and lowest data points in the image prior to the planefit.

Kurtosis — This is a non-dimensional quantity used to evaluate the shape of data about a central mean. It is calculated as

$$\text{Kurtosis} = \frac{1}{R_q^4}\frac{1}{N}\sum_{j=1}^{N}Z_j^4$$

Graphically, kurtosis indicates whether data are arranged flatly or sharply about the mean.

Line Density The number of zero crossings per unit length on the X and Y center lines of the box cursor. A zero crossing is a point where the Z values go through zero regardless of slope. This value is the total number of zero crossings along both the X and Y center lines divided by the sum of the box dimensions.

Maximum Depth (R_v) Lowest data point in examined region.

Max Height (R_{max}) Maximum vertical distance between the highest and lowest data points within the cursor box.

Max Peak ht (R_p) Maximum peak height within the analyzed area with respect to the mean data plane.

Mean The average of all the Z values within the enclosed area. The mean can have a negative value because the Z values are measured relative to the Z value when the microscope is engaged. This value is not corrected for tilt in the plane of the data; therefore, plane fitting or flattening the data changes this value.

Mean Roughness (R_a) Arithmetic average of the absolute values of the surface height deviations measured from the mean plane within the box cursor:

$$R_a = \frac{1}{N}\sum_{j=1}^{N}\left|Z_j\right|$$

Peak Count The number of peaks taller than the **THRESHOLD VALUE**.

Projected Surface Area Area of the selected data.

Raw Mean Mean value of image data within the cursor box you define without application of plane fitting.

Rms (R_q) This is the standard deviation of the Z values within the box cursor and is calculated as:

$$R_q = \sqrt{\frac{\sum (Z_i)^2}{N}}$$

where Z_i is the current Z value, and N is the number of points within the box cursor. This value is not corrected for tilt in the plane of the data; therefore, plane fitting or flattening the data changes this value.

R_z This is the average difference in height between the (**RZ COUNT** value) highest peaks and valleys relative to the **Mean Plane**.

Rz Count Number of peak/valley pairs that are used to calculate the value Rz.

Skewness	Measures the symmetry of surface data about a mean data profile, expressed as: $$\text{Skewness} = \frac{1}{R_q^3}\frac{1}{N}\sum_{j=1}^{N} Z_j^3$$ where R_q is the Rms roughness. Skewness is a non dimensional quantity which is typically evaluated in terms of positive or negative. Where **Skewness** is zero, an even distribution of data around the mean data plane is suggested. Where **Skewness** is strongly non-zero, an asymmetric, one-tailed distribution is suggested, such as a flat plane having a small, sharp spike (> 0), or a small, deep pit (< 0).
Surface Area	The three-dimensional area of the region enclosed by the cursor box. This value is the sum of the area of all of the triangles formed by three adjacent data points.
Surface Area Diff	Difference between the analyzed region's three-dimensional **Surface area** and its two-dimensional, footprint area.
Valley Count	The number of valleys shorter than the **THRESHOLD VALUE**.
Z Range	Peak-to-valley difference in height values within the analyzed region.

6.4 Section

The **Section** command displays a top view image, upon which one, two or three reference lines may be drawn. The cross-sectional profiles and fast Fourier transform (FFT) of the data along the reference lines are shown in separate windows. Roughness measurements are made of the surface along the reference lines you define.

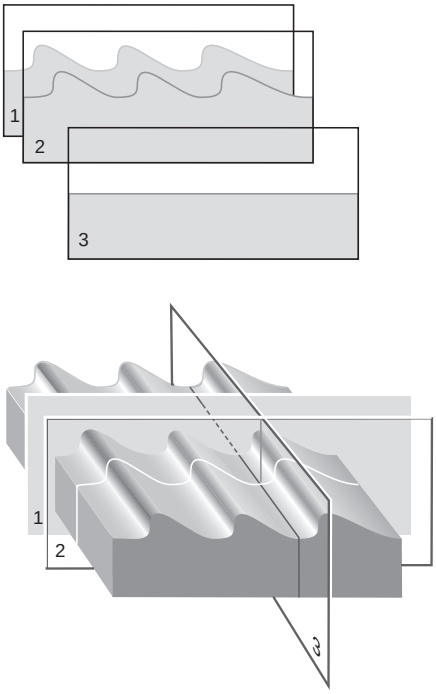
Section is probably the most commonly used **Analysis** command; it is also one of the easiest commands to use. To obtain consistently accurate results, ensure your image data is corrected for tilt, noise, etc. *before* analyzing with **Section**.

- **Sectioning of Surfaces: Overview:** Section 6.4.1
- **Section Procedures:** Section 6.4.2
- **Section Interface:** Section 6.4.3

6.4.1 Sectioning of Surfaces: Overview

Samples are sectioned to learn about their surface profiles. The **Section** command does not reveal what is *below* the surface—only the profile of the surface itself. When sectioning samples, you should first ascertain surface topology. Depending upon the topology and orientation of the sample, the results of **Section** analysis may vary tremendously.

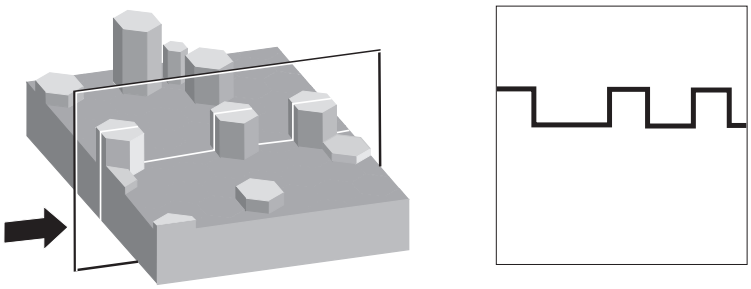
Figure 6.4a Section Analysis Orientation



In Figure 6.4a, the sample surface (a diffraction grating) is sectioned along three axes. Sections 1 and 2 are made perpendicular to the grating's rules, revealing their blaze and spacings. (Sections 1 and 2 may be compared simultaneously using two fixed cursor lines, or checked individually with a moving cursor.) Section 3 is made parallel to the rules, and reveals a much flatter profile because of its orientation.

The **Section** command produces a profile of the surface, then presents it in the **Section** grid (see Figure 6.4b).

Figure 6.4b Section Command Profile



Generally, **Section** analysis proves most useful for making direct depth measurements of surface features. By selecting the type of cursor (**Rotating Line**, **Rotating Box**, or **Horizontal Line**), and its orientation to features, you may obtain:

- Vertical distance (depth), horizontal distance and angle between two or more points.
- Roughness along section line: RMS, R_a, R_{max}, R_z.
- FFT spectrum along section line.

Features are discussed below. Refer to **Roughness:** Section 6.3 for additional information regarding roughness calculations.

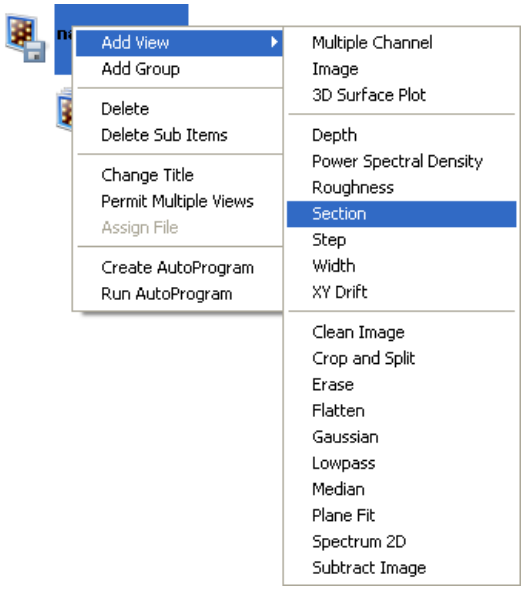
6.4.2 Section Procedures

1. Select an image file from the file browsing window at the right of the main window. Double click the thumbnail image to select and open the image.

2. You can open the **Section** view, shown in Figure 6.4e, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Section** from the popup menu. See Figure 6.4c.

Figure 6.4c Select **SECTION** from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **SECTION**.

Or

   - Select **ANALYSIS** > **SECTION** from the menu bar.

Or

3. Click the **Section** icon in the NanoScope toolbar.

4. The **Section View** appears showing results for the entire image.

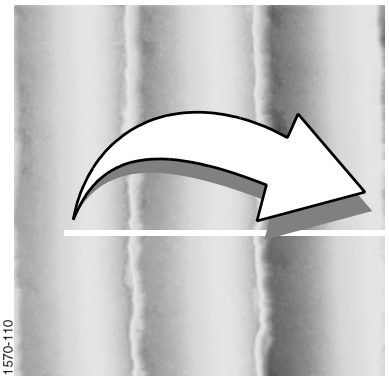
5. Before doing a section analysis, ensure that the image is properly oriented by removing any tilt or bow. This is especially important if a high level of precision is to be employed in measuring the blaze angle.

6. To remove any tilt which might be present, select **Modify** > **Plane Fit** or the **PLACE FIT** icon on the NanoScope toolbar. Set the **Plane Fit Order** parameter in the panel to **1ST**, then click the **EXECUTE** button. The image is fitted to a plane ("leveled") by fitting each scan line to a first-order equation, then fitting each scan line to others in the image. At this point, the image has not been appreciably altered, it has only been reoriented slightly.

7. In Section Analysis, to make a single-line section of the image, use the mouse to draw a line through the image, as in Figure 6.4d, and note the results.

8. Move the grid cursors along the section to make measurements.

Figure 6.4d Mouse Drawing Line



6.4.3 Section Interface

When a line is drawn on the image, the cross-sectional profile is displayed, and the FFT spectrum along the line is also displayed (see Figure 6.4e and Figure 6.4f). More detail about the FFT algorithm used may be found at http://www.fftw.org.

The markers may be positioned in the profile and FFT spectrum. The results window at the bottom of the display lists roughness information based on the position of the presently selected reference markers. Each marker pair is color coordinated with the data in the results window.

Figure 6.4e Section View—single monitor

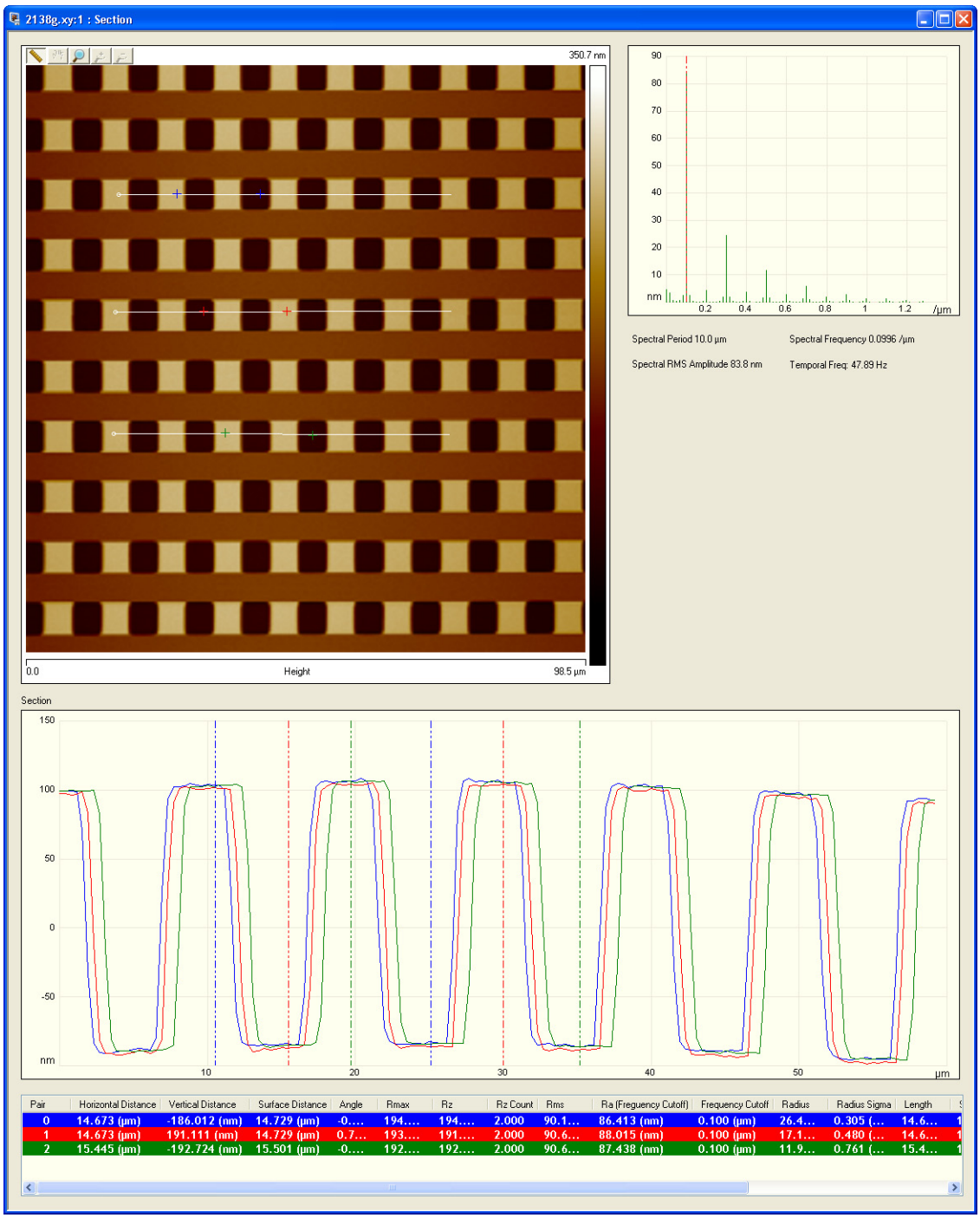
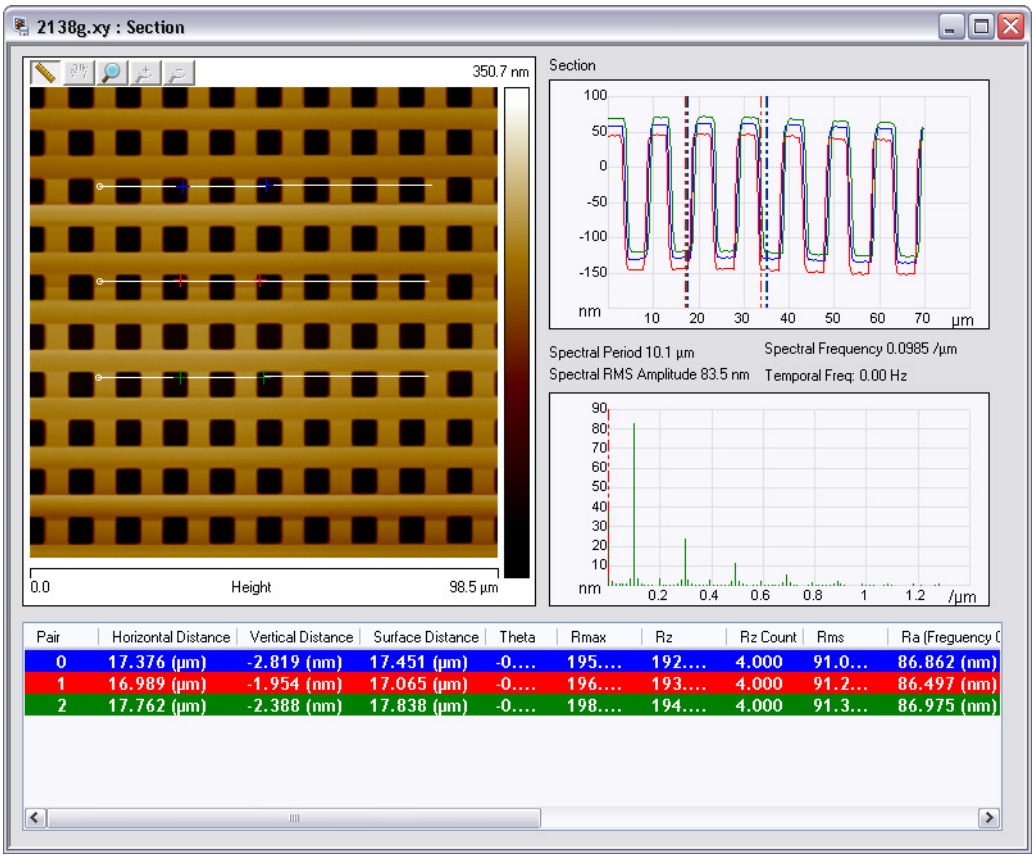


Figure 6.4f Section View—dual monitor



Grid Markers:

A pair of markers in the section grid and a single marker in the spectrum grid will automatically be drawn. Place the mouse cursor on the desired marker and left-click to move.

Marker pair 0 Default display color is blue. Slide the markers into the grid from the left or right side by clicking and holding the left mouse button. Data between the two markers will be displayed in the results window at the bottom of the display screen in blue.

Marker pair 1 Default display color is red. Slide the markers into the grid from the left or right side by clicking and holding the left mouse button. Data between the two markers will be displayed in the results window at the bottom of the display screen in red.

Marker pair 2 Default display color is green. Slide the markers into the grid from the left or right side by clicking and holding the left mouse button. Data between the two markers will be displayed in the results window at the bottom of the display screen in green.

Spectrum Marker Displays a slider cursor along the spectral data (e.g., FFT Spectrum).

Results Parameters:

The standard deviation RMS ($\mathbf{R_q}$), mean roughness ($\mathbf{R_a}$), the maximum height ($\mathbf{R_{max}}$), and the 10-point roughness ($\mathbf{R_z}$) for the segment between the reference markers are also listed in the **Results** window.

Results Parameters:

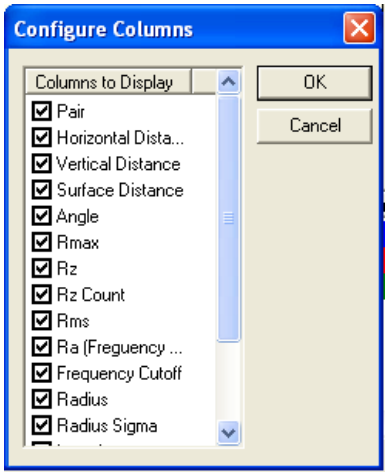
Length	Length of the roughness curve.
***Rms* (Standard Deviation)**	Standard deviation of the Z values between the reference markers, calculated as: $$RMS = \sigma = \sqrt{\frac{\sum (Z_i - Z_{ave})^2}{N}}$$ where Z_i is the current Z value, Z_{ave} is the average of the Z values between the reference markers, and N is the number of points between the reference markers.
***Ra* (Mean Roughness)**	Mean value of the roughness curve relative to the center line, calculated as: $$R_a = \frac{1}{L}\int_0^L \lvert f(x)\rvert dx$$ where L is the length of the roughness curve and $f(x)$ is the roughness curve relative to the center line.
***Rmax* (Maximum Height)**	Difference in height between the highest and lowest points on the cross-sectional profile relative to the center line (not the roughness curve) over the length of the profile, L.
***Rz* (Ten-Point Mean Roughness)**	Average difference in height between the five highest peaks and five lowest valleys relative to the center line over the length of the profile, L. In cases where five pairs of peaks and valleys do not exist, this is based on fewer points.
Freq. Cutoff (μm)	**Frequency Cutoff** measured in terms of a percentage of the root mean square.

Changing the cursor on the FFT changes l_c, the cutoff length of the high-pass filter applied to the data. The filter is applied before the roughness data is calculated; therefore, the position of the cutoff affects the calculated roughness values.

- **Rz Count**—number of peaks used for Rz computation
- **Radius**—radius of circle fitted to the data between the cursors
- **Radius Sigma**—mean square error of radius calculation
- **Surface Distance**—distance measured along the surface between the cursors
- **Horizontal Distance**—horizontal distance between the cursors
- **Vertical Distance**—vertical distance between the cursors
- **Angle**—angle of the imaginary line drawn from the first cursor intercept to the second cursor intercept
- **Spectral Period**—spectral period at the cursor position
- **Spectral Frequency**—spectral frequency at the cursor position
- **Spectral RMS Ampl.**—amplitude at the cursor position

Right-clicking in the bottom results window opens allows you to open a **Configure Columns** window, shown in Figure 6.4g, which lets you select which parameters will be computed and displayed.

Figure 6.4g Configure Columns Window



Mouse Operations for a Rotating Line Cursor:

- Mouse down, drag—Anchors the origin of a line segment and expands from the selected position, allowing a line segment to be drawn in any direction.
- Mouse up—Anchors the terminal point of the first (dashed) line segment and draws a moving reference line perpendicular to the fixed-line segment. The cross-sectional profile and the FFT along the reference line are displayed at this time. The position of the moving reference line tracks the movements of the mouse. When the mouse is stationary, the cross-sectional profile and the FFT of the data along the moving reference line is updated.
- Clicking on the center of the line and dragging moves the line on the image.
- Clicking on either end of the line rotates the line.

Mouse Operations for Rotating Box Cursor (Right-Click Selection):

- 1st click—Anchors the origin of a box and "rubber bands" out from the center of the selected position.
- As a reference, the cursor positions show up on the center line in the box.
- Clicking on the box—Allows the box to be moved (cursor inside box), or resized (cursor on edge of box). Clicking on the corner allows the box to be resized in two directions.
- Holding the **Shift** button down while clicking on the box and dragging in a circular direction rotates the box.

Mouse Operations for a Horizontal Line Cursor:

- Mouse down—Draws a horizontal line segment at that location.
- Clicking on the line and dragging moves the line on the image.

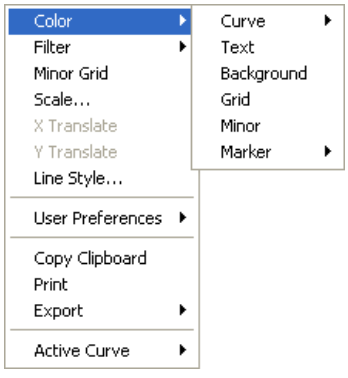
Using the Grid Display

Measurement cursors for histogram and cross section views in **Depth** and **Section** are provided to the left and right of the **Grid Display**. You can bring the cursors into the grid by placing the mouse cursor onto the measurement cursors, clicking and holding the left mouse button, and dragging them onto the grid. When you place the mouse cursor onto a measurement cursor, the cursor will change to a horizontal or vertical double-arrow cursor ↔ , which indicates you can grab and drag this cursor.

Right-clicking on the grid will bring up the **Grid Parameters** menu (see Figure 6.1f) and allow you to make the following changes:

Color	Allows operator to change the color of the • Curve (data) • Text • Background • Grid • Minor • Marker See Figure 6.4h.
Filter	Typically used for a Profiler Scan. • Type—Select None, Mean (default), Maximum, or Minimum • Points—Select 4k, 8k (default), 16k, or 32k
Minor Grid	Places a minor grid in the background of the Graph Window.
Scale	Allows user to auto scale, set a curve mean, or set their own data range
Line Style	For each curve, the operator can choose a connect, fill down, or point line.
User Preferences	**Restore**—Reverts to initial software settings **Save**—Saves all changes operator has made during this session. This becomes the new default settings.
Copy Clipboard	Copies the grid image to the Microsoft Clipboard
Print	Prints out the current screen view to a printer
Export	Exports data in bitmap, JPEG or XZ data format
Active Curve	Determines which curve you are analyzing

Figure 6.4h Grid Parameters Menu



6.5 Step

The **Step** command makes relative height measurements between two regions (steps) on sample surfaces. Typical applications include measuring film thickness and etch depths. **Step** works similarly to a **Section** command with an averaging box cursor, but its operation is simplified.

Step displays a top view of the image, then the user draws a reference line across the regions to be measured. A height profile is generated from averaged data on either side of the reference line in the box. Cursors—which are moved along the profile—define specific regions (steps). These may be measured (**Measure** button) relative to each other, with or without data leveling (**Level** button).

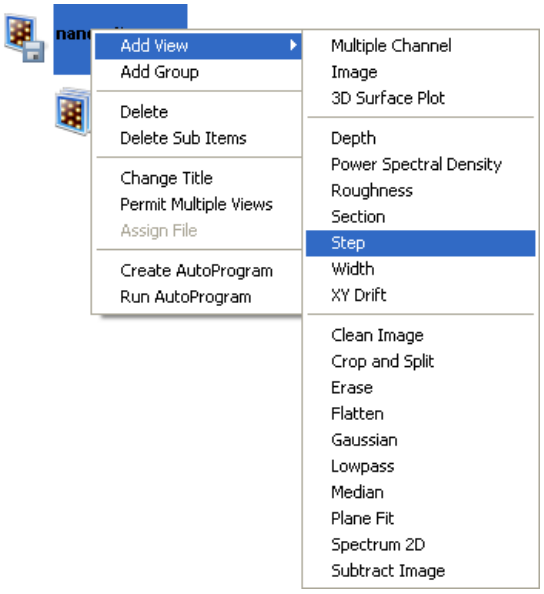
6.5.1 Step Procedures

1. Select an image file from the file browsing window at the right of the main window. Double click the thumbnail image to select and open the image.

2. You can open the **Step** view, shown in Figure 6.5b, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Step** from the popup menu. See Figure 6.5a.

Figure 6.5a Select **STEP** from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **STEP**.

Or

   - Select **ANALYSIS** > **STEP** from the menu bar.

Or

3. Click the **Step** icon in the NanoScope toolbar.

4. The **Step View** appears showing results for the entire image.

6.5.2 Step Interface

The Step interface, shown in Figure 6.5b and Figure 6.5c, includes a captured image and a graph of averaged height within a selected box. Two pairs of cursors (one black and one red) can be moved across this profile to define the steps to be measured. The region between each cursor defines a "step." The marker position is shown below the height graph.

Figure 6.5b Step Interface—single monitor

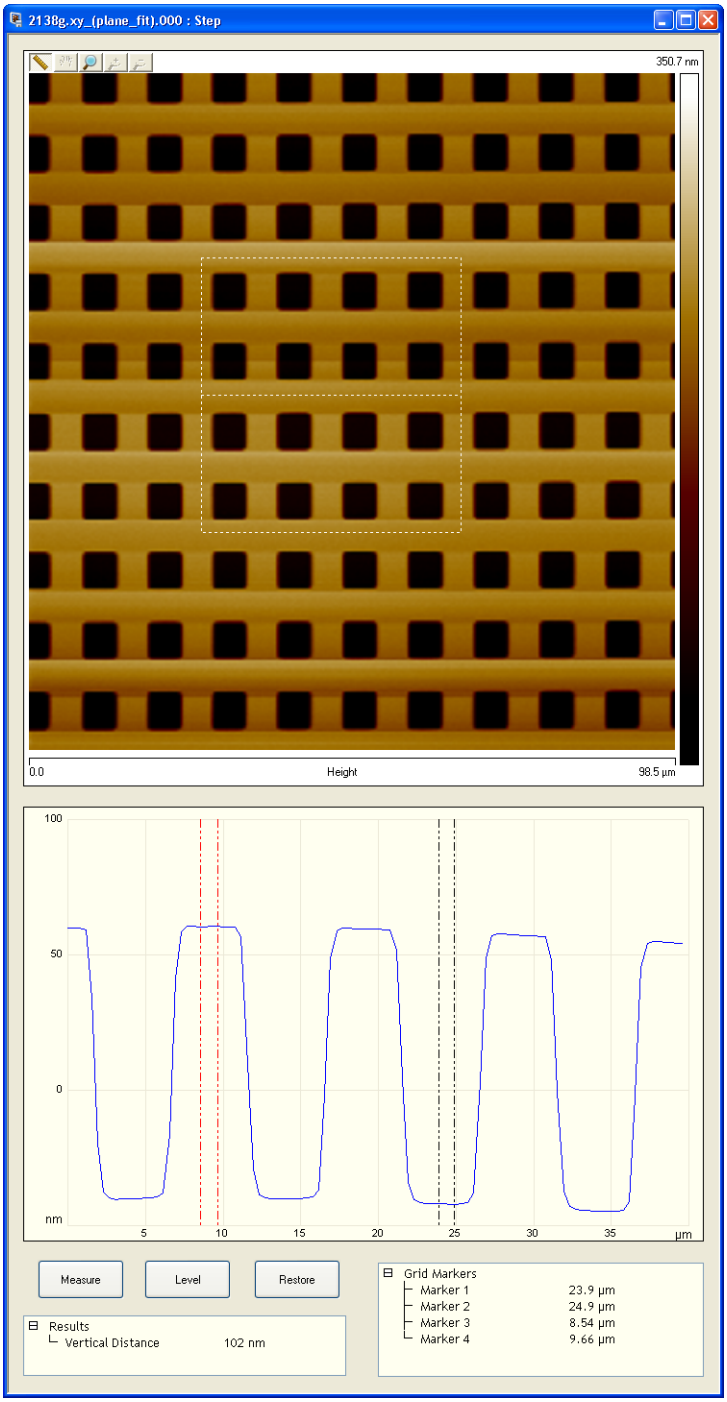
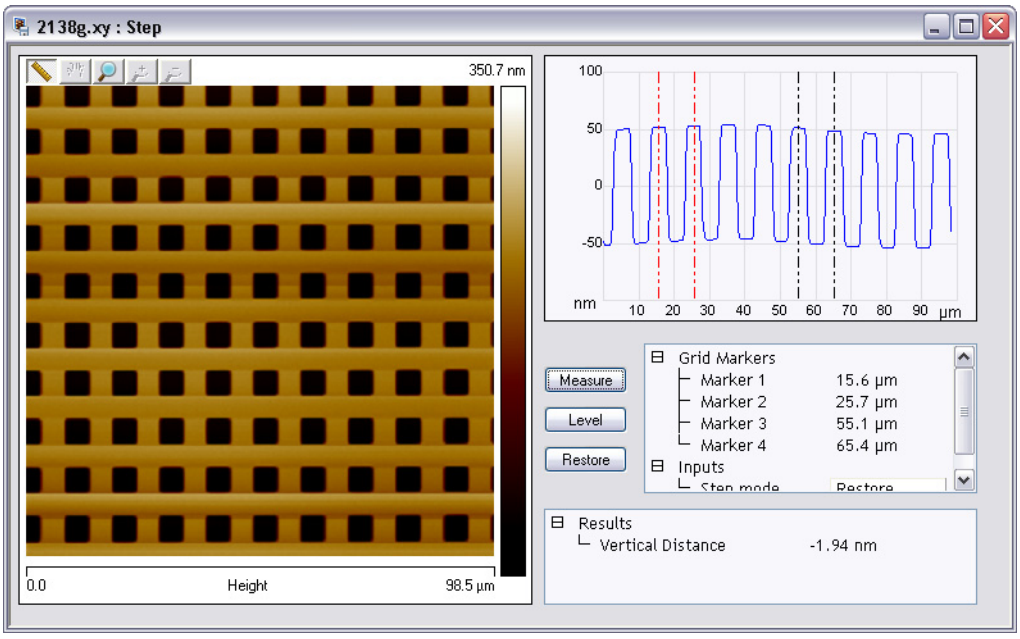


Figure 6.5c Step Interface—dual monitor

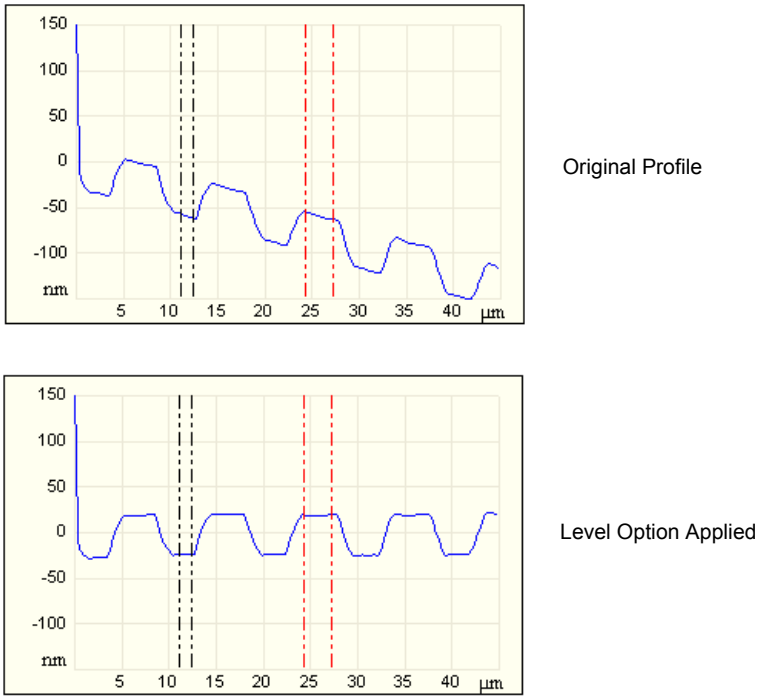


Step Display Menu Commands

Level

Reorients the profile so that the average height of each step region (between cursor pairs) is equal.

Figure 6.5d Level Option Profile



Measure

Displays the relative height between steps.

Restore

Returns the profile to its original, unleveled form. (Deselects the Level option.)

Results

Vertical Distance

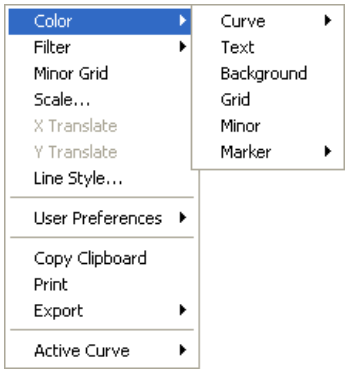
Displays the difference between the average height of each region (between cursor pairs). If the height of the region between the second pair of cursors is lower than the first's, this will be a negative value.

Using the Grid Display

Measurement cursors for the graph are automatically positioned based on the numerical values selected in the **Input** fields. Right-clicking on the grid will bring up the **Grid Parameters** menu (see Figure 6.5e) and allow you to make the following changes:

Color	Allows operator to change the color of the: • Curve (data) • Text • Background • Grid • Minor Grid • Markers See Figure 6.5e.
Filter	Typically used for a Profiler Scan. • Type—Select None, Mean (default), Maximum, or Minimum • Points—Select 4k, 8k (default), 16k, or 32k
Minor Grid	Places a minor grid in the background of the **Vision** window.
Scale	Allows user to auto scale, set a curve mean, or set their own data range
Line Style	For each curve, the operator can choose a connect, fill down, or point line.
User Preferences	Restore—Reverts to initial software settings Save—Saves all changes operator has made during this session. This becomes the new default settings.
Copy Clipboard	Copies the grid image to the Microsoft Clipboard
Print	Prints out the current screen view to a printer
Export	Exports data in bitmap, JPEG or XZ data format
Active Curve	Determines which curve you are analyzing

Figure 6.5e Grid Parameters Menu



6.6 Tip Qualification

Tip Qualification refers to estimating tip shape from appropriate characterizer samples and rating tips as good, worn, bad, suspect or no tip. A *characterizer* refers to a sample whose surface is well-suited to deducing tip condition when imaged using an SPM probe.

6.6.1 Overview

The **Tip Qualification** function incorporates the two separate capabilities of tip estimation and tip qualification. *Tip Estimation* generates a model of the tip based on an image of a *characterizer* and displays the model in the top-middle of the **Tip Qualification** window (see Figure 6.6f). *Tip Qualification* uses the estimate to determine whether the tip is acceptable for use.

- Check tips periodically for signs of wear. Exchange unacceptably worn tips.
- By using tip estimation and qualification to enforce tip acceptance criteria, metrological values can be compared from image to image, ensuring consistent, long-term comparability of samples.

Tip Estimation identifies a series of local peaks in the topographic image data and then successively analyzes each peak, refining a 3-dimensional tip model as it does so. At each peak, the slope away from the peak in all directions is measured, determining the *minimum* tip sharpness, as no data in the image can have a slope steeper than the slope of the tip. As this process is repeated for each local peak, any steeper slope than was found from all previously analyzed peaks causes the tip model to update to a new, sharper tip estimate.

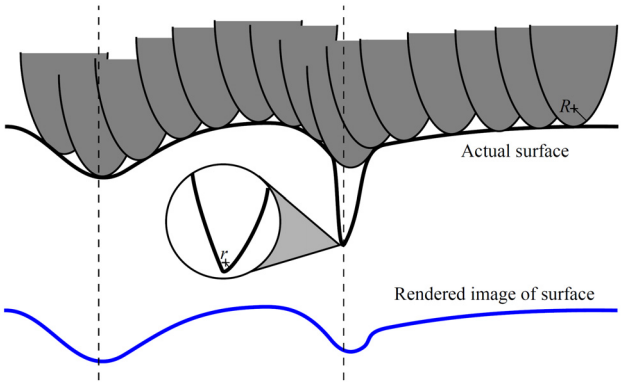
6.6.2 Probe/Sample Interactions and Tip Qualification

It is not useful to qualify a probe tip that is poorly matched to the sample to be imaged. Specifically, a tip cannot resolve the linear and angular aspects of any sample feature sharper than the tip itself. (However, even a blunt tip can resolve height accurately on a surface with shallow slopes.) Select a probe with a tip sharp enough to resolve the features of interest.

Tip Artifacts and Probe Selection

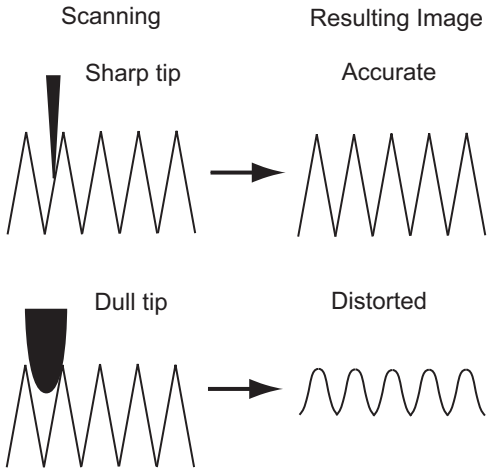
Atomic Force Microscope (AFM) images depend on the shape of the tip used to probe the sample. *Tip artifacts* refer to either the occurrence of features or the absence of features in an image that are not in the sample, but due to the tip used as compared (hypothetically) with an ideal tip of near-zero tip radius. In the simplest case, the finite size of the AFM tip does not allow it to probe narrow, deep fissures in a sample where the tip radius is greater than the radius of the recess (see Figure 6.6a).

Figure 6.6a A Tip Artifact: Failure to Image Trench Bottom Due to Excessive Tip Radius



Also, sharp sample features scanned with a dull tip are broadened in AFM images. Consequently, image measurements such as surface roughness and surface area depend on probe tip shape. An image generated with a sharp tip shows greater roughness and larger surface area than an image produced with a dull tip (see Figure 6.6b).

Figure 6.6b A Tip Artifact: Broadened Peaks Due to Excessive Tip Radius



The Estimated Tip Model is Characterizer-Dependent

The model generated by **TIP ESTIMATION** is not, in general, the actual shape of the tip. Because the tip model is constructed by analyzing the shapes of peaks in the image data, the accuracy of the model is limited by the sharpness of features on the characterizer. Only a surface with infinitely sharp features can produce an accurate model of the tip. Conversely, a surface having only large rounded features imparts its shape to the tip through Tip Estimation. Here are a few examples:

Figure 6.6c A Perfect Spike on the Characterizer Surface Yields a Perfect Tip Estimate

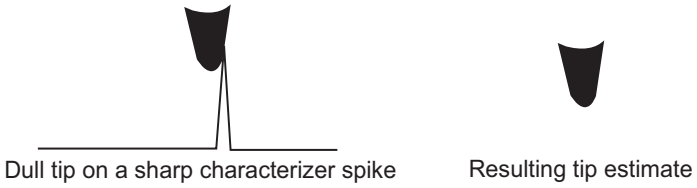
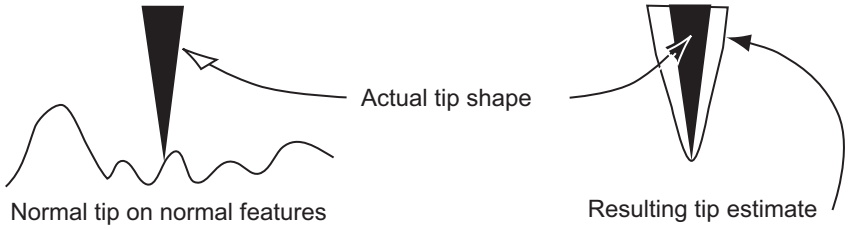


Figure 6.6d A Sample with No Sharp Features Yields a Dull Tip Estimate

Figure 6.6e Similar Characterizer Feature and Tip Size Yields a Combined Geometry Tip Estimate



Due to tip/sample interdependence, it is important to consider the effects of the characterizer features on the calculated tip model. Characterizer samples that provide the most accurate estimate of tip size and shape are those with many fine protrusions. Very flat characterizer samples provide the least useful estimate of tip shape.

Despite the dependence on characterizer characteristics, *Tip Estimation* and *Tip Qualification* can often provide a reliable method of tracking tip wear and ensuring that probes are changed when they become dull. For example, when making repeated measurements on suitable rough samples, *Tip Estimation* can provide very reproducible estimates of tip size and shape, which change in a predictable and consistent fashion as the tip wears.

To avoid tip artifacts, replace worn tips with sharper ones.

Based on thresholds set by the user, *Tip Qualification* software usually finds the tip status to be **GOOD**, **WORN**, or **BAD**. A tip status of **GOOD** indicates that the tip is still sufficiently sharp and that the image data should be acceptable. A tip status of **WORN** indicates that the tip is becoming dull and should be changed, but previous image data taken with this tip should still be acceptable. If a **BAD** status is returned, the tip should be changed and the current image data discarded. In cases where imaging errors are suspected, *Tip Qualification* may assign a status of **SUSPECT** or **NO TIP**.

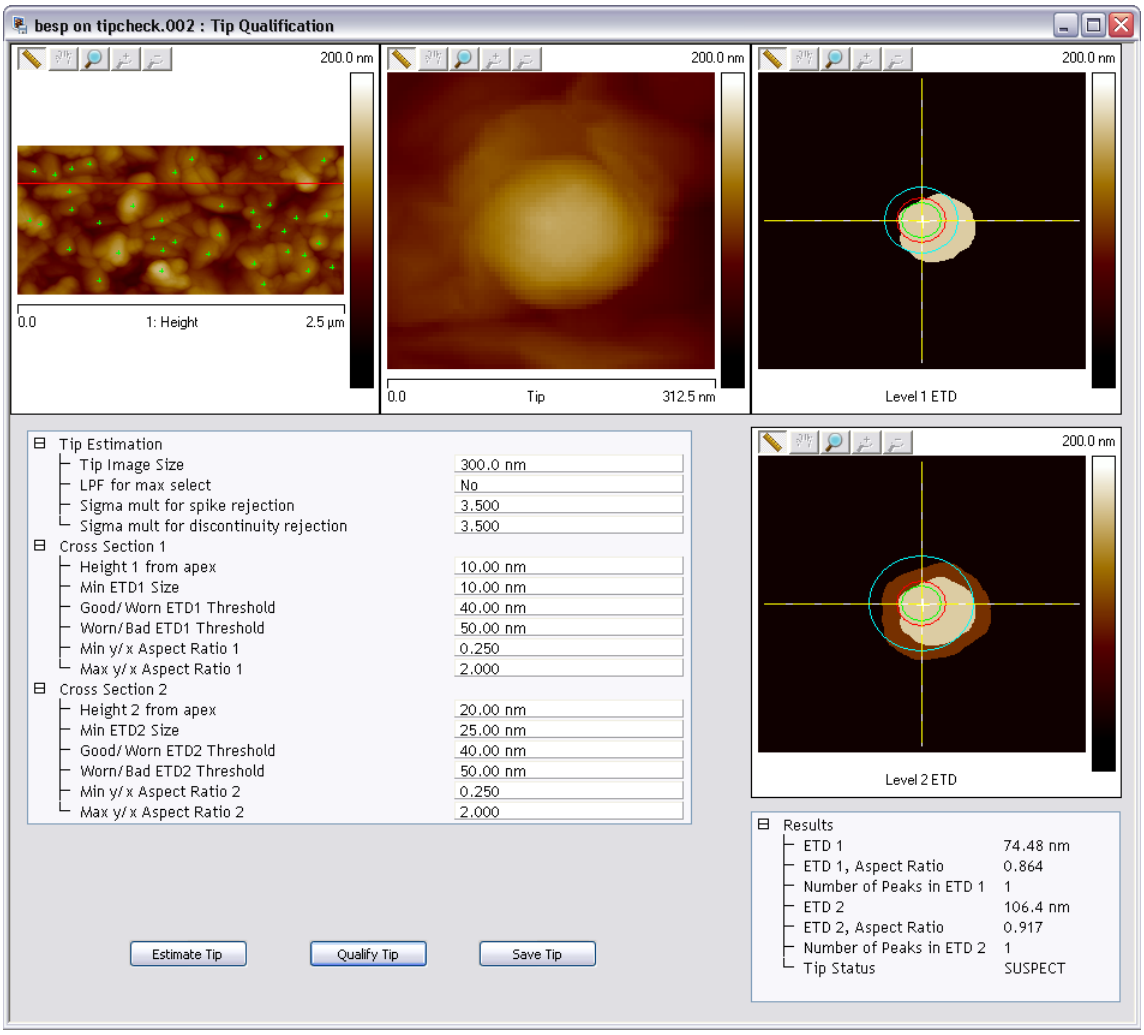
Characterizer Sample Selection

For the reasons cited in the last section, just as probe selection influences imaging results, characterizer sample selection influences probe tip characterization. An ideal characterizer sample for tip diagnosis has isolated extremely sharp peaks. Bruker provides a characterizer sample that is recommended for tip evaluation. The polycrystalline titanium roughness sample (part number RS, available at http://www.brukerafmprobes.com) has jagged features suitable for obtaining an accurate tip model.

6.6.3 Operating Principles of Tip Qualification

The result of running **Tip Qualification** is a display as exemplified in Figure 6.6f.

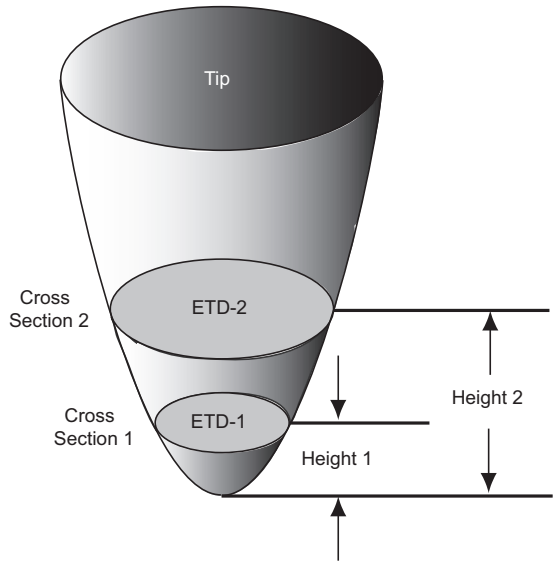
Figure 6.6f A Typical **Tip Qualification** Window



The top-left frame is the image analyzed to evaluate the tip. The top-middle frame, labeled **Tip**, is a top view image of the software model of the tip (looking into its apex).

Once a tip model has been generated, *Tip Estimation* extracts an estimate of the tip geometry in cross-sections at two different distances from the tip apex (see Figure 6.6g).

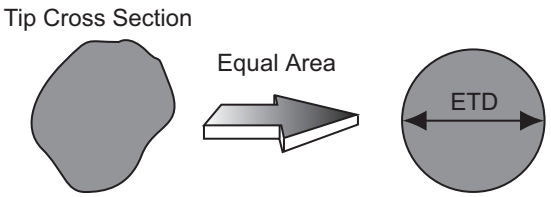
Figure 6.6g Estimated Tip Diameters at Two Heights from the Apex



The cross-section diagrams on the right in Figure 6.6f show the apparent size and shape of the tip at two different distances from its apex (labeled "**Level 1 ETD**" and "**Level 2 ETD**." In the level 1 cross-section, the roughly circular tip diameter is shown in light gray. In the lower-right frame of Figure 6.6f, the level 1 cross-section is shown again in light gray and the level 2 cross-section is shown darker. (The actual colors of the tip cross-sections depend on the color table selected.)

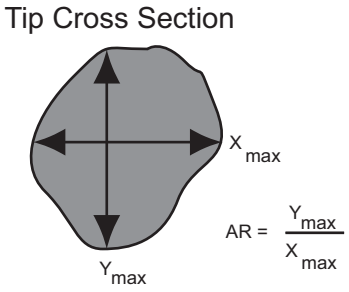
Tip Estimation then provides, at each cross section, two numerical measures of tip size and shape: effective tip diameter (ETD) and aspect ratio (AR). The *effective tip diameter* is defined as the diameter of a circle having the same area as the measured tip cross-section (see Figure 6.6h). The ETDs for both levels are shown in the frames on the right side of Figure 6.6f as **blue** circles.

Figure 6.6h An ETD Has the Same Area as the Cross Section It Represents



Aspect Ratio is defined as the ratio of the maximum vertical (Y) dimension to the maximum horizontal (X) dimension of a tip cross section (see Figure 6.6i).

Figure 6.6i Cross Section Aspect Ratio is Coordinate System Orientation-Dependent



Control of Tip Qualification Status

Tip Qualification generates a tip status based on the calculated values of ETD, AR and on threshold and limit values selected. There are two ETD thresholds that affect tip status:

- **Good/Worn ETD Threshold**—If the ETD is smaller than this number, the tip will usually be characterized as **GOOD**. The threshold diameters are shown as **green** circles in the ETD windows.

- **Worn/Bad ETD Threshold**—If the ETD is smaller than this threshold, but bigger than the **Good/Worn ETD Threshold**, it is characterized as **WORN**. If the ETD is larger than this number, it is characterized as **BAD**. These threshold diameters are shown as **red** circles in the **ETD** windows.

There are separate sets of ETD thresholds for the two tip levels (ETD 1 at **HEIGHT 1**, and ETD 2 at **HEIGHT 2**). There are also minimum and maximum limits for tip AR at each level. These limits detect when the image data produces a tip model of an oblong shape that is unlikely to accurately represent the tip. Usually an oblong tip model is induced by an imaging artifact, such as a noise streak not removed by discontinuity rejection. *The AR limits should not be adjusted.*

It takes some experimentation with a particular tip and characterizer sample type to find appropriate values for the various thresholds. The basic idea is to find the maximum ETDs (the diameters of the dullest tips) that provide reliable image data for your samples, then set the **Worn/Bad ETD Threshold**s based on these diameters. Then set the **Good/Worn ETD Threshold**s slightly smaller than the **Worn/Bad ETD Threshold**s.

An additional limit, **Min ETD Size**, is used to reject Tip Qualification results if the estimated tip is unreasonably small (indicating a tip that is sharper than physically likely). This is usually induced by imaging artifacts, such as noise spikes not removed by spike rejection. In most cases, **Min ETD Size** can be set at or near the same value as the height from the tip apex for both cross sections. So, if **Height 1** = `10NM`, a reasonable value for the **Min ETD Size** is also `10NM`.

> **Note:** A tip estimate rejected in this way returns **Tip Status** of `SUSPECT`.

Since the tip estimate is valid only where the tip contacts the characterizer sample, cross section heights should be selected to ensure that the tip makes “frequent” contact with the characterizer sample at those heights. Thus, the cross section heights should be below the sample peak-to-valley values. If the cross section heights are too high for the characterizer sample, the resultant ETD will tend to be very large and multiple apparent peaks will be found at that height.

6.6.4 Tip Qualification Procedures

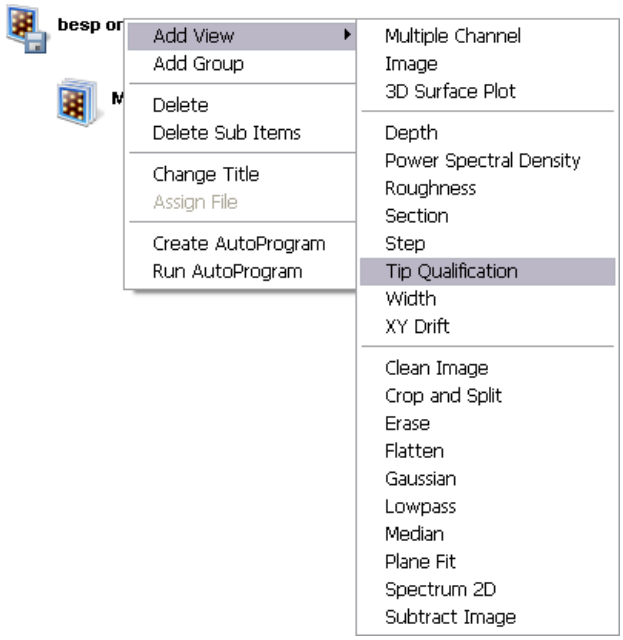
1. Scan (contact mode) the characterizer sample. Set the scan size to approximately 2.5µm. Characterizer image size is important because, along with **Tip Image Size** (see Tip Estimation Panel Parameters on page 297) and feature density, it determines how many peaks are used for the tip estimation (see Tip Qualification Buttons on page 296). To accurately estimate the tip shape, there must be many peaks (greater than 10 is good).

2. Select an image file of the characterizer sample from the file browsing window at the right of the main window. Double click the thumbnail image to select and open the image.

3. You can open the **Tip Qualification** view, shown in Figure 6.6k, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Tip Qualification** from the popup menu. See Figure 6.6j.

Figure 6.6j Select **TIP QUALIFICATION** from the workspace



Or

- Right-click on a thumbnail in the Multiple Channel window and select **TIP QUALIFICATION**.

Or

- Select **ANALYSIS** > **TIP QUALIFICATION** from the menu bar.

Or

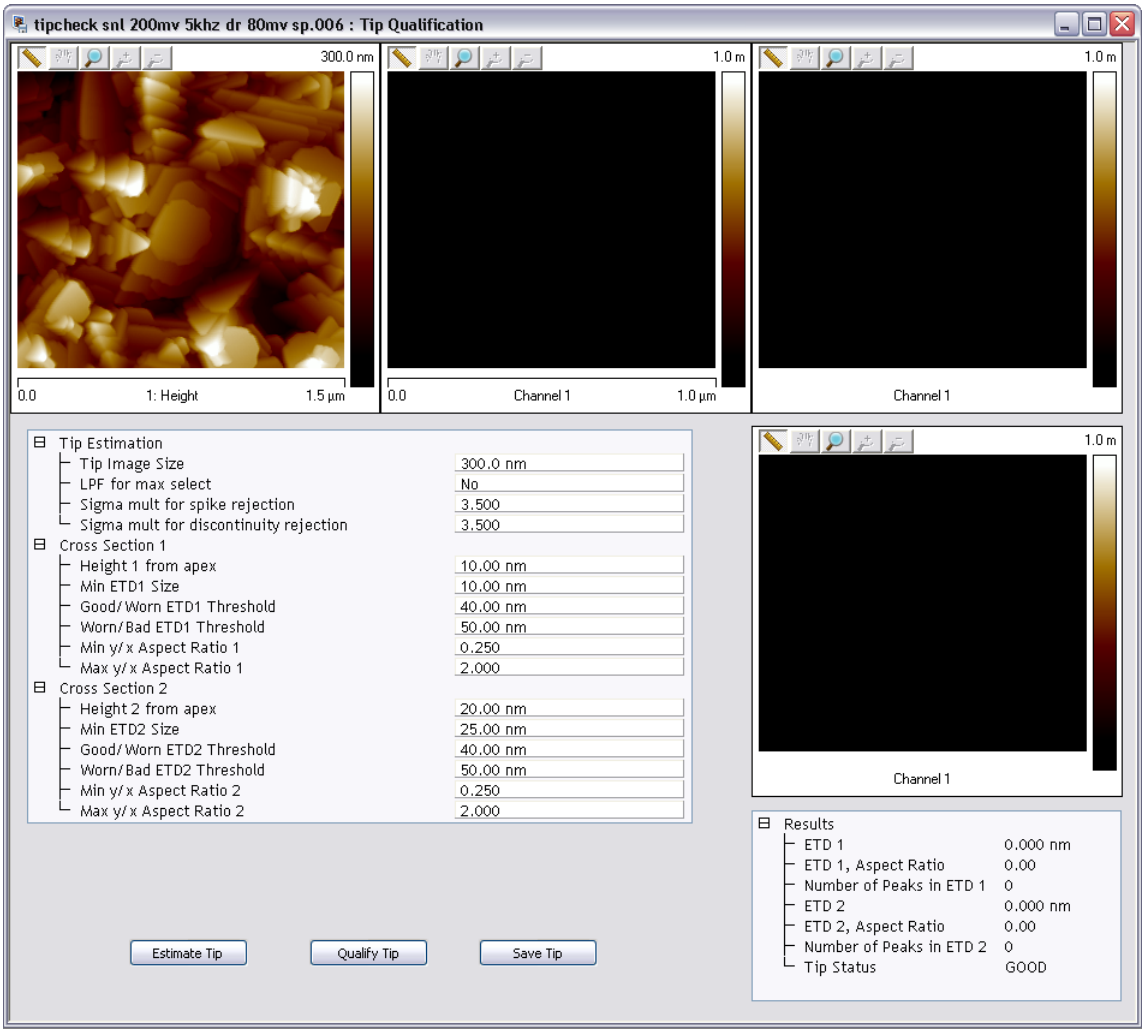
4. Click the **Tip Qualification** icon in the NanoScope toolbar.

5. The **Tip Qualification View** appears.

6.6.5 Tip Qualification Interface

The initial **Tip Qualification** interface is shown in Figure 6.6k.

Figure 6.6k The Tip Qualification Window before Calculations



Tip Qualification Buttons

ESTIMATE TIP—Performs a new tip assessment. A bottom-to-top, plan view rendering of the tip, labeled **Tip**, is shown in the middle-top image. The original image appears in the upper-left corner of the screen, with green markers (+) indicating the data peaks used for the estimation. If the **SAVE TIP** button is selected, the estimated tip image is saved to a file. This image can be loaded and analyzed in the same ways as other NanoScope images.

QUALIFY TIP—Results in:

1. If any "Tip Estimation" parameter or the analysis region has been changed, a new tip estimation is performed.

2. The tip cross sections and qualification results appear in the **Results** panel.

3. Tip status is determined based on the estimated tip shape.

SAVE TIP—Stores the estimated tip image as a NanoScope image file, allowing it to be analyzed using the standard NanoScope **MODIFY** and **ANALYZE** functions. A tip image is approximately the size specified by the **Tip Image Size** parameter and thus has fewer data points than a standard image.

Tip Estimation Panel Parameters

Tip Image Size—Sets the size of the image displayed in the upper-left corner of the **Tip Qualification** window. Calculated tip diameters are not expected to exceed **Tip Image Size**. For example, **Tip Image Size** = `120 nm` will result in a tip image approximately 120nm square. A reported ETD is the smallest odd integer multiple of the sample data resolution that is greater than or equal to the calculated tip diameter.

Tip Image Size also defines in a characterizer image the neighborhood size used to select the topographic maxima points used for Tip Estimation. For example, for **Tip Image Size** = `120 nm`, each selected maximum pixel is the tallest point topographically within an approximately 120nm square centered on the point. Therefore, a larger **Tip Image Size** may result in fewer selected maxima. More points provide more tip information, so select **Tip Image Size** to be as small as possible while also satisfying two other conditions:

1. **Tip Image Size** should exceed the ETD at as tall a height above the tip apex as is contacted imaging the characterizer sample. Determine this experimentally by varying **Tip Image Size** and observing the resultant top-middle image in the **Tip Qualification** window.

   Note: A good starting point for **Tip Image Size** is the sum of the maximum allowable tip diameter plus the diameter of a typical feature in the characterizer.

2. If and when "double tip" peaks appear in the image due to tip wear, their apexes should be no farther apart than one-half **Tip Image Size**. This ensures that multiple peaks from a "double tip" feature are not treated as separate features from the same peak (which would produce erroneous results and no longer guarantee an outside tip envelope).

   Note: Characterize image size and feature density also affect the number of selected maxima.

LPF (Low Pass Filter) **for max select**—Determines whether a lowpass filter is applied to the data before identifying selected points. The filtered data is only used for point selection, not for the actual tip calculation. This filter has the effect of reducing noise sensitivity. It is recommended that the filter be turned on (**YES**).

Sigma mult[iplier] **for spike rejection**—Sets a threshold for rejection of isolated upwards-oriented noise spikes. At each point (x,y) in an image, a difference Δ(x,y) is calculated between the pixel value at that point and the average value of the surrounding eight pixels. The average, μ, and standard deviation, σ, of all positive Δ(x,y)s in the image are then calculated. The normal (Gaussian) distribution with average value, μ, and standard deviation, σ, is then used to represent the actual distribution of positive Δ(x,y) values. If the value of **Sigma mult for spike rejection** is M, then points (x,y) whose Δ(x,y) value differs from μ by more than M*σ are rejected as local maxima in **TIP ESTIMATION**. The algorithm rejects as noise any unusually large pixel values as compared to the neighboring pixels. Because most pixel values are close to the average value of their neighbors, the Δ(x,y) distribution is skewed toward zero.

If **Sigma mult for spike rejection** = **0**, noise spike rejection is not performed. If the parameter value is > **0**, noise spike rejection is performed.

Sigma mult[iplier] **for Discontinuity Rejection**—Similar to **Sigma mult for spike rejection** (above), this parameter sets a threshold for rejection of entire rows of data where a discontinuity is detected, such as when the tip "trips" over a feature. If **Sigma mult for discontinuity rejection** = **0**, discontinuity rejection is not performed. If the parameter is > **0**, discontinuity rejection is performed as follows: for each row y, the average absolute value δ_y of the differences between each point and its immediate neighbor on the next line is calculated. The average μ and standard deviation σ of all such average differences δ_y is computed. Rows are rejected for a discontinuity where δ_y meets the following criterion:

$$\delta_y > \mu + M*\sigma$$

where M is **Sigma mult for discontinuity rejection**.

Points which fall within a **Tip Image Size** neighborhood centered on a discontinuity row are disqualified from contributing to **Tip Estimation**. Discontinuity rows are displayed as red horizontal lines on the image display.

> **Note:** **Tip Qualification** returns **SUSPECT** status when discontinuities are detected.

Tip Qualification Panel Parameters

Tips are cross-sectionally analyzed at two separate heights above the apex to determine tip status. These heights correspond to **Cross Section 1** and **Cross Section 2** (see Figure 6.6g). Parameters are appended with either a "1" or a "2," depending on which cross section they describe (e.g., **Height 1** and **Height 2**, respectively).

> **Note:** If cross-sectional analysis is desired at only one height, set **Height 1** to **0.00 NM**, and set **Height 2** to the desired value.

Height 1 [**Height 2**] (**From Apex**)—Distance from the tip apex at which the cross section is defined.

Min ETD1 [**ETD2**] **Size**—Minimum credible ETD at **Cross Section 1** [**2**]. If the calculated ETD is smaller than **Min ETD Size**, then **Tip Status** = **SUSPECT**.

Good/Worn ETD1 [**ETD2**] **Threshold**—Maximum ETD1 [ETD2] assigned **Tip Status** = **GOOD** (assuming that no other conditions such as an unacceptable aspect ratio or the presence of discontinuities result in a **SUSPECT Tip Status**).

Worn/Bad ETD1 [**ETD2**] **Threshold**—Maximum ETD1 [ETD2] assigned **Tip Status** = **WORN**. If ETD1 [ETD2] is greater than **Worn/Bad ETD1** [**ETD2**] **Threshold** then **Tip Status** = **BAD**.

Min y/x Aspect Ratio 1 [**Ratio 2**]—Maximum AR1 [AR2] assigned **Tip Status** = **SUSPECT** if ETD1 [ETD2] is less than **Worn/Bad ETD1** [**ETD2**] **Threshold**.

Max y/x Aspect Ratio 1 [**Ratio 2**]—Minimum AR1 [AR2] signed **Tip Status** = **SUSPECT** if ETD1 [ETD2] is less than **Worn/Bad ETD1** [**ETD2**] **Threshold**.

Tip Status is evaluated in the following order:

1. **SUSPECT**—Tips will be qualified as **SUSPECT** under any of the following conditions:

    - A discontinuity exceeding the **Sigma mult for discontinuity rejection** has been found in the data.

    - One of the aspect ratios of the tip is outside the range (**Min y/x Aspect Ratio**, **Max y/x Aspect Ratio**).

    - ETD1 or ETD2 is smaller than its **Min ETD1** [**ETD2**] **Size**.

2. **GOOD**—Both ETDs are less than the **Good/Worn ETD Threshold** parameter setting.

3. **BAD**—At least one of the ETDs is greater than its **Worn/Bad ETD Threshold** or one of the cross-sections intersects a large portion of the tip image boundary.

4. **WORN**—At least one of the ETDs falls between its **Good/Worn ETD Threshold** and **Worn/Bad ETD Threshold**.

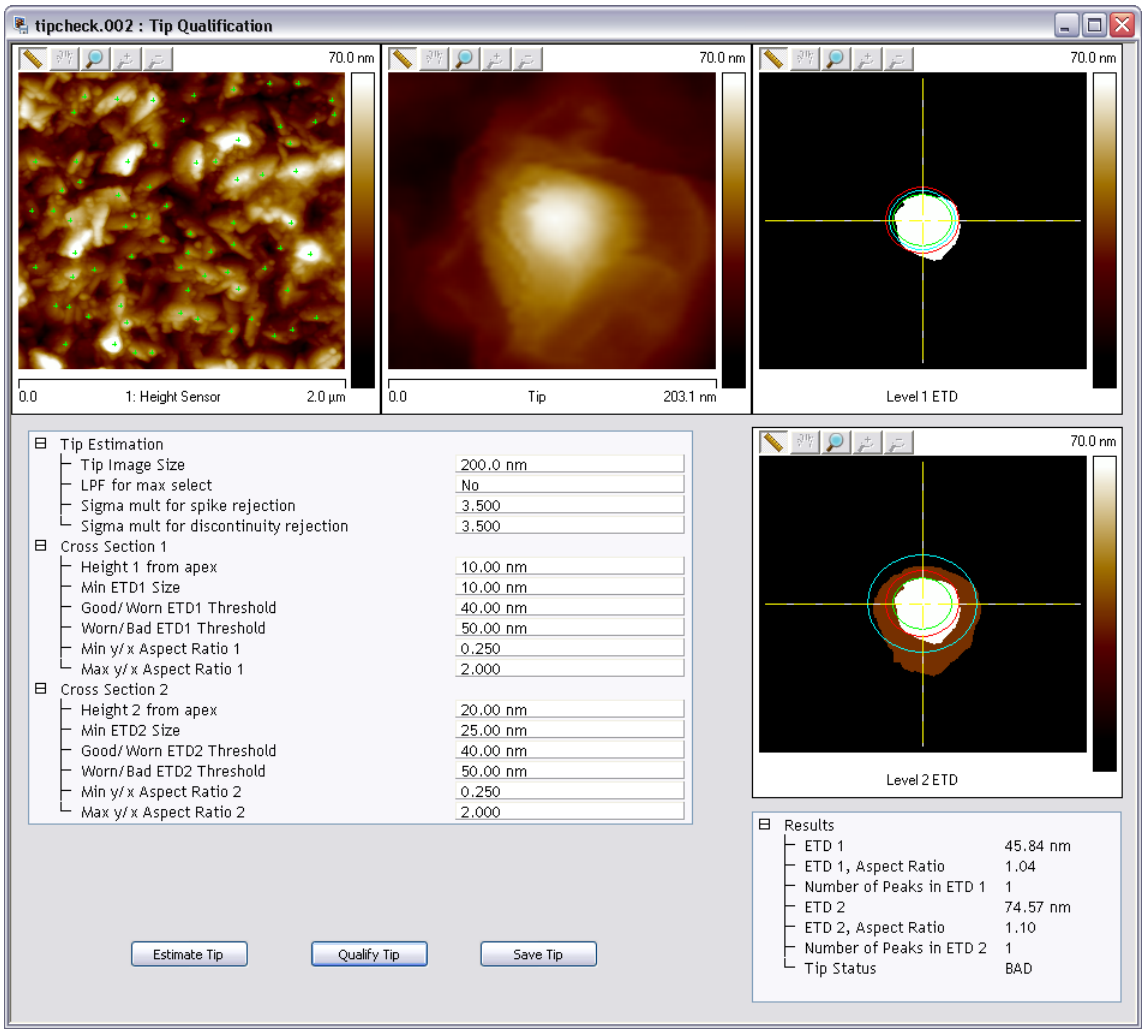
6.6.6 Running Tip Qualification

The essential procedure for performing tip qualification is as follows:

1. Load an image file (preferably of a characterizer sample).
2. Click the **Tip Qualification** icon in the NanoScope toolbar to open the T**ip Qualification** window.
3. Enter the **Tip Image Size** desired for the currently loaded tip and characterization image.
4. Select whether to apply a low pass filter to the image by selecting either **YES** or **NO** for parameter **LPF for max select**.

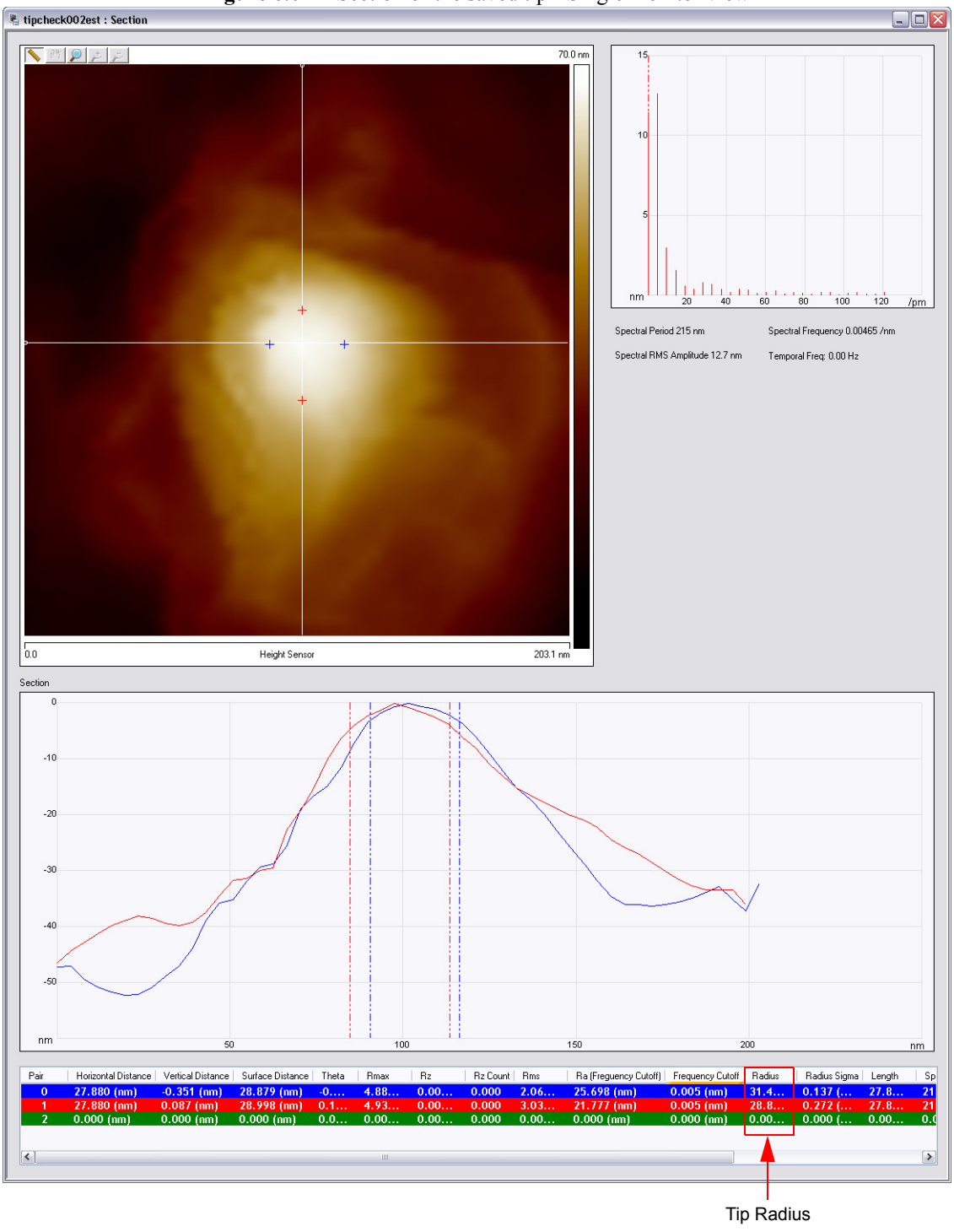
   Note: It is generally a good idea to use a low pass filter to ensure that small noise artifacts are removed before Tip Estimation. Noise mistaken for an imaged feature renders a misleading tip model. Additionally, large noise artifacts can be selectively removed by adjusting **Sigma mult for spike rejection** and **Sigma mult for discontinuity rejection**.
5. Enter values for all parameters in the **Cross Section** panels.
6. Click **ESTIMATE TIP**.
7. Click **QUALIFY TIP**.
8. View the **Tip Status** in the **Results** panel, shown in Figure 6.6l.

Figure 6.6l Tip Qualification Results



9. If the end radius of the tip is required, click **SAVE TIP** and then open the saved file. Click the **SECTION** icon to open the file and draw a cursor through the tip center, shown in Figure 6.6m. The radius of a circle fitted to the data between the cursors is displayed in the bottom of the **Section** window. See **Section:** Section 6.4 for more information.

Figure 6.6m Section of the saved tip - Single monitor view



6.7 Width

To analyze the width of features you have numerous choices which measure the height difference between two dominant features that occur at distinct heights. **Width** was primarily designed for automatically *comparing* feature widths at two similar sample sites (e.g., when analyzing etch depths on large numbers of identical silicon wafers).

The **Width** command is designed to automatically measure width between features distinguished by height, such as trenches and raised features.

The **Width** command is best applied when comparing similar features on similar sites. Width measurement on dissimilar sites is better performed using the **Section** command.

Refer to the following sections on **Width** analysis:

- **Width Theory:** Section 6.7.1
- **Width Procedures:** Section 6.7.2
- **Width Interface:** Section 6.7.3

6.7.1 Width Theory

The **Width** algorithm utilizes many of the same functions found in **Depth** analysis by accumulating height data within a specified area, applying a Gaussian low-pass filter to the data (to remove noise), then rapidly obtaining height comparisons between two dominant features. For example, 1) the depth of a single feature and its surroundings; or, 2) depth differences between two or more dominant features. Although this method of width measurement does not substitute for direct, cross-sectioning of the sample, it does afford a means for comparing feature widths between two or more similar sites in a consistent, statistical manner.

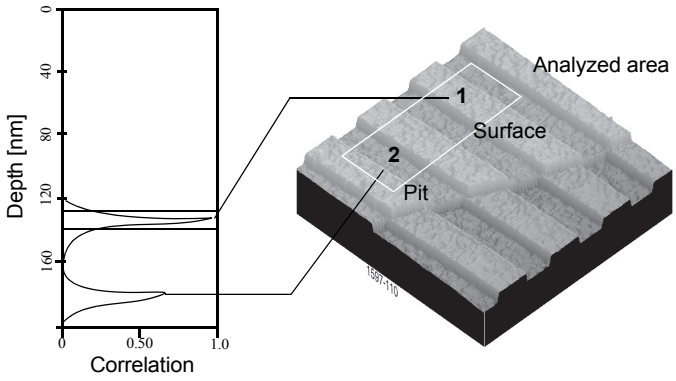
The **Width** window includes a top view image and a histogram; depth data is displayed in the results window and in the histogram. The mouse is used to resize and position the box cursor over the area to be analyzed. The histogram displays both the raw and an overlaid, Gaussian-filtered version of the data, distributed proportionally to its occurrence within the defined bounding box.

Histogram

Raw Data

Histograms for depth data are presented on the bottom of the **Width** window. The histogram peaks correspond to the distribution of depths of analyzed regions of the image (see Figure 6.7a).

Figure 6.7a Depth Histogram Analysis



Note: Color of cursor, data, and grid may change if user has changed the settings. Right-click on the graph and go to **Color** if you want to change the default settings.

Correlation Curve

The **Correlation Curve** is a filtered version of the **Raw Data Histogram** and is represented by a red line on the **Depth Histogram**. Filtering is done using the **Histogram filter cutoff** parameter in the **Inputs** parameter box.The larger the filter cutoff, the more data is filtered into a Gaussian (bell-shaped) curve. Large filter cutoffs average so much of the data curve that peaks corresponding to specific features are unrecognizable. On the other hand, if the filter cutoff is too small, the filtered curve may appear noisy.

The **Correlation Curve** portion of the histogram presents a lowpass, Gaussian-filtered version of the raw data. The low-pass Gaussian filter removes noise from the data curve and averages the curve's profile. Peaks which are visible in the curve correspond to features in the image at differing widths.

Peaks do not show on the correlation curve as discrete, isolated spikes; instead, peaks are contiguous with lower and higher regions of the sample, and with other peaks. This reflects the reality that features do not all start and end at discrete depths.

When using the **Width View** for analysis, each peak on the filtered histogram is measured from its statistical centroid (i.e., its statistical center of mass).

6.7.2 Width Procedures

Brief instructions can be found in the **Width Analysis Guidelines** window below the **Inputs** window.

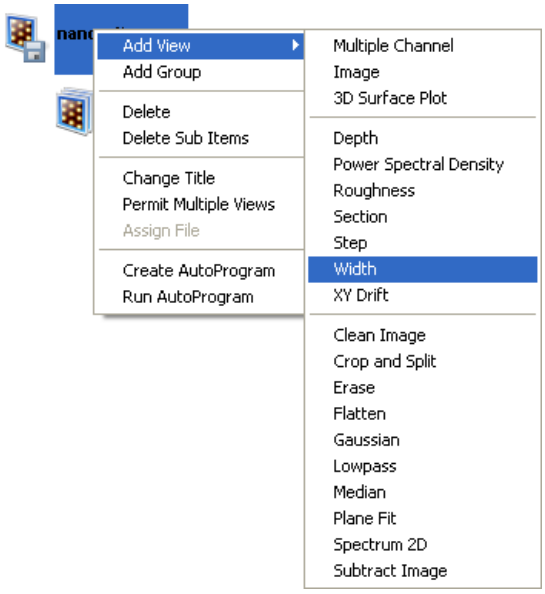
Note: The maximum recommended input file size is 512 lines by 512 samples/line.

1. Select an image file from the file browsing window at the right of the main window. Double click the thumbnail image to select and open the image.

2. You can open the **Width** view, shown in Figure 6.7c, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Width** from the popup menu. See Figure 6.7b.

Figure 6.7b Select **WIDTH** from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **WIDTH**.

Or

   - Select **ANALYSIS** > **WIDTH** from the menu bar.

Or

3. Click the **Width** icon in the NanoScope toolbar.

4. The **Width View** appears showing results for the entire image.

6.7.3 Width Interface

The **Width** interface includes a captured image, **Input** parameters and Grid Markers display, **Results** table, **Guidelines** and a **Depth Histogram** with grid markers, shown in Figure 6.7d.

1. Using the mouse, left-click and drag a box on the area of the image to analyze. The Histogram displays the depth correlation on this specified area.

   Note: If no box is drawn, by default, the entire image is selected.

2. Adjust the **Minimum Peak to Peak** to exclude non relevant depths.

3. Adjust the **Histogram Filter Cutoff** parameter to filter noise in the histogram as desired.

4. Adjust the threshold cursor along the histogram to set the level of the cutoff plane. The features above or below (depending on **Feature Direction**) this plane are a single shade in the selected area.

5. Right-click on the image in a region outside the box and click **Select Feature**.

6. Click on various regions inside of the box. Statistics in the table will be generated for each distinct (as defined by the **Input** parameters) feature.

   Note: “Distinct” features are displayed in blue.

   Note: To save or print the data, either copy, by right-clicking on the results table, and paste the text and export the Graphic or XZ Data or run the analysis in an **Auto Program** (see Chapter 8).

Figure 6.7c Width Interface

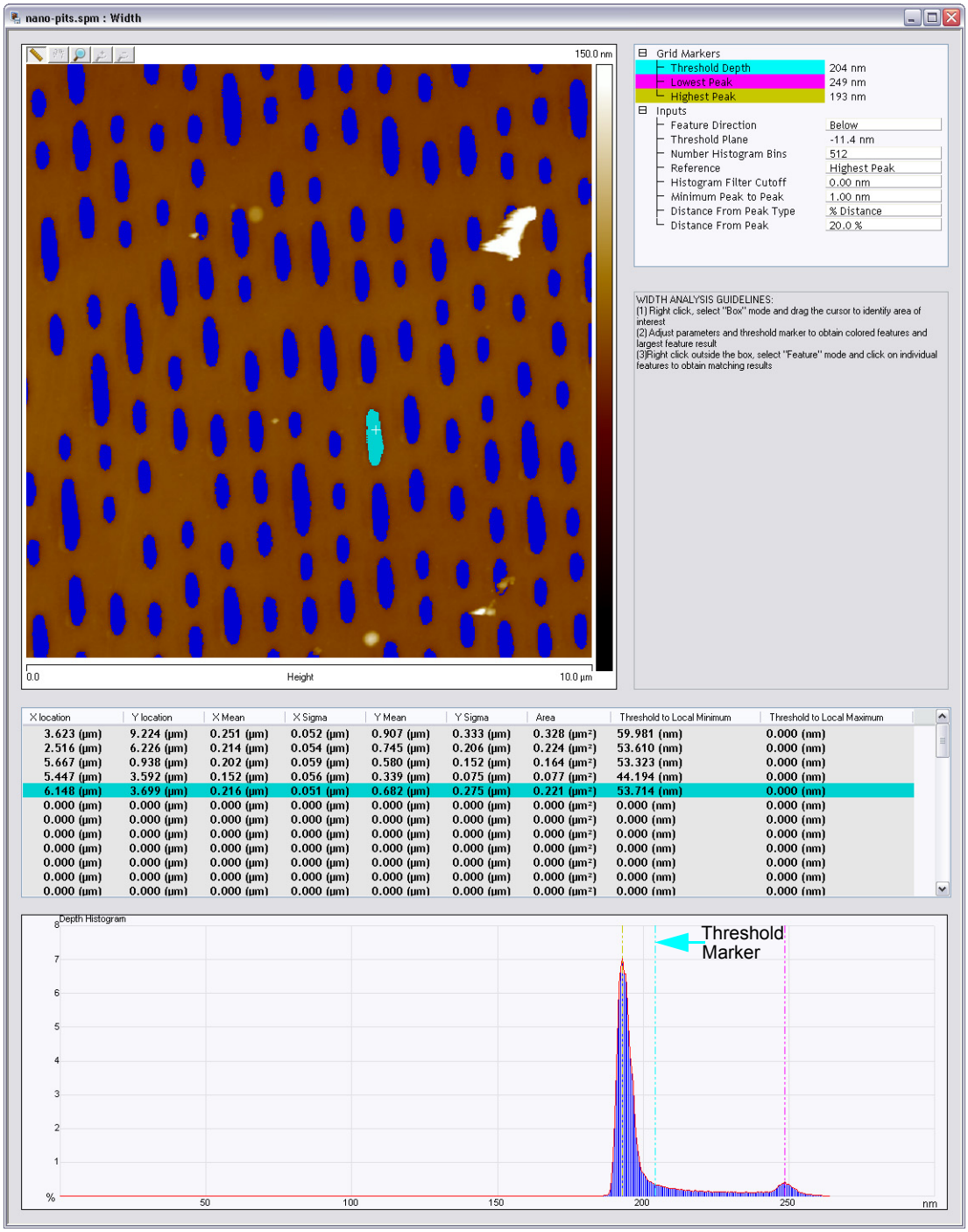
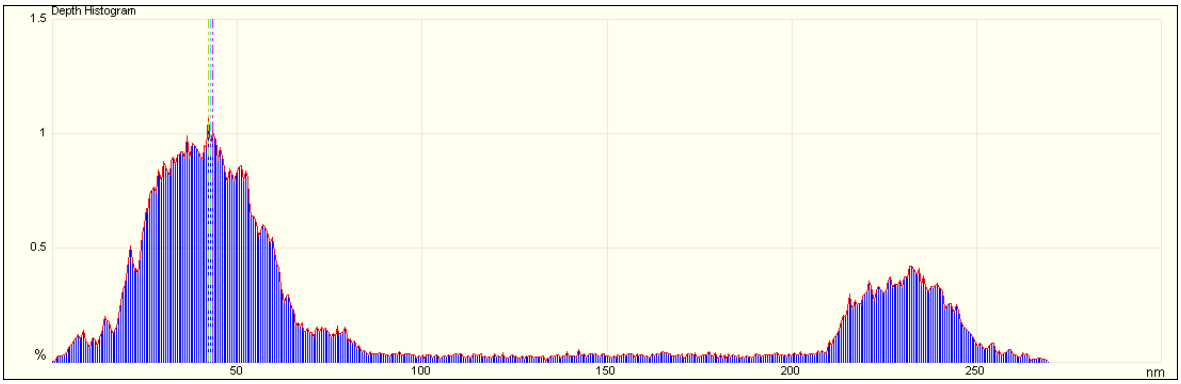


Figure 6.7d Depth Histogram



Width Input Parameters

The depth input parameters below define the slider cursor placement for determining the exact depth of a feature.

Feature Direction	Select above or below to indicate if features above or below the reference plane are to be analyzed.
Threshold Plane	The z height which is used as a minimum for the higher peak. This can be adjusted by moving the cyan Threshold Depth cursor in the depth histogram.
Number of Histogram Bins	The number of data points, ranging from 4 to 512, which result from the filtering calculation.
Reference	You may specify a reference point for the cursor. This feature is useful for repeated, identical measurements on similar samples. After moving the cursor to a specific point on the correlation histogram, that point is saved as a distance from whatever reference peak you choose. These reference peaks include: **HIGHEST PEAK**, **LOWEST PEAK**.
Histogram Filter Cutoff	Lowpass filter which smooths out the data by removing wavelength components below the cutoff. Use to reduce noise in the Correlation histogram.
Minimum Peak To Peak	Sets the minimum distance between the maximum peak and the second peak marked by a cursor. The second peak is the next largest peak to meet this distance criteria.
Distance From Peak	**% DISTANCE, ABSOLUTE DISTANCE**
Distance From Peak	Cursor distance from the **REFERENCE** peak

Grid Markers

Three user-adjustable markers are placed on the depth histogram:

Threshold Depth	Cyan. Distance from peak and distance from peak type.
Lowest Peak	Magenta. The right (larger in depth value) of the two peaks marked by the cursors.
Highest Peak	Gold. The left (smaller in depth value) of the two peaks chosen by the cursors. You can adjust min and max peaks by adjusting the **MINIMUM PEAK TO PEAK**.

Results Parameters:

X location	X location
Y location	Y location
X mean	The average of the highlighted X values within the enclosed area.
X sigma	The standard deviation of the measured X values.
Y mean	The average of the highlighted Y values within the enclosed area.
Y sigma	The standard deviation of the measured Y values.
Area	The area below the threshold in the selected region.
Threshold to Local Minimum	The distance from the **Threshold Plane** to a local minimum.
Threshold to Local Maximum	The distance from the **Threshold Plane** to a local maximum.

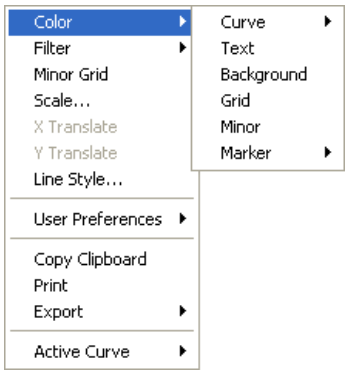
Using the Grid Display

Measurement cursors for the histogram are automatically positioned based on the numerical values selected in the **Input** fields. Right-clicking on the grid will bring up the **Grid Parameters** menu (see Figure 6.7e) and allow you to make the following changes:

Color	Allows operator to change the color of the: • Curve (data) • Text • Background • Grid • Minor Grid • Markers

Filter	Typically used for a Profiler Scan. • Type—Select None, Mean (default), Maximum, or Minimum • Points—Select 4k, 8k (default), 16k, or 32k
Minor Grid	Places a minor grid in the background of the **Vision** window.
Scale	Allows user to auto scale, set a curve mean, or set their own data range
Line Style	For each curve, the operator can choose a connect, fill down, or point line.
User Preferences	Restore—Reverts to initial software settings Save—Saves all changes operator has made during this session. This becomes the new default settings.
Copy Clipboard	Copies the grid image to the Microsoft Clipboard
Print	Prints out the current screen view to a printer
Export	Exports data in bitmap, JPEG or XZ data format
Active Curve	Determines which curve you are analyzing

Figure 6.7e Grid Parameters Menu



6.8 XY Drift

Due to temperature differences, thermal lateral drift can occur between two successive images while scanning. Using Offline **XY Drift** analysis, NanoScope software can calculate the lateral shift between two images. You can also manually enter the drift.

6.8.1 Offline XY Drift Analysis

Requirements

Two images captured within 1 day of each other are required. The capture and trace directions must be the same for both images (up/down, trace/retrace), and the images must have the same microscope configuration and scanner calibration properties.

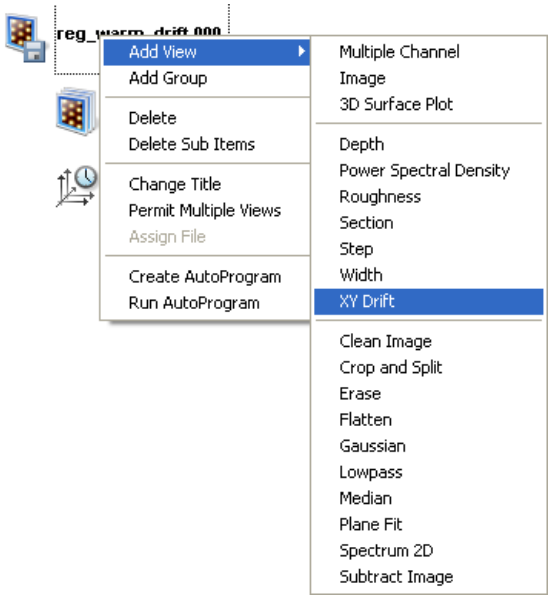
Procedure

To calculate XY Drift using NanoScope software:

1. Start with an earlier image and use *one* of the following methods to open the **XY Drift Analysis** view (see Figure 6.8b). Select an image file from the file browsing window at the right of the main window. Double click the thumbnail image to select and open the image.

   - Right-click on the image name in the **Workspace** and select **Add View** > **XY Drift** from the popup menu. See Figure 6.8a.

Figure 6.8a Select **XY DRIFT** from the workspace



Or

- Right-click on a thumbnail in the Multiple Channel window and select **XY DRIFT**.

Or

- Select **ANALYSIS** > **XY DRIFT** from the menu bar.

Or

2. Click the **XY Drift** icon in the NanoScope toolbar.
3. The **XY Drift View**, shown in Figure 6.8b and Figure 6.8c, appears showing one image.

XY drift corrections calculated from other than the two most recently captured images may not reflect current environmental conditions.

Figure 6.8b XY Drift Interface—single monitor

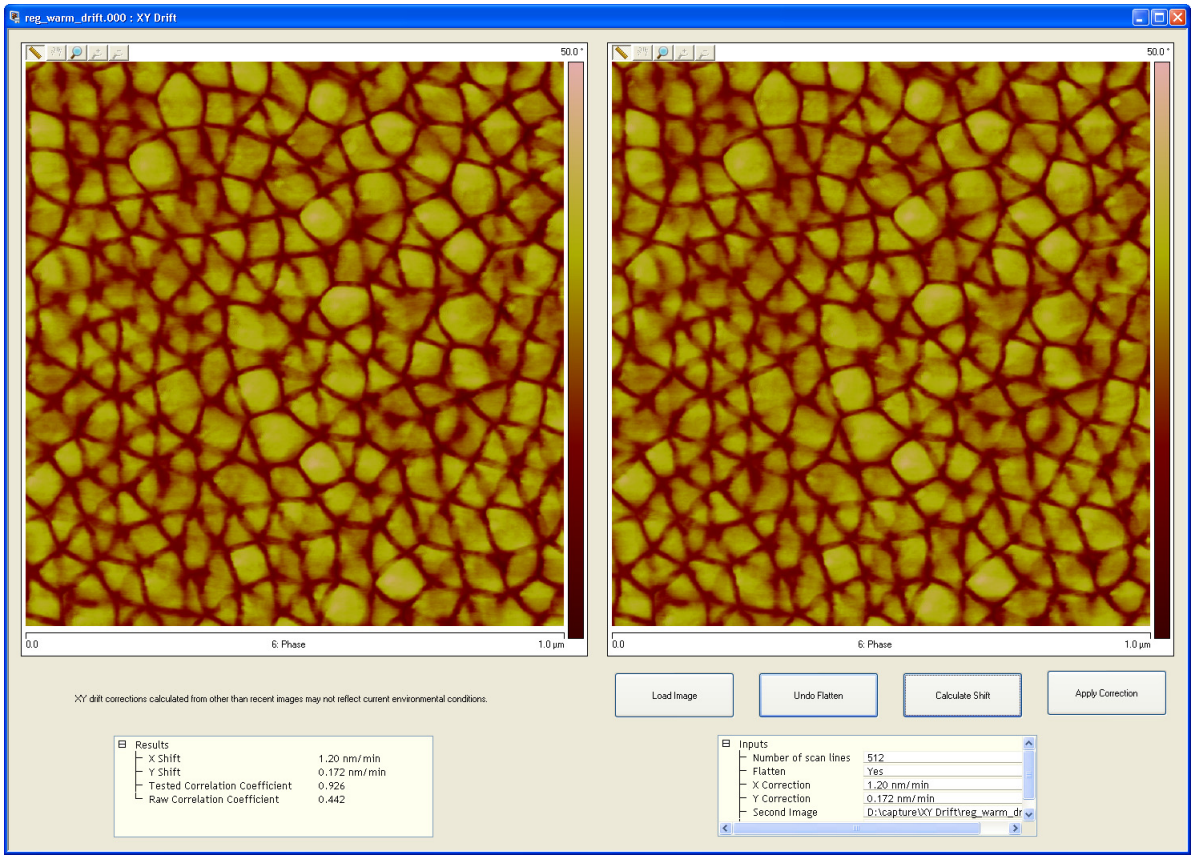
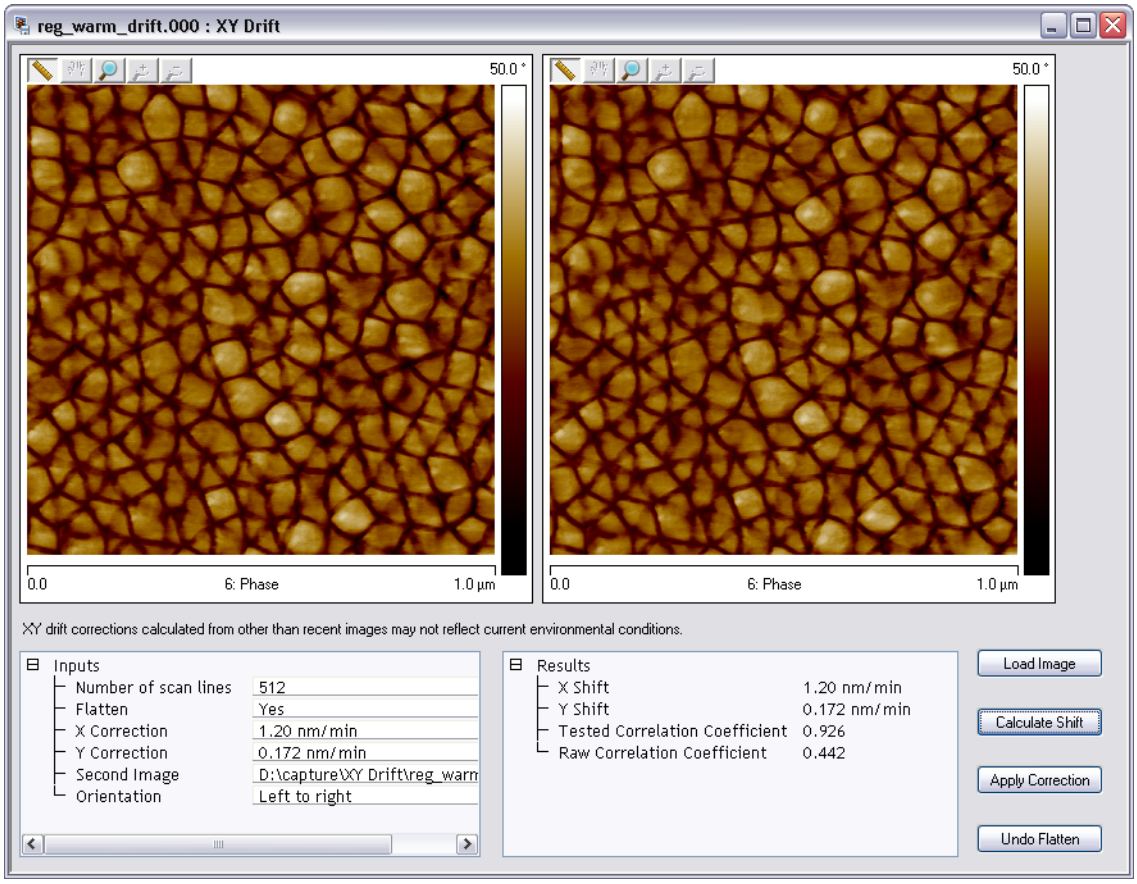


Figure 6.8c XY Drift Interface—dual monitor



4. Use the **Load Image** button to browse for the subsequent image.

5. Click the **Calculate Shift** button. The software will calculate the shift of the second image relative to the first image.

6. The results display in the **Results** panel.

    a. To apply the corrections in the **Inputs** box, click the **Apply Correction** button.

    Or

    b. You can also manually enter the correction values in the **Inputs** box. Click the **Apply Correction** button.

Input Parameters

Statistics used by the **XY Drift** analysis are defined in this section.

Number of scan lines	Specifies the number of lines to calculate.
Flatten	Flattens both images before the shift is calculated. (Use the **Undo Flatten** button to reverse the flatten).
X Correction	Specifies the amount of correction to apply to the X-axis of the scanner.
Y Correction	Specifies the amount of correction to apply to the Y-axis of the scanner.
Second Image	Defines the location of the second image used in the analysis.
Image resize factor	Speeds up the shift calculation by averaging for images larger than 512 pixels

Results Parameters

Results of the **XY Drift** analysis are presented in this section.

X Shift	Specifies the amount of calculated shift along the X-axis of the second image relative to the first.
Y Shift	Specifies the amount of calculated shift along the Y-axis of the second image relative to the first.
Tested Correlation Coefficient	Reports the correlation coefficient after correcting for the detected shift. A perfect correlation is 1.0. If the tested correlation coefficient is too low, then the calculation is not valid and should not be applied. You may need features that have more distinct contrast.
Raw Correlation Coefficient	Reports the correlation coefficient between the two images prior to processing.

XY Drift Buttons

Load Image	Browse to open the second image in the right box.
Calculate Shift	Compares left image to right image, and reports the shift statistics in the **Results** box.
Apply Correction	Applies the correction in the **Inputs** box to the second image.
Undo Flatten	**Undo Flatten** restores the image to its original form.

Chapter 7 Modify Commands

Modify commands are used to eliminate noise and correct for bow and tilt. These operations process the captured/stored image, then produce another (modified) version of the image

Refer to the following analysis commands available in the NanoScope software:

- **Image Filtering using Data Matrix (Kernel) Operations:** Section 7.1
- **Clean Image:** Section 7.2
- **Crop and Split:** Section 7.3
- **Erase:** Section 7.4
- **Flatten:** Section 7.5
- **Gaussian:** Section 7.6
- **Lowpass:** Section 7.7
- **Median:** Section 7.8
- **Plane Fit:** Section 7.9
- **Spectrum 2D:** Section 7.10
- **Subtract Image:** Section 7.11

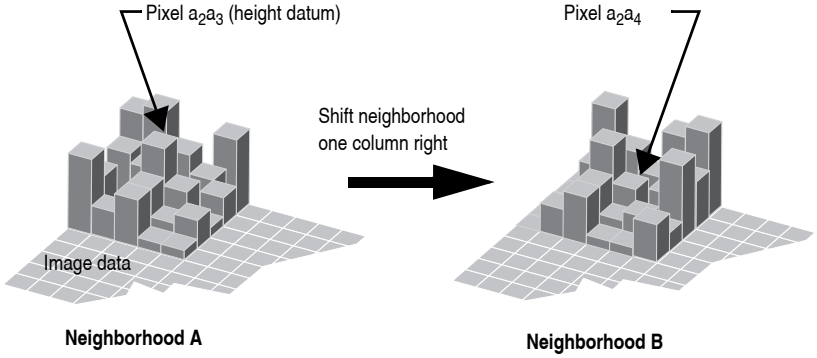
7.1 Image Filtering using Data Matrix (Kernel) Operations

A number of **Modify** image filters use matrix operations to achieve their effects. The matrix operations include:

- Clean Image
- Gaussian
- Lowpass
- Median

In each of these commands, data is analyzed in kernels (matrices), with every pixel individually recalculated based upon its neighboring values. For example, data which is undergoing a **Median** filter applies a 3 x 3 or 5 x 5 matrix operation to each image pixel. (Most filters utilize 3 x 3 matrices.)

Figure 7.1a Median Filter Example



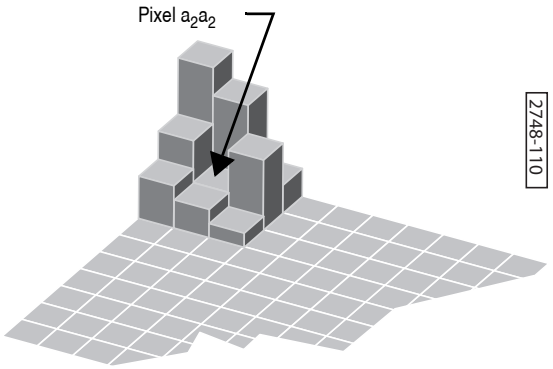
In the example in Figure 7.1a, each pixel is individually evaluated within its own local, 5 x 5 "neighborhood." Neighborhood A has pixel a_2a_3 at its center. For a **Median** filter, the 25 pixels in neighborhood A are evaluated to locate the median value pixel. The median value of neighborhood A is then mapped to a new pixel a_2a_3 in a *separate* data set.

The matrix is shifted over one column to define a new neighborhood ("B") with pixel a_2a_4 at its center. The median value for neighborhood "B" is found, then mapped to pixel a_2a_4 in the separate data set. The filtering process is repeated until all pixels have been remapped.

Note: In this and all other matrix operations, pixels are mapped to the new, separate data set without changing pixel values in the original image data until saved. (Matrices do not operate cumulatively on previously filtered data.) Filters include averaging (e.g., **Lowpass** filter) and non-averaging (e.g., **Highpass**) types.

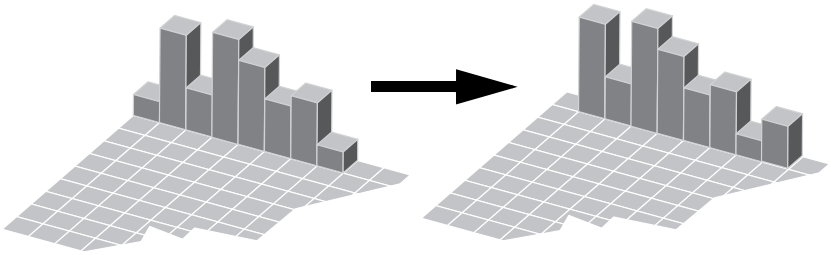
Most filters utilize 3 x 3 pixel matrixes (see Figure 7.1b), which tend to confine averaging effects to smaller areas. They process image data in a manner similar to the 5 x 5 matrix example in Figure 7.1a.

Figure 7.1b 3 x 3 Pixel Matrix



Gaussian filters utilize a 1 x N matrix, where N is determined by the **Filter size** parameter. In this instance, image data is analyzed in two-dimensional matrices which are shaped to a Gaussian curve where the sigma value (σ) is determined by the **Filter size** parameter. (see **Gaussian:** Section 7.6.)

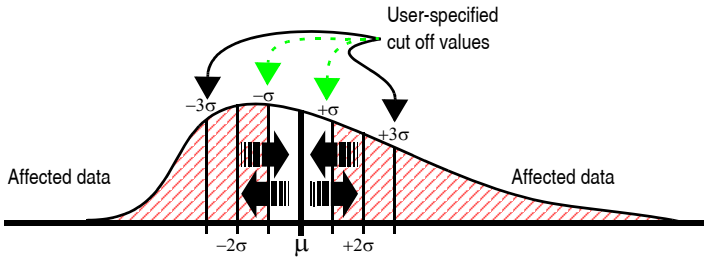
Figure 7.1c Gaussian Filter Example



7.2 Clean Image

The **Clean Image** command is used to smooth noisy image data within the cursor box you specify. The **Spike cut off** and **Streak cut off** commands define sigma cutoffs for spikes and streaks, respectively. Data points lying beyond the mean ± designated sigma values (σ) are replaced with the mean data value.

Figure 7.2a Clean Image Diagram

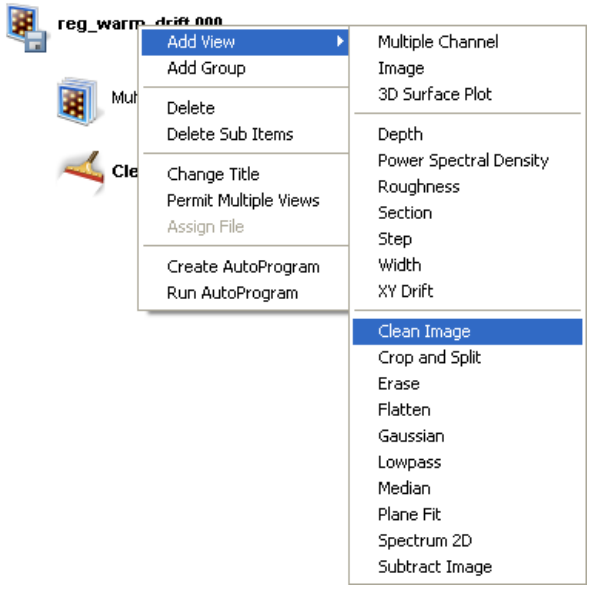


1. Select an image file from the file browsing window at the right of the main window. Double click the thumbnail image to select and open the image.

2. You can open the **Clean Image** view, shown in Figure 7.2c, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Clean Image** from the popup menu. See Figure 7.2b.

Figure 7.2b Select **CLEAN IMAGE** from the workspace



Or

- Right-click on a thumbnail in the Multiple Channel window and select **CLEAN IMAGE**.

Or

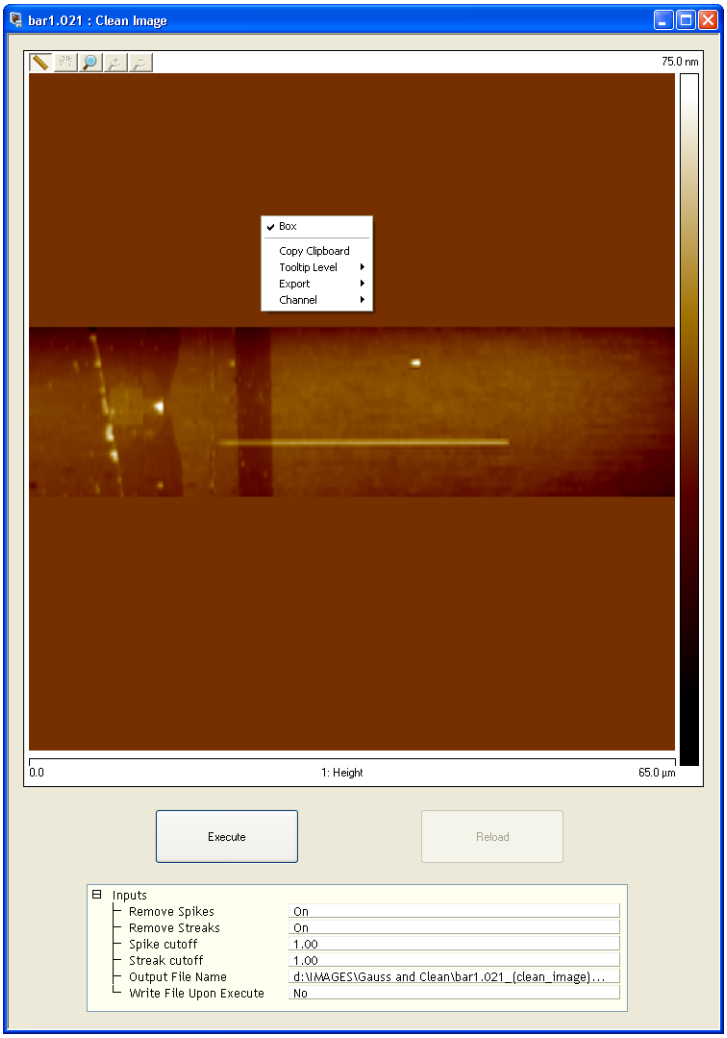
- Select **MODIFY** > **CLEAN IMAGE** from the menu bar.

Or

- Click the **Clean Image** icon in the toolbar.

3. A separate window opens, also displaying the image. Right-click in the image to display the **Clean Image** options menu (see Figure 7.2c and Figure 7.2e).

Figure 7.2c Clean Image Window



4. Click and drag in the image to define a box.
5. Configure the **Input** parameters.
6. Click **EXECUTE** to perform the operation.
7. To restore the unprocessed image, click the **RELOAD** button.

Figure 7.2d shows the image of Figure 7.2c after a clean operation with Spike and Streak cutoff both set to 1σ and Figure 7.2e shows the image of Figure 7.2c after a clean operation with Spike and Streak cutoff both set to 0.5σ.

Figure 7.2d Image of Figure 7.2c after a 1σ clean operation

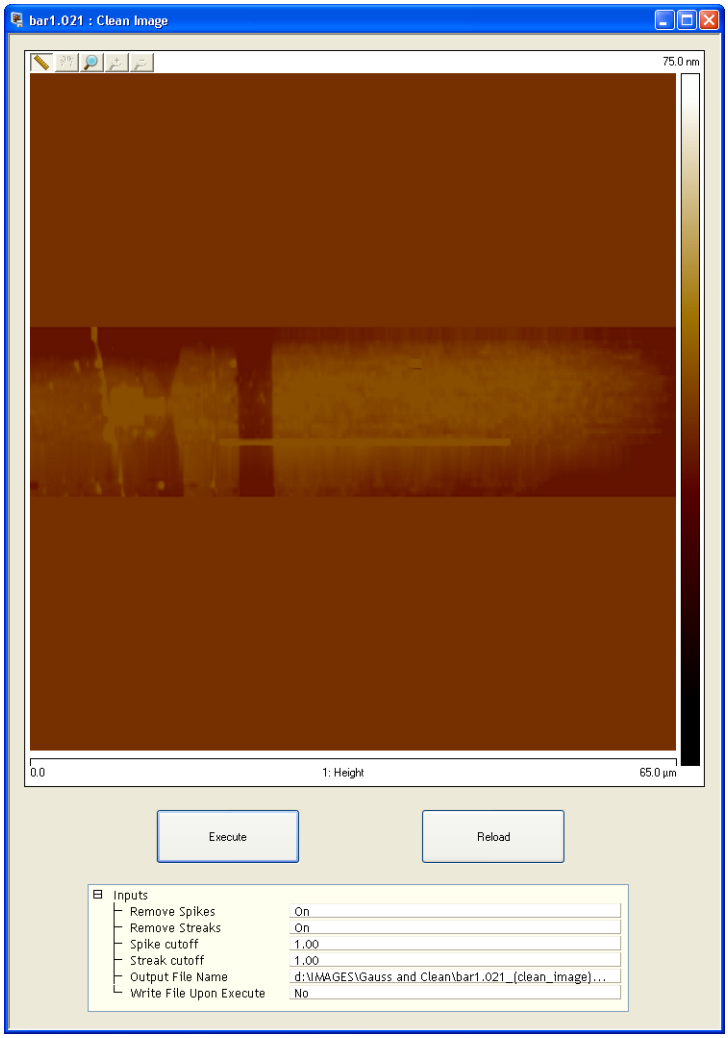
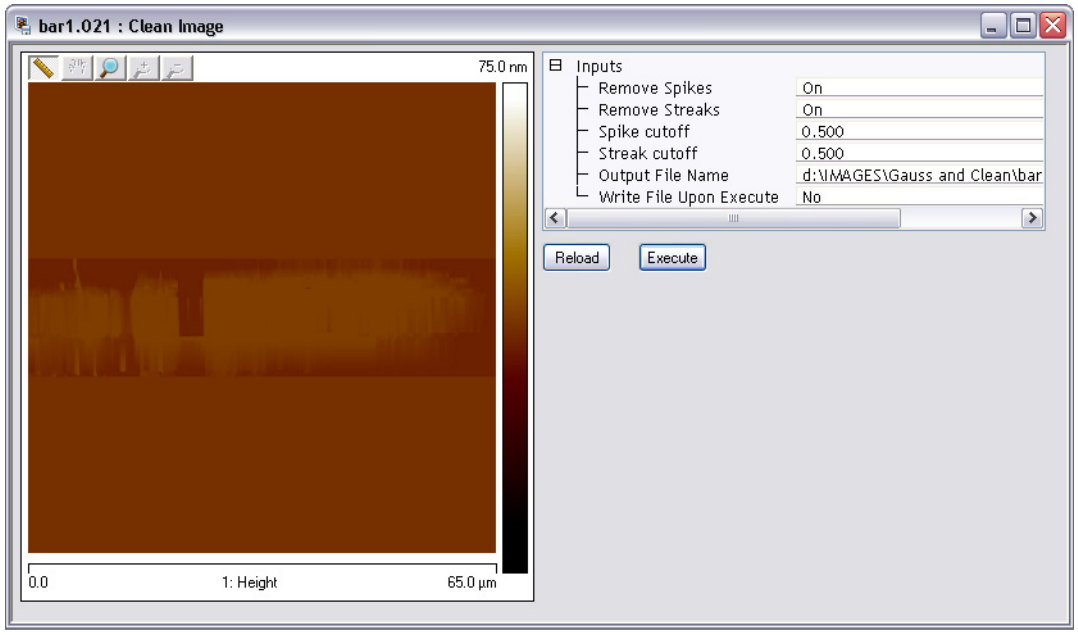


Figure 7.2e Dual monitor image of Figure 7.2c after a 0.5σ clean operation



Clean Image Input Parameters

Remove Spikes

Settings:

- **On**—Enables the **Spike cut off** value and applies it to data within the cursor box you specify.
- **Off**—Disables the **Spike cut off** value.

Remove Streaks

Settings:

- **On**—Enables the **Streak cut off** value and applies it to data within the cursor box you specify.
- **Off**—Disables the **Streak cut off** value.

Spike Cutoff

Number of sigma values to use as the cut off point for spike data. Data points lying outside the mean ± Spike cut off sigma value(s) are replaced by the mean data value.

Range:

- 0 to 10

Streak Cutoff

Number of sigma values to use as the cut off point for streak data. Data points lying outside the mean ± Streak cut off sigma value(s) are replaced by the mean data value.

Range:

- 0 to 10

Output File Name

Select the path of the extracted image file. Leave blank for immediate view/use without saving the altered image file

Write File Upon Execute

Writes the output file(s) when the Create File(s) button is clicked.

Buttons on the Clean Image Panel

Execute	Initiates the Clean Image command.
Reload	Restores the image to its original form by reloading the original file.

7.3 Crop and Split

The **Crop and Split** function replaces and expands the **Zoom** function used in version 7.0 and earlier releases of NanoScope software. Use the **Crop and Split** function to extract an image from a large Version 7 image for Version 5 analysis or to inspect only part of an image. NanoScope Version 5 software features a number of **Offline** functions currently not available in Versions 7 and 8 NanoScope software. **Crop and Split** will produce the largest Version 5 image size possible within the bounded region (128 x 128, 256 x 256 or 512 x 512).

Note: The image produced by this analysis is Version 5 compatible, however, if the image is later processed by a Version 7 analysis, the image may no longer be Version 5 compatible.

7.3.1 Crop and Split Procedure

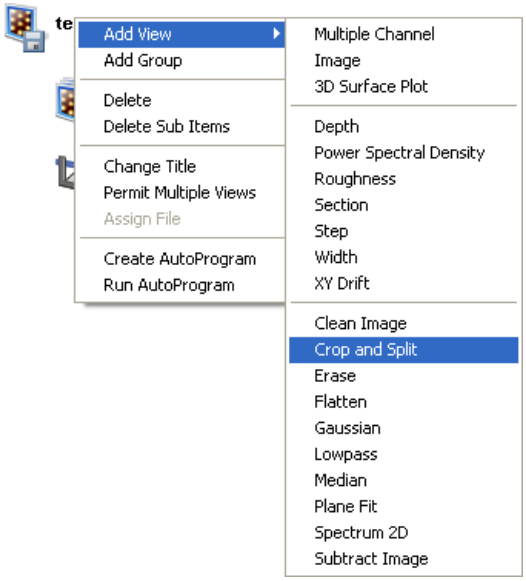
Use the **Crop and Split** function to isolate a portion of a high resolution image.

1. Open a large Version 7 or 8 image (larger than 512 x 512).

2. You can open the **Crop and Split** view, shown in Figure 7.3b, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Crop and Split** from the popup menu. See Figure 7.3a.

Figure 7.3a Select **CROP AND SPLIT** from the workspace



Or

- Right-click on a thumbnail in the Multiple Channel window and select **CROP AND SPLIT**.

Or

- Select **MODIFY** > **CROP AND SPLIT** from the menu bar.

Or

3. Click the **Crop and Split** icon in the toolbar.

4. The selected image opens in the **Crop and Split** dialog box (see Figure 7.3b and Figure 7.3c).

Figure 7.3b The **Crop and Split** window—single monitor

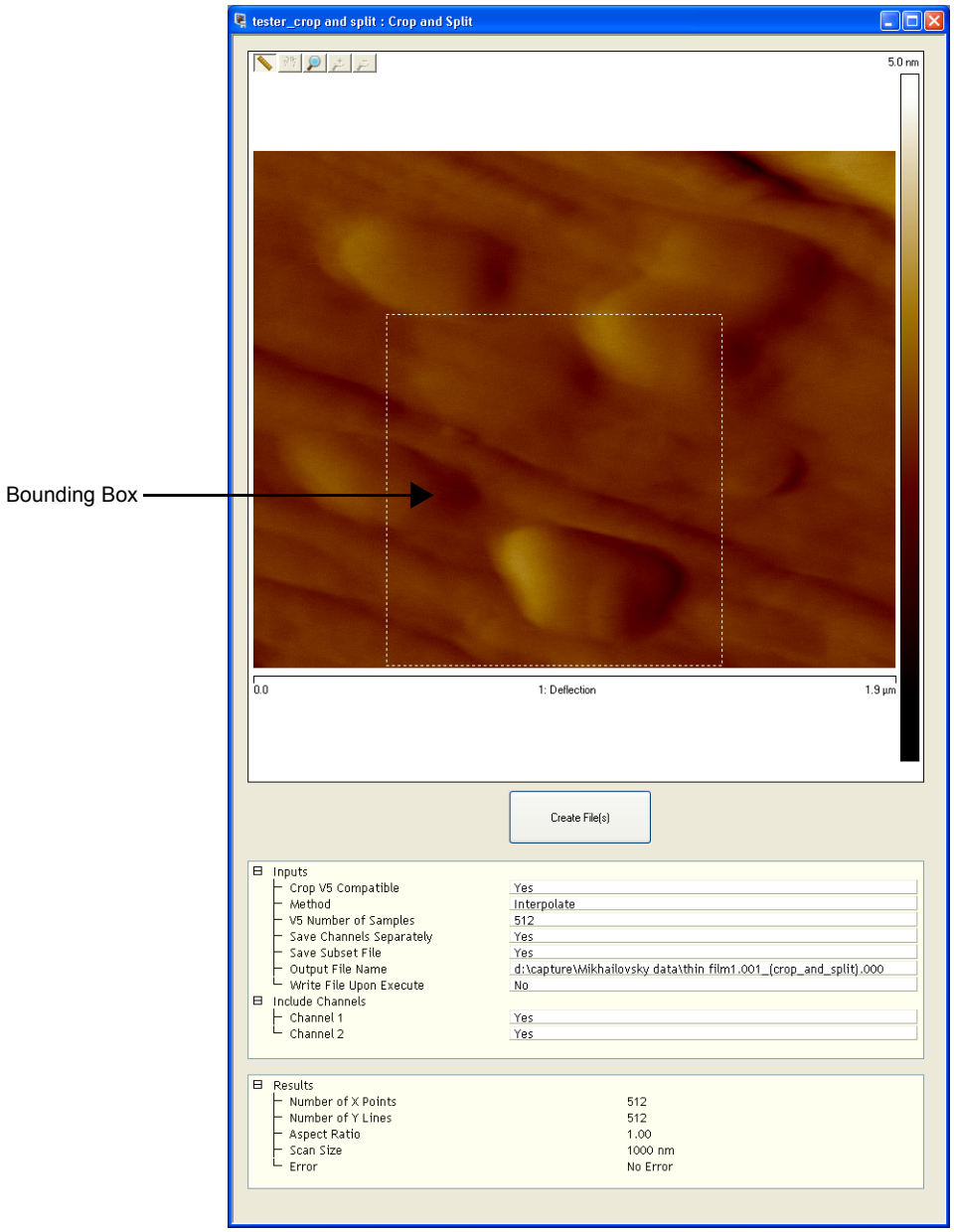
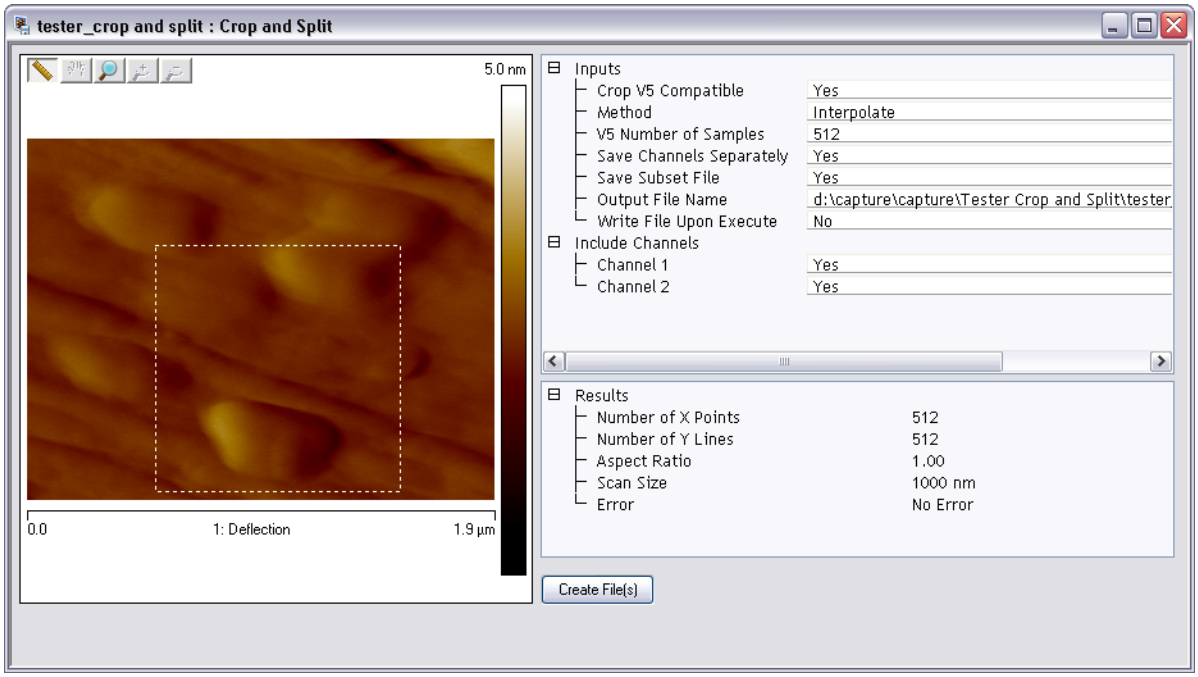


Figure 7.3c The **Crop and Split** window—dual monitor



5. Create a bounding box by dragging the mouse in the image (see Figure 7.3b or Figure 7.3c). Place the cursor inside the box, and while holding the mouse button, move the box to the location of interest. If **CROP V5 COMPATIBLE** is selected, the box is restricted to the largest possible Version 5-compatible image size (usually 512 x 512).

6. Select the **OUTPUT FILE NAME** by clicking on the file name and then clicking the box to the right of the file name. Select a location and name for the new image.

7. Click the **CREATE FILE(S)** button.

8. Use this new image for further (Version 5 or other) analysis.

7.3.2 Crop and Split Interface

Input Parameters

Crop V5 Compatible Settings:

- **YES**—A V5 compatible file (128 x 128, 256 x 256 or 512 x 512) is created from the image.
- **No**—Crops to arbitrary sizes.

Method Available with **CROP V5 COMPATIBLE** set to **YES.**

Settings:

- **INTERPOLATE**—Data points will be interpolated to create new image.
- **Replicate**—Data points will be used as is to create a new image.

V5 Number of Samples Available with **CROP V5 COMPATIBLE** set to **YES.**

Settings:

- **128, 256, 512**.

Save Channels Separately Settings:

- **Yes**— Individual files, named OriginalFileName_crop and splitN.f07, where N is the channel number (1 through 8), are created.
- **No**—One file with all selected channels will be created.

Save Subset File Settings:

- **Yes**—One file with all selected channels will be created.
- **Yes**— Individual files, named OriginalFileName_crop and splitN.f07, where N is the channel number (1 through 8), are created.

> **Note:** You must select **Yes** for either the **Save Channels Separately** or the **Save Subset File** commands.

Output File Name Select the path of the extracted image file.

Write File Upon Execute Writes the output file(s) when the Create File(s) button is clicked.

Include Channels Settings:

- **Yes**— This channel is included in the output file(s).
- **No**—This channel is not included in the output file(s).

Results Parameters

Number of X Points — Number of x points in the new image.

Number of Y Lines — Number of y lines in the new image.

Aspect Ratio — Aspect ratio of the new image.

Scan Size — Scan size of the new image. The units of this parameter are volts if the **Units** parameter (**Other Controls** panel) is set to **Volts**. The units are linear distance (nm or μm) if the **Units** parameter is set to **Metric**.

Error — Possible errors:

- **No Error**—(Default)
- **Not Enough X Points**—Original image has less than 512 points/line.
- **Invalid Aspect Ratio**—Zoomed image results in an aspect ratio greater than 256:1.
- **File Write**—A disk error occurred.
- **Unknown**—An unknown error has occurred.

Crop and Split Buttons

Create File(s) — An image is created from the portion of the high resolution image that is contained in the bounding box.

7.4 Erase

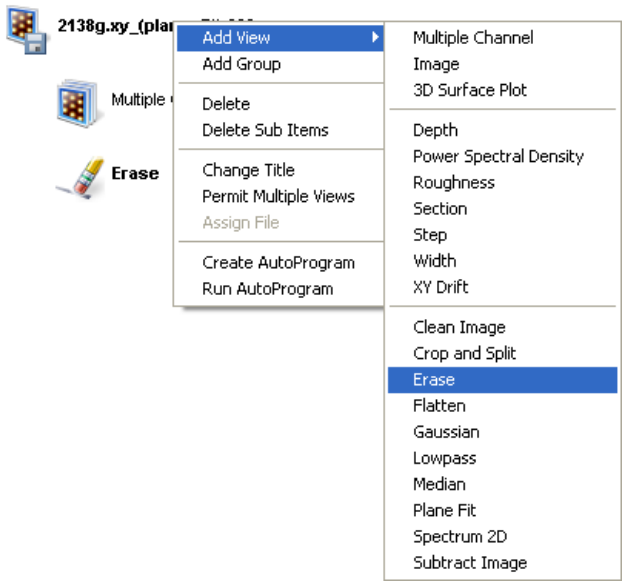
The **Erase** modify command is a retouching function for editing images. This function allows horizontal lines or areas to be replaced with an interpolation from the adjacent lines.

1. Select an image file from the file browsing window at the right of the main window. Double click the thumbnail image to select and open the image.

2. You can open the **Erase** view, shown in Figure 7.4b, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Erase** from the popup menu. See Figure 7.4a.

Figure 7.4a Select **ERASE** from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **ERASE**.

Or

   - Select **MODIFY** > **ERASE** from the menu bar.

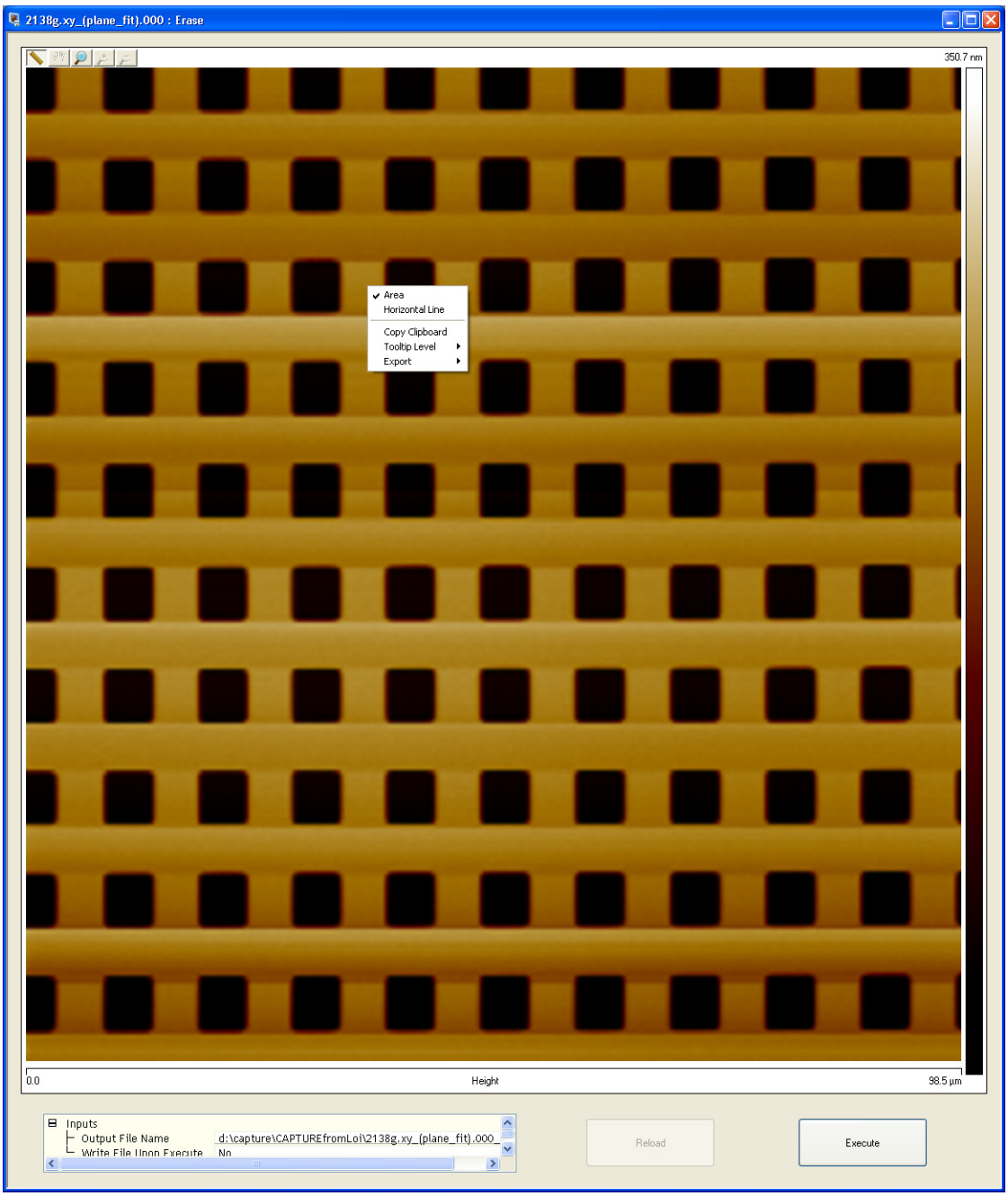
Or

3. Click the **Erase** icon in the toolbar.

4. A separate window opens, also displaying the image. Right-click in the image to display the **Erase** options menu (see Figure 7.4b). Select either **Horizontal Line** or **Area** and a check mark will appear. The option chosen will remain checked until another selection is made.

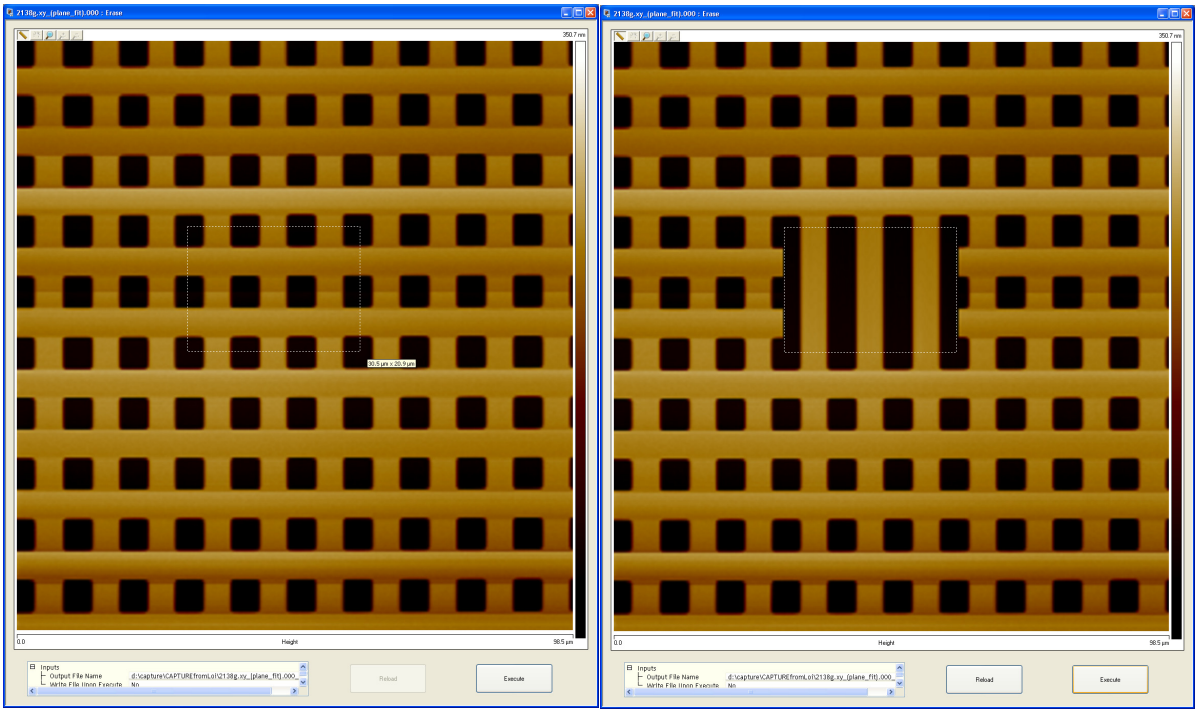
5. Click anywhere within the image to define a horizontal line, or click and drag in the image to define a box to be replaced.

Figure 7.4b Erase Options Menu



6. Click the **EXECUTE** button to perform the interpolation.

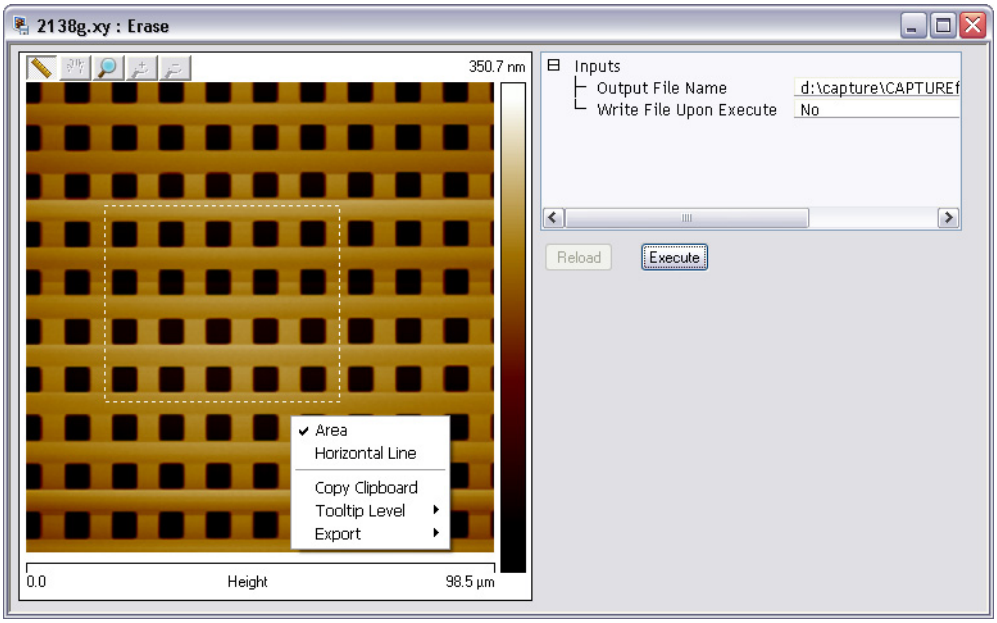
Figure 7.4c Effect of the erase interpolation on a rectangular area—single monitor



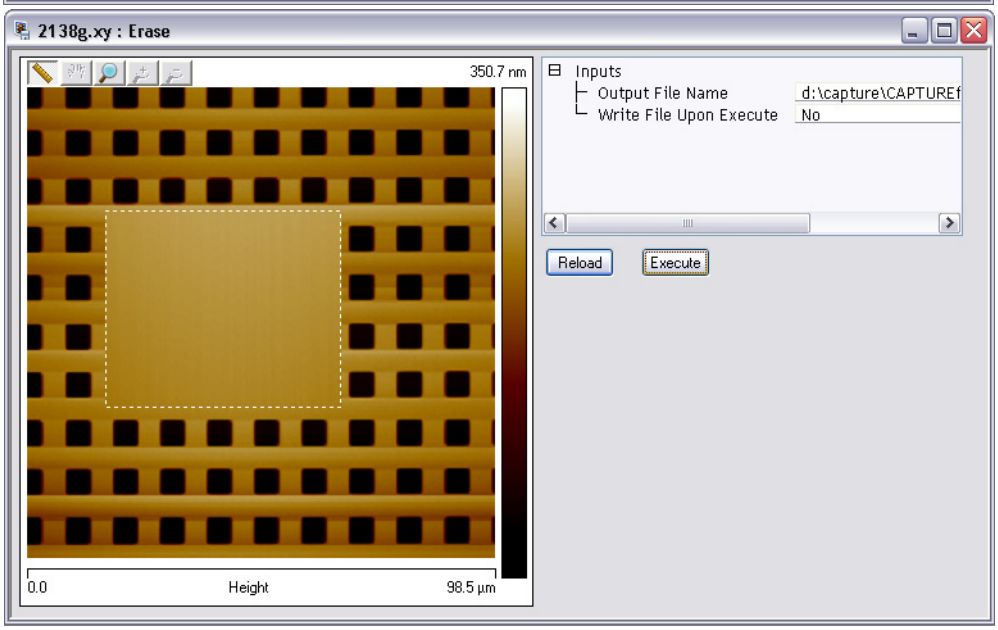
Before After

Figure 7.4d Effect of the erase interpolation on a rectangular area—dual monitor

Before



After



7. Right-click on an **Erase** feature of a modified image (either line or box) for options to complete the operation. Click **Delete** to erase the dashed construction lines from the display of the selected feature. Click **Clear All** to eliminate all construction lines from the display, while retaining the modifications to the image.

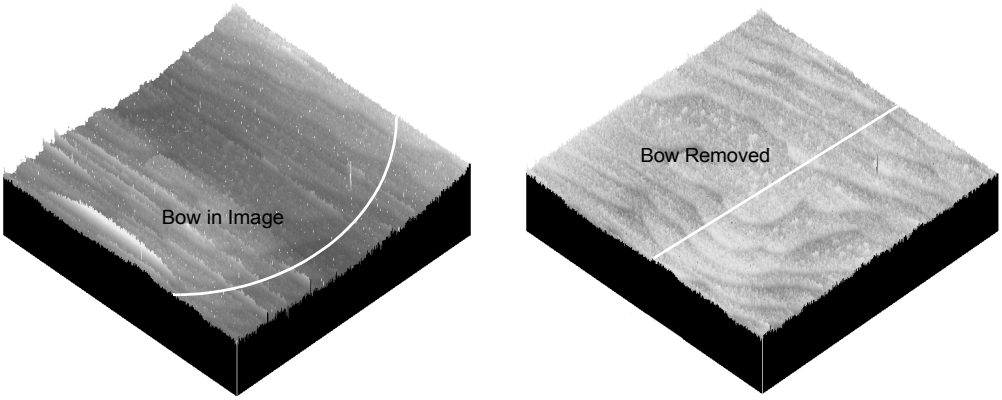
8. To eliminate all trace of **Erase** activity to an image, click the **Reload** button while the image is still open in the **Erase** panel.

7.5 Flatten

The **Flatten** command eliminates unwanted features from scan lines (e.g., noise, bow and tilt). It uses all unmasked portions of scan lines to calculate individual least-square fit polynomials for each line.

Flatten is useful prior to image analysis commands (e.g., **Depth**, **Roughness**, **Section**, etc.) where the image displays a tilt, bow or low frequency noise, which appear as horizontal shifts or stripes in the image.

Figure 7.5a Image Flattened



Refer to the following sections on **Flatten** analysis:

- **Flatten Theory:** Section 7.5.1
- **Flatten Procedures:** Section 7.5.2
- **Flatten View Interface:** Section 7.5.3

7.5.1 Flatten Theory

The **Flatten** command is a filter that modifies the data to delete low frequency noise and remove tilt from an image. Each line is fit individually to center data (0th order) and remove tilt (1st order), or 2nd or 3rd order bow. A best fit polynomial of the specified order is calculated from each data line and then subtracted out. In some cases, the stopband (box cursor to exclude features) can be used to remove regions of the image from the data set used for the polynomial fits. Click on the image to start drawing a stopband box. Right-click on a box to delete it or change its color.

Flatten Polynomials

The polynomial equations calculate the offset and slope, and higher order bow of each line for the data (see Table 7.5a).

Table 7.5a Flatten Polynomials

Order	Polynomial	Explanation
0	$z = a$	Centers data along each line.
1	$z = a + bx$	Centers data and removes tilt on each line [i.e., calculates and removes offset (a) and slope (b).
2	$z = a + bx + cx^2$	Centers data and removes the tilt and bow in each scan line, by calculating a second order, least-squares fit for the selected segment then subtracting it from the scan line.
3	$z = a + bx + cx^2 + dx^3$	Centers data and removes the tilt and bow in each scan line, by calculating a third order, least-squares fit for the selected segment then subtracting it from the scan line.

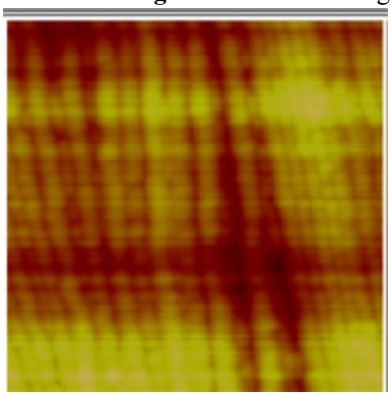
7.5.2 Flatten Procedures

For an image that contains a number of noisy scan lines, use the **Flatten** command to correct the problem.

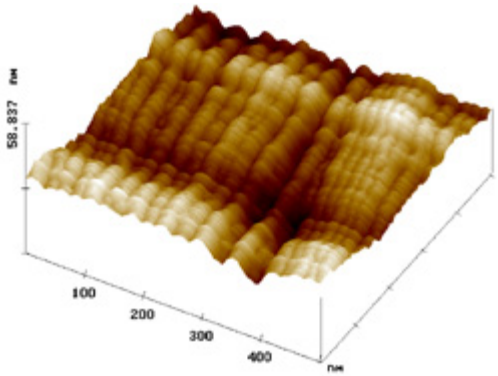
1. Open the image. Note disjointed scan lines which are misaligned along the Z-axis (some are high and some are low). This effect somewhat resembles an unshuffled deck of cards when viewed on-edge or appears as horizontal streaks or bands. The image may have bow along its Y-axis.

Figure 7.5b shows an image file in its original, raw form as an example for the **Flatten** command. Many of the image's scan lines are disjointed along the Z-axis.

Figure 7.5b Raw Image of Syndiatatic Polystyrene (500nm)



Top View of Image to Flatten

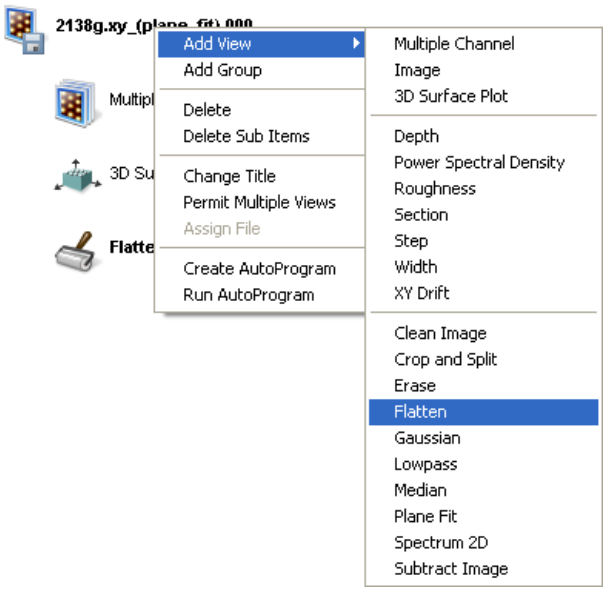


Surface Plot of Image showing Bow

2. You can open the **Flatten** view, shown in Figure 7.5e, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Flatten** from the popup menu. See Figure 7.5c.

Figure 7.5c Select **FLATTEN** from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **FLATTEN**.

Or

   - Select **MODIFY** > **FLATTEN** from the menu bar.

Or

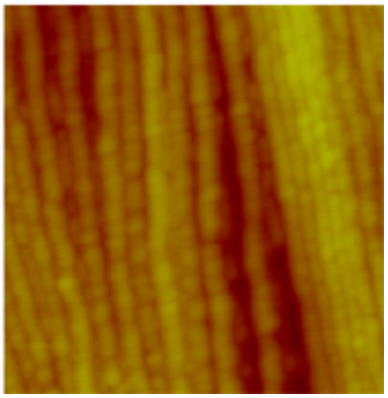
3. Click the **Flatten** icon in the toolbar.

4. Set the **Flatten Order** value to `0TH`. This removes the scan line misalignment.

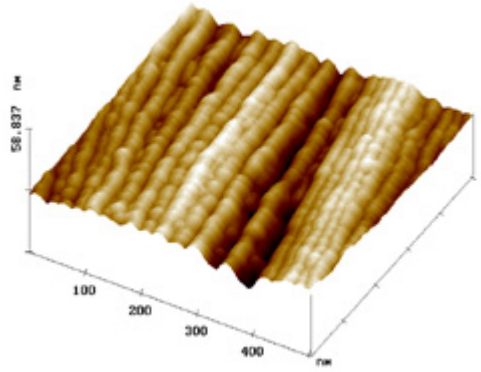
5. Click **Execute** to initiate the **Flatten** command. The flattened image appears on the display screen.

   Note: Figure 7.5d shows the same image file after using a zero-order **Flatten** (**Flatten Order** = `0TH`). The scan lines are now aligned.

Figure 7.5d Flattened Image of Syndiatatic Polystyrene (500 nm)



Top View of Flattened Image



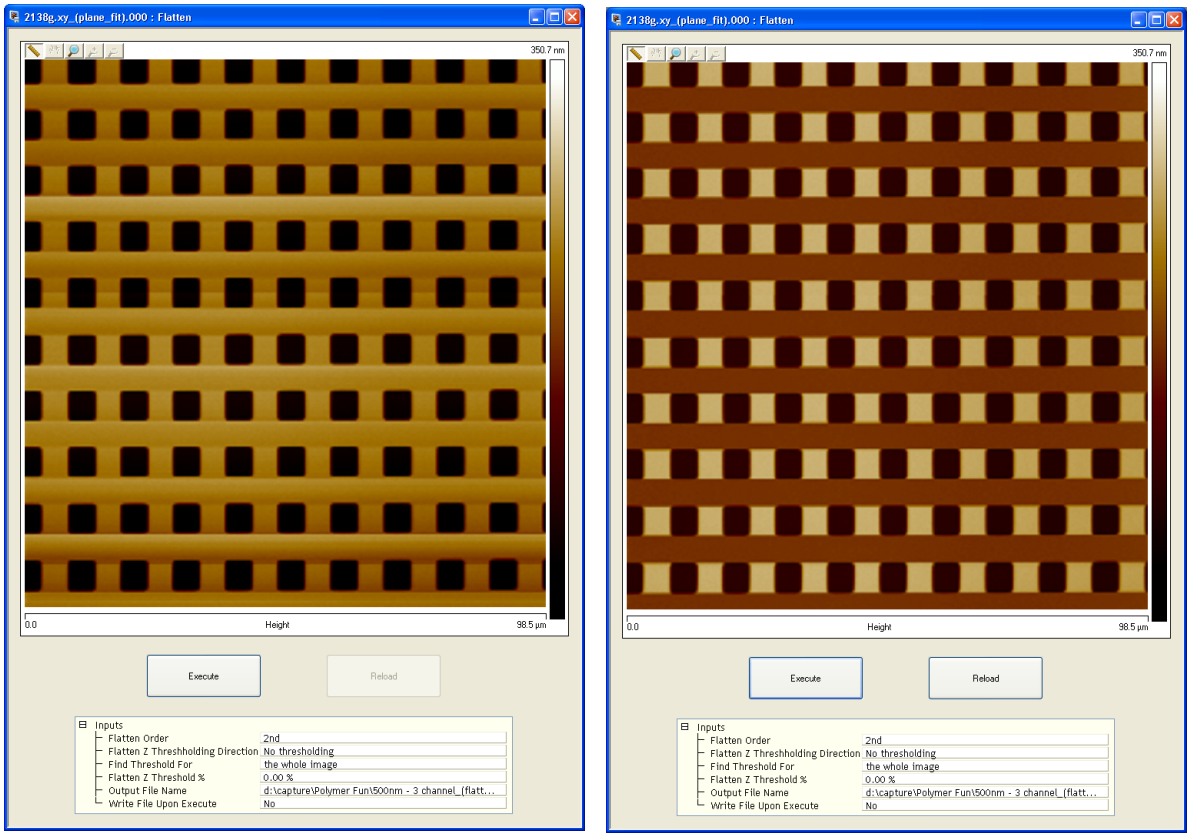
Surface Plot View of Flattened Image

6. To see a variety of effects using the **Flatten** command, enter different **Flatten order** values. Each new change may be undone by clicking on the **Reload** button.

7.5.3 Flatten View Interface

Click **Modify** in the menu bar and select **Flatten,** or click on the **Flatten** icon in the tool bar. A series of parameters appear in the **Flatten View**, allowing the order of the flatten polynomial to be selected and display parameters to be adjusted to your preference.

Figure 7.5e Flatten view—single monitor

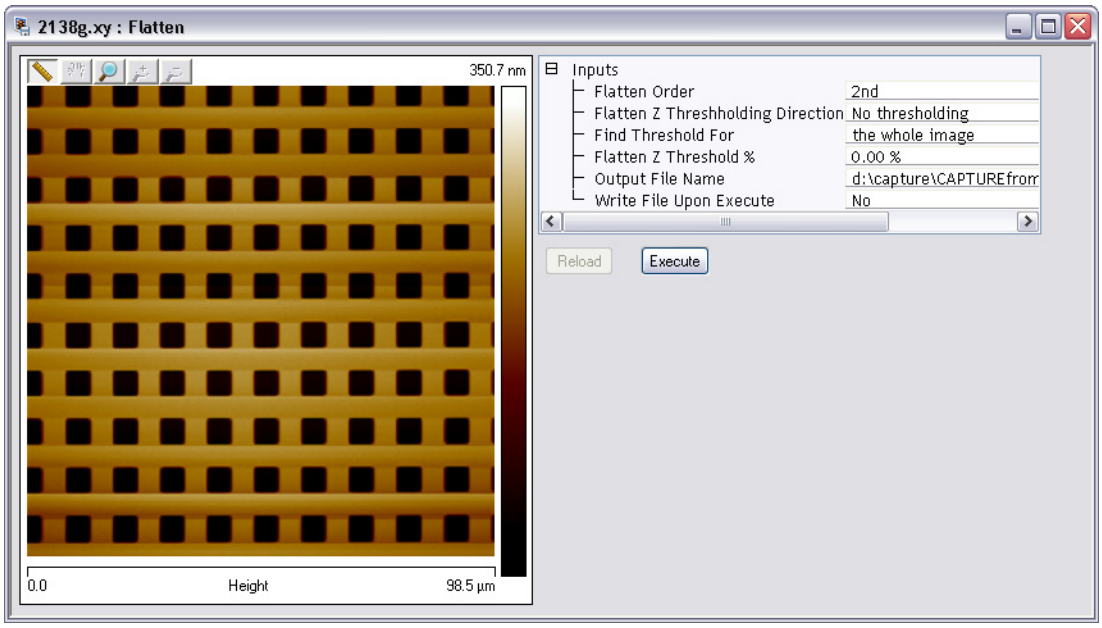


Before

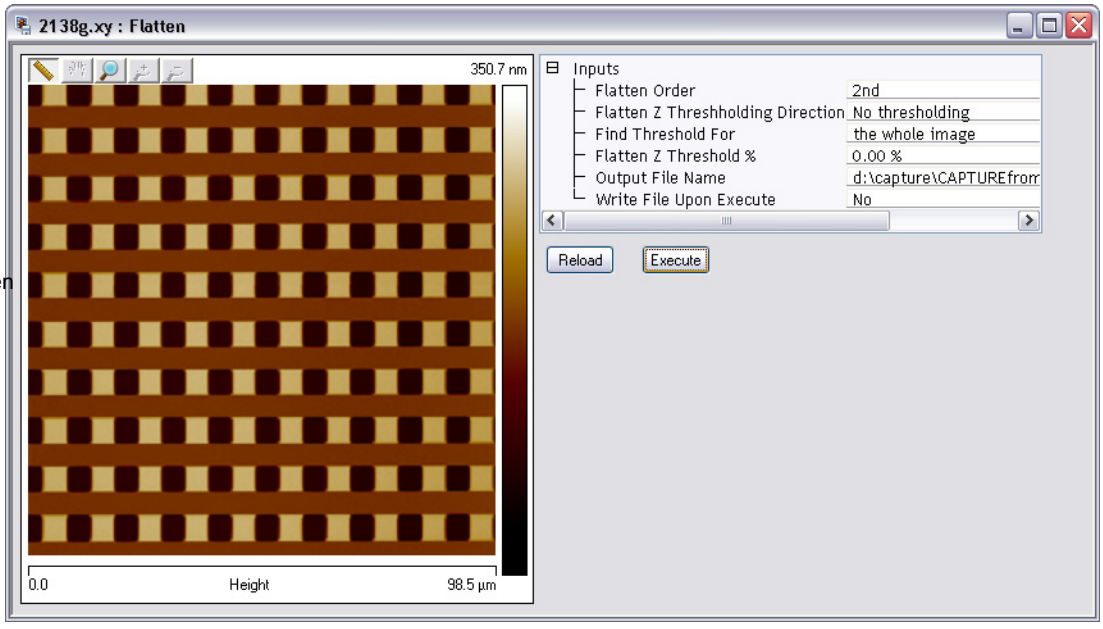
After 2nd order flatten

Figure 7.5f Flatten view—dual monitor

Before



After 2nd order flatten



Input Parameters:

Range and Settings:

Flatten Order

Flatten Order selects the order of the polynomial calculated and subtracted from each scan line.

Settings:

- **Zero Order (0th)**—Removes the Z offset between scan lines by subtracting the average Z value for the unmasked segment from every point in the scan line.
- **First Order (1th)**—Removes the Z offset between scan lines, and the tilt in each scan line, by calculating a first order, least-squares fit for the unmasked segment then subtracting it from the scan line.
- **Second order (2nd)**—Removes the Z offset between scan lines, and the tilt and bow in each scan line, by calculating a second order, least-squares fit for the unmasked segment then subtracting it from the scan line.
- **Third order (3rd)**—Removes the Z offset between scan lines, and the tilt and bow in each scan line, by calculating a third order, least-squares fit for the unmasked segment then subtracting it from the scan line.

Flatten Z Thresholding Direction

Specifies the range of data to be used for the polynomial calculation based on the distribution of the data in Z:

Range or Settings:

- **Use Z >=** —Uses the data whose Z values are greater than or equal to the value specified by the Z thresholding %.
- **Use Z <**—Uses the data whose Z values are less than the value specified by the Z thresholding %.
- **No thresholding**—Disables all thresholding parameters.

Flatten Threshold for

Applies the Thresholding values for the whole image or each line independently.

Range or Settings:

- **The whole image**
- **Each line**

Flatten Z Threshold %

Defines a Z value as a percentage of the entire Z range in the image (or data set) relative to the lowest data point.

Output File Name

Specifies the name of the file to be created. Leave blank for immediate view/use without saving the altered image file.

Write File Upon Execute

Writes the output file(s) when the Create File(s) button is clicked.

Buttons on the Flatten Panel

Execute

Initiates the command, based on the order selected.

Reload

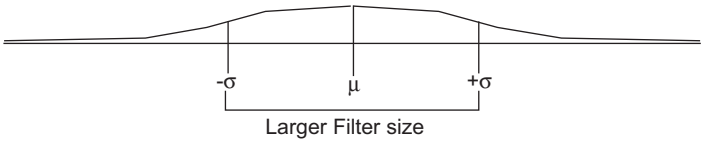
Restores the image to its original form by reloading the original file.

7.6 Gaussian

The single axis **GAUSSIAN** Filter permits analysis of images along either the X or Y axis with a 1-by-X kernel you define specified in Gaussian terms. The **FILTER SIZE** value corresponds to the sigma (σ) value of the Gaussian curve, encompassing approximately 68 percent of the data with the symmetric Gaussian curve centered over the operated-upon pixel.

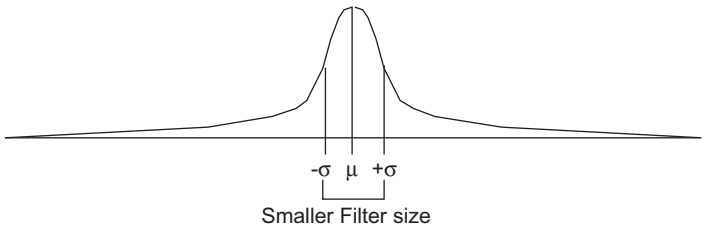
Larger **Filter size** values distribute the curve broadly (see Figure 7.6a). During **LOWPASS** filtering, this lends greater weight to values farther away from the pixel and increases the Gaussian filter's averaging effects upon the image. During **HIGHPASS** filtering, this subtracts a decreased average from each pixel, lessening the filter's impact.

Figure 7.6a Larger Filter Size



Smaller **Filter size** values concentrate curve data around the center value (see Figure 7.6b).

Figure 7.6b Smaller Filter Size



During **Lowpass** filtering, this lends less weight to pixels distant from the center, decreasing the Gaussian filter's ability to average local pixels with distant ones—the filter's impact is lessened. During **Highpass** filtering, the larger and more localized pixel average being subtracted from the operated-upon pixel value yields an enhanced impact upon the image.

Note: **Filter size** is specified in units of **Distance**, **Spatial Frequency**, **Time**, **Temporal Frequency**, and **#pixels**.

7.6.1 Gaussian Filter Panel

The **Gaussian Filter** panel is shown in Figure 7.6c and Figure 7.6d.

Figure 7.6c Gaussian filter panel—single monitor

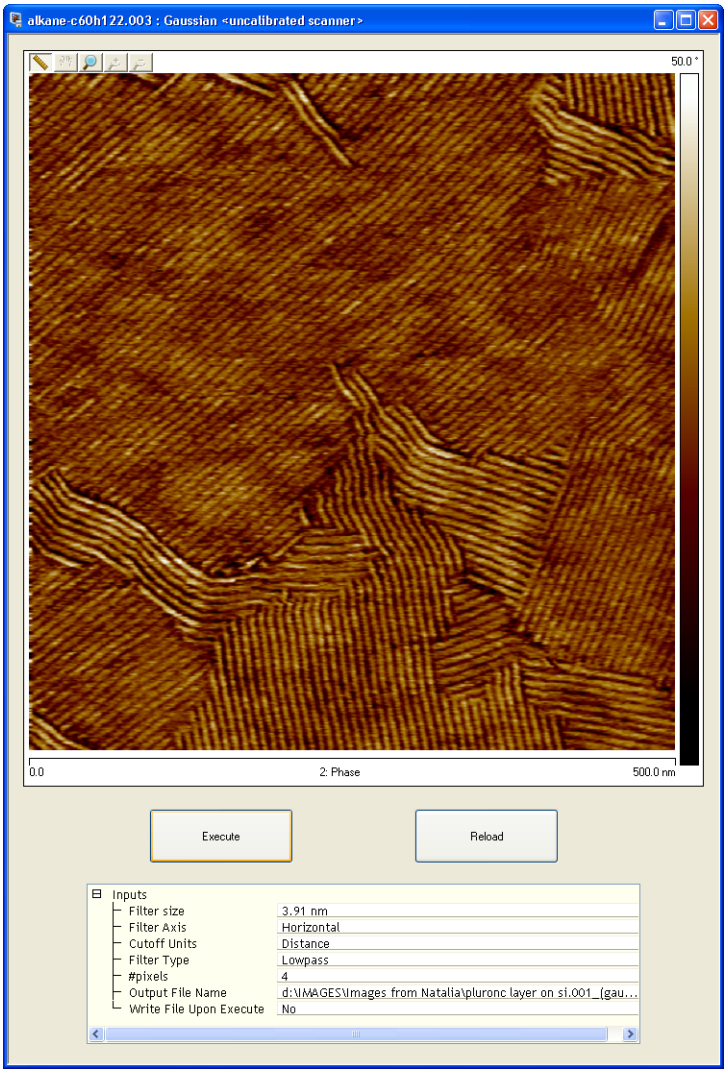
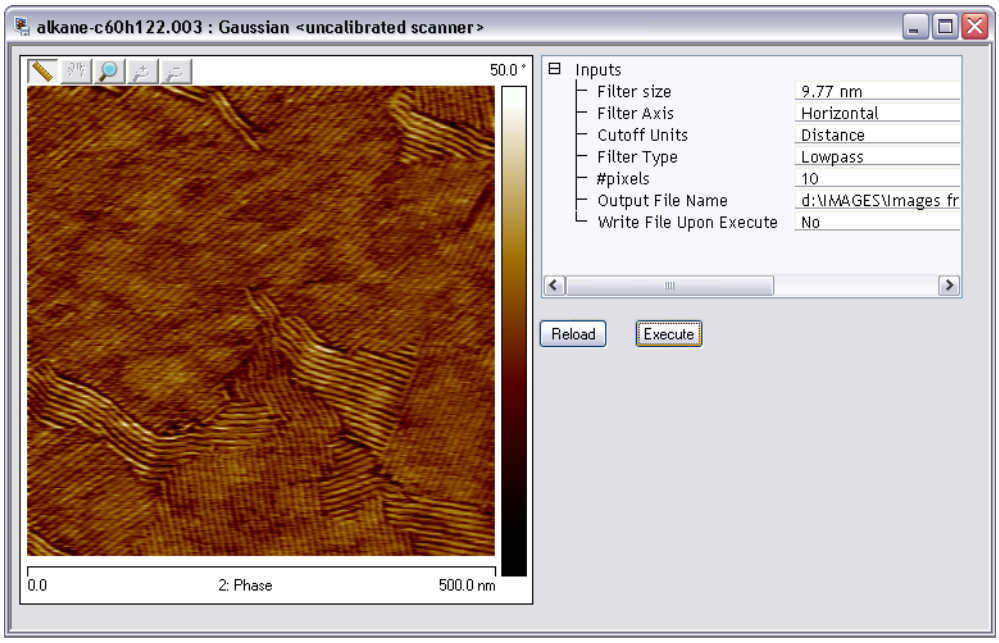


Figure 7.6d Gaussian filter panel—dual monitor



Parameters in the Gaussian Filter Panel

Filter size

Size of the scan line to be operated upon by the Gaussian filter kernel. This value is expressed in the **Cutoff Units** specified below.

Range and Settings:

- **Minimum** = **3** pixels
- **Maximum** = one-half scan size

Filter Axis

Settings:

- **HORIZONTAL**—Applies the one dimensional Gaussian filter along the X axis.
- **Vertical**—Applies the one dimensional Gaussian filter along the Y axis.

Cutoff Units

Selected units are applied simultaneously to the Filter size. (The **#pixels** field displays the pixel equivalent of the current Filter size value.)

Range and Settings:

- **DISTANCE**
- **SPATIAL FREQUENCY**
- **TIME**
- **TEMPORAL FREQUENCY**

Filter Type

Range and Settings:

- **LOWPASS** filtering allows longer wavelength features through while filtering out shorter wavelength features. The net effect is to remove noise in the form of spikes and fuzz on the image.
- **HIGHPASS** filtering allows shorter wavelength features through while filtering out longer wavelength features.

#pixels

The current **FILTER SIZE** in pixel units. This value may be used to both enter and monitor the **FILTER SIZE**.

Range and Settings:

- **Minimum** = **3** pixels
- **Maximum** = one-half scan size

Output File Name

Select the path of the extracted image file. Leave blank for immediate view/use without saving the altered image file

Write File Upon Execute

Writes the output file(s) when the Create File(s) button is clicked.

Buttons on the Gaussian Panel

Execute

Applies the **Gaussian Filter** to the currently loaded image.

Reload

Restores the image to its original form by reloading the original file.

7.6.2 Gaussian Kernel Algorithm

The general equation used to generate a 1-by-(N+1) Gaussian kernel is:

$$f_i = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{i}{\sigma}\right)^2}$$

Where i is in units of pixels, and σ is set by the **Filter size** value. Using this kernel, the filter output is:

Lowpass pixel value $$a_0' = \left(\sum_{\frac{-N}{2}}^{\frac{N}{2}} a_i f_i \right)$$

Highpass pixel value $$a_0' = a_0 - \left(\sum_{\frac{-N}{2}}^{\frac{N}{2}} a_i f_i \right)$$

The actual impact of filtering on an image is best demonstrated by reviewing examples of images before and after filtering. In the following example, both **Lowpass** and **Highpass** Gaussian filter capabilities are demonstrated.

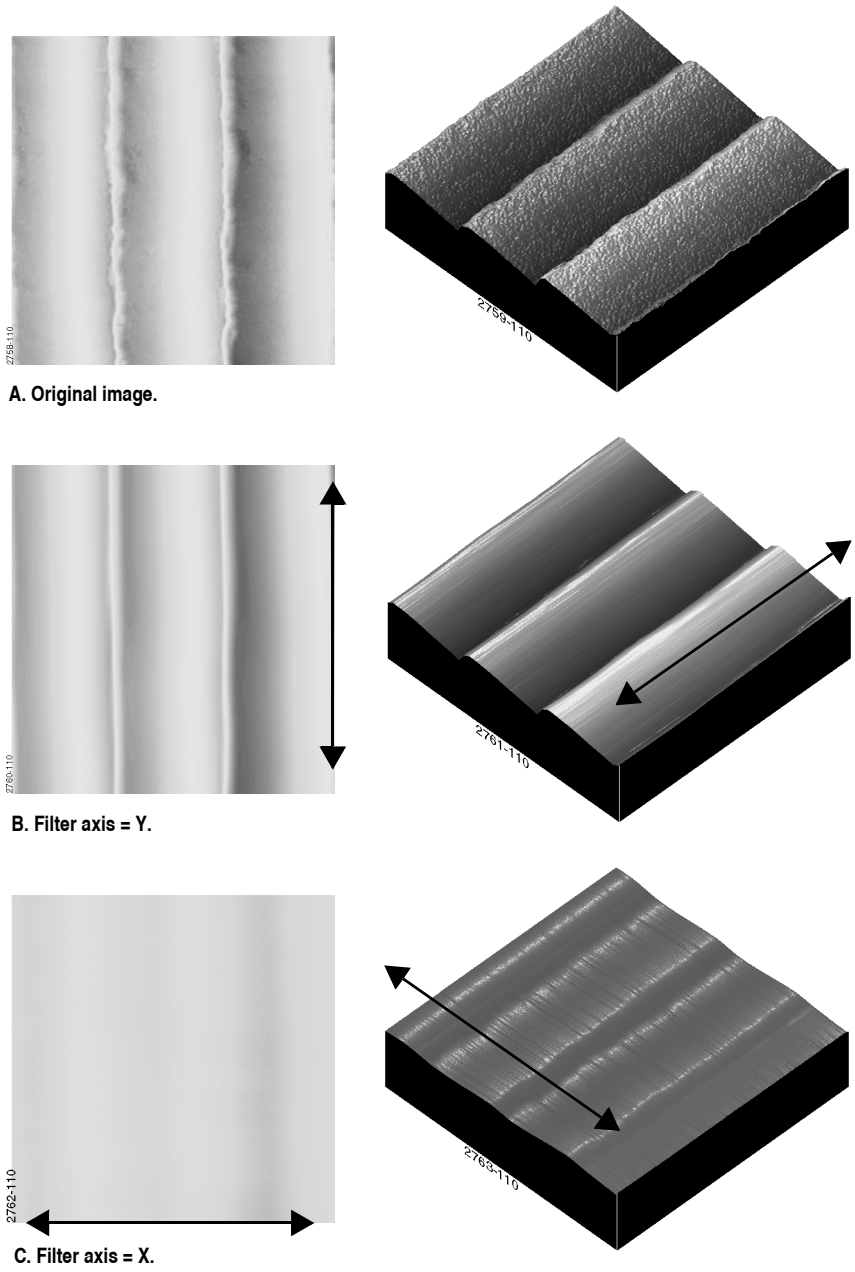
7.6.3 Lowpass Gaussian Filtering

During **LOWPASS** filtering, the **Gaussian Filter** has a unique ability to average features oriented orthogonally to the scan frame. For example, the **Gaussian** filter can average features running parallel to an image's Y scan axis while leaving features relatively unchanged along the X axis, or vice versa. This is a similar capability to the **Spectrum 2D** (see Section 7.10) function; however, it is more unidirectional (i.e., strictly operating along the X or Y axis). One such example is provided in the three views of a diffraction grating in Figure 7.6e.

The grating image **Scan size** is 1.872 microns. Applying a **Gaussian Filter** with **Filter size** of **250 nm** along the **Y** Filter axis results in view B. Notice that rulings running parallel to the Y axis are smoothed along their length by the filter, while features oriented orthogonal to the Y axis remain relatively unchanged. This results in an idealized (averaged) profile of the X axis.

In view C, the **Filter size** values is unchanged; however, the **Filter axis** has been rotated 90° to the **X** axis. The filter's impact upon the image here is very dramatic, destroying the ruling features in the image by averaging across their profile. The result is an almost flat surface.

Figure 7.6e Views of Diffraction Grating



7.6.4 Highpass Gaussian Filtering

Applications for **HIGHPASS** filtering are limited to detecting smaller features. Generally, higher frequency (shorter wavelength) features are enhanced, while sacrificing lower frequency (longer wavelength) features and height data.

One example of applying a Gaussian **Highpass** filter is provided in Figure 7.6f.

This 27.41-micron, MFM image reveals magnetic domains in a permalloy specimen. Although magnetic domains are visible on the original image, you may apply a **Gaussian** highpass filter to highlight boundaries between domains.

Figure 7.6f Magnetic Domains in a Permalloy Specimen

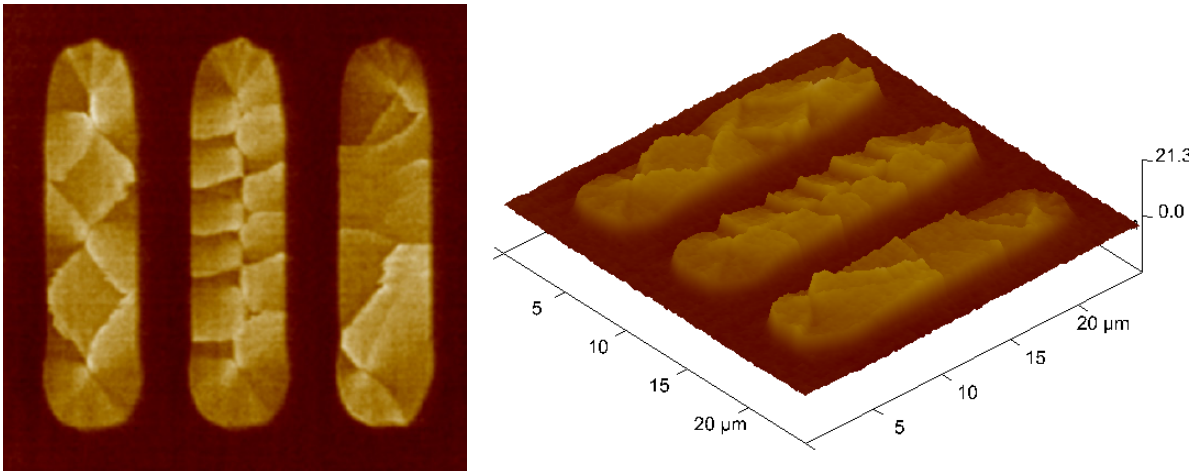


Figure 7.6f shows the magnetic force microscopy (MFM) image in its original form. This is an early MFM image of a permalloy specimen, and contains artifacts which are significantly reduced in phase analyzed images. Magnetic force is represented in the image as height data. Suppose the microscopist wanted to highlight the magnetic boundaries without regard to magnetic force (height data). A **Gaussian** Highpass filter would be appropriate.

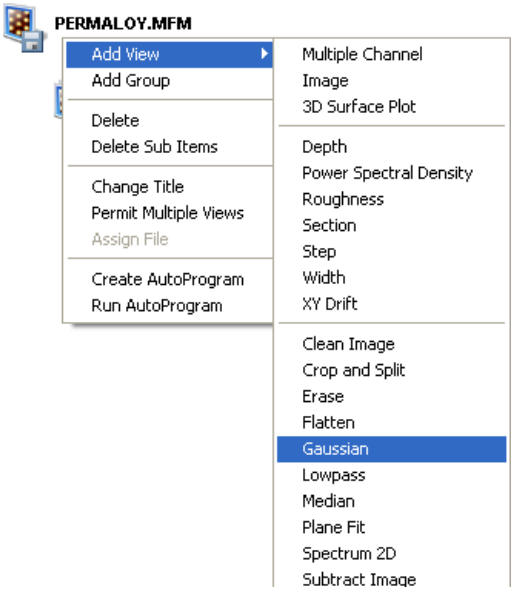
7.6.5 Procedure for the Gaussian Command

1. Select an image file from the file browsing window at the right of the main window. Double click the thumbnail image to select and open the image.

2. You can open the **Gaussian** view, shown in Figure 7.6c, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Gaussian** from the popup menu. See Figure 7.5c.

Figure 7.6g Select **GAUSSIAN** from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **GAUSSIAN**.

Or

   - Select **MODIFY** > **GAUSSIAN** from the menu bar.

Or

3. Click the **Gaussian** icon in the toolbar.

4. A separate window opens, also displaying the image.

5. Configure the **Input** parameters.

6. Complete the **Output File Name** field to save the result.

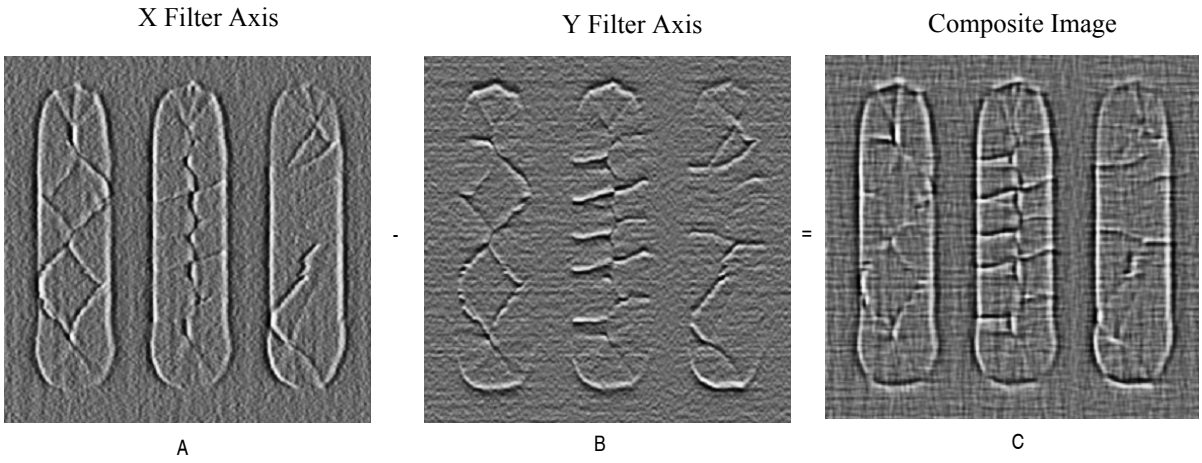
7. Click **EXECUTE** to perform the Gaussian filtering operation.

8. To restore the unprocessed image, click the **RELOAD** button.

Highpass Gaussian Filter Example

Example Explanation. First, the image is filtered along the X-axis by setting the **Filter axis** to **HORIZONTAL**. Clicking **Execute** activates the Gaussian filter,—the result is shown in Figure 7.6h, View A. Notice that features running parallel to the X-axis (e.g., the tips of each oval area) are washed out, while features running perpendicular to the X-axis are enhanced. Enter an **OUTPUT FILE NAME** to save the results for additional processing.

Figure 7.6h Gaussian Highpass-Filtered Images



Next, reload the image and filter along the Y-axis by setting the **Filter Axis** to **VERTICAL**. Clicking **Execute** activates the Gaussian filter—the result is shown in Figure 7.6h, View B. Notice that features running parallel to the Y-axis (e.g., the sides of each oval area) are washed out, while features running perpendicular to the Y-axis are enhanced. Enter an **OUTPUT FILE NAME** to save the results for additional processing.

To construct a composite image of the two Gaussian-filtered images, add them together. (This can be accomplished by subtracting an inverted image from another image.) A composite of the two filtered images is shown in Figure 7.6h, View C. This shows the domain boundaries clearly; however, all Highpass filtered images have lost their height data, including the composite.

7.7 Lowpass

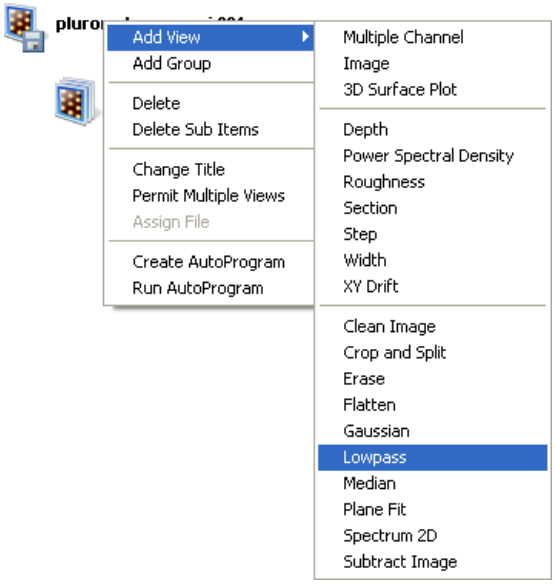
The **Lowpass** modify command applies spatial filtering to a captured image, suppressing high spatial frequency components. Each pixel in an image is replaced with the average value of the 3 × 3 pixels centered on it.

1. Select an image file from the file browsing window at the right of the main window. Double-click the thumbnail image to select and open the image.

2. You can open the **Lowpass** view, shown in Figure 7.7b and Figure 7.7c, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Lowpass** from the popup menu. See Figure 7.7a.

Figure 7.7a Select **GAUSSIAN** from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **LOWPASS**.

Or

   - Select **MODIFY** > **LOWPASS** from the menu bar.

Or

3. Click the **Lowpass** icon in the toolbar.

Figure 7.7b Lowpass image interface—single monitor

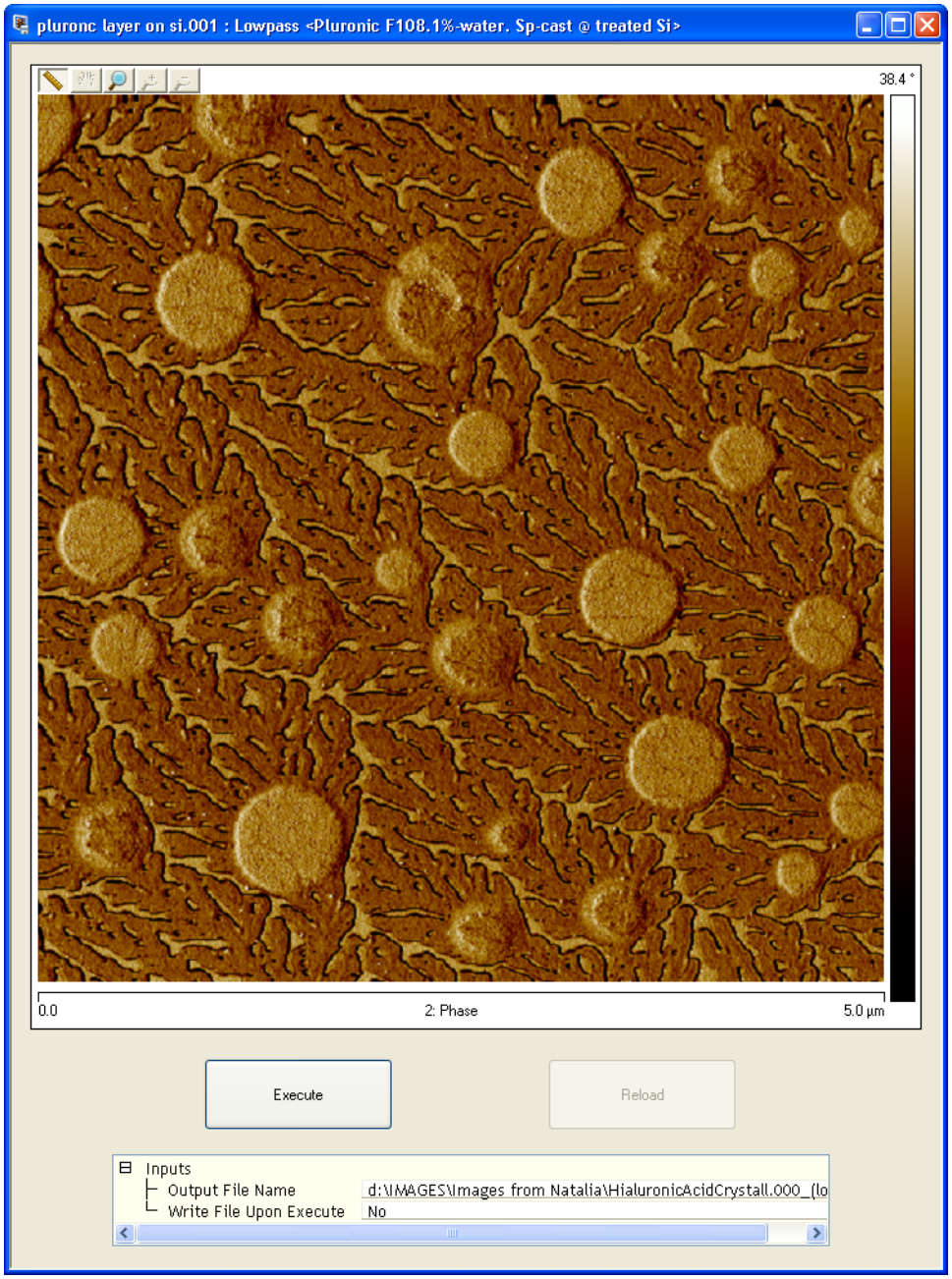
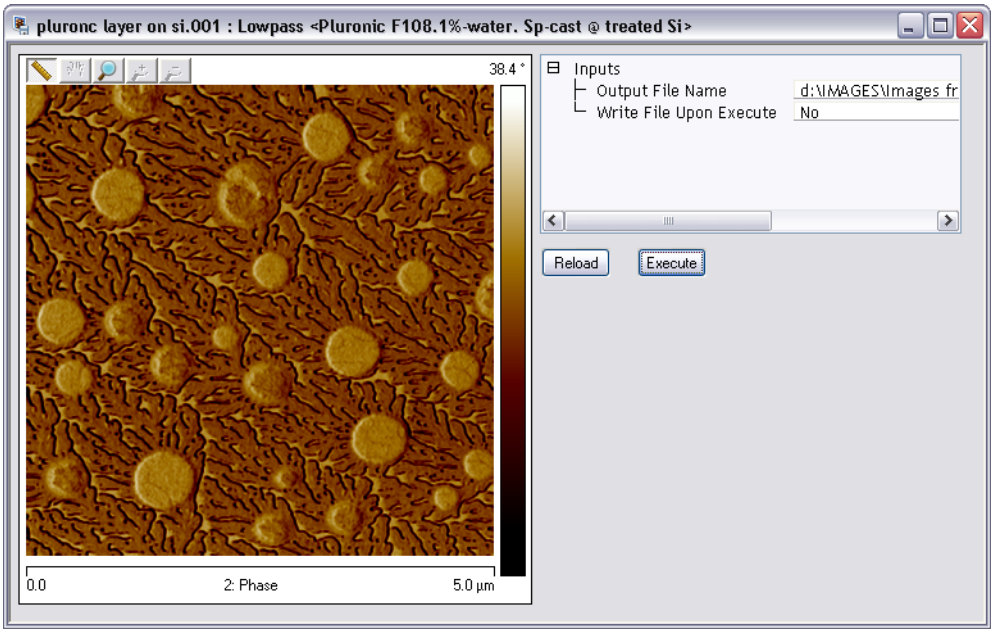


Figure 7.7c Lowpass image interface—dual monitor



4. Select the **OUTPUT FILE NAME**.

5. Click the **Execute** button in the **Lowpass** window to apply the low pass function to the copy of the image in both windows.

6. To restore the unprocessed image, click the **Reload** button.

   Note: There are no parameter controls for the **Lowpass** modify command.

7.8 Median

The **Median** modify command is similar to **Lowpass**; it reduces the contributions of high spatial frequency, reducing contrast in regions of high contrast. For each pixel in an image, **Median** substitutes the median pixel value of the n×n array of pixels centered around that pixel. The size of the filter's sliding window pixel array is set under **Inputs** > **Median Order**. Figure 7.8a illustrates the effect of three different size pixel arrays applied to the same image.

Figure 7.8a Different pixel arrays of the same image—single monitor

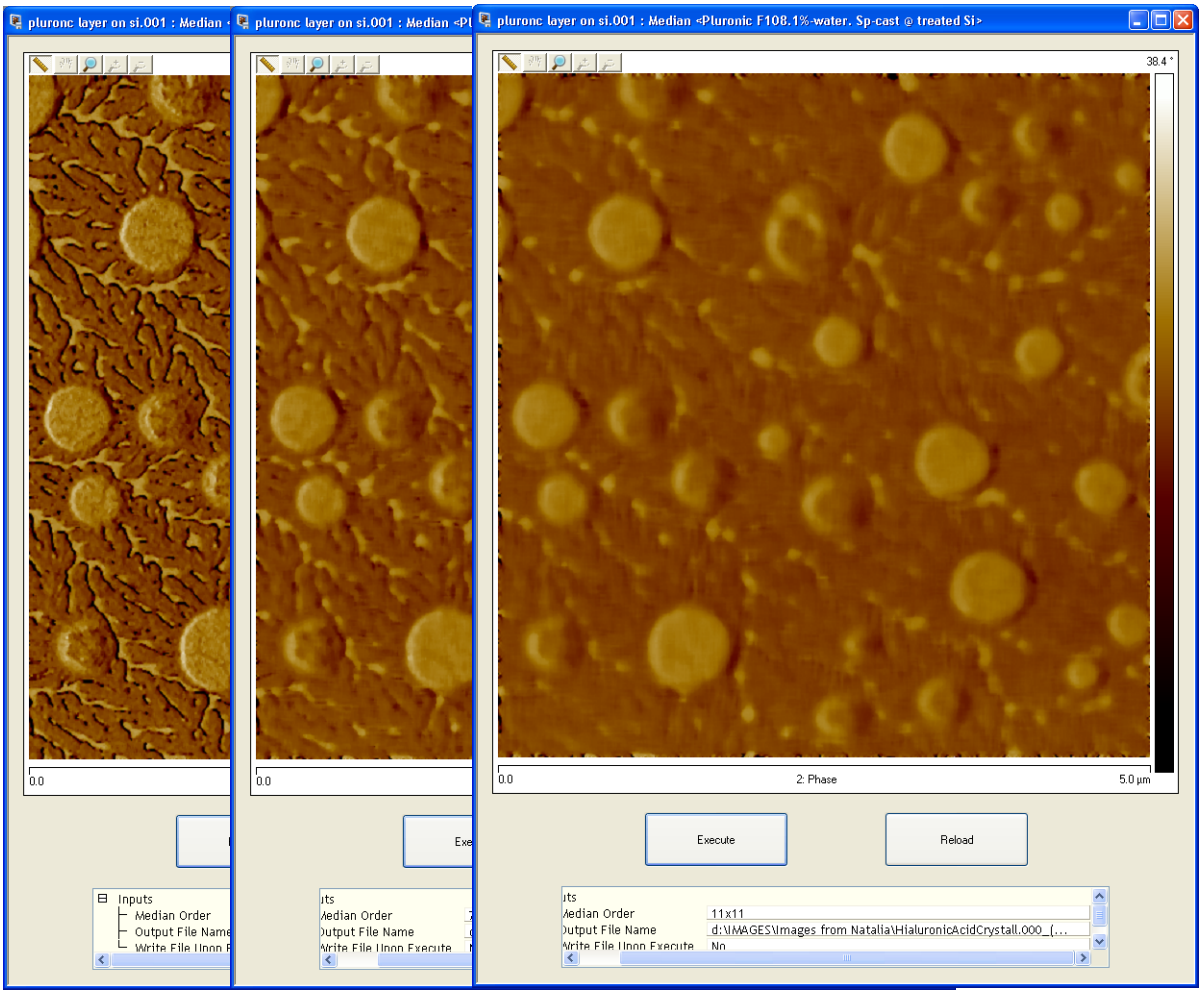
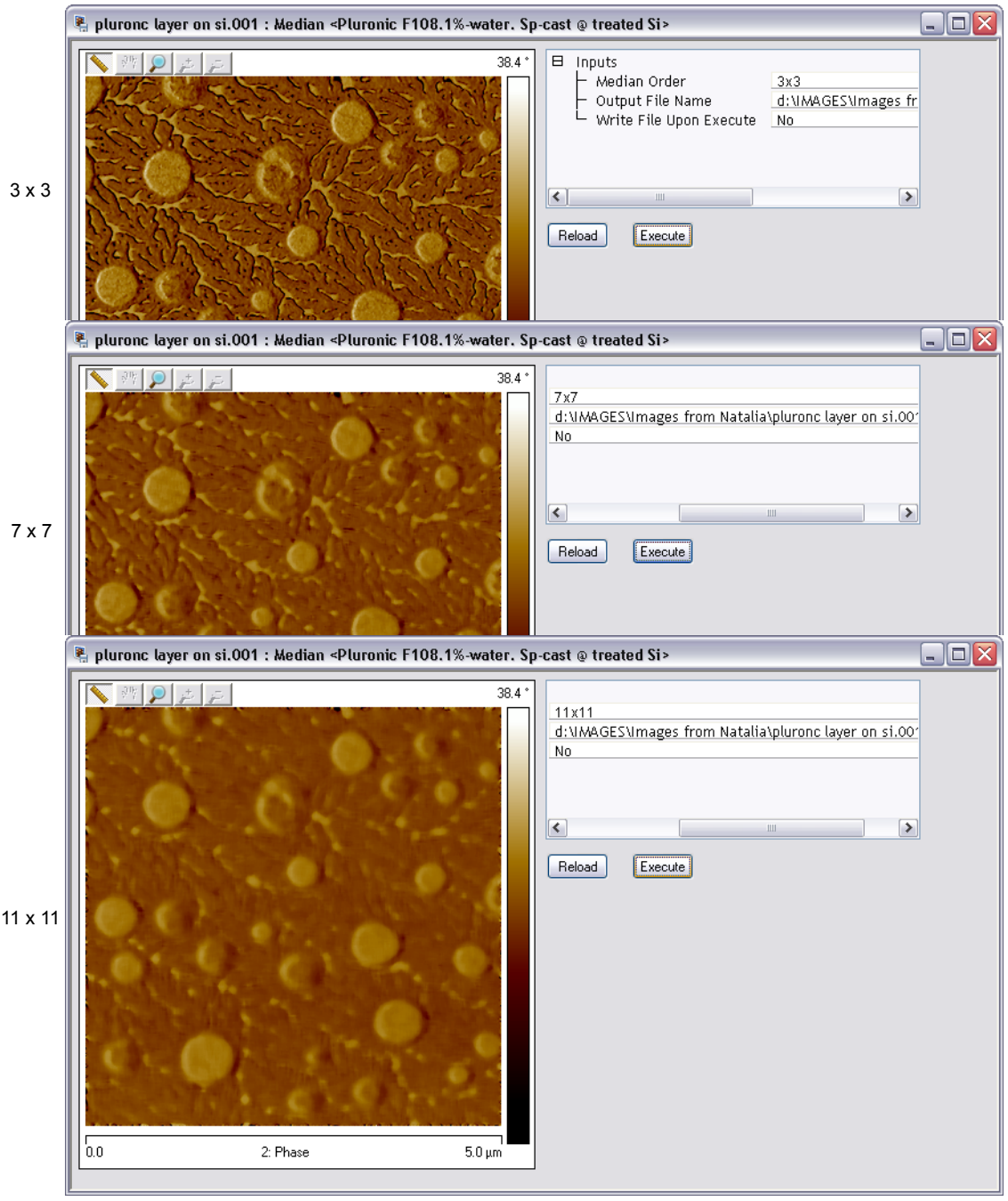


Figure 7.8b Different pixel arrays of the same image—dual monitor

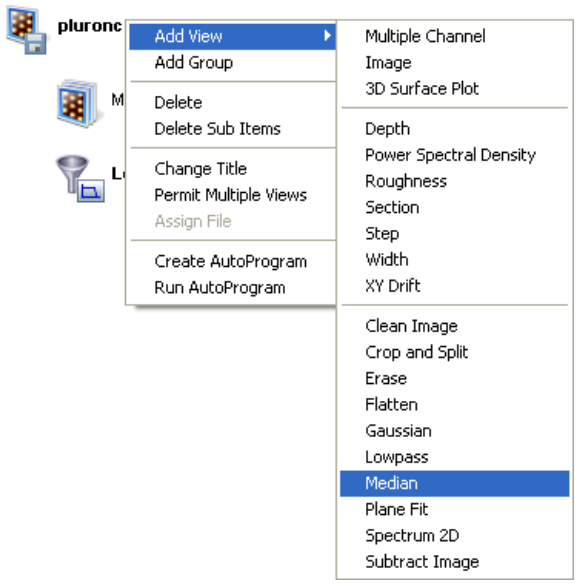


1. Select an image file from the file browsing window at the right of the main window. Double-click the thumbnail image to select and open the image.

2. You can open the **Median** view, shown in Figure 7.8a, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Median** from the popup menu. See Figure 7.8c.

Figure 7.8c Select **MEDIAN** from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **MEDIAN**.

Or

   - Select **MODIFY** > **MEDIAN** from the menu bar.

Or

3. Click the **Median** icon in the toolbar.

4. Select the **Median Order** from the **Inputs** menu: 3×3, 5×5, 7×7, 9x9, or 11×11.

5. Choose an **Output File Name**.

6. Click **Execute** to apply the **Median** filter.

7. Click **Reload** to start over.

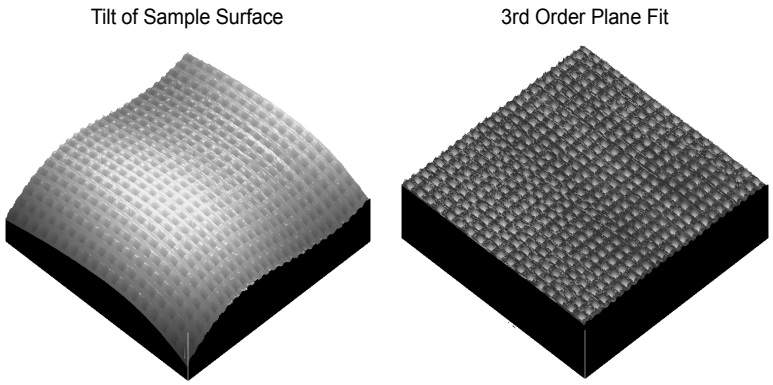
7.9 Plane Fit

The **Plane Fit** command computes a single polynomial of a selectable order for an image and subtracts it from the image. The **Plane Fit** operation can be applied to either or both of the XY directions.

Box cursors or passbands allow specific points to be used in the calculation of the polynomial. Click on the image to start drawing a passband box. Right-click on a box to delete it or change its color.

Figure 7.9a illustrates an image with tilt and bow which could affect the analysis of the surface data.

Figure 7.9a Visual Representation of Plane Fit



Refer to the following sections on **Plane Fit** analysis:

- **Fitted Polynomials:** Section 7.9.1
- **Plane Fit Procedures:** Section 7.9.2
- **Plane Fit Interface:** Section 7.9.3

7.9.1 Fitted Polynomials

Refer to Table 7.9a to view the polynomials that calculate the best plane fit for the images in the Plane Fit Auto function.

Table 7.9a Plane Fit Auto Equations

Order	Variable	Polynomial Equation
0	X	$z = a$
	Y	$z = a$
	XY (Add Higher Order Cross Terms for XY OFF)	$z = a$
	XY (Add Higher Order Cross Terms for XY ON)	$z = a$
1	X	$z = a + bx$
	Y	$z = a + by$
	XY (Add Higher Order Cross Terms for XY OFF)	$z = a + bx + cy$
	XY (Add Higher Order Cross Terms for XY ON)	$z = a + bx + cy + dxy$
2	X	$z = a + bx + cx^2$
	Y	$z = a + by + cy^2$
	XY (Add Higher Order Cross Terms for XY OFF)	$z = a + bx + cy + dxy + ex^2 + fy^2$
	XY (Add Higher Order Cross Terms for XY ON)	$z = a + bx + cy + dxy + ex^2 + fy^2 + gxy^2 + hx^2y + ix^2y^2$
3	X	$z = a + bx + cx^2 + dx^3$
	Y	$z = a + by + cy^2 + dy^3$
	XY (Add Higher Order Cross Terms for XY OFF)	$z = a + bx + cy + dxy + ex^2 + fy^2 + gxy^2 + hx^2y + jx^3 + ky^3$
	XY (Add Higher Order Cross Terms for XY ON)	$z = a + bx + cy + dxy + ex^2 + fy^2 + gxy^2 + hx^2y + ix^2y^2 + jx^3 + ky^3 + lxy^3 + mx^2y^3 + nx^3y^3 + ox^3y + px^3y^2$

7.9.2 Plane Fit Procedures

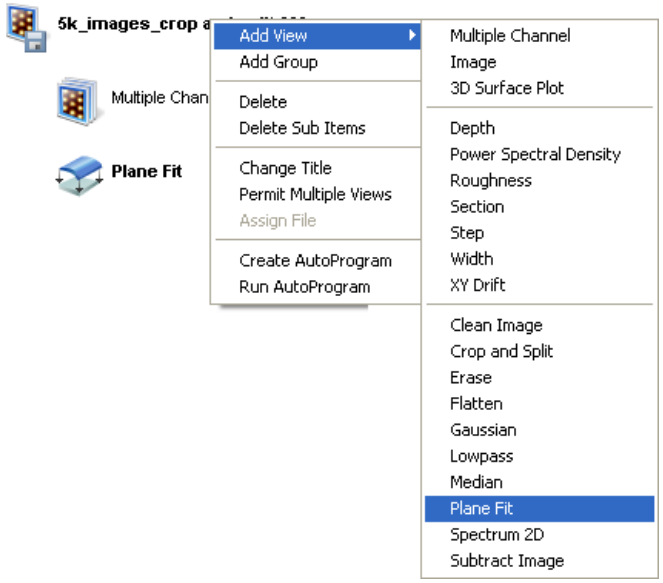
Use **Plane Fit** to correct the image distortion as follows:

1. Select an image file from the file browsing window at the right of the main window. Double-click the thumbnail image to select and open the image.

2. You can open the **Plane Fit** view, shown in Figure 7.9d, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Plane Fit** from the popup menu. See Figure 7.8c.

Figure 7.9b Select **PLANE FIT** from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **PLANE FIT**.

Or

   - Select **MODIFY** > **PLANE FIT** from the menu bar.

Or

3. Click the **Plane Fit** icon in the toolbar.

4. The **Plane Fit** input parameters appear along with the top view image.

5. Select **X**, **Y**, or **XY** as the **Plane Fit Mode**.

6. Select the **Plane Fit Order** as **0TH**, **1ST**, **2ND** or **3RD**.

7. Click **Execute**.

8. Notice that the image distortion is removed, reflecting a flat, planar profile.

Figure 7.9c Saddle Image Before Plane Fit

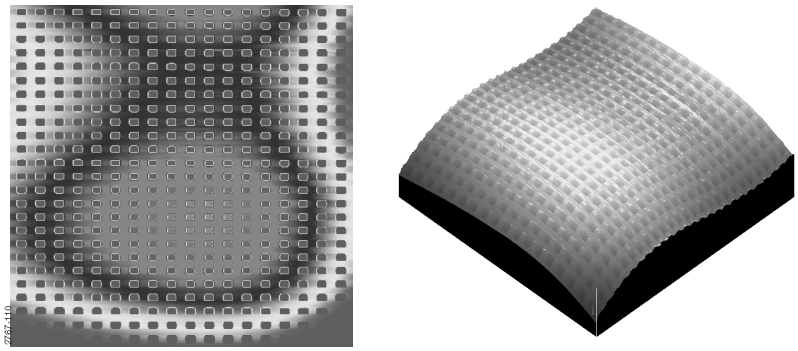


Figure 7.9d Plane fit view—single monitor

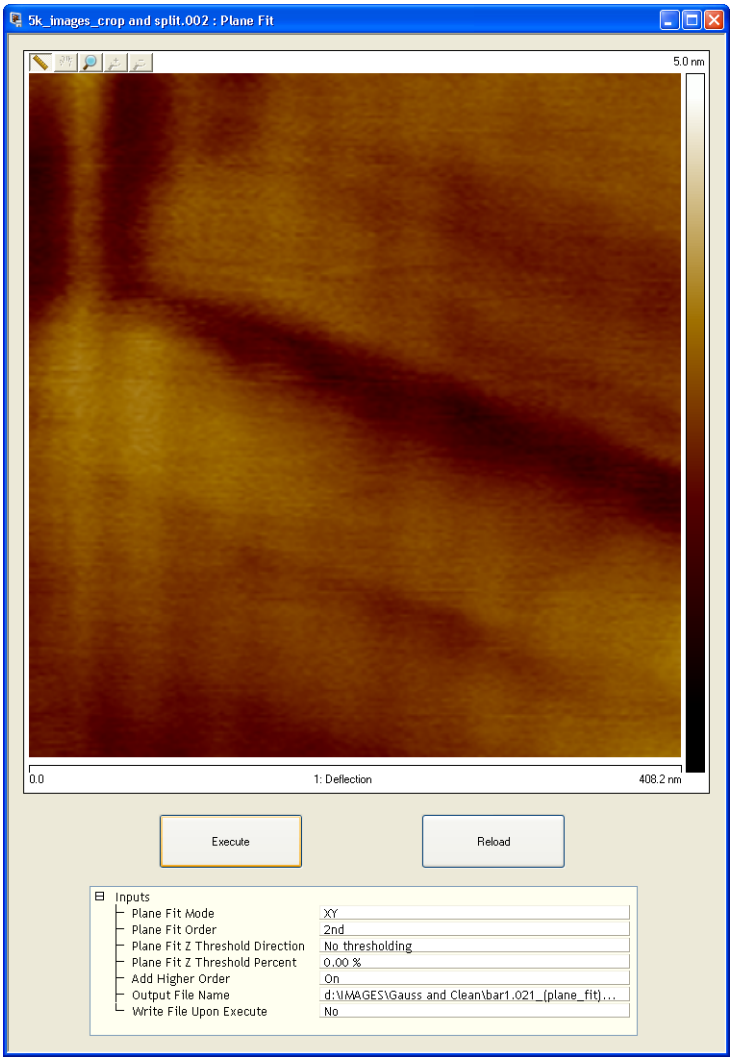


Figure 7.9e Plane fit view—dual monitor

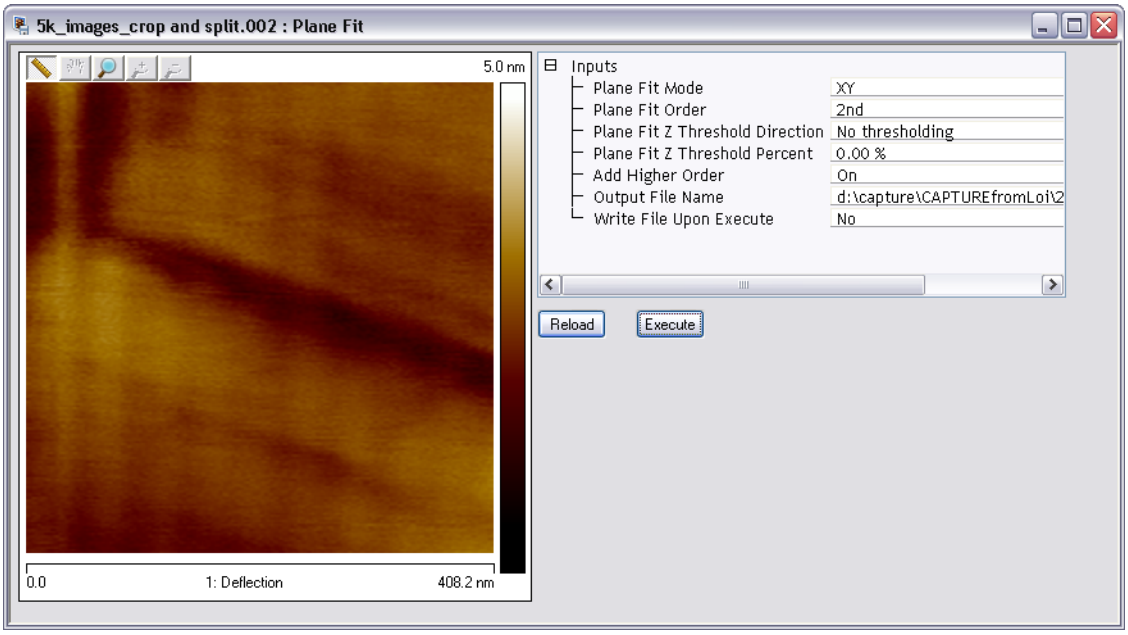
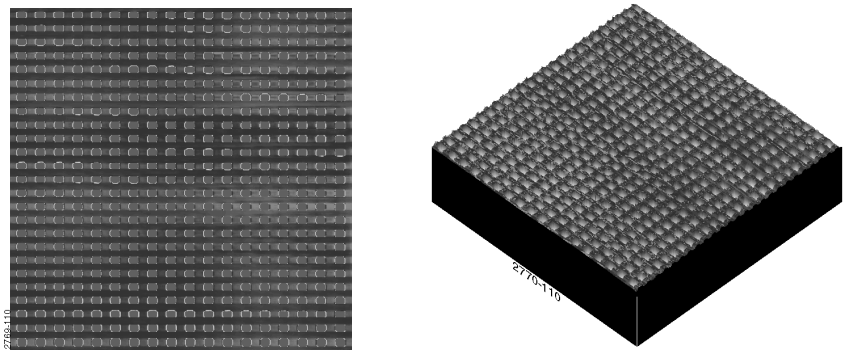


Figure 7.9f Plane Fit Image



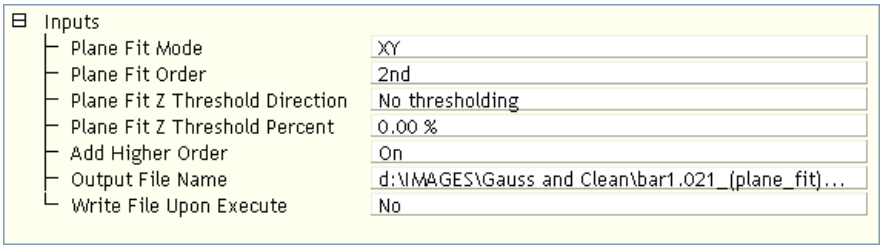
Now, experiment with this image to explore the range of **Plane Fit** capabilities. Try the following:

- Change the **Plane Fit Order** value to see its effects. Notice that there is a vast difference between a value of **1**, **2** or **3**.
- Try plane fitting in one axis (for example, X), but not the other. This generally keeps whatever distortions are presently oriented along the unused axis. For example, the image can be straightened along its Y axis, while leaving the X axis strongly bowed.
- Try using a different **Plane Fit Order** for the X and Y axis (for example, a setting of **3** for X, but a setting of **1** for Y.) This is similar to using one axis, but not the other.
- Compare the effect of **Plane Fit** with **Flatten**. Notice that each command has a significantly different impact; although, the difference is less noticeable for some types of images.

7.9.3 Plane Fit Interface

The **Plane Fit** dialog box, shown in Figure 7.9g, allows the display parameters and the **Plane Fit Order** to be adjusted to your preferences.

Figure 7.9g Plane Fit Inputs Dialog Box



Input Parameters:

Plane Fit Mode — **X**, **Y**, **XY**

Plane Fit Order — Selects the order of the plane calculated and subtracted from the image.

Settings:

- 0th—centers data.
- 1st—removes tilt.
- 2nd—removes 2nd order bow.
- 3rd—removes 3rd order bow.

Z Thresholding direction — Specifies the range of data to be used for the polynomial calculation based on the distribution of the data in Z:

Range or Settings:

- **Use Z > =** —Uses the data whose Z values are greater than or equal to the value specified by the Z thresholding %.
- **Use Z <**—Uses the data whose Z values are less than or equal to the value specified by the Z thresholding %.
- No Thresholding—Disables all thresholding parameters.

Z Thresholding Percent — Defines a Z value as a percentage of the entire Z range in the image (or data set) relative to the lowest data point.

Add Higher Order — Turning this on adds higher order cross terms to the polynomial fit when XY is chosen (see Table 7.9a).

Output File Name — Select the path of the extracted image file. Leave blank for immediate view/use without saving the altered image file.

Write File Upon Execute — Writes the output file(s) when the Create File(s) button is clicked.

Buttons on the Plane Fit Window:

Execute — Initiates the plane fit operation.

Reload — Restores the image to its original form.

7.10 Spectrum 2D

The **Spectrum 2D** (two-dimensional) function transforms images into the frequency domain via a 2D fast Fourier transform (FFT), then allows you to selectively pass or remove specific frequencies from the image. After selected frequencies are passed or removed, the image is reconstructed, yielding an improved version. The **Spectrum 2D** function is extremely useful in removing electrical and acoustic noise from images, and may also be used to isolate certain surface features (e.g., lathe lines on turned surfaces, load marks on ground or polished surfaces, etc.).

Noise removable using the **Spectrum 2D** function generally consists of two types: [1] high frequency electrical noise (most visible at atomic resolution); [2] lower-frequency acoustic noise from floor vibrations, air blowers, etc. The 2D spectral display is scaled according to the scan size of the original image

7.10.1 Spectrum 2D Procedures

Before beginning, it is advisable to make a backup copy of the original image file. The **Spectrum 2D** function is capable of making major changes to the image which, if saved, can destroy the original data.

The **Spectrum 2D** command allows filtering of images in the frequency domain through the 2-dimensional fast Fourier transform (FFT). The 2-D FFT (power spectrum) of the image is calculated and displayed. As the cursor is moved through the 2D plot, instantaneous results are displayed. Rectangular boxes representing either frequencies to pass (multiply by 1.0), passband, or frequencies to stop (multiply by 0.0), stopband, can then be selected. Finally, the inverse transform is performed on the filtered transform data to reconstruct a new filtered image.

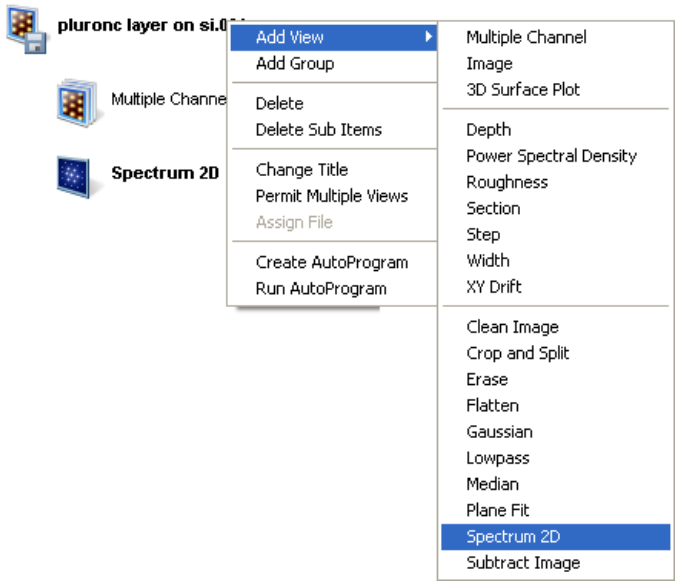
Use **Spectrum 2D** to correct the image distortion as follows:

1. Select an image file from the file browsing window at the right of the main window. Double-click the thumbnail image to select and open the image.

2. You can open the **Spectrum 2D** view, shown in Figure 7.10b and Figure 7.10d, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Spectrum 2D** from the popup menu. See Figure 7.10a.

Figure 7.10a Select **SPECTRUM 2D** from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **SPECTRUM 2D**.

Or

   - Select **MODIFY** > **SPECTRUM 2D** from the menu bar.

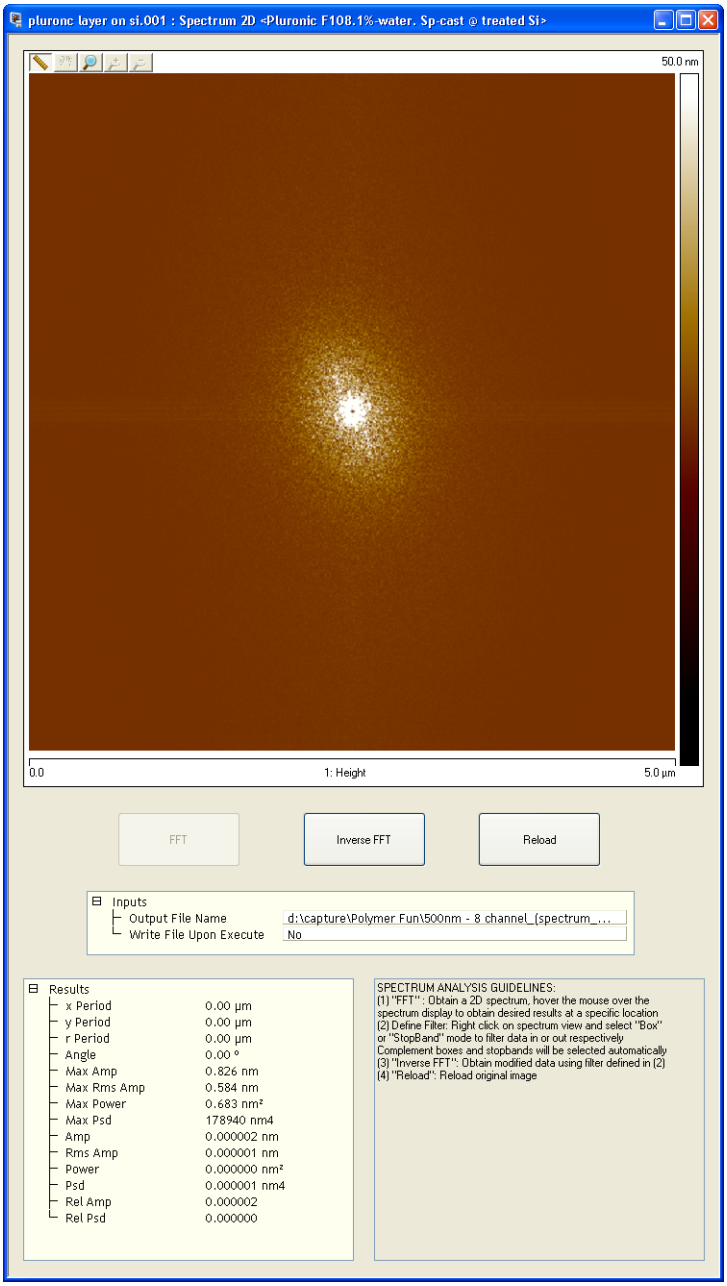
Or

3. Click the **Spectrum 2D** icon in the toolbar.

7.10.2 Spectrum 2D View

The **Spectrum 2D** view, shown in Figure 7.10b and Figure 7.10d, allows display parameters to be adjusted to your preferences.

Figure 7.10b The Spectrum 2D View



A spectrum 2D (FFT) image of alkane, $C_{60}H_{122}$, is shown in Figure 7.10d. The fundamental period is approximately 7.5nm.

Figure 7.10c Image of alkane $C_{60}H_{122}$

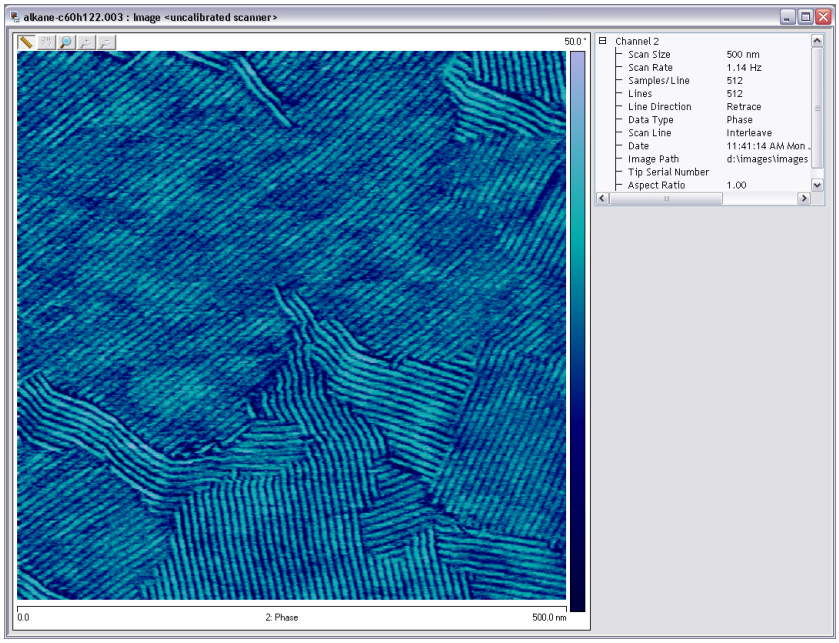
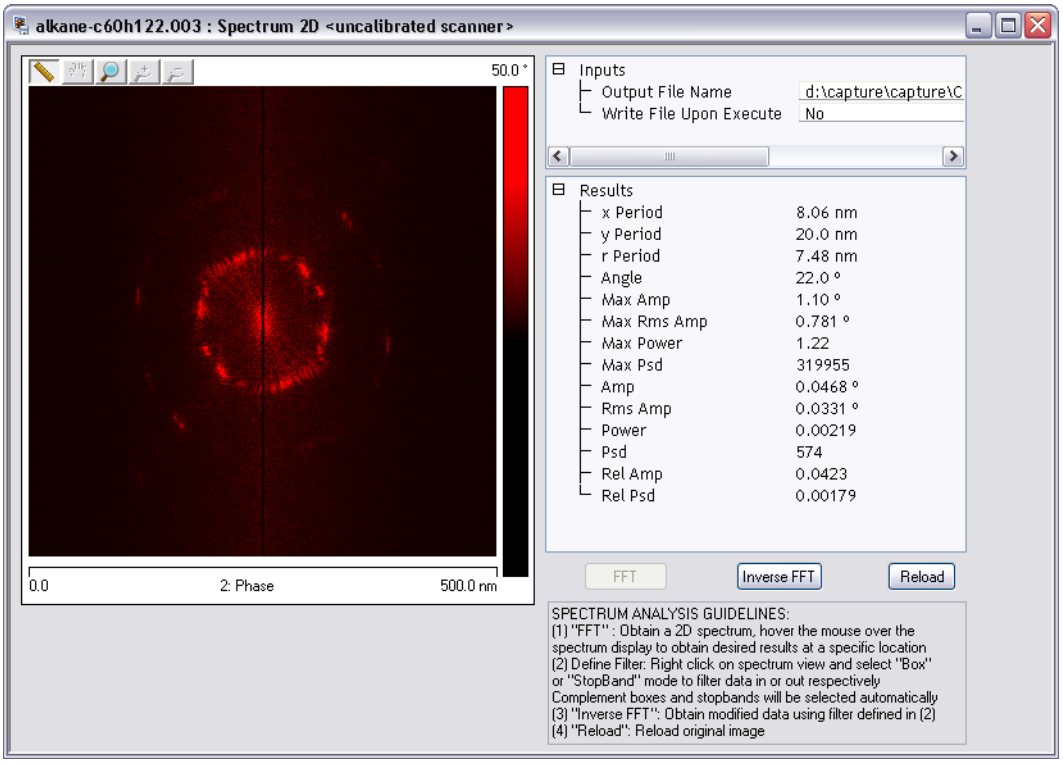


Figure 7.10d Spectrum 2D analysis of image of Figure 7.10c—dual monitor view



Input Parameters in the Spectrum 2D Panel

Output File Name	Select the path of the modified image file.
Write File Upon Execute	Writes the output file(s) when the Create File(s) button is clicked.

Buttons in the Spectrum 2D Panel

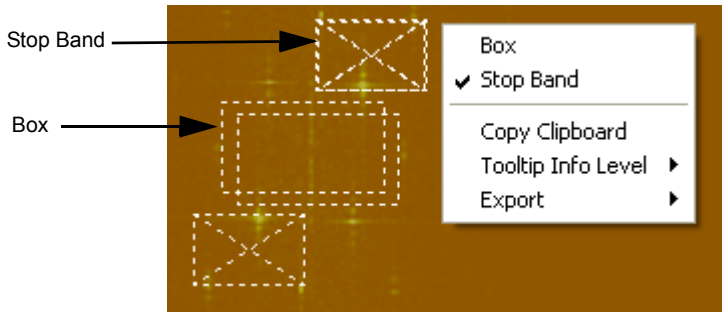
FFT	Initiates the two-dimensional FFT calculation.
INVERSE FFT	Computes the modified image using the filter parameters defined in the FFT step.
RELOAD	Reloads the original image.

Controls in Spectrum 2D

Right-clicking an image in a **Spectrum 2D**, shown in Figure 7.10e, window:

BOX	Puts the mouse in the passband mode. This allows placement of passband boxes which set the frequency data outside the boxes to zero. Data inside the boxes is passed.
STOP BAND	Puts the mouse in the stopband mode. This allows placement of stopband boxes which set the frequency data within the boxes to zero. The data outside of the boxes is passed. Stop-bands appear on the top view image as "X-ed" rectangles.

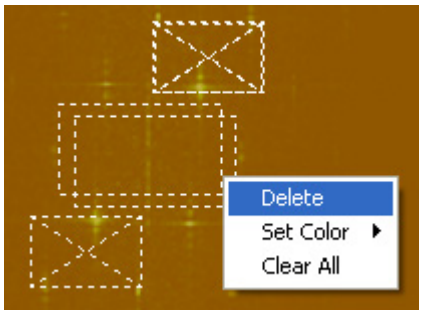
Figure 7.10e Select **BOX** or **STOPBAND**



Right-clicking inside a **BOX** or **STOP BAND** box in an (Fourier transformed) image, shown in Figure 7.10f, window:

DELETE	Erases the passband Box or Stopband box that enclose the cursor.
CLEAR ALL	Deletes all passband Box and Stopband boxes.
SET COLOR	Allows you to set the cursor and/or box colors.

Figure 7.10f **DELETE**, **SET COLOR** and **CLEAR ALL** buttons are active inside a passband or **STOPBAND** window.



Results Parameters in Spectrum 2D

X PERIOD	Spatial frequency in the x direction. The lowest frequency is at the center of the plot.
Y PERIOD	Spatial frequency in the y direction. The lowest frequency is at the center of the plot.
R PERIOD	Spatial frequency in the radial direction.
ANGLE	Arctangent of (y/x).
MAX AMP	The maximum amplitude (0-peak) of the transformed image.
MAX RMS AMP	The maximum of the RMS amplitude of the transformed image.
MAX POWER	The maximum power of the transformed image.
MAX PSD	The maximum power spectral density of the transformed image.
AMP	The amplitude of the 2D FFT at that spatial frequency.
RMS AMP	Amp/(sqrt(2))
POWER	$\text{Amplitude}^2 = (\text{2D FFT})^2$
PSD	Normalized power spectrum per number of points = $(\text{2DFFT} * \#\ x\_points * \#\ y\_points)^2/(\#\ x\_points * \#\ y\_points)$
REL AMP	Amplitude/(Max Amplitude)
REL PSD	PSD/(Max PSD)

Hints for Optimizing the Spectrum 2D Command

- If any passband boxes exist on the display, then data outside the passband boxes is deleted. Thus, it is superfluous to have a stopband box completely outside the confines of a passband box.
- Due to the symmetry of the transformed data about the line $f_x = -f_y$, all stopband and passband boxes drawn actually produce two boxes on the display.

See also: **Offline/Modify** menu: **Lowpass:** Section 7.7 command.

7.10.3 Example 1—Simplifying an Image

Regarding data contained within an image, *more* data is not always better. Sometimes it is desirable to *eliminate* components of an image to better isolate and accentuate another component of direct interest. The following example demonstrates how to utilize the Spectrum 2D function to simplify an image for analysis. The image utilized here is of lathed plastic used in the manufacture of contact lenses.

1. Load an image from the IMAGES DIRECTORY (or in the IMAGES folder on your installed system). Examine the image using the **3D Surface Plot** (see **3D Surface Plot:** Section 5.2) function.

Supposing you want to make a general, cross-sectional inspection of the sample's lathe lines, it may prove helpful to remove spikes and smaller, jagged features on the surface. Notice the surface topology may be analyzed in terms of two dominant influences: 1) lathe lines running parallel to the image's Y-axis; 2) a contiguous, jagged aspect to each lathe line (i.e., the lines themselves are not smooth streaks, but present a jagged profile along their length). Because the parallel lathe lines occur at longer wavelengths than the short-wavelength, jagged bumps and spikes, it is possible to separate these components using 2D spectral analysis.

2. With the image selected, click the **Spectrum 2D** icon. The **Spectrum 2D** panel appears as does the image. Click the **FFT** button.

The 2D spectrum of the image appears in the **Spectrum 2D** image window as a clustering of data having a narrow, horizontal band. This horizontal band reveals the prominence of the parallel lathe lines, and the fact that they are distributed uniformly along the X-axis of the image.

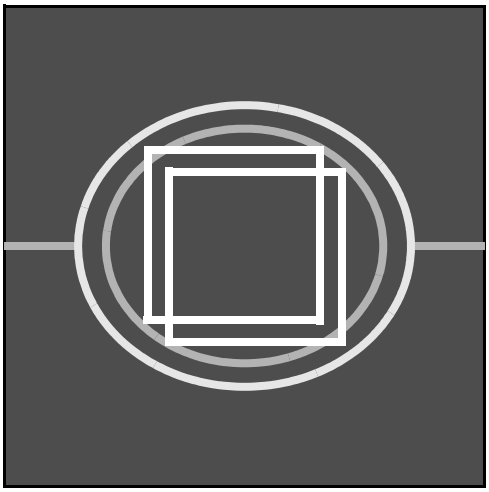
As the cursor is moved through the 2D plot, the **x period**, **y period** and **r period** values are displayed in a box to the right of the plot. Moving the cursor through the data cluster reveals that shorter wavelengths lie around the periphery of the plot, while longer wavelengths lie near the plot's center. Notice that the plot is bandwidth limited at its exact center; that is, nothing larger than the scan size of the image may be plotted here.

> **Note:** The term "wavelength" as used throughout refers to actual surface features, NOT the color of light used to represent those features.

The trick to using 2D spectral filtering lies in first identifying wavelength components of interest to you. This requires some interpretive ability on your part and is perfected with practice. When the sought-after component is identified, all that remains is to remove everything else.

One use of 2D spectral modification is in removing high frequency components, commonly referred to as "noise." (Whether the component is referred to as "noise," or simply as "high frequency features" of an image is analogous to whether or not to call unwanted plants "weeds.") High frequency components are rendered on images as finely spaced, jagged lines, spikes and fuzz.

Assuming you want to remove high frequency noise, you would seek to eliminate outer portions of the plot. This is easily done with the **Spectrum 2D** function by enclosing the central cluster of the plot within a passband drawn on the transformed image.



The objective here is to pass (allow) the central, longer wavelength portions of the plot, while stopping (disallowing) the shorter wavelength components located around the periphery of the plot. The **x period** and **y period** of the enclosed area are displayed to the right as the boxes are drawn.

3. Click on **Cursor / Box**, then draw a passband box around the central portion of the 2D spectral plot. Click **INVERSE FFT** to reconstruct the image with the high frequency components removed. To obtain the best view of the image, click on the **Image / 3D Surface Plot** function (or **3D Surface Plot** icon). Changes to the image are most obvious when viewing from an elevated angle.

When the image is reconstructed with its high frequency components removed, the most obvious change is smoother, more contiguous image features. Jagged lines and spikes are reduced, accentuating the longer wavelength features.

> **Note:** Filtering may also be accomplished by utilizing the **Modify** > **Lowpass** filter, although *without* selective wavelength controls.

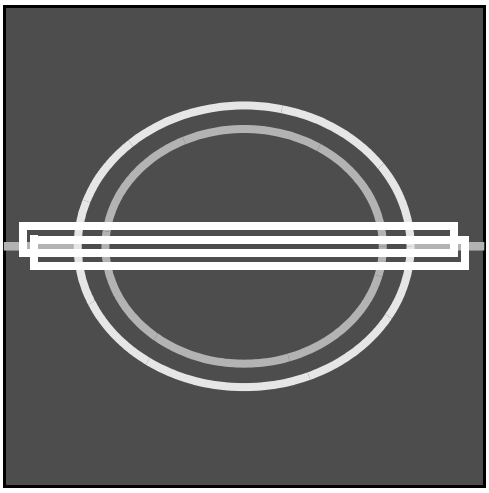
7.10.4 Example 2—Highlighting Features Using 2D Spectrum Modification

Another use of the Spectrum 2D function is in highlighting certain surface features by filtering out unwanted wavelengths. Continuing with the example of the lathed plastic, it is possible to isolate and accentuate lathe lines. (This might prove useful to an analyst intending to examine how cutting tool geometry imparts features to the surface of the plastic.) Conversely, it may also be used to isolate and accentuate smaller surface features inherent within lathe lines, while reducing the separation between lines.

1. Reload the image file used in Section 7.10.3; but *do not* save the previously filtered version of the image. When the image is reloaded, select the **Modify** > **Spectrum 2D** function, then click on the **FFT** button. As before, the 2D spectrum of the image is plotted. To isolate the

lathe lines, draw a thin, horizontal passband box across the center of the plot (see Figure 7.10g).

Figure 7.10g Horizontal Passband Box Illustration

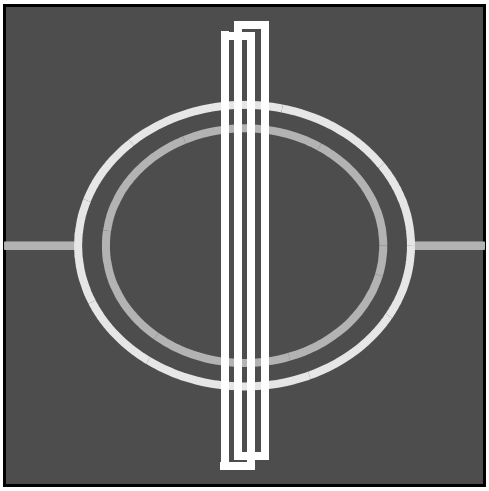


The intent is to pass most wavelengths inherent in the horizontally distributed lathe lines, while stopping those wavelengths inherent in the vertically distributed features of each line (i.e., the jagged contour running along each individual line). After the passband box is drawn, click on the **Inverse FFT** button to reconstruct the image. Use the **Image** > **3D Surface Plot** function to look closer at the reconstituted image. The change in the image quickly becomes evident; lathe lines stand out more dramatically and have been smoothed along their length. By analyzing a section across the lathe lines **ANALYSIS** > **SECTION**, a cleaner profile of lathe lines in the plastic is obtained.

The vertically distributed features of the lathe lines may be similarly examined by filtering out the horizontal components. By drawing a passband box vertically, it is possible to isolate and accentuate the features running along each individual lathe line (see Figure 7.10h)

Note: This type of analysis might prove helpful in a study of how tool chatter affects the surface, without regard to tool geometry.

Figure 7.10h Vertical Passband Box Illustration



7.10.5 Example 3—Removing External Noise

In Example 1 above (see Section 7.10.3), high frequency surface noise was removed by drawing a passband around the center spectral plot of the image. This type of noise tends to be evenly distributed across the surface and is inherent to the surface itself. Another type of noise is externally introduced, either due to electrical noise (especially during extremely high resolution, atomic scans), or due to acoustic noise introduced from air blowers, loud sounds, etc. Distinguishing one type of noise from another requires some experience. Here are a few guidelines.

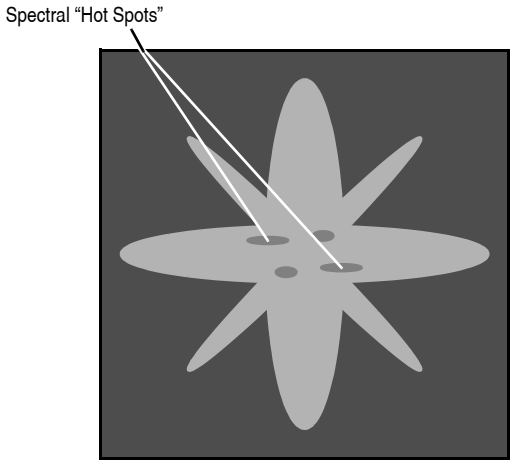
- Steady acoustic noise (such as from a constant pitch sound or moving air) and steady electronic noise, introduce *diagonal bands* to the image. These bands run parallel and are produced when the noise is introduced in sync with the scan. If the bands change their angle of orientation when the **Scan Size** or **Scan Rate** is altered, they are probably from this source. This type of noise can be easily removed from the image by using the **Spectrum 2D** function.

- Sporadic noise (such as from sudden, loud noises and/or powerful EMF spikes) introduce *isolated "noise lines"* which run partially or completely across the image. These may arise sporadically and without pattern. This type of noise *cannot* be removed from the image using the **Spectrum 2D** function; however, another function, **Modify** > **Erase**, easily removes this type of noise.

- To remove the diagonal bands characteristic of steady acoustic and electronic noise using the **Spectrum 2D** function, do the following:

1. Load the image, then click on the **Modify** > **Spectrum 2D** function. Click the **FFT** button to obtain the image's 2D spectral plot. If the image is of a more or less isotropic surface, search the spectral plot for bright "hot spots"—small islands of high spectral concentration—near its center.

Figure 7.10i Spectrum 2D Hot Spots



Note: Click on the **Zoom / 4:1** function to obtain a closer view of the “hot spots.”

Depending upon the distribution and orientation of the noise bands, the hot spots should be distributed at the same angle in the spectral plot as they are on the image. There may also exist other spectral hot spots which are actually part of the surface features; however, these are usually distributed at some other orientation. If the surface is anisotropic and includes some type of banding features naturally, isolating the noise bands proves more difficult, especially if they run parallel to the noise bands.

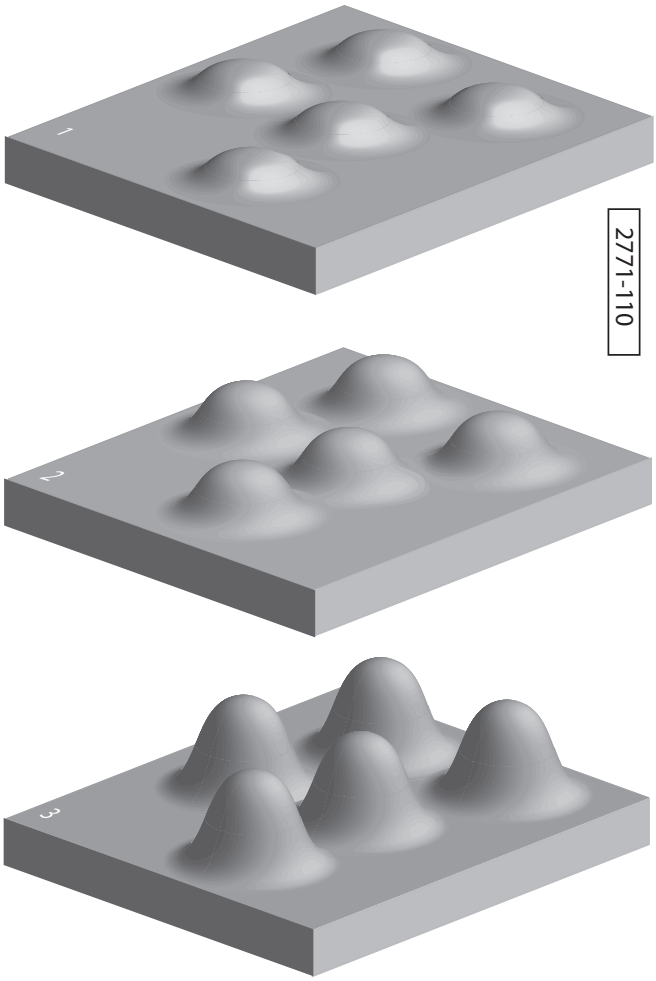
When the hot spots are located, draw a stopband box around them, then click on the **INVERSE FFT** button to reconstruct the image. The image should now appear without the noise bands. If noise bands are still present, click on the **RELOAD** option and try again by stopbanding different hot spots.

7.11 Subtract Image

The **Subtract Image** command enables data from one image to be subtracted from another. This proves most useful when comparing two or more images from a surface to determine changes over time, or to compare completely different images. The **Subtract Image** command cannot be directly applied to images having different pixel sizes (**Number of Samples** value). For example, a 256 x 256 pixel image cannot be directly subtracted from a 512 x 512 image.

Figure 7.11a diagrams an image subtraction and its effects. Surface **2**, when subtracted from surface **3**, yields surface **1** ("**3**" - "**2**" = "**1**"). Conversely, surface **1** plus surface **2** yields surface **3** ("**1**" + "**2**" = "**3**").

Figure 7.11a Effects of Image Subtraction

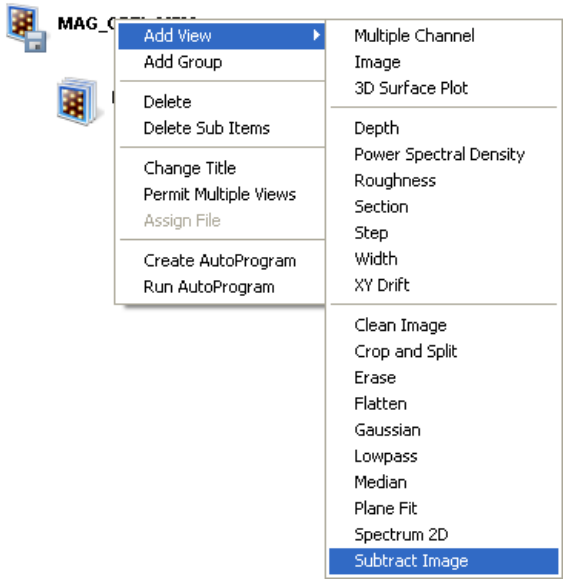


1. Select an image file from the file browsing window at the right of the main window. Double-click the thumbnail image to select and open the image.

2. You can open the **Subtract Image** view, shown in Figure 7.11c, using *one* of the following methods:

   - Right-click on the image name in the **Workspace** and select **Add View** > **Subtract Image** from the popup menu. See Figure 7.11b.

Figure 7.11b Select **SUBTRACT IMAGE** from the workspace



Or

   - Right-click on a thumbnail in the Multiple Channel window and select **SUBTRACT IMAGE**.

Or

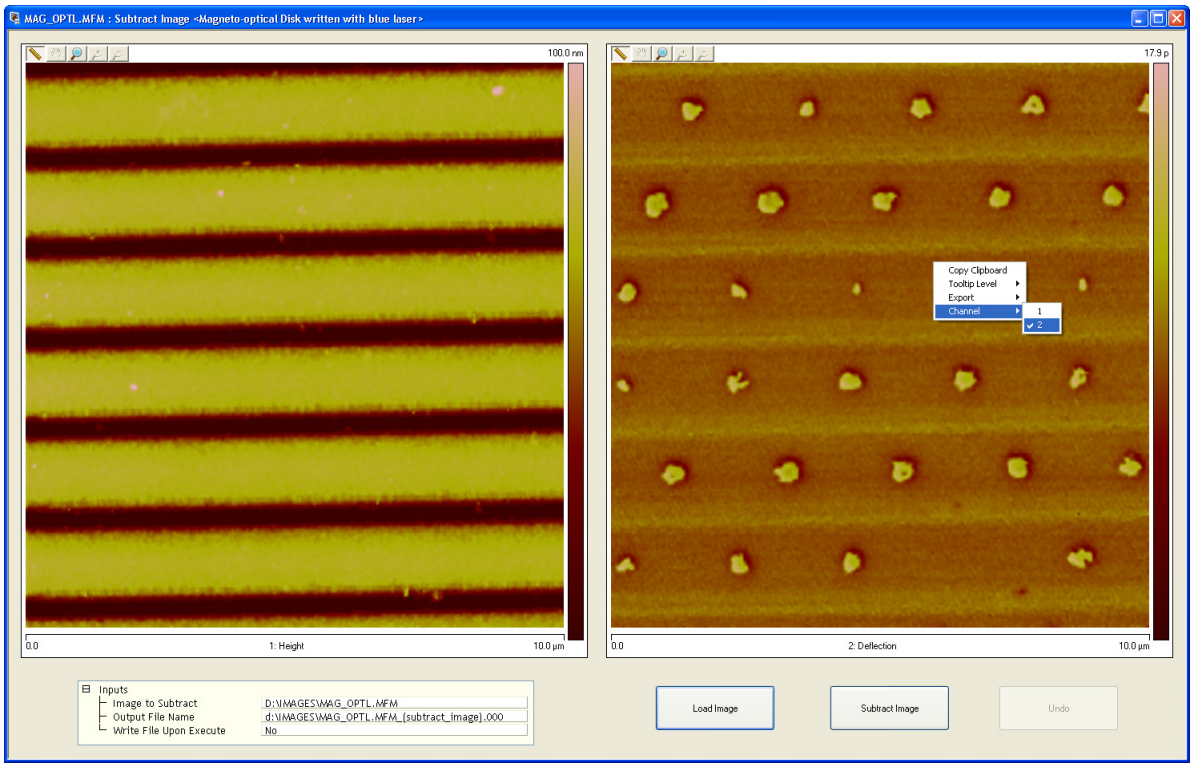
   - Select **MODIFY** > **SUBTRACT IMAGE** from the menu bar.

Or

3. Click the **Subtract Image** icon in the toolbar.

4. The Subtract Image view, shown in Figure 7.11c, opens.

Figure 7.11c Subtract Image view—single monitor



5. Select a file to subtract from the **Inputs** > **Image to Subtract** menu or click the **LOAD IMAGE** button to browse for a file.

6. If necessary, right click in either panel to change the channel.

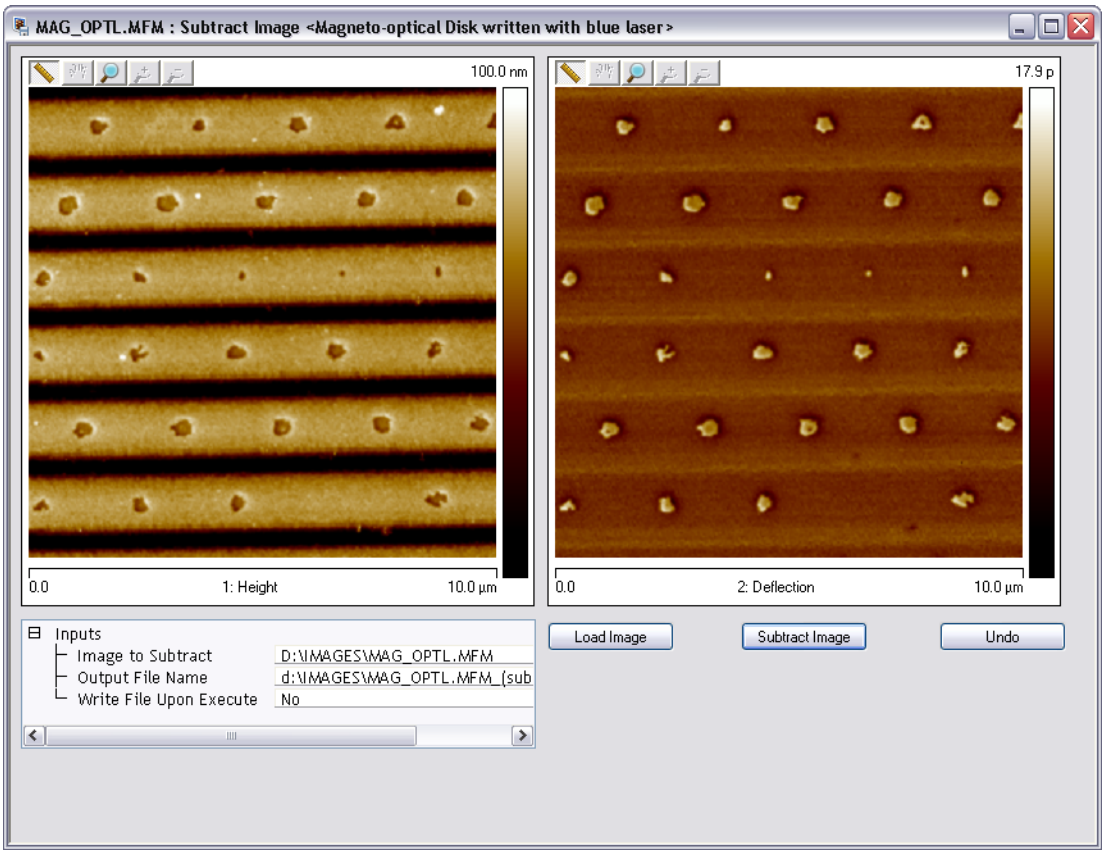
7. Click the **SUBTRACT IMAGE** button to subtract the image in the right panel from the image in the left pane. The result, which overrides the data in the active channel, is shown (see Figure 7.11d) in the left panel of the **Subtract Image** view.

   Note: When Data types are not the same, the calculation is performed as follows:

   - First Image Relative Z scale * first (left) image - Second image Relative Z scale * second (right) image = new image. The Relative Z scale must be greater than - 32767 and less than 32767.

8. Click **Undo** to restore the originally loaded file.

Figure 7.11d Subtract Image after channel 2 (right) was subtracted from channel 1.Dual monitor view.



Chapter 8 AutoProgram

An **AutoProgram** is a sequence of operations that may be applied automatically to at least one previously captured image. Typically, an **AutoProgram** is created to rapidly analyze a large number of images taken under similar conditions. Any **Offline** command except for **XY Drift** and **Subtract Image** may be included in an **AutoProgram**.

Refer to the following functions available in **AutoProgram** menu of the NanoScope software:

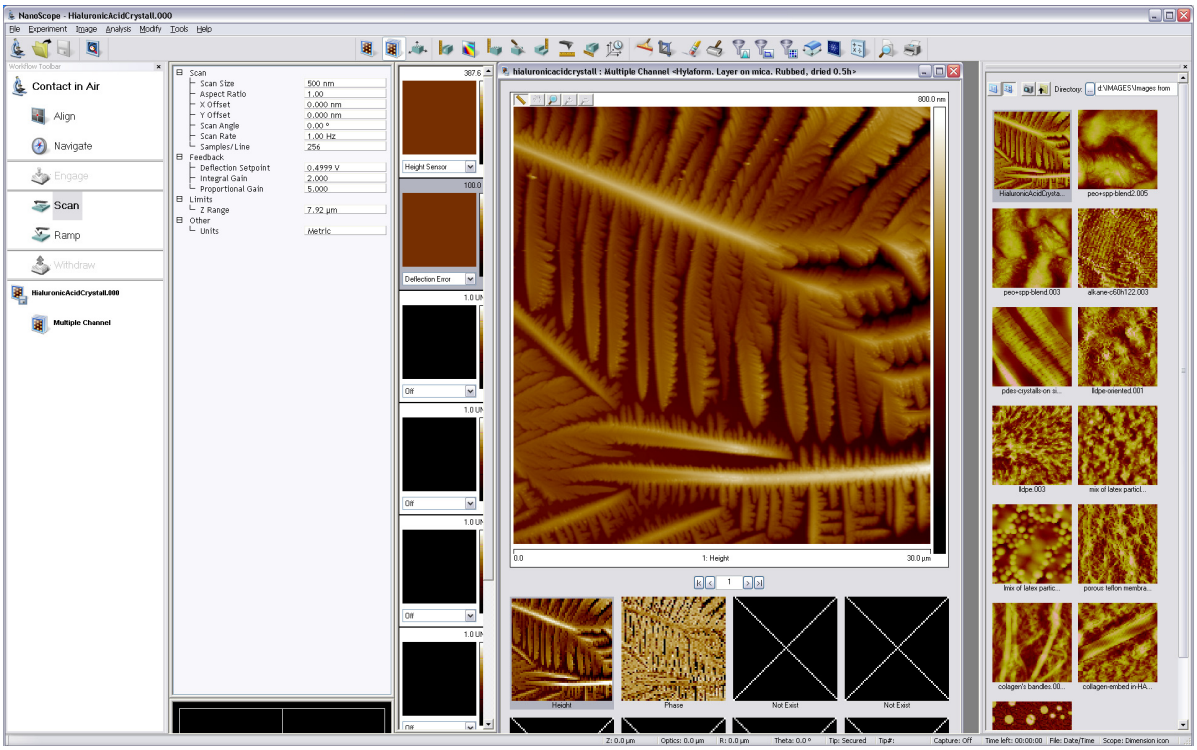
- **Creating an AutoProgram:** Section 8.1
- **Example command: Flatten:** Section 8.2
- **Example command: Depth:** Section 8.3
- **Example command: Roughness:** Section 8.4
- **Running AutoProgram:** Section 8.5

8.1 Creating an AutoProgram

Do the following to create an **AutoProgram**:

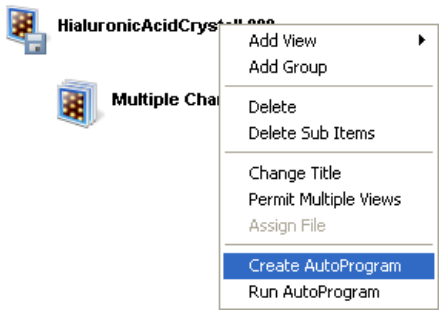
1. Select a directory, then an image file within it, from the file browsing window at the right of the **NanoScope** main window. Double-click its thumbnail to select and open the image. The image file name and the **Offline** icon, as well as a **Multiple Channel** icon and the words Multiple Channel are added to the **Workflow Toolbar (Workspace)**, and the image opens in the viewing window, shown in Figure 8.1a.

Figure 8.1a Open Image



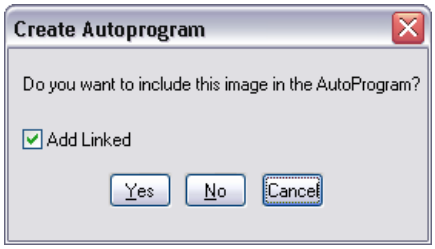
2. In the **Workflow Toolbar**, right-click on the image file name or its **Offline** icon and select **Create AutoProgram** (see Figure 8.1b). You may also right-click on the **Multiple Channel** icon or **Multiple Channel** and select **Create AutoProgram.**

Figure 8.1b Create AutoProgram



3. You are asked if you want to include the selected image to define the AutoProgram among the images processed by the AutoProgram (see Figure 8.1c). (Typically: **YES**.) The **ADD LINKED** box should also be checked. When linking, any changes made to the currently active view will then alter any linked views.

Figure 8.1c Include Selected Image Box



4. In the **AutoProgram Results View** (see Figure 8.1d):

   a. Right-click on **AutoProgram**, under the file name or icon appearing on the line under **Run Group**.

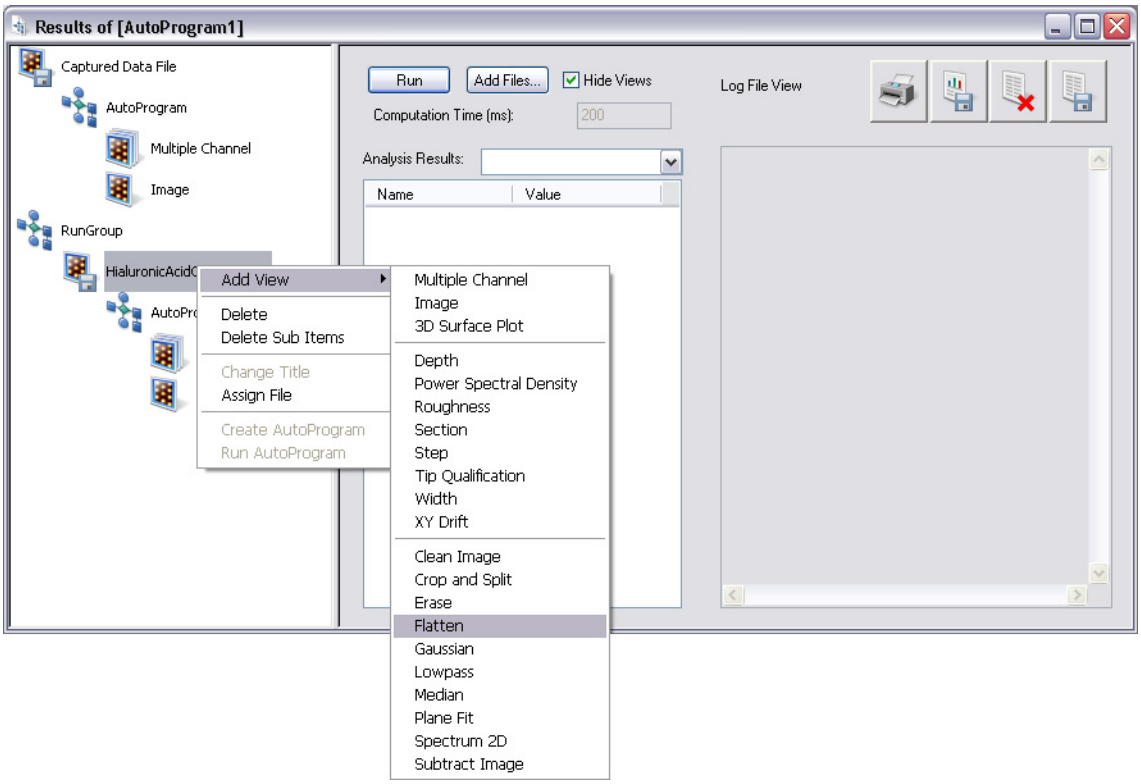
   b. Click **Add View** to add a view to the Autoprogram. This view will then be added to all files in the Autoprogram if they are linked.

   c. Click the view of an **Offline** command to be performed first by the AutoProgram.

   d. Repeat for additional views.

      Note: Example specifications of the **Flatten**, **Depth** and **Roughness** commands for inclusion in an AutoProgram are described next. Similar actions apply to include other **Offline** commands in an AutoProgram.

Figure 8.1d Add Views to be Included in an AutoProgram



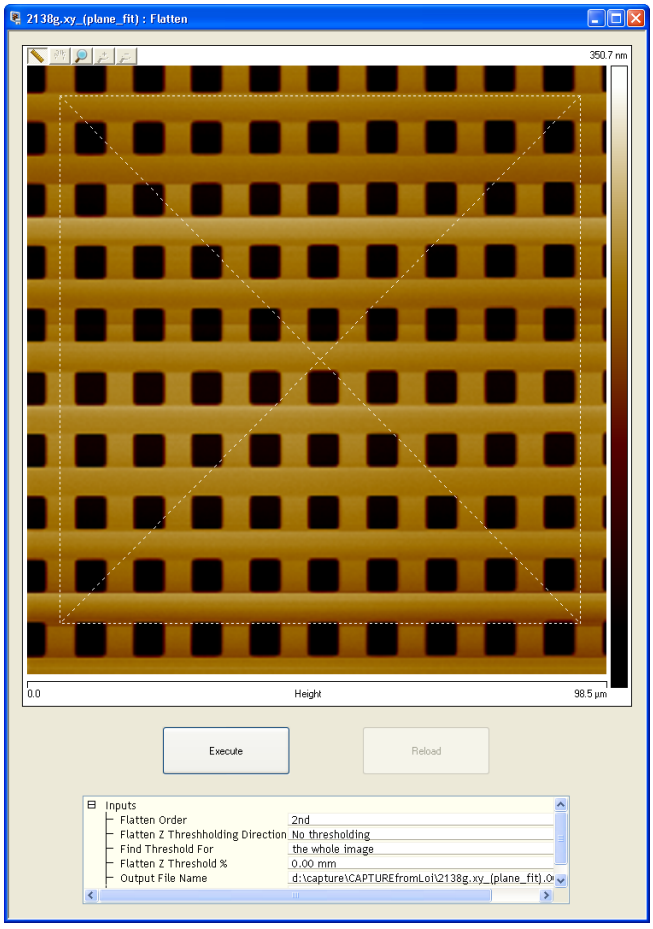
8.2 Example command: Flatten

To open the **Flatten View**:

1. Click the command name or icon that has been added to the **Run Group** Autoprogram.
2. Click in the image and drag open a box over features in the image that are to be excluded from the polynomial fit calculations (see Figure 8.2a). Typically, only featureless areas are used for flattening an image.
3. In the **Inputs** panel of the **Flatten View**, set parameter values to apply for all images operated on by the AutoProgram.
4. Close the **Flatten View**.

Note: Check the box **DO NOT USE DEFAULT CONFIGURATION SETTINGS** (Default Configuration Settings on page 116). This setting can affect drawn Stopband boxes and cursors which can be subsequently changed and used for later Autoprograms.

Figure 8.2a Specify a Flatten Operation

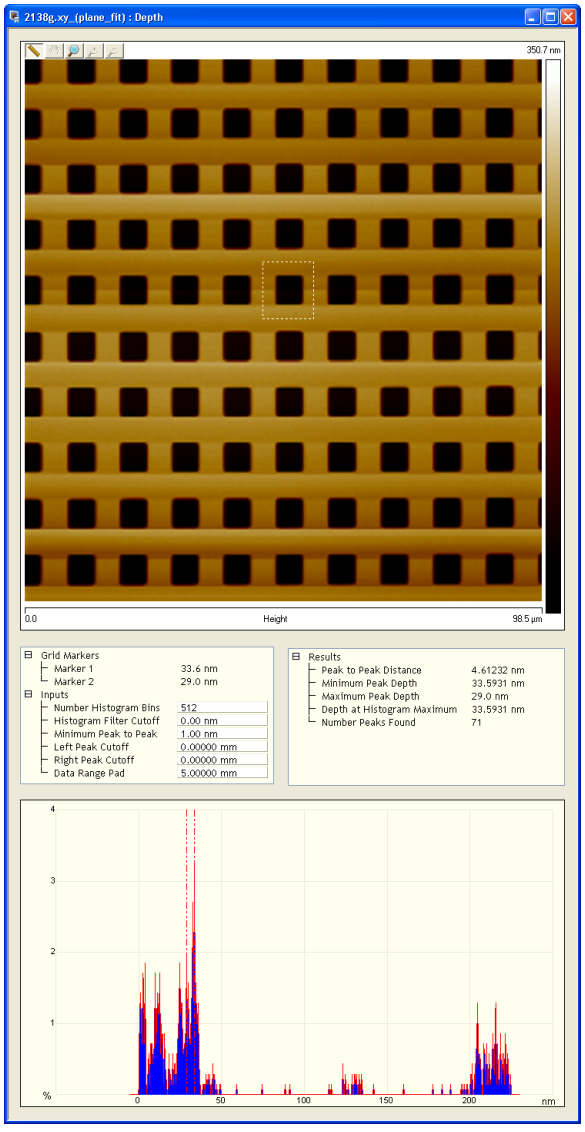


8.3 Example command: Depth

To open the **Depth View**:

1. Click the command name or icon that has been added to the **Run Group** Autoprogram.
2. Click in the image and drag open a box over an area that contains a height step (see Figure 8.3a).
3. In the **Inputs** panel of the **Depth View**, set parameter values that will apply for all images operated on by the AutoProgram.
4. Close the **Depth View**.

Figure 8.3a Specify a Depth Measurement

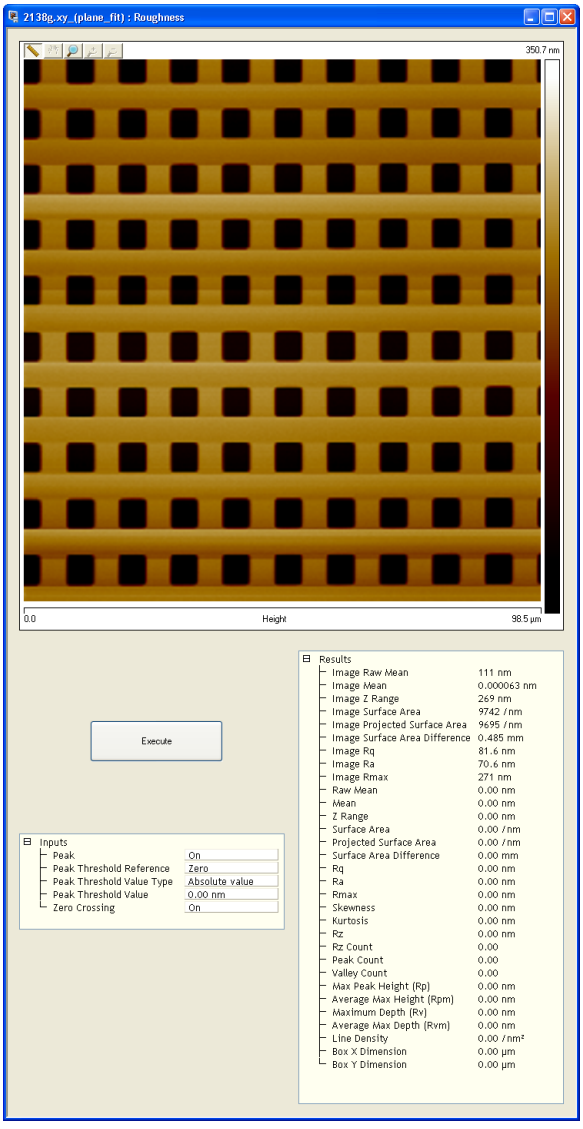


8.4 Example command: Roughness

To open the **Roughness View**:

1. Click the command name or icon that has been added to the **Run Group** Autoprogram.
2. Click in the image and drag open a box over an area where you would like the sample surface condition analyzed (see Figure 8.4a).
3. In the **Inputs** window, set parameter values that will apply for all images operated on by the AutoProgram.
4. Close the **Roughness View**.

Figure 8.4a Specify a Roughness Measurement for Inclusion in an AutoProgram



8.5 Running AutoProgram

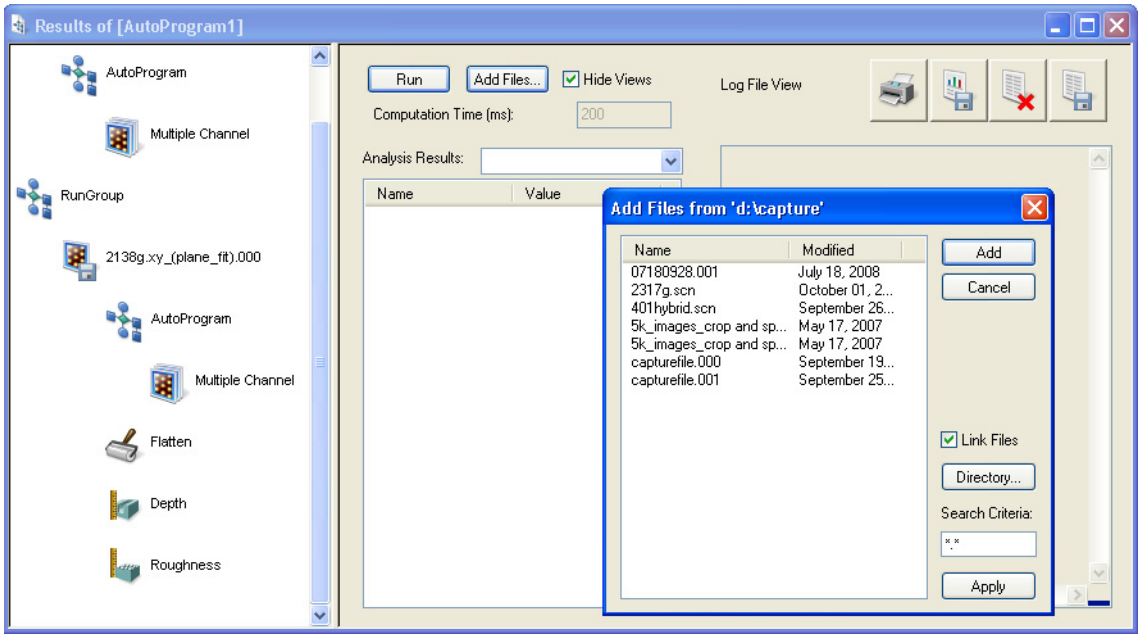
Once all commands are included in the **AutoProgram** list and their action specified, you are ready to run AutoProgram.

1. Click the **Add Files...** button in the **AutoProgram Results View** (see Figure 8.5a). The **Add Files** dialog box appears.

2. In the **Add Files** dialog box, select the **Link Files** box to have the same **AutoProgram** instructions apply to each file. Select files of interest and click **Add** to have the selected files included when the **AutoProgram** is run. Hold down the **Shift** key to select a consecutive group of files or the **Control** key to select more than one individual file.

3. In the **AutoProgram Results View**, check the **Hide Views** box if you don't want the images displayed, as they are automatically analyzed by the **AutoProgram**. If you want to see the images processed during **AutoProgram** execution, leave **Hide Views** unchecked. Increasing the value in **Computation Time** allows more time to view operations during Autoprogram execution.

Figure 8.5a Add Files Dialog Box

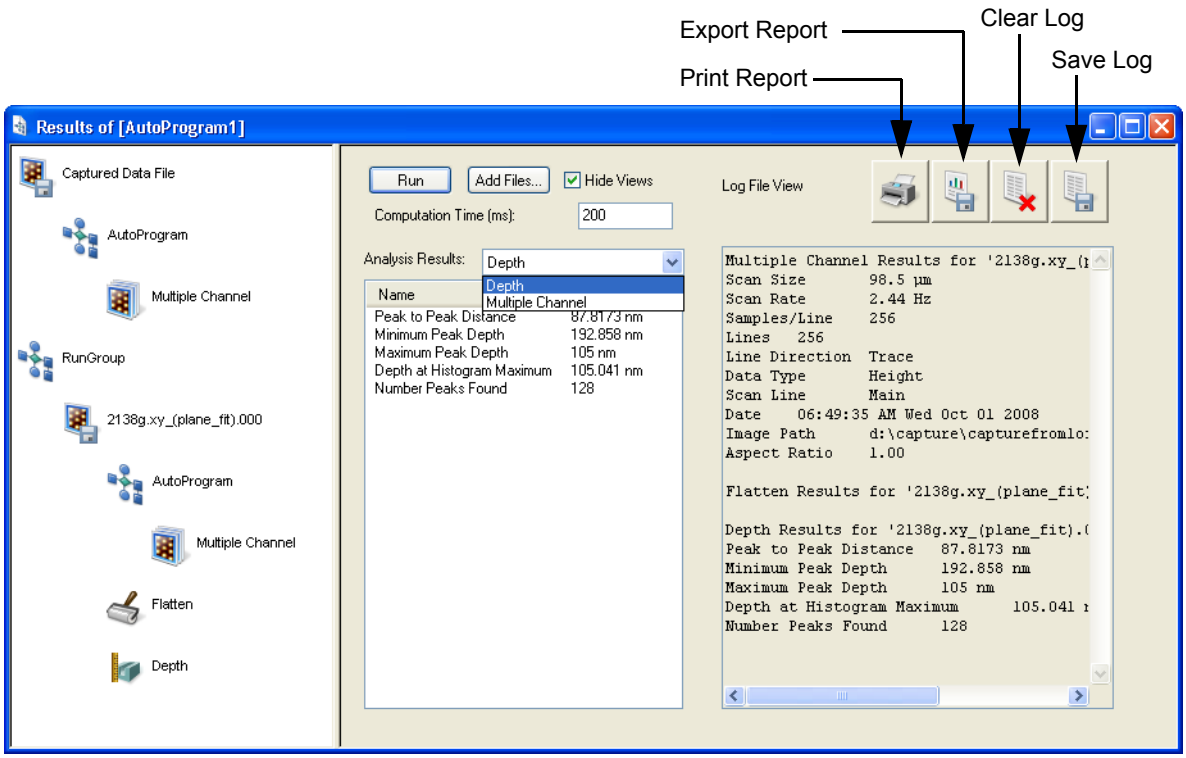


4. Click the **Run** button in the **Results of [AutoProgram]** view to start the **AutoProgram**.

   Note: The **RUN** button toggles to display **Stop** while the AutoProgram is running. Click it if you need to stop the process before it is completed. Clicking the **Run** button again restarts the **AutoProgram** at the first image.

5. Upon completion, the data appears in the **Log File View** property sheet (see Figure 8.5b).

Figure 8.5b Log File View Property Sheet



6. Results for individual analysis steps can be found in the **Analysis Results** drop-down menu, also shown in Figure 8.5b.

7. If you close the **Autoprogram Results** view without saving the Autoprogram, you will be prompted to save the Autoprogram as an .apg file.

8. To save the log file, select the **SAVE LOG** button in the **Log File View**.

9. To clear the log file, select the **CLEAR LOG** button in the **Log File View**.

10. Autoprogram results, with statistical analysis (termed reports), can be printed or exported as tab delimited text using the **PRINT REPORT** or **EXPORT REPORT** buttons.

Chapter 9 Recipes

The optional **Recipe** system allows you to automate most microscope functions using an easy to use graphical user interface (GUI).

> **Note:** The Recipes option is not available on all Bruker scanning probe microscopes.

Refer to the following analysis commands available in **Recipe** menu of the NanoScope software:

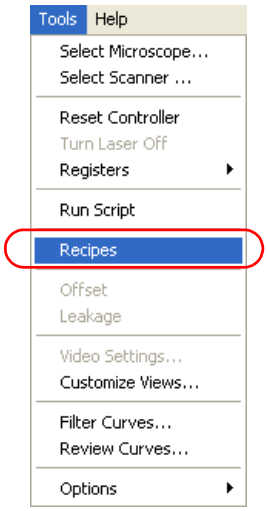
- **Starting the Recipe Menu:** Section 9.1
- **Creating a Recipe:** Section 9.2
- **Running a Recipe:** Section 9.3
- **Meta tags:** Section 9.4
- **Recipe Functions:** Section 9.5
- **Example 1: Teach and Run a Basic Recipe:** Section 9.6

Additional information about the Recipes function, including several example recipes, can be found in *The Recipes Cookbook*, Bruker part number 004-1021-000.

9.1 Starting the Recipe Menu

Start the **Recipe** view by clicking **TOOLS > RECIPES** in the NanoScope toolbar. See Figure 9.1a.

Figure 9.1a Start Recipes



A **Recipes** window will open.

9.1.1 Menu Bar Items

The menu bar includes:

- **File**—Accesses menu selections for opening and saving and recipe (.rcx) files.
- **Edit**—Allows the user to add or delete steps in the recipe.
- **Launch**—Allows the user to run a recipe.
- **About**—Provides access to online help “about” information.

Table 9.1a Recipe Menu Bar Items

File	**New Recipe**	Clears the existing recipe and starts a new recipe.
	Open Recipe	Opens a window to allow you to select an existing recipe.
	Save Recipe	Saves the current recipe to disk.
	Save Recipe As	Saves the current recipe to disk under a new file name.
Edit	**New**	Inserts a step below the current step.
	Delete	Deletes the selected step.
	Cut	Deletes the selected step and copies it to the clipboard.
	Copy	Copies the selected step to the clipboard.
	Paste	Pastes the contents of the clipboard below the selected step.
	Professor	Walks you through configuring the selected step.
	Move To	Moves the stage to the designated position.
	Re-Teach Alignments	Allows user to redefine alignments.
Launch	**Open & Run**	Opens a window, allowing you to select a recipe and then runs it.
	Run Current	Runs the current recipe.
About	**Help**	Opens this document.
	About Recipe Plug-In	Opens the About Recipe window.

9.2 Creating a Recipe

A new, blank recipe, “My Recipe,” is created when the **Recipe** window is opened. The **FILE** > **NEW RECIPE** clears the current recipe and allows you to create a new recipe. **FILE** > **OPEN RECIPE** clears the existing recipe (if saved) and opens a previously saved recipe.

The **Edit** > **New** function allows you to add recipe steps below a selected step. Right-clicking on a step also provides access to the **Edit** functions. Only functions that are allowed can be added. Other functions are grayed out. Recipe step order can be changed by dragging steps. Step order is enforced, i.e. moving a step to a logically impossible location is not allowed. Table 9.2a shows a list of allowable parent functions and Table 9.2b shows a list of allowed child functions.

Table 9.2a Allowed Parent Functions

Function	Allowed Parent Functions
Alignment	Load Sample, Real-time
Auto Tune	Alignment, Auto Tune, Image Analysis, Image Set, Load Sample, Real Time, Report, Site, Site Order
Capture Image	Measurement
Image Analysis	Alignment, Site, Site Order, Nanoscript, Real-time, Root
Image Export	Image Analysis, Image Capture, Image Set
Image Set	Alignment, Auto Tune, Load Sample, Measurement, Real-time, Root, Site, Site Order
Load Sample	Real-time
Measurement	Site
Move To	Alignment
Nanoscript	Alignment, Site, Site Order, Image Analysis, Root, Real Time
Real-time	Root
Report	Alignment, Site, Nanoscript, Image Analysis, Real-time, Root
Site	Alignment
Site Order	Alignment

Note: Root is displayed as My Recipe.

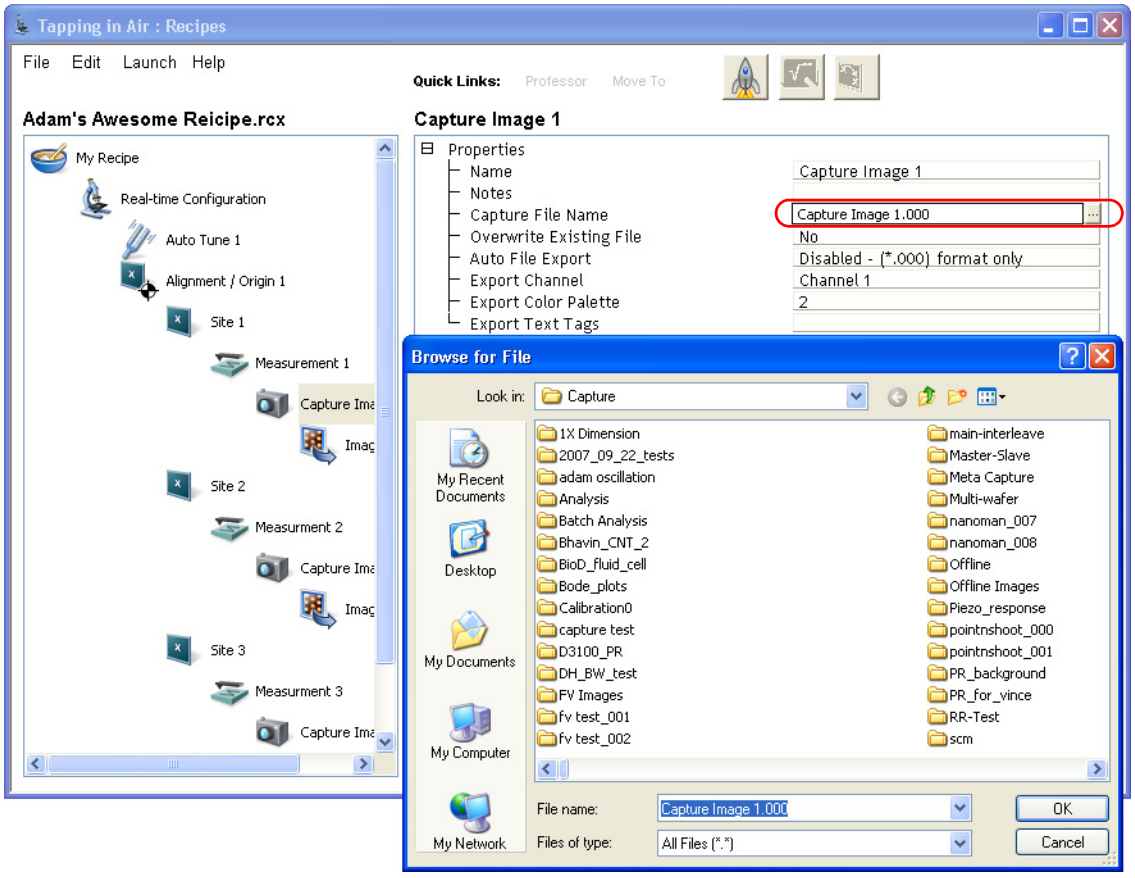
Table 9.2b Allowed Child Functions

Function	Allowed Child Functions
Alignment/Origin	Auto Tune, Image Set, Move To, Report, Site, Site Order
Auto Tune	Auto Tune, Image Set, Report
Image Analysis	Any Offline function, Image Export, Report
Image Capture	Auto Tune, Any Offline function, Image Export
Image Export	Image Export, Report
Image Set (offline)	Image Analysis, Report
Load Sample	Alignment/Origin, Auto Tune, Image Export, Image Set, Report
Measurement	Auto Tune, Capture Image, Image, Image Analysis, Image Set, Report
Nanoscript	Auto Tune, Image Set, Nanoscript, Report
Real-time	Alignment/Origin, Auto Tune, Image Analysis, Image Export, Image Set, Load Sample, Report
Root (My Recipe)	Image Analysis, Image Export, Image Set, Real-time, Report
Report	No children allowed
Site	Auto Tune, Image Analysis, Image Set, Measurement, Nanoscript, Report
Site Order	Auto Tune, Image Analysis, Image Set, Report, Site

Note: Root may have only one Real Time child. Site may have only one Measurement child.

You can browse for files by clicking the file browse button, shown in Figure 9.2a, that appears on the right when you select a file name.

Figure 9.2a File Browse Button



All recipe steps are given a **NAME** which you can override by typing in the **NAME** field.

All recipe steps have a **NOTES** field which allows you to insert comments.

Many recipe steps have a **PROFESSOR** associated with them. Click **PROFESSOR** to launch an assistance wizard that guides you through programming this recipe step. The **PROFESSOR** generally provides full access to the NanoScope software and interface for a given step.

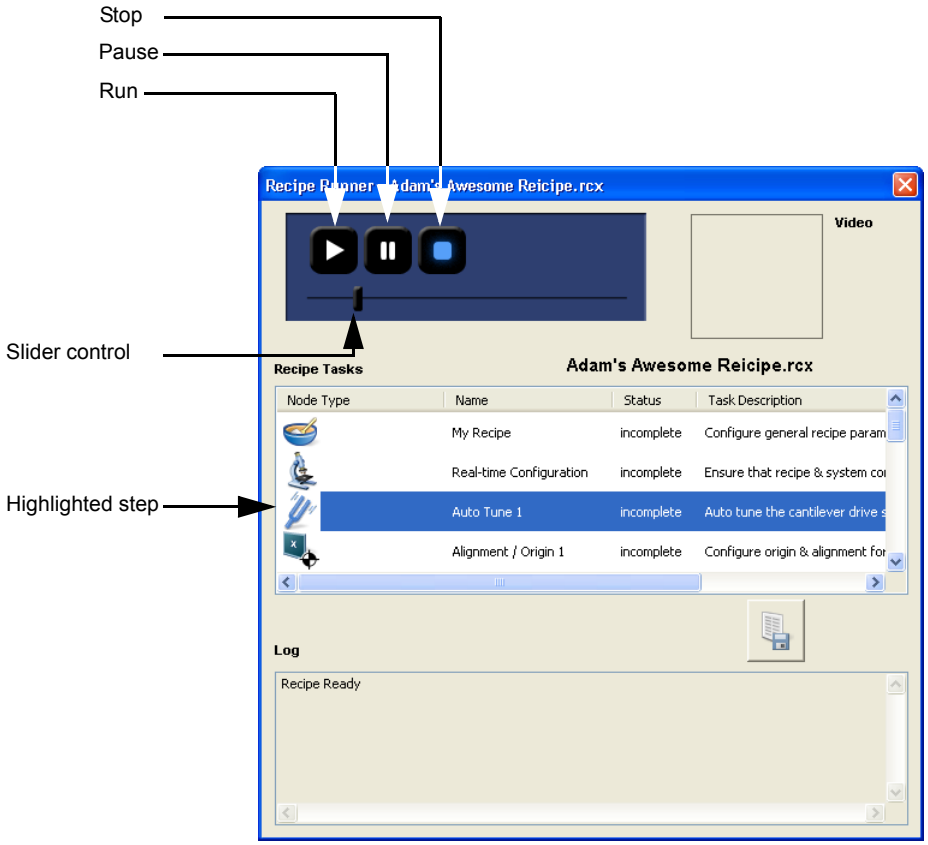
You may delete a step by highlighting that step and selecting **EDIT** > **DELETE** or right-clicking and selecting **DELETE**.

You may save you recipe with the **FILE** > **SAVE RECIPE** or **FILE** > **SAVE RECIPE AS** commands.

9.3 Running a Recipe

Click **Launch** > **Open & Run** or **Run Current** to run the current open recipe. This opens the **Recipe Runner** window, shown in Figure 9.3a. Click the **RUN** icon  in the **Recipe Runner** window to start running the recipe.

Figure 9.3a Recipe Runner Window



You start the recipe from any position by:

- Moving the **SLIDER CONTROL** to the desired position.
- Highlighting (by clicking) the desired step.

Click the **PAUSE** icon  in the **Recipe Runner** window to pause the running of the recipe.

Click the **STOP** icon  in the **Recipe Runner** window to stop running the recipe.

The **Log** window displays the recipe status.

9.3.1 Report files

A **Report** step may be inserted anywhere in a recipe and reports the activity of all parent nodes. Information in the report files includes all input and output parameters as well as run status (Incomplete, Pass or Fail). If programmed, a **Report** xml file will be generated. The xml file can be used as a data feed to generate multiple report formats. Use XSL Transformations (XSLT) — http://www.w3.org/TR/xslt to create a formatted output file from this xml file. Several default

XSLT files (html and text) are provided (in ..\plugins\recipes\stylesheets\). You can also make your own xls translation file if you're an advanced user to go from XML to any other text format. You can use the report file (or translated version) to integrate recipe output information with custom post processing software.

9.4 Meta tags

Meta tags can be used in all parameter fields that specify an output file name to be written and can also be used in the notes parameter field for all recipe functions. Export text tag parameters also support meta tags. For example, a time stamp meta tag can be entered into the name of a file to be captured. "MyFileName<TimeStampMonth><TimeStampDay>.000" would drop the month and day into a captured filename. Other recipe or microscope configuration data can also be used. For example, you could use the <LocX> and/or <LocY> tags to include the sample site location in your filename.

The most local version of the parameter is always used. This means that if the specified meta tag does not exist within the current recipe function, the meta tag parser will traverse from parent to grandparent function until the parameter is found. In this way, a notes parameter for a captured image can contain information about the microscope configuration.

9.4.1 Special Meta Tags

Time Stamp Meta Tags

Time Stamp Meta Tags
<TimeStampMonth>
<TimeStampMonthName>
<TimeStampDay>
<TimeStampYear>
<TimeStampHour>
<TimeStampMinute>
<TimeStampSecond>

Parent Function Reference Meta Tags

Time Stamp Meta Tags
<ParentFileName>
<ParentName>

Analysis nodes that produce a modified image can use <ParentFileName> in conjunction with the file overwrite option to overwrite the input file. <ParentName> is used to reference the <Name> parameter of the local function's parent function.

9.5 Recipe Functions

All Recipe Nodes contain **NAME** and **NOTES** fields which are for personal notation only and are not used for logical execution of the recipe.

9.5.1 Alignment/Origin

Defines an origin and a sample deskew angle from which the coordinates of all subsequent child site nodes are based.

Alignment Mode	Origin Only, Origin using X deskew, Origin using Y deskew.
Origin X	X-axis origin location in absolute stage units.
Origin Y	Y-axis origin location in absolute stage units.
Origin Z	Z-axis origin location in absolute stage units.
Speed	Speed at which the stage should move in percent of maximum speed.
Deskew Angle	Used to deskew the coordinate system defined by the above origin. In other words, all subsequent child sites will be shifted by the origin values, and rotated by the deskew angle.
Deskew Pt 1 - X	X location of the first point used to calculate the deskew angle.
Deskew Pt 1 - Y	Y location of the first point used to calculate the deskew angle.
Deskew Pt 2 - X	X location of the second point used to calculate the deskew angle.
Deskew Pt 2 - Y	Y location of the second point used to calculate the deskew angle.
Move To	Moves the stage to the designated position.
Professor	Yes

Meta Tags

Name	<Name>
Notes	<Notes>
Alignment Mode	<Mode>
Origin X	<OriginX>
Origin Y	<OriginY>
Origin Z	<Origin Z>
Speed	<Speed>
Deskew Angle	<DeskewAngle>
Deskew Pt 1 - X	<DeskewPt1X>
Deskew Pt 1 - Y	<DeskewPt1Y>
Deskew Pt 2 - X	<DeskewPt2X>
Deskew Pt 2 - X	<DeskewPt2Y>

9.5.2 Auto Tune

Tells the systems to measure and calculate the cantilever drive amplitude and frequency.

Start Frequency Starting point of the **Auto Tune** frequency sweep.

End Frequency Ending point of the **Auto Tune** frequency sweep.

Target Amplitude Targeted output signal amplitude *at the photodiode detector*. This value should *not* be confused with Drive amplitude, which is the amplitude applied directly to the cantilever itself (see Drive amplitude).

Range and Settings: **0.00** to **8.00 V**

Note: Dimension Series SPMs, nominal = 500mV
Small Sample MultiMode SPMs, nominal = 500mV

Peak Offset Percentage of cantilever's free-air resonant frequency to be automatically offset. Peak offset is used to compensate for changes in resonance before engagement due to the tip's interaction with the surface after engagement.

Range and Settings: **0** to **50%**; typical value = **0** to **10%**

Minimum Q Q is the value defined by the amount of oscillation it takes for a wave to drop to 1/e (e = 2.718) of its amplitude value (i.e. a wave with an amplitude of ten would have a Q of 10/e, or 3.6788). Minimum Q establishes a minimum "width of peak" value allowed by the AutoTune function.

Professor No

Meta Tags

Name	<Name>
Notes	<Notes>
Start Frequency	<StartFreq>
End Frequency	<EndFreq>
Target Amplitude	<TargetAmplitude>
Peak Offset	<PeakOffset>
Minimum Q	<MinimumQ>

9.5.3 Capture Image

Captures and saves an image to disk in nanoscope format. This image can be exported as a BMP, JPEG, or TIFF file. Captured images may be parent objects of analysis nodes so that the analysis takes place immediately after the data has been captured.

Capture File Name Name of file to be captured. A full path may be specified, but if a complete path is not specified the "default capture path" (displayed in the Properties window of the My Recipe node) is used.

Overwrite Existing File Specifies if the resulting image should overwrite an existing image file of the same name. If NO, a new, sequential file will be created.

Auto File Export DISABLED or the type of file to which the captured nanoscope image is exported.

Export Channel The **EXPORT CHANNEL** field specifies which channel should be exported.

Note: BMP, JPEG, and TIFF formats can not contain information about more than 1 channel.

Export Text Tags This field is used to put notes in the "notes" tag for TIFF files.

Professor No

Meta Tags

Name	<Name>
Notes	<Notes>
Capture File Name	<FileName>
Overwrite Existing File	<FileOverwrite>
Auto File Export	<FileExportType>
Export Channel	<FileExportChannel>
Export Text Tags	<FileExportTextTags>

9.5.4 Image Analysis

Analysis nodes are children of **CAPTURE IMAGE** or **IMAGE SET**. In combination with image parent nodes and report nodes as children, they are capable of producing numeric analysis results and/or resulting images. Analysis nodes can also be child nodes of other analysis nodes when analysis of a

filtered image (by another analysis node) is desired. E.g. if you want to perform a roughness analysis of images that have been flattened, you would configure your image tree as follows:

Data Channel	Selects which channel from the parent Image object to use for analysis.
Output Image Name	Name of output image. A full path may be specified, but if a complete path is not specified the "default capture path" (displayed in the Properties window of the My Recipe node) is used.
Overwrite Existing File	Specifies if the resulting image should overwrite an existing image file of the same name. If NO, a new, sequential file will be created.
File Export Channel	The **EXPORT CHANNEL** field specifies which channel should be exported. **Note:** BMP, JPEG, and TIFF formats can not contain information about more than 1 channel.
Export Text Tags	This field is used to put notes in the "notes" tag for TIFF files.
Additional Fields…	Additional fields are stored containing information about the analysis configuration. These fields will vary depending on the type of analysis you are doing. These fields are editable only through the Professor and the standard image analysis views.
Professor	Yes

Meta Tags

Name	<Name>
Notes	<Notes>
Data Channel	<Channel>
Output Image Name	<Output File Name>
Overwrite Existing File	<FileOverwrite>
Auto File Export	<FileExportType>
File Export Channel	<FileExportChannel>
Export Text Tags	<FileExportTextTags>

9.5.5 Image Export

Exports an image.

File Name	Name of output file.
Overwrite Existing File	Specifies if the resulting image should overwrite an existing image file of the same name. If NO, a new, sequential file will be created.
Export Type	The file type that will be exported: BMP, JPEG, TIFF.
Export Channel	The **EXPORT CHANNEL** field specifies which channel should be exported. **Note:** BMP, JPEG, and TIFF formats can not contain information about more than 1 channel.
Export Text Tags	This field is used to put notes in the "notes" tag for TIFF files.
Professor	No

Meta Tags

Name	<Name>
Notes	<Notes>
File Name	<FileName>
Auto File Export	<FileExportType>
File Export Channel	<FileExportChannel>
Export Text Tags	<FileExportTextTags>

9.5.6 Image Set (offline)

Specifies a set of previously captured files. May also be exported as a BMP, JPEG, or TIFF file using the Image **EXPORT** function.

Image List Names of previously captured NanoScope image files. A full path may be specified, but if a complete path is not specified the "default capture path" (displayed in the Properties window of the My Recipe node) is used.

Professor No

Meta Tags

Name	<Name>
Notes	<Notes>
Image List	<ImageList>
Auto File Export	<FileExportType>
File Export Channel	<FileExportChannel>
Export Text Tags	<FileExportTextTags>

9.5.7 Load Sample

Stops the recipe and moves the stage to a specified location so that a new sample can be loaded. An option is provided to re-teach all alignment/origin objects so that associated sites will adjust appropriately without being re-taught.

X X-axis stage location for re-load in absolute coordinates.

Y Y-axis stage location for re-load in absolute coordinates.

Z Z-axis stage location for re-load in absolute coordinates.

Speed Speed at which the stage should move in percent of maximum speed.

Re-Teach Alignments/Origin Turns on/off re-teaching of all alignment/origin objects in the recipe before continuing.

Professor No

Meta Tags

Name	<Name>
Notes	<Notes>
X	<LocX>

Y	<LocY>
Z	<LocZ>
Speed	<Speed>
Re-Teach Alignments/Origin	<TeachOrigin>

9.5.8 Measurement

Stores Real Time parameters used to configure the microscope. At run-time, it will use these parameters to engage the probe and scan the sample. Site may have only one measurement step.

Nanoscope Parameters Lists	Lists all parameters used to configure the microscope.
Professor	Yes

Meta Tags

Name	<Name>
Notes	<Notes>

9.5.9 My Recipe

Root node of recipe containing default capture and report folders.

Capture Directory	Default path to the directory that is used for storing and reading captured image files when a full path is not defined by the **CAPTURE FILE NAME**.
Report Directory	Default path to the directory used to store reports when a full path is not defined by the **REPORT OUTPUT XML FILE**.
Version	Contains Recipe plug-in version information (read only)
Professor	No

Meta Tags

Name	<Name>
Notes	<Notes>
Capture Directory	<CaptureDirectory>
Report Directory	<ReportDirectory>
Version	<Version>

9.5.10 Real-time Configuration

Realtime stores reference information about the microscope hardware that the recipe was written for. There may be only one Real Time step in a recipe.

Controller	Specifies the controller.
Microscope	Specifies the microscope.
Scanner	Specifies the scanner
Vision	Specifies the vision system.
Zoom	Specifies the optical system.
Professor	No

Meta Tags

Controller	<Controller>
Microscope	<Microscope>
Scanner	<Scanner>
Vision	<Vision>
Zoom	<Zoom>

9.5.11 Report

Report generates an XML formatted summary of recipe node results. Reports may be placed anywhere in the recipe and are used for local or global reporting. The report looks to its parent node and reports on all children of its parent, including itself.

All nodes in the recipe contain a "run status" output field that has the values **PASS**, **FAIL**, or **INCOMPLETE**. All input fields are copied to the output parameters to be reported with results.

Nanoscope Parameters Lists	Lists all parameters used to configure the microscope.
Report Output XML File	Input file to the stylesheet transformation program.
Stylesheet File	Specifies a xls xml transition file.
Formatted Output File	Final formatted output file. Does nothing if left blank.
Professor	No

Meta Tags

Name	<Name>
Notes	<Notes>

9.5.12 Site

Site moves the stage to a specified X, Y, Z position relative to its parent alignment/origin.

X	X-axis stage location in relative coordinates.
Y	Y-axis stage location in relative coordinates.
Z	Z-axis stage location in relative coordinates.
Speed	Speed at which the stage should move in percent of maximum speed.
Professor	Yes

Meta Tags

X	<LocX>
Y	<LocY>
Z	<LocZ>
Speed	<Speed>

9.5.13 Site Order

Site Order uses a comma separated values (CSV) file to re-order the sites at run-time. Sites to be re-ordered need to be child nodes of this node.

CSV File Name	Path and name of the CSV file.
Number of Columns	Specifies the number of columns in the CSV files. The CSV file may contain more columns than are used by the re-order operation. The unused columns will be ignored.
Site Reference Column	Specifies which column (1...N) in the CSV file will be used to reference the subsequent child site nodes. The data in the column may be a site number (By Index) or contain a case sensitive name field value (of the referred site) (By Name). See **Site Reference Type**, below.
Sort Weight Column	Specifies which column (1...N) in the CSV file will be used to weight the resulting sort order of the sites. This field may contain the resulting site index itself, a calculated floating point value or a percentage.
Image Name Column	Specifies which column (1...N) in the CSV file will be used to re-name sub-sequent Image capture file names for each site. If data in the specified column is null, an empty string or does not exist, this image re-name feature will be ignored. All child capture images will be renamed.
Site Reference Type	Specifies whether sites in the **SITE REFERENCE COLUMN** will be referenced by their index or by their name field value.
Sort Direction	Used to change the direction of the resulting site sort order.
Professor	No

Meta Tags

CSV File Name	<FileName>
Number of Columns	<NumColumns>
Site Reference Column	<SiteReferenceColumn>
Sort Weight Column	<SortWeightColumn>
Image Name Column	<ImageColumn>
Site Reference Type	<SiteReferenceOption>
Sort Direction	<SortOption>

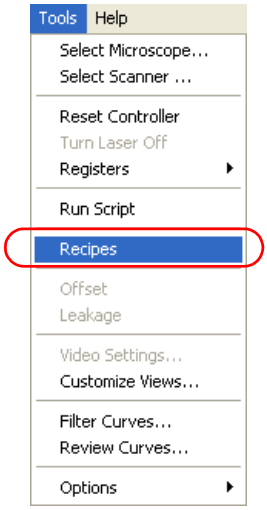
9.6 Example 1: Teach and Run a Basic Recipe

9.6.1 Teach a Real-time Recipe

1. Create a basic outline of the recipe.

   a. Start the **Recipe** view by clicking **TOOLS > RECIPES** in the NanoScope toolbar. See Figure 9.6a.

Figure 9.6a Start Recipes



   b. Add a **Real-time** step using *one* of the following methods:

   - Right-click on **MY RECIPE** in the **Recipes** window and click **NEW > REAL-TIME.**

     Or

   - Click **EDIT > NEW > REAL-TIME.**

   c. Add an **Alignment/Origin** step using *one* of the following methods:

   - Right-click on **REAL-TIME** in the **Recipes** window and click **NEW > ALIGNMENT/ ORIGIN.**

     Or

   - Click **EDIT > NEW > ALIGNMENT/ORIGIN**.

   d. Add an **Autotune** step using *one* of the following methods:

   - Right-click on **ALIGNMENT/ORIGIN** in the **Recipes** window and click **NEW > AUTOTUNE.**

Or

- Click on **ALIGNMENT/ORIGIN** and then click **EDIT > NEW** > **AUTOTUNE**.

e. Add a **Site** step using *one* of the following methods:

- Right-click on **ALIGNMENT/ORIGIN** in the **Recipes** window and click **NEW** > **SITE.**

Or

- Click on **ALIGNMENT/ORIGIN** and then click **EDIT > NEW** > **SITE**.

f. Add a **Measurement** step using *one* of the following methods:

- Right-click on **SITE** in the **Recipes** window and click **NEW** > **MEASUREMENT.**

Or

- Click on **SITE** and then click **EDIT > NEW** > **MEASUREMENT**.

g. Add a **Capture Image** step using *one* of the following methods:

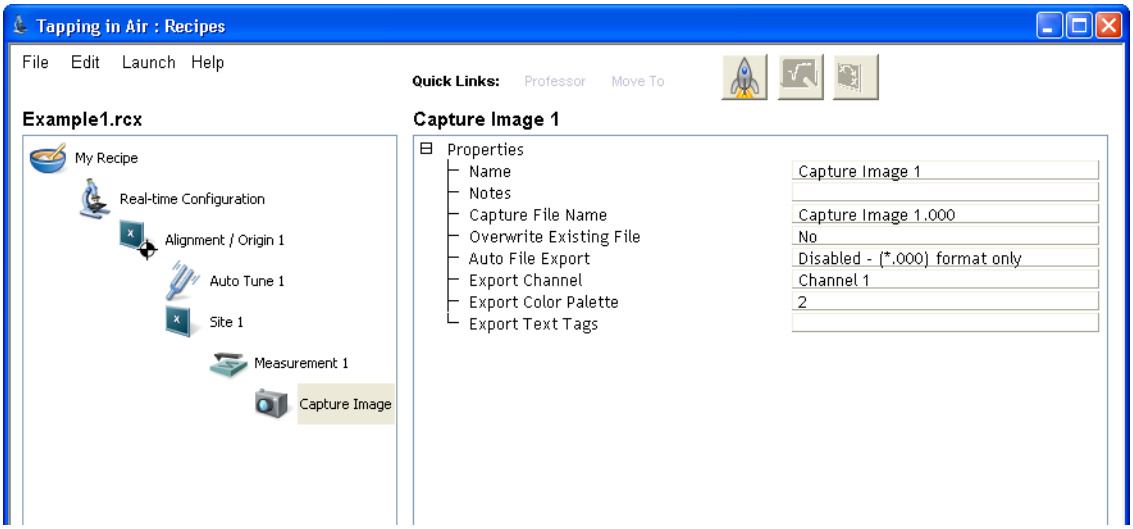
- Right-click on **MEASUREMENT** in the **Recipes** window and click **NEW** > **CAPTURE IMAGE.**

Or

- Click on **MEASUREMENT** and then click **EDIT > NEW** > **IMAGE CAPTURE**.

h. Select **FILE** > **SAVE** Recipe **AS** `D:\RECIPES\EXAMPLE1.RCX`. See in Figure 9.6b.

Figure 9.6b Example 1, Basic Outline



2. Teach Alignment

   a. Open the **Alignment PROFESSOR** using *one* of the following methods:

   - Right-click on **ALIGNMENT/ORIGIN** in the **Example1.rcx** window and click **PROFESSOR.**

     Or

   - Click on **ALIGNMENT/ORIGIN** and then click the **QUICK LINKS: PROFESSOR** button.

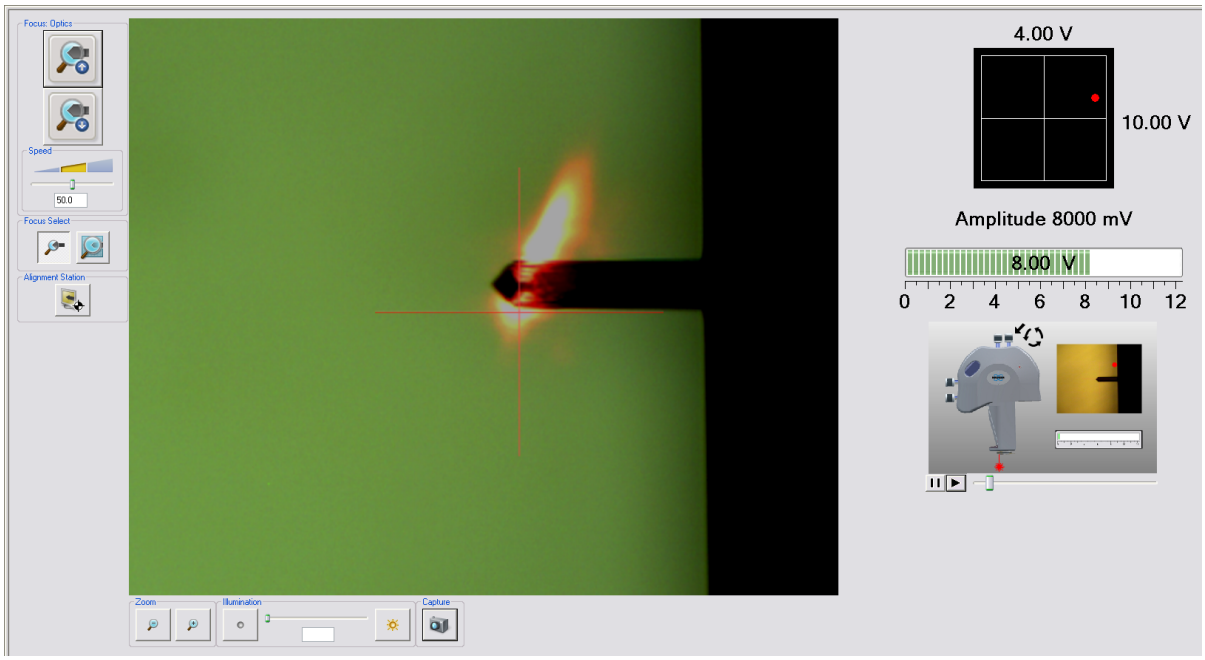
   b. Enter the relative stage speed and click **NEXT**.

   c. Select the **LEAVE STAGE IN CURRENT LOCATION** radio button. Click **NEXT**.

   d. Select the **ORIGIN ONLY** radio button. Click **NEXT**.

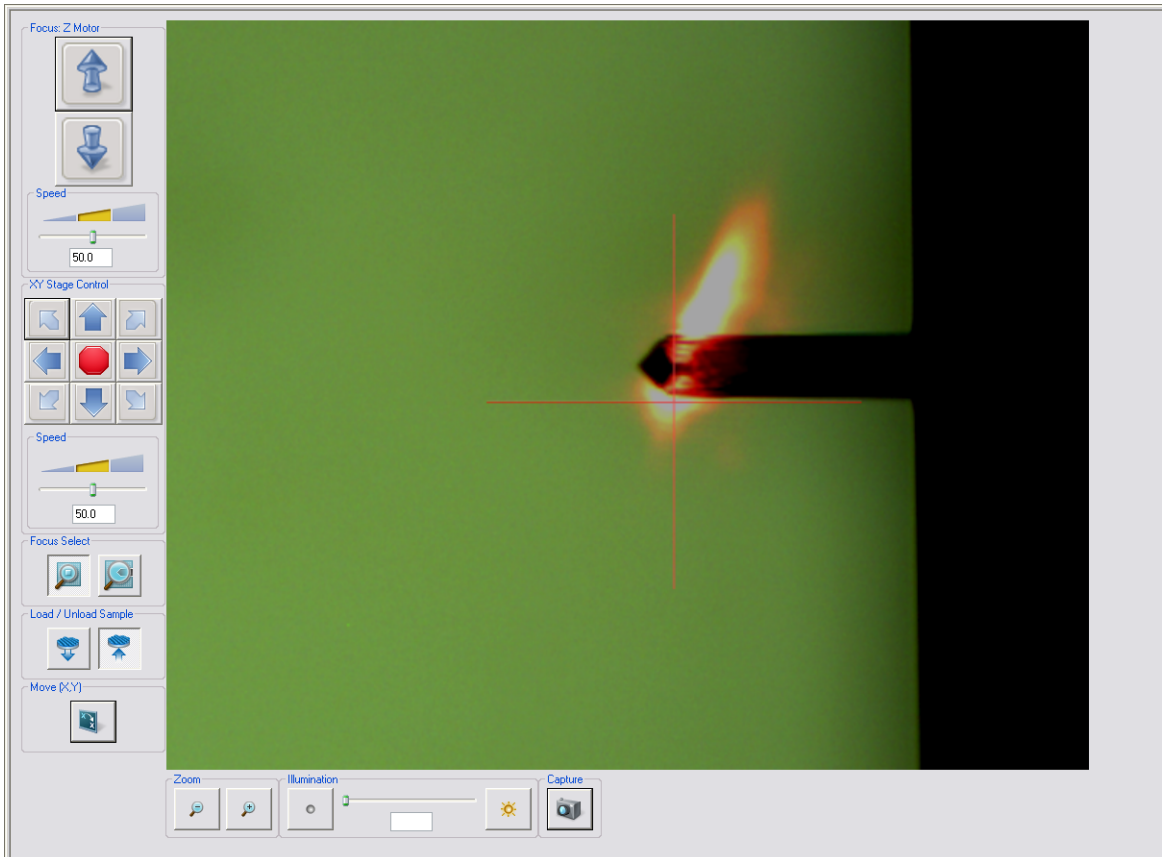
   e. Using the **Align** window, shown in Figure 9.6c, focus the optics on the tip and click **NEXT** when you are done.

Figure 9.6c Align Window



f. Using the **NAVIGATE** buttons, shown in Figure 9.6d, move the stage to the desired origin. Click **NEXT**.

Figure 9.6d Navigate Window



g. Click **FINISH**.

3. Set Auto Tune parameters.

   a. Click the **Auto Tune** step.

   b. Set the following properties (TESP probe, for example) in the **Properties** panel:

   - **START FREQUENCY**: 0 kHz.
   - **END FREQUENCY**: 400 kHz.
   - **TARGET AMPLITUDE**: 500 mV.
   - **PEAK OFFSET**: 5.00%.
   - **MINIMUM Q**: 0.

c. **SAVE** the **RECIPE**.

4. Teach Site 1.

   a. Open the **Site 1 PROFESSOR** using *one* of the following methods:

      - Right-click on **SITE 1** in the **Example1.rcx** window and click **PROFESSOR**.

        Or

      - Click on **SITE 1** and then click the **QUICK LINKS: PROFESSOR** button.

   b. Enter the relative stage speed and click **NEXT**.

   c. Select the **LEAVE STAGE IN CURRENT LOCATION** radio button. Click **NEXT**.

   d. Using the **NAVIGATE** buttons, shown in Figure 9.6c, move the stage to the desired position. Click **NEXT**.

   e. Click **FINISH**.

5. Set the Measurement parameters.

   a. Open the **Measurement PROFESSOR** using *one* of the following methods:

      - Right-click on **MEASUREMENT** in the **Example1.rcx** window and click **PROFESSOR**.

        Or

      - Click on **MEASUREMENT** and then click the **QUICK LINKS: PROFESSOR** button.

   b. Select the **LEAVE SYSTEM IN CURRENT STATE** radio button. Click **NEXT**.

   c. Configure the scan parameters in the **Scan Parameters** window.

   d. Click **FINISH**.

   e. Verify the parameters in the **Properties** list in the **Professor**.

6. Set the Capture Image parameters.

   a. Click the **Capture Image** step.

   b. Set the following properties:

      - Give a Capture File Name including an appropriate three digit extension. E.g. `SITE1IMAGE.000`.

      - Select `YES` for **OVERWRITE EXISTING FILE**.

- **AUTO FILE EXPORT**: DISABLED.

c. **SAVE** the **RECIPE**.

7. Set the default folders:

a. Click the **My Recipe** step.

b. Set the following properties:

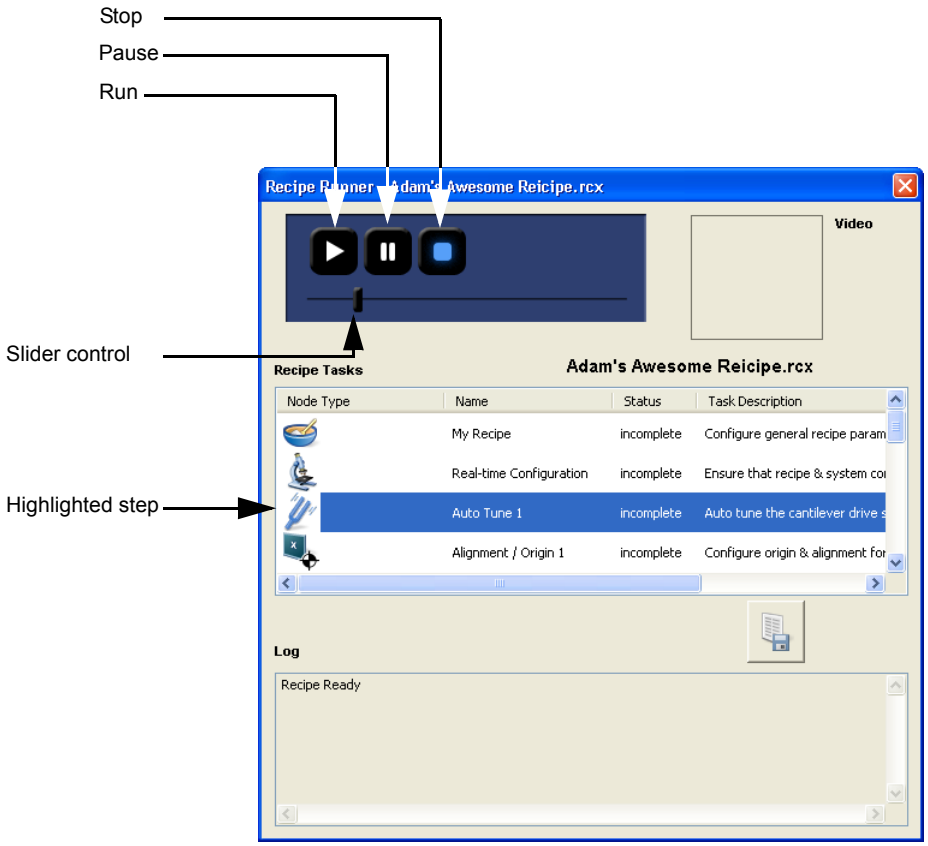
- Capture Directory D:\RECIPES\EXAMPLE1.
- Report Directory D:\RECIPES\EXAMPLE1.

c. Select **FILE > SAVE RECIPE**.

9.6.2 Run the Real-time Recipe

1. Click **LAUNCH** > **RUN CURRENT** to open the **Recipe Runner** window, shown in Figure 9.6e.

Figure 9.6e Recipe Runner Window



2. Click the **RUN** icon  in the **Recipe Runner** window to start running the recipe.
3. You may start at any step in the recipe by highlighting (clicking on) that step and clicking **RUN**.

9.6.3 Add an Additional Site

1. Add an additional **Site** step by cloning Site 1:
   - Right-click on the **SITE 1** step and click **COPY.**

     Or
   - Click on the **SITE 1** step and then clicking the **EDIT** > **COPY**.

     Then
   - Right-click on the **ALIGNMENT/ORIGIN** step and click **PASTE.**

     Or
   - Click on the **ALIGNMENT/ORIGIN** step and then clicking the **EDIT** > **PASTE**.
2. Change the settings for the cloned site:
   a. Enter `SITE 2` for **NAME**.
   b. Open the **PROFESSOR**.
   c. Navigate to the desired Site 2 location.
   d. **FINISH**.
3. Repeat Step 5 and Step 6 in **Teach a Real-time Recipe:** Section 9.6.1, if necessary.
4. Select **FILE > SAVE RECIPE**.

9.6.4 Teach an Offline Recipe

1. Create a basic outline of the offline recipe.
   a. Add an **Image Set** step using *one* of the following methods:
      - Right-click on **MY RECIPE** in the **Example1.rcx** window and click **NEW** > **IMAGE SET (OFFLINE).**

        Or

- Click on **MY RECIPE** and then click **EDIT > NEW** > **IMAGE SET (OFFLINE)**.

b. Add a **Flatten** step using *one* of the following methods:

- Right-click on **IMAGE SET 1** in the **Example1.rcx** window and click **NEW** > **IMAGE ANALYSIS > FLATTEN.**

Or

- Click on **IMAGE SET 1** then click **EDIT > NEW** > **IMAGE ANALYSIS > FLATTEN.**

c. Add a **Roughness** step as a child of the **Flatten** step using *one* of the following methods:

- Right-click on **FLATTEN** in the **Example1.rcx** window and click **NEW** > **IMAGE ANALYSIS > ROUGHNESS.**

Or

- Click on **FLATTEN** then click **EDIT > NEW** > **IMAGE ANALYSIS > ROUGHNESS.**

d. Add a **Report** step as a child of the **MY RECIPE** step using *one* of the following methods:

- Right-click on **MY RECIPE** in the **Example1.rcx** window and click **NEW** > **REPORT.**

Or

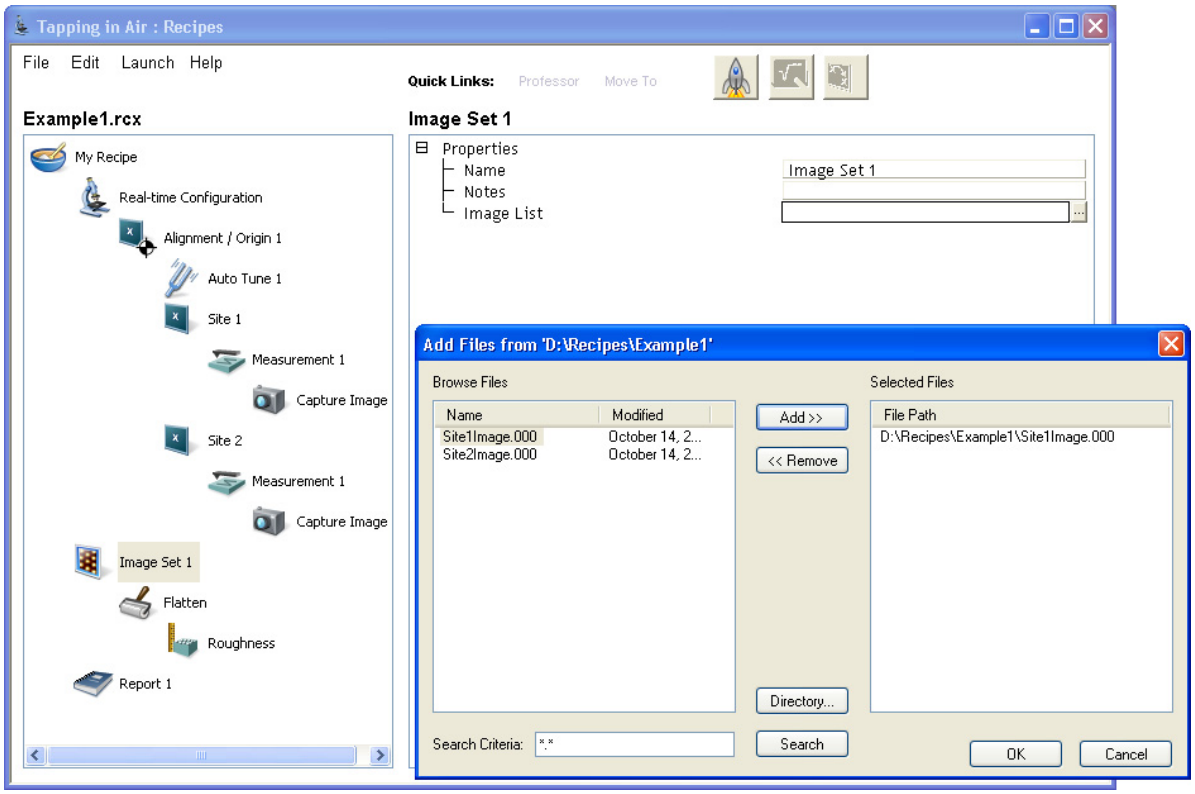
- Click on **MY RECIPE** and then click **EDIT > NEW** > **REPORT**.

2. Create the Image List.

a. Select Site1Image.000 in the D:\Recipes directory to add it to the Image List. See Figure 9.6f.

b. Place the cursor at the end of this and add “, D:\Recipes\Example1\Site2Image.000” manually into the **Image List** textbox because this image does not yet exist and cannot be selected from D:\Recipes. The Image List will now read “D:\Recipes\Example1\Site1Image.000, D:Recipes\Example1\Site2Image.000.”

Figure 9.6f Add Files to the Image List



3. Configure the **FLATTEN** step.

   a. Open the **Flatten PROFESSOR** using *one* of the following methods:

      - Right-click on **FLATTEN** in the **Example1.rcx** window and click **PROFESSOR.**

        Or

      - Click on **FLATTEN** and then click the **QUICK LINKS: PROFESSOR** button.

   b. Make appropriate changes to the input parameters in the **Flatten** analysis window.

   c. Click **NEXT**.

   d. Click **FINISH**.

4. Configure the **ROUGHNESS** step.

   a. Open the **Roughness PROFESSOR** using *one* of the following methods:

      - Right-click on **ROUGHNESS** in the **Example1.rcx** window and click **PROFESSOR.**

        Or

- Click on **ROUGHNESS** and then click the **QUICK LINKS: PROFESSOR** button.

b. Make appropriate changes to the input parameters in the **Roughness** analysis window. See **Roughness:** Section 6.3 for details.

c. Click **NEXT**.

d. Click **FINISH**.

5. Configure the **REPORT** step.

   a. Set the following properties:

   - **Name**: `REPORT1`.
   - Report Output XML File: `D:\RECIPES\REPORT1`.

6. Select **FILE > SAVE RECIPE**.

Appendix A File Formats

This appendix details file format information for NanoScope software Version 7.20. Customers often upgrade to newer software, therefore, this appendix also includes compatibility and conversion information for earlier software versions.

Note: For details on earlier file format information, refer to *Support Note 330 File Formats*.

This appendix includes the following information:

- **Overview:** Section A.1
- **File Compatibility:** Section A.2
- **Data File Organization:** Section A.3
- **Converting Data:** Section A.4
- **Converting Raw Data:** Section A.5
- **Electrochemistry:** Section A.6
- **General Format for CIAO Parameter Objects:** Section A.7

CAUTION: Before attempting data extraction on files, **always** make backup copies of the originals. If files become damaged due to loss of data, they may be irrecoverable.

ATTENTION: Toujours effectuer une copie des fichiers originaux avant d'en extraire des données. Si la perte de données endommageait des fichiers, ceux-ci pourraient être irrécupérables.

VORSICHT: Machen Sie bitte immer Backup-Files Ihrer Originaldaten, ehe Sie versuchen, Datenfiles selbst zu bearbeiten. Wenn Files durch Datenverlust beschädigt werden, könnten die Daten unwiederbringlich verloren sein.

A.1 Overview

File formats in the NanoScope software are of concern to users for at least two reasons:

- **Compatibility**—Processing older files using newer NanoScope software.
- **Converting file data**—Exporting data into third-party applications such as spreadsheets and statistical packages to evaluate data in unique ways.

The ability to extract data from files is for the purpose of applying third-party software packages and analyzing data in other formats. This may include displaying data in spreadsheets (e.g., Excel), statistical packages and expert systems. Typically, you extract data from the image files, then filter the data according to the requirements of their software. This section discusses how data files are organized to assist in extracting the file data.

A.2 File Compatibility

Bruker updates file formatting to ensure cross-compatibility of files between different versions of the NanoScope software. There are some exceptions.

Most NanoScope software can open files created by earlier versions of NanoScope software. Conversely, image files captured and saved by an earlier version of NanoScope software should open on any later version of NanoScope software. However, once the files are open and re-saved by a newer version, they are no longer usable in older versions of NanoScope software.

IMPORTANT!: To analyze old files using newer software versions and then to return the files to the older software version, make backup copies of the files with the old software BEFORE loading them into the newer software.

IMPORTANT!: Les Utilisateurs désirant analyser d'anciens fichiers en utilisant une nouvelle version de logiciel, et désirant également les retraiter par la suite dans l'ancienne version, doivent effectuer des copies (backup) de leurs fichiers AVANT de les charger dans la nouvelle version.

WICHTIG!: Anwender, die alte Datenfiles mit neuerer Software analysieren und später die Files wieder mit der alten Software einlesen wollen, sollten Backup-Kopien ihrer Files mit der alten Softwareversion machen, EHE sie diese mit der neuen Software laden.

A.3 Data File Organization

Images which are captured by the user are immediately stored in the NanoScope's capture directory as binary files. Depending upon the **Number of samples** taken, files will vary in size from about 41KB to 52MB per channel per image. Regardless of size, all files include: 1) a "header," containing various parameter settings used during the capture of the original image, a Ctrl-Z character to signal the end of the header, and "padding," comprised of random data; and, 2) data, stored two bytes (2^{16}) per pixel (2's complement).

File organization includes the following:

- **Header Files:** Section A.3.1
- **Parameters:** Section A.3.2
- **Control-Z (Ctrl-Z) Character:** Section A.3.3
- **Padding:** Section A.3.4
- **Raw Data:** Section A.3.5

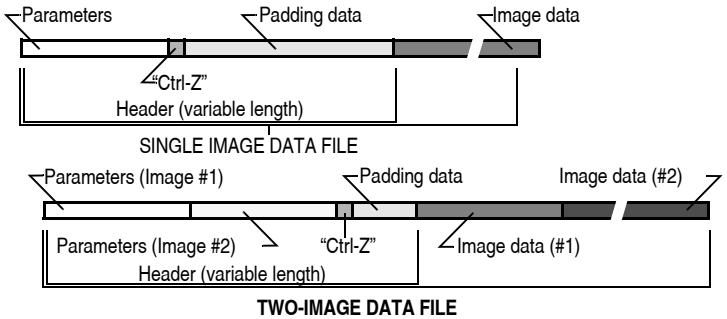
A.3.1 Header Files

The first portion of every image file contains a **header** file. The header file tells the software about the data which follows. The header file size depends upon the number of parameters used at the time that data is captured. Depending upon the type of file saved and the version of NanoScope software used when saving the file, the header may contain more than 2,000 parameters.

Each header is divided into separate lists (beginning with the characters *). Users typically, manipulate only a few of the parameters for each application. See the Parameters section for a few of the most important parameters and characters.

The header is also crucial to interpreting the data. The header information provides crucial parameter and setting information for converting ASCII file data. The end of the header file reveals where the actual data begins. Figure A.3a shows the size and relationship of the data file formats.

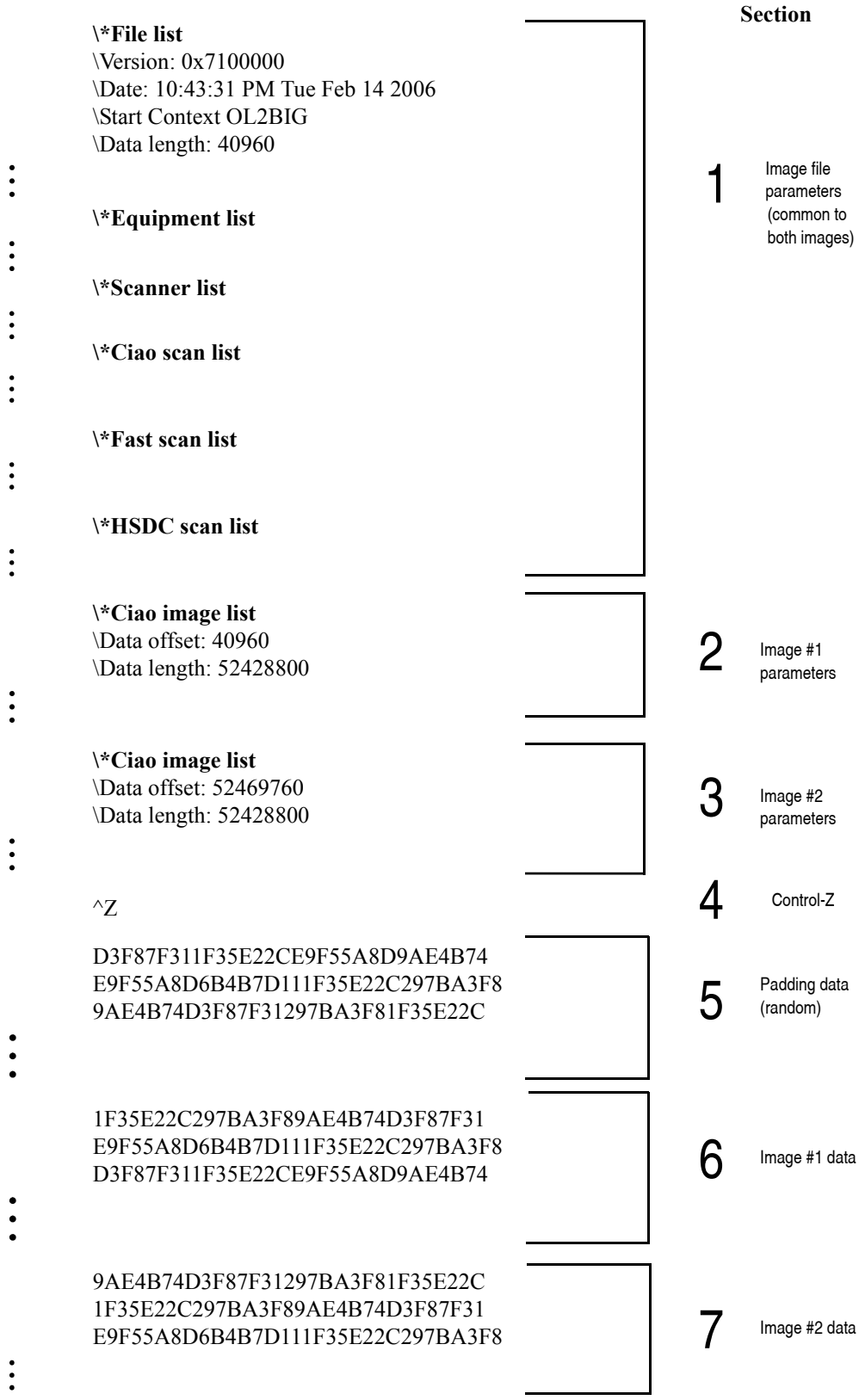
Figure A.3a Single and Two-Image Data File Structure



Two-Image Files

Files with two or more images contain separate parameter lists and image data. Figure A.3b illustrates data organization of a two-image files.

Figure A.3b Example of a Two-image Header File



Analysis of the Two-Image Header File

- **Section 1** includes parameters common to both images (only a few are shown here). The parameters are included within various lists beginning with *****. The type of image and the NanoScope software version also affect the lists and parameters. For example, the **\Data length** parameter in the ***File list** of this section is generally 40K and includes the entire header.

- **Section 2** contains parameters which are specific to image #1. In this example, only two are shown; however, there may be dozens. The **\Data offset** parameter is very important because it indicates the Nth byte where data for image #1 begins (here, it is 40960). The **\Data length** parameter indicates the length of data for image #1 in bytes (here, it is 52428800). By adding the **\Data offset** and **\Data length** together, the data offset for image #2 is found.

- **Section 3** contains parameters which are specific to image #2. The **\Data offset** parameter here indicates that data for image #2 begins at byte 52469760 and is 52428800 bytes in length.

- **Section 4** is a Ctrl-Z character which denotes the end of parameter lists.

- **Section 5** contains random padding data. This is added to the header to make it a predetermined length (specified in the first **\Data length** parameter at the start of the header) and is used to read the file into NanoScope software. Image files containing multiple images will have less padding than files containing only one image.

- **Section 6** contains image data specific to image #1. In this example, it begins at byte 40960 and is 52428800 bytes in length. Depending upon whether the image was captured at 128, 256, 512... samples per scan line, the length of data will vary.

- **Section 7** contains image data specific to image #2. In this example, it begins at byte 52469760 and is 52428800 bytes in length. The last data value in this section of the file denotes the end of the file.

A.3.2 Parameters

*** File List**—Denotes the beginning of several parameter lists. For example, ***Ciao Image list**, ***Equipment list**, etc. Each image in the file has its own image list (e.g., *Ciao image list).

\Version—Describes the version of software used.

\Data length—Length of header, Ctrl-Z character and padding in bytes.

\Samples/line—Number of pixels per scan line. This is the same as the **Number of samples** value on the **Real-time / Scan Controls** panel.

\Scan size—Height and width of the square scan area in nanometers.

\Z atten—Z-axis attenuation value. The total Z-axis range of data may be calculated from this number as follows:

$$\text{Total Z-axis range} = \frac{\text{Z atten value}}{65{,}536} \cdot 440$$

The Z attenuation value is divided by 65,536 (steps of resolution for Z scanner piezo), then multiplied times the Z-axis scanner voltage range (± 220 Volts) to yield the total Z-axis range of data.

\Data offset—Nth byte in the image file where raw data commences.

\Data length—Length of raw data stream in bytes. Divide this value by 2 to obtain the total number of pixels in the image.

\Z scale—Factor used to convert data to indicated units. E.g., for **\Z scale: 20000 nm**,

$$\text{data (nm)} = \frac{\text{pixel value}}{65{,}536} \cdot 20000$$

\Z sensitivity—Z-axis scanner sensitivity in nanometers per volt. To obtain the maximum Z-axis scanner travel, multiply this value by 440.

\Z scale magnify—Multiplier applied to Z-axis height data to render a NanoScope image on the display screen. For example, a value of 1.0 would render data on the display screen at the same scale as actual features. This value is generally of no use outside the NanoScope software environment.

A.3.3 Control-Z (Ctrl-Z) Character

A Ctrl-Z (ASCII value 26) character is used to show the end of the parameter lists and the beginning of padding. Users wishing to organize their data for spreadsheets may search for this character to locate the end of the parameter lists.

A.3.4 Padding

After the Ctrl-Z character, a quantity of random data—"padding"—is inserted into the file to make the header a fixed length specified in the first **\Data length** parameter at the start of the header. Padding contains no information, and exists only to accommodate various lengths of parameter lists for different image files.

A.3.5 Raw Data

Comprising the bulk of every image file is the raw data of the image itself. At the time of **Capture**, image data is stored 16-bits per pixel in the capture directory on the computer's hard drive. (Data is stored in 2's complement, LSB). The 16 bits accorded each pixel allows a 32K Z-axis resolution.

A.4 Converting Data

Refer to the following sections for preparing file data:

- **Preparing Data for Spreadsheets (Summary):** Section A.4.1 on Page 427
- **Preparing Data for Image Processing (Summary):** Section A.4.2 on Page 427
- **Converting Data Files into ASCII:** Section A.4.3 on Page 427

A.4.1 Preparing Data for Spreadsheets (Summary)

You may load data files into third-party, spreadsheet software (e.g., Excel, Igor Pro, Mathematica, etc.). To convert data in to a spreadsheet program, complete the following:

1. Convert the data into ASCII format—for example, by using the **File > Export > ASCII** command. (**NOTE**: This may increase the size of the file substantially.)
2. Select desired settings (see **Converting Data Files into ASCII:** Section A.4.3 on Page 427), then **SAVE**.
3. Load the file into a suitable editor where it may be prepared for third-party applications.
4. Load the raw data into the third-party software program and, if needed, condition the data according to important header parameters and requirements of third-party software application(s).
5. Analyze or modify the conditioned data as required.

A.4.2 Preparing Data for Image Processing (Summary)

You may convert data files into third-party, image processing software (e.g., Photoshop, CorelDraw). To convert the data into image processing software, complete the following:

1. Convert the data into TIFF format—for example, by right-clicking on the image thumbnail in the Browse window and selecting **EXPORT** > **TIFF** > **8-BIT COLOR**, **8-BIT GRAY SCALE** or **16-BIT GRAY SCALE**.
2. Load the TIFF file directly into the third-party, image processing software.
3. Process the image file. This may include cropping the image, filtering the image, adjusting contrast, brightness, color, etc.

A.4.3 Converting Data Files into ASCII

When NanoScope image files are captured and stored, they are in 2-byte, binary (LSB—least significant bit) form. Although some programs import raw, binary files, most users find they must convert the files into ASCII form first to use them. The converted file allows users to read the header information directly and works with many third-party programs requiring ASCII formatting. (Some users prefer to download the original, raw binary files into their third-party program, while using their ASCII version of the file as a guide map.)

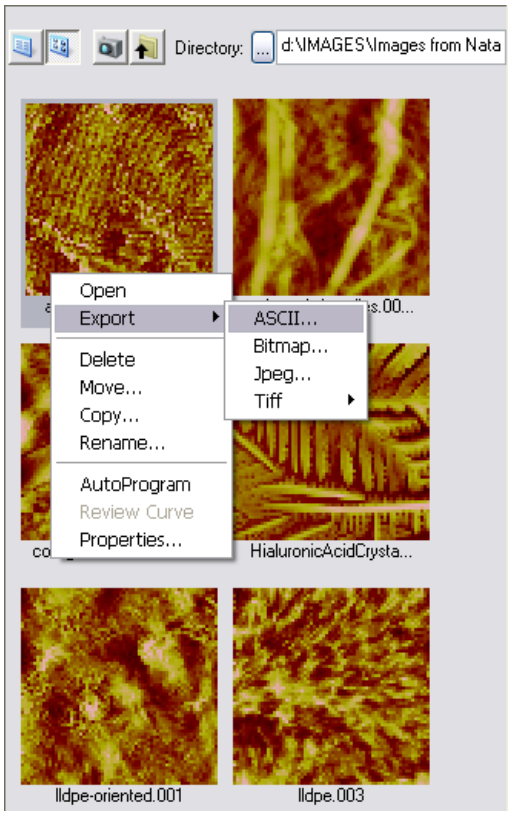
Note: Depending upon the software version used during capture of the image data, the actual file format and file size varies. Headers may include more than 2000 parameters, followed by Ctrl-Z, data padding, and raw data.

Convert captured data in to ASCII format by using the **File** > **Export** menu command. To convert files, complete the following:

1. Make a backup copy of the file to be converted and save it to a safeguarded archive.

2. Select a directory, then an image file within it, from the file browsing window at the right of the **NanoScope** main window. Right-click in the thumbnail image to open the menu shown in Figure A.4a.

Figure A.4a The ASCII Export Command

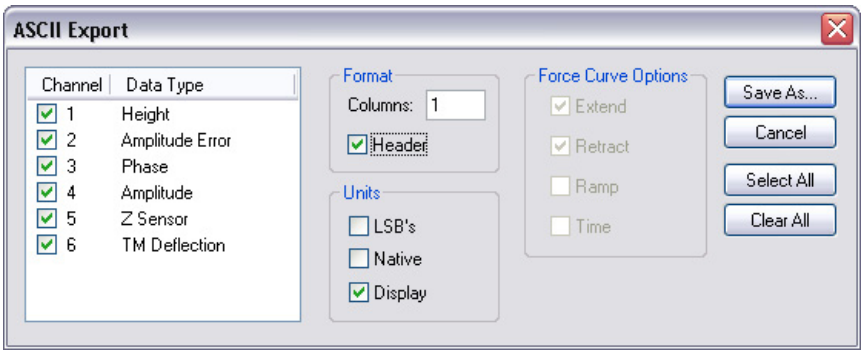


3. Click **Export** > **ASCII** to open the **Export** dialog box (see Figure A.4b).

4. Select the data **CHANNEL**s to be exported.

5. Choose the **COLUMN** format.

Figure A.4b The File Export Dialog Box



6. Select the units (nm, V, Deg...) in which to record the data in the new file by checking the appropriate boxes. Export the image header, ramp, or time information by selecting those check boxes.

Note: In order to convert the ASCII data from binary (LSB) data to useful values (Phase, Frequency, Current, etc.), you must save the information in the header.

7. Click **Save As...**, designate a directory path and filename, and click **Save**.

A.5 Converting Raw Data

Before bringing raw data into a third-party application, the user can first convert the data.

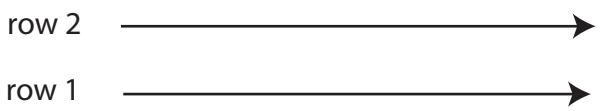
Usually, this means simply multiplying all values by a constant to convert them into common measuring units. Once converted, the data becomes more meaningful to analyze.

By using parameters in the header, it is possible to convert and analyze data for various purposes. Users need only understand how parameters are related to extract the maximum amount of information from their files. In the raw data information, each numeric value is relative horizontally and vertically.

A.5.1 Data Organization

Data is row-ordered starting at the lower left corner. See Figure A.5a.

Figure A.5a Exported image data organization



A.5.2 Calculating Scaling Values

In order to calculate height data from LSB form (no longer necessary if you export the data in **DISPLAY Units** — see **ASCII Export:** Section 2.5.6 on Page 60), convert it by using the Z scale value. Recall that raw data recorded from each scan is scaled to the maximum resolution of the Z-axis scanner (± 32,768). Whether features are related in terms of "height" or "depth" is irrelevant. What matters most is that features be accurately represented in meaningful units.

To convert raw data into metric units, use the following relation:

$$\text{Z height} = \frac{(\text{data point value})(\text{Z scale})(\text{Sens. Z scan})}{2^{16}}$$

Note: The **Z scale** value in a parameter list includes the value and the units (for example, **Z scale: 1.57541 µm**). In this example, the units of measure are in microns (µm).

Calculating X and Y Pixel Width from Raw Data

To obtain the X axis pixel width, use the following relation:

$$X = \frac{\text{Scan size}}{(\text{Samples/line}) - 1}$$

To obtain the Y axis pixel width, use the following relation:

$$Y = \frac{\text{Scan size}}{(\text{Number of Lines}) - 1}$$

A.5.3 Calculating Raw Data Values

This section details equations to calculate values for **analysis** (e.g., amplitude, phase, etc.).

Note: Only one set of values may be found for each Z scale. That is, the Zscale units are different for each type of image (Hz for Frequency, or nA for Current), and the Zscale for a Height image (for example) may not be used to find values for Phase.

The equations for converting the LSB data points into various values are as follows:

Height

$$\text{Height} = \frac{data\ point}{65536} \times Z\ scale\ height\ value$$

Phase:

$$\text{Phase} = \left(\frac{\text{Data point}}{65536}\right) ¥ \left[\text{Z scale phase} ¥ \left(\frac{180°}{65536}\right)\right]$$

Frequency

$$\text{Frequency} = \left(\frac{\text{Data point}}{65536}\right) \times \left[Z\ scale\ freq \times \left(\frac{25e^{6}}{2^{32}}\right)\right]$$

Potential

$$\text{Potential} = \left(\frac{\text{Data point}}{65536}\right) \times \left[Z\ scale\ pot \times \left(\frac{2 \cdot In\ 2\ max}{65536}\right)\right]$$

Current (nA)

$$\text{Current} = \left(\frac{\text{Data point}}{65536}\right) \times \left[Z\ scale\ amplitude \times \left(\frac{2 \cdot In\ 1\ max}{65536}\right) \times In\ sensitivity\right]$$

Amplitude (nm)

$$\text{Amplitude} = \left(\frac{\text{Data point}}{65536}\right) \times \left[Z\ scale\ amplitude \times \left(\frac{2 \cdot In\ 1\ max}{65536}\right) \times \left(\frac{In\ sensitivity}{Detect\ sens}\right)\right]$$

For LFM Aux data, the torsional deflection of the cantilever in volts (or whatever else, depending, on the definition of the input sensitivity) can be calculated by applying the following formula to each point in the data file:

$$\text{Deflection} = \left(\frac{\text{Data point}}{65536}\right) \times \left[Z\ scale\ Aux\ A \times \left(\frac{2 \cdot In\ 2\ max}{65536}\right) \times In\ sensitivity\ Aux\ A\right]$$

In this formula, the parameter **Aux A** and **In sensitivity aux A** can be substituted with the corresponding parameters for **Aux B, Aux C,** and **Aux D**. In order to get the **In sensitivity aux (A,B,C,D)** parameters to

appear in the header, you must select **Tools** > **Calibrate** > **Detector**, highlight the parameter, and then press enter.

A.5.4 Force Curve File Format Information

When exporting the force curve in ASCII format, it is recommended that the file be exported twice, once with the header and once without. The one without the header should be exported in Spreadsheet format (comma delineated).

When you import the file without the header into MS Excel each value should come up as a separate entry. `\Samps/line` in the `\*Ciao force list` displays the number of samples in the retract curve followed by the number of samples in the extend curve. `\Data length` is the number of samples/line *2 (2 bytes/point) *2 (extend + retract). The scan size in Z is calculated by looking at the `\Z Scan size` value in the `\*Ciao force list` in the header and the `Sens. ZSens` in the `\*Scanner list`. Then do the following calculation.

In the header, find the line "`\*Ciao force list`" and "`\Scan Size`". The Scan Size is in 16-bit values. Convert to nm by:

$$\text{Size (nm)} = \frac{\text{Z Scan size} \cdot \text{Sens. Zsens}}{(\text{Number of Data points} - 1)}$$

In some cases it may be necessary to calculate the force to determine the vertical (Deflection) axis of a curve. The following calculation may be used, as long as the microscope is in **ContactMode** and **Input Atten** is set to **1x**.

$$\text{Value (nm)} = \text{data point (LSB)} \cdot \text{Sens. DeflSens} \cdot \text{Z scale}$$

Note that the above equation only works when calculating force vs. separation. When calculating force vs. Z, *Z magnify force* must be removed from the calculation. When calculating deflection vs. Z, the spring constant must also be removed from the calculation.

When interested only in the deflection of the curve, the calculation below will suffice. Divide by the number of samples to get the Z step per data point. This value is also found in the "`\*Ciao force image list`" near the header end.

Force Data Organization

In later versions, the data changes and is opposite from previous versions of software. For example, the first **n** samples of data includes the **Extend** curve from the closest approach to the farthest distance. The next **n** data points are the **Retract** curve data from the closest to farthest distance.

Converting the Force Data to Volts

The actual data is again in 16-bit values for the input signal. Convert to volts by:

$$\text{Value (V)} = \frac{\text{Value (LSB)}}{65536} \cdot (\text{Full Volt Range})$$

The volt range is **20V** for **Contact Mode** when In Atten is 8X. Its 2.5 for 1X In Atten. If you are in **TappingMode** looking at deflection (normal mode using Nanoindentation), it's 5V (see the table below).

Microscope Mode	InAtten / Deflection	Volt Range
Contact mode	8X	10V
Contact mode	1X	1.25V
TappingMode	(normal mode)	5V

The Detector Sensitivity is under the "`\Ciao scan list`", as "`\DeflSens`" in units of $\frac{\text{V of detector}}{\text{nm of Z}}$.

Force Curve File Format

To find the Z scan size and steps, refer to the Sample Parameter List for an Image File, Figure A.7a and complete the following:

1. Under `\*Ciao Force List` are the parameters that describe Z:
   `\@Z scan start:` (last number is in volts)
   `\@Z scan size:` (last number is also in volts)

You can convert using the `\@Sens. Zscan:` which shows the value and units (typically 12.5 nm/V) under the `\*Scanner list` line.

2. Find the number of pixels/line of data is under the `\*Ciao` force image list (usually last) as:
   `\Samps/line:` nnn [where nnn is the number of pixels in each direction]

Also in the *Ciao section is the Data Type:
`\@4: Image Data: S` [data type] "data description"

Data type is usually Deflection or Amplitude and can be "`Deflection`", "`TM Deflect.`" or "`Amplitude`".

A.5.5 Force Volume File Format Information

The curve data should be right after the image height data. The curve data is the data collected at each Z point as in a normal single force curve file. If deflection, volts is given by:

$$\text{Deflection (V)} = \frac{\text{Data point (LSB)}}{65536\text{(LSB)}} \cdot \frac{10\text{(V)}}{\text{Input atten (1 or 8)}}$$

Using the value for deflection in volts (V), it is possible to calculate the deflection in nanometers (nm) using the equation:

$$\text{Defl (nm)} = \frac{\text{Deflection (V)}}{\text{Detector Sensitivity (V/nm)}}$$

The way force volume works, it gets tricky to figure which image pixel corresponds to which force curve data. The data and force curve are in the same order: bottom to top, left to right. There are three pixel numbers that are needed:

- Under "`\*[NC]AFM`" image list, "`\Samps/line`" gives the number of image pixels/ line, 128, 256, 512...

- Under "`\*Force`" image list, "`\Samps/line: n m`", where `n` is the number of samples per Force line.
- Under "`\*Force cal.`" list is the "`\force/line: n m`" parameter, where `n` is the number of force curves / image line.

Consider a square block of pixels that represents one force curve. Including the data in the bottom left corner, a simple analysis allows the identification of which pixel corresponds to which curve. If the number of samples/force line is 128 and the number of force curves/image data is 32 and there are 256 pixels/image data, then there is a curve every 256/32 or 8 pixels. The next image data line with force curves is the 8th one from that line. Since there are 128 samples/force curve, they are 256 pixels or 512 bytes each. Thus, the first image pixel matches the first force curve, the 8th pixel matches the second force curve 512 bytes later, etc.

Even though there are 3 data displays during Force Volume (Image, Force plot and FV Image), the FV image is **NOT SAVED**. It is calculated during both the Real-time and Off-line display from the force curve data as described above.

A.6 Electrochemistry

A.6.1 EC File Format

The EC file format is:

1. Header: ASCII plus padding to make it 40960 bytes long. Data offset and length of each segment are specified. Image parameters are also recorded.
2. Image data body, 2 bytes/datapoint.
3. EC data: Potential vs. Time, 2 bytes/datapoint.
4. EC data: Current vs. Time, 2 bytes/datapoint.

A.6.2 Data Conversion

Potential

$$\text{Potential} = \frac{data\ point}{65536} \times 20 \times \textit{Potential Sensivity value}$$

Current

$$\text{Current} = \frac{data\ point}{65536} \times 20 \times \textit{Current Sensivity value}$$

Potential Sensitivity and Current Sensitivity can be found in the header file as EPotSens and ICellSens respectively. For example:

\@Sens. EPotSens: V 1.000000 V/V

\@Sens. ICellSens: V 100.0000 ~A/V

A.7 General Format for CIAO Parameter Objects

In the file header some parameters start with '\@' instead of simply '\'. This is an indication to the software that the data that follows is intended for a CIAO parameter object. After the '@', you might see a number followed by a colon before the label. This number is what we call a “group number” and can generally be ignored.

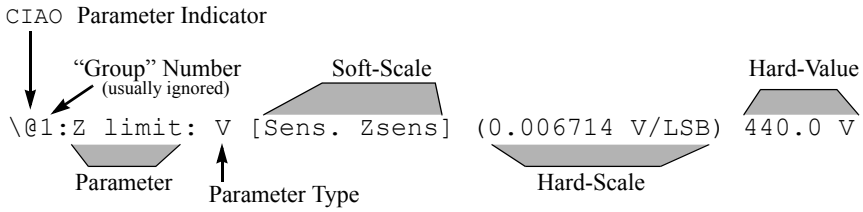
Further, after the label and its colon, you will see a single definition character of 'V', 'C', or 'S'.

- V means **Value** – a parameter that contains a double and a unit of measure, and some scaling definitions.
- C means **Scale** – a parameter that is simply a scaled version of another.
- S means **Select** – a parameter that describes some selection that has been made.

A.7.1 Value Parameters

The **Value** (identified by the letter “V”) parameters have the following format:
[soft-scale] (hard-scale) hard-value.

Example 1: Value parameter format



LSB

Since the NanoScope is a digital device, all data is numeric. We call this number in its rawest form a **LSB** (i.e., scaling values on ADCs and DACs as Volts per Least-Significant-Bit). The LSB is the digital representation of volts or frequency and is a 16 bit integer.

Hard value

The hard value is the analog representation of a measurement. It is simply the value read on the parameter panel when you set the **Units**: to **Volts**. The hard-value is the value you would read with a voltmeter inside of the NanoScope electronics or inside the head. This value is always in volts with the exception of the Drive Frequency (which is in Hertz) and some STM parameters (which are in Amps).

A value parameter might be missing a soft-scale or a hard-scale, but must **always** have a hard-value.

Hard Scale

The hard scale is the conversion factor we use to convert LSBs into hard values. We use the prefix “hard-” in hard-scale and hard-value because these numbers are typically defined by the hardware itself and are not changeable by the user.

Soft Value

A soft-value is what the user sees on the screen when the **Units:** are set to Metric.

Soft Scale

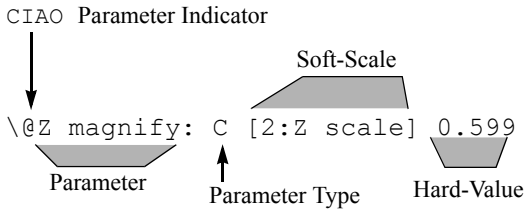
The soft-scale is what we use to convert a hard-value into a soft-value. Soft-scales are user defined, or are calibration numbers that the user divines. Soft-scales in the parameters are typically not written out — rather, another tag appears between the brackets, like [Sens. Zsens]. In that case, you look elsewhere in the parameter list for tag and use that parameter's hard-value for the soft-scale.

Note: The name of a soft scale can change from one microscope, controller or software version to the next. A common problem occurs when users create programs that look for the soft scale directly instead of parsing the value parameter to find the name of the soft scale that must be used.

A.7.2 Scale Parameters

The **Scale** parameters (identified by the letter "C") have the following format:
[soft-scale] hard-value.

Example 2: Scale parameter format

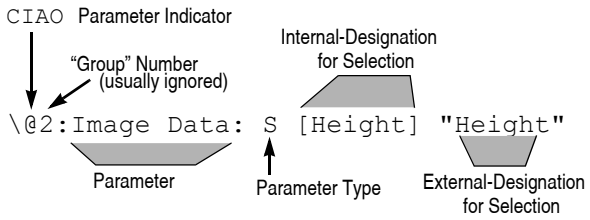


- The hard-value is almost always a scalar value.
- The soft-scale always points to another parameter – this parameter is the target of the scaling action.
- Most often used for the Z magnify parm to allow user to change scaling of Z scale in Off-line without actually affecting the real data in the file.

A.7.3 Select Parameters

The **Select** parameters (identified by the letter "S") have the following format:
[Internal-designation for selection] "external-designation for selection"

Example 3: Select parameter format



A.7.4 Procedures to Interpret Data in a Height Image

To find the Z scale conversion factors, refer to Figure A.7a to complete the following calculation:

1. Find the **Z scale** line. Note that the parameter "`Sens. Zsens`" appears in brackets and specifies the **soft scale** to the user.

2. Locate the `[Sens. Zsens]` in the **Scanner List**.

Figure A.7a Sample Parameter List for an Image File

```
\*File list
\Version: 0x07200000
\Date: 06:47:11 PM Fri Apr 20 2007
\Start context: OL2BIG
\Data length: 40960
\@Sens. Zsens: V 12.50000 nm/V
.
\*Ciao scan list
\Scan Size: 2000 nm                                  //Scan Size
\X Offset: 0 nm
\Y Offset: 0 nm
\Rotate Ang.: 1.5708
\Samps/line: 512                                     // # Pixels in each image line
\Lines: 512                                          // # of lines
\Y disable: Enabled
\Aspect Ratio: 1:1
\Bidirectional Scan: Disabled
\Scan line shift: 0
\Scan Rate : 0.498246
.
.
\*Ciao image list
\Data offset: 40960                                  // Offset from file start to binary data for this channel
\Data length: 524288                                 // Length of data in this image channel
\Bytes/pixel: 2
.
.
\@Z magnify: C [2:Z scale] 0.5987848
\@2:Z scale: V [Sens. Zsens] (0.006713765 V/LSB) 5.344157 V
\@2:Z offset: V [Sens. Zsens] (0.006713765 V/LSB) -21.60000 V
```

The hard scale (e.g., 0.006713765 V/LSB) is the scale at which the file was originally captured. However, to help minimize round off errors in the off-line processing, the software automatically scales the image data to

the full range of the data word. While the hard value of the Z scale is updated, the hard scale is not. Therefore, this hard scale should be ignored and we will calculate a *corrected hard scale*:

$$corrected\ hard\ scale = \frac{hard\ value}{65536}$$

Once we know the *corrected hard scale*, we can convert the *LSBs* that represent the data points in the image to *hard* or *soft values*.

$$hard\ value\ =\ LSB \times corrected\ hard\ scale$$

$$soft\text{-}value\ =\ soft\text{-}scale \times hard\ value$$

Using these formulas, it is possible to deduce all one might want to know about the data.

Converting Raw Data into Height

The raw data in the file is a series of signed 16 bit (2 byte) integers. The numbers in the data file are called LSBs (and, for our purposes, assigned a unit of 'LSB'). In order to convert the raw data in the file, use the number from the file and multiply it by both the hard-scale and the soft-scale.

For example, using the above parameter list in Figure A.7a, the corrected hard scale would be:

$$\frac{5.344157\text{V}}{2^{(8\cdot 2)}} = \frac{5.344157\text{V}}{65536} = 0.00008154536\frac{\text{V}}{\text{LSB}}$$

Now, if we had a value of 54 in the data file, the result would be:

$$(54\text{LSB}) \cdot \left(0.00008154536\frac{\text{V}}{\text{LSB}}\right) \cdot \left(12.50\frac{\text{nm}}{\text{V}}\right) = 0.005504\text{nm}$$

Note: The same procedure may be used to calculate frequency, current, potential, amplitude data, etc., by using the appropriate Z scale. However, each data set requires a specific Z scale. For example, the Z scale for potential may not be used to calculate frequency.

What is the range of the data in the file?

The range of data in the file may be found by multiplying the hard-value by the soft-scale. Using the hard-value and soft-scale values from the example above:

$$5.344157\text{V} \cdot 12.50\frac{\text{nm}}{\text{V}} = 66.80\text{nm}$$

How can I calculate the displayed Z scale for use in my own analysis programs?

Data is expanded in the NanoScope file after capture to prevent round-off in the Off-line calculations. The expansion procedure changes the Z scale to correspond with the new scale of the expanded data. Yet, in Off-line, the software displays the data with the original Z scale used to capture it.

You can use Z magnify to discover the displayed Z scale. The modified Z scale is 67 nm. Z magnify (from the Sample Parameter List for an Image File, Figure A.7a) tells us there is a scale of 0.5987848 missing. So the data on the screen in the NanoScope off-line is displayed at 40 nm. This trick also works if the user changed the displayed Z scale in Offline.

Appenix B Color Tables

2.1 List of Color Tables

Table 2.1a display a list of the 26 NanoScope color tables with **Contrast** = 0 and **Offset** = 0.

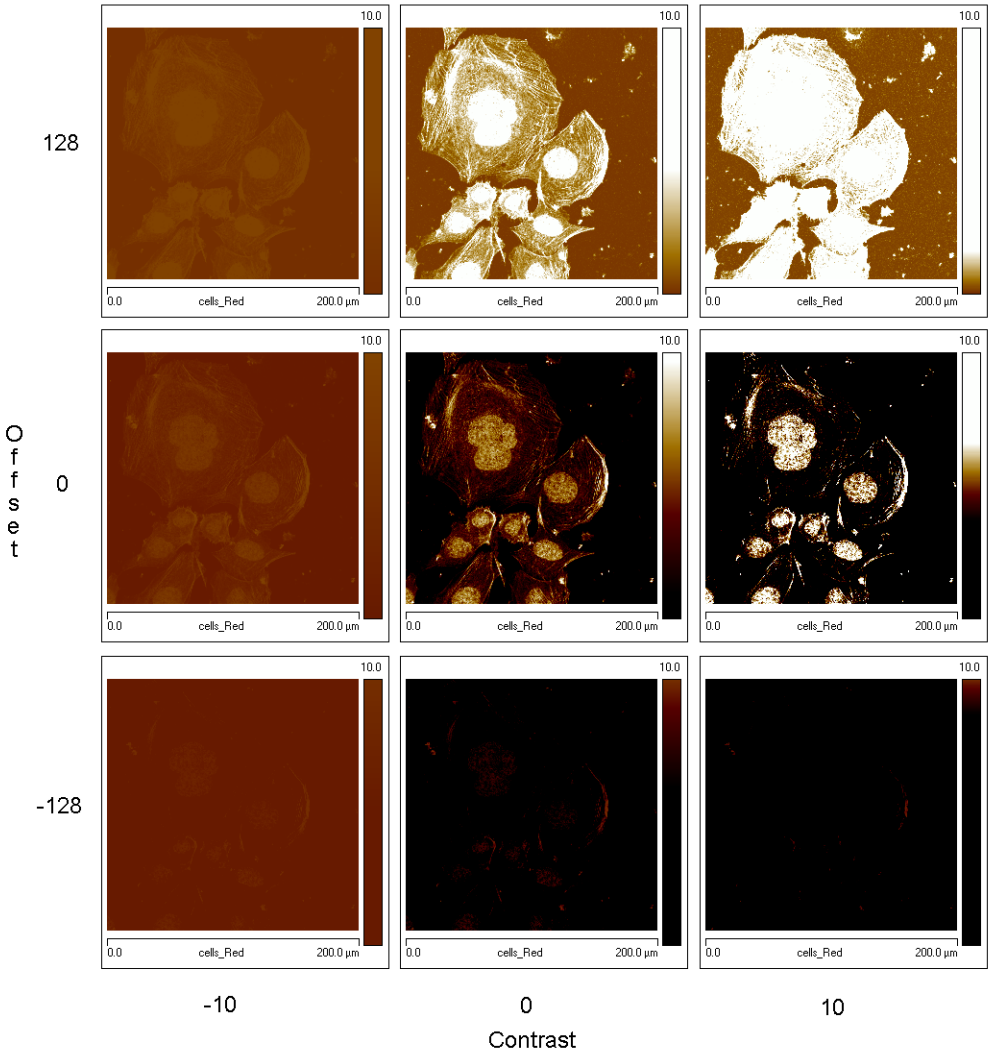
Table 2.1a NanoScope Color Tables

Color Table ID	Colors
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Color Table ID	Colors
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	

Both **Contrast** and **Offset** have a major effect on displayed colors. An example is shown for **Color Table 12** in Figure 2.1.

Figure 2.1a Effect of **Contrast** and **Offset** on displayed color for **Color Table** 12



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