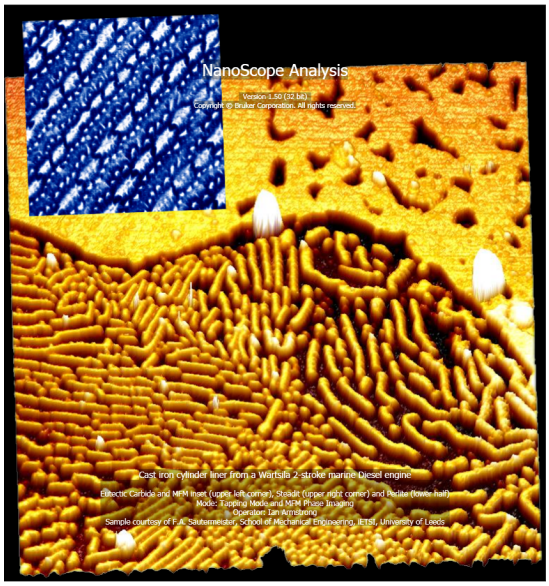
NanoScope Analysis1.50



NanoScope Analysis 1.50 provides offline analysis functions for NanoScope and SpmLab captured data files.

The NanoScope Analysis 1.50 manual consists of the following main areas:

About the PDF version of this manual

This manual was written in and for html presentation but a PDF version was prepared for users who requested it. Screen images in the PDF manual will sometimes be less clear than those in the html manual but a printed version may be better than the screen versions. Pagination, particularly that of tables, may be less than optimal.

Chapter 1: Welcome to NanoScope Analysis 1.50

NanoScope Analysis 1.50 comes with some great new functionality to expand your experimental capabilities and to improve the user experience. Click on the topics below for brief explanations and links to more information.

1.1 Online Help

Bruker's help manuals are linked directly to the NanoScope Analysis software, accessible from the menu toolbar. Better yet, use the F1 key to open the online help to an area related to your current operations. Please note that the manual will look at the active panel in the software, so try clicking on the area of the screen that you're most interested in knowing about before using the F1 key. Not the right information? The online help is also indexed and fully searchable.

1.2 New features for NanoScope Analysis 1.50 r2:

Enhancements to the Color Scale

A new feature, Add Color Point has been added to the Color Scale function, increasing your color display options.

24 bit bitmaps

24 bit bitmaps replaced 256 color bitmaps, resulting in higher quality image display.

1.3 New features for NanoScope Analysis 1.50 r1:

Offline analysis has been removed from NanoScope software version 9 and later and has been replaced by equivalent functions in NanoScope Analysis.

Support for Windows 7® 64-bit

NanoScope Analysis 1.50 supports Windows 7 64 bit as well as Windows 7 and Windows XP 32 bit systems. The Windows 7 64-bit architecture provides access to more physical memory, paving the way for faster data processing.

The Run History *dialog is now called* Run AutoProgram*, and has enhancements.*

3D Lighting in the 2D View

Allows you to make more detailed, vivid images.

Expanded Export Functionality

Export is now called Journal Quality Export with more options to control exported images and movies.

Images with 3D lighting can also be exported and placed into movies.

3D images can now be exported with all the options of Journal Quality Export, including 3D movies.

Support for MIRO

MIRO support has been added to NanoScope Analysis 1.50.

S Parameters added to the Roughness analysis

NanoScope Analysis 1.50 adds calculation of S parameters.

Patterned Sample Analysis Improved

Patterned Sample Analysis no longer requires a MATLAB® runtime library, is written in C++ and is over 10 times faster.

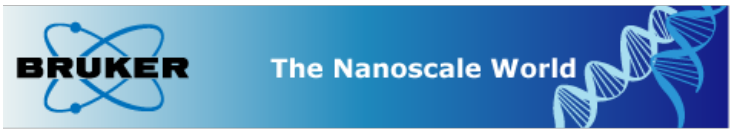
Flatten Improved

Flatten now includes a histogram with a movable cursor that allows you to more easily set the threshold height for excluded data.

1.4 Previous Software Releases

- NanoScope Analysis 1.40 New Features (page 5)
- NanoScope Analysis 1.30 New Features (page 7)

1.5 Join the Conversation at The Nanoscale World



This online forum allows you unprecedented access to AFM experts around the world, at Bruker and beyond. Post your questions, browse for advice, and share your own knowledge with AFM peers. This is also your portal for Applications Notes documentation and feature requests. We look forward to hearing from you!

1.6 More Questions?

See Technical Support at Bruker (page 337) to contact us directly with your questions, comments, or concerns.

1.7 NanoScope Analysis 1.40 New Features

NanoScope Analysis 1.40 introduced many new functions, some of which include enhanced nanomechanical property analysis. Click on the topics below for brief explanations and links to more information.

1.7.1 New features for NanoScope Analysis 1.40 r3:

Force Volume

Force Volume Mapping now includes quantitative nanomechanical property calculations. Force Volume has been used for many years by researchers to collect an array of force curves over an image area. Many users have created their own analysis routines to analyze these force curves and present maps of the calculated sample stiffness, modulus and tip-sample adhesion. Now these calculations can be done within the NanoScope software in real-time and offline in NanoScope Analysis. Calculations include Hertz and Sneddon modulus models and tip-sample adhesion.

1.7.2 New features for NanoScope Analysis 1.40 r2:

Modify Force Parameters

The ***Modify Force Parameters*** function lets you change the ***Deflection Sensitivity***, ***Spring Constant***, ***Tip Radius***, ***Tip Half Angle*** and the ***Sample's Poisson Ratio***.

Indentation Analysis

The ***Indentation*** function lets you fit various indentation models to measured force curves.

Baseline Correction

The ***Baseline Correction*** function measures baseline tilt and applies a linear correction to the whole force curve.

Boxcar filter

The ***Boxcar*** filter applies a moving average filter to your data.

MATLAB utilities

MATLAB utilities included with NanoScope Analysis allow you to interface MATLAB with NanoScope force and force volume data.

1.7.3 New features for NanoScope Analysis 1.40:

Run History

Once one image has been analyzed, filtered and/or exported, the same sequence of actions can be applied to multiple images.

Image Export

Allows you to export publication quality images from NanoScope Analysis.

Make movies

When using ***Run History***, a movie can be created from exported images.

Patterned Sample Analysis (optional)

Allows you to characterize regularly patterned samples.

Support for more data types

Electrochemistry (EC) data channels are now supported, as well as TIFF-directed point-and-shoot.

Support for SIS Files

NanoScope Analysis fully supports SIS files created by Bruker ScanPanel software.

1.8 NanoScope Analysis 1.30 New Features

NanoScope Analysis 1.30 introduced several new functions. Click on the topics below for brief explanations and links to more information.

1.8.1 New features for NanoScope Analysis 1.30:

Color table editor

This new dialog allows you to choose a color table and customize it according to your preferences. You can optimize the color scheme for a given image and save that color scheme for use on future analyses.

Synchronized analysis and cursors

Cursors and analyses can now be applied across multiple data channels and files, improving productivity and enabling easier comparison of data across data types and files.

Small monitor support

Additional monitor size support now includes netbooks, laptops, and multiple monitors.

High-resolution 3D rendering

NanoScope Analysis can now render up to 2048 points per line by default with the capability to render even higher resolution images as required.

Linearity verification

You can now verify scanner performance within NanoScope Analysis.

Chapter 2: The NanoScope Analysis User Interface

The NanoScope Analysis user interface is shown in Figure 2.0a. The major areas are described.

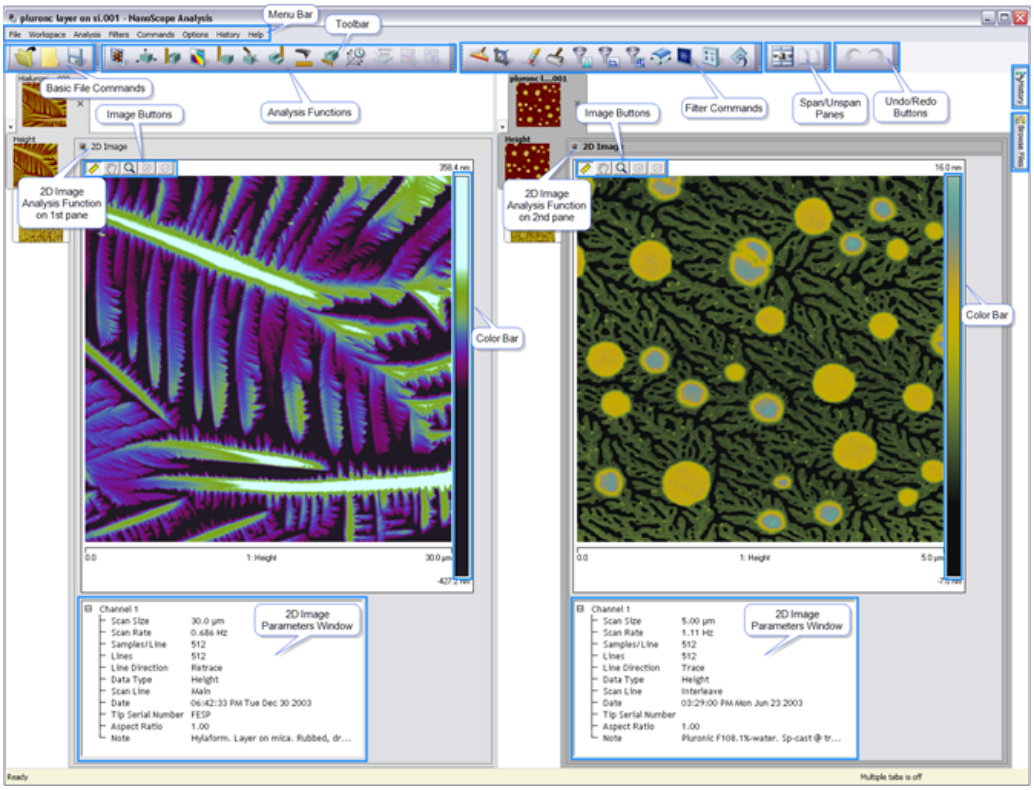


Figure 2.0a: NanoScope Analysis User Interface

Chapter 3: Installation and Basic Requirements

3.1 Basic Requirements

To use NanoScope Analysis1.50, a computer with the following capabilities is needed:

- 2GHz minimum, 3GHz recommended
- 1GB RAM required, 2GB RAM recommended
- 50GB Hard Drive minimum
- Windows XP, Vista, or Windows 7.

NOTE: 64 bit versions of NanoScope Analysis require Windows 7.

3.2 Installation

To install NanoScope Analysis1.50, follow the directions below:

1. Login as an Administrator in Windows. Copy NanoScope Analysis installer to the hard disk. The installer for 1.50 is approximately 600 MB.
2. Double click the installer to begin the installation process. A ***Welcome*** window will immediately appear. Click **Next**.
3. The next window asks you to select a database server and authentication method. Selecting the default server and authentication method are the preferred methods for the vast majority of NanoScope Analysis users. A few users may want to select their own SQL servers. Click **Next**.
4. The next window will be the end user license agreement. Choose I Accept and Next to continue installation. The license may also be Printed for future reference, if required.
5. Enter the username, company name and click Next.
6. Choose the destination location where setup will install the files. Once the correct path has been identified, click Next and Install to proceed.
7. At this point, NanoScope Analysis setup will check prerequisites behind the scenes. Setup will install the following list of packages, if the necessary versions are not found on the system.
    - .Net framework 4.0
    - Visual Studio 8.0 merge modules.

NOTE: If the above packages are not installed correctly, a 'NsDataAnalysisExt.dll failed to register' error message will appear. If this error message appears, uninstall NanoScope Analysis and reinstall it.

Chapter 4: File Commands

The NanoScope Analysis user interface includes a ***Menu*** bar at the top of the program window. Many commands accessed from the menu bar are similar to what you might find in other word processing and SPM software programs. ***File commands*** enable the user to perform frequent tasks in NanoScope Analysis software.

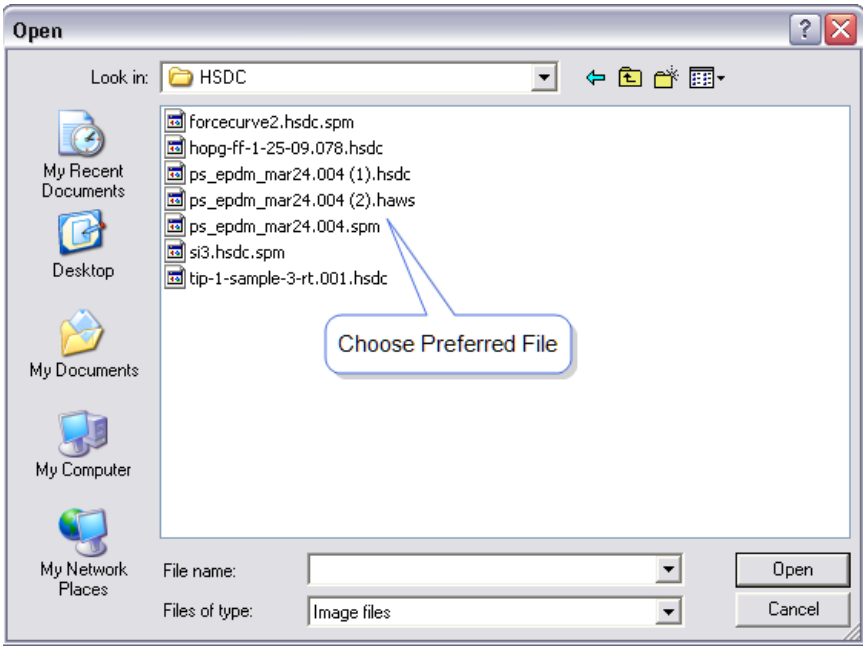
The following File Command sections are included in NanoScope Analysis 1.50:

4.1 Basic File Commands

Basic file commands are common to most Windows applications. They include opening, closing, saving and printing files. Users familiar with Windows will already know how these commands work. Many of these basic file commands can be executed by either clicking on the associated icon or by using the ***File*** menu.

4.1.1 Opening a File

1. To open a file, click on the Open File icon or select **File > Open** from the ***Menu*** bar.
2. Clicking on the Open File icon brings up the ***Open*** window:



3. Choose the preferred file and click Open.
4. The chosen file will open in ***2D Image*** view.

4.1.2 Closing a File

To close a file, click on the **Close File** icon or click on the ***File*** Menu and select Close (open filename) or Close All.

4.1.3 Saving a File

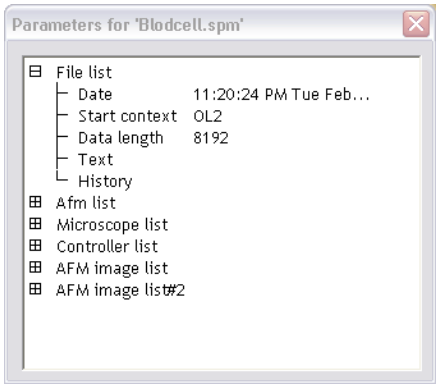
To save a file, click on the ***File*** menu and select Save (open filename) or Save As (open filename) to save the file with a different name. Additionally, clicking on the **Save** icon will save a file.

4.1.4 Printing a File

To print a file, click on the ***File*** menu and select **Print**. To view a print preview in advance of printing, choose **File > Print Preview** from the ***File*** menu. Print settings may also be changed by selecting **File > Print Setup** from the ***File*** menu.

4.1.5 Display File Properties

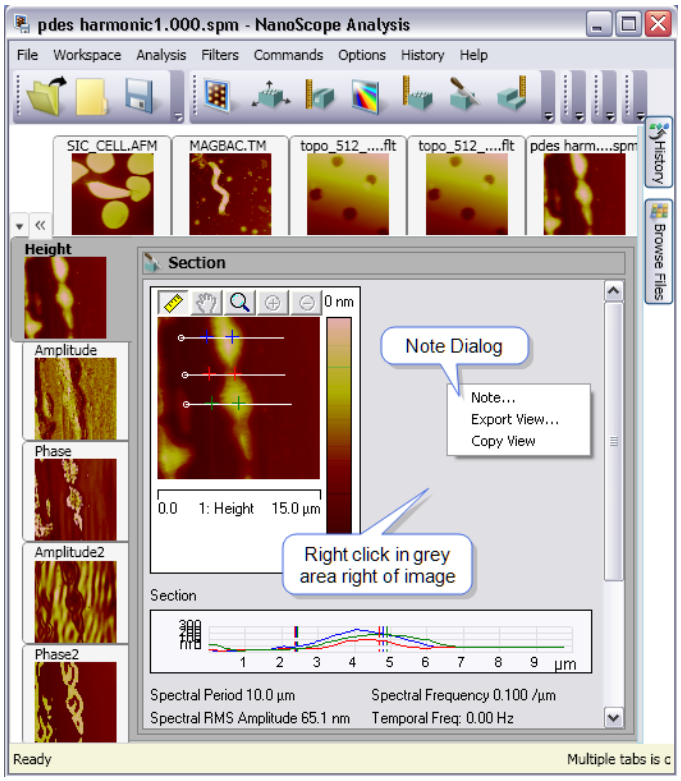
To display the properties of a given file, first open that file in NanoScope Analysis. Once the file is open, select **File > Display Properties** from the ***File*** menu. The Parameters window for the particular image will open:



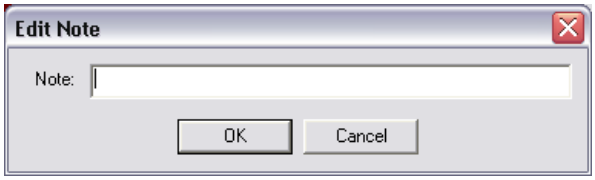
Click on the +/- signs to expand or collapse each data field.

4.1.6 Add a Note

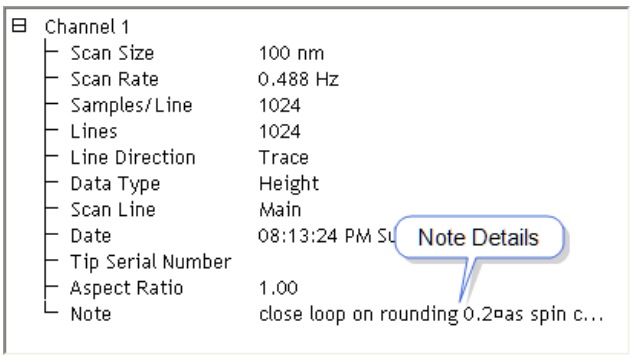
A **Note** can be added to any open image by right clicking on the area adjacent to the image or by selecting **File > Add a Note To...** from the ***Menu*** bar. When right clicking adjacent to an image, a dialog appears with ***Note*** as a choice:



Selecting ***Note*** opens the ***Edit Note*** window where the ***Note*** can be added:



Type in the preferred ***Note*** and click OK. To access the ***Note*** at a later time, click on the 2D Image button. Note is the bottom parameter in the ***2D Image*** parameters area:



4.2 The Browse Window

Open the **Browse** window by moving the mouse over the **Browse Files** button on the upper right side of the main window. Directory icons appear in the Browse window. Double-click a folder icon to browse that directory. Click the **Pin** button  to keep the Browse window in place. Clicking the Pin button a second time will put the Browse window back to the original location.

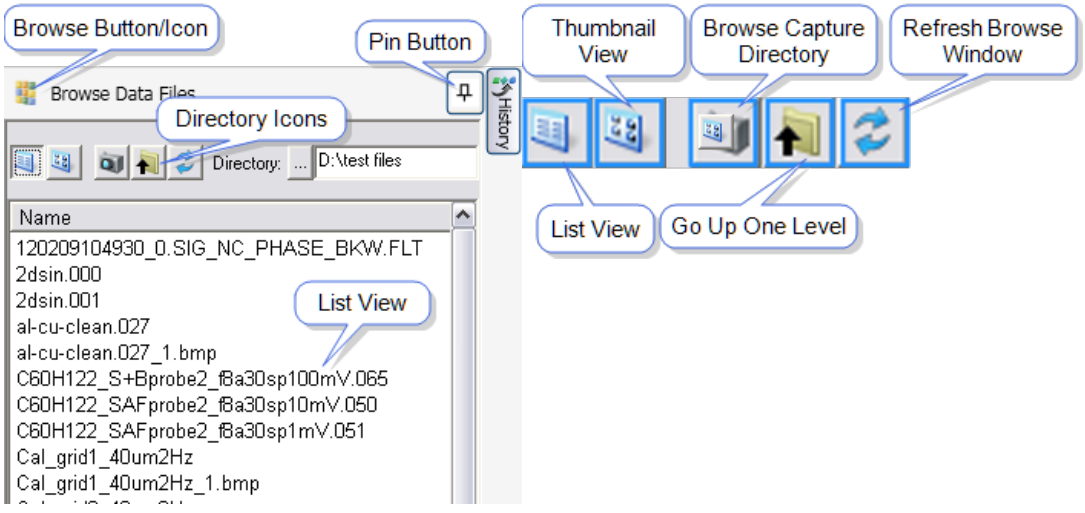


Figure 4.2a: Browse Window & Browse Window Icons

4.2.1 List View

Selecting the first icon of the Browse window initiates a List View of file information:

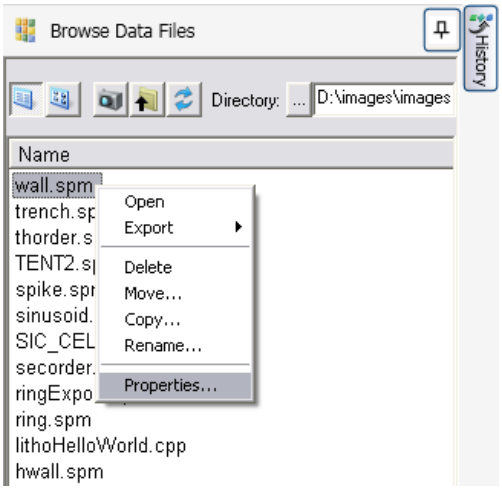


Figure 4.2b: List View

Right clicking the on a file and clicking on properties allows for viewing of several SPM parameters for that particular file. See Figure 4.2c.

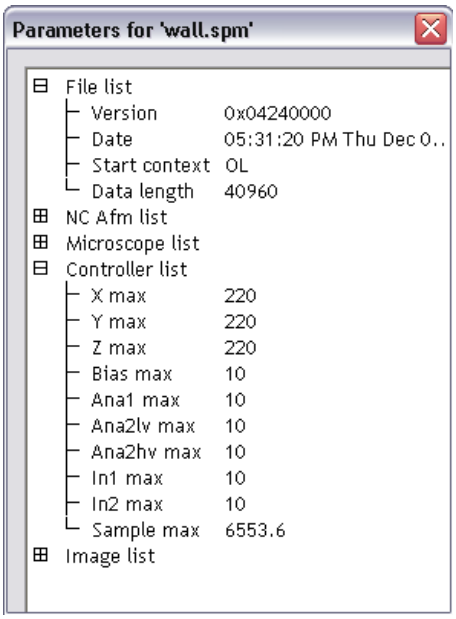


Figure 4.2c: File Parameters

Configuring the List View

Right-clicking in the ***List View*** (but not on a file name) opens a dialog that allows you to choose the displayed NanoScope fields. See Figure 4.2d.

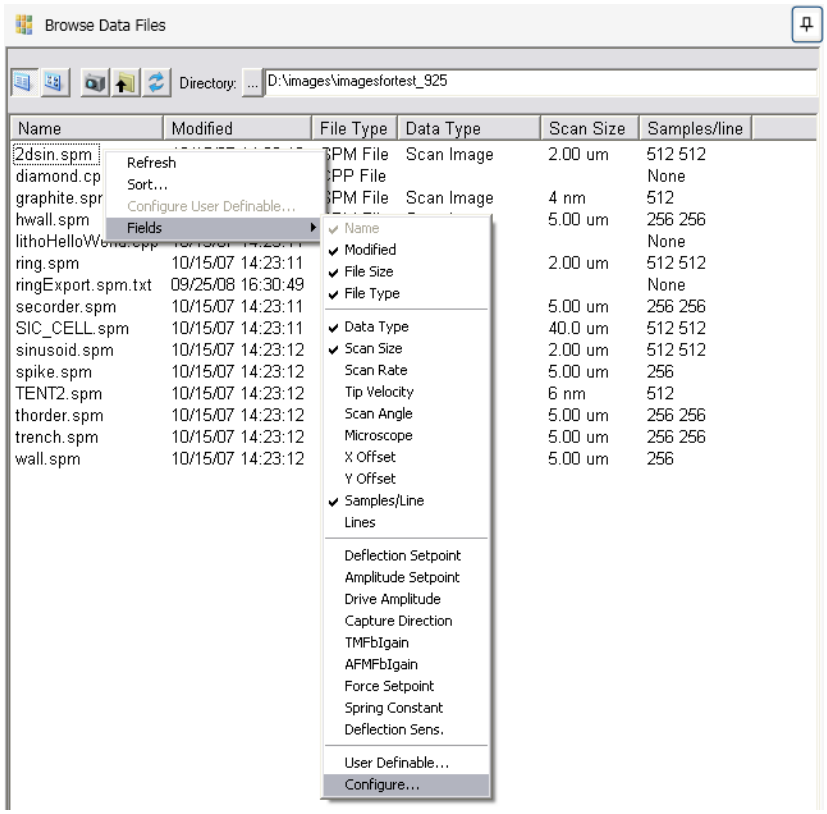


Figure 4.2d: Configure List View Fields

Click **User Definable** to open the ***Browse Column Configuration*** window, show in Figure 4.2e, that allows you to select a user-defined field. Click the ... button to the right of the ***Header String*** field to open the ***Select a Parameter*** window, shown in Figure 4.2f, and select a parameter from the drop-down lists. Set the ***Width*** to more than 0 pixels to view it.

NOTE: The parameter choices in the ***Select a Parameter*** window are determined by the first file in the ***Browse Window List View***.

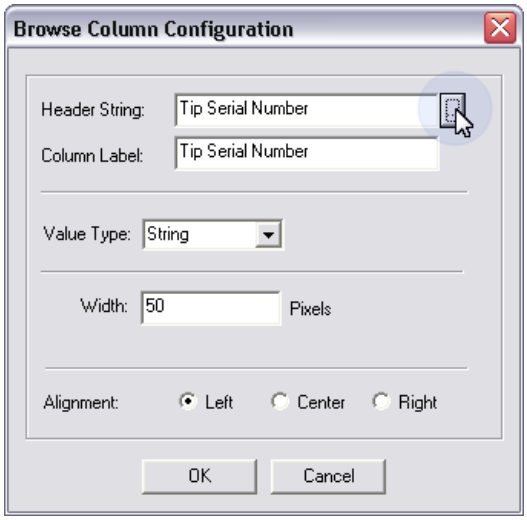


Figure 4.2e: The Browse Column Configuration window

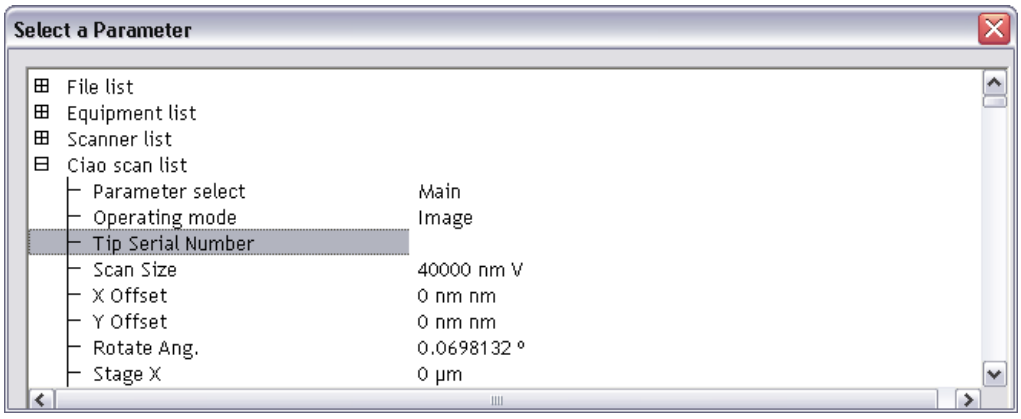


Figure 4.2f: Parameter Selection

Sorting entries in the List View may be done sequentially, e.g. first sort by time, second sort by a another field...

4.2.2 Thumbnail View

Clicking the second icon in the upper left of the file Browse window causes thumbnail presentation of image files, shown in Figure 4.2g.

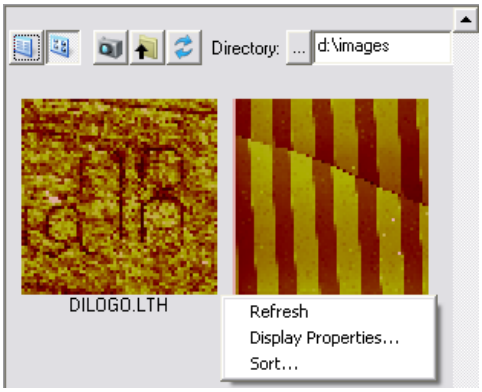


Figure 4.2g: Thumbnail Images in the Browse Window

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 4.2h. Double-click on a thumbnail to open the image for further analysis.

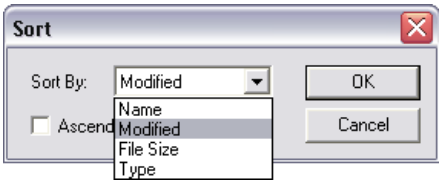


Figure 4.2h: Sorting Thumbnails

Image Display

If no images are selected, right-clicking in the 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 4.2i.

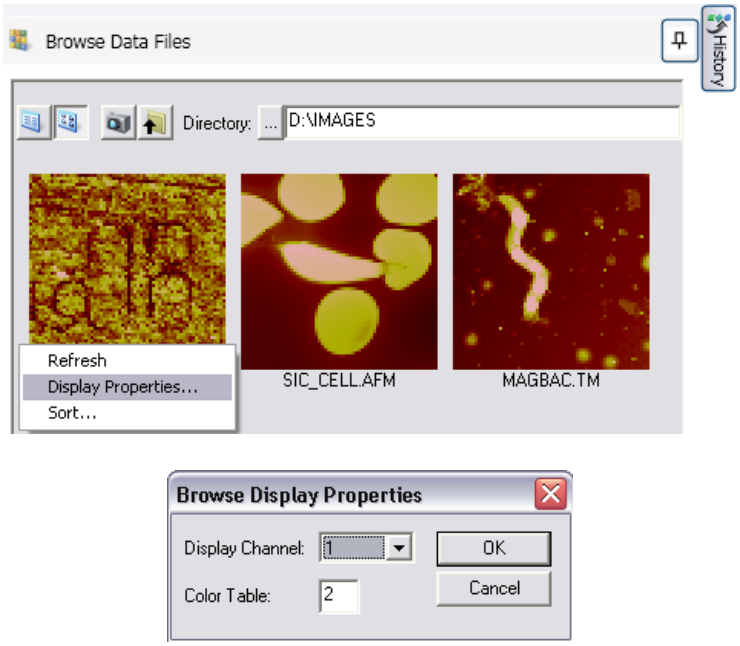


Figure 4.2i: Browse Display / Color Table Selection and Properties

4.2.3 Capture Directory

Clicking the **Capture Directory** icon in the upper left of the Browse window displays file information, in either text or thumbnail presentations, of the ***Capture Directory*** (default is D:\capture).

4.2.4 Go Up One Level

Clicking on the **Go Up One Level** icon in the upper left of the Browse window lets the user browse for files on their computer or network(s).

4.2.5 Refresh Browse Window

Clicking the **Refresh Browse Window** icon in the upper left of the Browse window refreshes the icons (or list) in the Browse window.

4.2.6 Drag & Drop

Images can be dragged and dropped from the ***Browse Files*** window and opened automatically in NanoScope Analysis. This can be done from the ***List*** view or the ***Thumbnail*** view.

Select the file or multiple files (by using Shift+click) from the ***Browse Files*** window in either the ***List*** view or ***Thumbnail*** view. Drag the selected files into the Workspace. The selected files will open.

4.3 Converting Data

Refer to the following sections for preparing file data:

Preparing Data for Spreadsheets (Summary) (page 22)

Preparing Data for Image Processing (Summary) (page 22)

Converting Data Files into ASCII (page 22)

4.3.1 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 from The Browse Window (page 16).

NOTE: This may increase the size of the file substantially.

2. Select desired settings (see Converting Data Files into ASCII (page 22)), 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 applications.
5. Analyze or modify the conditioned data as required.

4.3.2 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 (page 16) 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.

4.3.3 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 from The Browse Window (page 16). 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 browse window at the right of the NanoScope Analysis main window. Right-click in the thumbnail image to open the menu shown in Figure 4.3a.

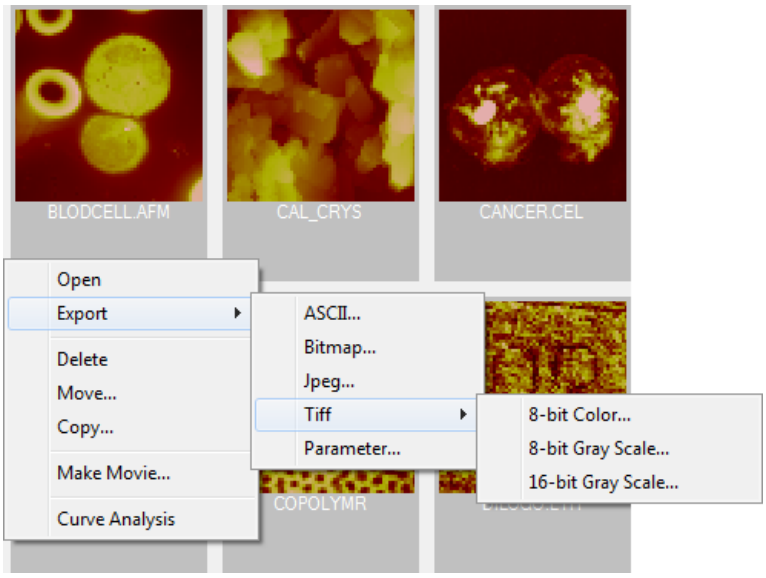


Figure 4.3a: The ASCII Export Command

3. Click **Export > ASCII** to open the ***Export*** dialog box, shown in Figure 4.3b.
4. Select the data ***Channels*** to be exported.
5. Choose the ***Column*** format.

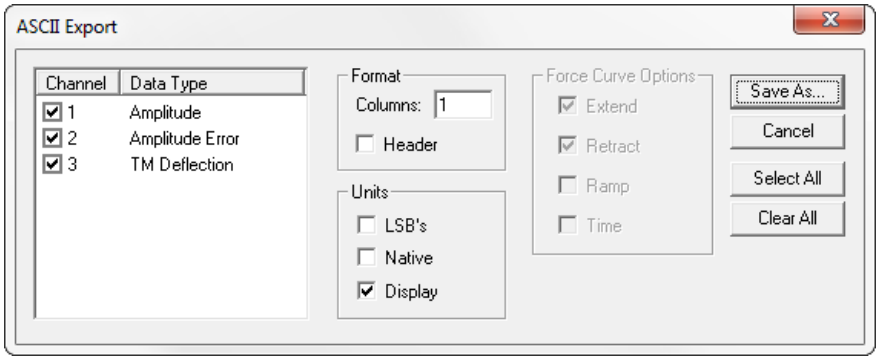


Figure 4.3b: The File Export Dialog Box

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***.

4.4 Set Units

Click **Commands** > **Set Units** in the NanoScope Analysis Menu Bar to open the ***Switch Units*** window, shown in Figure 4.4awhich allows you to Switch the Units of an image (2D or 3D).

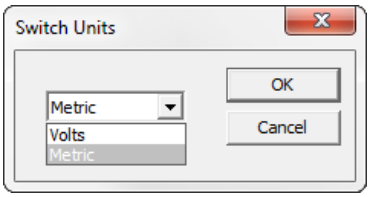


Figure 4.4a: The ***Switch Units*** window

4.5 Set Sensitivity

The ***Set Sensitivity*** filter allows you to change the sensitivity before or after executing a filter.

1. To ***Set Sensitivity***, select **Commands** > **Set Sensitivity** from the ***Menu*** bar, shown in Figure 4.5a.

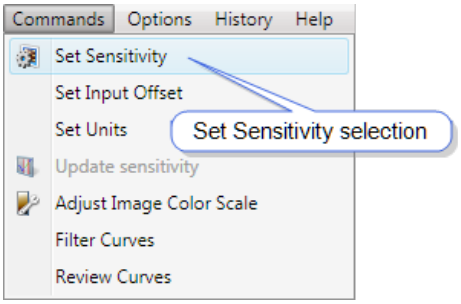


Figure 4.5a: The Set Sensitivity Menu

2. The ***Set Image Sensitivity*** window, shown in Figure 4.5b, will appear enabling you to switch channels and modify the sensitivity as desired.

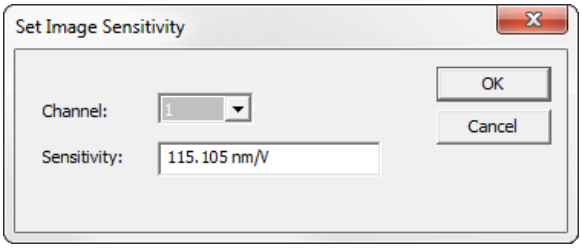


Figure 4.5b: Set Image Sensitivity window

3. Click **OK** to set the sensitivity to the newly chosen settings.
4. To go back to the original sensitivity settings, click on the **Undo** icon or go back in the data ***History***.

4.6 Common Image Control Actions

4.6.1 Image Buttons

Clicking the Image buttons above a captured image performs the following functions:

- **Measure** - Left click, hold, and drag out a line. The length of the line appears in a box near the line anytime the cursor is on the line.
- **Pan** - From a zoomed image, 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 precious zoom level.
- **Resize Down** - Resized the image down to the previous zoom level.
- **3D Lighting** - Illuminates the image by uniform light whose angle may be varied. See 3D Lighting Parameters.

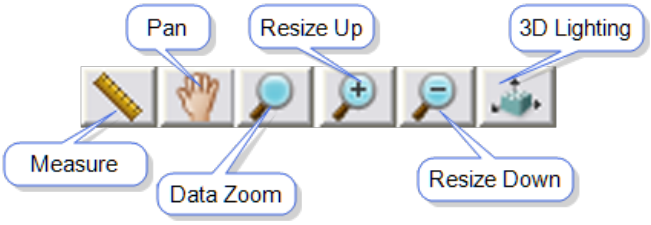


Figure 4.6a: Image Buttons

4.6.2 Right-clicking On an Image

Right clicking on an image will bring up a menu, shown in Figure 4.6b.

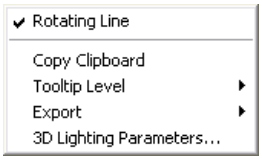


Figure 4.6b: Depiction of Dialog When Image is Right Clicked

The following tasks are available by right clicking on an image:

- **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, in bmp format, to the Windows clipboard.
- **Tooltip Level**:
  - Basic
  - Medium
  - Advanced
  - None
- **Export** - Exports the image as a bitmap.
- **3D Lighting Parameters** - Clicking this button opens the ***Adjust 3D Lighting*** dialog box, shown in Figure 4.6c, that allows you to change the incident angle of the lighting by dragging the slider controls or entering the angles in the boxes. You may also adjust the angle of the light by pressing Ctrl and the Right Mouse button and then moving the mouse.

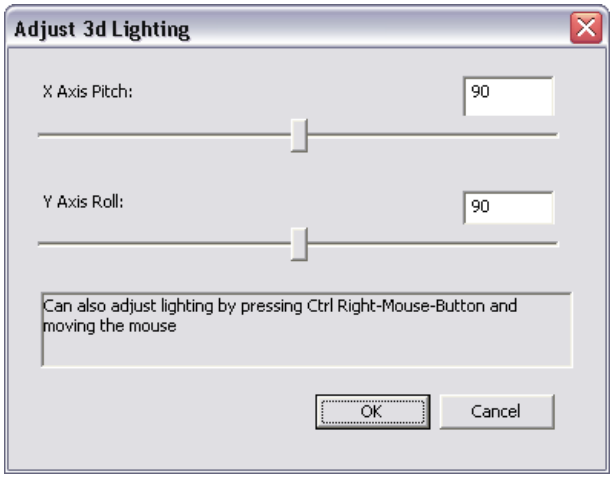


Figure 4.6c: The Adjust 3D Lighting dialog

4.6.3 Right Clicking On an Image Window

Right clicking in the ***Image*** window, but not on the image will allow for the following tasks:

- **Note** - Adds notes to the image file
- **Export View** - Exports the current view as a jpeg image
- **Copy View** - Copies the current view to the clipboard

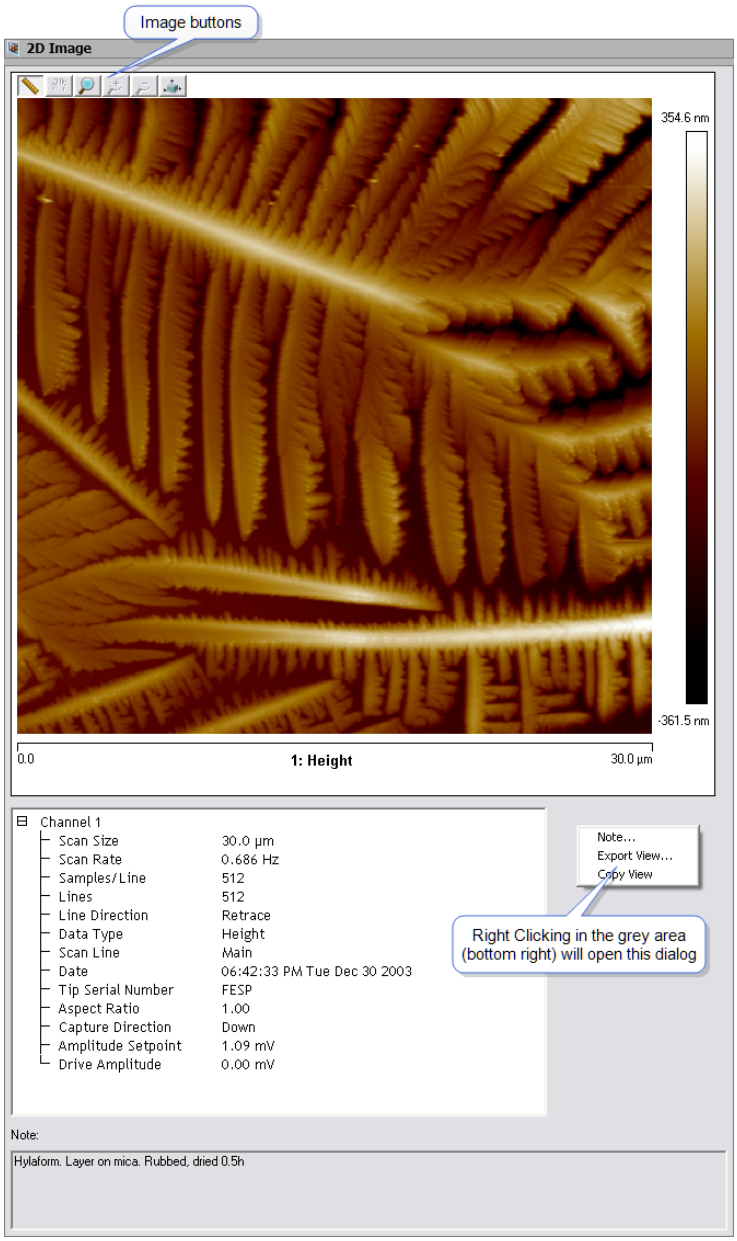


Figure 4.6d: Depiction of Right-clicking on an Image Window

4.6.4 Color Tables

The Color Scale (page 29) page shows how to change the image appearance.

4.6.5 Using the Mouse Within a Captured Image

The following functions are available by using your mouse within a captured image:

- **Left click anywhere in an image window, drag line out and release** - Creates a line of X length, at 0° angle in the image window.
- **Place cursor on line** - Displays the 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 either end of line and drag** - Changes length and/or angle of the line.
- **Right click** - Clicking the right mouse button when the cursor is on the line accesses the Image Cursor menu.

Figure 4.6e: Image Cursor Menu

The ***Image Cursor*** menu enables the following functions:

- **Delete** - deletes the line.
- **Flip Direction** - switches the line end to end.
- **Show Direction** - Adds a small arrowhead to the line to indicate direction.
- **Set Color** - Allows you to change the color of the line.
- **Clear All** - Deletes all lines.

4.7 Color Scale

4.7.1 Right Clicking on the Color Bar

Right-clicking in the color bar along the right side of the image will open the ***Color Scale*** option. Clicking on the ***Color Scale*** option will open the ***Image Color Scale Adjust*** dialog box, shown in Figure 4.7a.

NOTE: Changes to the min or max of the color scale will change the data history.

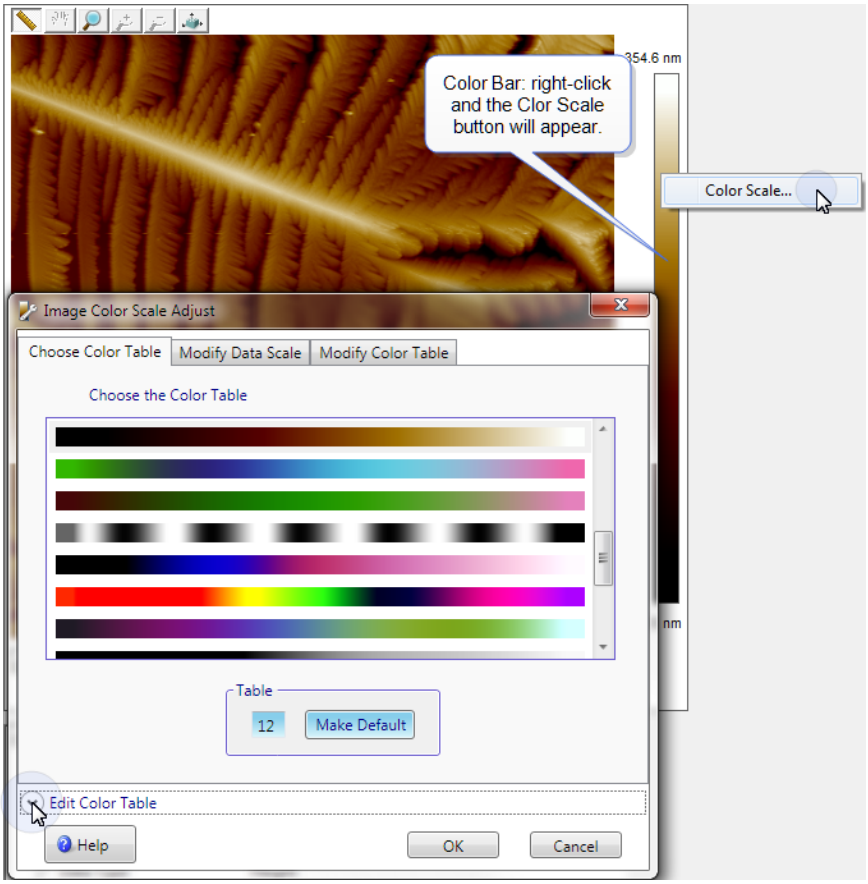


Figure 4.7a: The Color Scale Dialog

The ***Image Color Scale Adjust*** dialog allows the following image adjustments:

Color Tables

There are 26 available color scales. For instance, Color Table 0 is grayscale while Color Table 1 features blue.

You may change the Color Table by clicking one of the color table images or by entering a color table number into the ***Table*** window. You may also make that the default color table for new files.

Figure 4.7b displays a list of the 26 NanoScope color tables with ***Contrast*** = 0 and ***Offset*** = 0.

Color Table ID	Colors
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	

Figure 4.7b: NanoScope Color Tables

Header Color Table vs. Default Color Table

NanoScope can now (since version 8.00) save the color table number (for each data channel) that was used when the image was captured in the file header. NanoScope Analysis can use these color tables or they can be overridden by the ***Default Color Table***. Click ***Options*** > ***Default Color Table*** choose to use either the color table stored in the image file header or the ***Default Color Table***. See Figure 4.7c. Changing this selection causes the browser to change display modes. Images that are already open will not change modes, but newly opened files will open in the new mode. All thumbnails should reflect the selected mode.

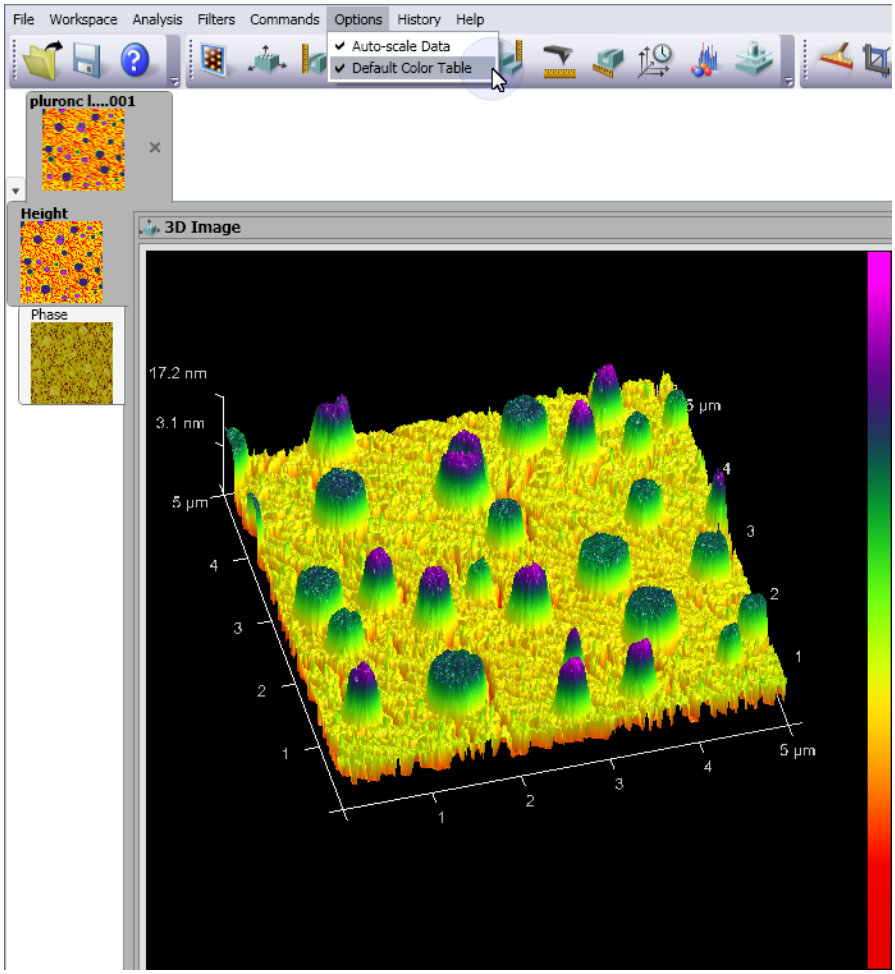


Figure 4.7c: Select ***Default Color Table*** or Header Color Table

4.7.2 Edit Color Table

Click the ***Edit Color Table*** button, shown in Figure 4.7a, to open the ***Color Table Editor*** panel, shown in Figure 4.7d.

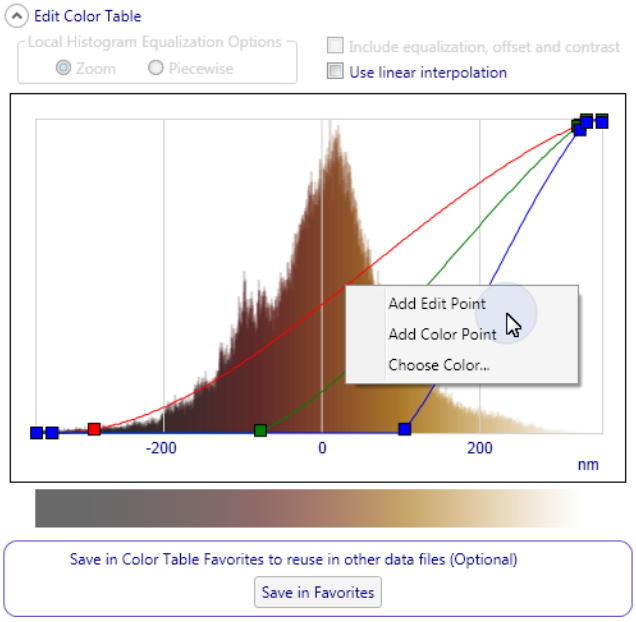


Figure 4.7d: The ***Color Table Editor***

The ***Color Table Editor*** displays a histogram of the data and cubic spline histograms of the Red, Green and Blue channels.

You may add ***Edit Points*** to a channel by highlighting that channel, right-clicking and selecting ***Add Edit Point***. See Figure 4.7e. You may move ***Edit Points*** by left-clicking the point and dragging it. Delete ***Edit Points*** by right-clicking on the point and selecting ***Delete Point***.

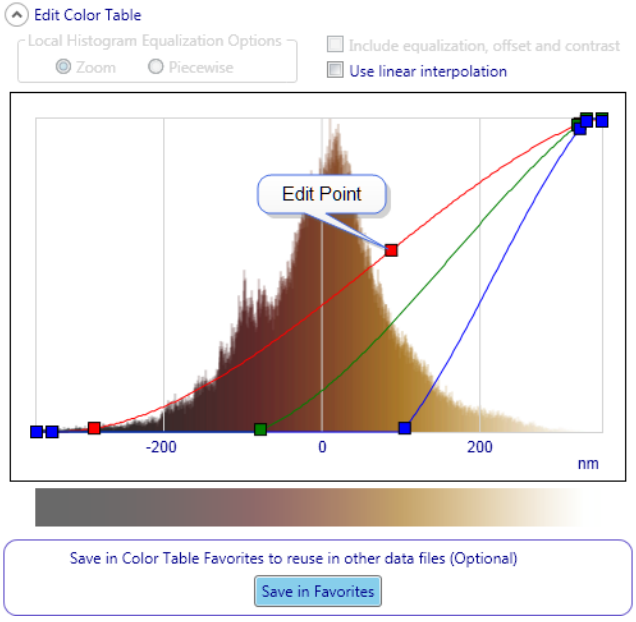


Figure 4.7e: Edit Point added to the red channel

You may also add ***Color Points*** to a channel by highlighting that channel, right-clicking and selecting ***Add Color Point***. See Figure 4.7f. You may move a ***Color Point*** by left-clicking the point and dragging it. Convert ***Color Points*** to ***Edit Points*** by right-clicking on the point and selecting ***Remove Link***.

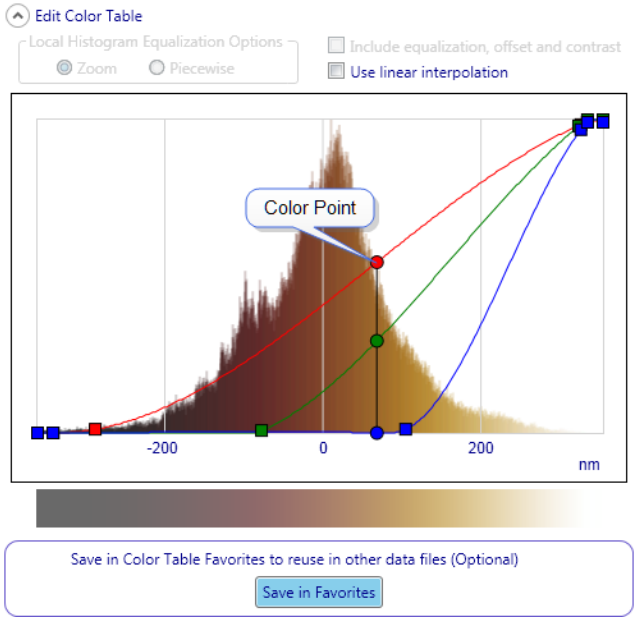


Figure 4.7f: Color Points added

Change from cubic spline to linear interpolation by checking ***Use linear interpolation***.

You may also ***Choose a Color*** by right-clicking one of the RGB (Red, Green, Blue) curves and selecting ***Choose Color***. See Figure 4.7d. This opens the ***Color*** selection window, shown in Figure 4.7g.

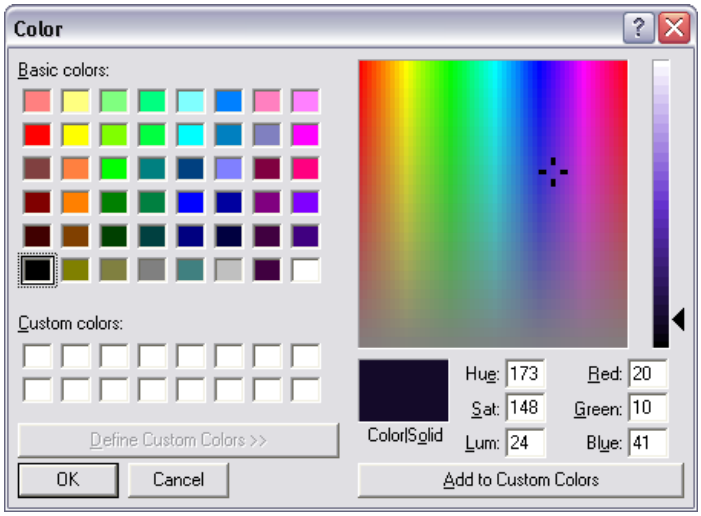


Figure 4.7g: The ***Color*** selection window

The ***Color*** selection window allows you to choose a color for the selected (by cursor) X value. The ***Color*** selection window allows you to drag a cursor to select Hue and Saturation and drag the right cursor to select Lightness. The mapping from HSL (Hue, Saturation, Lightness) to RGB is also displayed. You may also select from a palate of predefined basic colors.

Data Scale

The ***Modify Data Scale*** tab provides several methods to scale your data.

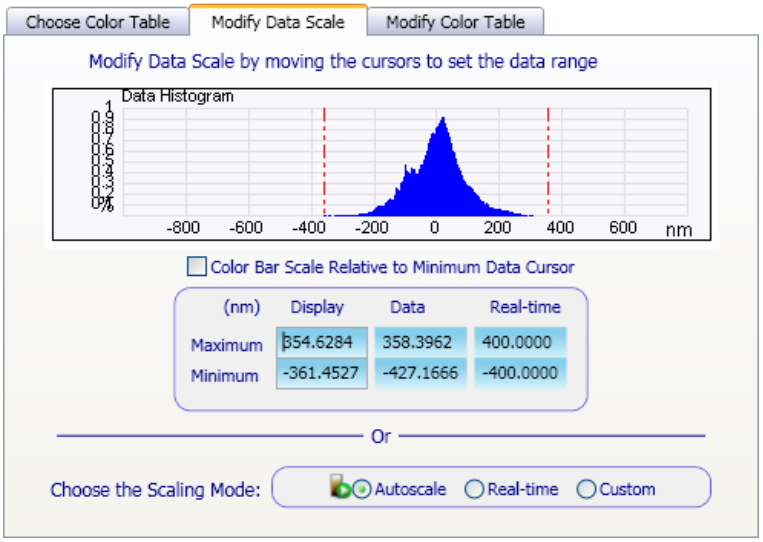


Figure 4.7h: The data scale dialog box

Clicking the ***Color Bar Scale Relative to Minimum Data Cursor*** button sets the top label of the Data Scale to the data range and removes the bottom label.

NOTE: This function is unavailable in MIRO because the layers do not have a real data scale.

Dragging the red cursors in the ***Data Histogram*** will set the ***Scaling Mode*** to ***Custom*** and clip the data. The modified values will be reflected in the ***Display*** fields.

You may also enter ***Minimum*** and ***Maximum*** values in the ***Display*** fields to clip the data.

The ***Display*** fields correspond to the minimum and maximum values of the data that is mapped to the color table.

The ***Data*** fields display the minimum and maximum values of the stored data.

The ***Real-time*** fields display the minimum and maximum vales of the scales stored in the header when the data was captured. This data is centered at 0. Click the ***Real-time*** radio button to use these values.

The ***Autoscale*** option sets the data scale to be (Range Factor)*(range of data after clipping) where (Range Factor)=1.5.

A clip function, illustrated in Figure 4.7i, that removes 0.5% of the low and high pixels is used to accommodate long tails in the distribution.

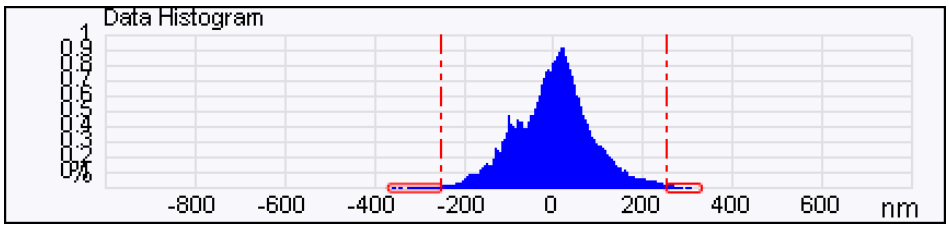


Figure 4.7i: Histogram of image with the low clip and high clip portions circled.

Modify Color Table

The ***Modify Color Table*** tab, shown in Figure 4.7j, provides several additional methods to modify the color table.

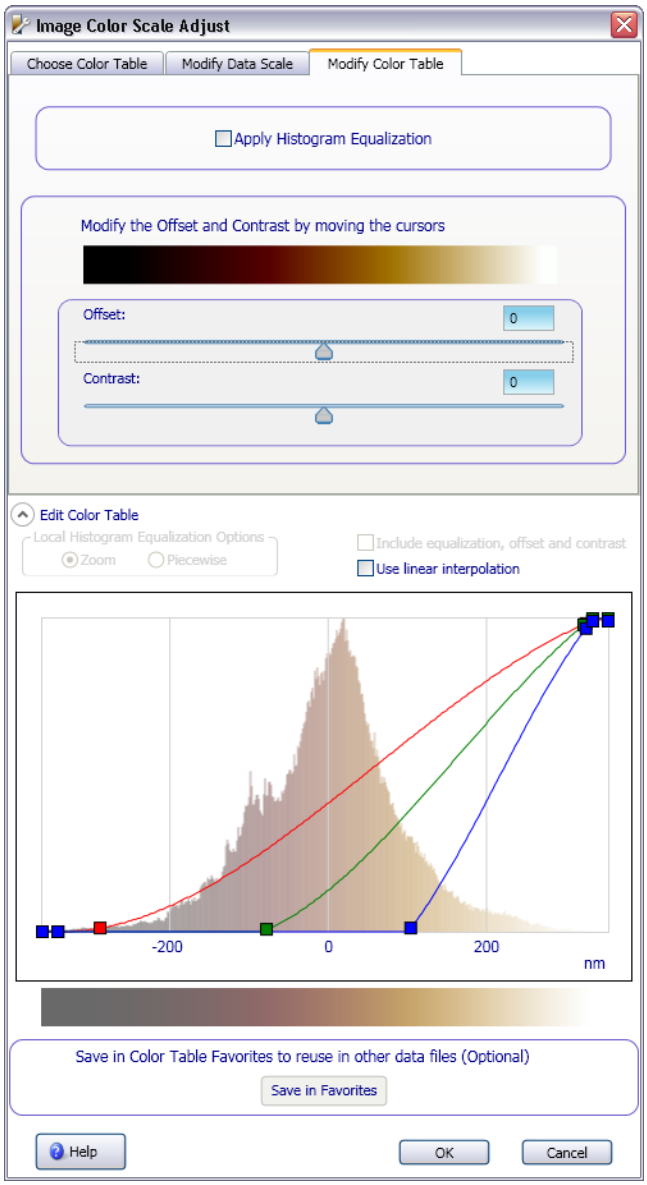


Figure 4.7j: The ***Modify Color Table*** tab

Histogram Equalization

Histogram Equalization is perhaps the most powerful of NanoScope Analysis color functions. ***Histogram Equalization*** converts the RGB values to HSL and modifies the normalized Lightness based on the cumulative histogram. This has the effect of associating the largest lightness change with the largest data change, increasing the contrast in rapidly changing areas. See Figure 4.7k for an example.

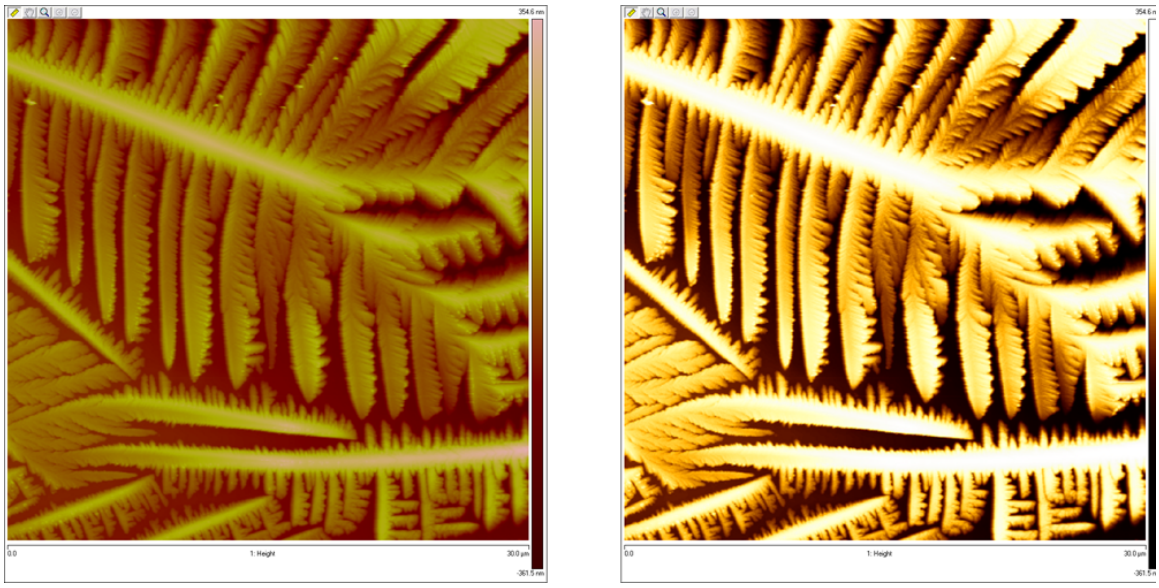


Figure 4.7k: Image without (left) and with (right) ***Histogram Equalization***

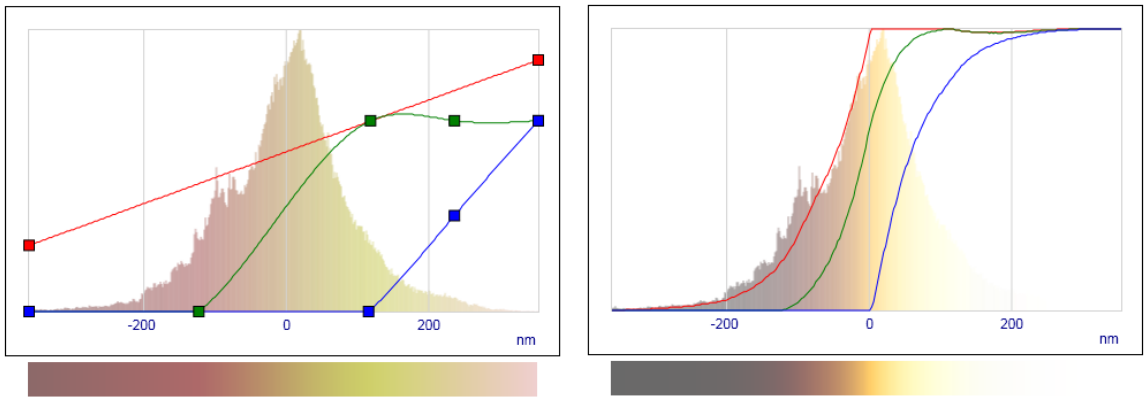


Figure 4.7l: Histogram of images in Figure 4.7k

Histogram Equalization Options

The ***Zoom Histogram Equalization Option*** is best used to change weighting of one region relative to another. Use the ***Zoom Histogram Equalization Option*** by moving the top cursor (in the histogram display) and the bottom cursor (in the color scale display). Refer to Figure 4.7m and Figure 4.7n for an example. Moving the bottom cursor to the right, relative to the top cursor, emphasizes the low end of the data while moving the bottom cursor to the left, relative to the top cursor, emphasizes the higher data.

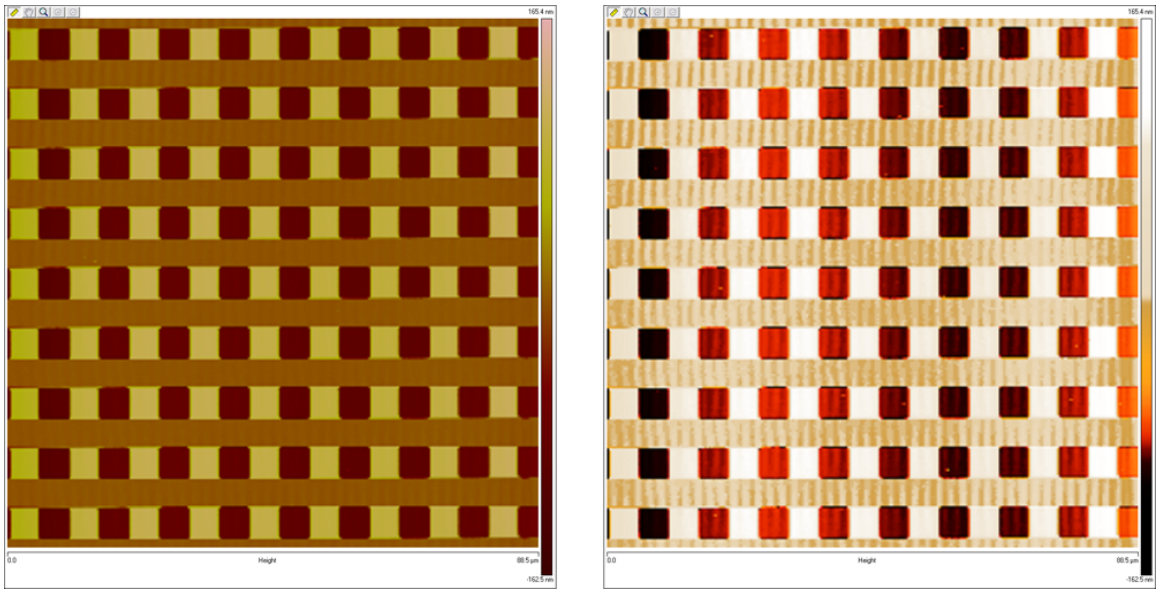


Figure 4.7m: Image without (left) and with (right) ***Zoom Histogram Equalization***

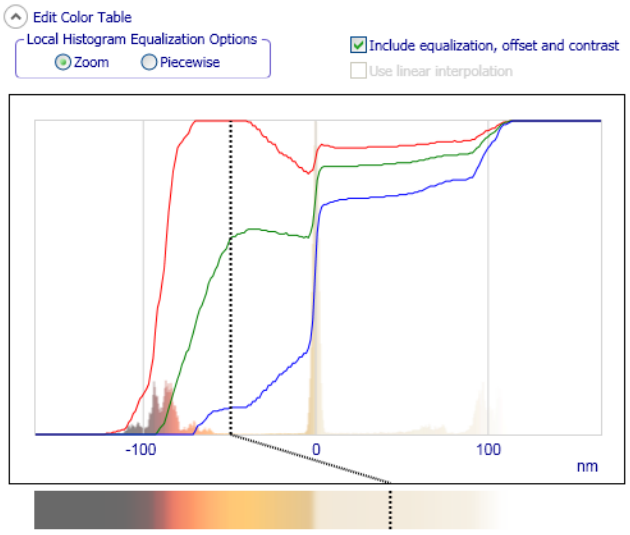


Figure 4.7n: The histogram of the right image in Figure 4.7m.

The ***Piecewise Histogram Equalization Option*** is particularly useful when the data histogram is bimodal. Use the ***Piecewise Histogram Equalization Option*** by right-clicking to add cursors (see Figure 4.7p).

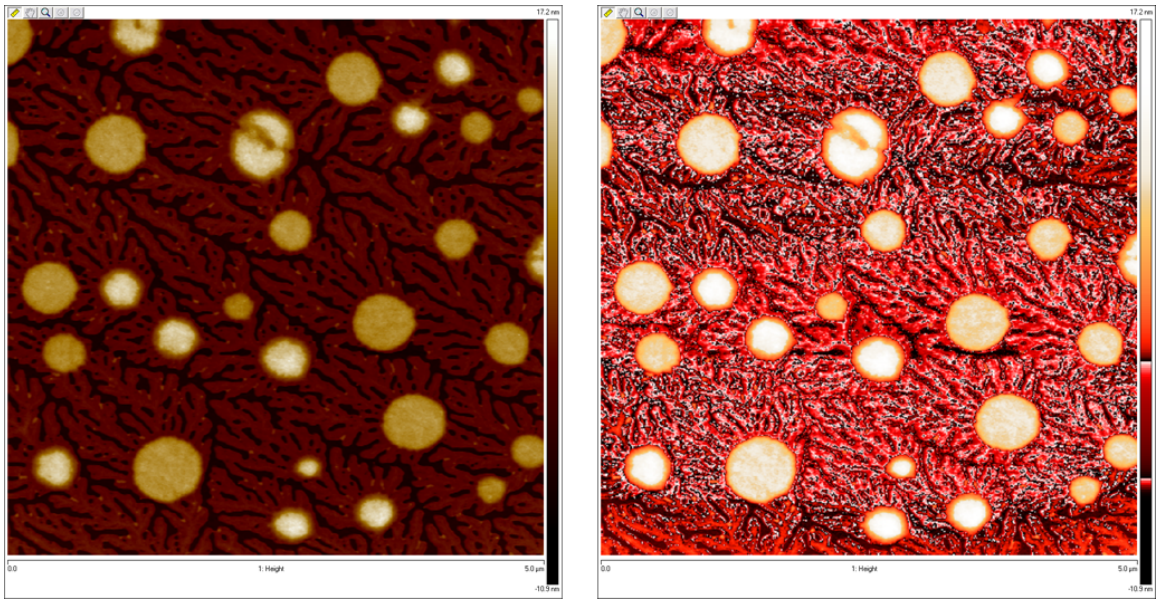


Figure 4.7o: Image without (left) and with (right) ***Piecewise Histogram Equalization***

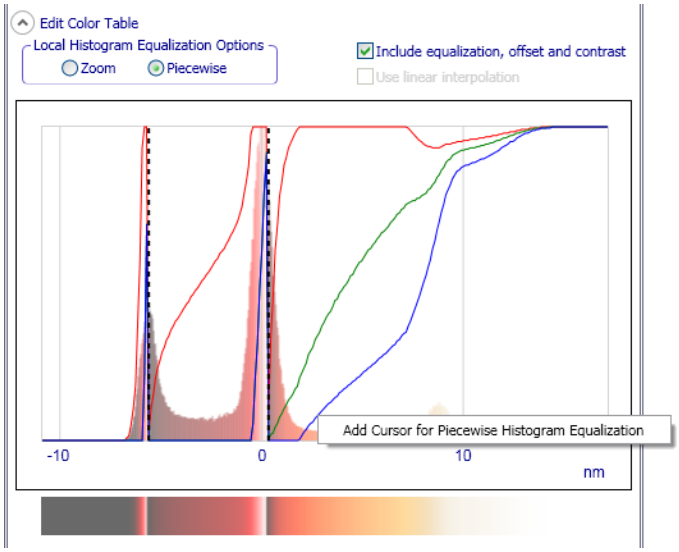


Figure 4.7p: The histogram of the right image in Figure 4.7o.

Offset and Contrast

Both Contrast and Offset have a major effect on displayed colors. An example is shown for Color Table 12 in Figure 4.7r.

Offset — Number (-128 to +128) — designates offset colors in the displayed image (e.g., 120 shows illuminated background on image). Offset effectively changes the color value around which the color scale is mapped.

Contrast — Number (-10 to +10) — designates contrast of colors in displayed image (e.g., -10 shows little change while 10 shows highest contrast)

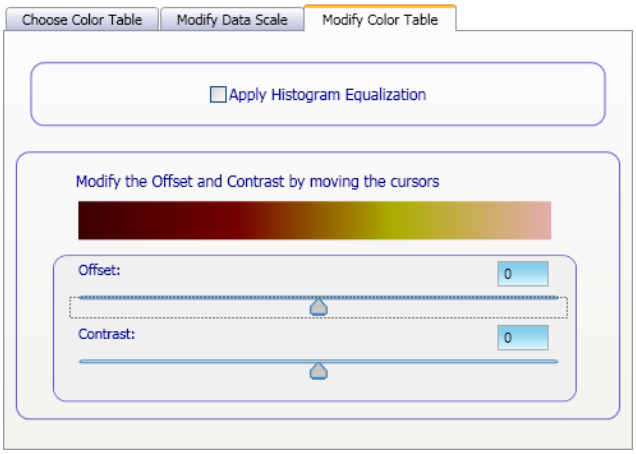


Figure 4.7q: The ***Offset and Contrast*** dialog box

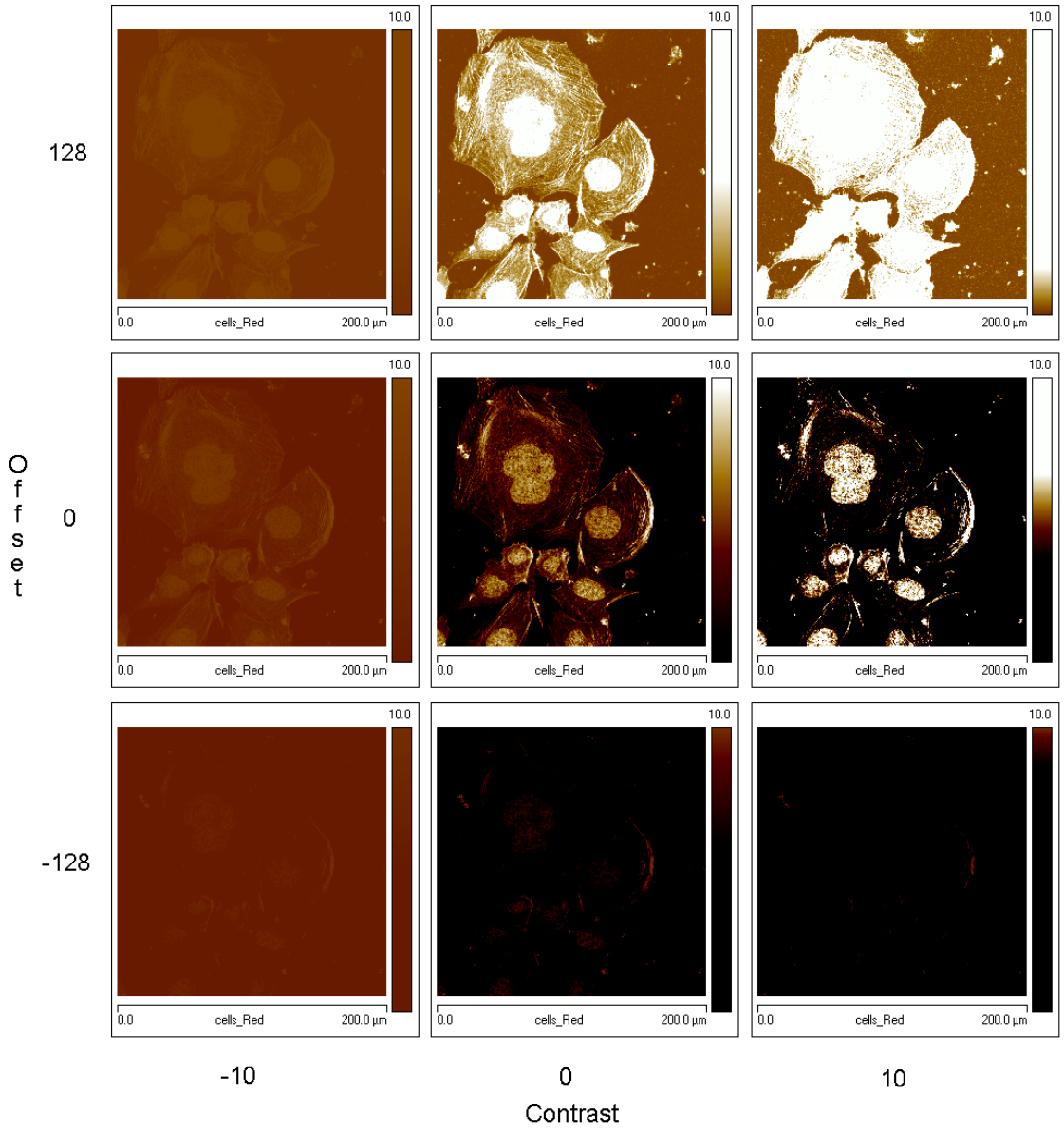


Figure 4.7r: Effect of Contrast and Offset on displayed color for Color Table 12

4.8 Common Grid Controls

Measurement cursors for the histogram are automatically positioned based on the numerical values selected in the ***Input*** fields. Right-clicking on the grid will open the Grid Parameters menu and allow for the following changes:

Parameter	Description
Color	Allows the operator to change the color of the: Curve, Text, Background, Grid, Minor Grid, and 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 the 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 Preference	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, JEPG, or XZ data format.
Active Curve	Determines which curve you are analyzing.

Table: 4.0a Common Grid Control Parameters

4.9 Workspaces

Workspaces save and restore all NanoScope Analysis open files, the ***Data History*** for each open file, and the desktop configuration. As such, Workspaces allow the user to save their work, and then continue where they left off at a later time, without modifying the image files.

The desktop configuration includes the Span and UnSpan Panes and the ability to Pin and Unpin the Browse Files and History windows. With Workspaces, there are many alternate ways to configure the look and feel of the NanoScope Analysis.

4.9.1 Saving a Workspace

To Save a Workspace select **Workspace > Save Workspace As...** from the Menu bar.

The Save As dialog window will open allowing the user to pick a location to save the Workspace and to enter an appropriate Workspace name into the **File Name** field. After entering the File Name, click **Save** to execute the command.

4.9.2 Opening a Workspace

To Open a previously saved Workspace, select **Workspace > Open Workspace...** from the Menu bar. The Open dialog window will open allowing the user to choose the preferred Workspace to open. Choose the preferred Workspace and click on the **Open** button. The selected Workspace will open.

4.10 File Context Commands

File Context commands enable different views and aid in applying cursors to images. ***File Context*** commands can be accessed by right clicking on any tabbed image. The dialog shown in Figure 4.10a will appear.

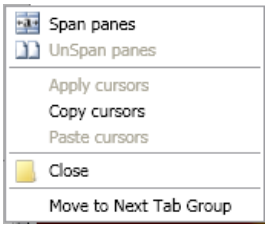


Figure 4.10a: File Context Commands Window

4.10.1 Span/UnSpan Panes

The ***Span Panes*** and ***UnSpan Panes*** commands allow you to choose 1 or 2 panes in the NanoScope Analysis view. The **Span Panes**  and **UnSpan Panes**  buttons are located on the ***Icon*** toolbar. The **Span Panes** and **UnSpan Panes** commands can also be accessed in the ***Tab Context*** menu by right clicking on any tabbed image, as shown below.

When **UnSpan Panes** is chosen and 2 panes are showing, the *active pane* is indicated by the darker gray background. See Figure 4.10b and Figure 4.10c for details.

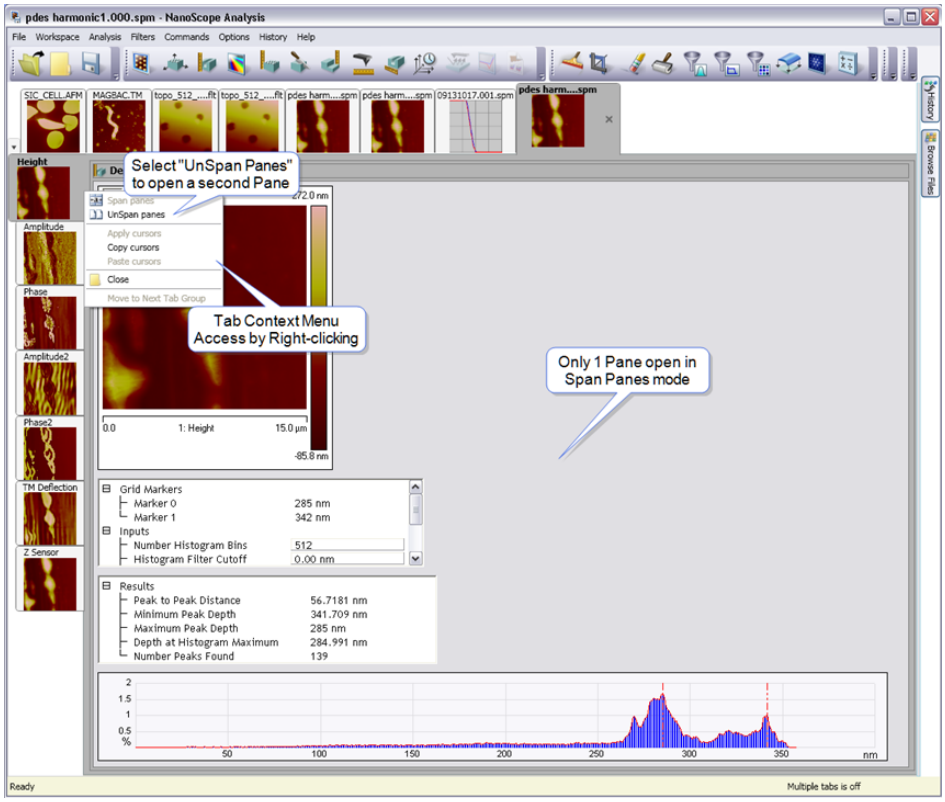


Figure 4.10b: Span Panes Enabled

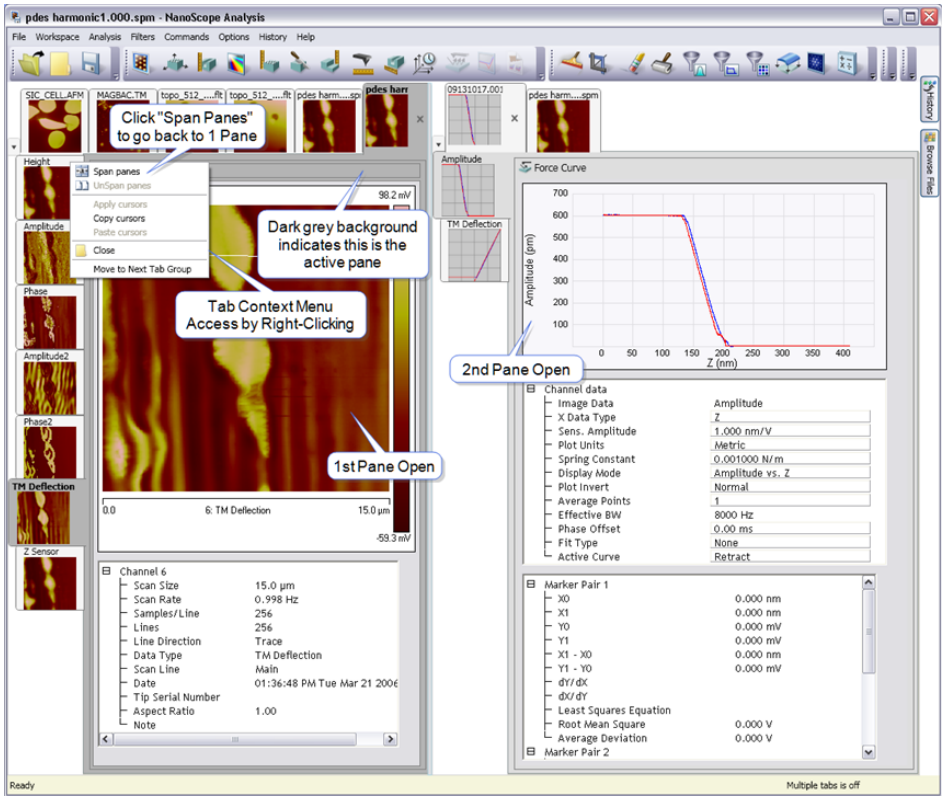


Figure 4.10c: UnSpan Panes Enabled (Note Active Pane in Dark Gray)

UnSpan Panes Example

The following example demonstrates the use of the **UnSpan Panes** function to simultaneously apply an Analysis function to different channels of the same image.

1. Load an image file into NanoScope Analysis.
2. Click the **UnSpan Panes** icon to open two analysis windows.
3. Load the same file into the other analysis window.
4. Choose a second image channel (Potential in this example).
5. Shift +Click or Ctrl+Click on the appropriate image thumbnail on the left side of the image to activate multiple channels.
6. Select and run an analysis function from the NanoScope Analysis toolbar (Section in this example).
7. The results, shown in Figure 4.10d, will appear in both windows.

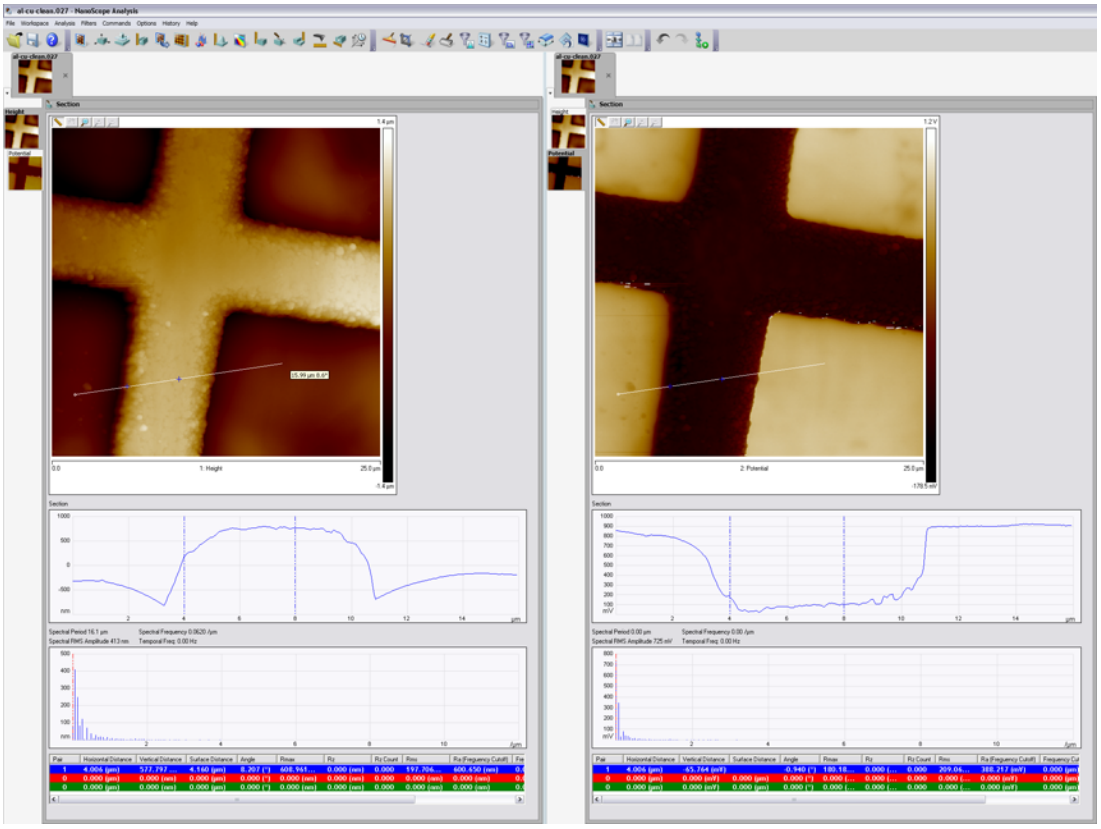


Figure 4.10d: Section results in the Height and Potential channels

4.10.2 Apply Cursors

Cursors added to one channel can be applied onto other channels. Follow the steps below to apply cursors to multiple channels.

1. Select the channels you wish to add cursors to by using **Shift+Click** to select more than one tabbed image. When multiple channels are selected the box around them will turn dark gray.
2. Choose the preferred Analysis (***2D Image***, ***Section***, ***Step***, etc...) and select it by clicking on the icon. This will put all the selected images in the same ***Analysis*** mode.
3. Draw the preferred cursor(s) into the first image.
4. **Right Click** on any of the other multiple-selected tabbed imaged. The ***File Context Menu*** will appear. Choose ***Apply Cursors***.

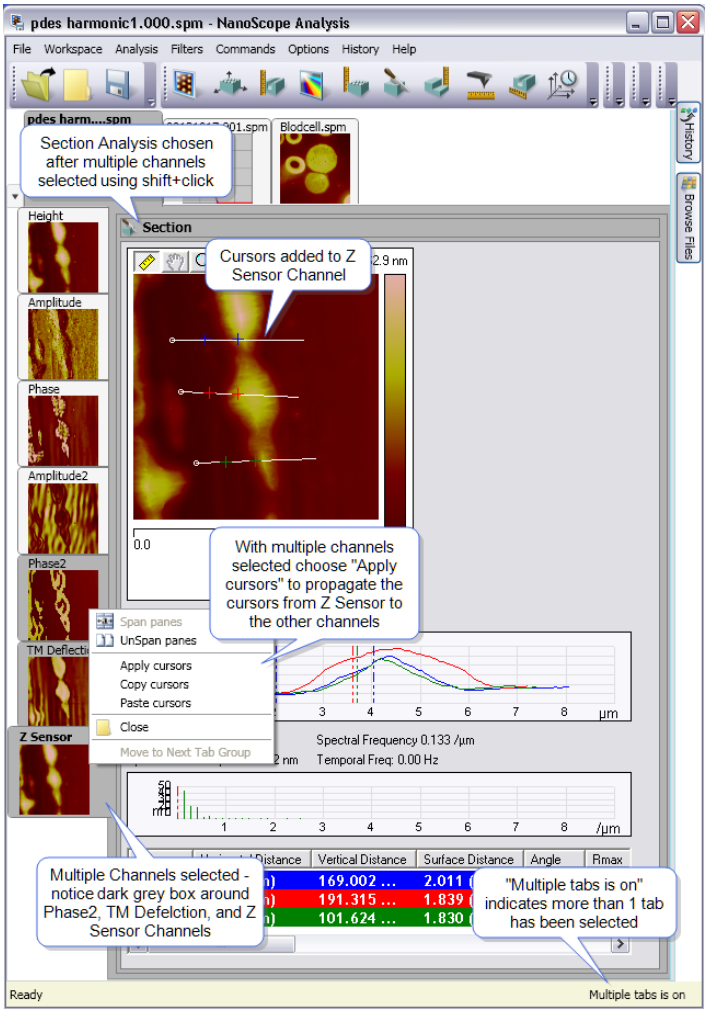


Figure 4.10e: Apply Cursors

5. The cursors added to the first image will now be added to the other selected images. See Figure 4.10f.

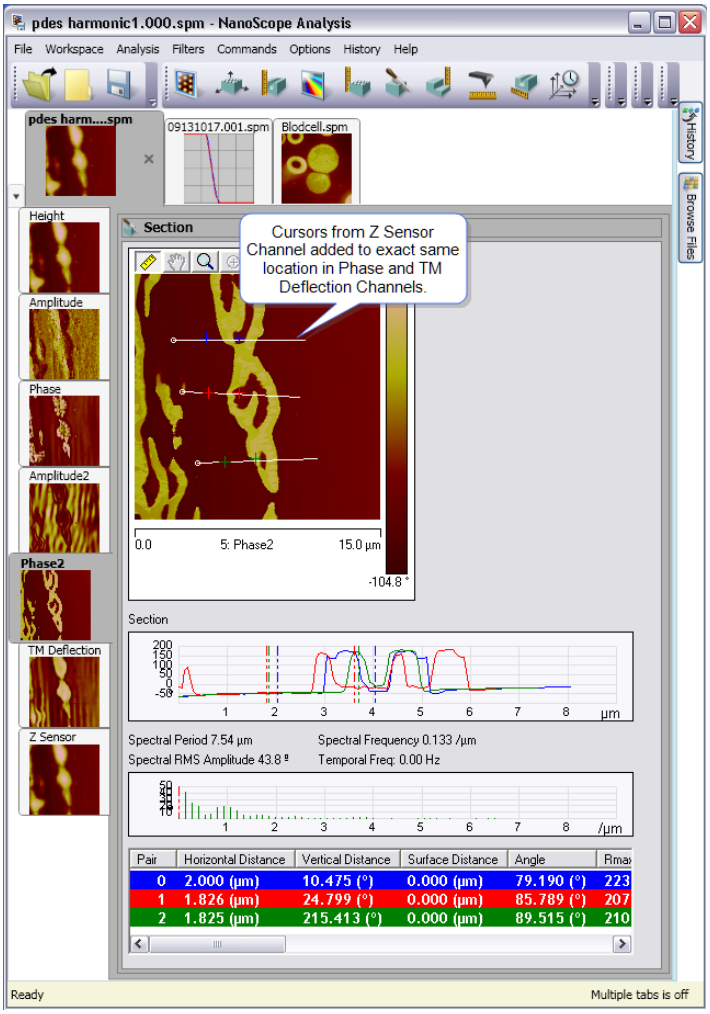


Figure 4.10f: Cursors Applied to Other Channels

4.10.3 Synchronized Cursors/Analyses

Synchronized cursors (mouse events) allow you to select multiple channels (via **Shift+click** or **Ctrl+click**) in single or multiple files regardless of which pane or tab they appear. Operations will be carried out on all these selected channels.

The ***Multiple Tabs is On*** message, shown in Figure 4.10g, will appear in the lower right corner of the NanoScope Analysis screen when you have selected more than on channel.

Figure 4.10g: Multiple Tabs is On message

- Synchronized cursors allow you to draw one marker (box, line..) in an open image and have that marker drawn in all selected channels.

- Synchronized cursors can be applied only across the same type of NanoScope Analysis view (e.g. 2D, 3D, Depth...) and image aspect ratio.
- If the view includes an **Execute** button, it is necessary to click **Execute** in each view.
- Synchronized cursors work with the ***3D Image*** function. If you select multiple files in/for a 3D Image, rotating, changing the lighting... on one changes all.

The synchronized cursor function enables easy comparison of data in different channels/files, thereby improving productivity.

4.10.4 Close

The ***File Context*** menu can also be used to ***Close*** a file. Right-click on any tabbed image and select ***Close*** to shut down that particular file.

4.10.5 Move to Next/Previous Tab Group

The ***Move to Next/Previous Tab Group*** is a convenient way to view files already open in NanoScope Analysis. The ***Move to Next/Previous Tab Group*** selection is only functional when you are in the ***UnSpan Panes*** view with 2 panes showing and with more than 1 file open. Selecting the ***Move to Next Tab Group*** will open the next tabbed image group and push the current tabbed group to the second pane. Conversely, selecting the ***Move to Previous Tab Group*** will reload the previous tab group in the second pane.

4.11  Auto-scale Data Option

The ***Auto-scale Data*** option allows for automatic scaling of data using minimum and maximum values from the file dataset.

The default for ***Auto-scale Data*** is **On**. Turning **Off** ***Auto-scale Data*** will enable the NanoScope Analysis software to use the data scale found in the header file. To turn ***Auto-scale Data*** **Off**, select **Options** > **Auto-scale Data** from the ***Menu*** bar. The check mark next to ***Auto-scale Data*** will disappear. The ***Auto-scale Data*** option only affects the file when it is first opened. If the user changes the data scale in the dialog, the auto-scaling will be turned **Off** and cannot be turned back **On** without re-opening the file.

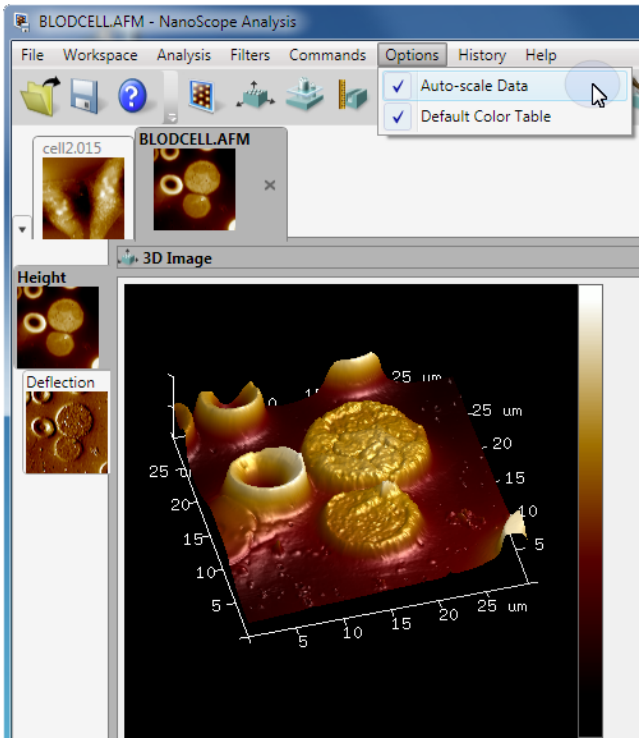


Figure 4.11a: Auto-scale data menu

The ***Autoscale*** option sets the data scale to be (Range Factor)*(range of data after clipping) where (Range Factor)=1.5.

A clip function, illustrated in Figure 4.11b, that removes 0.5% of the low and high pixels is used to accommodate long tails in the distribution.

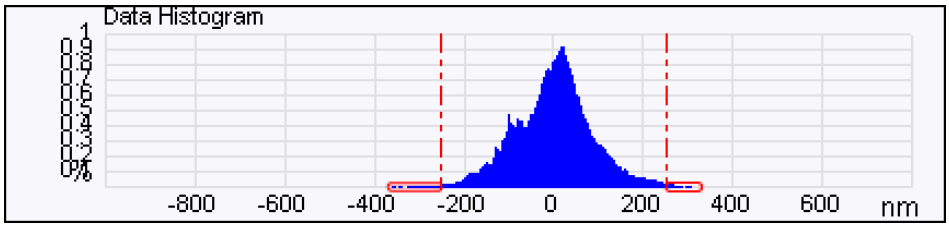


Figure 4.11b: Histogram of image with the low clip and high clip portions circled.

4.12 Exporting Images

4.12.1 Exporting from the Browse window

You may export images, in either **ASCII**, **Bitmap**, **JPEG** or **Tiff** formats from the ***Browse*** window by right-clicking single or multiple images (shift right-click), shown in Figure 4.12a. After the export format has been selected, a new window, shown in Figure 4.12b, will open allowing selection of the ***Channel*** and ***Color Table***.

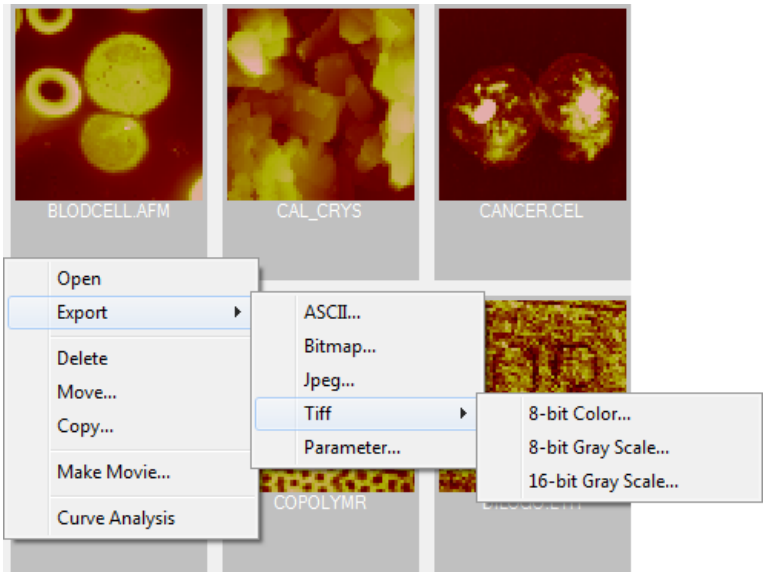


Figure 4.12a: Exporting Multiple Images from the Image ***Browse*** window

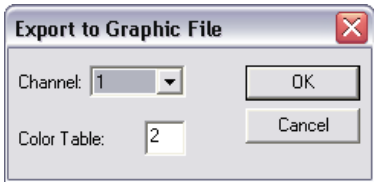


Figure 4.12b: Selecting the ***Channel*** and/or ***Color Table***

4.13 Data History

Data History enables the user to restore previous raw data with the click of a button. This command can be useful, if at any point, the user prefers to revert to data from an earlier time an analysis session.

Executing a Filter:

- Causes the Filter icon and/or Filter name to be displayed in the ***History*** menu
- Creates a new history item and view containing the modified raw data
- Saves the unmodified raw data in the ***Data History*** so the user can restore it, if required.

4.13.1 Procedure

Data History can be accessed by selecting **History** > **(Particular History Item)** from the ***Menu*** bar or by opening the ***History*** window by clicking on the ***History*** icon on the right side of the NanoScope Analysis view.

Press the **Pin** button to keep the ***History*** window in place. Then double click on the appropriate ***Data History*** item to access it. Pressing the **Pin** button a second time will put the ***History*** window back to the original location.

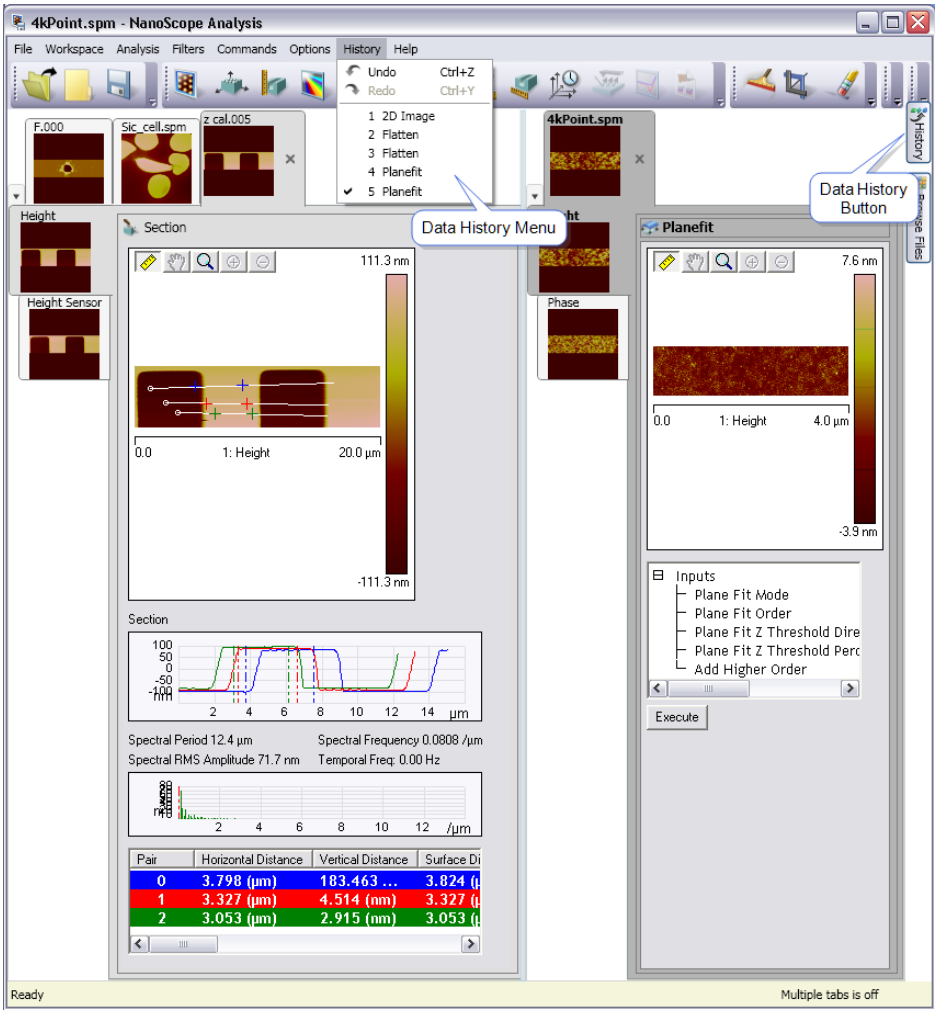


Figure 4.13a: Data History Menu

4.13.2 Undo/Redo Buttons

The **Undo** and **Redo** buttons provide a simple option to move backward or forward in the ***Data History***. Clicking on the **Undo** button will remove the top item in the ***Data History***. Clicking on the **Redo** button will restore the next ***Data History*** item. If no ***Data History*** item has been selected or undone, the **Undo** and **Redo** buttons will remain un-selectable. In addition to using the icons on the ***Icon*** toolbar, one can also select **History** > **Undo** or **History** > **Redo** from the ***Menu*** bar to execute these commands.

4.13.3 Modifying the Data History

You may **Close** data history items by selecting that item in the History window, right-clicking and choosing **Close** as shown in Figure 4.13b.

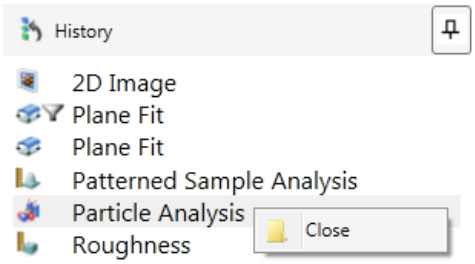


Figure 4.13b: Close a ***History*** item

You may insert Filter and Analysis functions after an existing item into the data history by highlighting that item and then selecting the new function. See Figure 4.13c.

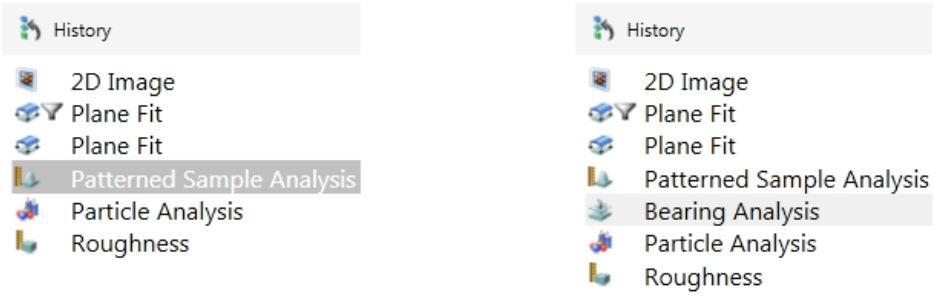


Figure 4.13c: Bearing Analysis function inserted into the Data History after Patterned Sample Analysis. Before (left) and After (right).

If you execute or delete a Filter Command, you will be asked, via a pop-up window, shown in Figure 4.13d, if you wish to undo the changes done to the file by the filter and delete items after that filter or accept the data modifications and rerun the entire history list.

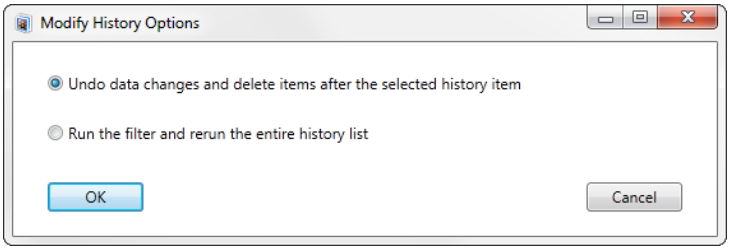


Figure 4.13d: The ***Modify History Options*** window.

4.14 Run AutoProgram

The ***Run AutoProgram***, formerly named ***Run History***, function allows you to perform a sequence of operations that may be applied automatically to at least one previously captured image. Typically, ***Run AutoPropram*** is used to rapidly analyze a large number of images taken under similar conditions. Applying a fixed Data Scale (page 34) to multiple images is a good example of the Run AutoProgram function. Any Offline command except for XY Drift (page 153) may be included in ***Run AutoProgram***.

4.14.1 Configuring Run AutoProgram

To configure Run AutoProgram within NanoScope Analysis:

1. Click the **Run AutoProgram** icon on the NanoScope Analysis toolbar or click **History** > ***Run AutoProgram*** as shown in Figure 4.14a.

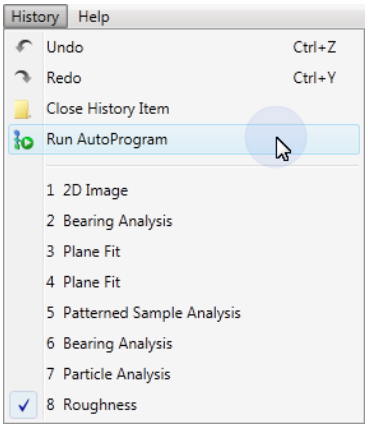


Figure 4.14a: The ***History*** Menu

2. This opens the ***Run AutoProgram*** window, shown in Figure 4.14b.

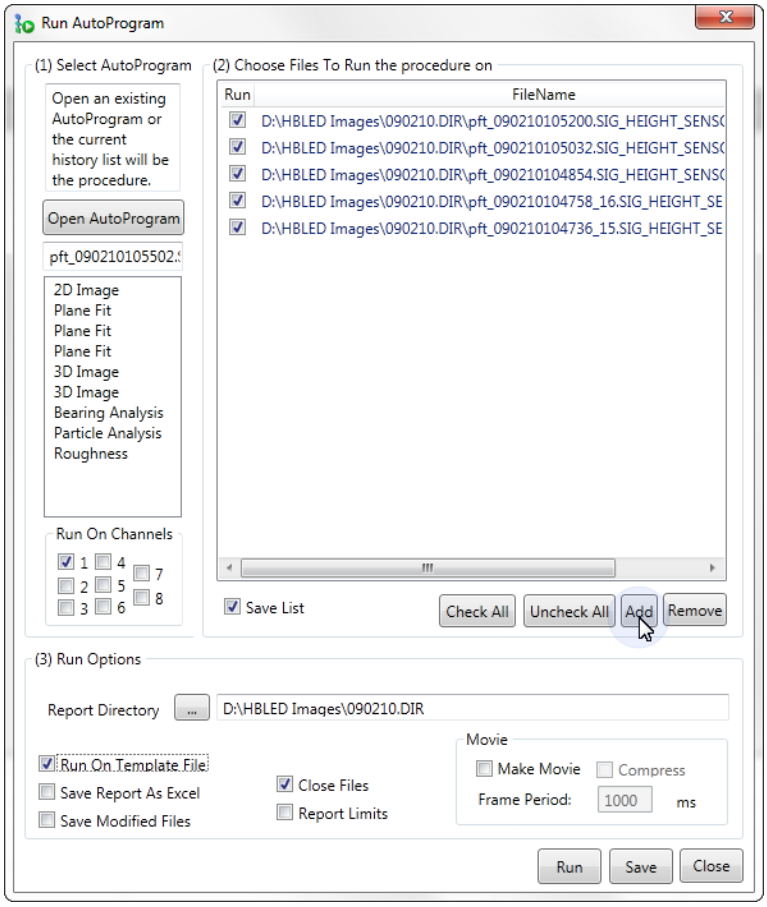


Figure 4.14b: The ***Run AutoProgram*** window

3. Select an existing AutoProgram file (*.apg) or use the current history list, shown below the **Open AutoProgram** button.
4. Click the **Add** button in the ***Run AutoProgram*** window. The ***Select Multiple Files*** dialog box, shown in Figure 4.14c, appears.

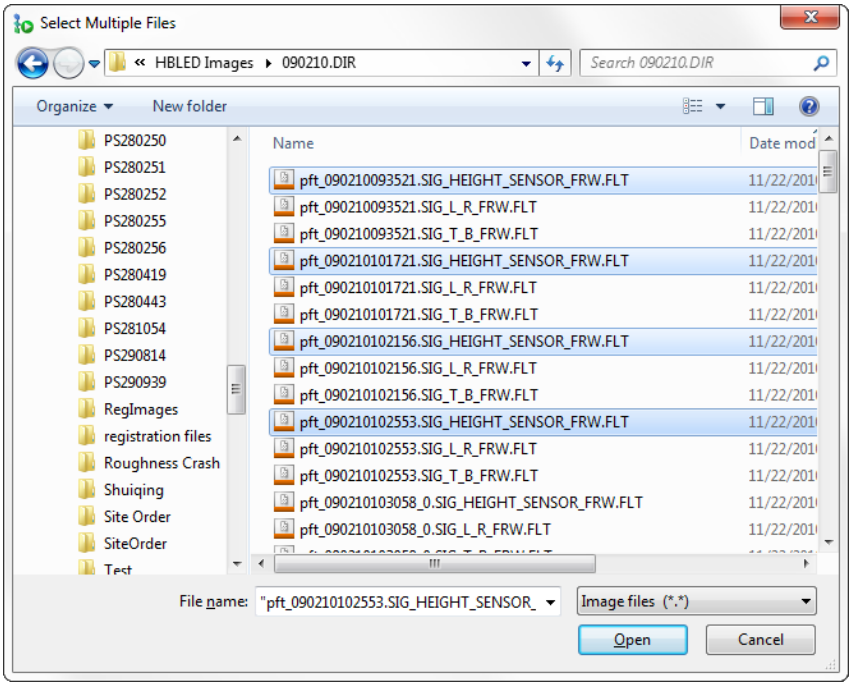


Figure 4.14c: The ***Add Files*** dialog box

5. Add individual files by clicking, a range of files by Shift-clicking or select multiple files by Ctrl-clicking. You may also add selected files by dragging them from The Browse Window (page 16) or from a Windows Explorer window into the ***Select Multiple Files*** or ***Drag files from Browse Window here*** dialog boxes.
6. Select which ***Channels*** you wish to be analyzed.
7. Select the ***Report Directory*** to store the output files.
8. The ***Run AutoProgram*** window, shown in Figure 4.14b, will display the files which are to be operated on. You may remove files from this list by highlighting the file and clicking **Remove**. You may also select or deselect a file by checking the **Run** box.
9. Click the **Save List** box to save your file list so that this list will appear the next time you open ***Run AutoProgram***.

NOTE: AutoPrograms created within NanoScope software will not run in NanoScope Analysis software.

4.14.2 Running an AutoProgram

Once all commands are included in a Run AutoProgram list and their action specified, you are ready to Run AutoProgram. Use this command to make movies.

1. Select the ***Run*** Options shown in Table: 4.0b and Table: 4.0c.

Parameter	Description
Close Files	Closes the files as AutoProgram operations are completed.
Run On Template File	Runs the AutoProgram operations on the Template file as well as the selected files.
Report Limits	Adds detailed pass/fail data to the report.
Save Report As Excel	Saves the Report as an Excel file.
Save Modified Files	Saves the files that have been modified by the AutoProgram.

Table: 4.0b *AutoProgram Run Options*

Option	Description
Make Movie	Makes a movie (AVI format) of the selected frames. **NOTE:** You must have an Export Images step before making a movie. **NOTE:** The **Make Movie** function requires that no tiff files exist in the selected directory.
Frame Period	The time between individual frames.
Compress	Compresses (JPEG) the AVI movie.

Table: 4.0c *AutoProgram Run Movie Options*

2. Click **Run**.

Run AutoProgram will then produce results, in Excel, AVI or text format, and log files.

Suggestions for Creating Movies

1. Sort your selected files in time order. The AVI file will be created in the order they are placed in the ***Choose Files to Run the procedure On*** dialog box. Refer to Configuring the List View (page 17) for sorting details.
2. Use either Frame Up or Frame Down images to make the amount of time between pixels constant.
3. Use either Trace or Retrace frames.
4. The recommended resolution (selected in the Exporting Images (page 50) function) is 96 dpi (screen resolution). Higher resolutions are (usually) wasted.
5. Bruker strongly recommends setting the ***Keep Original Pixels*** option to **No** (selected in the Exporting Images (page 50) function) because many AVI players do not support variable resolution.
6. If your exported images contain text, Bruker recommends that you do not compress the output file.

Run AutoProgram Troubleshooting

The Run AutoProgram function uses a Microsoft SQL Server database to store and retrieve NanoScope Analysis history. This database, stored on the local computer, grows with use. If you would like to reduce the size of the file associated with this database, you can clear unused records from the database:

1. Click **Help** > **About NanoScope Analysis** to open the ***About*** window, shown in Figure 4.14d.
2. Click the **Clear Database** button to remove unused records.

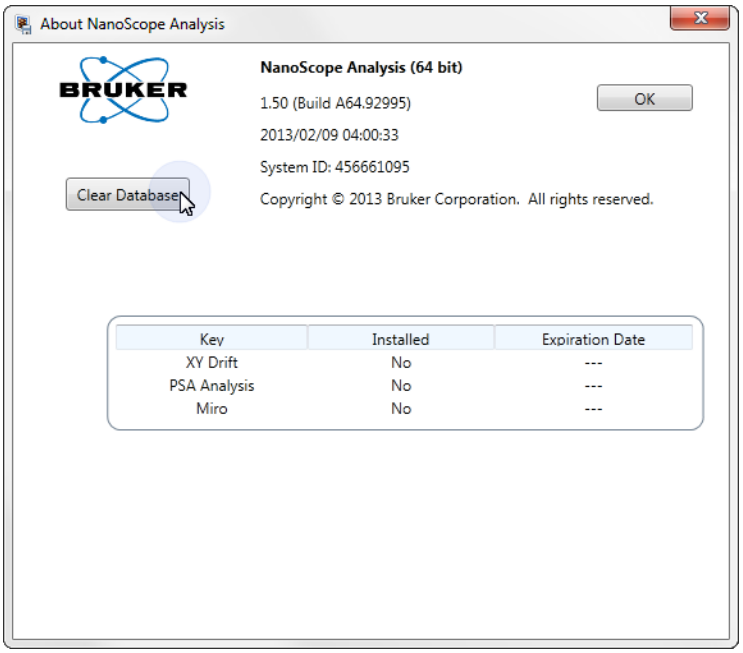


Figure 4.14d: Clear Database

Chapter 5: Analysis Functions

Analysis Functions relate to analyzing 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, modifications, and storage of the collected data. The analysis may be automated (i.e. in auto programs) or completed manually. In general, the analysis commands provide methods for quantifying the surface properties of samples.

Analysis Functions can be opened using the ***Menu*** bar or by clicking on the appropriate icon from the ***Icon*** Toolbar. These ***Analysis*** icons are identical to the icons used in NanoScope V8 software.

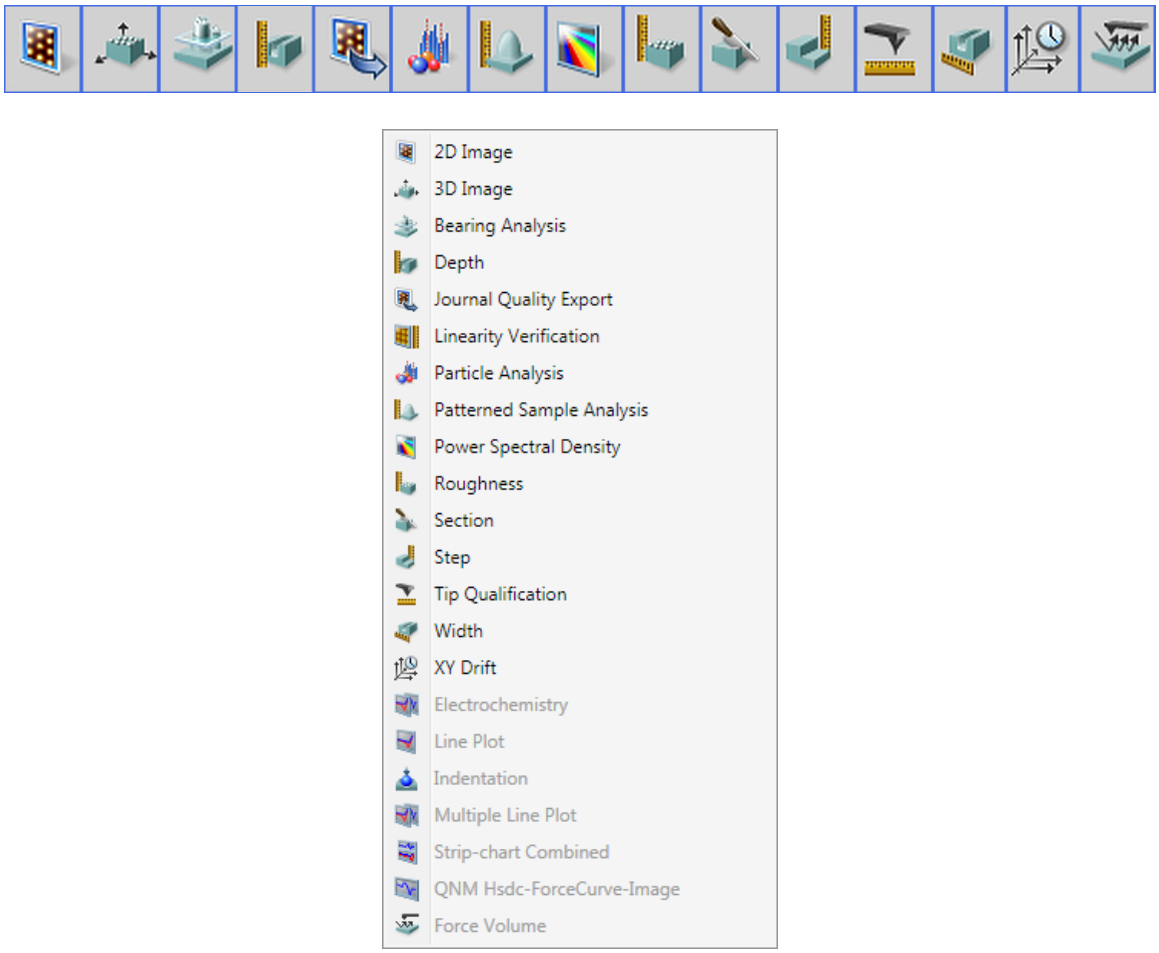


Figure 5.0a: Analysis Icons Toolbar and Menu

The following ***Analysis Functions*** are available in NanoScope Analysis 1.50:

- 2D Image (page 60)
- 3D Image (page 65)
- Bearing Analysis (page 73)

- Depth (page 80)
- Journal Quality Export (page 84)
- Linearity Verification (page 88)
- Particle Analysis (page 90)
- Patterned Sample Analysis (page 98)
- Power Spectral Density (PSD) (page 105)
- Roughness (page 112)
- Section (page 123)
- Step (page 131)
- Tip Qualification (page 135)
- Width (page 147)
- XY Drift (page 153)
- Electrochemistry
- Force Volume (page 226)

5.1  2D Image

The ***2D Image*** analysis displays the selected image with color-coded height information in a two-dimensional perspective. ***2D Image*** analysis is the default analysis of NanoScope Analysis such that when an image is initially opened it is always rendered in ***2D Image***.

5.1.1 2D Image Procedure

1. Select the ***2D Image*** analysis by selecting Analysis > 2D Image from the ***Toolbar*** menu or by clicking on the 2D Image icon from the ***Icon*** toolbar.
2. The file is opened in the ***2D Image*** window, shown in Figure 5.1a.

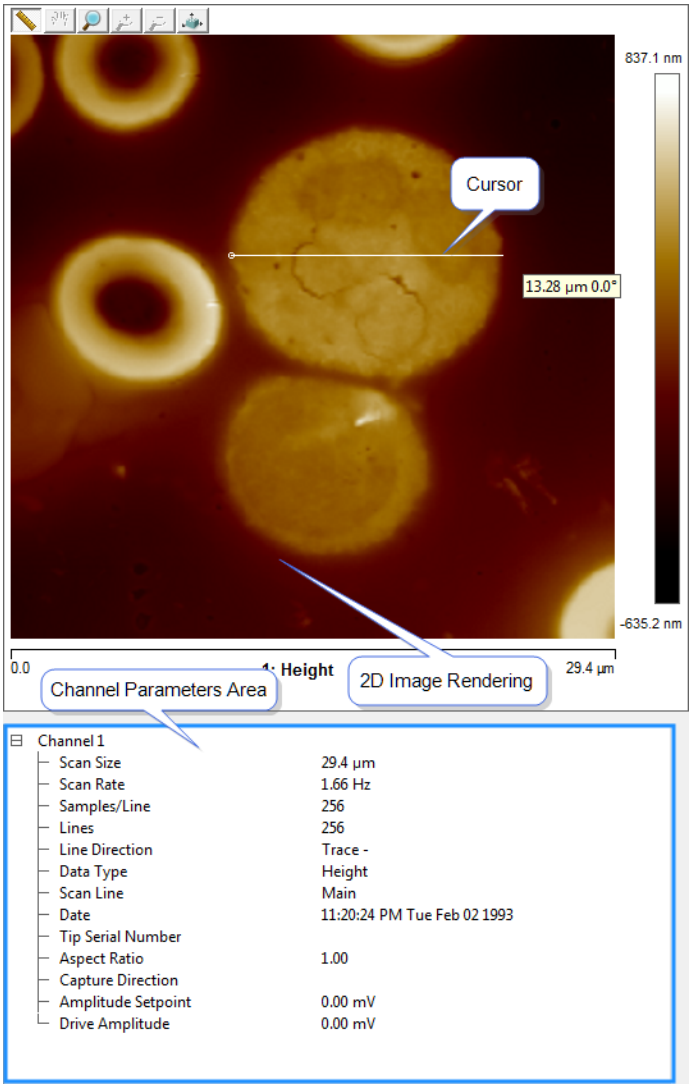


Figure 5.1a: 2D Image Menu and Window

3. Right click in the ***Channel Parameters*** area and select Show All. The ***Channel Parameters*** appear with checkboxes next to them. By un-checking the boxes, you can determine which ***Channel Parameters*** are shown and which parameters are hidden. This is a convenient way to hide rarely-used parameters. When satisfied with the checked and un-checked boxes, right-click the ***Channel Parameters*** area and select Show All again. Only the checked parameters will now show in the ***Channel Parameters*** area.

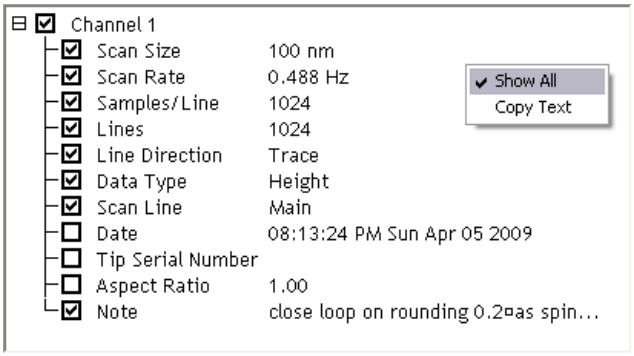


Figure 5.1b: Channel Parameters Hide / Show Selection

4. Right click in the ***Channel Parameters*** area and select **Copy Text**.
5. A new dialog, shown in Figure 5.1c, will appear notifying the user that the data from the ***Channel Parameters*** area has been copied to the clipboard. The user can now save the data into their preferred medium.

Figure 5.1c: Dialog Indicating Text has been Copied to the Clipboard

6. To determine length and angle measurements, use the mouse to draw a cursor in the preferred location on the ***2D Image*** rendering.
7. Length and angle measurements are show next to the mouse icon when the mouse is placed over the drawn cursor.
8. After a cursor has been drawn it is possible to get more detailed information on the length and angle measurements. Right click anywhere in the ***2D Image*** rendering (except on the drawn cursor). Choose Tooltip Level > Basic, Medium, Advanced, or None. See Figure 5.1d.

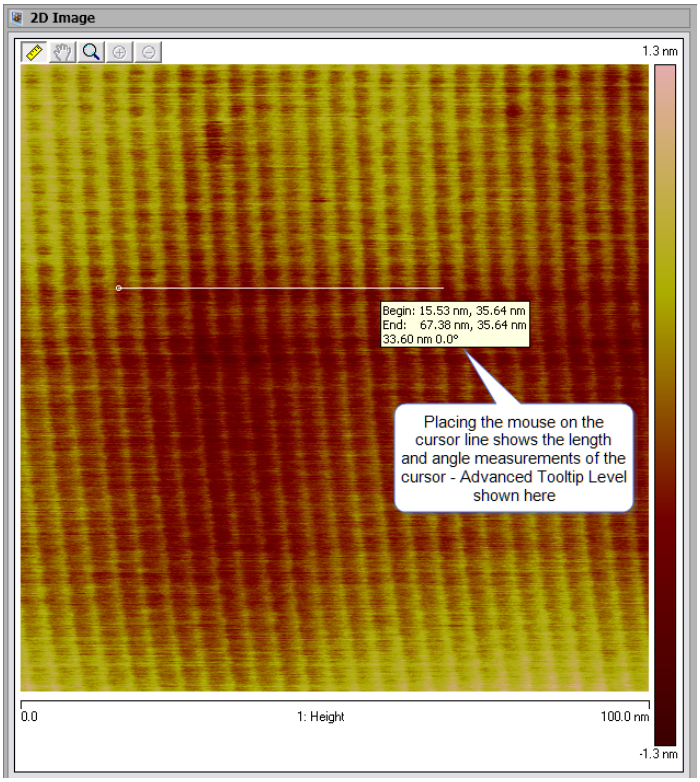


Figure 5.1d: Cursor Length and Angle Measurements

9. To export the ***2D Image*** rendering, right click anywhere in the ***2D Image*** rendering and select Export > Screen Display. Name the file and choose the location to save it. The preferred file for saving exported images is .bmp. See Figure 5.1e.

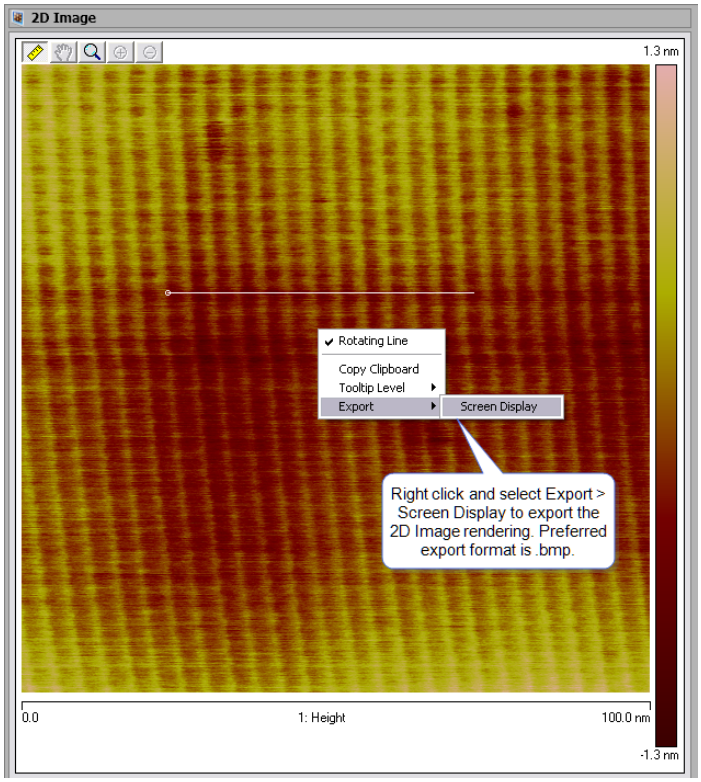


Figure 5.1e: Export Menu

Parameter	Description
Scan Size	Length of each scan line for a given image
Scan Rate	Number of scan lines per second
Samples/Line	Number of sample data points per scan line
Lines	Selects the number of lines to scan in a frame
Line Direction	Trace (left to right) or Retrace (right to left); defined when the image was originally taken
Data Type	Data Type is defined by the channel selection when the image was originally taken
Scan Line	Choose Main or Interleave; defined when the image was originally taken
Date	Time and date scan was taken
Tip Serial Number	Serial number of tip; must be manually entered by operator when the image was originally taken
Aspect Ratio	Image ratio of width to height
Note	User added, description of file

Figure 5.1f: 2D Image Parameters

5.2  3D Image

The ***3D Image*** view displays the selected image with color-coded height information in a three-dimensional, oblique perspective. ***3D Image*** allows selection of the viewing angle and illumination angle for a modeled light source.

3D Image Procedure

1. Select the ***3D Image*** analysis by selecting **Analysis** > **3D Image** from the ***Toolbar*** menu or by clicking on the **3D Image** icon from the ***Icon*** toolbar.
2. The ***Projection***, ***Plot Type***, ***Skin Type***, ***Label Type***, and ***Background Color*** 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.
3. 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.
4. 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.
5. 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**.
6. Clicking and holding the right button while moving the mouse up and down changes the light pitch. This is only available when ***Plot Type*** is set to **Mixed**.

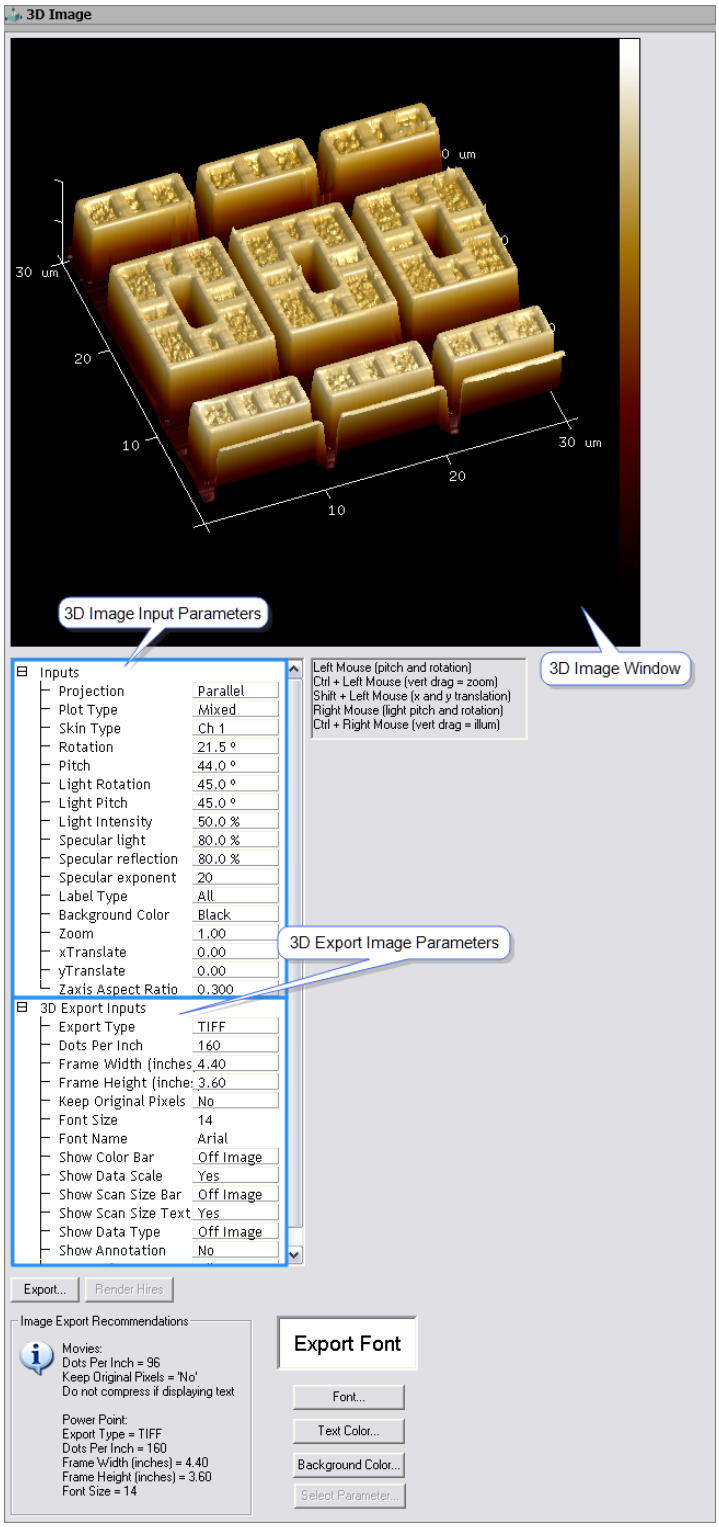


Figure 5.2a: 3D Image Menu & Window

NOTE: NanoScope Analysis versions prior to 1.30 rendered a maximum of 512 points/line in 3D. Version 1.30 and later render up to 2048 points/line by default, with a **Render Hires** button to render higher resolution images.

Skin Type Example

Skin Type allows you to paint the 3D surface with colors taken from an alternative channel. This is useful for comparing property channels with the surface topography.

The following example demonstrates the use of ***Skin Type***, ***Color Scale*** and other commonly used 3D parameters using a SRAM/SCM sample.

1. After the image is opened, click on the ***3D Image*** icon. Change the ***Projection*** parameter to **Perspective** and the ***Plot Type*** to **Height**.

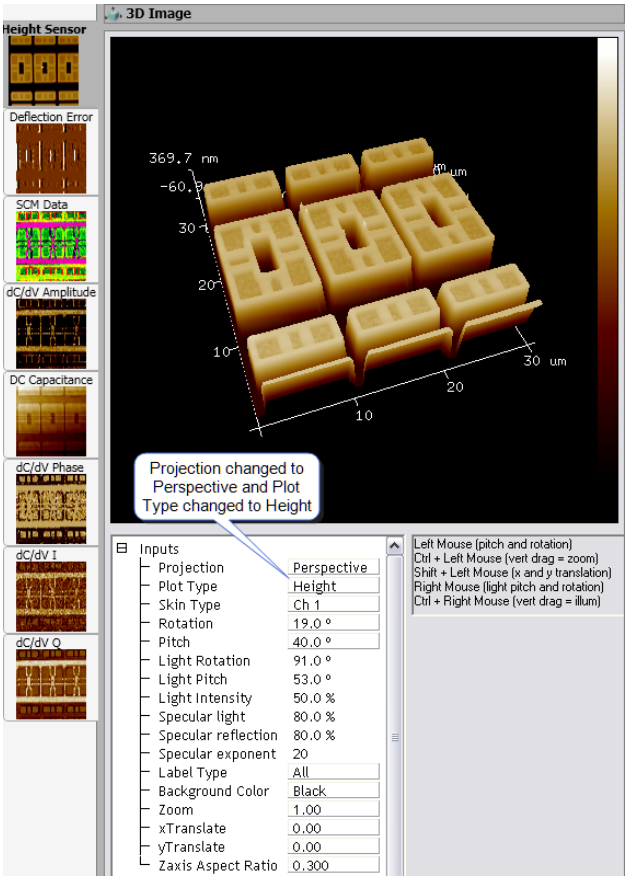


Figure 5.2b: Image opened in ***3D Image*** view

2. Click on the tab for the alternative channel to be painted onto the surface of the ***3D Image***. Change the ***Color Scale*** to #17.

NOTE: The top of the color table at 44.1 degrees is violet. The bottom pixels in the image are red at about -18 degrees.

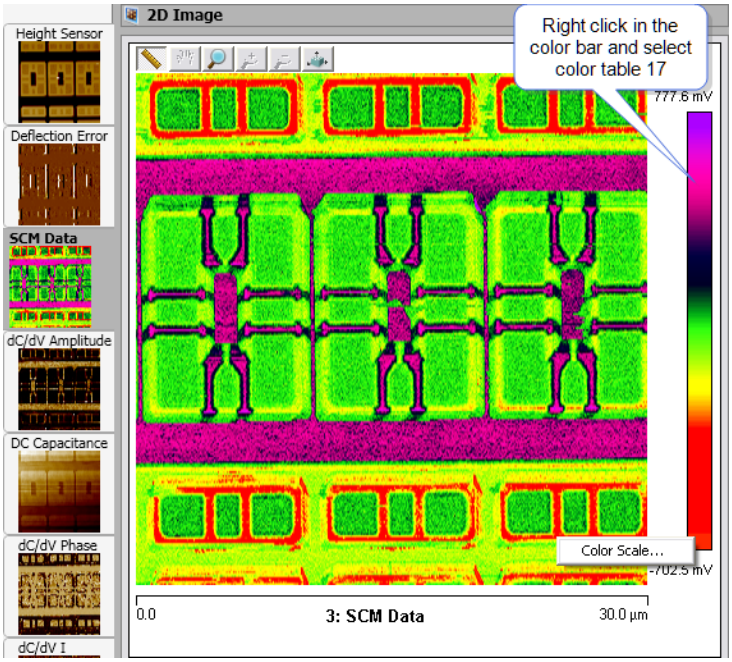


Figure 5.2c: Color Table 17 Selected on Alternative Channel

3. Return to the original channel and choose the ***Skin Type*** of the alternative channel. The data of the alternative channel will now be painted onto the 3D surface.

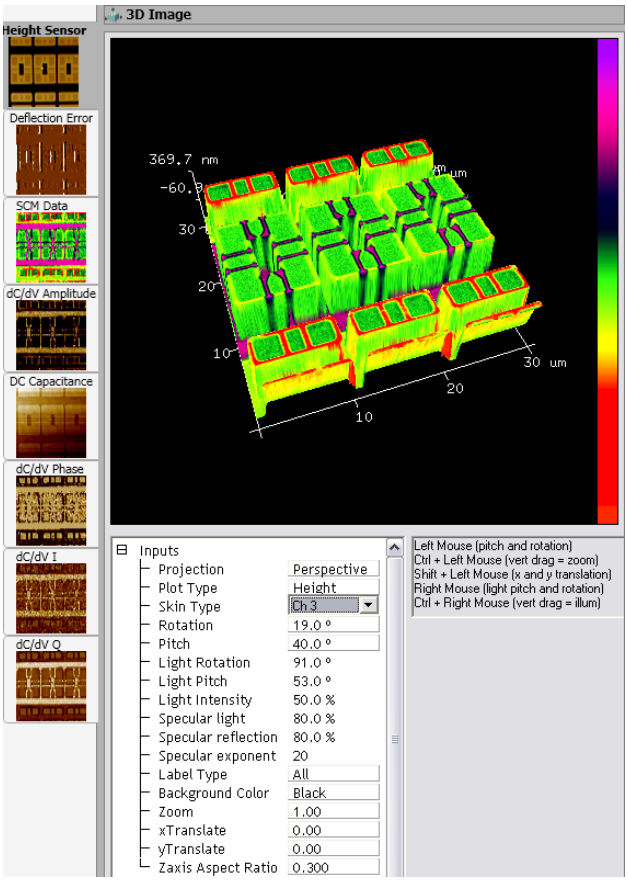


Figure 5.2d: Skin Type of Original Channel Modified to Color Scale 17

4. Return to the original channel and change ***Projection*** to **Parallel** and ***Plot Type*** to **Mixed**.

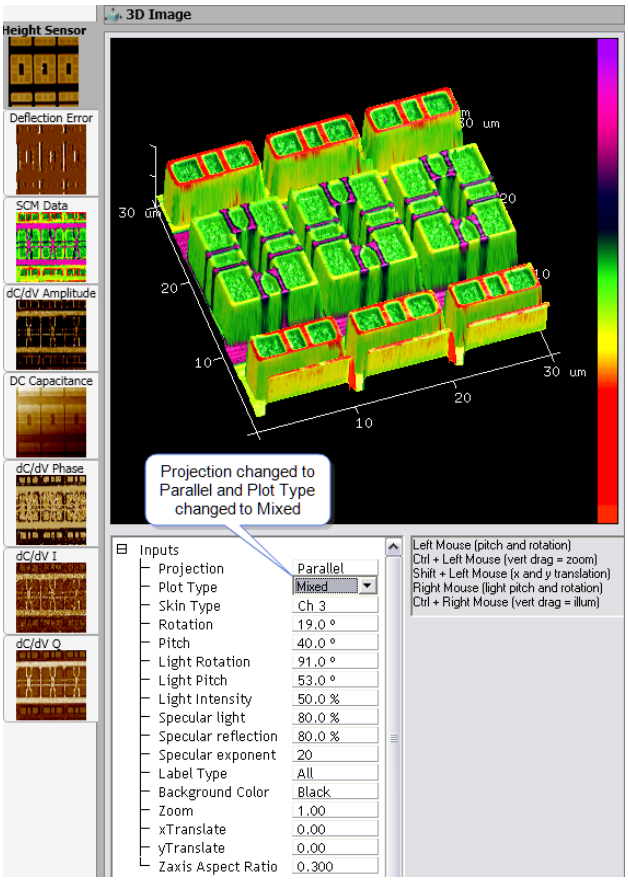


Figure 5.2e: Projection and Plot Type Values Changed on Original Channel

Controls

Parameter	Description
Projection	*Settings*: • 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	*Setings*: • **Height** displays the image with the surface of the image painted according to the skin channel and the color table. • **Wire** displays the image as a line representation of the scanned data. The color of the line is determined by the skin channel and the color table. • **Mixed** adds the effect of illumination to the height display.

Parameter	Description
Skin Type	By default, Skin Type is determined by the current channel. Selecting a different channel paints the 3D surface with the data from the selected channel. The range of the color table used is determined by the range shown in the chosen skin channel.
Rotation	The Rotation parameter changes as the viewing angle by rotating the displayed image about the Z axis relative to its captured orientation. Zero degrees indicates the image is rendered as captured (straight on).
Pitch	The Pitch parameter changes the viewing angle by manually changing the pitch of the Y axis in the three-dimensional surface plot image. Zero degreed indicates a top down view of the captured image.
Light Rotation	The Light Rotation parameter rotates the light source in the horizontal plane (xy plane). This is only available when the ***Plot Type*** is set to **Mixed**. 90 degrees of ***Light Rotation*** indicates the light source is on the right.
Light Pitch	The ***Light Pitch*** parameter 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**. 90 degrees indicates the light pitch is coming from above (high noon).
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**.
Specular Light	Specular Light, Specular Reflection, and Specular Exponent all control the reflection of light (shininess) on the 3D image.
Label Type	Label Type - The Label Type parameter selects whether labels or axes are displayed with the image. All displays the axes with labels. Axis displays all the axes without labeling. None displays the image without labels.
Background Color	Changes the background color to black or white
Zoom	Zooms in on the image. Larger numbers increase the zoom level and smaller numbers decrease the zoom level. 1.5 will typically come close to filling the image frame.
xTranslate	Moves the image up or down in the image window.
yTranslate	Moves the image left or right in the image window.
Zaxis Aspect Ratio	Allows you to control the relative height of the Z axis display *Range*: 0.0 to 1.0 where 0.0 produces a flat display while 1.0 produces a display whose Z axis is equal is size to the X and Y axes.

Table: 5.0d 3D Image Parameters

Button	Description
Export	Allows you to export a publication quality image. The **Export** function allows you to make 3D movies. Refer to Journal Quality Export (page 84) for a discussion of ***3D Export Input Parameters***.
Load Skin	Loads a file (channel) to be used as a skin. Used *only* for NanoDrive files because each NanoDrive channel is a separate file.
Unload Skin	Unloads a skin. Used *only* for NanoDrive files because each NanoDrive channel is a separate file.
Render Hires	Re-renders the image at higher resolution. Applies to images greater or equal to 2048 samples/line.

Table: 5.0e 3D Image Buttons

5.3 Bearing Analysis

Bearing Analysis provides a method of plotting and analyzing the distribution of surface height over a sample. Bearing Analysis may be applied to the entire image, or to selected areas of the image, using a rubber band box. Moreover, regions within the selected area can be blocked out by using "stop bands" to remove unwanted data from the analysis.

Bearing Analysis Theory

Bearing Analysis reveals how much of a surface lies above or below a given height. This measurement provides additional information beyond standard roughness measurements. (Surface roughness is generally represented in terms of statistical deviation from average height; however, this gives little indication of height distribution over the surface.) By using bearing analysis, it is possible to determine what percentage of the surface (the "bearing ratio") lies above or below any arbitrarily chosen height. In industries where materials are polished or chemically etched, this is a particularly useful tool. For example, bearing analysis is frequently used in silicon etching processes to observe changes in etched features over an interval of time.

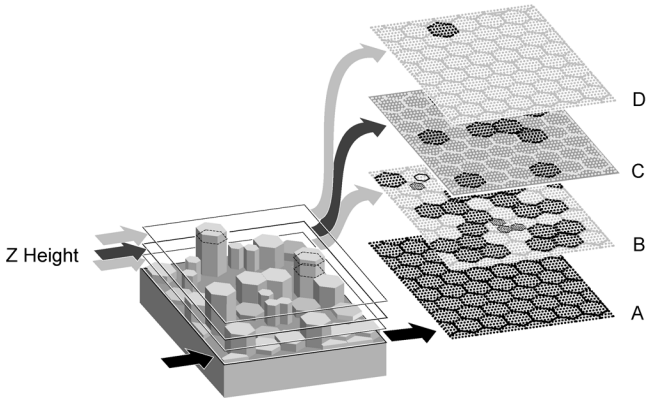


Figure 5.3a: Bearing Analysis Illustration

Figure 5.3a represents how Bearing Analysis generates a histogram of feature height based upon the occurrence of pixels at various Z heights. At Z height "A," virtually all of the surface is included (corresponding to a Bearing ratio of 100, or 100 percent of the area). At Z height "D," the pixel count is much reduced, representing a smaller Bearing ratio (approximately 2-5 percent of the area).

Bearing Analysis Procedure

1. Select an image file from the file Browse window at the right of the main window. Double-click or drag

the thumbnail image to select and open the image.

2. Open the Bearing Analysisby selecting **Analysis > Bearing Analysis** from the Menu bar or by clicking the **Bearing Analysis** icon in the Icon toolbar.
3. Use the  **Filters > Plane Fit** function to remove all tilt before running Bearing Analysis.

The Bearing Analysis function displays a top view of the image, then calculates and displays bearing area curves and surface height histograms for lines or areas drawn on the image. See Figure 5.3b.

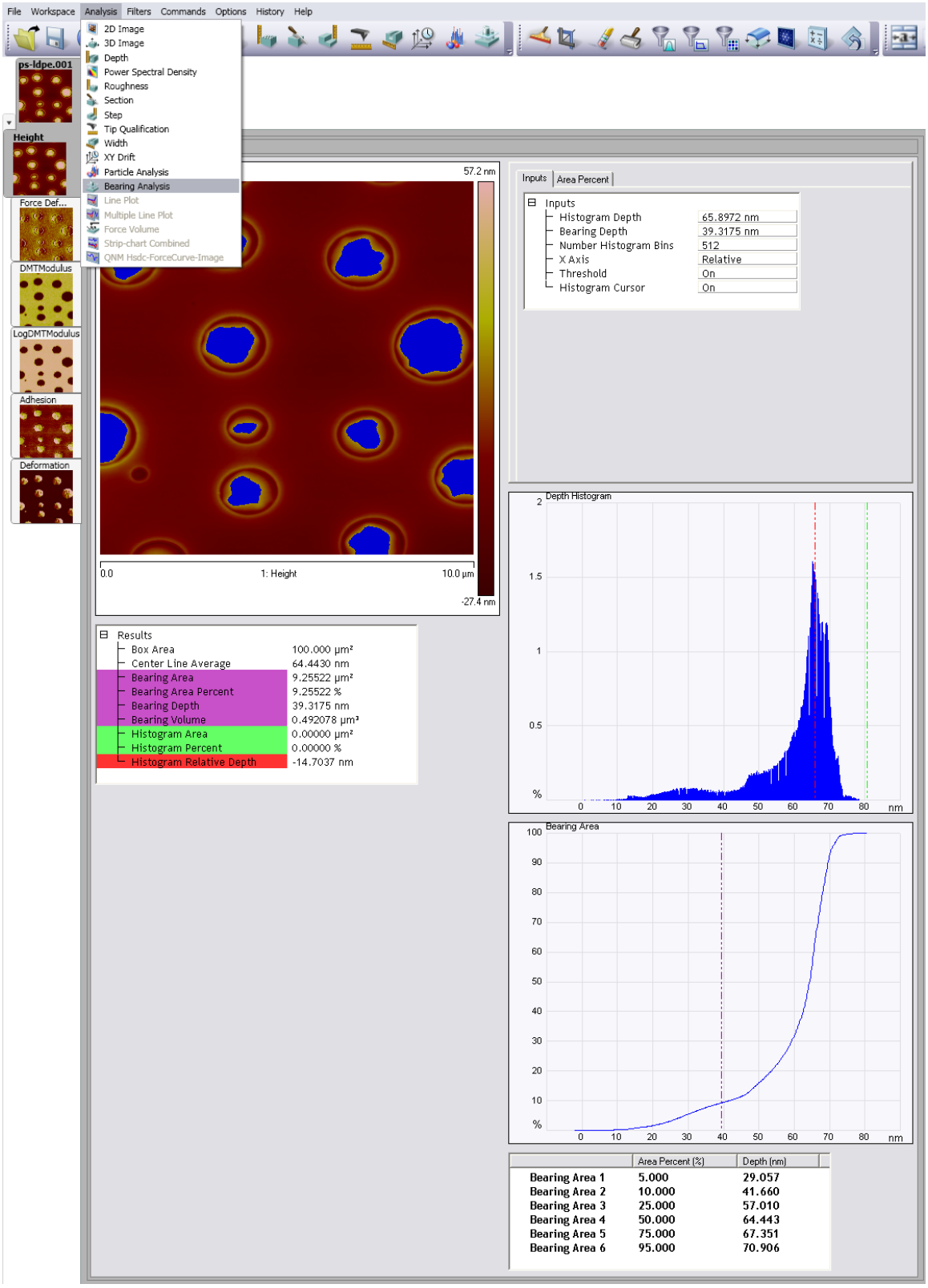


Figure 5.3b: The Bearing Analysis Interface

The word bearing means the relative roughness of a surface in terms of high and low areas. The bearing area curve is the integral of the surface height histogram and plots the percentage of the surface above a reference plane as a function of the depth of that plane below the highest point in the image.

4. Plotted data includes all data points, noise spikes and holes. If noise is to be filtered out, it should be removed before using the Bearing Analysis function by executing one of the filtering commands (e.g., Gaussian (page 176), Lowpass (page 187), Median (page 190)).
5. Using the mouse, left-click and drag a box on the area of the image to analyze. The ***Depth Histogram*** displays the depth information about this specified area.
6. Move the cursors to select the ***Bearing Depth*** and set the ***X Axis***, ***Threshold*** and ***Histogram*** input parameters.

NOTE: If no box is drawn, by default, the entire image is selected.

Bearing Analysis Interface

The Bearing Analysis interface includes a captured image, ***Input*** parameters, ***Results*** parameters, a ***Depth Histogram*** and a ***Bearing Area*** plot as shown in the image above.

Parameter	Description
Histogram Depth	User input field that corresponds to the red cursor in the ***Depth Histogram*** display and the red boxes in the ***Results*** parameters. Moving the red cursor in the ***Depth Histogram*** display will modify the ***Histogram Depth*** input parameter while changing the ***Histogram Depth*** input parameter will move the red cursor.
Bearing Depth	The ***Bearing Depth*** reference plane. User input that corresponds to the magenta cursor in the ***Bearing Area*** display. Moving the magenta cursor in the ***Bearing Area*** display will modify the ***Bearing Depth*** input parameter while changing the ***Bearing Depth*** input parameter will move the magenta cursor.
Number of Histogram Bins	The number of data points which result from the filtering calculation. **NOTE:** Having more histogram bins than pixels is unnecessary.
X Axis	**Relative**: Plots the data relative to the highest point. Points that are lower than the highest point will have higher depths. **Absolute**: Plots the real (i.e., measured) numbers.
Threshold	**On**: Points higher than the Bearing Depth (magenta cursor) in the Bearing Area plot are displayed as blue in the image. **Off**: Points higher than the Bearing Depth (magenta cursor) in the Bearing Area plot are not displayed in the image.
Histogram Cursor	Turns the green Histogram cursor On and Off.

Table: 5.0f Bearing Analysis ***Input*** Parameters

NOTE: Clicking in the image will reset all the cursors and their corresponding input parameters.

Parameter	Description
Box Area	The area of the selected analysis region.
Center Line Average	The height at which half the points in the selected area are above and half are below.
Bearing Area	Area covered by all of the points above the selected Bearing Depth.
Bearing Area Percent	The percentage of the surface above the Bearing Depth reference plane.
Bearing Depth	The Bearing Depth reference plane. Identical to the Bearing Depth input parameter.
Bearing Volume	Sample volume defined above the bearing depth plane.
Histogram Area	The area of the histogram bin covered by the points at the depth indicated by the red histogram cursor.
Histogram Percent	The percentage of the total number of points in the histogram bin at the depth indicated by the red histogram cursor.
Histogram Depth	The depth of the red histogram cursor position relative to highest point in the image.
Histogram Relative Depth	The Histogram Depth (red cursor) relative to the Histogram (green) Cursor. Active when the Histogram Cursor is On.

Table: 5.0g Bearing Analysis ***Results*** Parameters

Patterned Sample Analysis Results

If you have previously run Patterned Sample Analysis (page 98), the ***Bottom Result*** is used as an ***Input*** to ***Bearing Analysis*** and additional PSA results parameters, shown in Figure 5.3c and Table: 5.0h, are computed.

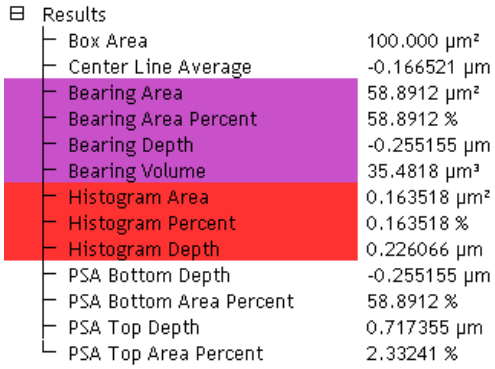


Figure 5.3c: Results panel with Patterned Sample Analysis

Parameter	Description
PSA Bottom Depth	The Bottom Depth Area.
PSA Bottom Area Percent	The percentage of the total area occupied by the Bottom Depth.

Parameter	Description
PSA Top Depth	The Top Depth Area.
PSA Top Area Percent	The percentage of the total area occupied by the Top Depth.

Table: 5.0h PSA parameters in Bearing Analysis Results

Area percent

The **Area Percent** tab allows the input of Bearing ratios:

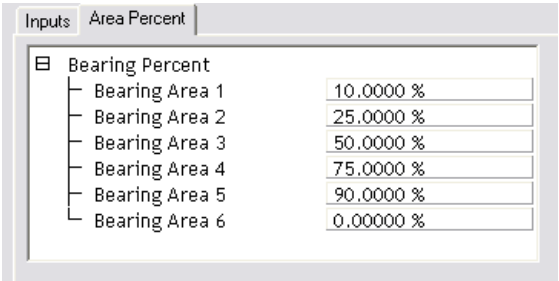


Figure 5.3d: The ***Area Percent*** input

The ***Area Percent*** tab allows input of up to six different bearing ratios. For example, if 50% is entered for the ratio, the box displayed in the ***Bearing Area Result***s window, shown in Figure 5.3e, measures the depth above which 50% of the data points are above.

	Area Percent (%)	Depth (nm)
Bearing Area 1	10.000	14.931
Bearing Area 2	25.000	23.833
Bearing Area 3	50.000	37.187
Bearing Area 4	75.000	196.323
Bearing Area 5	90.000	219.693
Bearing Area 6	0.000	-6.770

Figure 5.3e: The ***Bearing Area Results*** window

The ***Bearing Area results window***, shown in Figure 5.3e, displays depth data for specifically entered bearing ratios.

Using the Grid Display

Right-clicking in the plot area will bring up the ***Grid Parameters*** menu.

Figure 5.3f: Grid Parameters Menu

The following adjustments are available to change the way that the plots appear:

Parameter	Description
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	Allows user to auto scale, set a curve mean, or set their own data range
Scale	For each curve, the operator can choose a connect, fill down, or point line.
Line Style	Total number of peaks included within the data histogram.
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

Table: 5.0i Plot Appearance Parameters

5.4  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*** analysis 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).

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.

Depth Histogram

Figure 5.4a 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.

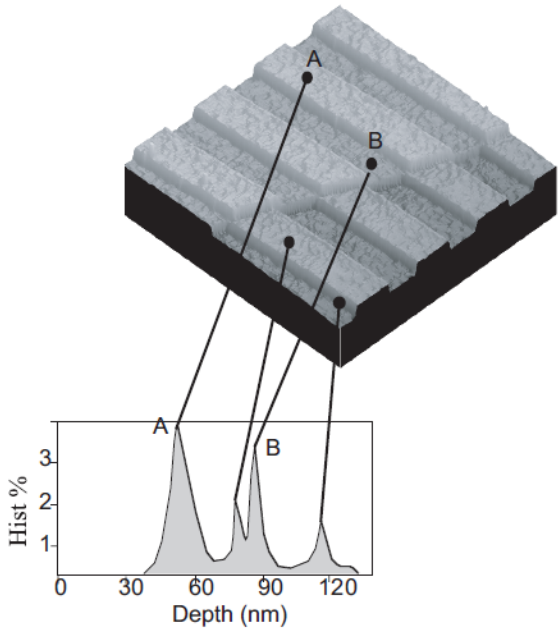


Figure 5.4a: Depth Image and Corresponding Histogram

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 low-pass, 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).

Depth Procedures

1. Select an image file from the file ***Browse*** window at the right of the main window. Double click the thumbnail image to select and open the image.
2. Open the ***Depth*** analysis by selecting Analysis > Depth from the ***Menu*** bar or by clicking on the Depth icon in the ***Icon*** toolbar.

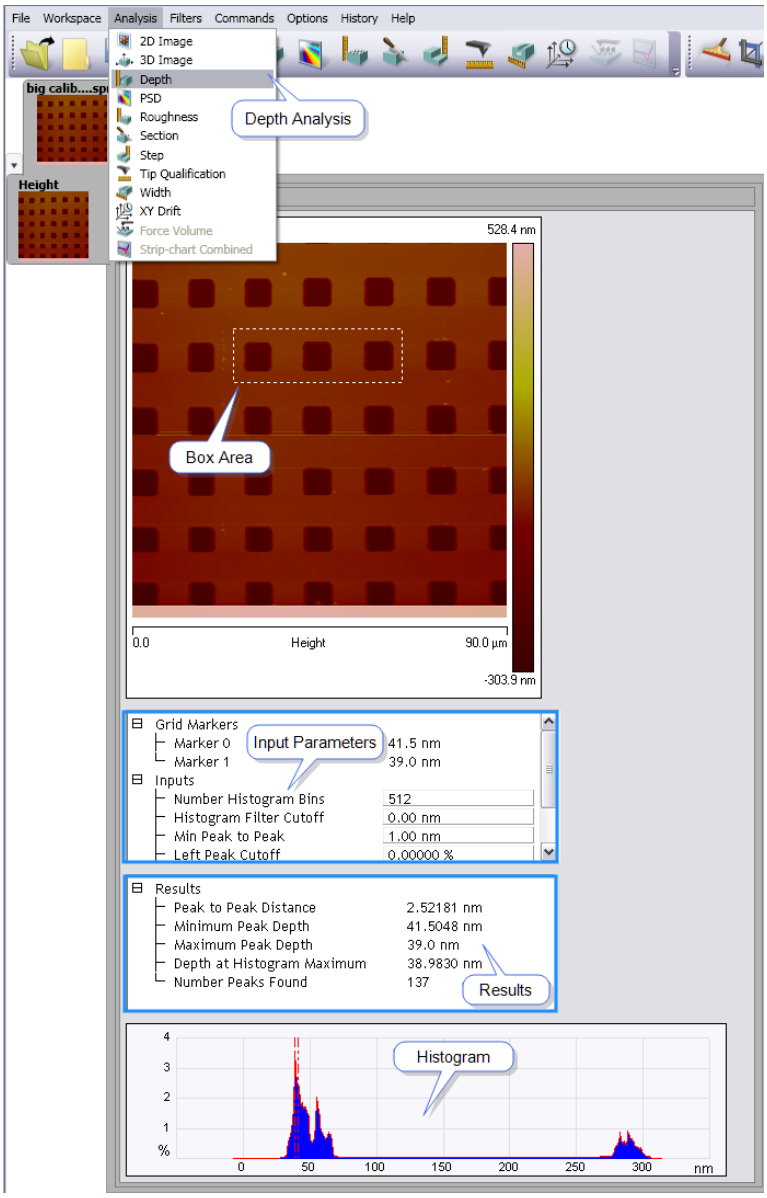


Figure 5.4b: Depth Analysis Menu & Window

3. 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.

4. Adjust the Minimum Peak to Peak to exclude non relevant depths.
5. Adjust the Histogram Filter Cutoff parameter to filter noise in the histogram as desired. Note the results.

Depth Interface

The ***Depth*** interface includes a captured image, ***Grid Markers***, ***Input*** parameters, ***Results*** parameters and a

correlation ***Histogram*** shown in Figure 5.4b.

Parameter	Description
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 smoothes 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. Note: At 0%, only the maximum point on the curve is included. At 25%, only the maximum 25% 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. Note: At 0%, only the maximum point on the curve is included. At 25%, only the maximum 25% of the peak is included in the calculation of the centroid.
Data Range Pad	Creates a buffer region at either end of the histogram.
X Axis	**Relative**: Plots the data relative to the highest point. Points that are lower than the highest point will have higher depths. **Absolute**: Plots the real (i.e., measured) numbers.

Table: 5.0j Depth Parameters

Parameter	Description
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.

Table: 5.0k Depth Results Parameters

Using the Grid Display

Right-clicking on the grid will bring up the ***Grid Parameters*** menu.

Figure 5.4c: Grid Parameters Menu

The following adjustments are available to change the way that the plots appear:

Parameter	Description
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 (defualt), Maximum, or Minimum -Points - Select 4k, 8k (default), 16k, or 32k
Minor Grid	Allows user to auto scale, set a curve mean, or set their own data range
Scale	For each curve, the operator can choose a connect, fill down, or point line.
Line Style	Total number of peaks included within the data histogram.
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

Table: 5.0l Plot Appearance Parameters

5.5 Journal Quality Export

The **Journal Quality Export** function allows you to export publication quality images from NanoScope Analysis. The image will be exported to the same directory with as OriginalFileName_Channel#.ExportType.

The Journal Quality Export function retains settings from the last use of this function.

To Export a high quality image:

1. Click the **Journal Quality Export** icon on the NanoScope Analysis toolbar or select **Analysis** > **Journal Quality Export** from the menu.
2. Choose appropriate Export options in the ***Inputs*** panel, shown in Table: 5.0m.

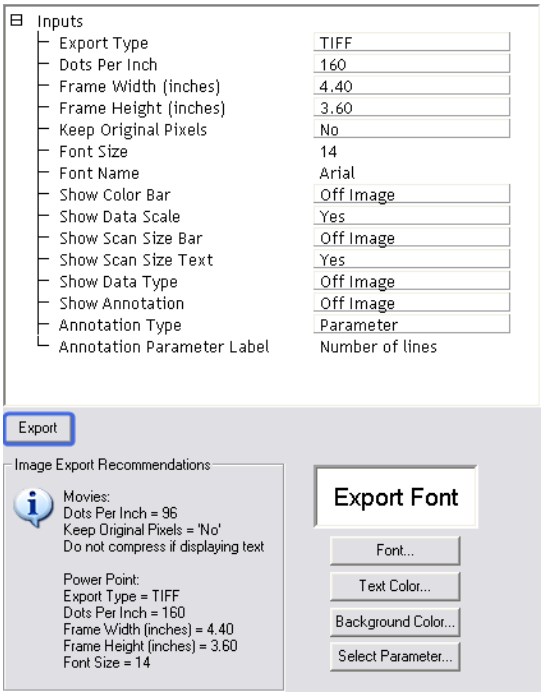


Figure 5.5a: Export image options

3. Click **Export**. The file will be exported to the same directory as the original image file.

Export options are described in Table: 5.0m.

Parameter	Description
Export Type	*Settings*: • **Bitmap** • **Tiff** • **Jpeg** • **Png**
Dots Per Inch	The resolution of the output file.
Frame Width (inches)	The width, in inches, of the output file. **NOTE:** This includes the Color Bar and associated Data Scale.
Frame Height (inches)	The height, in inches, of the output file. **NOTE:** This includes the Scan Size Bar, Data Type label and off-image annotation.

Parameter	Description
Keep Original Pixels	*Settings*: • **No** • **Yes**
Font Size	Selects the font size used for the Data Scale, Scan Size and Data Type display. **NOTE:** Bruker recommends lossless (Tiff or Png) or no (Bitmap) compression for images that include text.
Show Color Bar	*Settings*: • **No** • **Off Image**: Displays the color scale to the right of the image. • **On Image**: Displays the color scale on the image.
Show Data Scale	*Settings*: • **No** • **Yes**: Displays the data scale **NOTE:** ***Show Color Bar*** must be set to **Off** or **On Image** to enable ***Show Data Scale***.
Show Scan Size Bar	*Settings*: • **No** • **Off Image**: Displays the scan size bar below the scan. • **On Image**: Displays the scan size bar on the image.
Show Data Type	*Settings*: • **No** • **Off Image**: Displays the Data Type below the Scan Size bar • **On Image**: Displays the Data Type below the Scan Size bar
Show Annotation	Displays user-selected annotation. *Settings*: • **No** • **Off Image** • **On Image**
Annotation Type	Selects the type of annotation. *Settings*: • **File Name** • **Time** • **Date** • **Parameter**
Annotation Parameter Label	Clicking the **Select Parameter** button, shown in Figure 5.5a, opens the ***Select a Parameter*** window, shown in Figure 5.5b, that allows you to chose a selected parameter that will appear in the annotation. Click the **+** sign to expand the list and then click a parameter. Close the window to apply your selection.

Parameter	Description
Font	Opens a window that allows you to chose a font, style and size
Text Color	Opens a window that allows you to chose a font color.
Background Color	Opens a window that allows you to chose the color of the background that surrounds the image.

Table: 5.0m Export Options

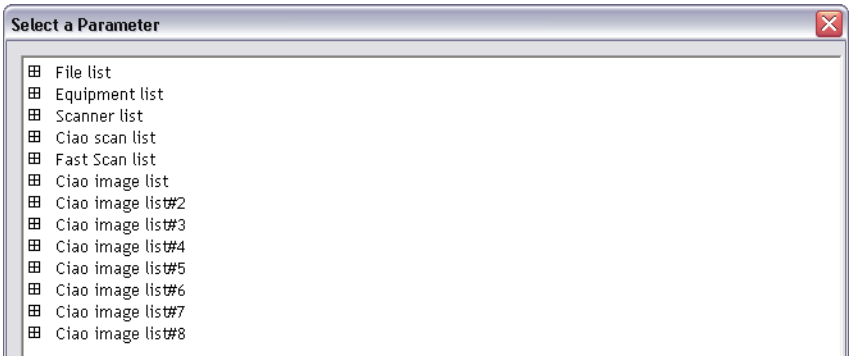


Figure 5.5b: The ***Select a Parameter*** window

Figure 5.5c shows an image that has been exported.

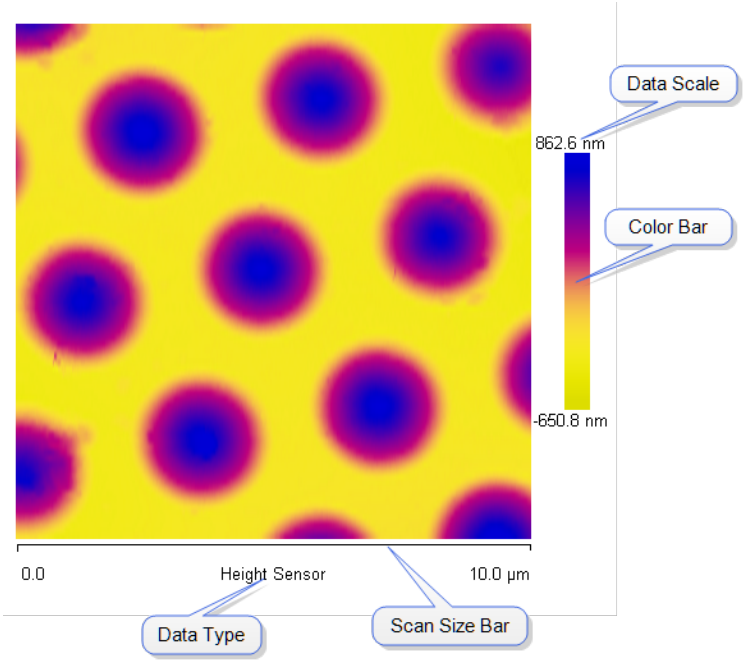


Figure 5.5c: Exported Image with no annotation

5.6 Linearity Verification

The ***Linearity Verification*** function requires an image of a Bruker calibration standard. If you run Linearity Verification on an unsuitable sample, you will receive an error message "Linear Verification Analysis requires data from a calibration standard."

The ***Linearity Verification*** function is used by Bruker personnel for quality control.

NOTE: The Linearity Verification function requires images that are tilted less than 3 degrees.

5.6.1 Linearity Verification Procedure

1. Open the image and click ***Analysis*** > ***Linearity Verification***.
2. The ***Linearity Verification*** window, shown in Figure 5.6a, opens.
3. Enter the ***Specified Pitch*** in the ***Inputs*** window.

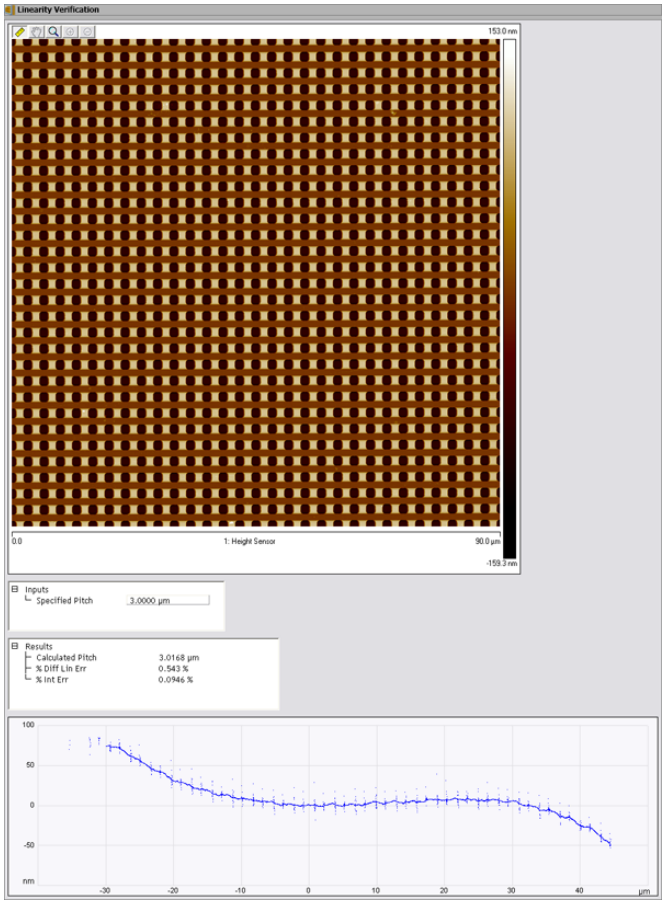


Figure 5.6a: The Linearity Verification window

4. The ***Calculated Pitch*** and the ***Percent Differential*** and ***Integral Errors*** are displayed in the ***Results*** window, shown in Figure 5.6b.

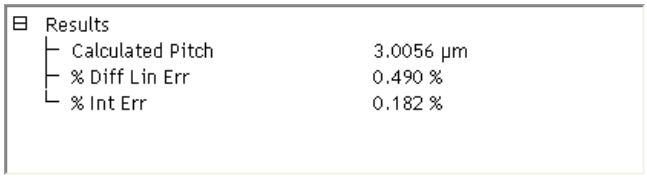


Figure 5.6b: The ***Linearity Verification Results*** window

5.6.2 Linearity Verification Results

The Linearity Verification function produces a plot as well as several calculated results:

Result	Description
Calculated Pitch	The average pitch
% Diff Lin Err	Root mean square of the differential error (i.e. error at point i vs error at point i + 1 or i - 1) as a percent of the mean pitch.
% Int Err	Maximum absolute error - the largest individual error value - as a percent of scan size

5.7 Particle Analysis

The ***Particle Analysis*** command defines features of interest based on the height of pixel data. This command was designed for analyzing well isolated particles or features of interest. Particles may be analyzed singly or in quantities. Particles in this context, are conjoined pixels above or below a given threshold height.

The analysis includes a histogram of particle size, which can be used to identify specific particles by size. Measurements on this analysis include: the mean area and standard deviation of the particle sizes, the total number of particles, a correlation histogram, and a depth histogram.

Figure 5.7a illustrates how particles can be isolated by height. This type of analysis works well on materials in which particle size or type is linked to height.

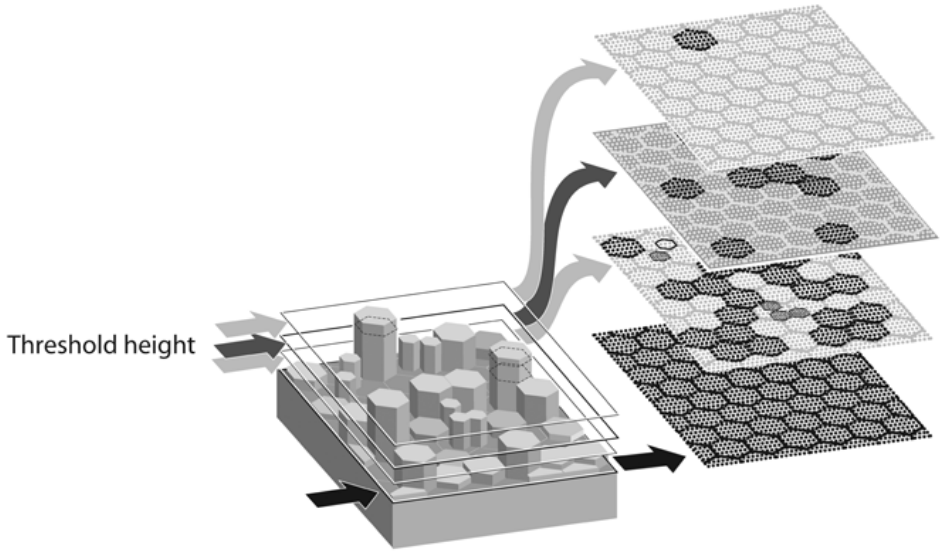


Figure 5.7a: Particles Isolated by Height

Dilate & Erode

As applied to the ***Particle Analysis*** command on NanoScope Analysis images, **Dilate** is used to clump grains together and **Erode** is used to separate grains. Pixels comprising an image are evaluated in square matrices (i.e., neighborhoods), sized according to the ***Neighborhood Size*** and ***Number Pixels Off*** parameters. Executing **Dilate** will increase the size of particles. Conversely, executing **Erode** will decrease the size of particles.

Dilate—The effect of digital dilation is to conjoin otherwise separate grains, and to mend broken grains. If the ***Number Pixels Off*** for **Dilate** parameter is set to 1, the dilation process is triggered if even one pixel is off, making dilation more sensitive at a setting of 1. Furthermore, if the **Dilate *Neighborhood Size*** is large, dilation

Neighborhood Size Neighborhood Size setting and a small ***Number Pixels Off*** for **Dilate** setting. Minimum dilation is attained with a small **Dilate *Neighborhood Size*** setting and a large ***Number Pixels Off*** for **Dilate** setting.

Erode—The effect of digital erosion is to separate grains which otherwise touch or conjoin one another. If the ***Number Pixels Off*** for **Erode** parameter is set to **1**, the erosion process is triggered if even one pixel is off, making erosion more sensitive at a setting of **1**. Furthermore, if the ***Erode Neighborhood Size*** is large, erosion is applied to larger areas of the image. Therefore, maximum erosion is obtained with a large ***Erode Neighborhood Size*** setting and a small ***Number Pixels Off*** for **Erode** setting. Minimum erosion is attained with a small **Erode *Neighborhood Size*** setting and a large ***Number Pixels Off*** for **Erode** setting.

Particle Analysis Procedure

The ***Particle Analysis*** command is designed to detect and measure the lateral and vertical dimensions of isolated particles on the sample surfaces. The procedure for using ***Particle Analysis*** is as follows:

1. Open an image in NanoScope Analysis.
2. Select **Analysis** > **Particle Analysis** from the ***Menu*** bar or click on the **Particle Analysis** icon from the ***Icon*** toolbar. The file opens in the ***Particle Analysis*** window with the **Detect** tab showing.

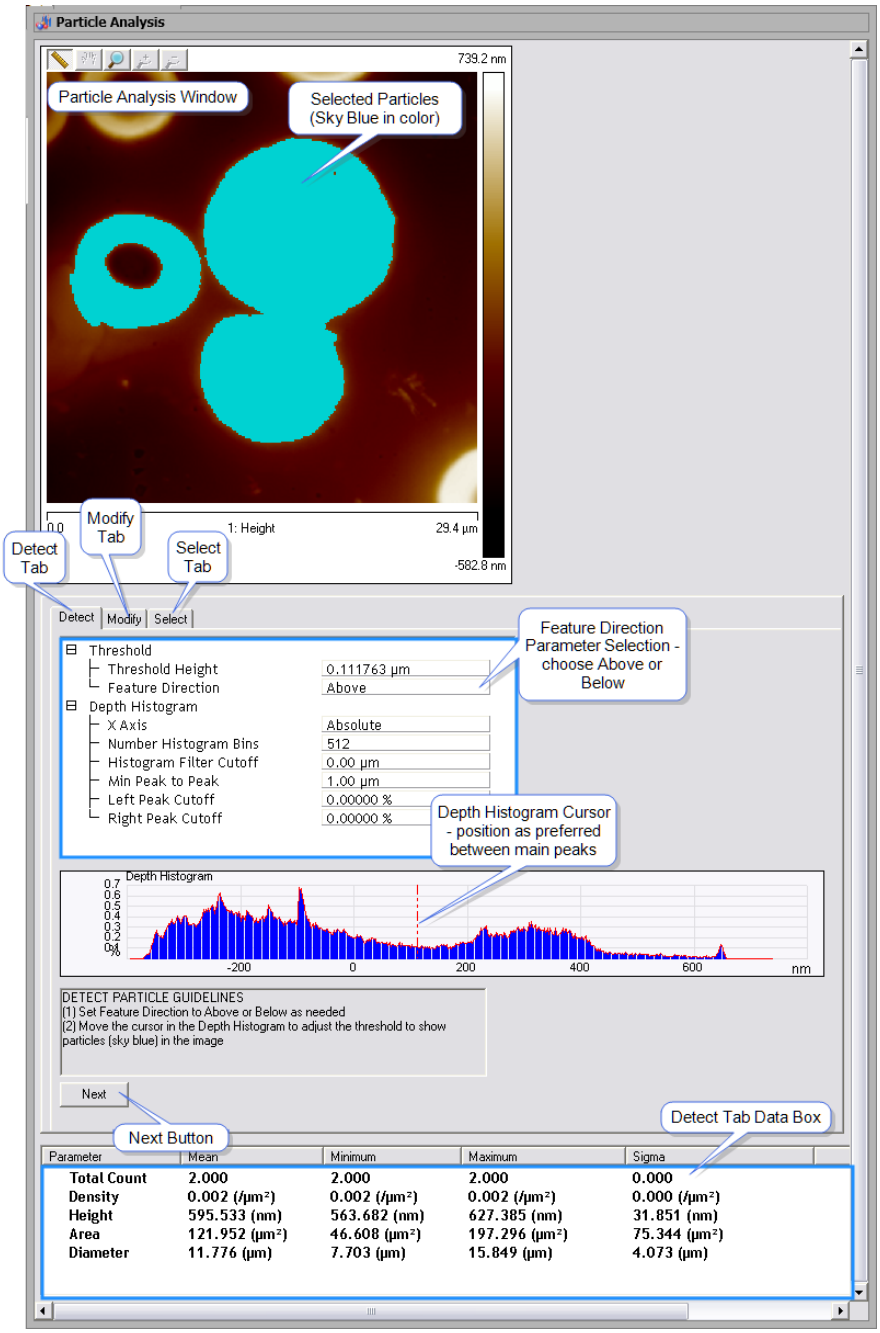


Figure 5.7b: Particle Analysis Menu & Window

3. Choose **Above** or **Below** from the ***Feature Direction*** parameter in the ***Detect*** tab. If the interested features are above the surface, choose **Above**. If they are below the surface, for example pits, choose **Below**.
4. Adjust the threshold by moving the red vertical cursor in the ***Depth Histogram*** to the preferred location (usually between the two most defined peaks). The particles (features of interest) will turn to sky blue in the ***Particle Analysis*** window. Data for the selected particles is captured at the bottom of the window in the ***Detect*** tab ***Data Box***.

5. When satisfied with the particles selected in the ***Particle Analysis*** window, click the **Next** button at the bottom of the ***Detect*** tab. NanoScope Analysis opens the ***Modify*** tab.

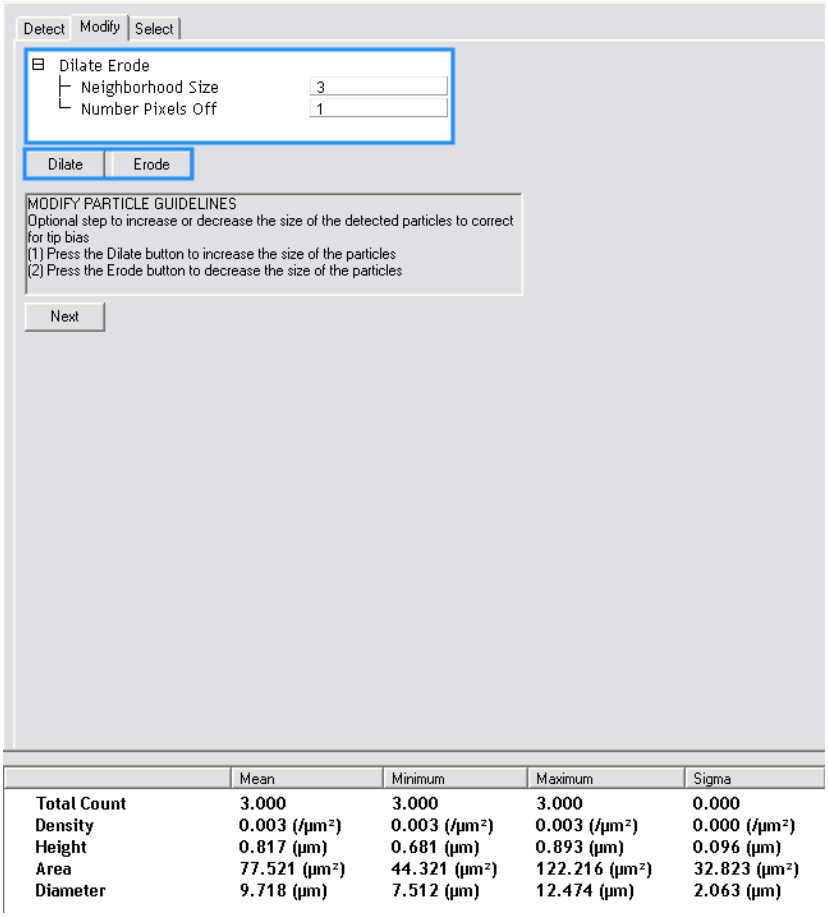


Figure 5.7c: ***Modify*** Tab

6. Adjust the **Erode** and **Dilate** parameters as preferred. For details on the Erode and Dilate parameters, please click on the following link: Dilate & Erode. Once completed, click the **Next** button. NanoScope Analysis opens the ***Select*** tab.

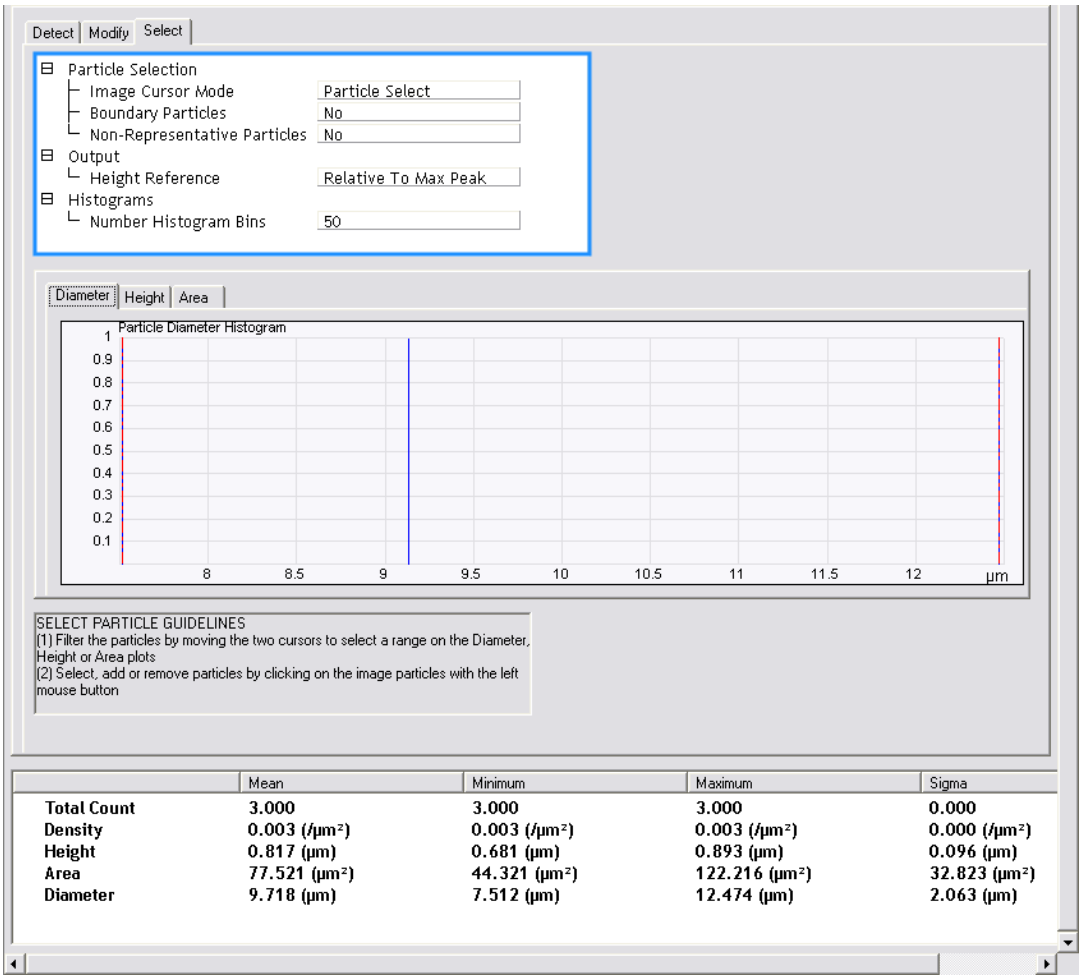


Figure 5.7d: *Select* Tab

7. Modify the Select tab parameters to get the desired results. For details on the Select tab parameters, click on the following link Select Tab Parameters. The ***Select*** tab also contains 3 histograms: Diameter, Height, and Area. Each histogram provides a different way to analyze particles. Slide the cursor laterally along the bottom of each histogram to highlight each particle plotted. The corresponding data for each particle is displayed in the Data Box at the bottom of the window.

Particle Analysis Interface

Parameter	Description
Threshold:	
Threshold Height	Sets the threshold height. Unlike the slider cursor, this parameter allows for precise pinpointing of threshold values.
Feature Direction	Select **Above** or **Below**, depending if particles are in high or low-lying (e.g. pits) areas of the image.
Depth	

Parameter	Description
Histogram :	
X Axis	Choose **Relative** (to highest) or **Absolute**.
Number of Histogram Bins	The number of data points which result from the filtering calculation. **NOTE:** Note: Having more histogram bins than pixels is unnecessary.
Histogram Filter Cutoff	Lowpass filter which smoothes out the wavelengths that lie below the cutoff in the depth correlation histogram. Used to reduce noise in the Correlation histogram.
Min 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. Note: At 0%, only the maximum point on the curve is included. At 25%, only the maximum 25% 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. Note: At 0%, only the maximum point on the curve is included. At 25%, only the maximum 25% of the peak is included in the calculation of the centroid.

Table: 5.0n *Detect Tab* Parameters

Parameter	Mean	Minimum	Maximum	Sigma
Total Count	Average count of particles in data set	Minimum count of particles in data set	Maximum count of particles in data set	Standard deviation of total count of particles in data set
Density	Average density of all particles in data set	Minimum density of all particles in data set	Maximum density of all particles in data set	Standard deviation of density of all particles in data set
Height	Average height of all particles in data set relative to the ***Threshold Height***.	Minimum height of all particles in data set relative to the ***Threshold Height***.	Maximum height of all particles in data set relative to the ***Threshold Height***.	Standard deviation of height of all particles in data set relative to the ***Threshold Height***.
Area	Average area of all particles in data set	Minimum area of all particles in data set	Maximum area of all particles in data set	Standard deviation of area of all particles in data set
Diameter	Average diameter of all particles in data set	Minimum diameter of all particles in data set	Maximum diameter of all particles in data set	Standard deviation of diameter of all particles in data set

Table: 5.0o *Detect Tab* Data Box

Parameter	Description
Dilate *Erode*:	
Neighborhood Size	N x N square pixel matrix used to Dilate/Erode an image where N equals the Neighborhood Size. For example, a Dilate/Erode Neighborhood Size of 3 uses a 3 x 3 matrix to evaluate local erosion in the image.
Number Pixels Off	Number of "Off" pixels required in a square matrix of Dilate/Erode Neighborhood Size to apply to Dilation/Erosion.

Table: 5.0p *Modify Tab* - Dilate & Erode Parameters

Parameter	Description
Particle Selection:	
Image Cursor Mode	Choose Particle Select, Particle Remove or Particle Accumulate.
Boundary Particles	*Settings:* • **Yes**— includes particles along the boundary of the cursor box. • **No**— includes only those grains which fall entirely within the boundary of the cursor box.
Non-Representative Particles	*Settings:* • **Yes**—everything above the Threshold Height is included • **No**—filters out particles whose area is less than the average area minus 3 sigma of that area.
Output:	
Height Reference	Choose **Relative to Threshold** or **Relative to Max Peak**.
Histograms:	
Number of Histograms	The number of data points which result from the filtering calculation. **NOTE:** Note: Having more histogram bins than pixels is unnecessary.

Table: 5.0q *Select Tab* Parameters

Patterned Sample Analysis Results

If you have previously run Patterned Sample Analysis (page 98), the ***TopResult*** is used as an ***Input*** to ***Particle Analysis*** and the ***PSA Top Width***, shown in Figure 5.7e, is computed.

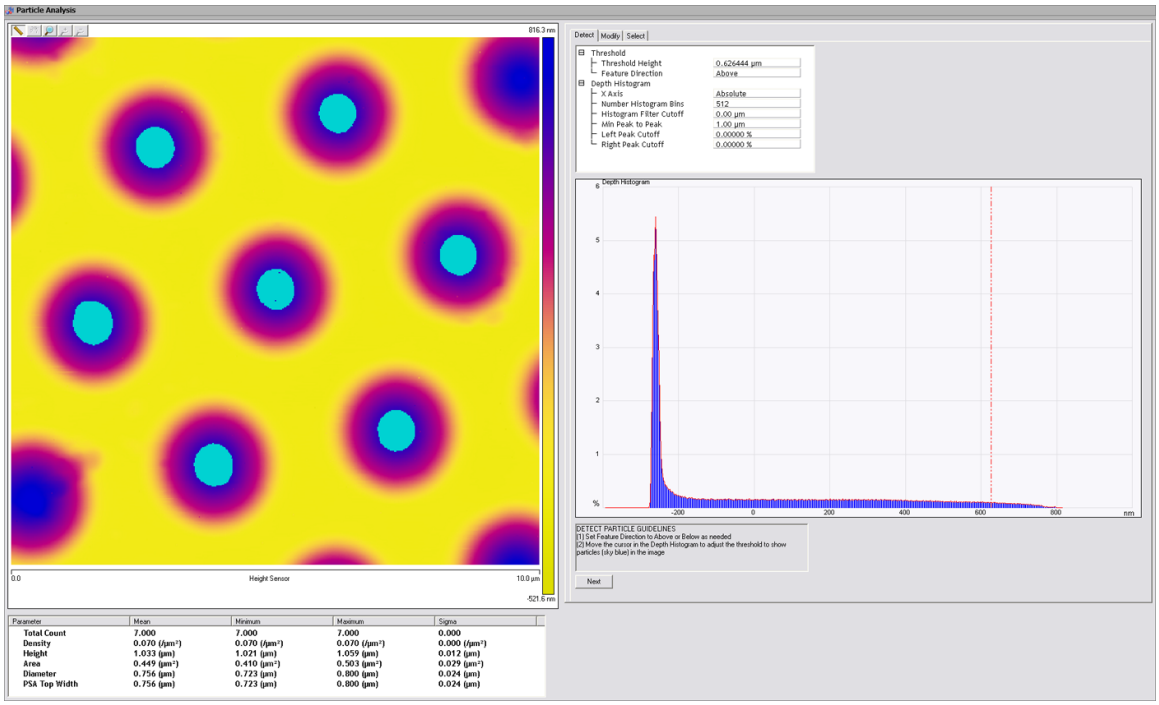


Figure 5.7e: *Particle Analysis* window with PSA input

5.8 Patterned Sample Analysis

Patterned Sample Analysis is an optional NanoScope Analysis feature that allows you to characterize regularly patterned samples. Typical samples include image sensors and LED arrays.

Patterned Sample Analysis automatically corrects the tilt of each line and then finds peaks (objects). Partial objects are screened out. Remaining objects are numbered from left to right, bottom to top. The user selects the shape of the base of each object (circular, ellipsoidal or rectangular) and selects locations for angle calculation. The analysis displays the height and location of each found object, maximum base width and top, middle and bottom angles on the left and right sides of each object. Statistics over all found objects are also reported.

Patterned Sample Analysis Procedure

1. Open an image in NanoScope Analysis.
2.  Execute a 1st order Plane Fit (page 192) on the data.

Some samples may require that you exclude the patterned objects and use just the sample base for the plane fit correction calculation. Do this by:

3. Set ***Plane Fit Mode*** to **XY**.
4. Set ***Plane Fit Order*** to **1st**.
5. Set ***Plane Fit Z Thresholding Direction*** to **Use Z <** .
6. Set ***Plane Fit Z Threshold Percent.*** to exclude the patterned objects. Excluded data will be shown in blue.

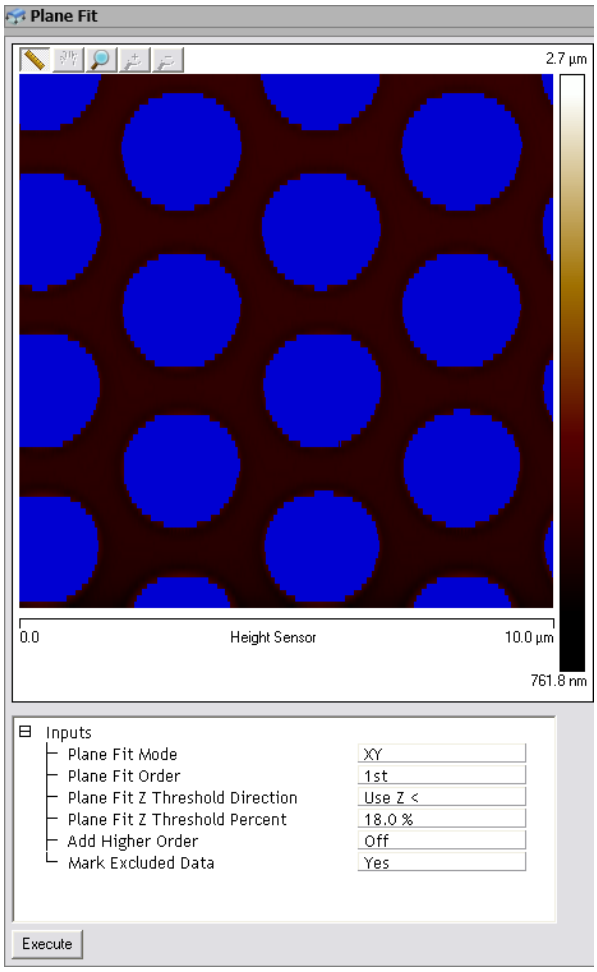


Figure 5.8a: Plane Fit to PSA Example. ***Plane Fit Z Threshold Percent.*** was set to 18%

7. Click **Execute**.
8. Select **Analysis** > **Patterned Sample Analysis** from the ***Menu*** bar or click the **Patterned Sample Analysis** icon in the NanoScope Analysis toolbar. The file opens in the ***Patterned Sample Analysis*** window.
9. Select a ***Feature Type*** in the ***Inputs*** panel, shown in Figure 5.8d. Available inputs are **Ellipse**, **Rectangle**, **Sphere** and **Cone**.
    - Select **Rectangle** for objects that have a rectangular in-plane shape, **Sphere** for objects that have a circular in-plane shape, **Ellipse** for objects that have an elliptical in-plane shape and **Cone** for objects with a circular in-plane shape and a conical (but with an essentially flat top) X-Z and/or Y-Z cross-section. Figure 5.8b displays a **3D Image** of a sample suitable for the **Cone** option while Figure 5.8c displays a **3D Image** of a sample suitable for the **Sphere** option.

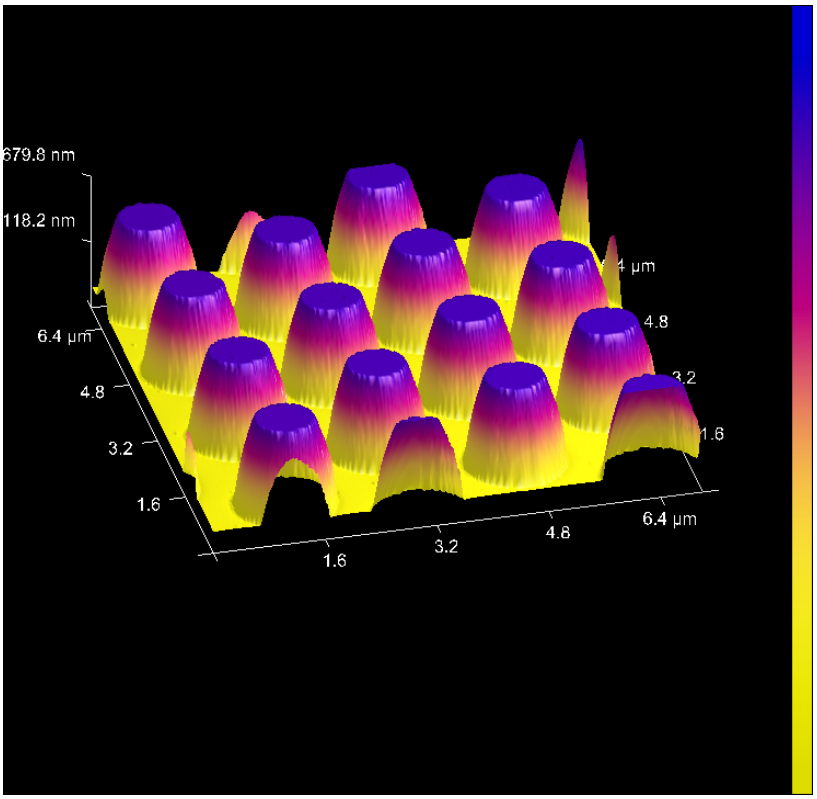


Figure 5.8b: 3D Image of typical **Cone** objects

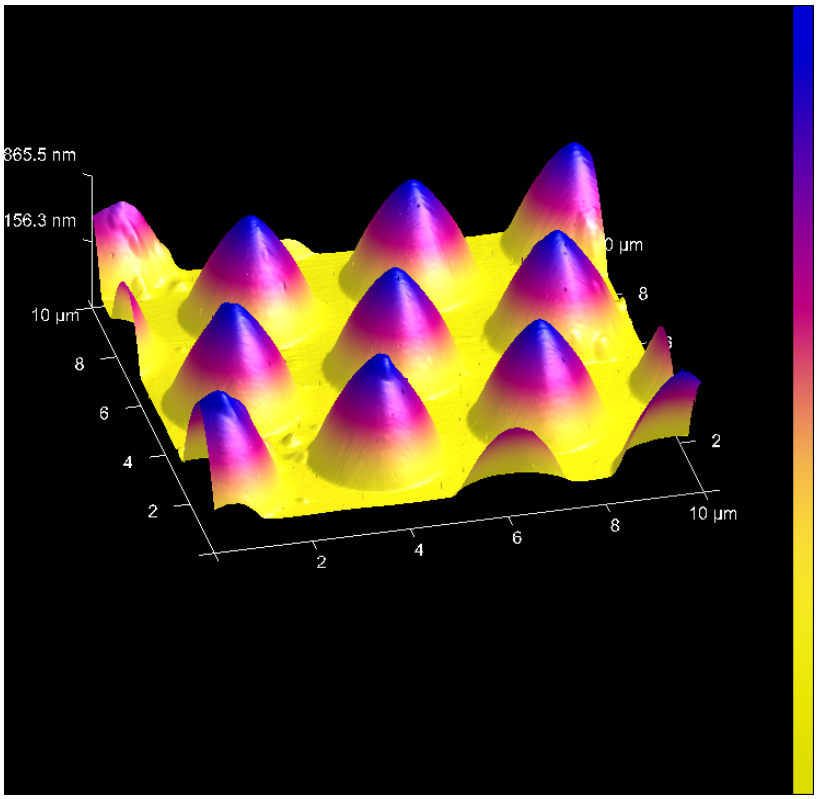


Figure 5.8c: 3D Image of a sample suitable for the **Sphere** option.

10. Define locations for the angle measurements in the ***Inputs*** panel, shown in Figure 5.8d.

Inputs	
Feature Type	Sphere
Top Angle Location	25.0000 %
Top Angle Bandwidth	20.0000 %
Middle Angle Bandwidth	20.0000 %
Bottom Angle Location	25.0000 %
Bottom Angle Bandwidth	20.0000 %
Height Screen	20.0000 %
Top Height	10.0000 %
Bottom Height	0.00000 %
Tip Width	0.00000 µm

Figure 5.8d: *Inputs* for Patterned Sample Analysis

Definitions of geometrical parameters that are used to compute the ***Results*** are shown in Figure 5.8e and described in Table: 5.0r.

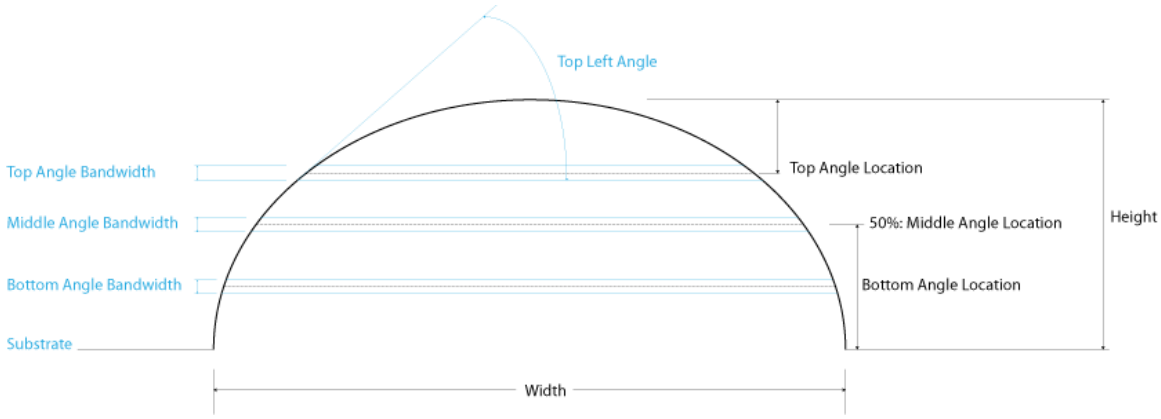


Figure 5.8e: *Inputs* description

11. Define a ***Height Screen*** and ***Top Height***. See Table: 5.0r for definitions.

Input	Description
Feature Type	*Settings:* • Ellipse • Rectangle • Sphere • Cone
Top Angle Location	Defined as a percentage of the Height down from the peak.
Top Angle Bandwidth	The width, defined as a percentage of the peak, of the height used for computation of the ***Top Angles***.
Middle Angle Bandwidth	The width, defined as a percentage of the peak, of the height used for computation of the ***Middle Angles***.
Bottom Angle Location	Defined as a percentage of the Height up from the substrate.
Bottom Angle Bandwidth	The width, defined as a percentage of the peak, of the height used for computation of the ***Bottom Angles***.
Height Screen	Excludes objects if they are lower by ***Height Screen*** % of maximum height.
Top Height	The ***Top Height*** input is a percentage of the Height down from the peak and is used to calculate the Top Width (shown as ***Top*** in the Results table).
Bottom Height	The ***Bottom Height*** input is a percentage of the Height up from the substrate.
Tip Width	User input that is subtracted from the Width results.

Table: 5.0r *Inputs* description

NOTE: The ***Middle Location*** is defined as the mid-point (50%) between the substrate and object peak.

NOTE: A line that connects the edge at the bottom point of the ***Bandwidth*** to the top point of the ***Bandwidth*** defines the angle with respect to horizontal at that location.

12. The peak locations and angle calculations are computed whenever an ***Input*** parameter is changed.

NOTE: The computation time is approximately proportional to the number of pixels in the image.

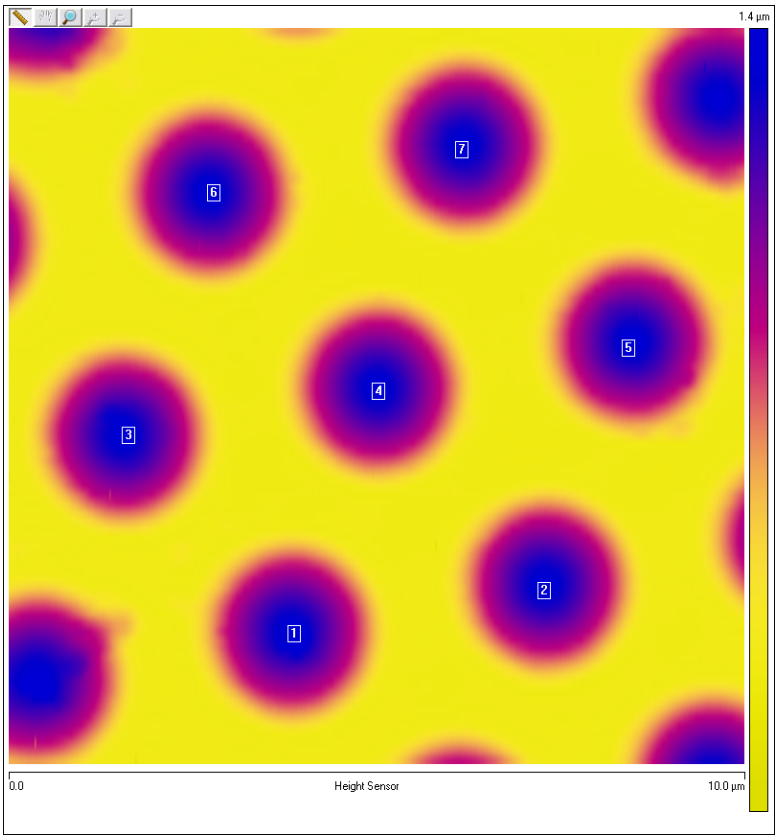


Figure 5.8f: Patterned Sample Analysis image showing found peaks

Result	N	Width (µm)	Height (µm)	X Axis (µm)	Y Axis (µm)	Z Axis (µm)	RMS Err (µm)	Top Left (°)	Top Right (°)	Middle Left (°)	Middle Right (°)	Bottom Left (°)	Bottom Right (°)	X Center (µm)	Y Center (µm)	Pitch Angle (°)	Pitch (µm)	Bottom (µm)	Top (µm)
PSA	1	2.891	1.099	1.439	1.439	1.439	0.157	34.489	34.926	38.137	41.020	47.657	49.033	3.858	1.839	10.405	3.455	-0.272	0.717
PSA	2	2.793	1.103	1.431	1.431	1.431	0.139	28.502	28.213	40.464	39.194	46.130	48.872	7.256	2.463			-0.316	0.677
PSA	3	2.871	1.062	1.449	1.449	1.449	0.158	35.358	31.531	42.538	42.539	47.602	49.113	1.618	4.496	10.760	3.458	-0.276	0.680
PSA	4	2.910	1.073	1.451	1.451	1.451	0.145	35.066	34.882	42.074	41.614	47.951	49.988	5.015	5.142	9.692	3.449	-0.271	0.695
PSA	5	3.047	1.080	1.456	1.456	1.456	0.160	35.584	34.713	42.148	42.574	46.632	49.919	8.415	5.722			-0.280	0.692
PSA	6	2.949	1.074	1.467	1.467	1.467	0.159	35.142	35.312	42.386	41.766	47.543	49.481	2.768	7.821	10.099	3.444	-0.287	0.679
PSA	7	2.871	1.069	1.436	1.436	1.436	0.136	35.030	34.226	42.112	41.194	47.896	49.386	6.158	8.425			-0.270	0.692
Avg	0	2.905	1.080	1.447	1.447	1.447	0.151	34.167	33.400	41.408	41.414	47.344	49.399			10.239	3.452	-0.282	0.690
Min	-1	2.793	1.062	1.431	1.431	1.431	0.136	28.502	28.213	38.137	39.194	46.130	48.872			9.692	3.444	-0.316	0.677
Max	-2	3.047	1.103	1.467	1.467	1.467	0.160	35.584	35.312	42.538	42.574	47.951	49.988			10.760	3.458	-0.270	0.717
Range	-3	0.254	0.040	0.036	0.036	0.036	0.025	7.082	7.098	4.400	3.380	1.821	1.115			1.067	0.014	0.045	0.040
StDev	-4	0.079	0.015	0.013	0.013	0.013	0.010	2.521	2.613	1.597	1.148	0.690	0.431			0.393	0.005	0.016	0.013

Figure 5.8g: Patterned Sample Analysis Results table

Patterned Sample Analysis Results

Patterned Sample Analysis results from the image shown in Figure 5.8f are shown in Figure 5.8g.

Result	Description
N	The number of the found peak, shown in Figure 5.8f.
Width (µm)	The width at the base of that peak.
Height (µm)	The height of the peak.
X Axis (µm)	Diameter of the elliptical or spherical fit in the X direction.
Y Axis (µm)	Diameter of the elliptical or spherical fit in the Y direction.
Z Axis (µm)	Diameter of the elliptical or spherical fit in the Z direction.
RMS Err (µm)	RMS error between the measured surface and the fit.
Top Left (°)	Angle, in degrees, at the Top Left of the peak.
Top Right (°)	Angle, in degrees, at the Top Right of the peak.
Middle Left (°)	Angle, in degrees, at the Middle Left of the peak.
Middle Right (°)	Angle, in degrees, at the Middle Right of the peak.
Bottom Left (°)	Angle, in degrees, at the Bottom Left of the peak.
Bottom Right (°)	Angle, in degrees, at the Bottom Right of the peak.
X Center (µm)	The X location of the peak.
Y Center (µm)	The Y location of the peak.
Pitch Angle (°)	The angle, with respect to horizontal (X axis) of the peaks.
Pitch (µm)	The pitch of the peaks along the line that is closest to 0 degrees.
Bottom (µm)	The mean baseline Z value.
Top (µm)	The maximum Z value.

Table: 5.0s Patterned Sample Analysis Results description

Some Patterned Sample Analysis results, e.g. ***Bottom*** and ***Top***, are used in subsequent Bearing Analysis (page 73), Particle Analysis (page 90) and Roughness (page 112) Analysis.

5.9 Power Spectral Density (PSD)

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.

PSD and Surface Features

The synthetic surface represented in 5.9 consists of essentially two dominant wave forms: a long period waveform along the X-axis, and a shorter period waveform along the Y-axis.

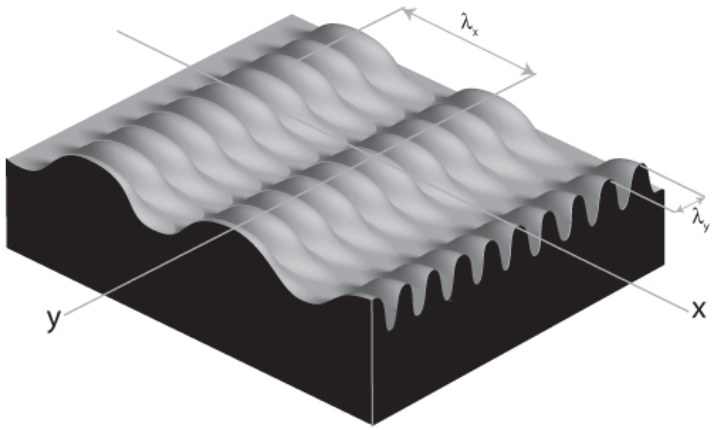


Figure 5.9a: Wavelength Depiction

A 2-dimensional power spectral density plot of this surface would consist 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.

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.

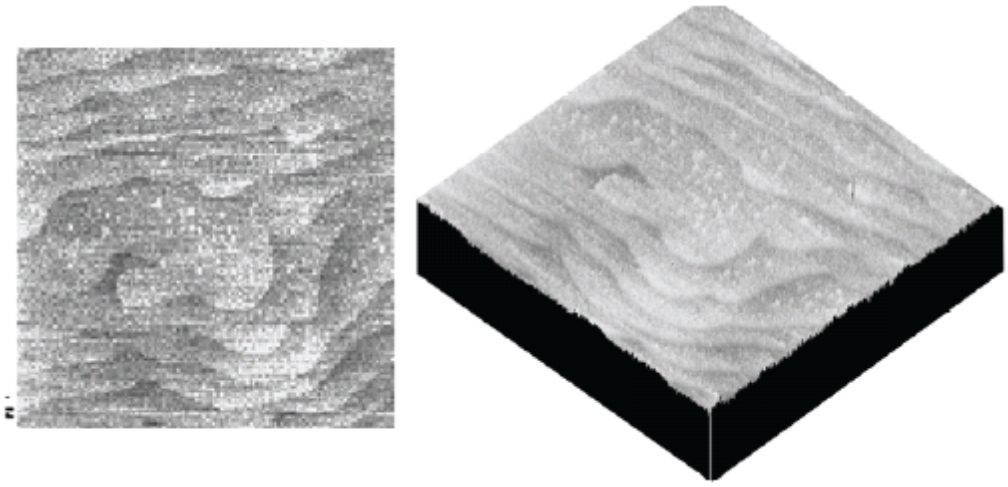


Figure 5.9b: Epitaxial Gallium Arsenide

This surface above 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.

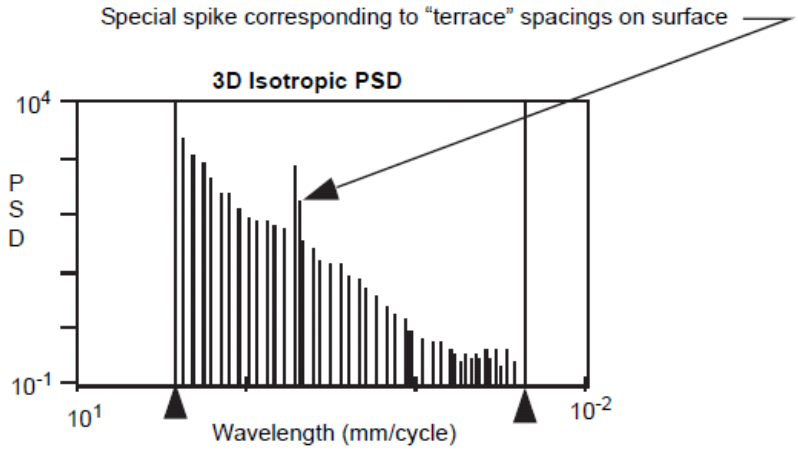


Figure 5.9c: PSD Analysis of Epitaxial Gallium Arsenide

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.

PSD Algorithm

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:

$$PSD(f) = \frac{2d_o}{N}\left|\sum_{n=1}^{N} e^{\frac{i\,2\pi}{N}(n-1)(m-1)} z(n)\right|^2 \qquad \text{for } f = \frac{m-1}{Nd_o}$$

Where frequencies, f, range from 1/L to (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.

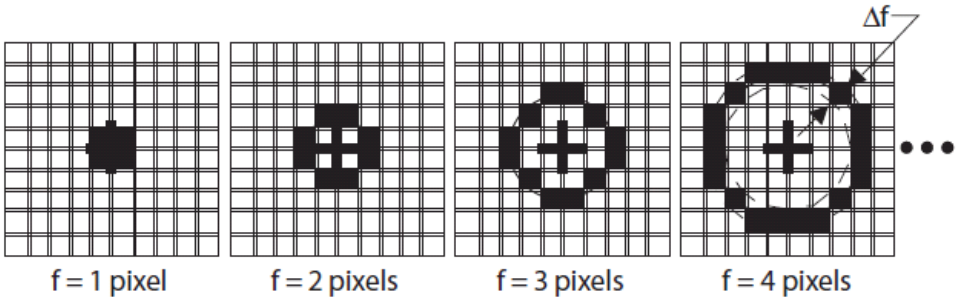


Figure 5.9d: Progressive Data Sampling

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 (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.

Power Spectral Density Procedure

1. Select an image file from the ***Browse*** window at the right of the main window. Double click the thumbnail image to select and open the image.
2. Open the ***PSD*** analysis by selecting Analysis > PSD from the ***Menu*** bar or by clicking on the PSD icon in the ***Icon*** toolbar. The ***PSD*** window, shown in Figure 5.9e, opens to allow ***PSD*** plotting.

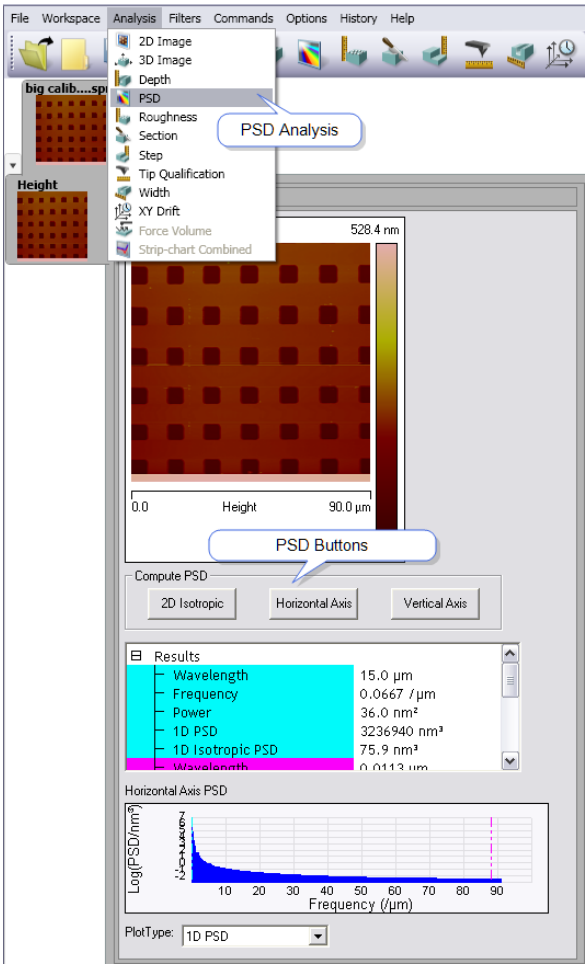


Figure 5.9e: PSD Menu & Window

PSD Interface

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 ***PSD*** analysis.
- Horizontal Axis—Executes a one-dimensional ***PSD*** analysis along the X-axis.
- Vertical Axis—Executes a one-dimensional ***PSD*** 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.

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 un-checking the appropriate boxes.

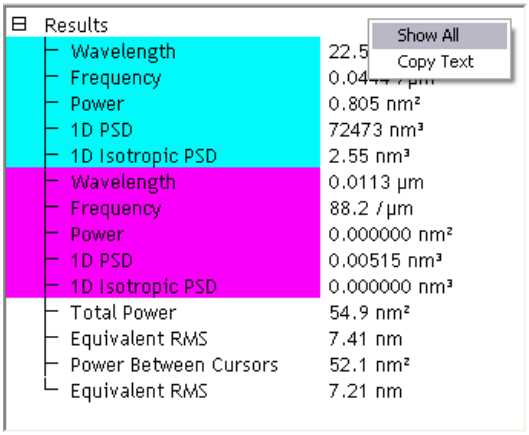


Figure 5.9f: PSD Results Window

Parameter	Description
Wavelength	The wavelength at current cursor positions. See λ_x and λ_y in the Figure: Wavelength Depiction
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 measured in nm^2; P/(Δf)
1D Isotropic PSD	One-dimensional isotropic power spectral density measured in nm^2; P/(2πf)
2D Isotropic PSD	Two-dimensional isotropic power spectral density measured in nm^4; P/2πf(Δf)
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 contained by the frequencies between the cursors. It is calculated as the square root of the integral of the power between the cursors.

Table: 5.0t PSD Parameters

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.

Changing Parameters of the Spectrum Plot

The ***Spectrum Plot*** window displays results of the ***PSD*** analysis. The window has two cursors whose color corresponds to the shaded areas in the ***Results*** window. Move either of the 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. Both cursors can be moved 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.

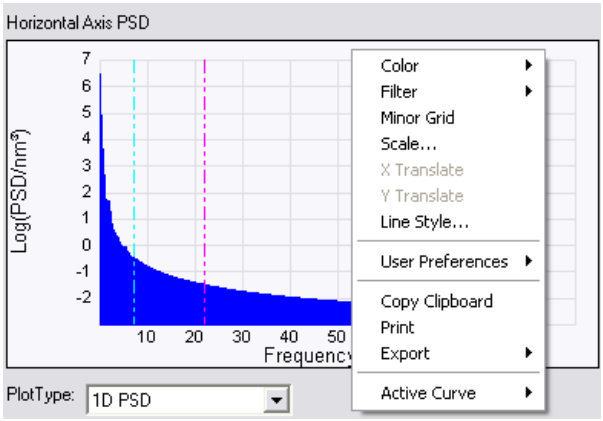


Figure 5.9g: Spectrum Plot Window, Right-click to Change Parameters

5.10  Roughness

The ***Roughness*** command generates a variety of statistics of 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 stop bands (excluding features).

Most industrial standards for roughness measurement call for ***Plane fitting*** data before calculating values. ***Plane fitting*** applies a temporary first-order plane fit before calculating statistics. On many surfaces, especially those which are tilted, this yields different values from those seen in raw (un plane fitted) 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, 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*** or ***Plane fit*** 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.

Roughness Theory

Regarding the effects of ***Plane fitting*** on Roughness statistics—when ***Roughness*** analysis is applied to an image, statistical values are calculated according to the heights of each pixel in the image. ***Plane fitting*** and ***Flattening*** (used to correct images for tilt and bow) reorient these pixels in a manner which can affect roughness statistics dramatically on some surfaces. This is especially true of surfaces having broad, coplanar features. For more information on ***Plane fitting***, see Plane Fit (page 192).

When ***Roughness*** analysis is applied to an image or a portion of an image, the data is automatically plane fit (first order) beforehand. This is done to accord with ASME and ISO metrological standards. (Only the Raw Mean and Mean parameters are exempt from this operation, being calculated from raw data only.) To avoid unexpected results due to plane fitting, 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.

Many ***Roughness*** results are affected by the **OL Plane Fit** parameter that was previously set during image capture. There are three options for this parameter: **None**, **Offset**, and **Full**. The **Full** option automatically subtracts a first order plane in order to make the average value and the average slope zero. The **Offset** option subtracts a constant in order to make the average value of the image zero. The **None** option leaves the data unaltered; thus, the **Mean** equals the **Raw Mean**.

Regarding Basic ***Roughness*** Measurements—***Average Roughness*** (Ra) is one of the most commonly used roughness statistics. Figure 5.10a represents two surfaces having the same average roughness.

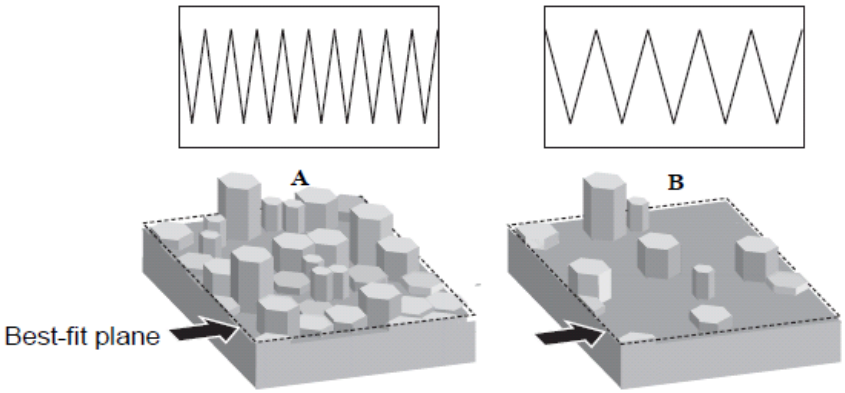


Figure 5.10a: Roughness Depiction

Similarly, a number of other roughness values are based upon least-squares calculations (e.g., RMS roughness, or Rq), 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***.

Roughness Procedure

1. Select an image file from the file ***Browse*** window at the right of the main window. Double click the thumbnail image to select and open the image.
2. Open the ***Roughness*** analysis by selecting Analysis > Roughness from the ***Menu*** bar or by clicking on the **Roughness** icon from the ***Icon*** toolbar. The ***Roughness*** view, shown in Figure 5.10b, appears showing the results for the entire image.

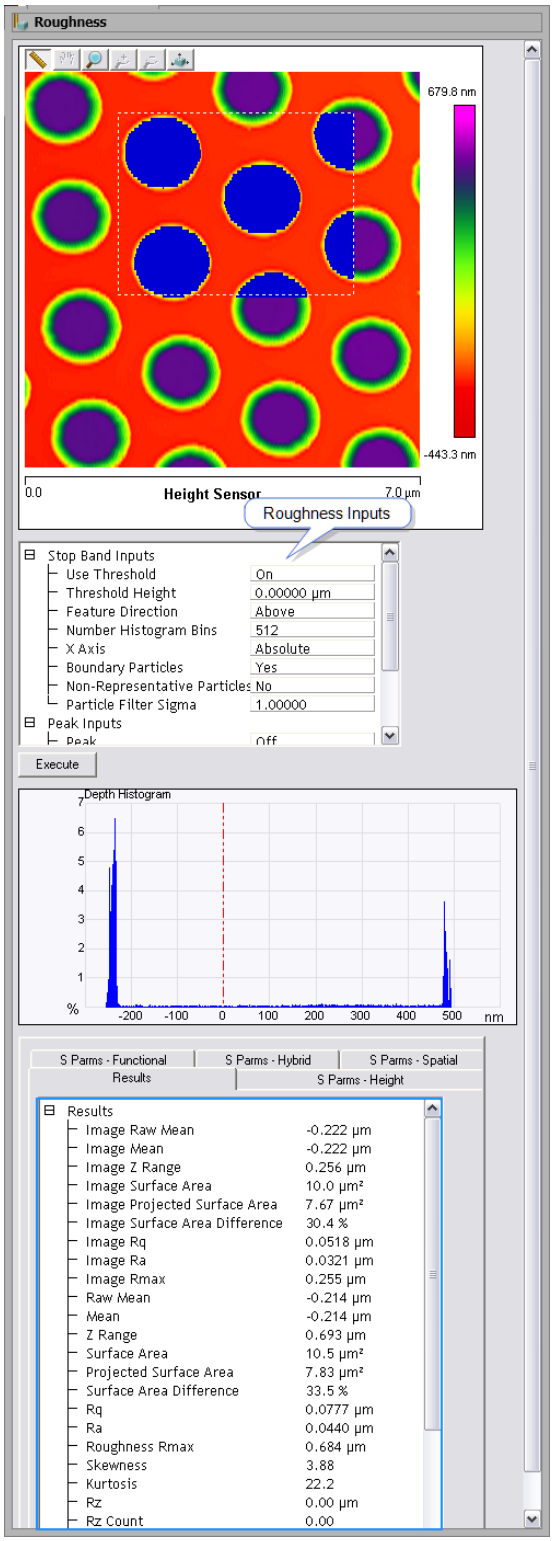


Figure 5.10b: Roughness Analysis Menu & Window

3. 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.
4. 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.
5. To exclude an area not defined by boxes:
    - Set ***Use Threshold*** to **On**.
    - Set the ***Feature Direction*** as needed.
    - Move the Depth Histogram cursor to exclude the data you wish to exclude as shown in the image.
6. Click the **Execute** button to calculate the ***Roughness*** outside the box.

Input parameters for roughness are discussed in Roughness Parameters (page 116).

5.10.1 Roughness Parameters

Stop Band Input Parameters

Stop band inputs allow you to exclude parts of the image from Roughness (page 112) Analysis.

Parameter	Description
Use Threshold	Uses the ***Threshold Height*** to exclude data from the analysis. **NOTE:** ***Use Threshold*** is, by default, set to **On** when Patterned Sample Analysis (page 98) has been run.
Threshold Height	Height used for threshold. **NOTE:** Moving the ***Depth Histogram*** cursor will modify the ***Threshold Height***. **NOTE:** When Patterned Sample Analysis (page 98) has been run, the ***Bottom*** result from Patterned Sample Analysis is used for ***Threshold Height***
Feature Direction	Select **Above** or **Below**, depending if features are in high or low-lying (e.g. pits) areas of the image.
Number Histogram Bins	The number of data points which result from the filtering calculation. **NOTE:** Note: Having more histogram bins than pixels is unnecessary.
X Axis	Applies to the ***Depth Histogram*** X axis. *Settings:* • **Absolute**—data remains unchanged. • **Relative**—data is relative to the top point.
Boundary Particles	*Settings:* • **Yes**— includes particles along the boundary of the cursor box. • **No**— includes only those grains which fall entirely within the boundary of the cursor box.
Non-Representative Particles	*Settings:* • **Yes**—everything above the Threshold is included • **No**—filters out small particles based on the ***Particle Filter Sigma***.
Particle Filter Sigma	Large sigma values filter out less while small sigma values filter out more.

Table: 5.0u Stop Band Input Parameters

Peak Input Parameters

There are two important configurations for the input parameters that control the way that Roughness calculate

statistics: ***Peak*** and ***Zero Crossing***.

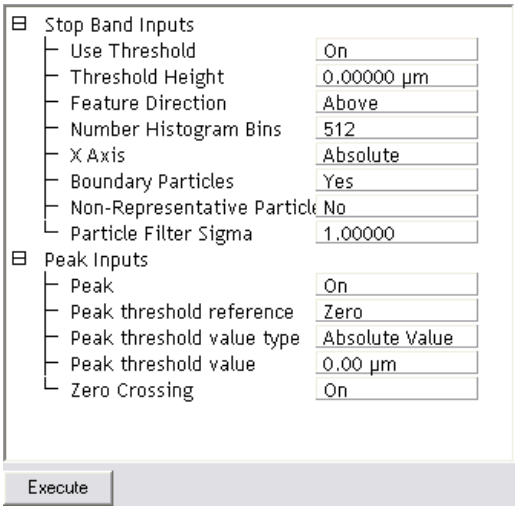


Figure 5.10c: Roughness Inputs

Some parameters are reported only when certain subroutines are turned on.

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:

Command	Definition
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.

Table: 5.0v *Peak* Settings

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.

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. 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.

NOTE: The parameters that begin with "Image" are calculated from the entire image excluding ***Stop Bands*** when the **Execute** button is clicked. The other parameters are only calculated for the region within a **Box** when the **Execute** button is clicked.

Parameter	Description
Image Raw Mean	Mean value of data contained within the whole image, except for stop bands. This is calculated as if the OL Plane fit were set to None during image capture.
Image Mean	Mean value of data contained within the whole image, except for stop bands. This is calculated after the OL Plane fit set during image capture has been applied.

Parameter	Description
Image Z Range	Maximum vertical distance between the highest and lowest data points in the image prior to the planefit.
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 Projected Surface Area	Area of the image rectangle (X x Y).
Image Surface Area Difference	Difference between the image's three-dimensional Surface area and two dimensional projected surface area.
Image Rq	Root mean square average of height deviations taken from the mean image data plane, expressed as: $\sqrt{\frac{\sum Z_i^2}{N}}$
Image Ra	Arithmetic average of the absolute values of the surface height deviations measured from the mean plane. $R_a = \frac{1}{N}\sum_{j=1}^{N} \lvert Z_j \rvert$
Image Rmax	Maximum vertical distance between the highest and lowest data points in the image following the planefit.
Raw Mean	Mean value of image data within the cursor box you define without application of plane fitting. This is calculated as if the OL Planefit were set to None during image capture.
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. This is calculated after the OL Planefit set during image capture has been applied.
Z Range	Peak-to-valley difference in height values within the analyzed region.
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.
Projected Surface Area	Area of the selected data.
Surface Area Difference	Difference between the analyzed region's three-dimensional Surface area and its two-dimensional, footprint area.
Rq	This is the standard deviation of the Z values within the box cursor and is calculated as:

Parameter	Description
	$R_q = \sqrt{\frac{\sum (Z_i)^2}{N}}$ 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.
Ra	Arithmetic average of the absolute values of the surface height deviations measured from the mean plane within the box cursor: $R_a = \frac{1}{N}\sum_{j=1}^{N} \lvert Z_j \rvert$
Rmax	
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, onetailed distribution is suggested, such as a flat plane having a small, sharp spike (> 0), or a small, deep pit (< 0).
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.
Rz	This is the average difference in height between the (R_Z 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.
Peak Count	The number of peaks taller than the Threshold Value.
Valley Count	The number of valleys shorter than the Threshold Value.
Max Peak ht (Rp)	Maximum peak height within the analyzed area with respect to the mean data plane.
Average Max Height (Rpm)	Average distance between the (Peak Count value) highest profile points and the mean data plane.
Maximum Depth (Rv)	Lowest data point in examined region.

Parameter	Description
Average Max Depth (Rvm)	Average distance between the (Valley Count value) lowest profile points and the mean data plane.
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.
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.

Table: 5.0w *Roughness Results*

Patterned Sample Analysis Results

If you have previously run Patterned Sample Analysis (page 98), the ***Bottom Result*** is used as an ***Input***.

S Parameters

S parameters focus on the 3D nature of the surface. Additional information about S parameters can be found in ISO 25178.

S Parameters - Height

Parameter	Description
Sa	Sa is the Average Roughness evaluated over the complete 3D surface: $S_a = \iint_a \lvert Z(x,y)\rvert (dx)dy$
Sku	Sku is the Kurtosis of the 3D surface texture. A histogram of the heights of all measured points is established and the deviation from an ideal Normal distribution is represented by Sku: $S_{ku} = \frac{1}{S_q^4}\iint_a (Z(x,y))^4 (dx)dy$
Sp	Sp, the Maximum Peak Height, is the height of the highest point.
Sq	Sq is the Root Mean Square roughness evaluated over the complete 3D surface: $S_q = \iint_a (Z(x,y))^2 (dx)dy$

Parameter	Description
Ssk	Ssk is the Skewness of the 3D surface texture. A histogram of the heights of all measured points is established and the deviation from an ideal Normal distribution is represented by Ssk: $Ssk = \frac{1}{S_q^3}\int_a\int (Z(x,y))^3(dx)dy$
Sv	Sv, the Maximum Valley Depth, is the depth of the lowest point.
Sz	Sz, the Maximum Height of the Surface; Sz = Sp - Sv.

S Parameters - Functional

Parameter	Description
Sbi	Sbi, is the Surface Bearing Index: $Sbi = \frac{Sq}{TrueHeight(0.05)}$
Sci	Sci, is the Core Fluid Retention Index: $Sci = \left(\frac{V_v(h_{0.05}) - V_v(h_{0.8})}{A}\right)/(Sq)$
Svi	Svi, is the Valley Fluid Retention Index: $Svi = \left(\frac{V_v(h_{0.8})}{A}\right)/(Sq)$
Sm	Sm is the Surface Material Volume – Volume from top to 10% bearing area: $Sm = \left(\frac{V_m(h_{0.10})}{A}\right)$
Sc	Sc is the Core Void Volume – Volume enclosed: $Sc = \left(\frac{V_v(h_{0.10}) - V_v(h_{0.80})}{A}\right)$
Vv	Sv is the Surface Void Volume – Volume from 80% to 100% bearing area: $Sv = \left(\frac{V_v(h_{0.80}) - V_v(h_{1.00})}{A}\right)$

S Parameters - Hybrid

Parameter	Description
Sdq	Sdq, the Root Mean Square Surface Slope comprising the surface, evaluated over all directions: $Sdq = \sqrt{\frac{1}{A}\int_0^{LxLy}\int \left(\left(\frac{\partial}{\partial x}Z(x,y)\right)^2 + \left(\frac{\partial}{\partial y}Z(x,y)\right)^2\right)dydx}$
Sdr	Sdr, the Developed Interfacial Area Ratio, is expressed as the percentage of additional surface area contributed by the texture as compared to an ideal plane the size of the measurement region:

Parameter	Description
	$Sdr = \frac{(TextureSurfaceArea - CrossSectionalArea)}{CrossSectionalArea}$
Sds	Sds, the Density of Summits, is the number of summits per unit area. Summits are derived from peaks. A peak is defined as any point, above all 8 nearest neighbors. Summits are constrained to be separated by at least 1% of the minimum "X" or "Y" dimension comprising the 3D measurement area. Additionally, summits are only found above a threshold that is 5% of Sz above the mean plane. $Sds = \frac{NumberOfPeaks}{Area}$
Ssc	Ssc is the Mean Summit Curvature for the various peak structures. Ssc is evaluated for each summit and then averaged over the area: $Ssc = \frac{1}{N}\int_{SummitArea}\int \left(\left(\frac{\partial^2}{\partial x^2}Z(x,y)\right)+\left(\frac{\partial^2}{\partial y^2}Z(x,y)\right)\right)(dx)dy$

S Parameters - Spatial

Parameter	Description
Sal	Sal, the Auto-Correlation Length, is a measure of the distance over the surface such that the new location will have minimal correlation with the original location. Sal = Length_Of_Fastest_Decay_Of_Auto_Correlation_Function_To_0.2_In_Any_Direction.
Std	Std, the texture direction, is determined by the Angular Power Spectral Density Function and is a measure of the angular direction of the dominant lay comprising a surface. Std is defined relative to the Y axis.
Std Minor	Std Minor shows the 2nd most conspicuous direction of texture.
Str	Str, the Texture Aspect Ratio, is a measure of the spatial isotropy or directionality of the surface texture.

Previous topic: Roughness (page 112)

5.11  Section

The **Section** command displays a top view image, upon which up to 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

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, it is important to ascertain surface topology before applying the Section analysis. Depending upon the topology and orientation of the sample, the results of Section analysis may vary tremendously.

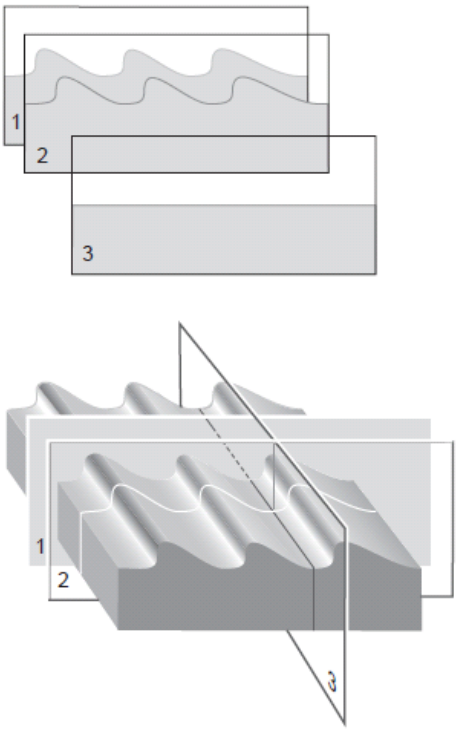


Figure 5.11a: Examples of Section Analysis

The sample surface above (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 Cross Section Plot.

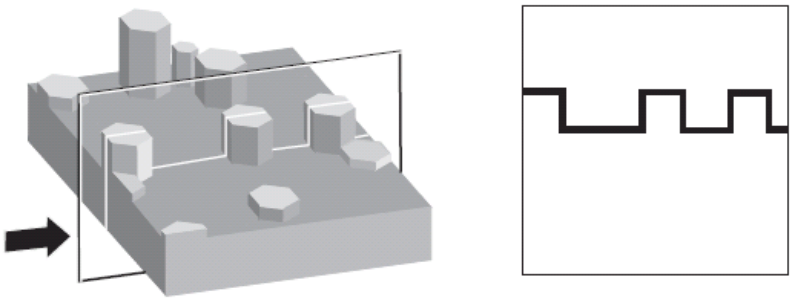


Figure 5.11b: Cross Section Plot Profile

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. See Roughness (page 112) for additional information regarding roughness calculations.

Section Procedures & Interface

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. To remove any tilt which might be present, use the ***Planefit*** modification feature. See Plane Fit (page 192) for more information.

To perform Section analysis:

1. Select an image file from the file Browse window at the right of the main window. Double-click the thumbnail image to select and open the image.
2. Open the Section analysis by selecting **Analysis > Section** from the Menu bar or by clicking on the Section icon in the ***Icn*** toolbar.

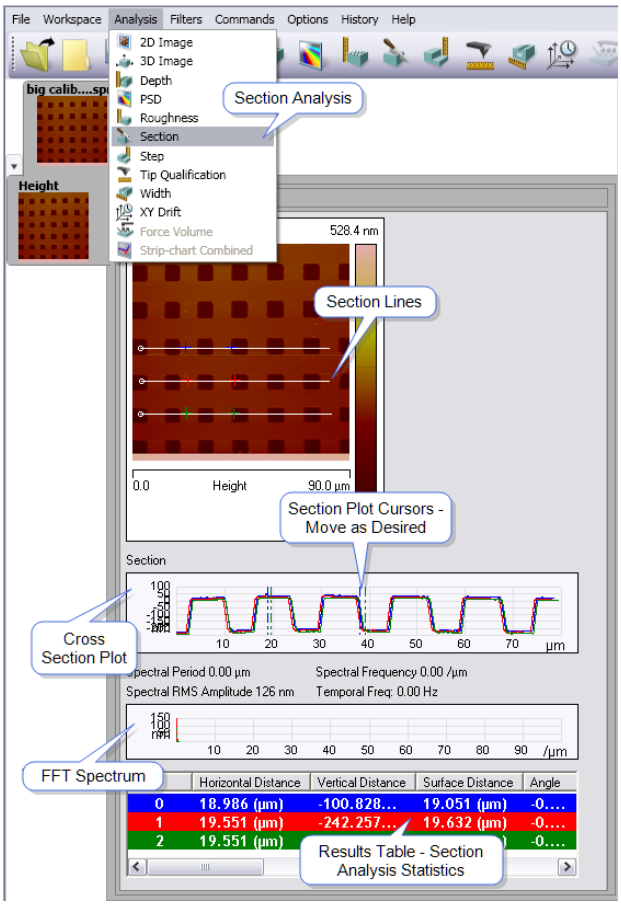


Figure 5.11c: Section Analysis Menu & Window

3. Draw a line across the image by clicking and dragging the cursor.

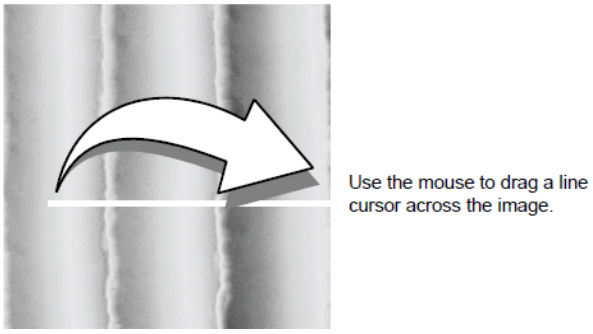


Figure 5.11d: Depiction of Mouse-Line Dragging to Insert Cursor(s)

4. When a line is drawn on the image, the cross section is displayed in the main plot and a FFT spectrum is displayed directly below this.
5. Move the grid cursors left and right along the section by clicking and dragging the plot markers on the section plot.

6. On the plot below the image, a cross section of the topography data is displayed. There are two colored cursors on each section plot which correspond to the markers on the image of similar color. Statistics for the Section analysis are displayed below the plot.
7. Additional lines may be drawn on the image in the same fashion as the first. Up to three Section lines may be drawn on the image at any one time. A ***Section*** line may be moved on the image by clicking and dragging the center of the line. A section line may be deleted by right clicking and selecting "delete."

Section Results

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. Data between the two markers will be displayed in the results window at the bottom of the display screen in blue.

The results columns may be customized to display only information you are interested in by right clicking on the results table.

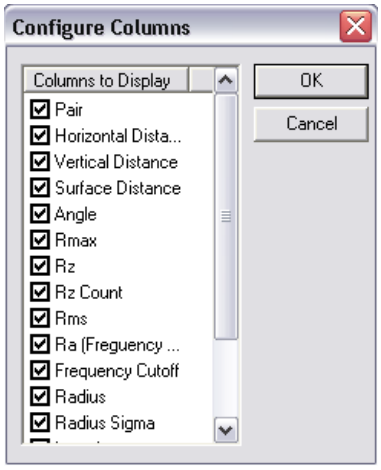


Figure 5.11e: Configure Columns Window - Right-click on Results Table to access

Result	Description
Horizontal Distance	The measured horizontal distance between the two cursors.
Vertical Distance	The measured vertical distance between the two cursors.
Surface Distance	The distance measured along the surface between the two cursors, including change in translation as well as distance traveled over topography.
Angle	Angle of the imaginary line drawn from the first cursor intercept to the second cursor intercept.
R_{max} (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.

Result	Description
R_z (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.
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 Zi is the current Z value, Zave is the average of the Z values between the reference markers, and N is the number of points between the reference markers.
R_z Count	The number of peaks used for the R_z computation.
R_a (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.
Frequency Cutoff (um)	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.
Radius	Radius of circle fitted to the data between the cursors.
Radius Sigma	Mean square error of radius calculation.
Length	Length of the roughness curve.
Spectral Period	Spectral period at the cursor position.
Spectral Frequency	Spectral frequency at the cursor position.
Spectral RMS Amplitude	Amplitude at the cursor position.

Table: 5.0x Section Results Columns

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 and allow you to make the following changes:

Grid Parameter	Description
Color	Allows operator to change the color of the: -Curve -Text -Background -Grid -Minor -Marker
Filter	Typically uses 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 Preference	Restore—Reverts to initial software settings Save—Saves all changes operator has made during this session. This becomes the new default settings.

Grid Parameter	Description
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

Table: 5.0y Grid Parameters

5.12  Step

The ***Step*** analysis 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*** analysis 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).

5.12.1 Step Procedure

1. Select an image file from the file ***Browse*** window at the right of the main window. Double-click the thumbnail image to select and open the image.
2. Open the ***Step*** analysis by selecting Analysis > Step from the ***Menu*** bar or by clicking on the Step icon from the ***Icon*** toolbar. The ***Step*** window appears showing the results for the entire image.
3. To run the ***Step Analysis*** for a region of the image, use the mouse to draw a rotating box in the desired location. The ***Step*** interface includes a captured image and a graph of averaged height within a selected box.
4. By holding down the shift key while dragging the edge of the box, it can be rotated. Rotation is sometimes required when features of interest are not horizontal.
5. In the height graph area below the image, two pairs of cursors (one black and one red) can be moved across this profile to define the steps to be measured. To insert cursors, move the mouse in the height graph to the left of the Y axis. The cursor will change to a double-headed arrow. Using the left mouse button, drag the double-headed arrow to the desired step location. This can be repeated for a second cursor. The region between each pair of cursors defines a “step.” The marker position is shown below the height graph.
6. Once the two pairs of cursors are added to the height graph, the system will report the vertical distance between the average heights of the two steps in the Results area.

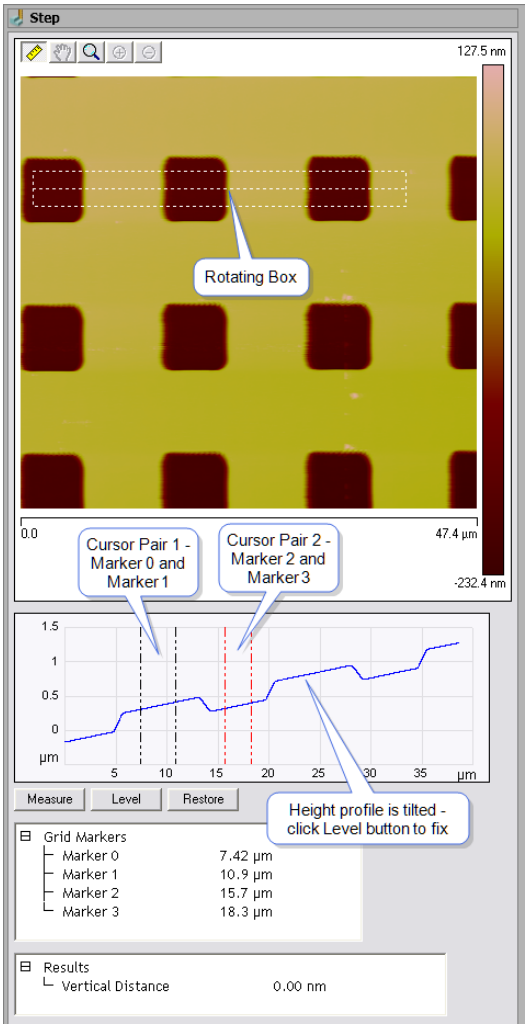


Figure 5.12a: Step Analysis Unleveled

7. If the profile is tilted, click on the Level button and, using the cursors, select two steps that should have the same height. The slope of the profile changes to level the two steps.

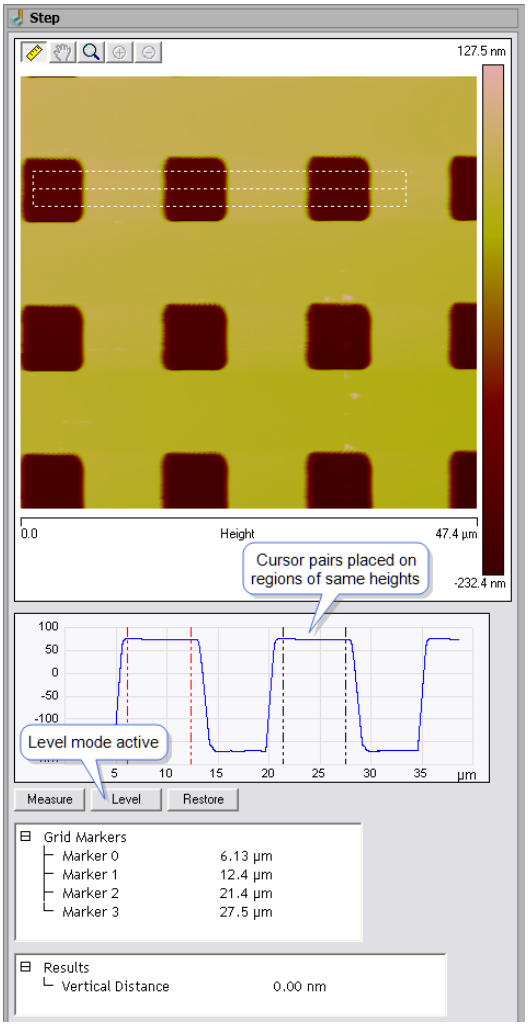


Figure 5.12b: Step Analysis Leveled

8. To measure the vertical distance between the leveled steps, click on the Measure button again and readjust the cursors to compare the preferred steps.

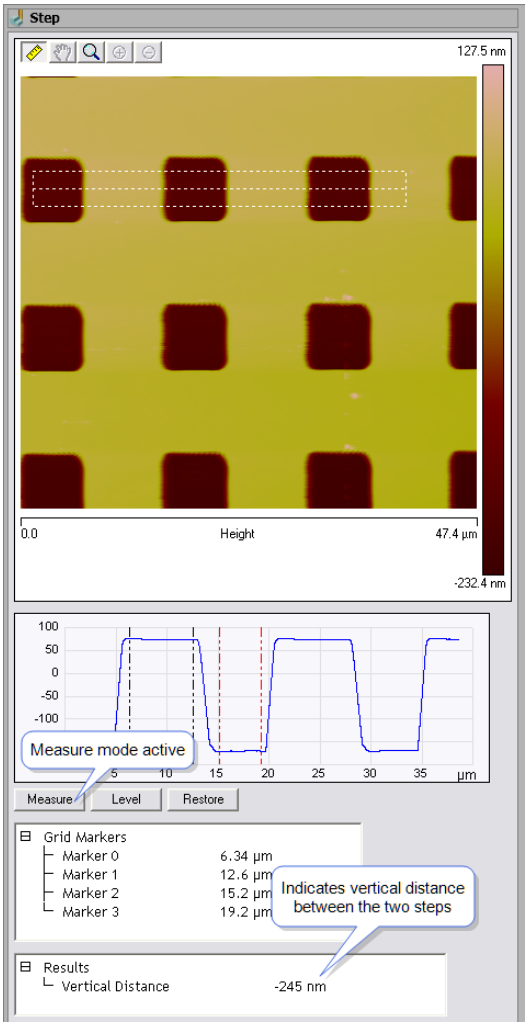


Figure 5.12c: Step Analysis in Measure Mode

5.12.2 Step Display Menu Commands & Results

Parameter	Description
Measure	Displays the relative height between steps
Level	Re-orients the profile so that the average height of each step region (between cursor pairs) is equal
Restore	Returns the profile to its original, unleveled form (De-selects the Level option)
Step Results:	
Vertical Distance	Displays the distance 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 firsts's, this will be a negative value.

5.13  Tip Qualification

Tip Qualification refers to estimating tip shape from appropriate *characterizer* samples and rating tips as good, worn, bad, suspect, or no tip. The ***Tip Qualification*** function incorporates the two separate capabilities: ***Tip Estimation*** and ***Tip Qualification***.

Tip Estimation

Tip Estimation generates a model of the tip based on an image of a standard *characterizer* sample. A *characterizer* refers to a sample whose surface is well suited to deducing tip condition when imaged using an SPM probe.

In ***Tip Estimation***, local peaks in a topographic image are successively analyzed, refining a 3-dimensional tip model. At each peak, the slope away from the peak in all directions is measured, determining the minimum tip sharpness (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.

Tip Qualification

Tip Qualification uses the tip estimate to determine whether the tip is acceptable for use. This feature can be used to check tips periodically for signs of wear, and to exchange unacceptably worn tips. By using tip qualification to enforce tip acceptance criteria, metrological values can be compared from image to image, ensuring consistent, long-term comparability of samples.

Theoretical Foundation for 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.) Therefore, select a tip sharp enough to resolve the features of interest.

Tip Artifacts

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.

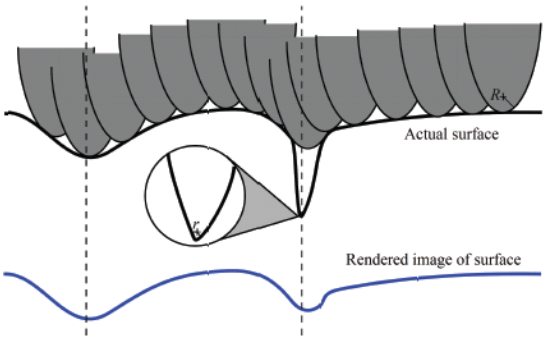


Figure 5.13a: Tip Artifact Depiction

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.

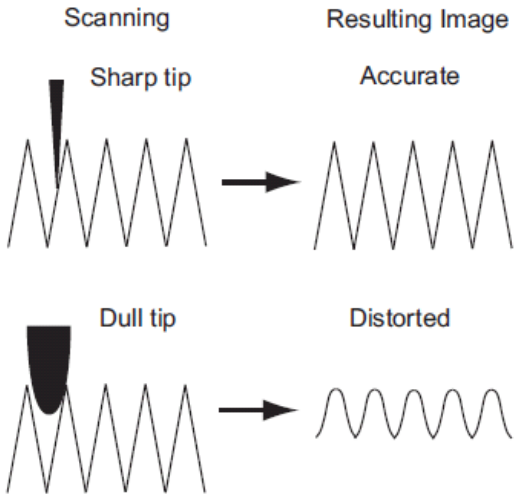


Figure 5.13b: Effects of Tip Sharpness

Sample Dependence of Tip Qualification

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*.

Characterizer samples that provide the most accurate estimate of tip size and shape are those with many fine protrusions, since they typically have very sharp features. Even these samples are not perfect, and only a surface with infinitely sharp features can produce an perfectly accurate model of the tip:

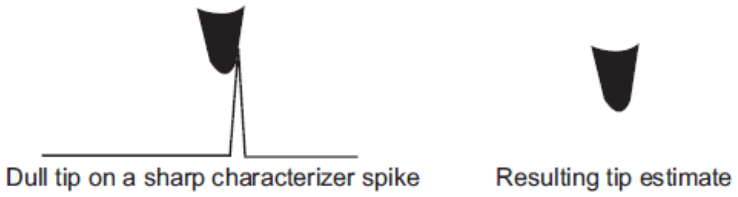


Figure 5.13c: Characterizer - Dull Tip on Sharp Characterizer

A surface having only large rounded features provide the least useful estimate of tip shape:

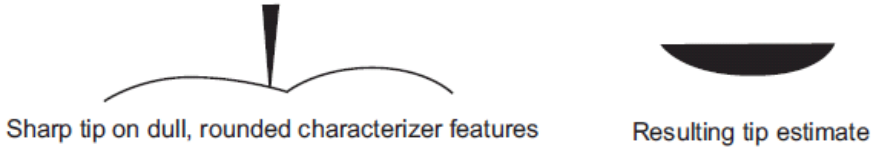


Figure 5.13d: Sharp Tip on Rounded Characterizer

Similar feature size of the *characterizer* and tip will yield a combined geometry for the tip shape:

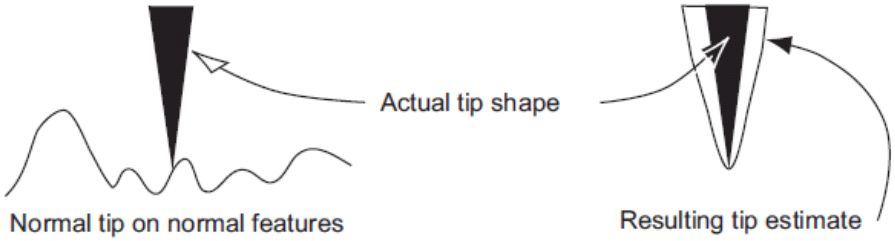


Figure 5.13e: Typical Characterizer

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.

Tip Quality Thresholds

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

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.

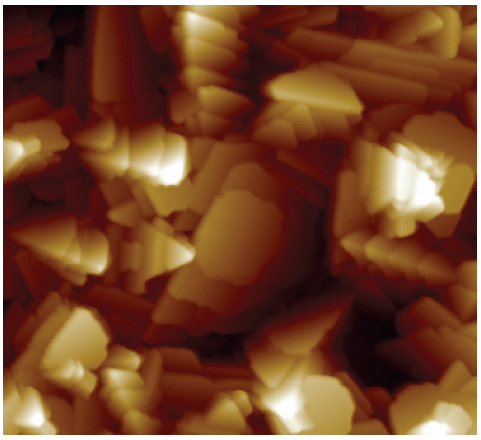


Figure 5.13f: Polycrystalline Titanium Roughness Sample

Operating Principles of Tip Qualification

The result of running ***Tip Qualification*** is a display similar to that shown in Figure 5.13g.

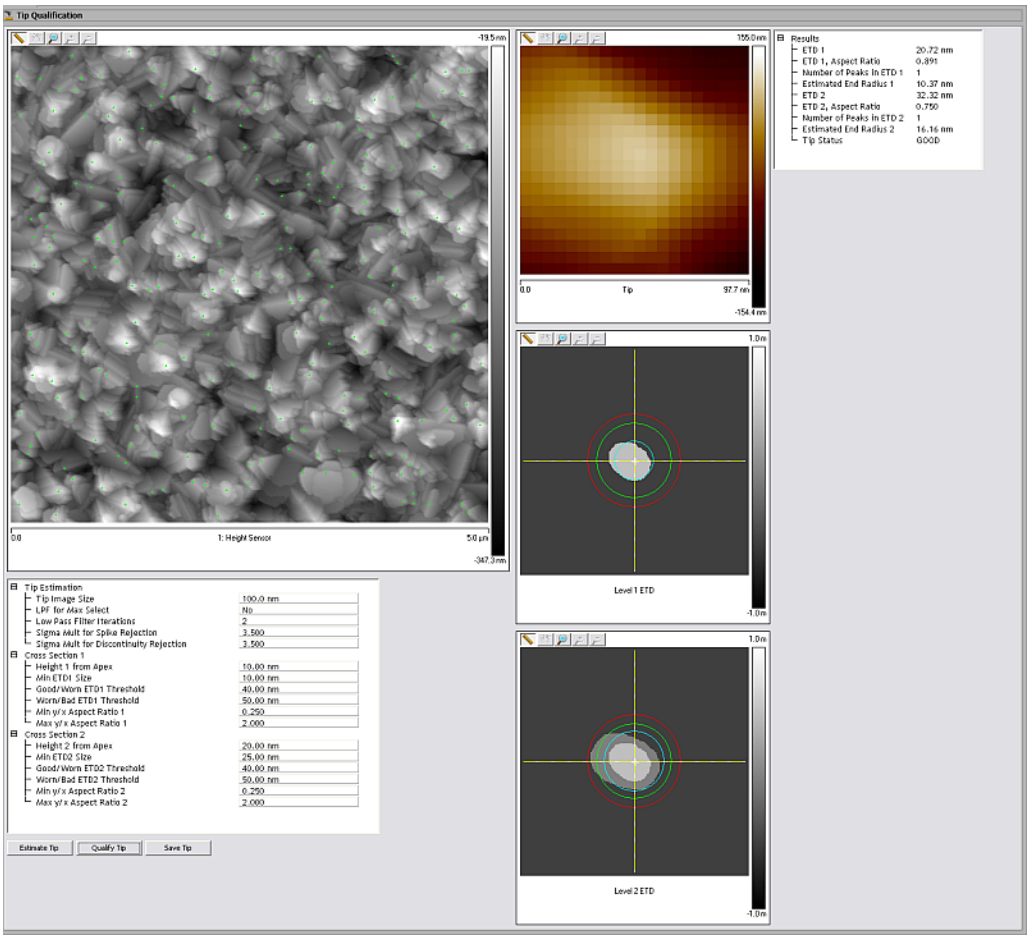


Figure 5.13g: A typical Tip Qualification window

The top-left frame is the image analyzed to evaluate the tip. The top-right 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, as seen in Figure 5.13h.

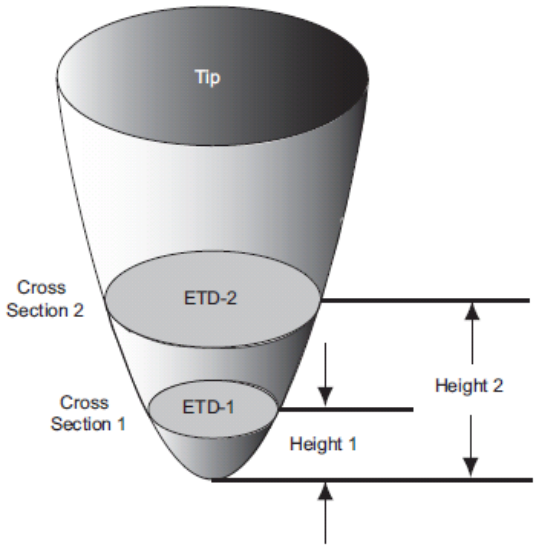


Figure 5.13h: Tip Estimation Cross-Sections Depiction

The cross-section diagrams on the right in Figure 5.13g 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 5.13g, 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 5.13i). The ETD is shown below as a circle to the right.

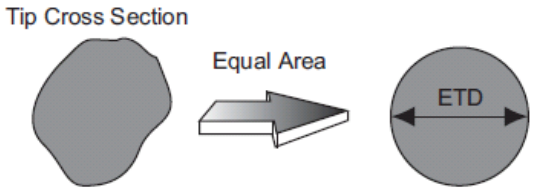


Figure 5.13i: ETD Depiction

Aspect Ratio is defined as the ratio of the maximum vertical (Y) dimension to the maximum horizontal (X) dimension of a tip cross section as seen in Figure 5.13j.

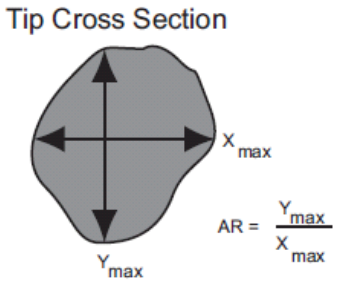


Figure 5.13j: Aspect Ratio Depiction

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 Thresholds*** based on these diameters. Then set the ***Good/Worn ETD Thresholds*** slightly smaller than the ***Worn/Bad ETD Thresholds***.

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***.

Because 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.

Tip Qualification Procedures

1. Scan (contact mode) the *characterizer* sample. Set the scan size to approximately 2.5um. *Characterizer* image size is important because, along with Tip Image Size (page 144) and feature density, it determines how many peaks are used for the tip estimation. To accurately estimate the tip shape, there must be many peaks (greater than 10 is good).
2. Select the captured 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. Open the ***Tip Qualification*** Analysis by selecting **Analysis** >**Tip Qualification** from the ***Menu*** bar or by clicking on the **Tip Qualification** icon in the ***Icon*** toolbar. The initial ***Tip Qualification*** view appears.
4. Enter the ***Tip Image Size*** desired for the currently loaded tip and characterization image.
5. 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***.

6. Enter the number of ***Low Pass Filter Iterations***.

NOTE: This applies a Lowpass (page 187) Filter to the image *n* times. peak and slope finding are performed on the filtered data. You should use this filter for images taken at Scan Rates greater than 5 Hz. Bruker recommends that you set ***LPF for Max Select*** to No when you use this filter.

7. Enter values for all parameters in the ***Cross Section*** panels.
8. Click **Estimate Tip**.
9. Click **Qualify Tip**.
10. View the ***Tip Status*** in the ***Results*** panel.
11. 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. The radius of a circle fitted to the data between the cursors is displayed in the bottom of the ***Section*** window. Refer to Section (page 123) for more information.

Tip Qualification Interface

Tip Qualification Buttons

Button	Description
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*: • If any “Tip Estimation” parameter or the analysis region has been changed, a new tip estimation is performed.

Button	Description
	• The tip cross sections and qualification results appear in the ***Results*** panel. • 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 Analysis Functions (page 59) and Filter Commands (page 163). A tip image is approximately the size specified by the ***Tip Image Size*** parameter and thus has fewer data points than a standard image.

Table: 5.0z Tip Qualification buttons

Group	Parameter	Description
Tip Estimation	***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 120 nm 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 120 nm 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**: Characterizer image size and feature density also affect the number of selected maxima.
	LPF 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**) unless you use the ***Low Pass Filter Iteration***s function.
	Low Pass Filter Iterations	Number of times to apply the Lowpass (page 187) filter to the data before finding peaks and slopes.
	Sigma Mult 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)

Group	Parameter	Description
		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 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 δy 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 δy is computed. Rows are rejected for a discontinuity where δy 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.
Cross Section 1		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***. 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 from Apex	Distance from the tip apex at which the cross section is defined.
	Min ETD1 Size	Minimum credible ETD at ***Cross Section 1***. If the calculated ETD is smaller than ***Min ETD Size***, then ***Tip Status*** = **Suspect**.
	Good/Worn ETD1 Threshold	Maximum ETD1 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***).
	Word/Bad ETD1 Threshold	Maximum ETD1 assigned ***Tip Status*** = **Worn**. If ETD1 is greater than Worn/Bad ETD1 Threshold then ***Tip Status*** = **Bad**.
	Min y/x Aspect Ratio 1	Maximum AR1 assigned Tip Status = **Suspect** if ETD1 is less than ***Worn/Bad*** ETD1 Threshold.

Group	Parameter	Description
	Max y/x Aspect Ratio 1	Minimum AR1 signed Tip Status = **Suspect** if ETD1 is less than ***Worn/Bad*** ETD1 Threshold.
Cross Section 2	***Height 2 from Apex***	Distance from the tip apex at which the cross section is defined.
	Min ETD2 Size	Minimum credible ETD at ***Cross Section 2***. If the calculated ETD is smaller than Min ETD Size, then ***Tip Status*** = **Suspect**.
	Good/Worn ETD2 Threshold	Maximum 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***).
	Word/Bad ETD2 Threshold	Maximum ETD2 assigned ***Tip Status*** = **Worn**. If ETD2 is greater than ***Worn/Bad*** ETD2 Threshold then ***Tip Status*** = **Bad**.
	Min y/x Aspect Ratio 2	Maximum AR2 assigned ***Tip Status*** = **Suspect** if ETD2 is less than ***Worn/Bad*** ETD2 Threshold.
	Max y/x Aspect Ratio 2	Minimum AR2 signed ***Tip Status*** = **Suspect** if ETD2 is less than ***Worn/Bad*** ETD2 Threshold.

Table: 5.0aa Tip Estimation Panel Parameters

Tip Status	Result
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.

Table: 5.0ab Tip Status **Results** - Evaluated in the order listed

5.14  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.

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.

5.14.1 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 5.14a).

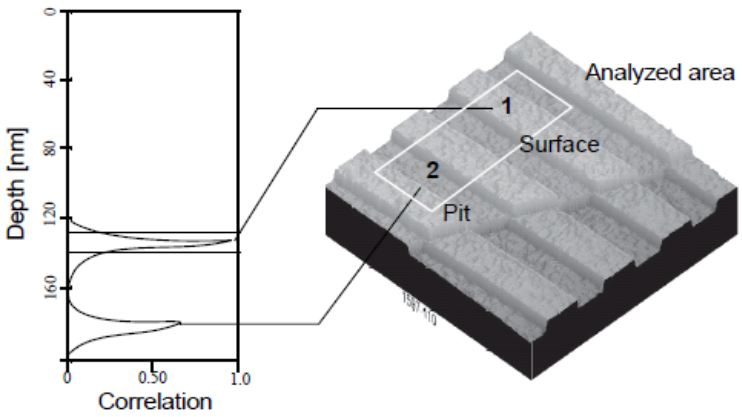


Figure 5.14a: Width Image and Corresponding Histogram

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).

Width Procedures

1. Select an image file from the file ***Browse*** window at the right of the main window. Double-click the thumbnail image to select and open the image.
2. Open the ***Width*** analysis by selecting Analysis > Width from the ***Menu*** bar or by clicking on the Width icon in the ***Icon*** toolbar.
3. The ***Width*** view, shown in Figure 5.14b, appears showing results for the entire image.

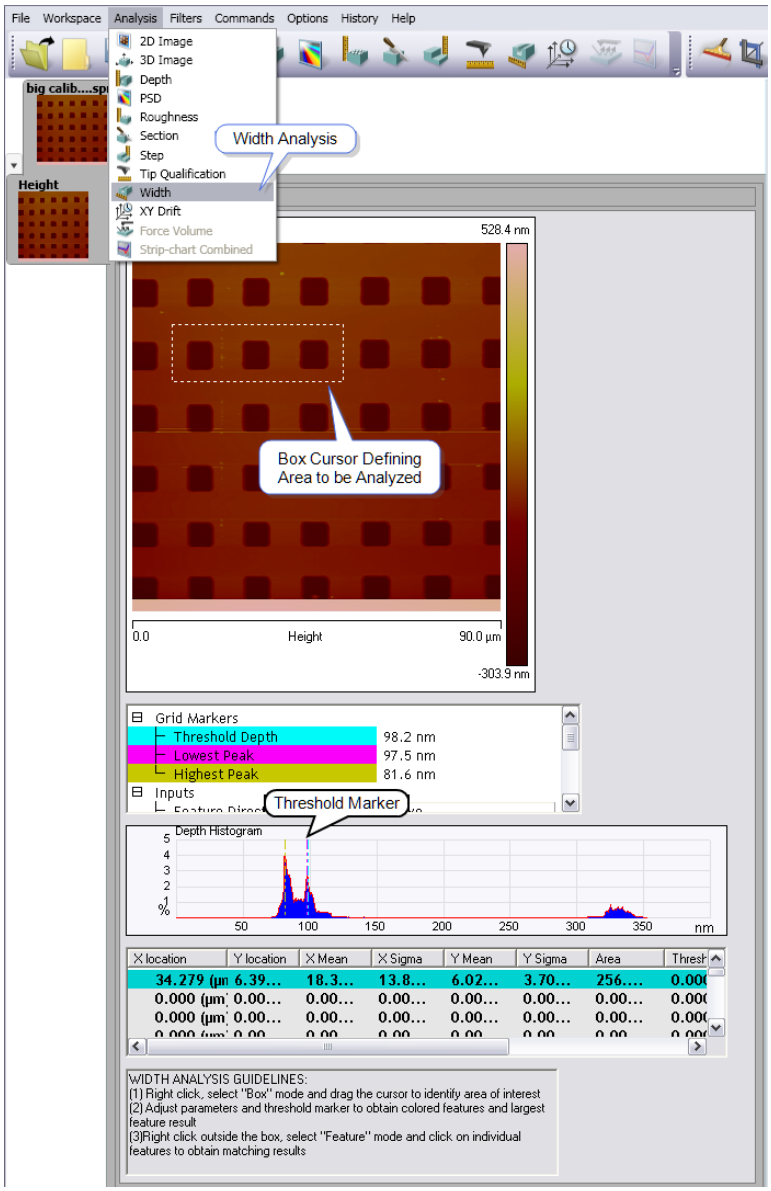


Figure 5.14b: Width Analysis Menu & Window

Width Interface

The ***Width*** interface includes a captured image, ***Input*** parameters and ***Grid Marker***display, ***Results*** table, ***Guidelines*** and a ***Depth Histogram*** with grid markers.

1. Using the mouse, left click and drag a box around a particular section of the image. The analysis automatically adjusts the results.

NOTE: If not 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.
7. 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.

Width Parameters

The depth input parameters below define the slider cursor placement for determining the exact depth of a feature.

Parameter	Description
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 smoothes 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

Table: 5.0ac Width Parameters

Three user-adjustable markers are placed on the depth histogram:

Parameter	Description
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.

Table: 5.0ad Grid Markers

Parameter	Description
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.

Table: 5.0ae Results Parameters

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, as seen below, and allow for the following changes:

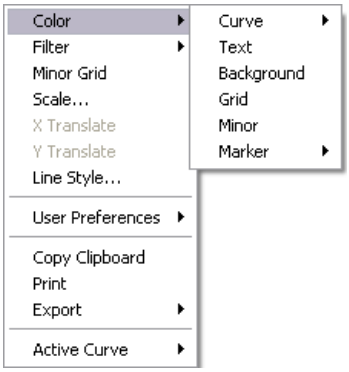


Figure 5.14c: Grid Parameters Menu

Parameter	Description
Color	Allows the operator to change the color of the: Curve, Text, Background, Grid, Minor Grid, and 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 the 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 Preference	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, JEPG, or XZ data format.
Active Curve	Determines which curve you are analyzing.

Table: 5.0af Plot Appearance Parameters

5.15 XY Drift

Due to temperature differences, thermal lateral drift can occur between two successive images while scanning. ***XY Drift*** analysis, an optional feature of NanoScope Analysis, can calculate the lateral shift between two images. You can also manually enter the drift.

Requirements

Two images captured sequentially with the same scan direction 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.

XY Drift Procedure

To calculate ***XY Drift*** using NanoScope Analysis:

1. Identify the two images to be compared with ***XY Drift*** analysis, and open the first (chronologically) of the two images.
2. Open the ***XY Drift*** analysis view by selecting Analysis > XY Drift from the menu bar or by clicking on the XY Drift icon in the ***Icon*** toolbar.
3. The ***XY Drift*** view, shown in Figure 5.15a, opens showing the selected image.

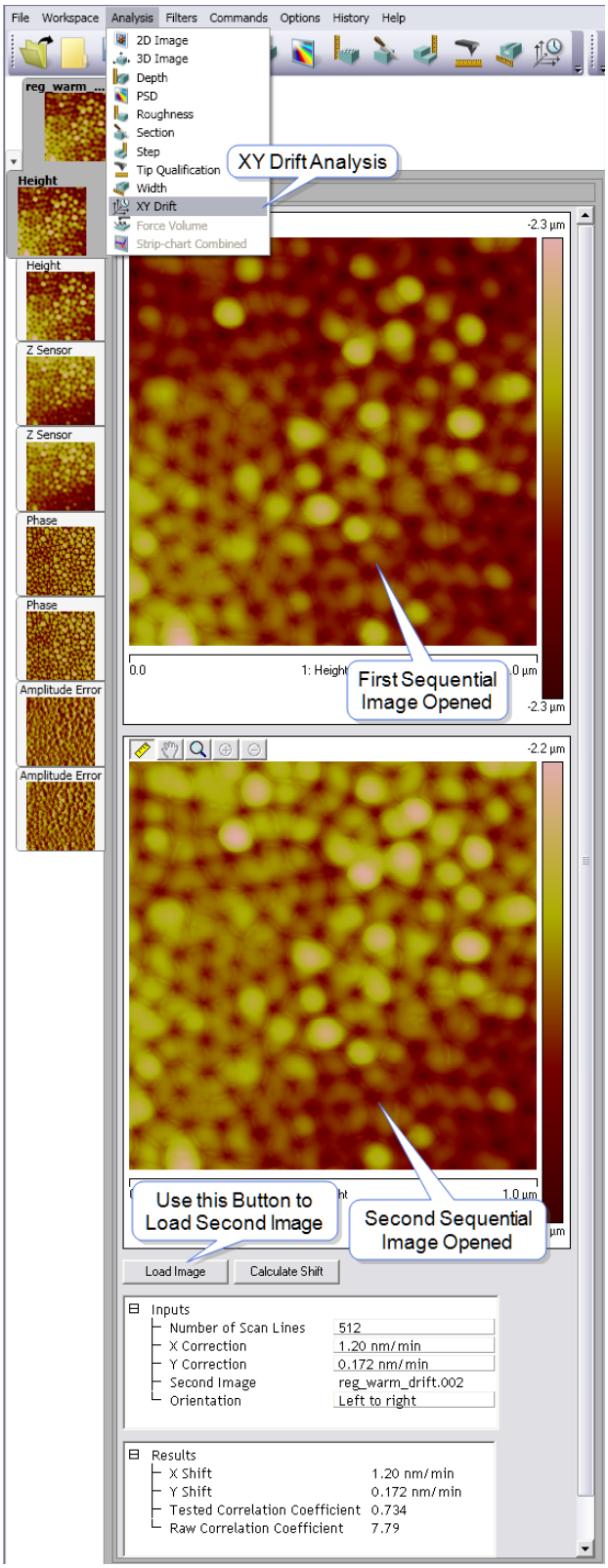


Figure 5.15a: XY Drift Analysis Menu & Window

4. Use the Load Image button to browse for the subsequent image and open it.
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.
7. To apply the corrections in the ***Inputs*** box, click the Apply Correction button.
8. You can also manually enter the correction values in the ***Inputs*** box. Click the Apply Correction button.

NOTE: ***Apply Correction*** affects RealTime by applying a drift correction to the RealTime images. Do not use ***Apply Correction*** if this is not your intent.

XY Drift Parameters

Statistics used by the **XY Drift** analysis are defined in this section.

Parameter	Description
Number of scan lines	Specifies the number of lines to calculate.
Flatten	Flattens both images before the shift is calculated. (Use the Undo Flattenbutton 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

Table: 5.0ag XY Drift Parameters

Results of the **XY Drift** analysis are presented in this section.

Parameter	Description
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.

Table: 5.0ah Results Parameters

Parameter	Description
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.

Table: 5.0ai XY Drift Buttons

5.16 Electrochemical SPM

The electrochemical display environment, shown in Figure 5.16a, displays one channel of the image, three plots and a plot control panel.

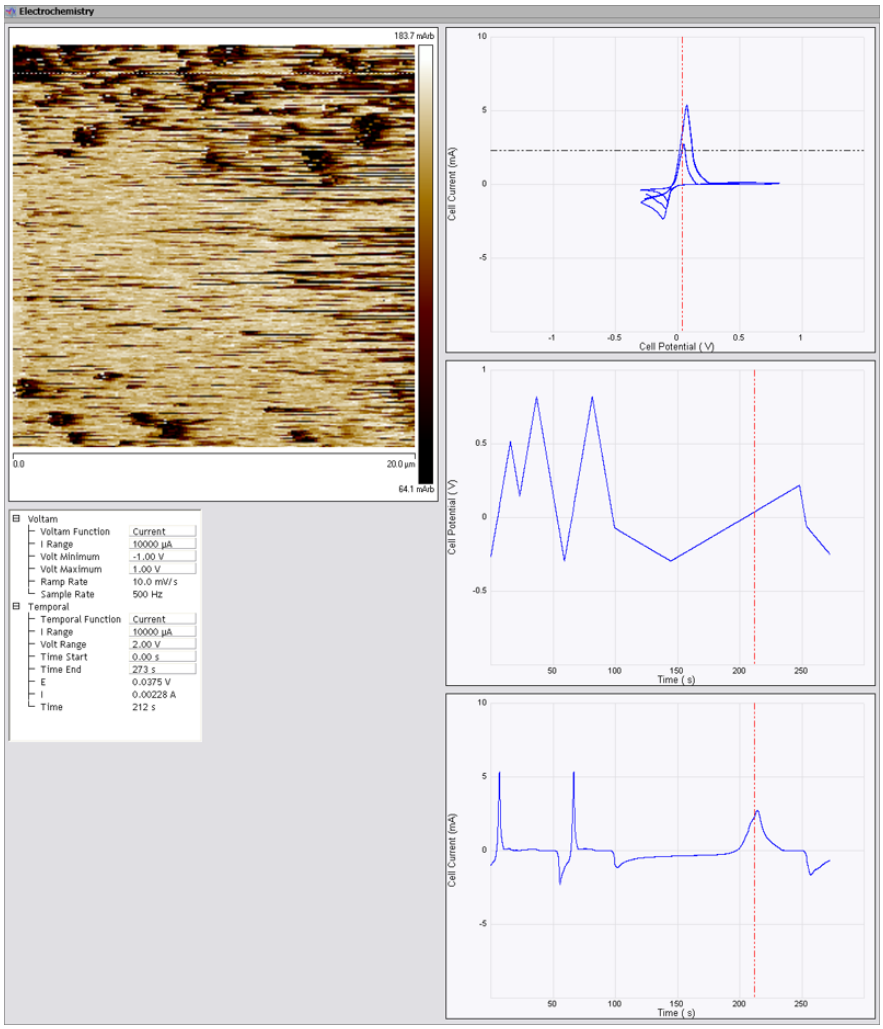


Figure 5.16a: The NanoScope Analysis Electrochemistry display window showing a PeakForce DMT modulus image

The ***Voltammogram*** (top plot) plots current along the vertical axis versus potential along the horizontal axis. This can be ***Itip*** vs. ***Etip*** (STM) or ***I*** vs. ***E*** or one of the calculated values, current density, charge, etc. vs., ***E***.

NOTE: The calculated values are all based on the electrochemical cell current, ***I***, and *not* on STM tip current, ***Itip***.

In the ***Temporal*** (bottom two) plots, the horizontal axis is always time. A voltage (top) and a current (bottom) are plotted versus time. The voltage can be the electrochemical cell potential, ***E***, or the potential of the STM tip, ***Etip***. The current can be electrochemical cell current, ***I***, one of its derivative quantities; e.g., charge, current density, etc., or it can be the current flowing through the STM tip, ***Itip***.

The time scale on the ***Temporal*** graph does not necessarily correspond to the time required to capture an SPM image for the following reasons:

1. The total number of data points is limited to 62,254. Hence, the product of the ***Sample Rate*** and ***Time*** range is limited to 62,254. For example, when one attempts to collect 1000 seconds of data, the maximum ***Sample Rate*** is 62 Hz.
2. If the time to capture an image exceeds the time to record the maximum of the 62,254 electrochemical data points that can be stored, only the last 62,254 data points are saved. The data points prior to the last 62,254 data points are lost. Time zero on the ***Temporal*** graph reflects the start of the last 62,254 data points.
3. To display on the ***Temporal*** graph only a portion of the stored data points, for example, the last 30,000 of 62,254 data points recorded using a ***Sample Rate*** of 100 Hz, define ***Time Start*** equal 300 seconds (roughly one-half of the maximum of 623 seconds for this case) and ***Time End*** equal 623 seconds in the plot controls dialog box for the NanoScope Analysis software. In this case, time zero on the ***Temporal*** graph would actually be the first data point after the 300-second marker.

Cursors

A mouse click-and-hold-and-drag may be used in the ***Temporal*** plot windows to display data at any point in the experiment.

The markers in all three plots will follow the position of the cursor as the mouse is dragged (click and hold) in the plot. The electrochemical cell data (***E***, ***I***, ***Time***) at the position of the marker is displayed in the ***Temporal*** panel of the plot controls dialog box in the lower left of the EC window.

A marker on the ***Voltammogram*** will indicate the corresponding data as potential vs. current. The vertical line in the ***Temporal*** plot indicates, in time, when the first line of the SPM image was captured. As the ***Temporal*** marker is moved, a horizontal line on the SPM image will move to the scan line that was captured at approximately the same time. See Figure 5.16a. In addition, the mouse may drag (click-and-hold) the line on the image to any scan line, and this will move the ***Temporal*** and ***Voltammogram*** markers to the appropriate positions and update the electrochemical cell data display.

Note that it is possible to have data displayed in the ***Temporal*** plot across such a time window that it does not correspond to any of the data in the SPM image. This is because when an SPM image is captured, the last 62,254 electrochemical data points are also recorded in the file, and only a portion of the electrochemical data recorded may correspond to the time required to capture the SPM image; i.e., the image may have taken less time to capture than the last 62,254 electrochemical data points.

A mouse Ctrl-click-and-hold-and-drag may be used in the plot windows to zoom in on a portion of the data. Clicking the magnifying glass in the lower left corner of the plot window resets the plot.

Plot Controls Dialog Box

The parameters in the plot controls dialog box, shown in Figure 5.16b and described in Table: 5.0aj, allow you to scale and clip the electrochemical data.

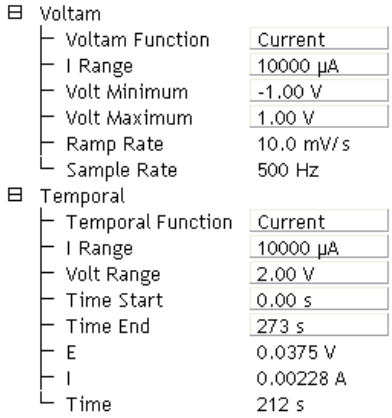


Figure 5.16b: The electrochemistry plot control dialog box

Parameter Group	Parameter	Description
Voltam	***Voltam Function***	Indicates the quantities plotted along horizontal and vertical axes of the voltammogram. *Settings:* • Charge • Chrg Dens • Current • Cur Dens • Log Cur • Lg Cur Dens • Tip Current When this parameter is ***Itip***, the current through STM tip is plotted vs. ***Etip***. All other settings (e.g., current, charge) have the electrochemical cell parameter plotted vs. ***E***.
	I Range	Controls the vertical scale of the ***Voltammogram*** graph.
	Volt Minimum	Voltage corresponding to left edge of ***Voltammogram*** graph.
	Volt Maximum	Voltage corresponding to the right edge of the ***Voltammogram*** graph.
	Ramp Rate	Indicates the ramp rate at the time of capture.
	Sample Rate	The rate of electrochemical data recording at the time of capture.
	Tip Reference	STM only. Indicates whether the STM tip potential, ***Etip***, or tip bias, ***Ebias***, is kept constant during ramping.
	Ramp Electrode	Indicates which electrode (working or STM tip) was ramped at time of capture.
Temporal	***Temporal Function***	Indicates what parameter is plotted along the vertical axis vs. time along horizontal axis. *Settings:* • Charge • Chrg Dens • Current • Cur Dens • Log Cur • Lg Cur Dens • Tip Current
	I Range	Controls the current scale of the ***Temporal*** graph.

Parameter Group	Parameter	Description
	V Range	Controls the voltage scale of the ***Temporal*** graph.
	Time Start	Start time of displayed data (left edge of plot).
	Time End	End time of displayed data (right edge of plot). **NOTE:** The system will record the current and voltage vs. time data starting from time = 0 in the Temporal graph. The current is integrated starting at time = 0 of the Temporal graph. Any data that fits into the Temporal graph will be displayed. Voltammogram will display data within the time range of the Temporal graph.
	E	Cell potential at marker position.
	Etip	STM only. Potential of the tip relative to the reference electrode.
	Ebias	STM only. Voltage difference between tip and sample, ***Etip*** - ***E***.
	I	Cell current at marker position.
	Time	Time at marker position relative to start of ***Temporal*** plot. The data is normally displayed using the ***Temporal*** Time range at the time of capture.

Table: 5.0aj Plot Controls parameters

Chapter 6: Filter Commands

All ***Filter Commands*** modify the file data and/or metadata and will cause a new view to be opened with the results of the chosen filter. The user can restore the previous data by going to the previous step in the data ***History*** or by executing the ***Undo*** command.

Filter Commands can be opened using the ***Menu*** bar or by clicking on the appropriate icon from the ***Icon*** toolbar. These ***Filter*** icons are identical to the icons used in NanoScope V8 software.

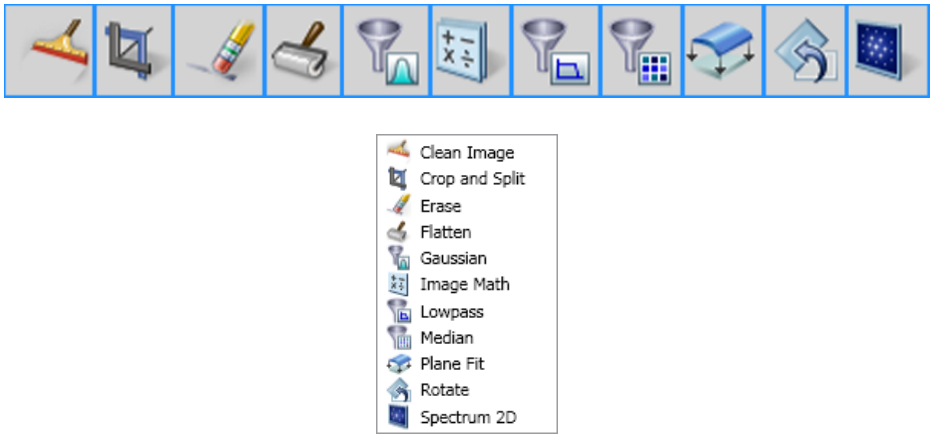


Figure 6.0a: Filter Icon Toolbar & Menu Commands

The following ***Filter Commands*** are available in NanoScope Analysis 1.50:

- Clean Image (page 164)
- Crop & Split (page 167)
- Erase (page 170)
- Flatten (page 172)
- Gaussian (page 176)
- Image Math (page 184)
- Lowpass (page 187)
- Median (page 190)
- Plane Fit (page 192)
- Rotate (page 197)
- Spectrum 2D (page 198)

6.1 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.

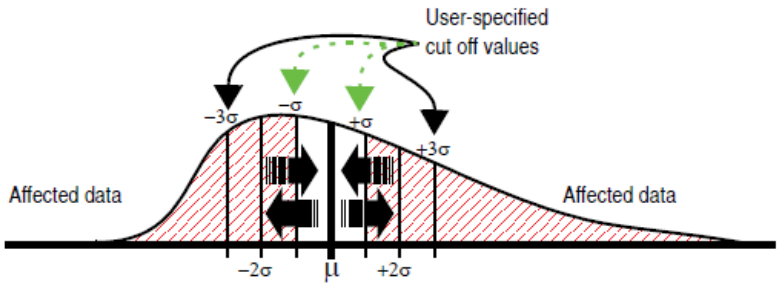


Figure 6.1a: Cutoff Values Depiction

Clean Image Procedure

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. Open the ***Clean Image*** view by selecting Filter > Clean from the ***Menu*** bar or by clicking on the Clean icon from the ***Icon*** toolbar.

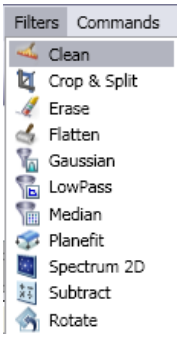


Figure 6.1b: Clean Selection from Menu Bar

3. A separate window opens displaying the image. Right click the image to display the ***Clean Image*** options menu.

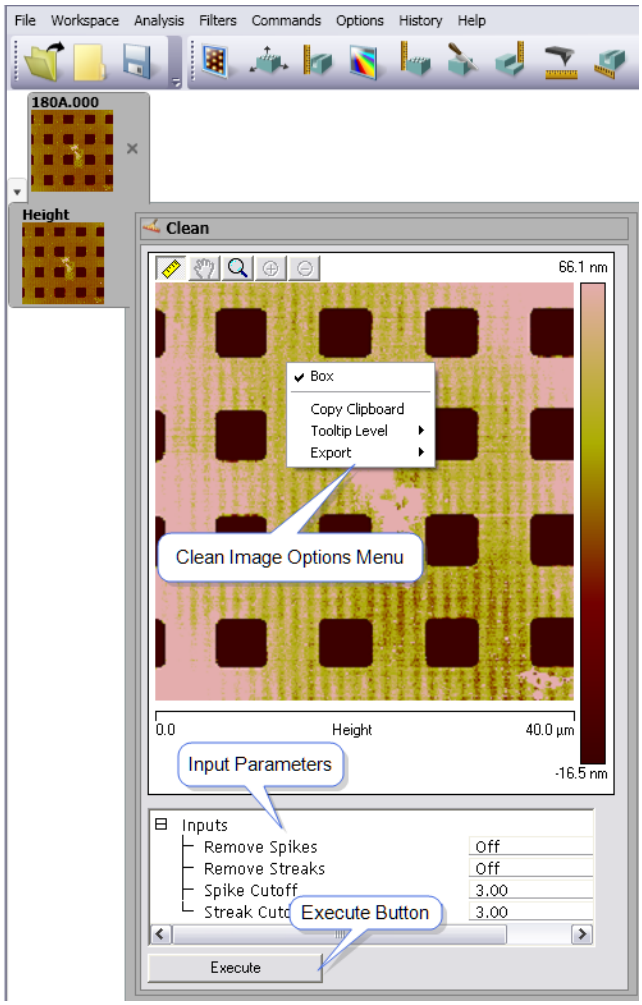


Figure 6.1c: Clean Image Window

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 on the Undo icon. From here one can go back in the data history to get to the preferred image.

Clean Image Interface

Parameter	Description
Remove Spikes	*Settings:* • **On**: Enables the **Spike cut off** value and applies it to data within the cursor box you specify. • **Off**: Disables **Spike cut off** value.

Parameter	Description
Remove Streaks	*Settings:* • **On**: Enables the **Streak cut off** value and applies it to data within the cursor box you specify • **Off**: Disables **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

Table: 6.0ak Clean Image Parameters

Parameter	Description
Execute	Initiates the Clean Image command.

Table: 6.0al Buttons on the Clean Image Panel

6.2  Crop & Split

The ***Crop & Split*** function replaces and expands the ***Zoom*** function used in version 7.0 and earlier releases of NanoScope software. Use the ***Crop & 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 & 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.

Crop and Split Procedure

Use the ***Crop & Split*** function to isolate a portion of a high resolution image.

1. Open an image that you wish to crop. (larger than 512 x 512).
2. Open the ***Crop & Split*** view by selecting Filter > Crop & Split from the ***Menu*** bar or by clicking on the Crop & Split icon in the ***Icon*** toolbar.
3. The selected image opens in the ***Crop & Split*** dialog box.

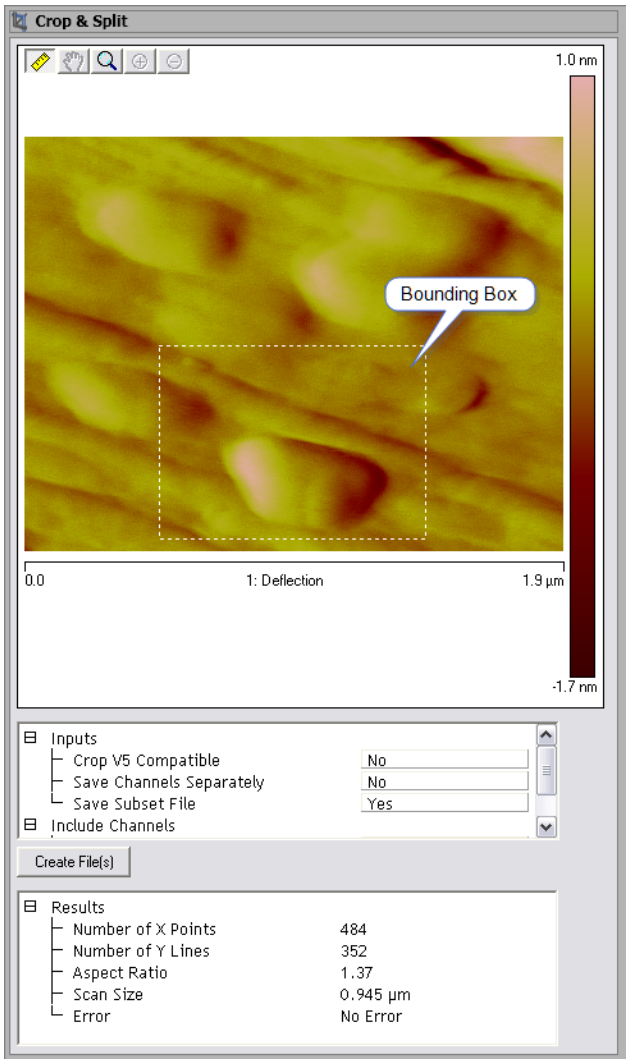


Figure 6.2a: Crop & Split Window

4. Create a bounding box by dragging the mouse in the image. 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).
5. Click the Create File(s) button.
6. Choose Filename in the ***Save As*** dialog.

Crop and Split Interface

Parameter	Description
Crop V5 Compatible	*Settings:* -Yes - A V5 compatible file (128x128, 256x256, or 512x512 is created from the image. -No - Crops to arbitrary sizes.
Method	Available with Crop V5 Compatible set to Yes.

Parameter	Description
	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 - 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. You must select Yes for either the Save Channels Separately or the Save Subset File commands.
Include Channels	*Settings:* -Yes - The channel is included in the output file(s) -No - This channel is not included in the output file(s).
Number of X Points	Number of x points in the new image.
Number of Y Points	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 ration greater than 256:1 -File Write - A disk error occurred -Unknown - An unknown error as occurred.

Table: 6.0am Crop & Split Parameters

Button	Description
Create File (s)	An image is created from the portion of the high resolution image that is contained in the bounding box.

Table: 6.0an Crop & Split Buttons

6.3  Erase

The ***Erase*** 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.

6.3.1 Erase Procedure

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. Open the ***Erase*** View by selecting Filter > Erase or by clicking on the Erase icon in the ***Icon*** toolbar. A separate window opens, also displaying the image.

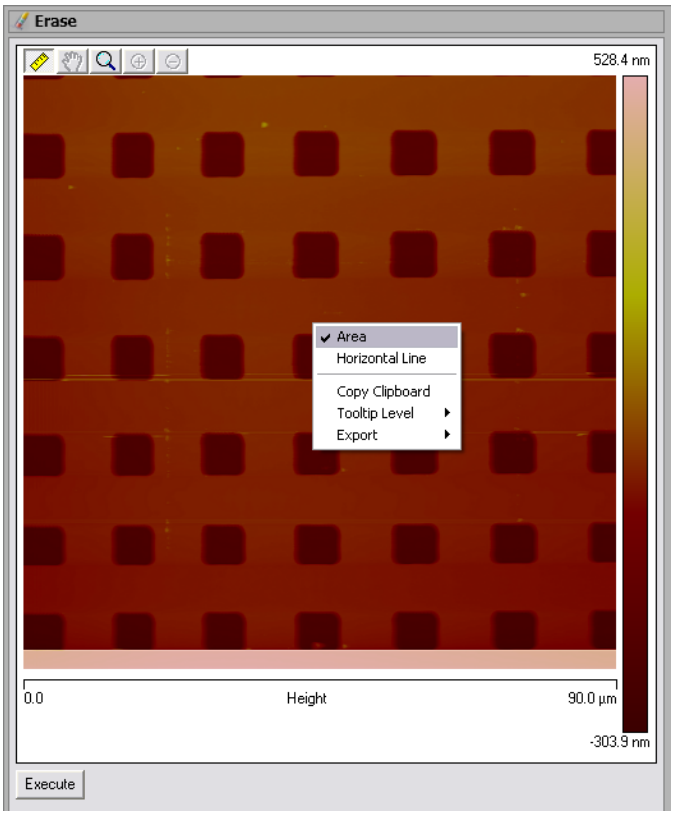


Figure 6.3a: Erase Window

3. Right-click in the image to display the ***Erase Options*** menu. Select either **Horizontal Line** or **Area** and a check mark will appear. The option chosen will remain checked until another selection is made.
   - **Area** - Selects a region to be erased
   - **Horizontal Line** - Selects a single line to be erased.
4. Click anywhere within the image to define a horizontal line, or click and drag in the image to define a box to be replaced. When selecting a line, the line applies to the entire scan line of the image, regardless of whether you are zoomed into a region on the image.
5. Click the **Execute** button to perform the interpolation.

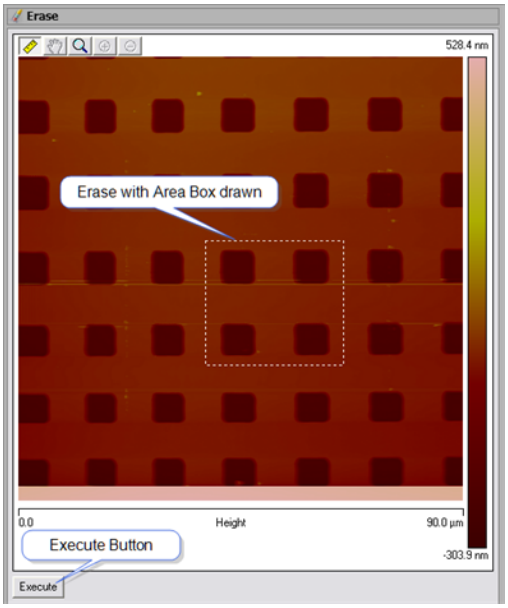


Figure 6.3b: Erase Area with Box Drawn

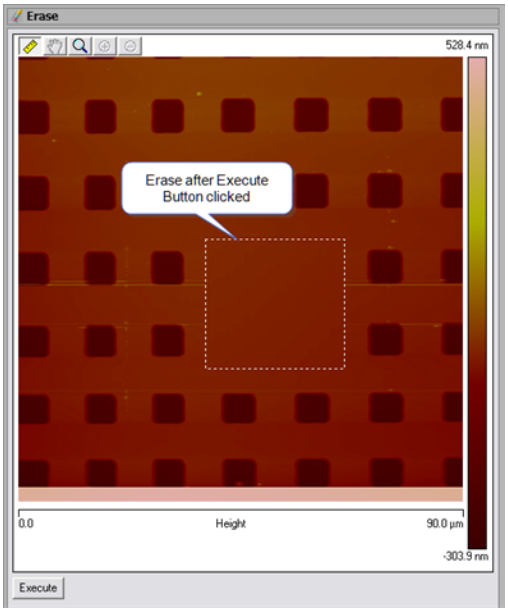


Figure 6.3c: Erase Area After Execute Button Clicked

6. 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.
7. To eliminate all trace of ***Erase*** activity to an image, click the Undo button while the image is still open in the ***Erase*** panel.

6.4 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.

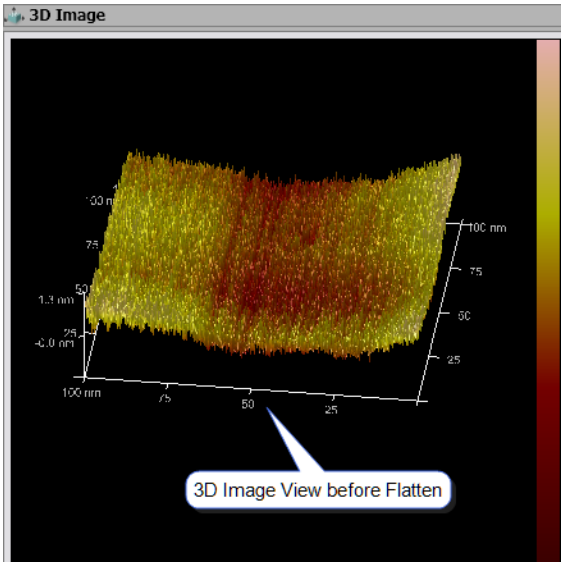


Figure 6.4a: Image with Bow

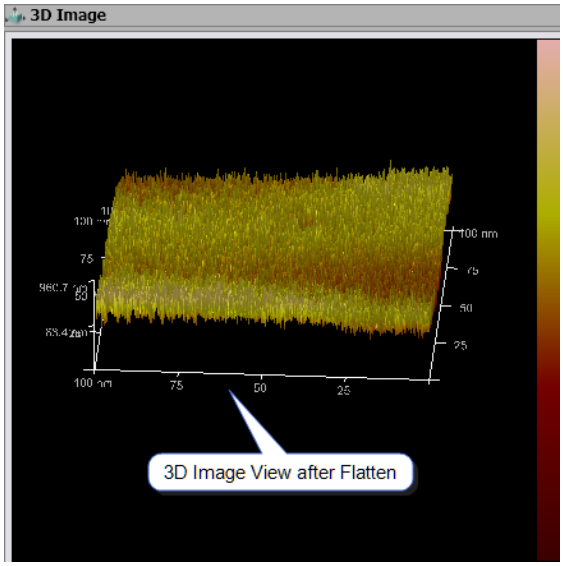


Figure 6.4b: Image with Bow Removed

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 (0^{th} order) and remove tilt (1^{st} order), or 2^{nd} or 3^{rd} 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 as per the table below.

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.

Table: 6.0ao Flatten Polynomials

Flatten Procedure

For an image that contains a number of noisy scan lines, use the ***Flatten*** command to correct the problem.

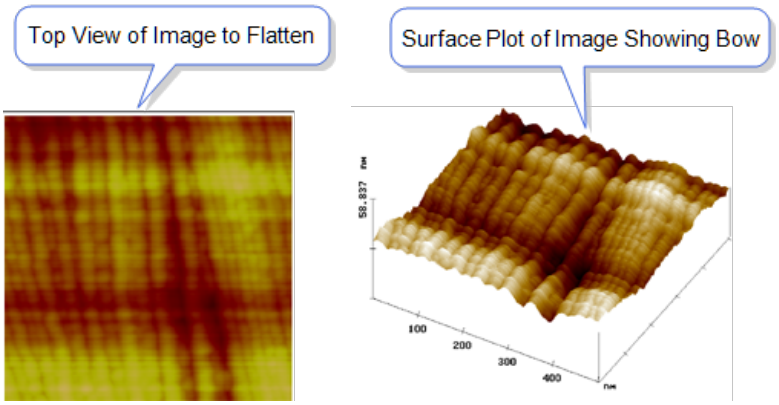


Figure 6.4c: Raw Image of Syndiatatic Polystyrene (500nm)

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.
2. Select **Filters** > **Flatten** on the ***Menu*** bar or click on the **Flatten** Icon from the ***Icon*** toolbar.
3. Set the flatten order to **0th**. This removes the scan line misalignment.
4. Click **Execute** to initiate the ***Flatten*** command. The flattened image appears on the display screen.

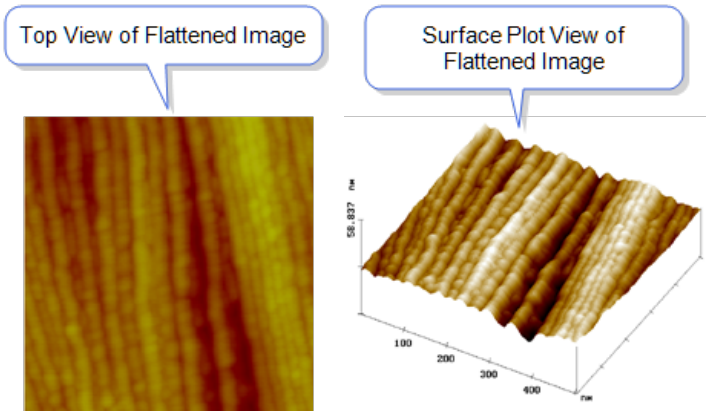


Figure 6.4d: Flattened Image of Syndiatatic Polystyrene (500 nm)

5. To see the variety of effects using the ***Flatten*** command, enter different ***Flatten Order*** values. Each new change may be undone by clicking on the **Reload** button.

Flatten Interface

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 preference.

Input Parameters

Parameter	Description
Flatten Order	Select 0th, 1st, 2nd, or 3rd
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: *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.

Parameter	Description
Find Threshold for	Applies the Thresholding values for the whole image or each line independently. *Settings*: • **The whole image** • **Each line**
Mark Excluded Data	Displays (in blue) data that has been excluded (by the Z Thresholding operation) from the calculation.
Number Histogram Bins	The number of data points in the histogram.
Threshold Height	Defines a Z value relative to the lowest data point.
Use Histogram	Displays a histogram of the height allowing you to, more easily, using the dashed red cursor, set the **Threshold Height** for excluded data. *Settings*: • **On** • **Off**

Table: 6.0ap Flatten Range, Settings and Buttons

Button	Description
Execute	Initiates the Flatten operation.

Table: 6.0aq Buttons on the ***Flatten*** Panel

6.5  Gaussian

Gaussian filter applies either a ***Lowpass*** or a ***Highpass*** digital filter to an image along either the ***Horizontal*** or the ***Vertical*** axis.

Lowpass Gaussian Filter

The ***Lowpass Gaussian Filter*** eliminates high frequency (sharp) features oriented along either the X or Y axis of the scan. The practical effect upon the image is a loss of detail or "blurring" effect.

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*** function, although applied to only the X or Y axis.

Consider the scan of the grating below, with prominent features oriented along the x axis.

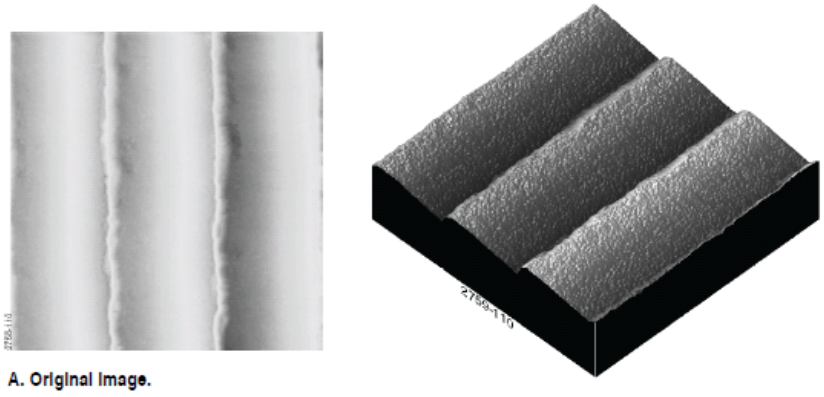


Figure 6.5a: Grating with Prominent X-Axis Features

Applying a ***Lowpass Gaussian Filter*** along the ***Vertical*** (Y) axis results in elimination of noise in the image.

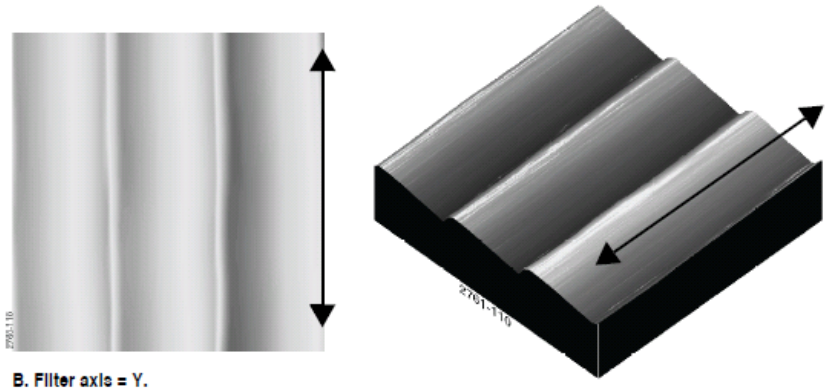


Figure 6.5b: Noise Removed by Applying Lowpass Gaussian Filter to Y Axis

NOTE: 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.

Applying the ***Lowpass Gaussian Filter*** to the ***Horiztonal*** (X) axis destroys the ruling features in the image by averaging across their profile.

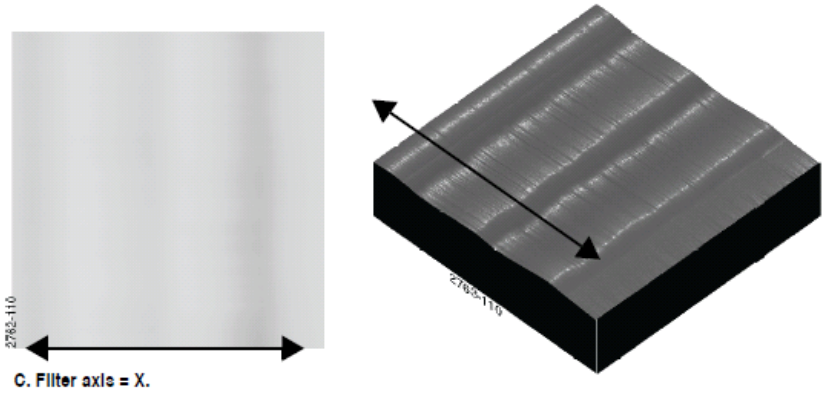


Figure 6.5c: Lowpass Gaussian Filter Applied to Horizontal X Axis

NOTE: Notice how the filter has eliminated the prominent high frequency features along the axis which the filter has been applied, resulting in an almost flat surface.

Highpass Gaussian Filter

The ***Highpass Gaussian Filter*** eliminates low frequency (dull) features oriented along either the X or Y axis of the scan. The "DC" (average) value is also eliminated, resulting in an image containing only the transitions from one region to the next. This filter is typically used for edge detection of different regions or grain bounders.

One example of applying a ***Gaussian Highpass*** filter is the magnetic domains in a permalloy specimen, as shown below.

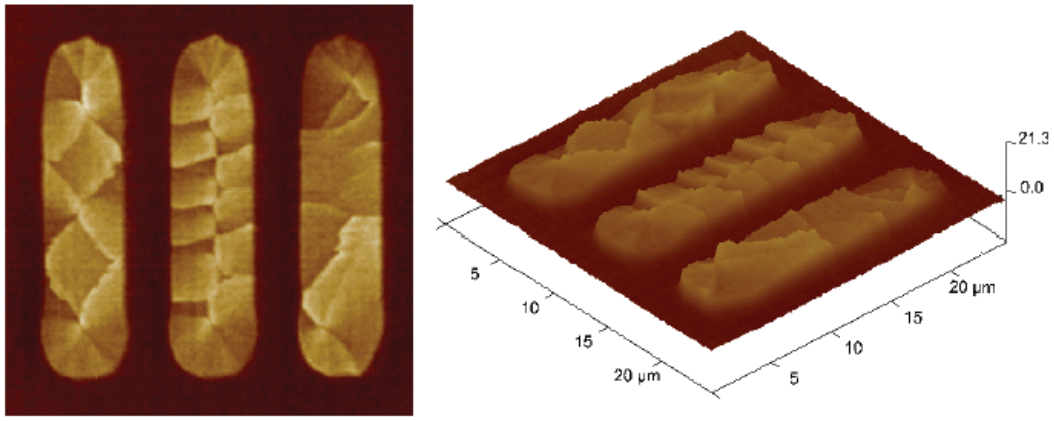


Figure 6.5d: Permalloy Specimen

NOTE: The figure 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.

When the image is filtered using the ***Horizontal*** setting, the high frequency features along the X-axis are highlighted.

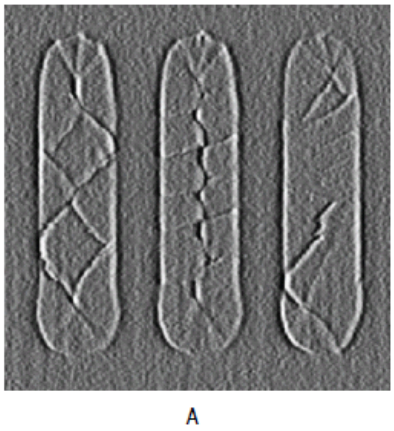


Figure 6.5e: Highpass Gaussian Filter Using Horizontal Setting

NOTE: 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.

When the image is filtered using the ***Vertical*** setting, the high frequency features along the Y-axis are highlighted.

B

Figure 6.5f: Highpass Gaussian Filter Using Vertical Setting

NOTE: 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.

A composite of the two images shows the domain boundaries clearly. All of the low frequency features have been removed, leaving only the transitions between the grain boundaries.

C

Figure 6.5g: Highpass Gaussian Filter Using Horizontal & Vertical Settings

NOTE: To construct a composite image of the two Gaussian-filtered images, add them together. (This can be accomplished by using the subtract feature with an inverted image) See Image Math (page 184) for further details.

Gaussian Kernel Algorithm

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.

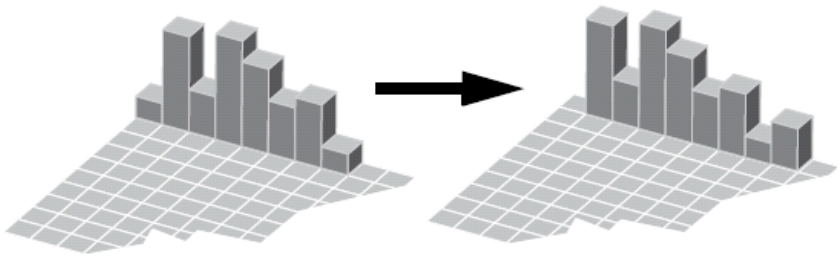


Figure 6.5h: Gaussian Filter Depiction

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:

$$\text{Lowpass pixel value} \qquad a_0' = \left(\sum_{\frac{-N}{2}}^{\frac{N}{2}} a_i f_i \right)$$

$$\text{Highpass pixel value} \qquad a_0' = a_0 - \left(\sum_{\frac{-N}{2}}^{\frac{N}{2}} a_i f_i \right)$$

Gaussian Filter Size

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.

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.

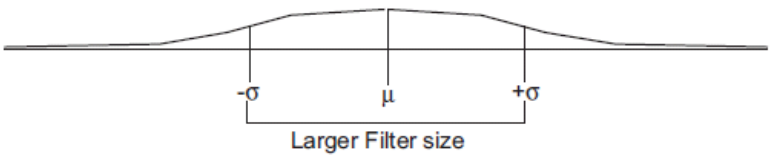


Figure 6.5i: Larger Filter Size

Smaller Filter size values concentrate curve data around the center value

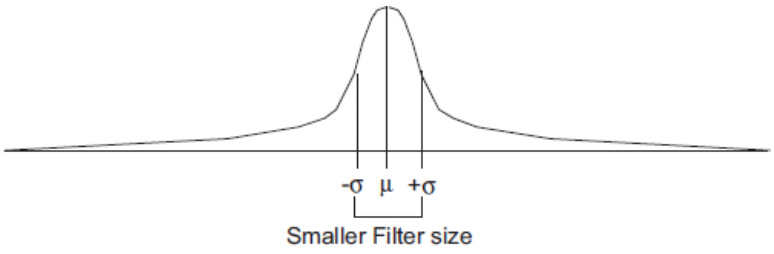


Figure 6.5j: Smaller Filter Size

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.

Filter size is specified in units of ***Distance***, ***Spatial Frequency***, ***Time***, ***Temporal Frequency***, and ***#pixels***.

Gaussian Filtering Procedure

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. Open the ***Gaussian*** view by selecting **Filter > Gaussian** from the Menu bar or by clicking on the **Gaussian** icon in the ***Icon*** toolbar.

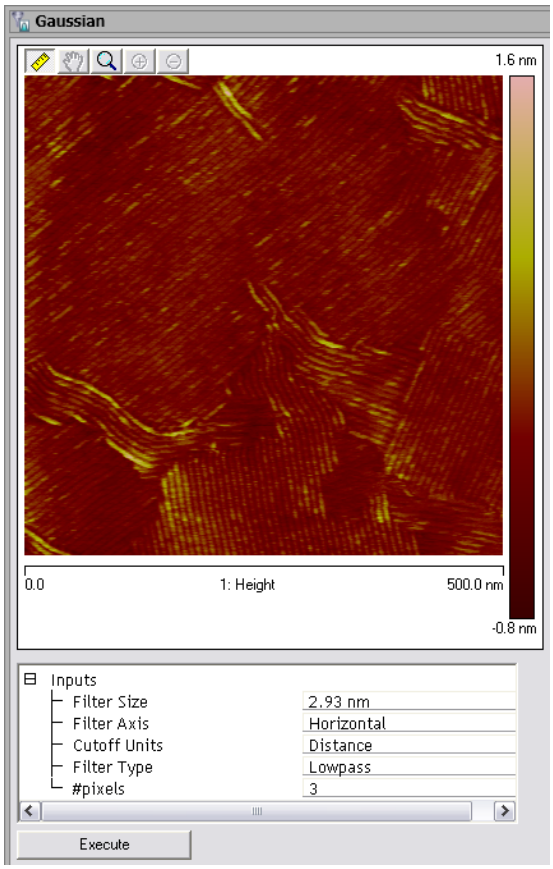


Figure 6.5k: Gaussian Window

3. Configure the ***Input*** parameters.
4. Click **Execute** to perform the Gaussian filtering operation.
5. To restore the unprocessed image, click the **Reload** button or go back in the data ***History***.

6.5.1 Gaussian Filter Interface

Parameter	Description
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.

Parameter	Description
Cutoff Units	Selected units are applied simultaneously to the Filter size. (The #pixelsfield 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

Table: 6.0ar Gaussian Parameters

6.6 Image Math

Image Math commands enable data from one image to operate on data from another image. Permitted operations include addition, subtraction, multiplication and division. For instance, the subtract image operation proves most useful when comparing two or more images from a surface to determine changes over time, or to compare completely different images.

NOTE: ***Image Math*** operations 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 6.6a 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”).

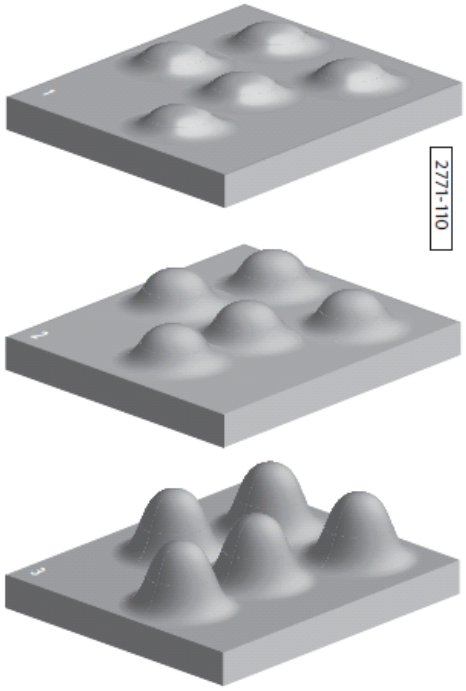


Figure 6.6a: Subtract Image Depiction

6.6.1 Image Math Procedure

1. Select an image file from the file browsing window at the right of the main window. Double-click or drag the thumbnail image to select and open the image.
2. Open the ***Image Math*** view by selecting Filter > Image Math or by clicking the Image Mathicon on the ***Icon*** toolbar. The original image appears in Image A (top). A unit matrix (all "1"s) is loaded into Image B.

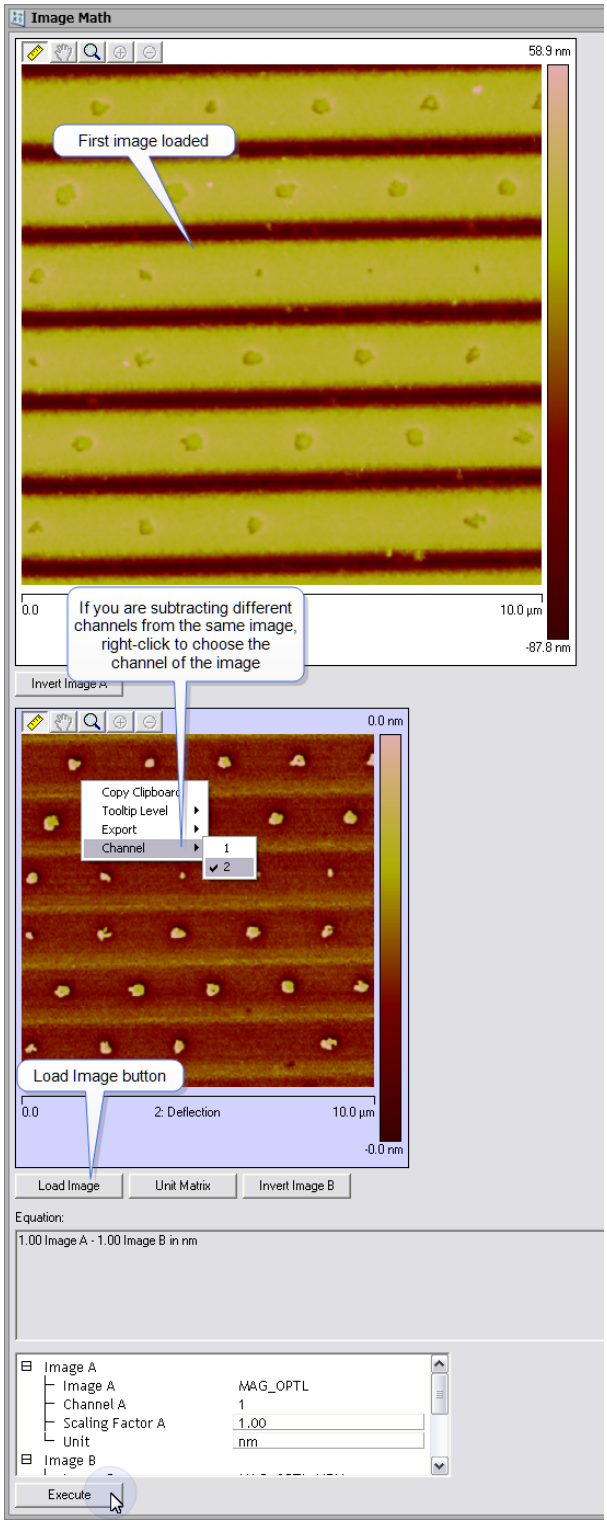


Figure 6.6b: Image Math Window

3. Click the Load Image button to browse for a second file.
4. If necessary, right click on the second image panel to change the channel (see Figure 6.6b). The channel may also be changed by entering the channel number into the ***Image Math dialog box***, shown in Figure 6.6c.
5. Select the ***Operator*** (+, -, *, /) and ***Scaling Factors***

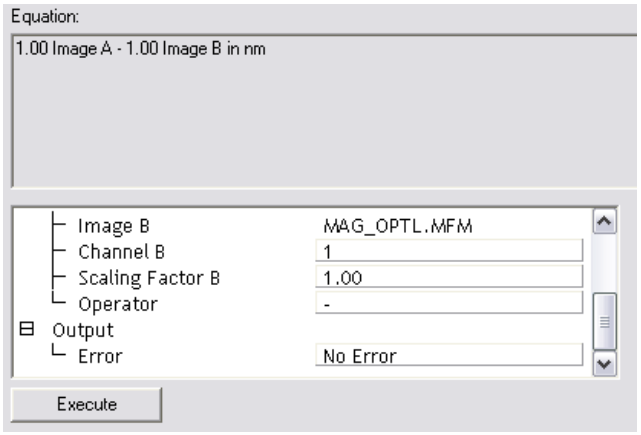


Figure 6.6c: The ***Image Math*** dialog box

6. Click the Execute button to perform the operation on Image A. The result, which overrides the data in the active (A) channel, is shown in the top panel of the ***Image Math*** view. Error are displayed the in Image Math dialog box shown in Figure 6.6c.
7. You may invert (multiply by -1) either image without clicking ***Execute*** by clicking the Invert Image buttons.

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 or use ***History*** to restore the originally loaded file .

6.7  Lowpass

The ***Lowpass*** command effectively suppresses the high spatial frequency component by averaging the 3x3 pixel region centered on each pixel.

Data is analyzed in kernels (matrices), with every pixel individually recalculated based upon the values of its neighboring pixels.

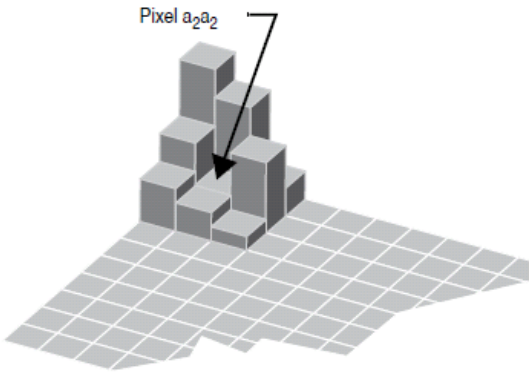


Figure 6.7a: Lowpass Data Analysis Depiction

The ***Lowpass*** filter always uses a 3x3 kernel.

Because of long reaching legacy reasons, we call this filter ***Lowpass***. Yes, it would have been better if named we had called it ***Mean*** or ***Average*** filter. If you are looking for a "real" lowpass filter, see the Gaussian (page 176) or Spectrum 2D (page 198) image modification functions.

6.7.1 Lowpass Procedure

1. Select an image file from the ***Browse*** window at the right of the main window. Double-click the thumb-nail image to select and open the image.
2. Open the ***LowPass*** view by selecting Filter > Lowpass from the ***Menu*** bar or by clicking on the Lowpass icon from the ***Icon*** toolbar.

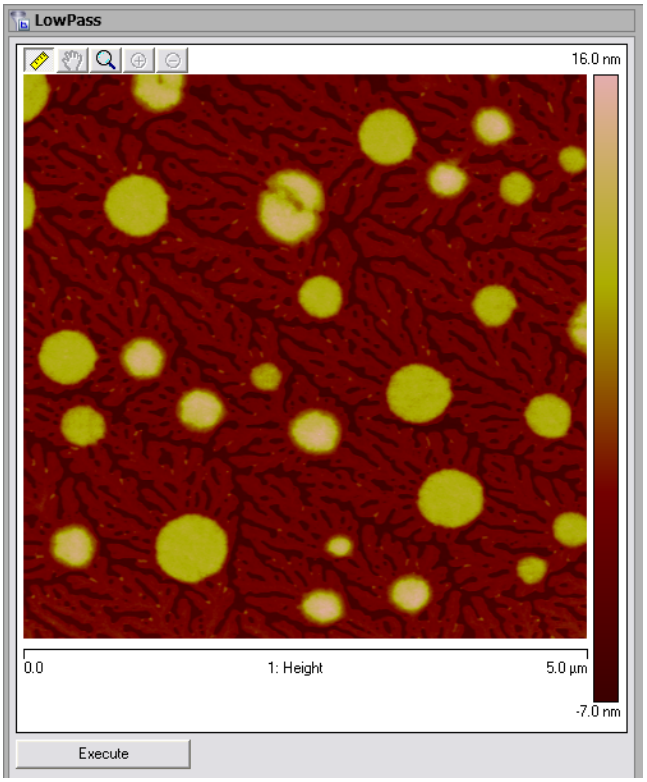


Figure 6.7b: LowPass Window

3. Click the **Execute** button to apply the filter to the image.
4. To restore the unprocessed image, click the **Undo** button or go back in the data ***History***.
5. The filter always applies a 3x3 filter to the image. The filter may be applied multiple times for increased blurring effects, as seen below.

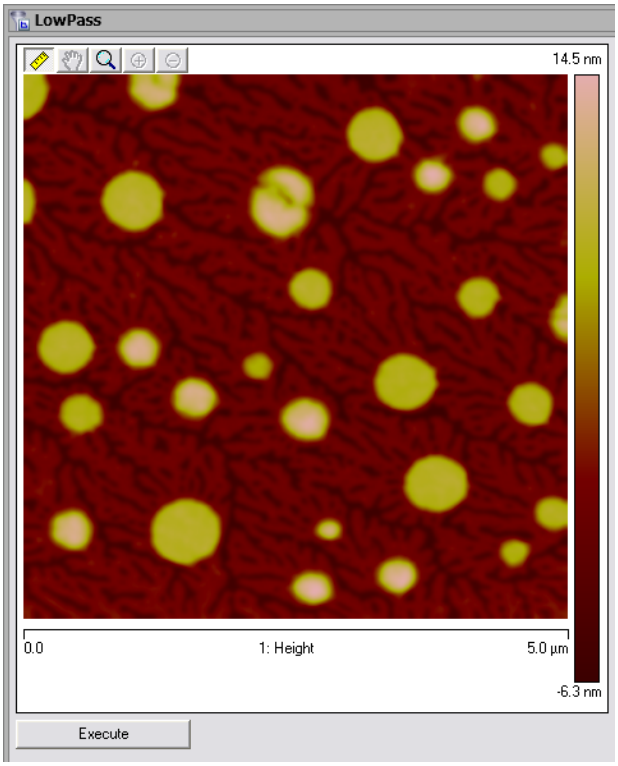


Figure 6.7c: LowPass Filter Applied, Blur Increased

6.8 Median

The ***Median*** modify command is similar to ***Lowpass***; it reduces the contributions of high spatial frequency, reducing contrast in regions of high contrast. The advantage of ***Median*** over ***Lowpass*** (averaging) filter is that the Median will eliminate lone "bad pixels" without significantly affecting the resolution of the image.

6.8.1 Median Theory

In the ***Median*** command, 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 3x3 or 5x5 matrix operation to each image pixel.

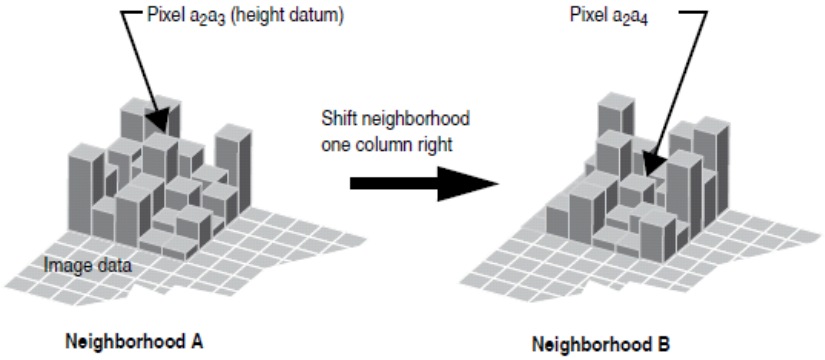


Figure 6.8a: Median Data Analysis Depiction

NOTE: Each pixel is individually evaluated within its own local, 5x5 “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.

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.)

The size of the filter’s sliding window pixel array is set under Inputs > Median Order. Increasing the Median Order increases the pool of pixels from which each value is calculated, and effectively increases the blurring effects of the filter.

NOTE: The effects of three different size pixel arrays (3x3, 7x7, 11x11, left to right) applied to the same image are shown below.

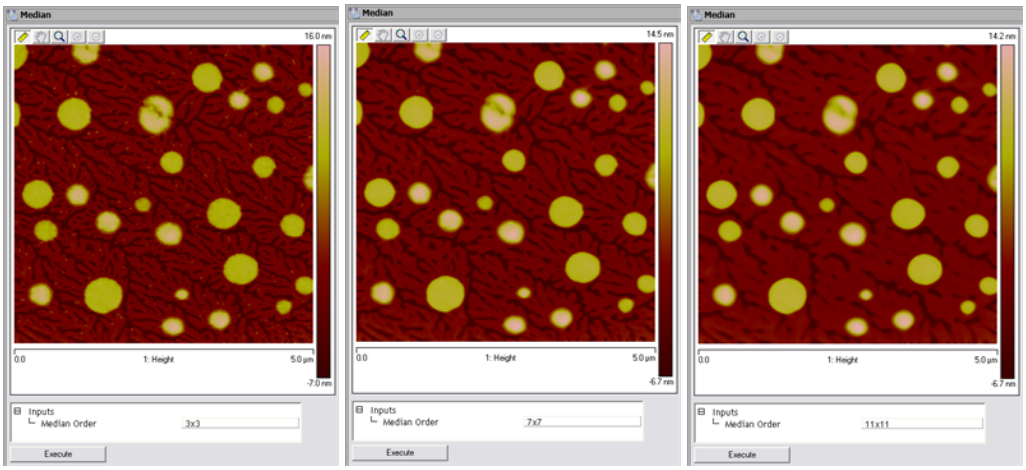


Figure 6.8b: Median Pixel Array Effects

6.8.2 Median Procedure

1. Select an image file from the ***Browse*** window at the right of the main window. Double click the thumbnail image to select and open the image.
2. Open the ***Median*** filter by selecting Filter > Median from the ***Menu*** bar or clicking on the Median icon from the ***Icon*** toolbar.
3. Select the Median Order from the Inputs menu: 3x3, 5x5, 7x7, 9x9, or 11x11.
4. Click Execute to apply the ***Median*** filter.

6.9 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 6.9a depicts an image with tilt and bow which could affect the analysis of the surface data.

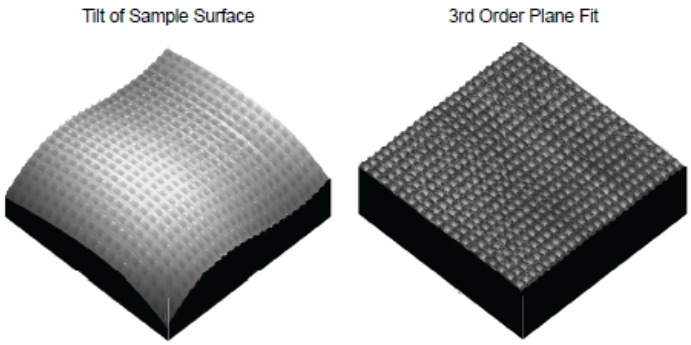


Figure 6.9a: Visual Representation of Planefit

Fitted Polynomials

Refer to Table: 6.0as to view the polynomials that calculate the best plane fit for the images in the ***Plane Fit*** function.

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	$z = a+by+cy^2$

Order	Variable	Polynomial Equation
	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)	$z = a + bx + cy + dxy + ex^2 + fy^2+ gxy^2 + hx^2y + ix^2y^2 + jx^3 + ky^3 + lxy^3 + mx^2y^3 +nx^3y^3 +ox^3y + px^3y^2$

Table: 6.0as Fitted Polynomials

Plane Fit Procedure

Use ***Plane Fit*** to correct an image for distortion as follows:

1. Select an image file from the file ***Browse*** window. Double click the thumbnail image to open the image.
2. Select ***Filters > Plane Fit***from the ***Menu*** bar or click on the ***Plane fit*** icon from the ***Icon*** toolbar.
3. The ***Plane Fit*** input parameters appear along with the top view image.
4. Select X, Y, or XY as the ***Plane Fit Mode***.
5. Select the ***Plane fit Order*** as ***Oth***, ***1st***, ***2nd***, or ***3rd***.
6. Click ***Execute***
7. Notice that the image distortion is removed, reflecting a flat, planar profile.

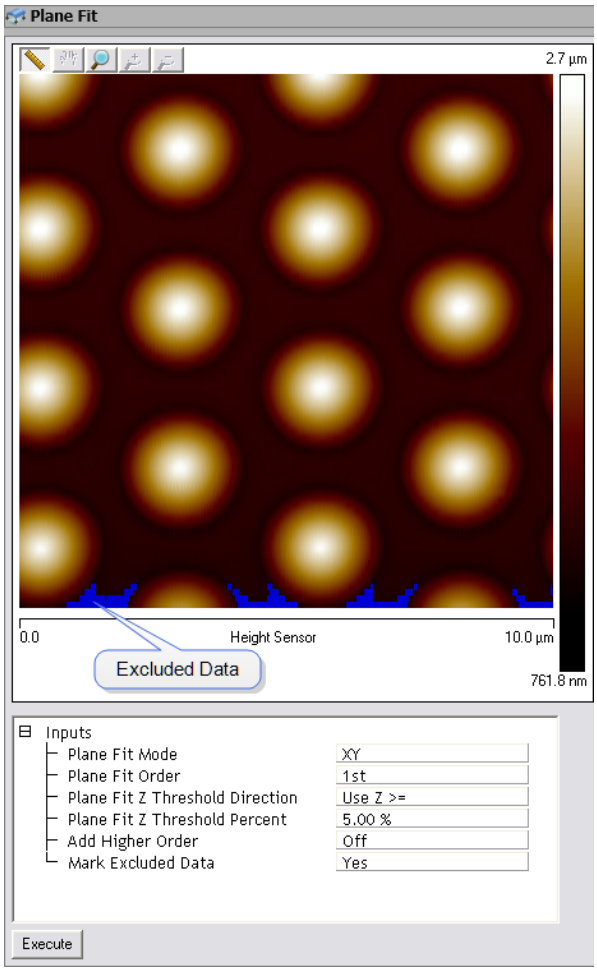


Figure 6.9b: ***Plane Fit*** View

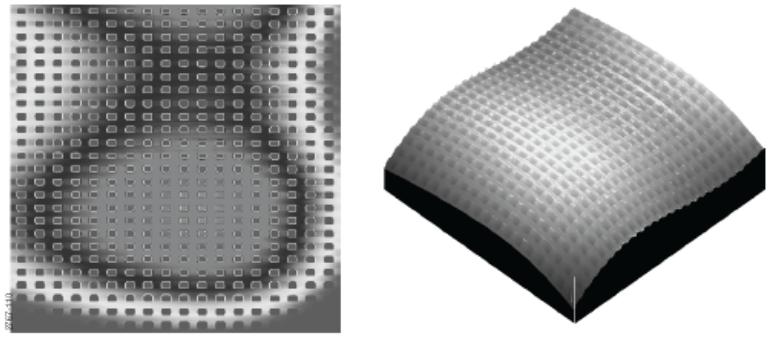


Figure 6.9c: Saddle Image Before Plane fit

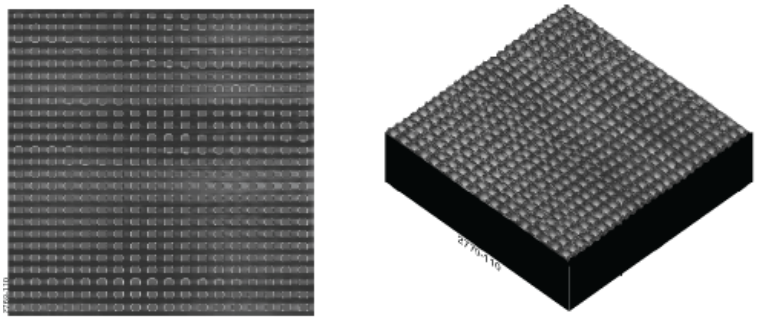


Figure 6.9d: Image after Plane Fit

Now, experiment with an 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 planefitting 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 ***Planefit 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.

Plane Fit Interface

The ***Plane Fit*** dialog box allows the display parameters and the ***Plane Fit Order*** to be adjusted to your preferences.

Parameter	Description
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.

Parameter	Description
Plane Fit Z Thresholding Direction	Specifies the range of data to be used for the polynomial calculation based on the distribution of the data in Z: *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.
Plane Fit Z Threshold 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.
Mark Excluded Data	Displays (in blue) data that has been excluded (by the Z Thresholding operation) from the calculation.

Table: 6.0at ***Plane fit*** Parameters

Button	Description
Execute	Initiates the plane fit operation.

Table: 6.0au Buttons on the ***Plane Fit*** Panel

6.10 Rotate

The ***Rotate*** filter command allows for the arbitrary rotation of images.

6.10.1 Rotate Procedure & Interface

1. Select an image file from the file browsing window at the right of the main window. Double-click or drag the thumbnail image to select and open the image.
2. Open the ***Rotate*** filter by selecting Filter > Rotate from the ***Menu*** bar or by clicking the Rotate icon in the ***Icon*** toolbar. The ***Rotate*** window, shown in Figure 6.10a,opens.

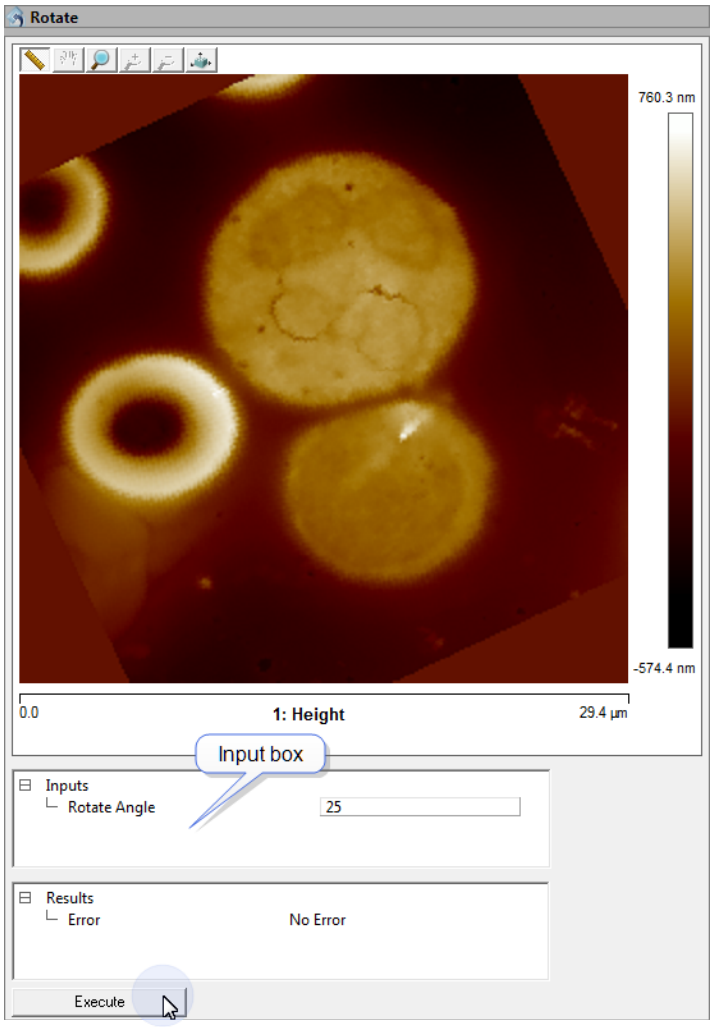


Figure 6.10a: Rotate Menu & Window

3. In the ***Input*** box, enter the preferred rotation angle and click the **Execute** button. The image is rotated to the desired angle. Use the **Undo** and **Redo** buttons to go back and forth, as desired.

6.11 Spectrum 2D

The ***Spectrum 2D*** (two-dimensional) image modification function transforms image data (spatial domain) into the frequency domain and back via a 2D fast Fourier transform (FFT). By selectively passing or removing specific frequencies from the spectrum, filtered images may be reconstructed, yielding modified and enhanced versions of the image data.

The ***Spectrum 2D*** function may be used either as a ***high pass***, ***low pass***, or ***band pass***, or ***notch*** filter. Practical applications include removing electrical and acoustic noise from images or isolating certain surface features (e.g., lathe lines on turned surfaces, load marks on ground or polished surfaces, etc.).

Using Spectrum 2D as a Low Pass Filter

Sometimes it is desirable to eliminate high frequency components of an image to better isolate and remove noise from an image. Typically, this would be done with the ***Spectrum 2D*** function by enclosing the central cluster of the spectrum within a passband.

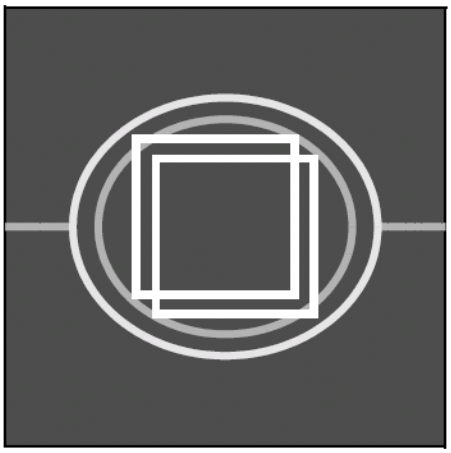


Figure 6.11a: Passband Example

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.

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.

Using Spectrum 2D to Highlight Features (Band Pass Filter)

The ***Spectrum 2D*** function may be used to highlight certain surface features by filtering out spatial frequencies

along a particular axis. It is possible to do this by drawing a band pass region over a particular region of the spectrum. This might be useful in isolating and accentuating smaller surface features inherent within lines oriented along a particular axis.

To filter out vertcially oriented features, a passband should be drawn on with horizontal orientation on the spectrum. Horizontally distributed features would be passed, while vertically oriented features would be filtered.

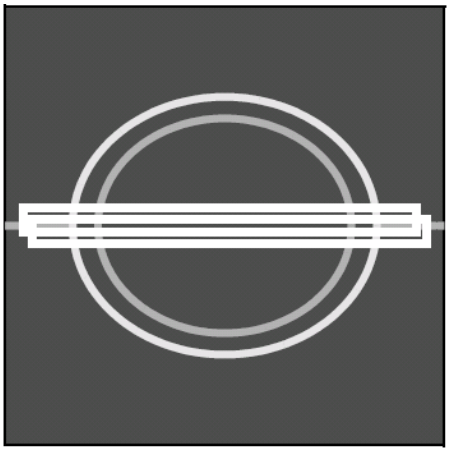


Figure 6.11b: Horizontal Passband

Conversely, the vertically distributed features may be similarly examined by drawing a passband vertically, thus filtering out the horizontal components.

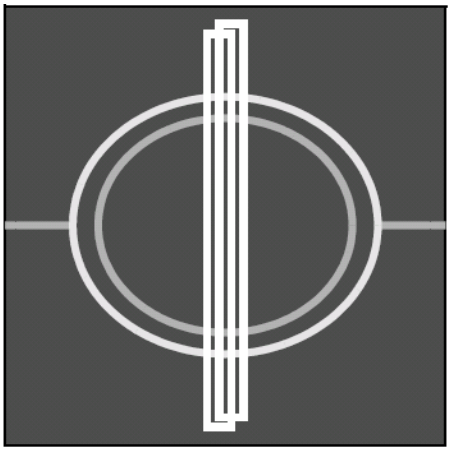


Figure 6.11c: Vertical Passband

Using Spectrum 2D to Remove Noise (Notch Filter)

If high frequency surface noise is evenly distributed across the spectrum, a passband around the center of the

spectral plot could be used as low pass filter to remove multi-spectral high frequency features. However, if the image contains high frequency noise of a particular frequency, then ***Spectrum 2D*** may also be used as a ***Notch Filter*** to remove only the offending frequency.

If the noise source is a particular electrical or vibrational frequency, the frequency shows up in the FFT spectrum as spectral "hot spots". These spots may be removed by drawing a stop band over just these regions and then performing an InverseFFT.

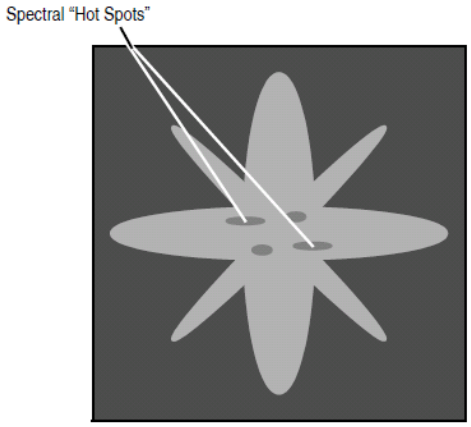


Figure 6.11d: Example of Hot Spots

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.

Spectrum 2D Procedures

The ***Spectrum 2D*** command allows filtering of images in the frequency domain through the 2-dimensional Fast Fourier transform (FFT). As the cursor is moved through the 2D plot, instantaneous results are displayed.

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. Doubleclick the thumbnail image to select and open the image.
2. Open the ***Spectrum 2D*** view by selecting Filter > Spectrum 2D or by clicking on the Spectrum 2D icon from the ***Icon*** toolbar.

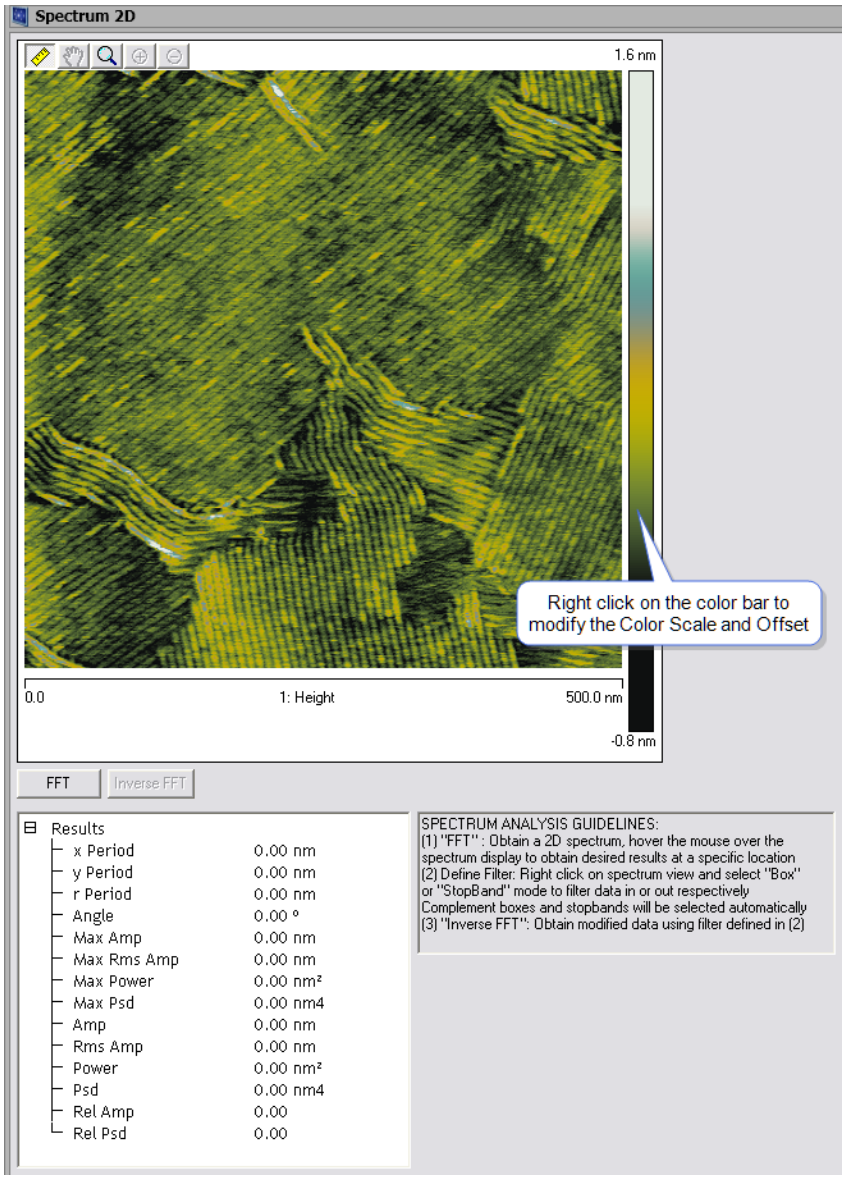


Figure 6.11e: Spectrum 2D Window

3. Click on the FFT button to perform a two dimensional Fast Fourier Transform on the data. The frequency spectrum image will appear in the image view.
4. Sometimes the finer high frequency features of the transformed image are not visible without adjusting the color settings. Experiment with the color mapping using the Offset and Scale values (right click on the color scale) to best view the FFT spectrum's finer features. Refer toColor Scale (page 29) for details.

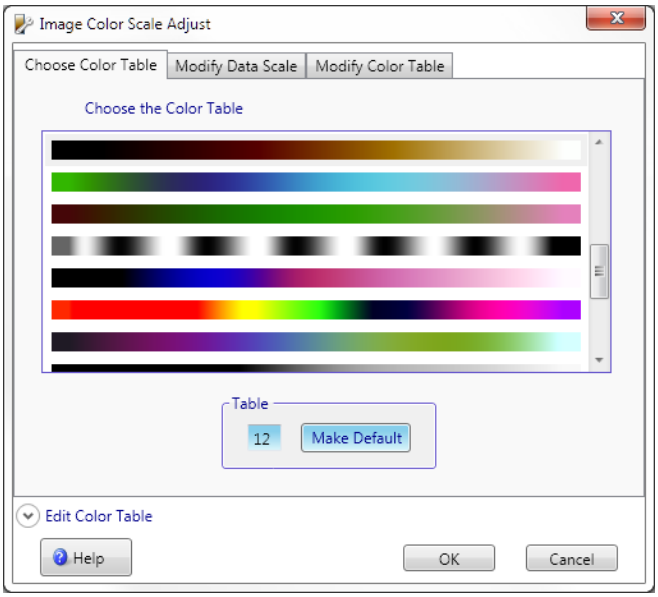


Figure 6.11f: Color Scale Window

5. Select regions to filter by right clicking to select mode. Selected regions may either be marked to include in the filter with the passband ***Box*** or excluded with the ***Stop Band***.

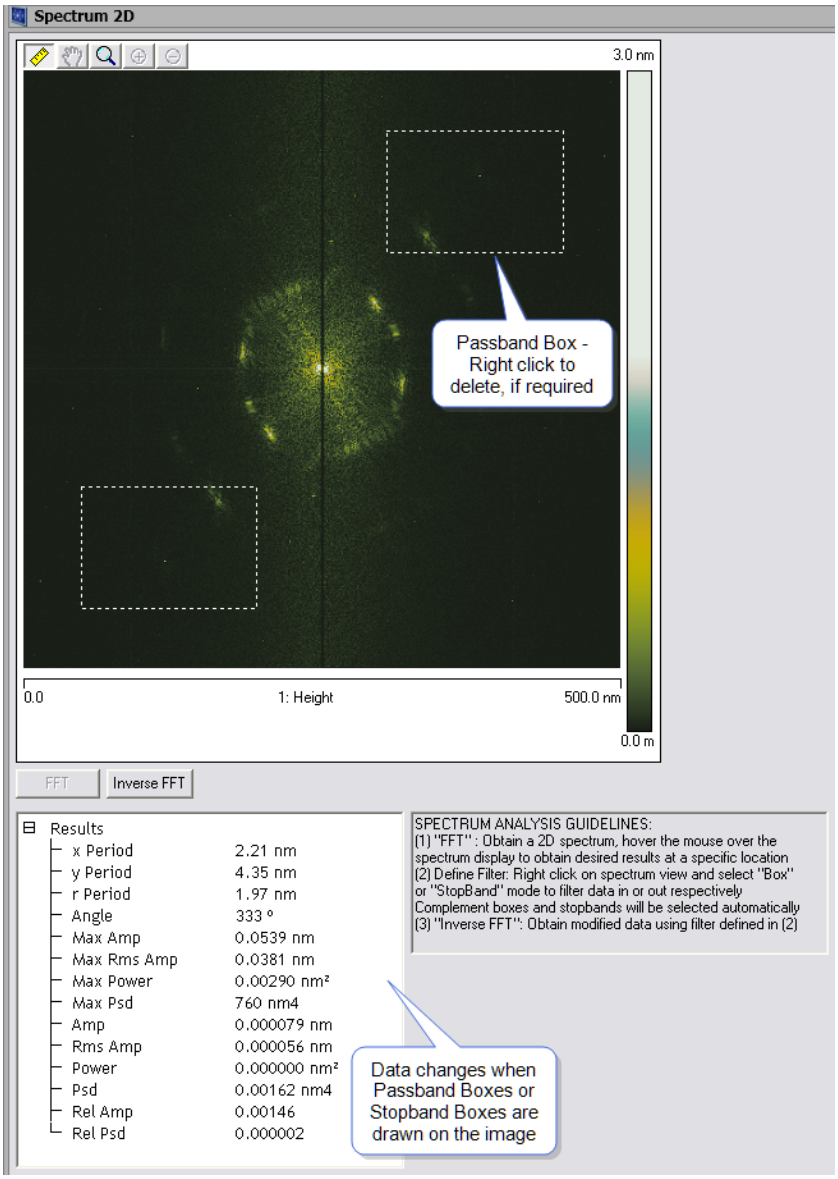


Figure 6.11g: Passband Boxes Drawn Into Image

6. 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.
7. 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.
8. Individual boxes and stopbands may be deleted by right clicking on an individual box and selecting the ***Delete*** command. The entire field of boxes and stopbands may be cleared with the ***Clear All*** command.
9. When the desired regions are selected, press the ***InverseFFT*** to return to the spatial domain.

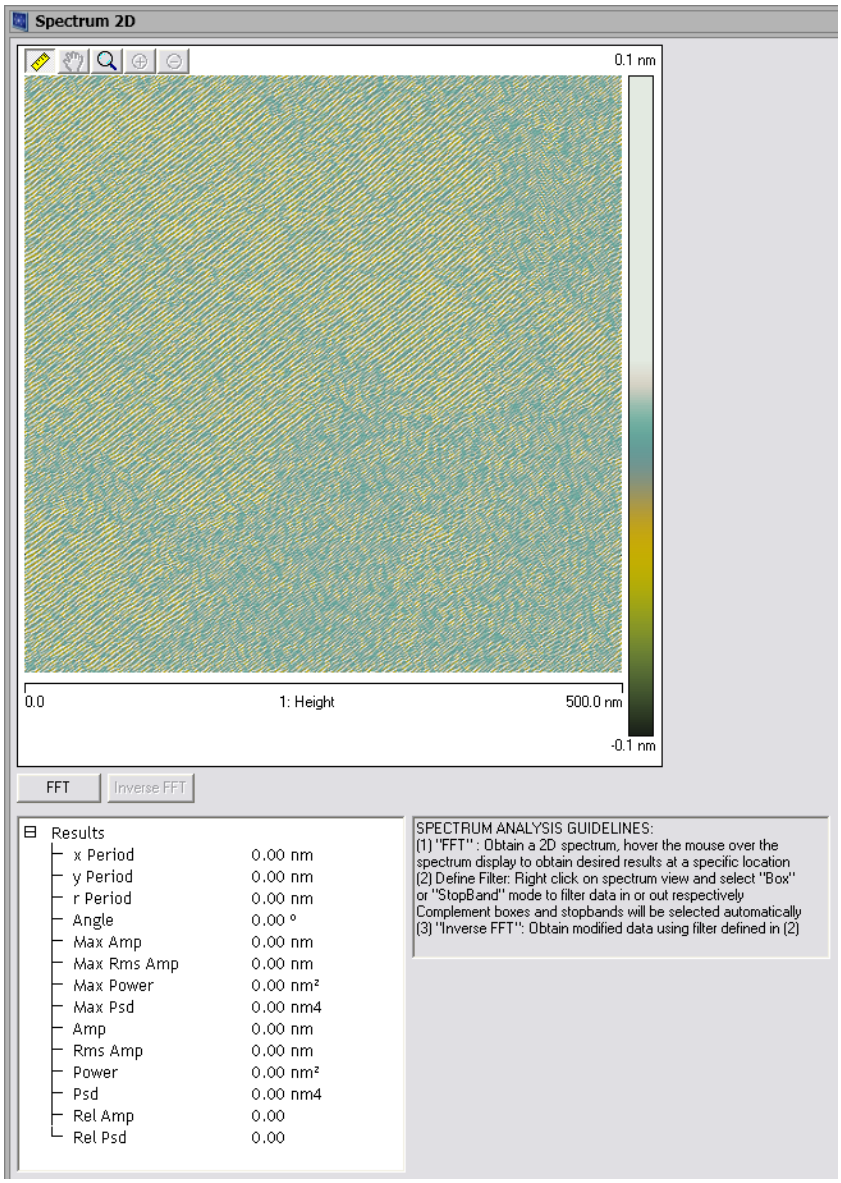


Figure 6.11h: Spatial Domain

10. You may pass back and forth between the spatial and frequency domains, or you may reload the image to start over by clicking on the original image in the data ***History***.

Parameter	Description
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	The maximum of the RMS amplitude of the transformed image.

Parameter	Description
RMS Amp	
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	Amplitude2 = (2D FFT)2
Psd	Normalized power spectrum per number of points = (2DFFT * # x_points * # y_points)2/(# x_ points * # y_points)
Rel Amp	Amplitude / (Max Amplitude)
Rel Psd	PSD / (Max PSD)

Table: 6.0av Results Parameters in Spectrum 2D

Chapter 7: Force Curve & Ramping Analysis

Force Curve analysis functions display the results of experiments where the tip-sample separation is varied at each XY position. ***Ramping*** analysis functions are two-dimensional data sets where up to three data channels are measured simultaneously while a control parameter (z-position, tip bias, sample bias, etc...) is varied. During the Ramping, the XY position is held constant.

Force Commands can be opened using the ***Menu*** bar or by clicking on the appropriate icon from the ***Icon*** toolbar.

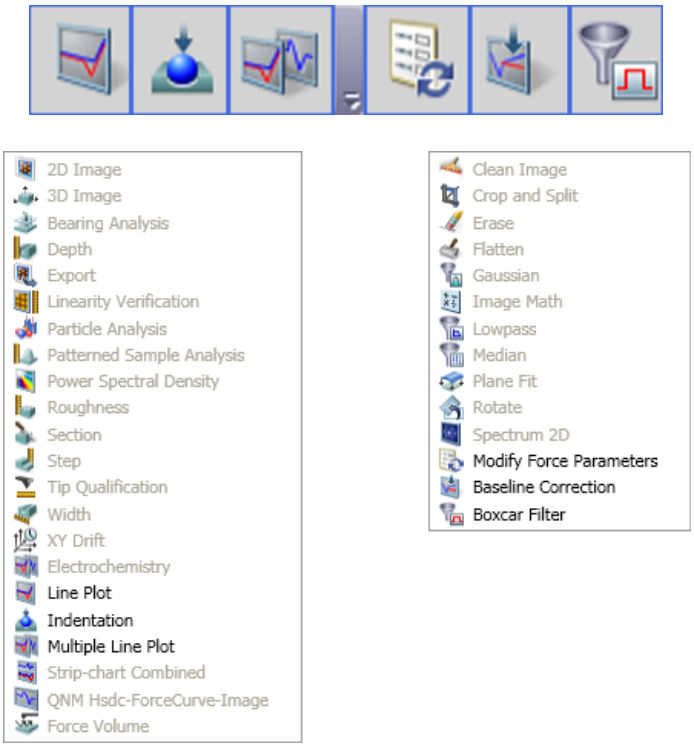


Figure 7.0a: The Force icons (above) and the Analysis Force menu (bottom left) and Filters Force menu (bottom right)

The following ***Force Curve*** analysis and ***Ramping*** analysis commands are available in NanoScope Analysis 1.50:

- Line Plot & Multiple Line Plot
- Line Plot - Update Sensitivity
- Indentation Analysis (page 244)
- Force Volume
- Review Force Curves (page 236)
- Filtering Multiple Force Curves (page 237)
- Multiple Curve analysis (MCA)
- Modify Force Parameters (page 243)

- Baseline Correction (page 249)
- Boxcar Filter (page 252)
- MATLAB Utilities (page 254)

7.1 Force Curves and Run AutoProgram

You may can use the Run AutoProgram (page 54) function to process and analyze a group of force curves. For instance, you may wish to change the Tip half Angle and Sample Poisson's Ratio then Correct the Baseline and then perform an Indentation Analysis (page 244). See Figure 7.1a.

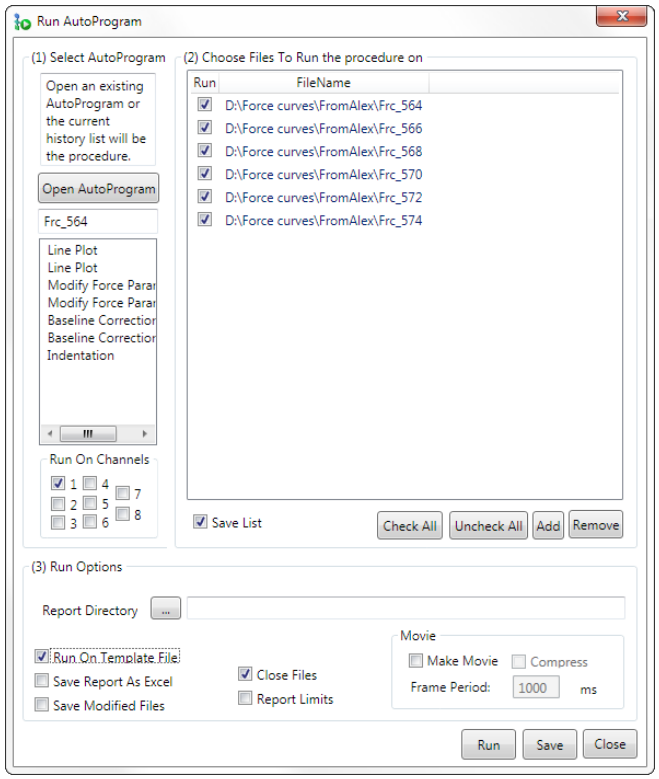


Figure 7.1a: Force functions **Run AutoProgram**

7.2 Line Plot & Multiple Line Plot

Theory

Line Plots and ***Multiple Line Plots*** allow visualization of two-dimensional data sets such as Ramps, ***Strip-charts***, and ***High Speed Data Capture*** (HSDC). Ramps are two-dimensional data sets where up to three data channels are measured simultaneously while a control parameter (z-position, tip bias, sample bias, etc...) is varied. ***Strip-charts*** record up to 8 channels of data versus time. ***HSDC*** is a special kind of strip-chart that allows up to 2 high speed channels and two medium speed channels to be compared versus time.

A ***Force Curve*** is a type of ramp whereby scanner's vertical position is typically plotted versus either the cantilever deflection (Contact AFM), or the amplitude of the cantilever oscillation (Tapping Mode). The X, Y position is held constant at the center of the previous scan.

Other types of ramps are used in STM (current vs. sample bias), SCM (dC/dV vs. sample bias), PFM (PR amplitude or Phase vs. tip bias), etc.

Force Curve Procedure

To use the ***Line Plot*** analysis in the NanoScope Analysis, open the preferred force curve image in the software by clicking on the Open File button or by clicking on the Browse Files button. Once the image is open follow these steps:

1. When the image is opened it should look similar to the image below. The marker data is non-existent as no markers have been added to the ***Line Plot***.

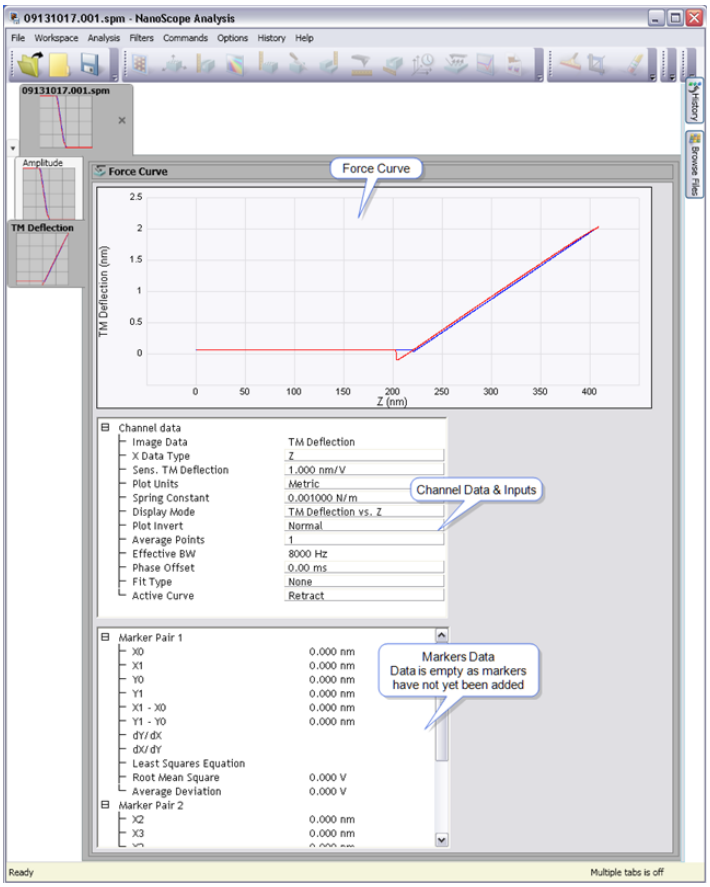


Figure 7.2a: The Line Plot Window

2. To add markers to the ***Line Plot***, position the mouse in the ***Line Plot*** graph area to the left of the Y axis. The standard cursor will change to a double-headed cursor (see Figure 7.2b). When the *double-headed cursor* appears, left-click the mouse, and drag the cursor to the desired position on the ***Line Plot***. The data for the position is automatically updated in the ***Marker Pair Results*** area.

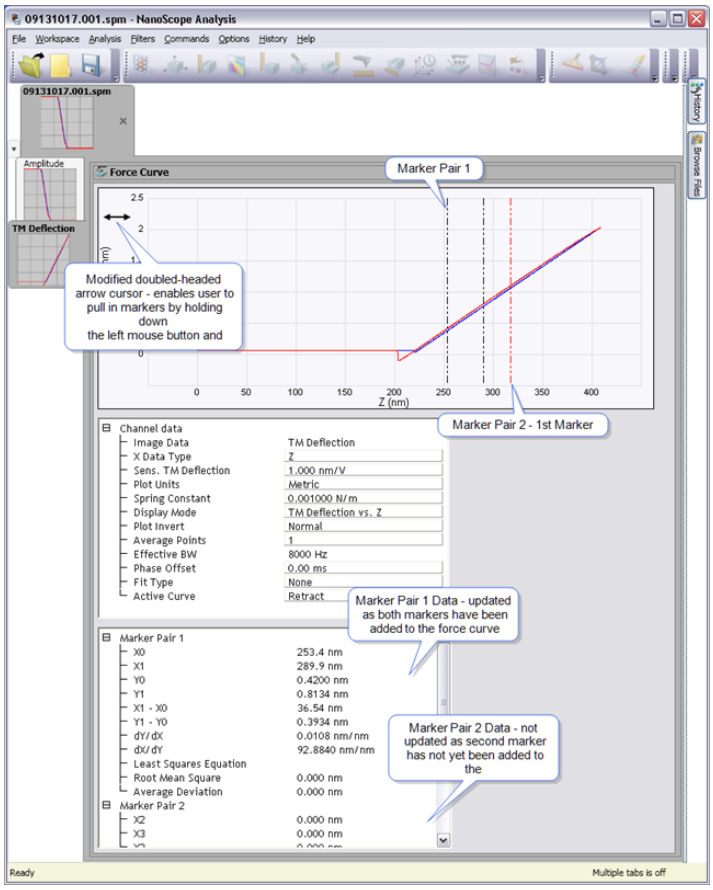


Figure 7.2b: Adding Markers to a Line Plot

3. To open a ***Multiple Line Plot***, click on the ***Multiple Line Plot*** icon from the Analysis toolbar.See the ***Multiple Line Plot*** window shown in Figure 7.2c.

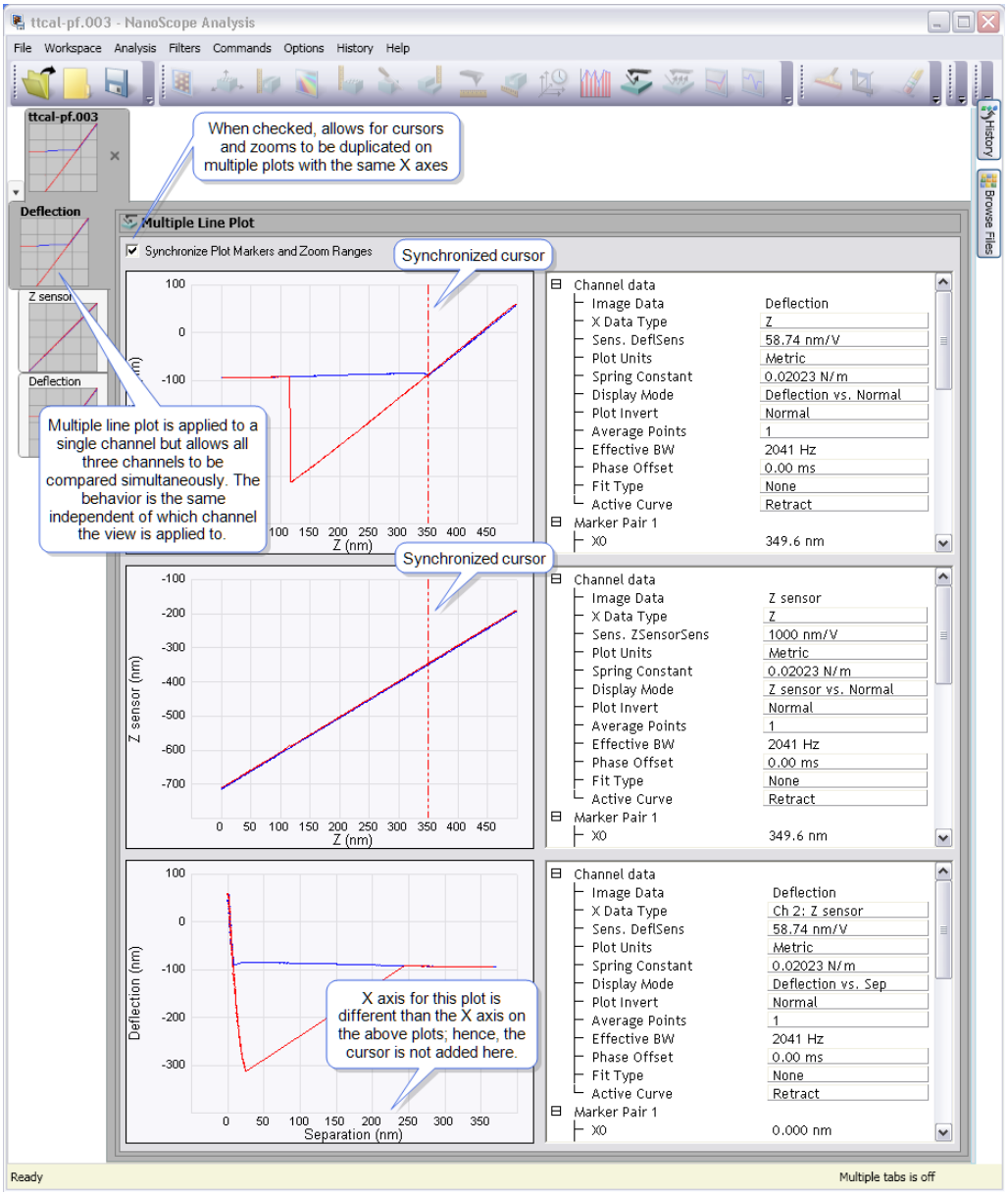


Figure 7.2c: Multiple Line Plot Window

4. To measure adhesion, change the Active Curve parameter to Retract, and the Plot Units to Force. Move Marker 0 in Pair 1 just to the left of the pull-off point and Marker 1 in Pair 1 to the right of the pull-off point. See Figure 7.2d.

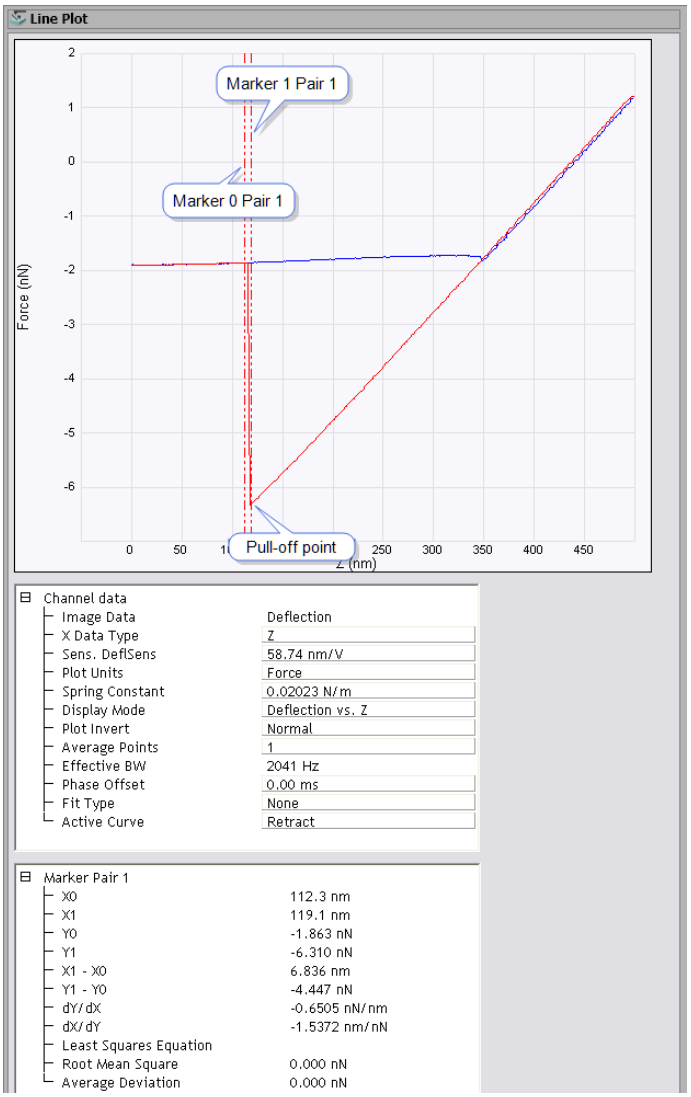


Figure 7.2d: Adhesion Measurement Example

5. To Zoom in on the area of interest hold down the Control key and draw a box in the preferred area of the Line Plot. To zoom back out, double-click on the image or click on the magnifying glass icon.

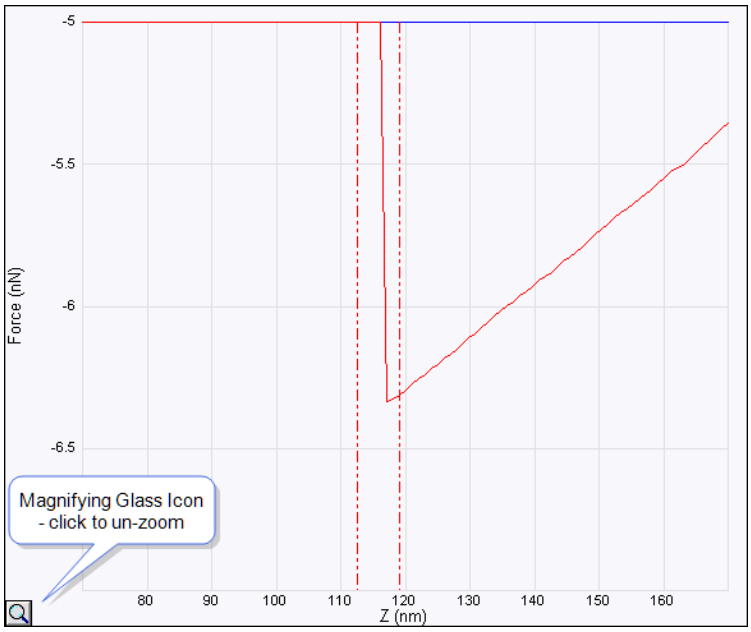


Figure 7.2e: Zoom Example

6. To re-center the Y-axis drag a horizontal cursor from the top or bottom of the Line Plot. Once the cursor is positioned in the preferred location, right click in the plot and select Y-Translate.

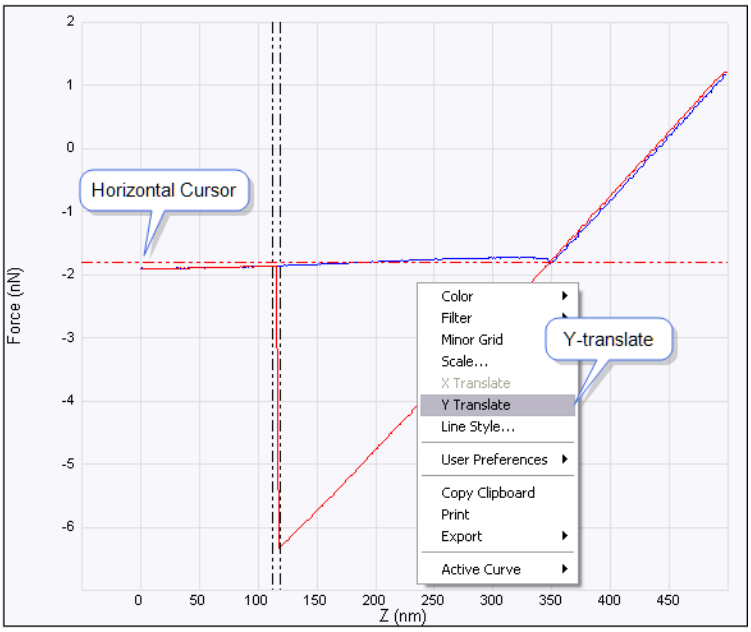


Figure 7.2f: Y-Translate Example

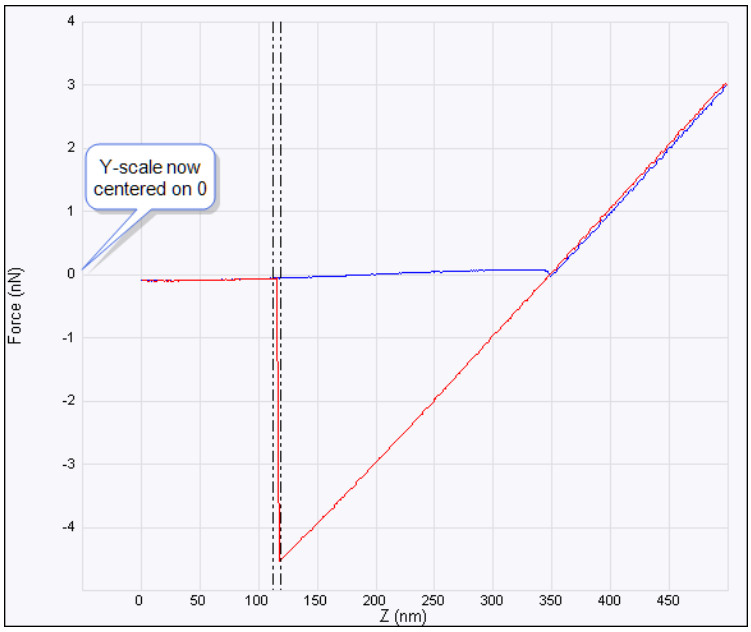


Figure 7.2g: Y-Translate In Effect

7. It is often advantageous to change the color of many of the items in the Line Plot so that they can be differentiated. To change the color of the Curves, Text, Background, Grid, or Markers, right click in the Line Plot and select Color > Preferred item to change. See Figure 7.2h.

NOTE: Curve 1 is called the Trace curve and curve 2 is called the Retrace curve. The Trace curve is done first and the Retrace second. In a Force Curve, the Trace curve is always bringing the tip and sample together, while the Retrace is separating them.

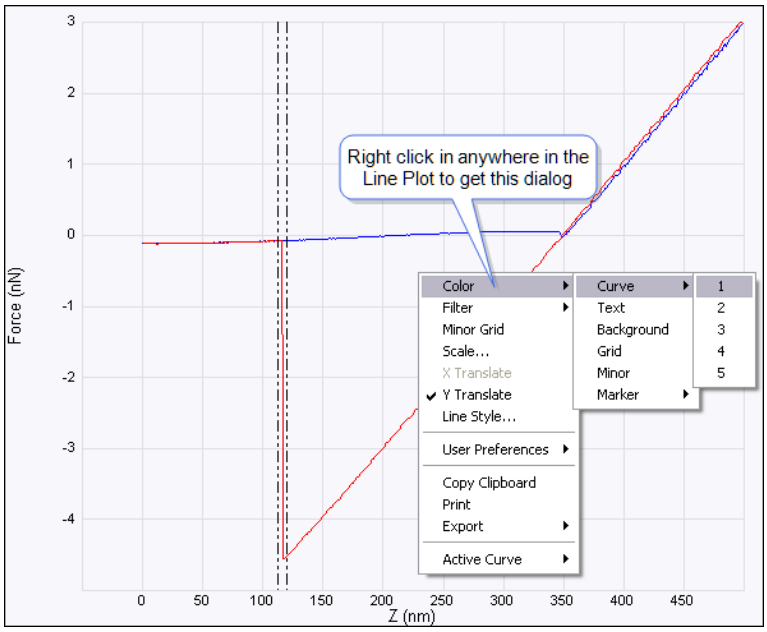


Figure 7.2h: Options to Change Color of Plot Items

8. It is sometimes helpful to add a Minor Grid to the Line Plot background. To do this, right click anywhere in the Line Plot and select Minor Grid. The background changes to add the Minor Grid per the image below.

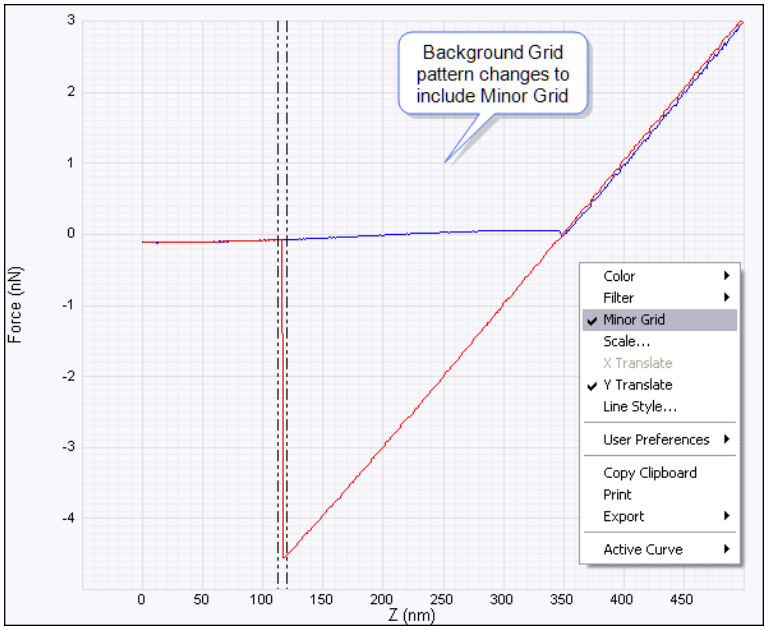


Figure 7.2i: Minor Grid Example

9. It is sometimes helpful to change the Line Style in the Line Plot. Choices for Line Style include Connect (Default), Fill Down and Point. To change the Line Style right click anywhere in the Line Plot and select Line Style.... The ***Grid Style*** dialog will open allowing the user to choose the preferred Line Style for each Curve. Make the selection and click the OK button.

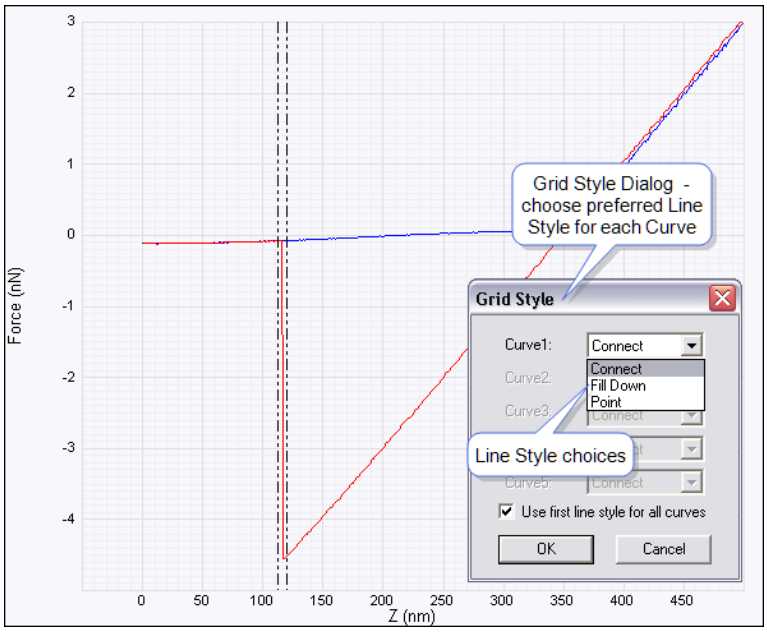


Figure 7.2j: Line Style Selection

10. Line Plot data or images are often required for Export. To Export, right click anywhere in the Line Plot and select Export > Graphic or XZ Data. The ***Save As*** dialog will open allowing the user to choose the location and filename for the exported file. The preferred graphic file to save images in is .bmp.

NOTE: When exporting XZ data, the data consists of a multi-column text file that represents the data as plotted (including X and Y translate, etc).

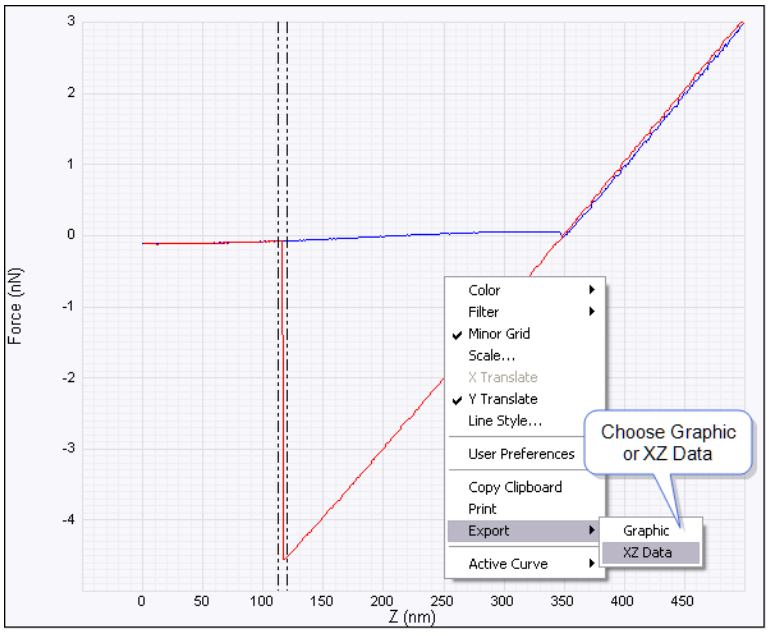


Figure 7.2k: Export Example

Display Mode & Hertzian Fit Example

The purpose of a separation plot is to show the force versus the tip-sample separation. This type of plot is necessary when fitting contact mechanics and pulling models.To create this type of plot requires an accurate deflection sensitivity and one of the data channels to be either deflection or TM deflection.

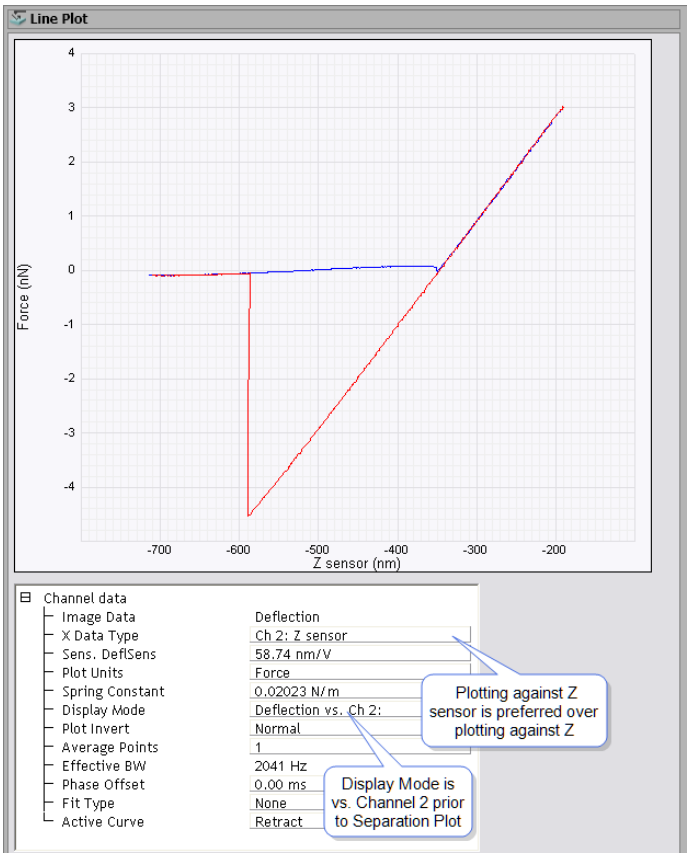


Figure 7.2l: Deflection vs. Z, Prior to Separation

1. Choose the separation mode.

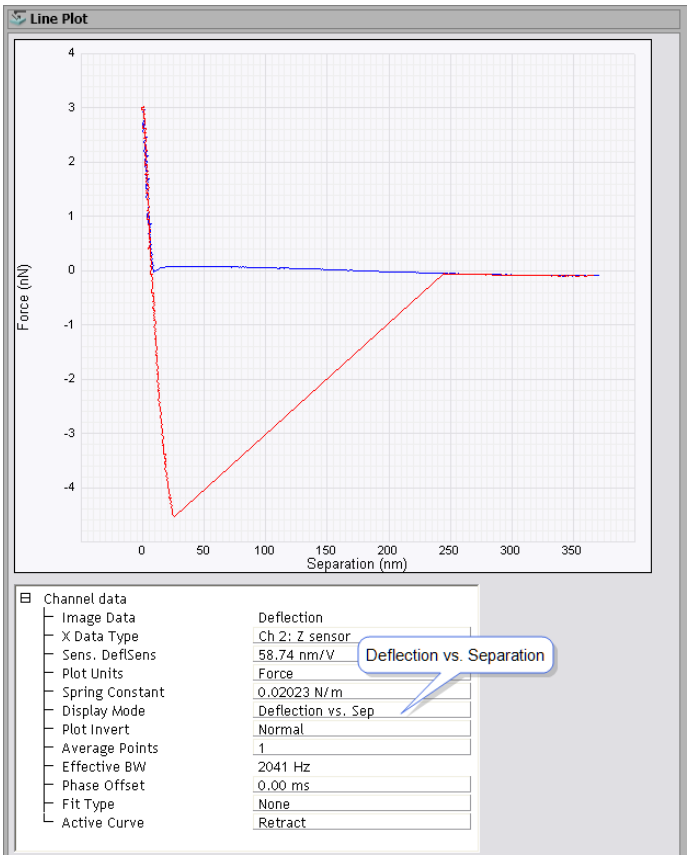


Figure 7.2m: Deflection vs. Separation

2. Place the cursors on the Plot in the unloading region. Zoom if for additional accuracy.
3. Active Curve should be set to Retract.
4. Set the Fit Type to Hertzian.

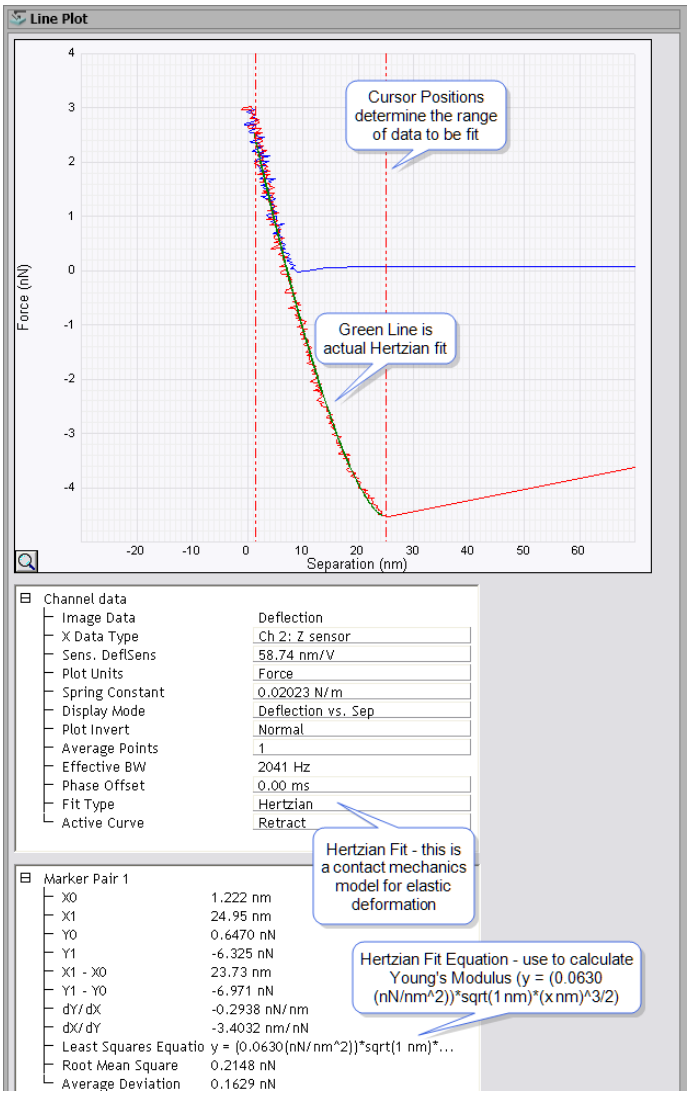


Figure 7.2n: Hertzian Fit Example

General Ramping: Piezoresponse Force Microscopy (PFM) Example

1. In PFM the tip or sample bias is ramped while observing the amplitude and/or phase of the cantilever deflection. In this case, the tip bias was ramped from -5V to +5V. PFM ramping is a powerful tool for observing the ferro-electric properties of materials.

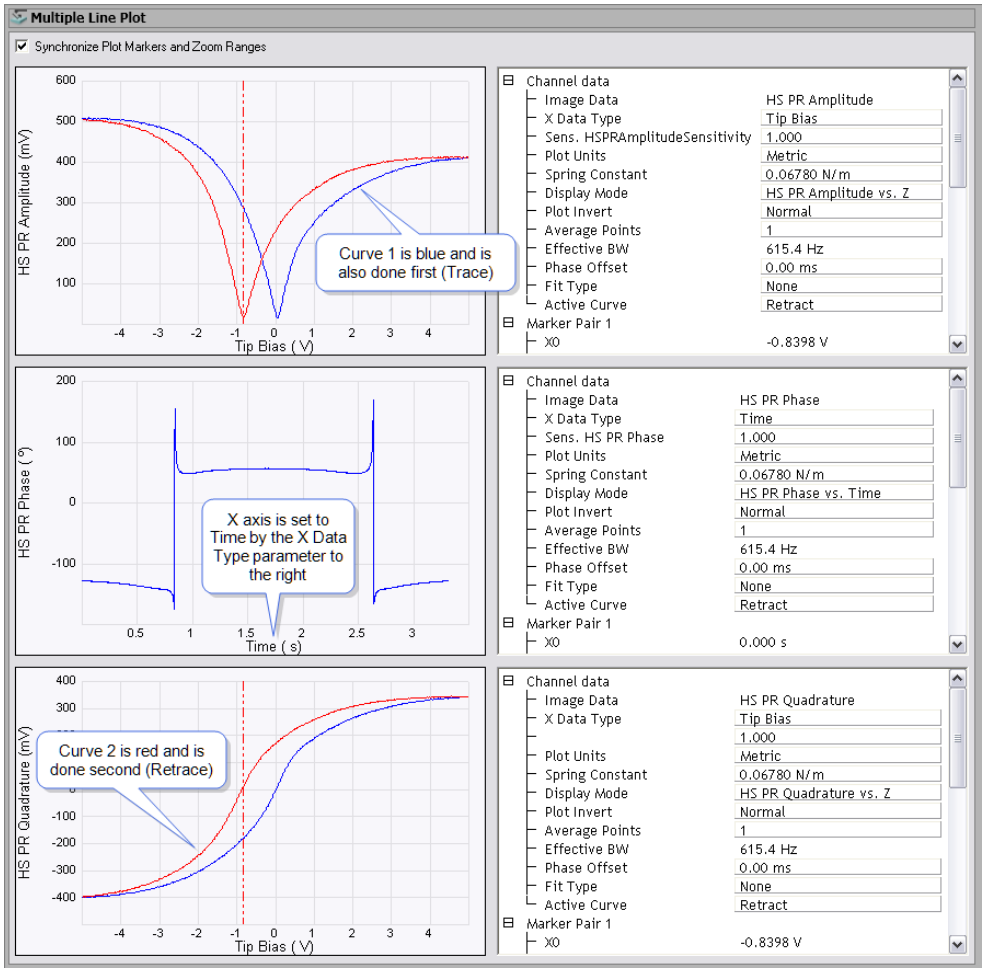


Figure 7.2o: PFM Example

Force Curve Interface

Parameter	Description
Image Data	Type of data originally taken for the particular channel (Y-axis).
X Data Type	Type of data that the channel data is being plotted against. This data displays on the X axis. Choices include Time, Ramp Channel (e.g. Z), or any of the other collected data channels.
Sens. Deflection	Sensitivity of the data channel. The name depends on the mode and what channel is being collected. Some examples include Sens. TM Deflection, Sens. DeflSens, etc...
Plot Units	Selects the units for the Y-axis of the plot. Switches parameters in the Results panel between units of Volts (V), Metric (nm or µm), or Force (nN).
Spring Constant	Used to calculate the Force if Plot Units are Force.

Parameter	Description
Display Mode	Changes the X-axis data to separation (including the effect of cantilever bending). Two options: Deflection vs. Ramp Channel (e.g. Z) or Deflection vs. Sep. Separation = deflection - Z position + constant (determined such that the separation is Zero at the turn around point)
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)/(Average Points)
Phase Offset	Shift horizontal position of plot to compensate for averaging of endpoint data.
Fit Type	Choose from None, Line, Hertzian, or WLC (Worm-like Chain - pulling model)
Active Curve	Choose from Approach or Retract

Table: 7.0aw Channel Data Input Parameters

Parameter	Description
Marker Pair 1:	
X0	Horizontal position of first marker, Marker Pair 1
X1	Horizontal position of second marker, Marker Pair 1
Y0	Vertical position of first marker, Marker Pair 1
Y1	Vertical position of second marker, Marker Pair 1
X1 - X0	Horizontal distance between markers in Marker Pair 1
Y1 - Y0	Vertical space between markers in Marker Pair 1
dY/dX	Slope of Marker Pair 1; calculated from endpoints
dX/dY	1/Slope of Marker Pair 1; calculated from endpoints
Least Squares Equation	Equation of the fit
Root Mean Square	RMS deviation from the fit
Average Deviation	Average deviation from the fit
Marker Pair 2:	
X2	Horizontal position of first marker, Marker Pair 2
X3	Horizontal position of second marker, Marker Pair 2
Y2	Vertical position of first marker, Marker Pair 2
Y3	Verticaln position of second marker, Marker Pair 2
X3 - X2	Horizontal distance between markers in Marker Pair 2
Y3 - Y2	Vertical space between markers in Marker Pair 2

Parameter	Description
dY/dX	Slope of Market Pair 2; calculated from endpoints
dX/dY	1/Slope of Marker Pair 2; calculated from endpoints
Least Squares Equation	Equation of the fit
Root Mean Square	RMS deviation from the fit
Average Deviation	Average deviation from the fit

Table: 7.0ax Marker Pair Parameters

Force Curve - Update Sensitivity

NanoScope Analysis allows for the updating of sensitivity on ***Line Plot*** files. To learn about this capability, go to the following link: Line Plot - Update Sensitivity

7.3 Force Curve - Update Sensitivity

NanoScope Analysis allows for the updating of sensitivity on ***Force Curves*** files. The goal of updating the sensitivity of a ***Force Curve*** is to calibrate the Y axis (Cantilever Deflection for Contact Mode or Amplitude for Tapping Mode).

7.3.1 Update Sensitivity Procedure

1. When updating sensitivity it is important to use the Z sensor channel (Height sensor) if available and to set the Active Curve to Retract. When placing cursors, it is preferred to place them such that they are over a linear section of the plot (not too close to the pull off or peak force). Additionally, select as long of a section as possible.

NOTE: When using the Update Sensitivity function, it is assumed that there is no deformation of the tip or sample. This requires a hard sample for the results to be valid.

2. After the ***Force Curve*** file has already been opened in NanoScope Analysis, select Command > Update Sensitivity from the ***Menu*** Bar, as shown in the image below.

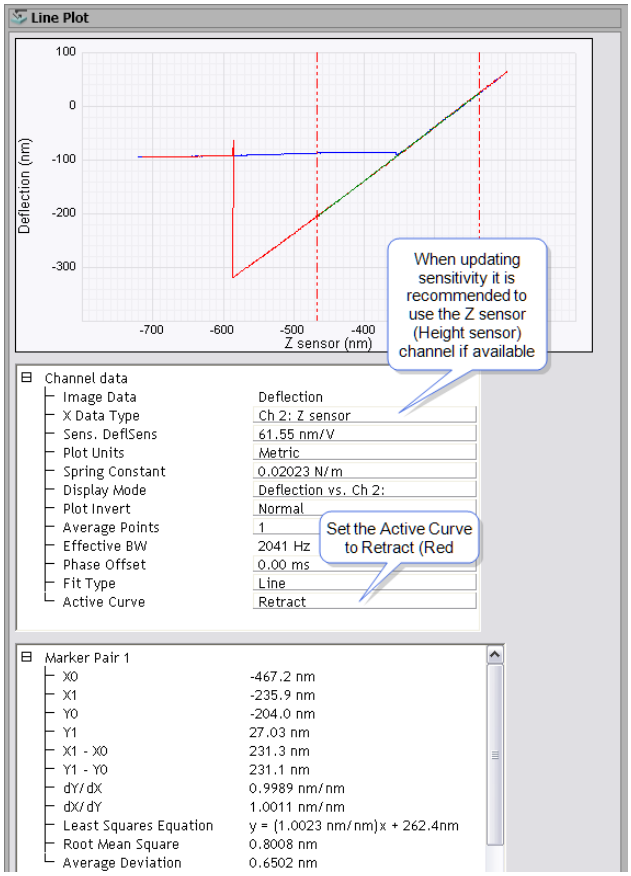


Figure 7.3a: Update Sensitivity Selection

3. The ***NanoScope Analysis*** window, shown below, will appear. Choose Yes to update the sensitivity.

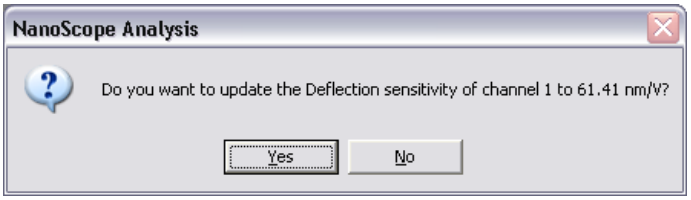


Figure 7.3b: NanoScope Analysis Window

4. The sensitivity is updated in the ***Force Curve*** window, as seen below.

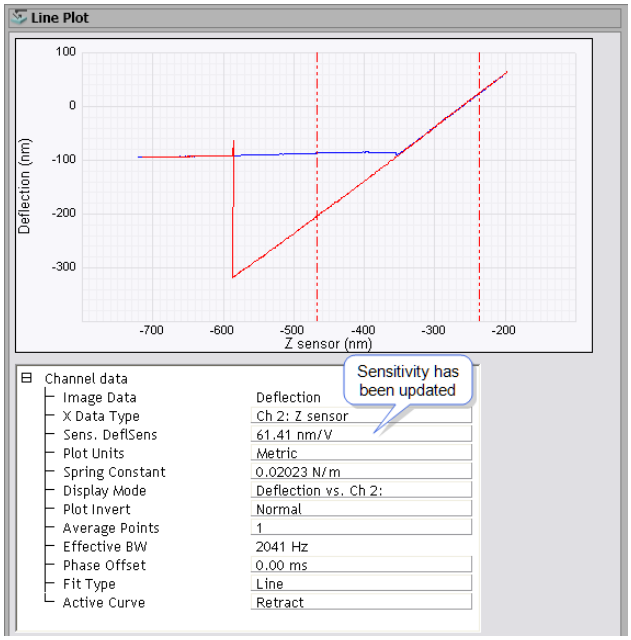


Figure 7.3c: Sensitivity Updated

7.4 Force Volume

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.

Theory

A single force curve records the force on the tip as it approaches and retracts from a point on the sample surface. When the Force reaches a user specified "trigger" value, the system records the height for that pixel and the tip retracts. 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. The height image is composed of the relative Z positions of the trigger points.

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, electric and magnetic fields. Force volume imaging enables the measurement of forces at various Z-positions and at thousands of (X,Y) positions during a single image scan.

7.4.1 Force Volume Procedure

1. Display individual force curves by first opening the file and then selecting the **Single** radio button from the ***Force Curve Mode*** selection dialog. Click the left mouse button on a specific pixel in any of the 3 images to display the associated ***Force Curve*** in the ***Force Plot*** region (see Figure 7.4a).

NOTE: The pixels in the images are marked with white crosses.

2. The Z value of the ***Deflection Error*** is displayed in the force volume image as a red vertical cursor at that particular Z value. Adjust the red cursor in the ***Force Plot*** region to find the position in the ***Deflection Error*** image that shows good contrast.

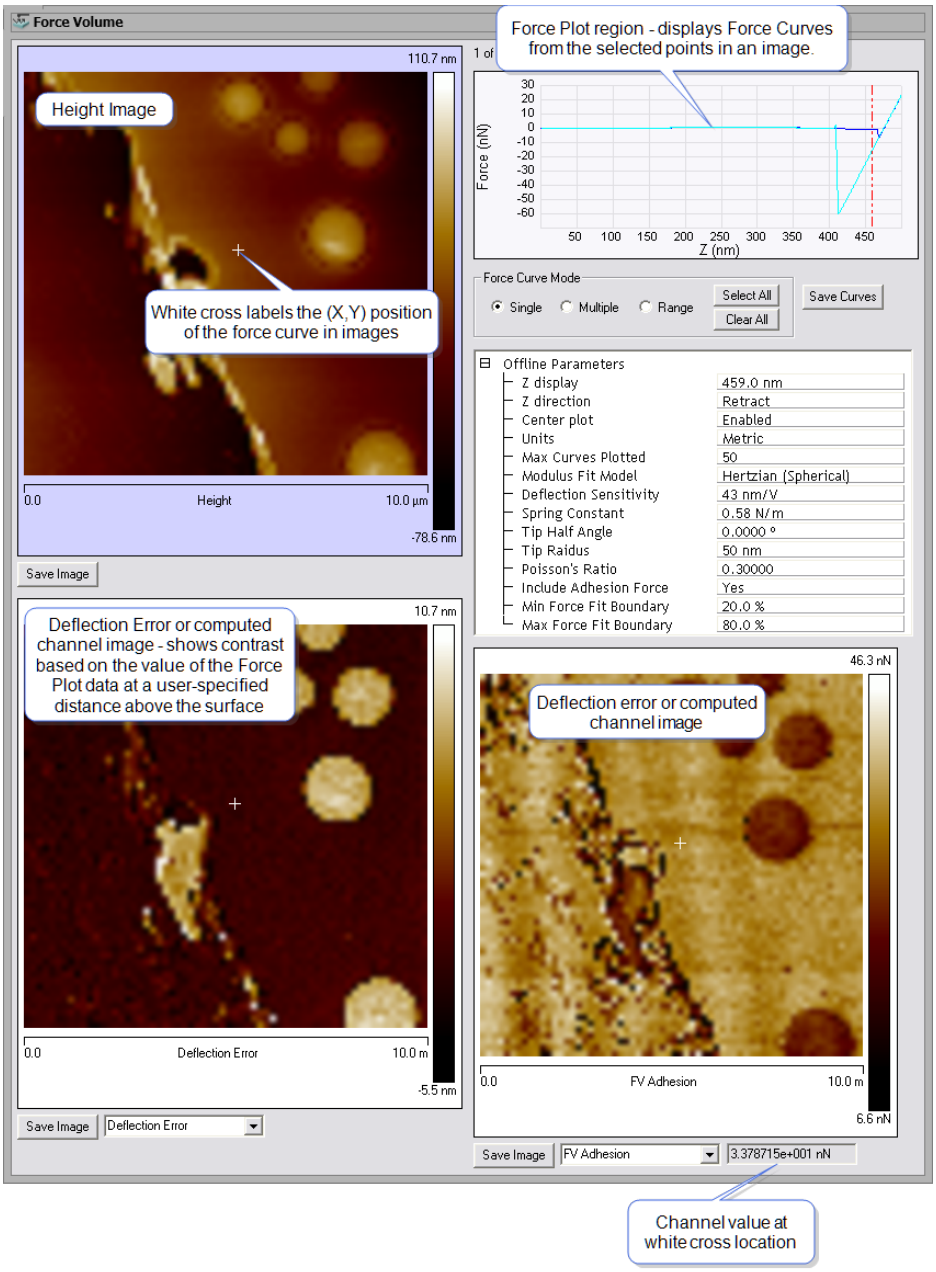


Figure 7.4a: Initial Force Volume View

3. Selecting the **Multiple** radio button from the ***Force Curve Mode*** selection dialog will display several force curves in the ***Force Plots*** region. Click an image in 2 areas with different contrast to display the associated force curve in the ***Force Plot*** region. Superimpose multiple force curves by selecting multiple pixels. Click on the **Clear All** button in the ***Force Curve Mode*** selection dialog to erase the force plots region. The source of the contrast in the image should now be depicted in the ***Force Plot*** region.

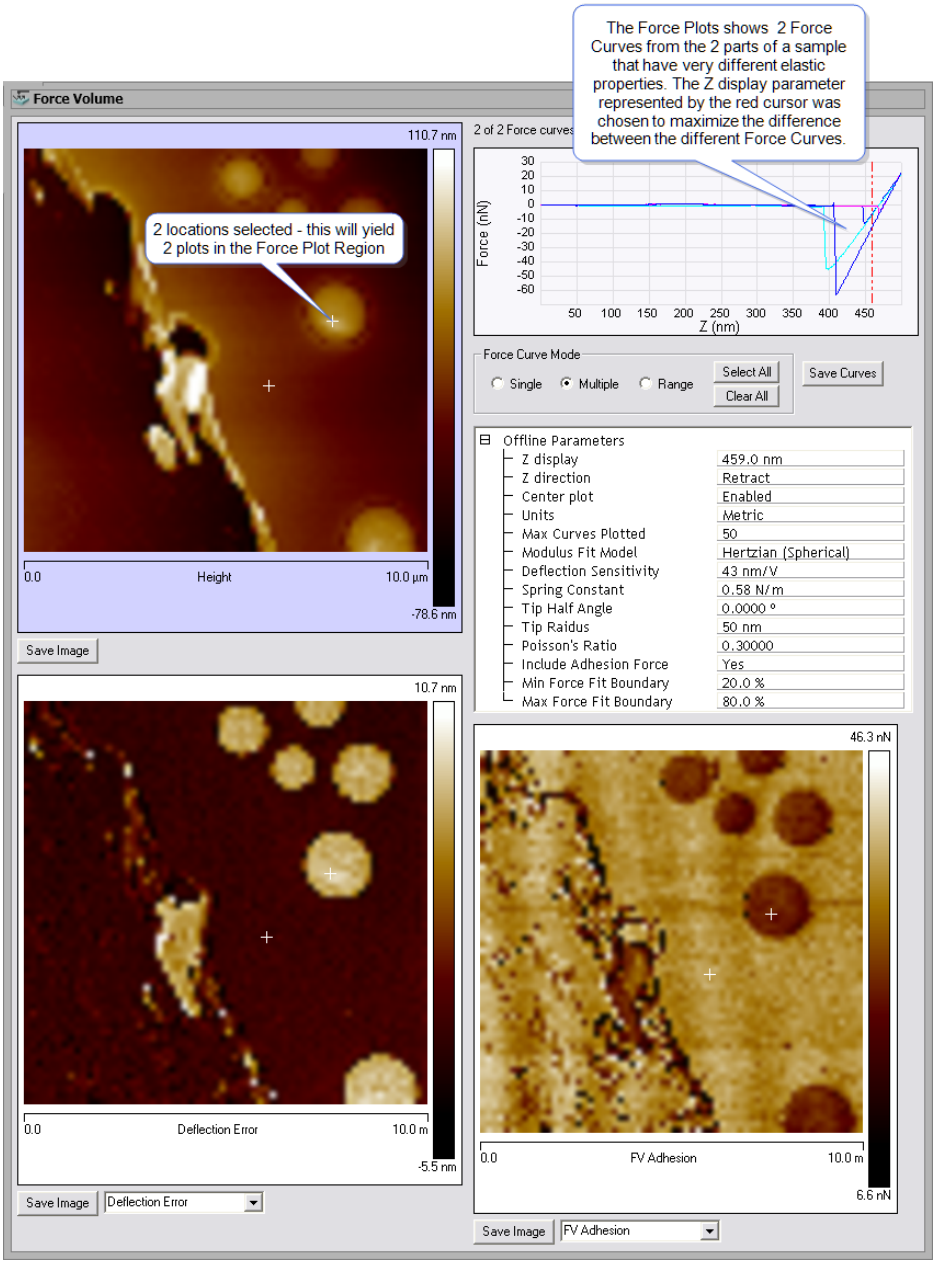


Figure 7.4b: Selecting Appropriate Z Display

4. Selecting the range radio button from the ***Force Curve Mode*** selection dialog will display all of the force curves in a selected box in the ***Force Plots*** region. To draw a box, place the cursor in an image, click the left mouse button and drag the box to the desired size. The ***Force Plots*** region will be automatically updated with the data for the chosen area.
5. 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. If

multiple force curves are displayed, clicking **Save Curves** saves each curve as its own standard ***Force Curve*** file.

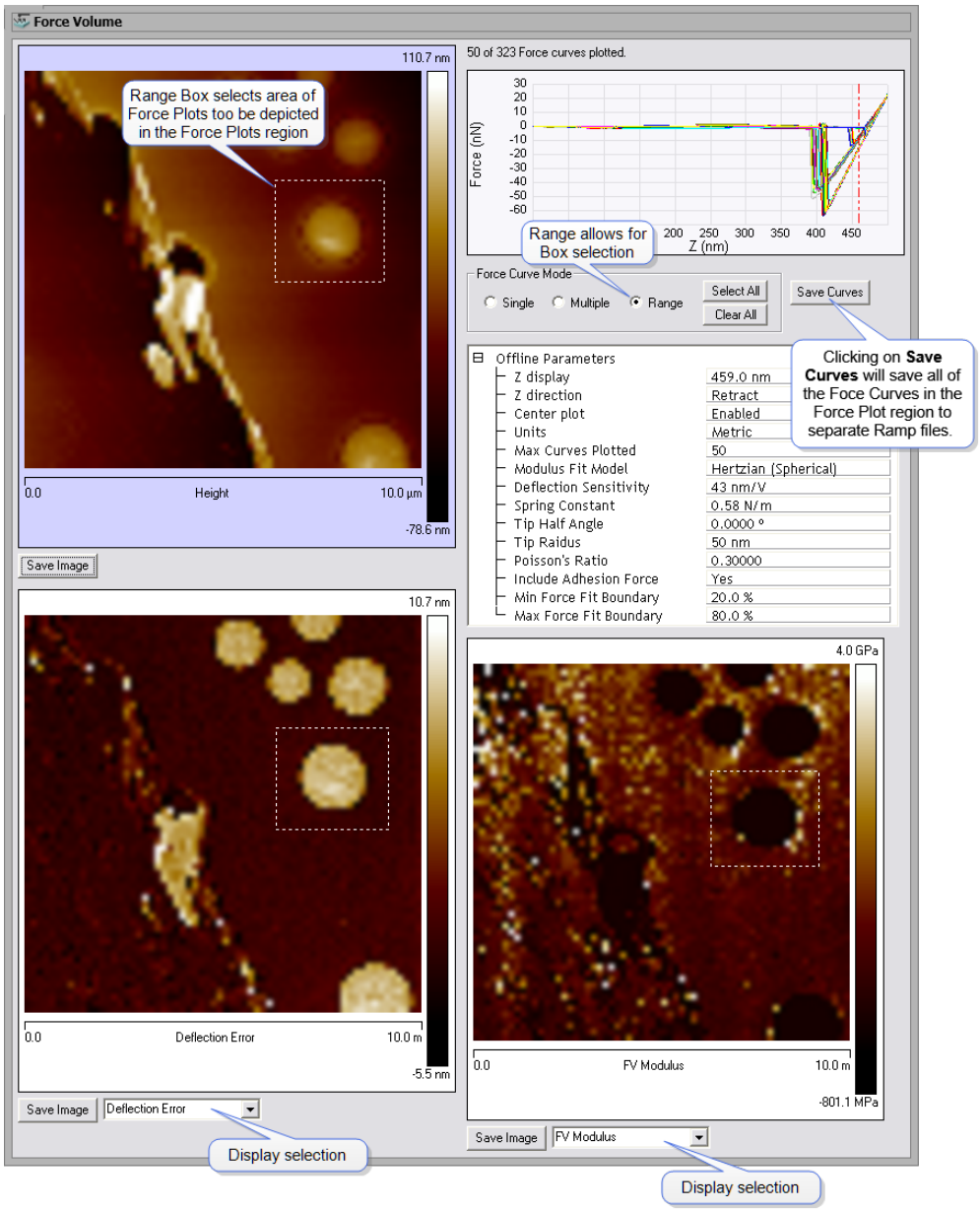


Figure 7.4c: Using the **Range** Box

Force Volume Interface

Parameter	Description
Single	Displays the associated force curve for the selected pixel chosen in an image.
Multiple	Displays several force curves in the force plots region for the selected pixels chosen in an image.

Parameter	Description
Range	Displays several force curves in the force plots region for the selected area chosen in an image.
Select All	Plots all Force Curves in the Force Plots region.
Clear All	Erases the Force Curves shown in the Force Plots region.
Save Curves	Saves each Force Curve as its own standard Force Curve file that can be opened separately in NanoScope Analysis.

Table: 7.0ay Force Curve Mode Selections & Buttons

Parameter	Description
Z display	The Z display parameter determines the Z position of the Slice to be displayed in the Deflection Error image. 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.
Z direction	The Z direction parameter determines which portion of the force curve, Extend or Retract, is shown in the bottom 2 images. For example, if adhesion forces are probed, then the Retract portion should be used.
Center plot	When Center Plot is **On**, any additional Force Curves added to the Force Plot will be translated vertically so that the leftmost data points in the curve are Zero. If Center Plot is **Off**, added Force Curves are not translated.
Units	Choose: Volts or Metric
Max Curves Plotted	The maximum number of force curves that will be plotted.
Modulus Fit Model	The model type used to analyze the force curves: • Hertz model (spherical indenter) (page 231) • Sneddon (conical indenter) (page 232)
Deflection Sensitivity	The cantilever deflection per unit of separation.
Spring Constant	The cantilever spring constant.
Tip Half Angle	The half angle of the probe tip.
Tip Radius	The radius of the probe tip.
Poisson Ratio	The sample's Poisson ratio.
Include Adhesion Force	Including Adhesion Force means that calculations are performed based on forces relative to the adhesion force.

Parameter	Description
Minimum Force Fit Boundary	Defined as a percentage of the [(Maximum Force) - (Minimum Force)]. See Figure 7.4f for details.
Maximum Force Fit Boundary	Defined as a percentage of the [(Maximum Force) - (Minimum Force)]. See Figure 7.4f for details.
Data Scale	• **Auto Scale** employs the Auto-scale Data Option (page 49) to remove outlying data points. • **Full Scale** displays the data using the minimum and maximum data values.

Table: 7.0az Force Volume Parameters

7.4.2 Nanomechanical Property Mapping

The mechanical mapping function in force volume lets you fit various indentation models to measured force curves and compute the sample modulus and adhesion.

7.4.3 Models

Several indentation models are available:

Hertz model (spherical indenter)

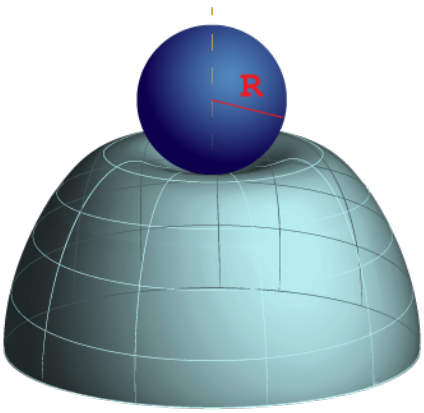


Figure 7.4d: Contact between a sphere and an elastic half-space

$$F = \frac{4}{3}\frac{E}{(1-\upsilon^2)}\sqrt{R}\delta^{3/2}$$

Equation 1: Hertzian model

F = force (from force curve)

E = Young's modulus (fit parameter)

ν = Poisson's ratio (sample dependent, typically 0.2 - 0.5)

R = radius of the indenter (tip)

δ = indentation

Equation 1 may be linearized in separation by taking both sides to the 2/3 power, shown in Equation 2.

$$(F)^{2/3} = \left(\frac{4}{3}\frac{E}{(1-\upsilon^2)}\sqrt{R}\right)^{2/3}\delta$$

Equation 2: Linearized Hertz equation

Sneddon (conical indenter)

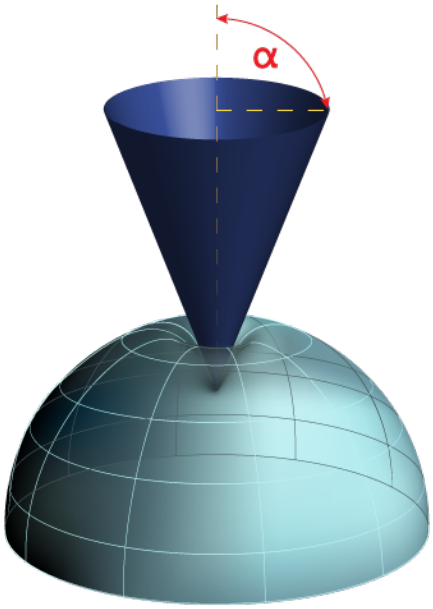


Figure 7.4e: Contact between a cone and an elastic half-space

$$F = \frac{2}{\pi}\frac{E}{(1-\upsilon^2)}\tan(\alpha)\delta^2$$

Equation 3: Sneddon model

where

F = force (from force curve)

E = Young's modulus (fit parameter)

ν = Poisson's ratio (sample dependent, typically 0.2 - 0.5)

α = half-angle of the indenter

δ = indentation

Equation 3 may be linearized in separation by taking both sides to the 1/2 power, shown in Equation 4.

$$(F)^{1/2} = \left(\frac{2}{\pi}\frac{E}{(1-\upsilon^2)}\tan(\alpha)\right)^{1/2}\delta$$

Equation 4: Linearized Sneddon equation

Depending on the model, Young's modulus is computed from the slope of either Equation 2 or Equation 4.

Stiffness (linear)

The stiffness model extrapolates a straight line fit to the maximum indentation.

Nanomechanical Property Mapping Procedure

1. If you are using the **Hertzian** model, enter the probe ***Tip Radius***.
2. If you are using the **Sneddon** model, enter the probe ***Tip Half Angle***.
3. Enter the ***Sample's Poisson Ratio***.
4. Decide if you wish to ***Include Adhesion Force***.
   Including Adhesion Force means that calculations are performed based on forces relative to the adhesion force. Otherwise, calculations are performed on absolute force values.
5. Enter a value for the ***Minimum Force Fit Boundary***. The ***Minimum Force Fit Boundary*** is defined as a percentage of the [(Maximum Force) - (Minimum Force)]. See Figure 7.4f.
6. Enter a value for the ***Maximum Force Fit Boundary***. The ***Maxmimum Force Fit Boundary*** is defined as a percentage of the [(Maximum Force) - (Minimum Force)].
   These boundaries define the region through which the fit model is computed.

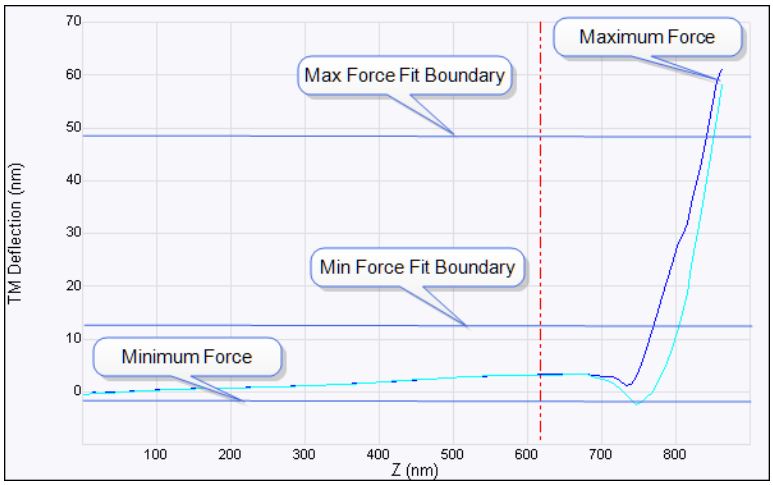


Figure 7.4f: Minimum and Maximum Force Fit Boundaries defined

7. Select a ***Modulus Fit Model***:
- Hertz model (spherical indenter) (page 231)
- Sneddon (conical indenter) (page 232)
8. Select the ***Z direction*** that you wish to use for the ***Modulus Fit Model***: **Extend** or **Retract**.

NOTE: You choice of ***Z direction*** here also determines which portion of the Real-time force curve cycle, **Extend** or **Retract**, is shown in the force volume image.

8. Enter the ***Spring Constant***.
9. Select which property you wish to display in each of the two force volume images:
   - **Deflection Error**
   - **FV Modulus**: Maps the modulus using the selected ***Modulus Fit Model***.
   - **FV Log Modulus**: Maps the log of the modulus using the selected ***Modulus Fit Model***.
   - **FV Stiffness**: Maps the Stiffness (linear) (page 233).
   - **FV Adhesion**: The peak force below the baseline. See Figure 7.4g.

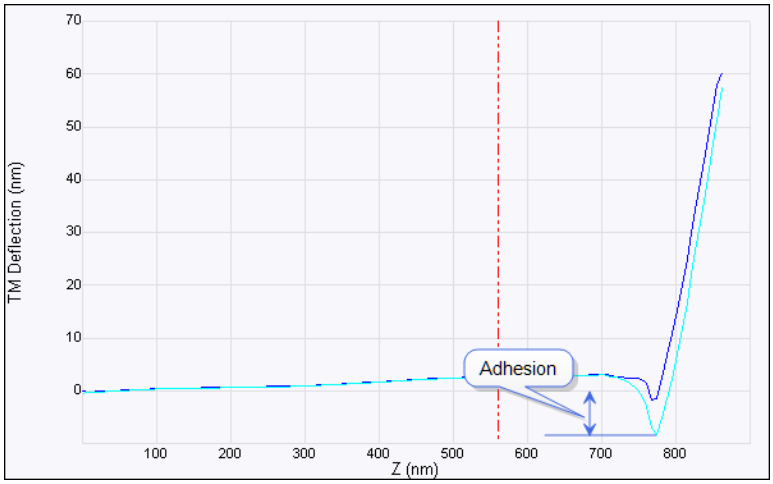


Figure 7.4g: Adhesion

NOTE: 1st order baseline correction, which removes baseline tilt as well as offset, is performed before adhesion mapping.

10. The **Save Image** button, found at the bottom of each image, saves the selected display (see above).

7.5 Review Force Curves

A force spectroscopy session can yield dozens if not hundreds of individual force plots.

1. To facilitate comparison of plots and deletion of files deemed unworthy of inclusion, click **Commands** > **Review Curves**.
2. The ***Review Force Curve***s window, shown in Figure 7.5a, opens.
   a. Enter the path to the ***Directory*** whose contents are the force plot files of interest.
   b. Select a ***Sort*** category: **Date**, **TMR** (scanning Trace Minus Retrace) or **Name**.

NOTE: The TMR values are proportional to the area between the approach and retract curves.

   c. Select a ***Sort*** order: **Ascending** (box checked) or **Descending** (box unchecked).
   d. Select the ***Plot Units*** (vertical axis) units: **Volts**, **Metric** or **Force**.
   e. Select the ***Plot*** number.
   f. Select the ***Trace***(s) to plot: **Extend**, **Retract** or **Both**.

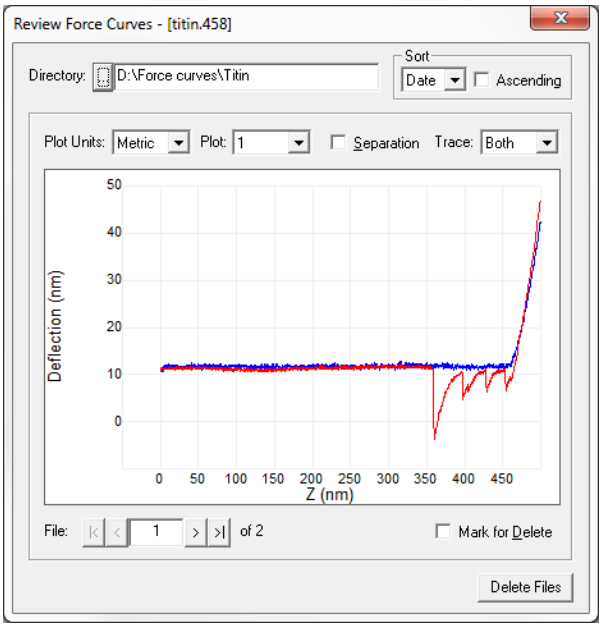


Figure 7.5a: The ***Review Force Curves*** window for reviewing multiple force plot files

3. Advance through the ordered set of files by clicking the arrow buttons in the bottom left of the ***File*** text box or using the keyboard arrow keys.
   a. Click **Mark for Delete**, d, or the keyboard Delete key for any force plot you wish to discard from the set.

NOTE: Files marked for deletion are not sent to the recycling bin until the **Delete Files** button is clicked. You may remove the check from the **Mark for Delete** at any time prior to this.

4. Zooming on a plot is accomplished by pressing Ctrl, left-clicking and dragging in the plot. Zooming out is done by double-clicking in the plot area.

7.6 Filtering Multiple Force Curves

Another way to quickly delete force curves uses the **Filter Curve**s function.

1. You may apply selection criteria to delete force curves by selecting, from the main menu, **Commands** > **Filter Curves**.
2. The ***Filter Force Curves*** window, shown in Figure 7.6a, opens.
   a. Enter the path to the ***Directory*** whose contents are the force plot files of interest.
   b. Enter the ***Plot*** number that you wish to analyze.
   c. Enter a ***Minimum Distance*** from the contact point below which data will be ignored.
   d. Enter a ***Minimum Force*** from the contact point to qualify peaks.
   e. Enter the number of ***Average Points*** to use. To reduce noise, peak values are computed by averaging ±(***Average Points***)/2 around a point.

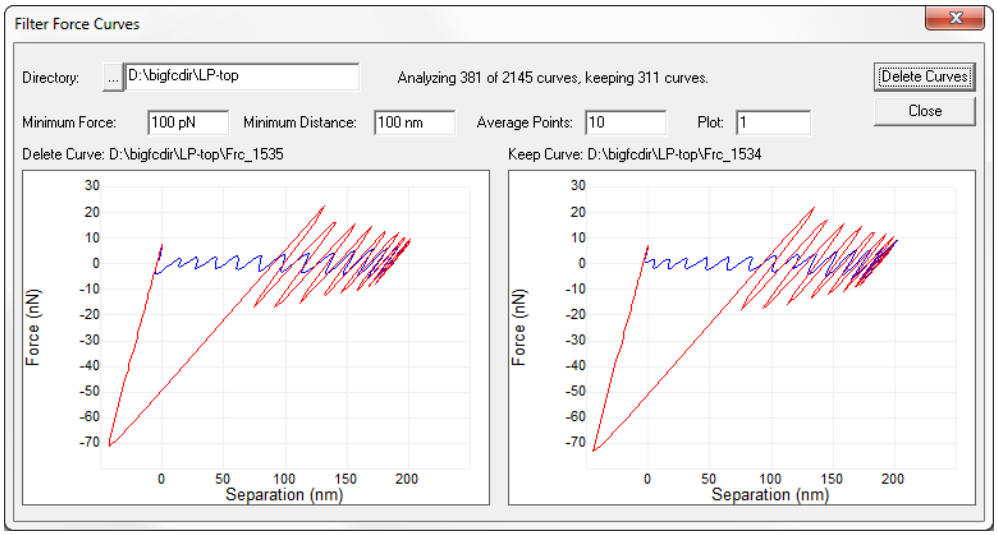


Figure 7.6a: The Filter Force Curves window

3. Click **Delete Curves** to analyze, using the criteria in the ***Filter Force Curve***s window, the force curves in the selected directory. Click **Cancel** to abort the process.
4. Files meeting the deletion criteria will be shown in the left window, shown in Figure 7.6a, and a message, ***Confirm File Delete***, will be displayed asking if you wish to send the specified file to the Recycle Bin.

7.7 Multiple Curve Analysis (MCA)

Multiple Curve Analysis enables the evaluation of multiple force plots.

MCA Procedure

To open a ***MCA*** file in NanoScope Analysis, double click on a NanoScope ***MCA*** file in the ***Browse Files*** view or navigate to the preferred ***MCA*** file from the **Open File** icon  . If the file is indeed an ***MCA*** file, it will be opened in the ***MCA*** window automatically.

Click **Add Files...** in the ***MCA*** window to open a file selection window and click the files to be analyzed. Choose the preferred files and click **Add**. These files are then added to the file list in the ***MCA File Information Register***. Files in that list may be removed individually or multiply by clicking the file name and then clicking **Remove Files**. Files may be selectively displayed by clicking in the Plot field — an X will be displayed — of the ***MCA File Information Register***.

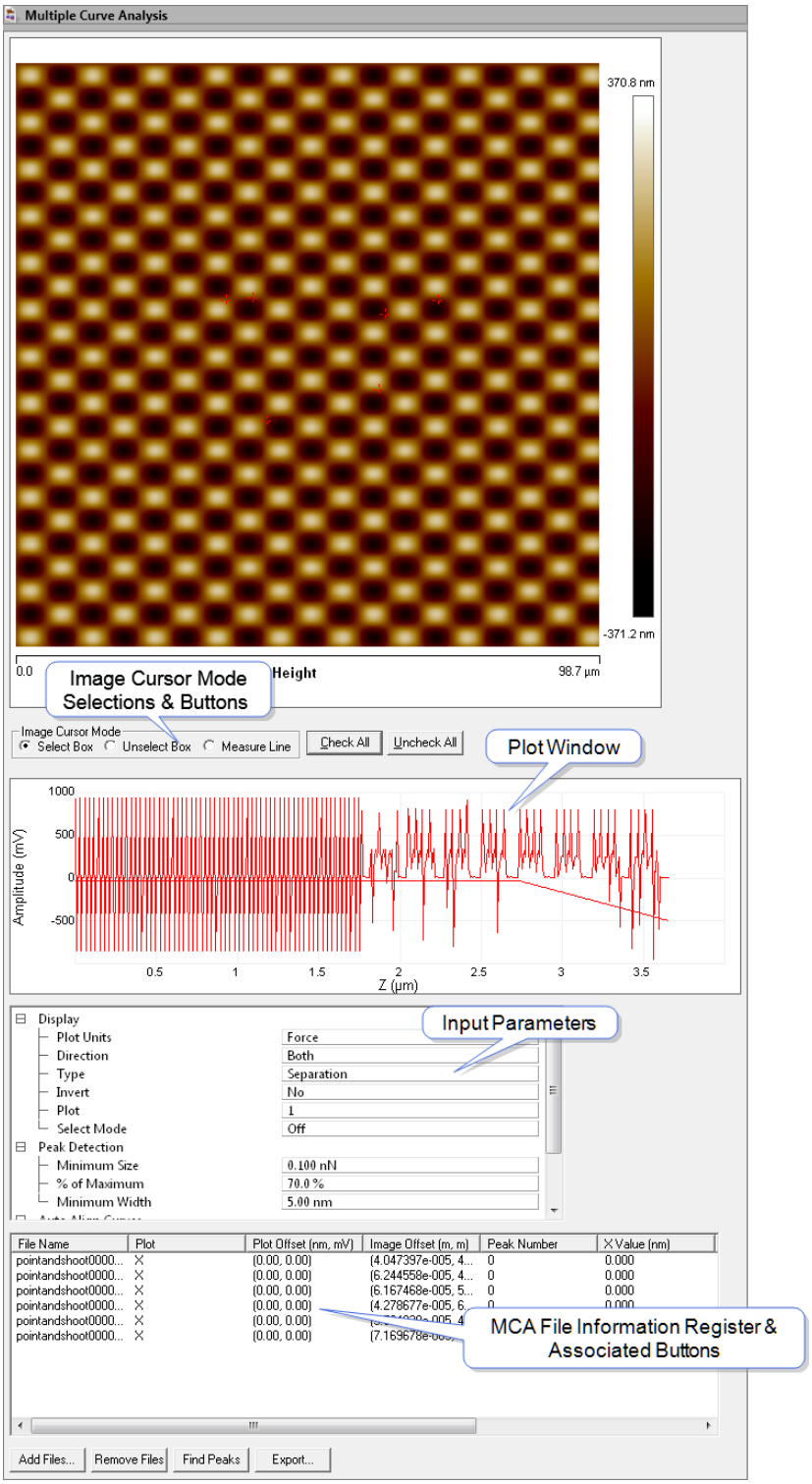


Figure 7.7a: Multiple Curve Analysis Window

Right-clicking a file in the ***MCA File Information Register*** opens a menu, shown in Figure 7.7b, that allows checking or unchecking all files in the list as well as functions that affect plotting parameters, discussed below.

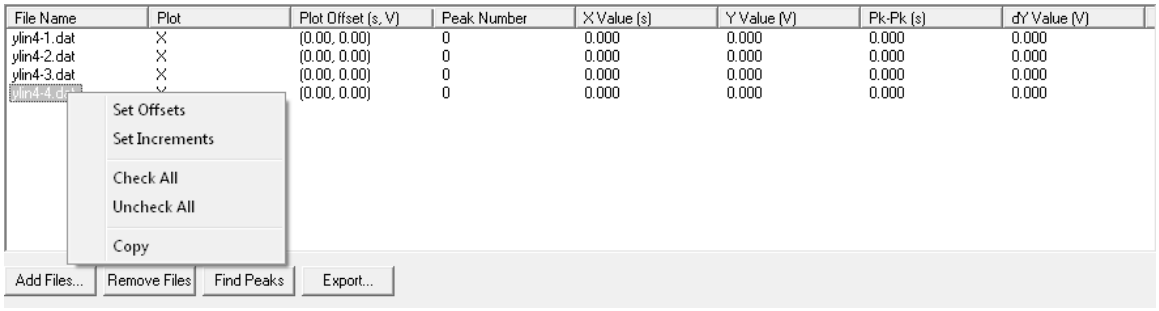


Figure 7.7b: The right-click menu.

Arrow keys move a plot by an increment defined in the Set Increments menu, shown in Figure 7.7c.

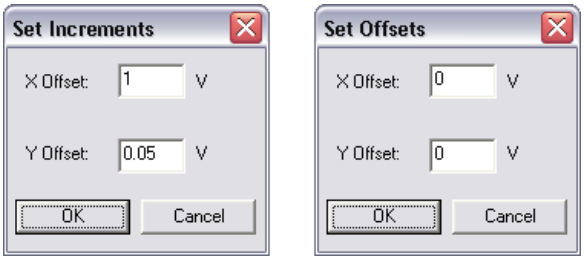


Figure 7.7c: The Set Increments and Set Offsets menus

Double-clicking a file in the ***MCA File Information Register*** opens that file in a new window (tab on top) with each channel shown as a tab on the left.

MCA Interface

Parameter	Description
Select Box	Selects the points inside the drawn box
Unselect Box	Selects points outside the drawn box
Measure Line	Measures the length of a drawn line
Check All	Selects all points
Uncheck All	Deselects all points

Table: 7.0ba ***Image Cursor Mode*** Selections & Buttons

Group	Parameter	Description
Display	*Plot Units*	The user can choose either Force, Volt or distance (Metric) on the Y axis.
	Direction	The Extend option plots and looks for peaks only in the Extend direction. The Retract option plots and looks for peaks only in the Retract direction.
	Type	Either Z or Separation. Z displays the Z position of the piezo measured by a capacitive sensor. Separation displays the corrected (for cantilever deflection) Z data.
	Invert	The Y axis is inverted when Yes is selected.
	Plot	Enter the channel to be plotted, and hit Enter.
	SelectMode	On turns all curves to color number one and the selected (by mouse or arrow key) curve to its plot color.
Peak Detection	*Minimum size*	Finds peaks greater than the value entered here.
	Percentage of Max	The Y variable must fall by this percentage to be considered a peak.
	Minimum Width at % Max	A peak must have a width (at Percentage of Max of the peak's absolute value) greater than the Minimum Width at % Max to be considered a peak.
Auto Align Curves	*X-axis auto-zero*	Either On (at the contact point), Off or User.
	Y-axis auto-zero	Either On, Off, User or Cascade which increments the Y offset of each plot by the Cascade Offset.
	Cascade Offset	Define the Y offset to be used here when the Y Axis Auto-zero is set to Cascade.

Table: 7.0bb MCA Parameters

Parameter	Description
Add Files	Opens a file selection window that allows files to be added in the Multiple Force window.
Remove Files	Deletes selected (by clicking) files from the Multiple Force window
Find Peaks	Finds peaks using the filters (rules) selected in the Peak Detection functions in the Input Parameters window. The X Offset and Y Offset, Peak Number, X Value, Y Value, Peak-To-Peak and DY Values are shown in the table below the plot window, as shown in Figure 7.7b.
Export	Saves the results from Find Peaks in a tab-delimited text file.

Table: 7.0bc MCA File Information Register

Creating MCA Files

MCA files are automatically created by NanoScope Point and Shoot ramp mode. MCA files may also be

created by combining multiple force curves. This is required for files created by NanoDrive software.

You may create an mca file by selecting multiple .dat files (using Shift or Ctrl), right-clicking and selecting **Curve Analysis** as shown in Figure 7.7d.

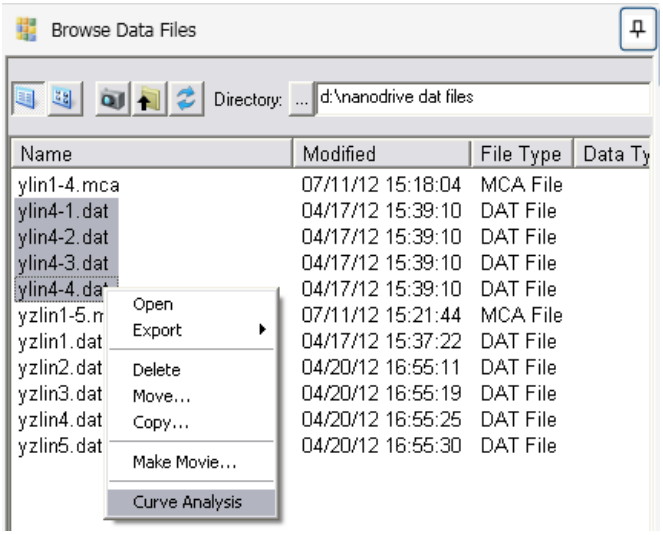


Figure 7.7d: Select **Curve Analysis**

This opens a window, shown in Figure 7.7e, that allows you to choose the mca file name and directory.

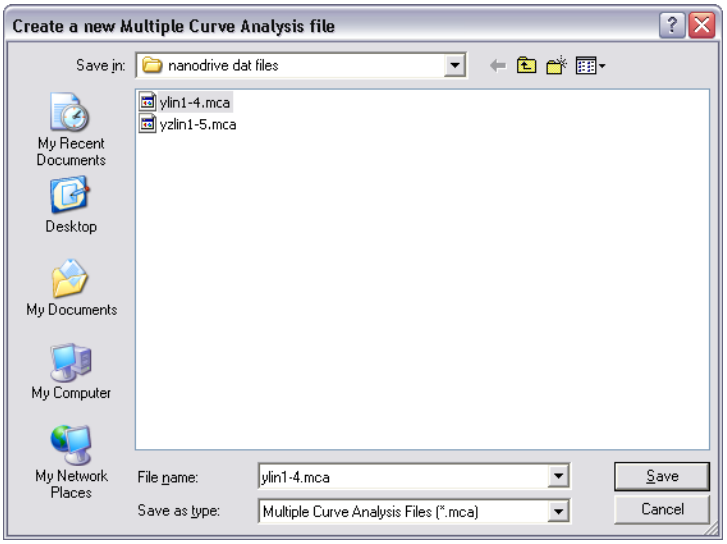


Figure 7.7e: Create an MCA file

Choose a directory, a file name and click **Save**.

7.8 Modify Force Parameters

The Modify Force Parameters function lets you change the ***Deflection Sensitivity***, ***Spring Constant***, ***Tip Radius***, ***Tip Half Angle*** and the ***Sample's Poisson Ratio***.

7.8.1 Cases where you might use this function

- You forget to enter your spring constant before collecting data and later want to correct the saved force curve files.
- When using a functionalized probe you often want to calibrate the deflection sensitivity at the end of the experiment. You then need to update all of your saved data with the correct value.

7.8.2 Modify Force Parameters Procedure

Either:

- Click the ***Change*** check box next to the parameter that you wish to modify, then click in the appropriate ***New Value*** field, edit and click **Execute**.

or

- Click in the appropriate ***New Value*** field and enter the new value (the ***Change*** check box will be checked) and click **Execute**.

See Figure 7.8a.

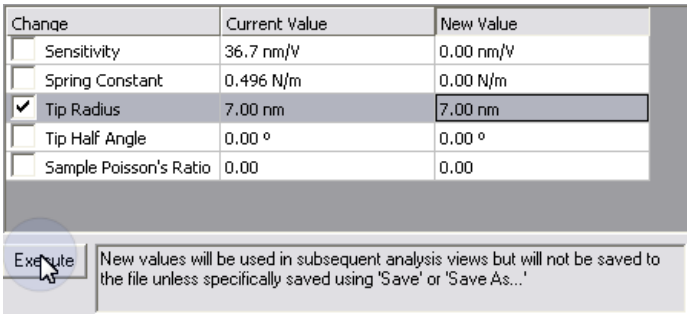


Figure 7.8a: The Modify Force Parameters window

NOTE: The modified values will be used in subsequent NanoScope Analysis functions but will not be saved to the file unless you **Save** the file.

7.9 Indentation Analysis

The Indentation function lets you fit various indentation models to measured force curves and compute Young's modulus.

7.9.1 Models

Several indentation models are available:

Hertz model (spherical indenter)

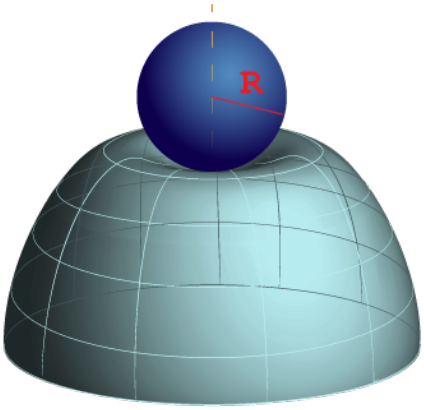


Figure 7.9a: Contact between a sphere and an elastic half-space

$$F = \frac{4}{3}\frac{E}{(1-\upsilon^2)}\sqrt{R}\delta^{3/2}$$

Equation 1: Hertzian model

where

F = force (from force curve)

E = Young's modulus (fit parameter)

ν = Poisson's ratio (sample dependent, typically 0.2 - 0.5)

R = radius of the indenter (tip)

δ = indentation

Sneddon (conical indenter)

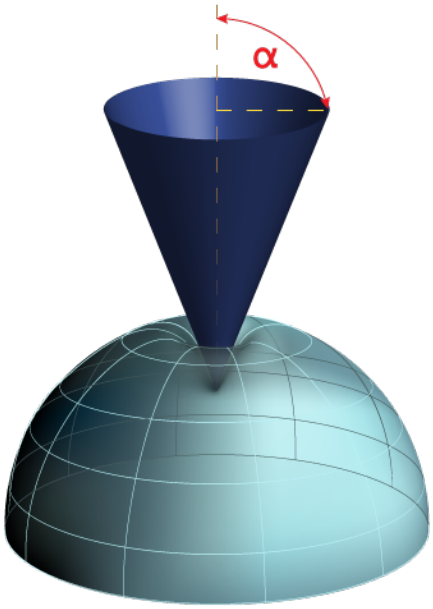


Figure 7.9b: Contact between a cone and an elastic half-space

$$F = \frac{2}{\pi}\frac{E}{(1-\upsilon^2)}\tan(\alpha)\delta^2$$

Equation 2: Sneddon model

where

F = force (from force curve)

E = Young's modulus (fit parameter)

ν = Poisson's ratio (sample dependent, typically 0.2 - 0.5)

α = half-angle of the indenter

δ = indentation

Stiffness (linear)

The stiffness model extrapolates a straight line fit to the maximum indentation.

Indentation Analysis Procedure

1. Select the ***Active Curve***:
    - **Extend**: blue curve

- **Retract**: red curve

2. Select the ***Fit Method***:
   - **Contact Point Based**:
     Uses a nonlinear least squares fit to either the Hertz or Sneddon models, above, and goes through the contact point, determined in Step 4.
   - **Linearized Model**
     Equation 1 (Hertz model) may be linearized in separation by taking both sides to the 2/3 power, shown in Equation 3, and Equation 2 may be linearized by taking both sides to the 1/2 power, shown in Equation 4.

$$(F)^{2/3} = \left(\frac{4}{3}\frac{E}{(1-\upsilon^2)}\sqrt{R}\right)^{2/3}\delta$$

Equation 3: Linearized Hertz equation

$$(F)^{1/2} = \left(\frac{2}{\pi}\frac{E}{(1-\upsilon^2)}\tan(\alpha)\right)^{1/2}\delta$$

Equation 4: Linearized Sneddon equation

Because these equations are linear, they no longer are forced through the origin so that the contact point is not needed. In the ***Linearized Model*** case, Young's modulus is computed from the slope of these equations.
The Minimum Force, shown in Figure 7.9d, is determined as follows:

Starting a the lowest separation, a straight line is least squares-fitted to 5% of the points on the curve and its slope is calculated.

Another straight line is drawn with the starting point incremented by one using the above method.

This process is repeated and stopped when the local slope becomes positive.

The Minimum Force is subtracted before the force curves are linearized.

You may manually move the Minimum Force point by dragging the dashed blue line, shown in Figure 7.9d.

NOTE: Baseline Correction (page 249) should be applied before this model is used.

3. Decide if you wish to ***Include Adhesion Force***
   Including Adhesion Force means that calculations are performed based on forces relative to the adhesion force. Otherwise, calculations are performed on absolute force values.
4. Select the ***Contact Point Algorithm*** available for ***Fit Method*** = **Contact Point Based**:
   - **Best Estimate**:
     A line drawn between the first and last points of the force curve is subtracted from each point in the force curve, effectively rotating it. The point with the resulting minimum value is selected as the contact point. This method emphasizes the minimum force at the contact point while de-emphasizing forces due to noise or interference in the non-contact region, reducing the likelihood that the wrong point is selected.
   - **Treat as Fit Variable**:

This approach starts with the contact point determined by the **Best Estimate** method, above, and then searches points of increased separation (up to 5% increase in Z) and computes goodness of fit (R^2) for each point. The point with the best goodness of fit is used as the contact point. The contact point is indicated by the dashed vertical line, shown in Figure 7.9e. You may manually move the calculated contact point by dragging this line.

5. Move the top horizontal cursor to adjust the ***Max Force Fit Boundary***.
   The ***Max Force Fit Boundary*** percentage is defined as the distance as the percentage of [(Maximum Force) - Minimum Force].
6. Move the bottom horizontal cursor to adjust the ***Min Force Fit Boundary***.
   The ***Min Force Fit Boundary*** percentage is defined as the distance as the percentage of [(Maximum Force) - Minimum Force].
7. Select the ***Fit Model***
   - **Hertzian**: Spherical indenter
   - **Sneddon**: Conical indenter
   - **Stiffness**: Linear spring

The goodness of fit, R^2, is computed between the ***Max*** and ***Min Force Fit Boundaries***. The fitted force curve, however, is displayed from the maximum force to the minimum force (or 0, if adhesion has not been included).

The output is a goodness of fit, R^2, the ***Young's Modulus*** and ***Reduced Modulus*** (or ***Stiffness*** for **Linear *Fit Models***).

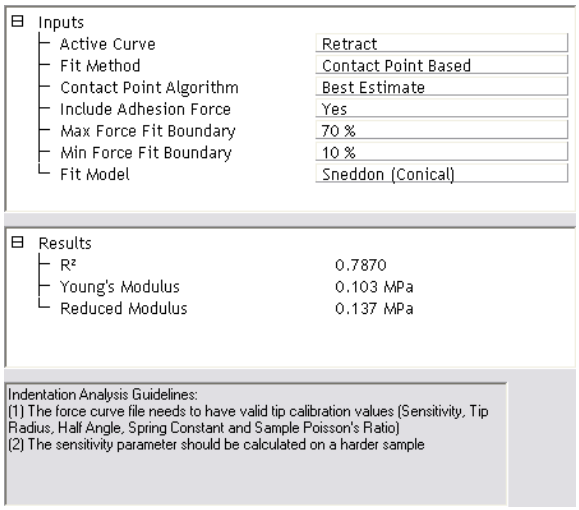


Figure 7.9c: The Indentation menu

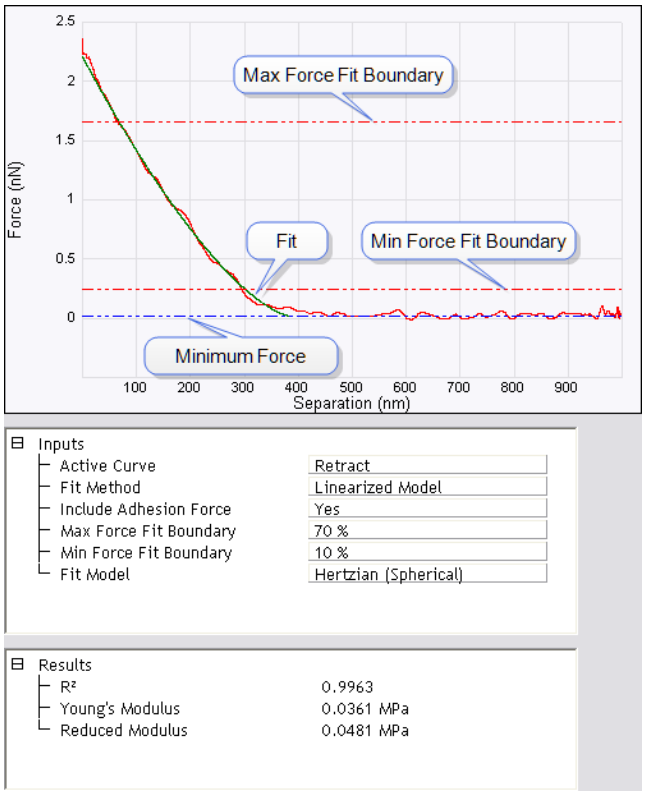


Figure 7.9d: Force plot with a linearized fit

Figure 7.9e shows a Hertzian fit (green curve) to a force curve.

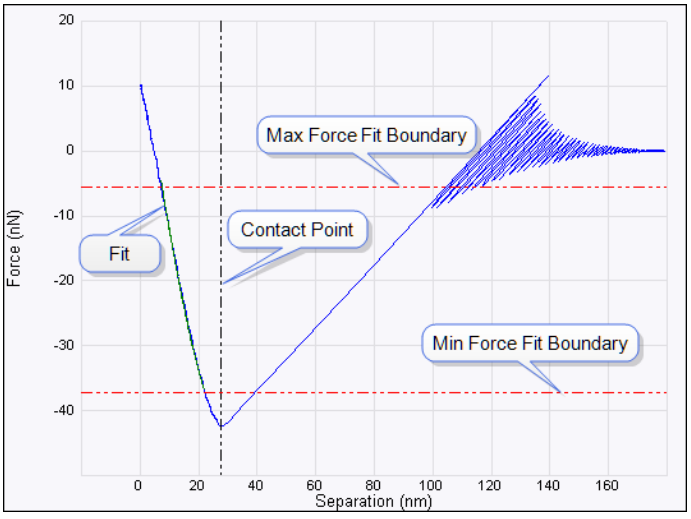


Figure 7.9e: Hertzian fit to a force curve

7.10 Baseline Correction

The Baseline Correction function measures baseline tilt and offset and applies a linear correction to the whole force curve.

7.10.1 Cases where you might use this function

Force curves can have a small amount of baseline tilt caused by the detector configuration. Though insignificant in many measurements, it's sometimes desirable to remove this artifact in force curves involving very low forces.

7.10.2 Baseline Correction Procedure

1. Select the force curve ***Direction*** that you wish to correct.:
   - **Extend**: blue curve
   - **Retract**: red curve
   - **Both**: blue and red curves
2. Choose the Y-axis ***Plot Units***:
   - **Volt**
   - **Metric**
   - **Force**
3. Choose the X-axis plot ***Type***:
   - **Z**
   - **Separation**
4. Choose the ***Correction Order***:
   - **0th** Removes offset
   - **1st** Removes tilt as well as offset (0th order)
5. Choose the ***Extend Baseline Source***:
   Selects which baseline to use for the Extend direction of the force curve:
   - **Extend**
   - **Retract**
6. Choose the ***Retract Baseline Source***
   Selects which baseline to use for the Retract direction of the force curve:
   - **Extend**
   - **Retract**
7. Move the cursors to select the ***Baseline Start*** and ***Stop*** percentages.

NOTE: The cursor colors match their associated baseline sources, blue corresponds to **Extend** while red corresponds to **Retract**.

8. Click **Execute** to apply the correction. See Figure 7.10a.

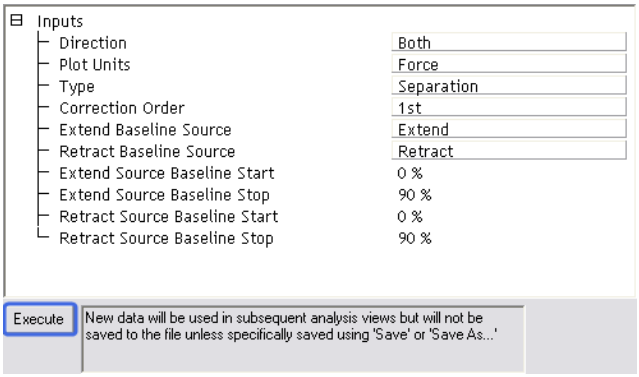


Figure 7.10a: The Baseline filter window

NOTE: The modified values will be used in subsequent NanoScope Analysis functions but will not be saved to the file unless you **Save** the file.

Figure 7.10b shows a force curve before and after application of the Baseline Correction filter.

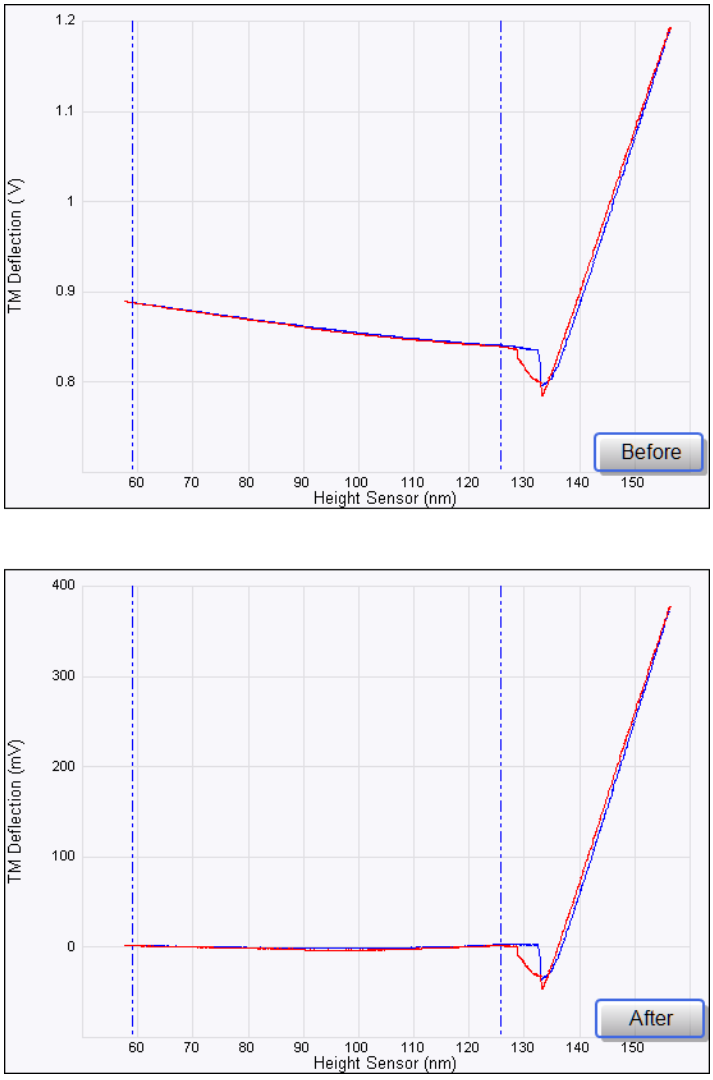


Figure 7.10b: Force curve before and after application of the Baseline Correction filter

7.11 Boxcar Filter

The Boxcar filter applies a moving average filter with weight of 0 or 1 (over a selectable number of points) to your data. A boxcar filter is frequently employed to reduce measurement noise.

7.11.1 Boxcar Filter Procedure

1. Select the ***Direction***:
   - **Extend**: blue curve
   - **Retract**: red curve:
   - **Both**: blue and red curves:
2. Select the number of ***Average Points*** to use in the moving average.

The filter will be centered about the current point of the ***Average Points*** is odd. If ***Average Points*** is even, there will be one more trailing point than leading point.

3. Click **Execute** to apply the filter. See Figure 7.11a.

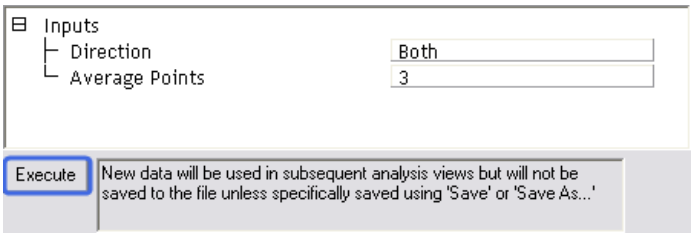


Figure 7.11a: The Boxcar filter window

NOTE: The modified values will be used in subsequent NanoScope Analysis functions but will not be saved to the file unless you **Save** the file.

Figure 7.11b shows a force curve before and after application of the Boxcar filter (10 points) which was used to remove thermal noise.

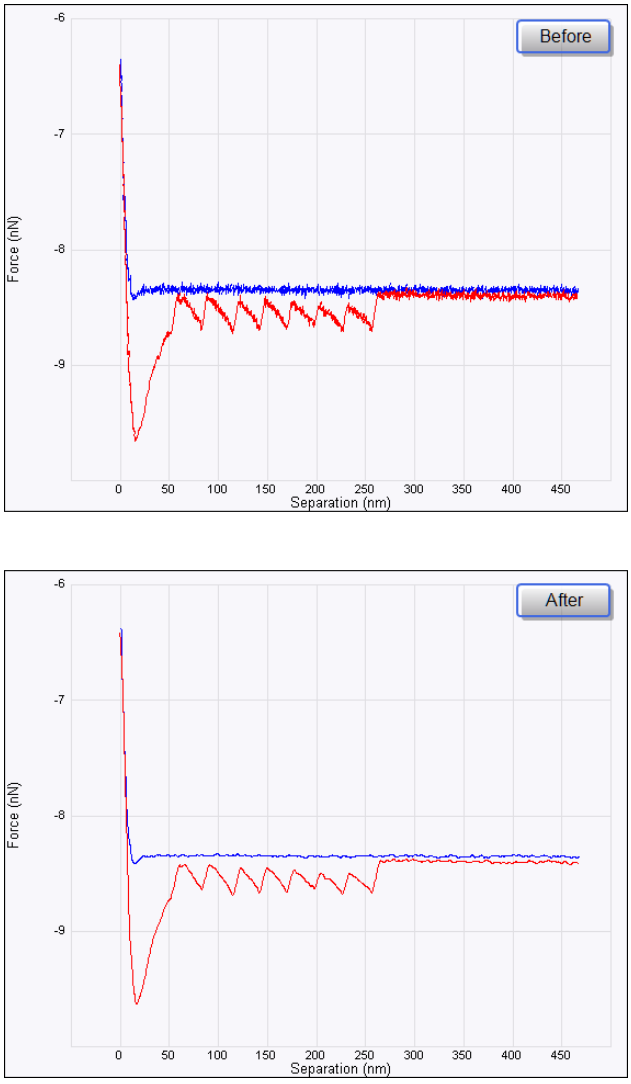


Figure 7.11b: Titin pulling before and after application of the Boxcar filter (10 points)

7.12 MATLAB Utilities

NanoScope Analysis includes a MATLAB utility, *NSMatLabUtilities.m* (in the root directory of NanoScope Analysis), that extracts force curves, force volume data, HSDC data and image data from NanoScope files for use by MATLAB. This allows you to, for instance, compare arbitrary force models with measured data.

Bruker also provides MATLAB examples, *NSMatLabExamples.m* (in the root directory of NanoScope Analysis), that demonstrate the use of MATLAB to analyze NanoScope force curves.

NOTE: 64 bit windows users will need to install Microsoft Windows SDK (Software Development Kit) for Windows 7 in order to use the matlab toolbox with 64bit matlab. Additional information is available from MathWorks at MATLAB Windows 64-bit support. The SDK can be downloaded from Windows 7 SDK download.

7.12.1 NSMatlabUtilities

The NSMatlabUtilities class implements NanoScope file I/O utilities.

The NSMatlabUtilities class has 6 properties:

1. FileName – Current file name
2. IsOpen – A value indicating whether the file is open
3. METRIC – Option to retrieve data in metric units
4. VOLTS – Option to retrieve data in volts
5. FORCE – Option to retrieve data in force units
6. RAW – Option to retrieve data in LSB

NSMatlabUtilities

Constructs the NSMatlabUtilities class.

Example:

```
NSMU = NSMatlabUtilities();
```

Open(FileName)

Opens the file whose name is specified in the parameter FileName

Example:

```
NSMU.Open('Example.spm');
```

Close()

Closes the file

Example:

```
NSMU.Close();
```

GetForceCurveData

Returns force curve data from a force curve file.

Syntax:

[trace, retrace, scaleUnit, dataTypeDesc] = GetForceCurveData(ChannelNumber, UnitType)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file.
UnitType: this.METRIC, this.VOLTS, this.FORCE, this.RAW

Output:

trace: array of trace data
retrace: array of retrace data
scaleUnit: scale unit string
dataTypeDesc: data type dscription

Example:

[trace, retrace, scale_units, type_desc] = NSMU.GetForceCurveData(1, NSMU.METRIC);

GetHSDCData

Returns HSDC data from a HSDC file.

Syntax:

[data, scaleUnit, dataTypeDesc] = GetHSDCData(ChannelNumber, UnitType)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file.
UnitType: this.METRIC, this.VOLTS, this.RAW

Output:

data: array of hsdc channel data
scaleUnit: scale unit string
dataTypeDesc: data type dscription

Example:

[data, scale_units, type_desc] = NSMU.GetHSDCData(1, NSMU.METRIC);

GetForceVolumeImageData

Returns force volume image data from a force volume file.

Syntax:

[data, scaleUnit, dataTypeDesc] = GetForceVolumeImageData(UnitType)

Input:

UnitType: this.METRIC, this.VOLTS, this.RAW

Output:

data: array of hsdc channel data
scaleUnit: scale unit string
dataTypeDesc: data type dscription

Example:

[data, scale_units, type_desc] = NSMU.GetForceVolumeImageData(NSMU.RAW);

GetForceVolumeForceCurveData

Returns force volume force curve data from a force volume file.

Syntax:

[trace, retrace, scaleUnit, dataTypeDesc] = GetForceVolumeForceCurveData(CurveNumber, UnitType)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file.
UnitType: this.METRIC, this.VOLTS, this.FORCE, this.RAW

Output:

trace: array of force volume force curve trace data
retrace: array of force volume force curve retrace data
scaleUnit: scale unit string
dataTypeDesc: data type dscription

Example:

[trace, retrace, scale_units, type_desc] = NSMU.GetForceVolumeForceCurveData(1, NSMU.VOLTS);

GetImageData

Returns image channel data from an image file

Syntax:

[data, scaleUnit, dataTypeDesc] = GetImageData(ChannelNumber, UnitType)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file.
UnitType: this.METRIC, this.VOLTS, this.RAW

Output:

data: array of image data
scaleUnit: scale unit string
dataTypeDesc: data type dscription

Example:

[data, scale_units, type_desc] = NSMU.GetImageData(1, NSMU.RAW);

GetZSensitivityUnits

Returns Z Sensitivity unit for a specific ChannelNumber

Syntax:

[unit] = GetZSensitivityUnits(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file.

Output:

Unit: Z sensitivity units

Example:

ZSensitivityUnits1 = NSMU.GetZSensitivityUnits(1);

GetScalingFactor

Returns the Scaling factor for a specific ChannelNumber

Syntax:

[factor] = GetScalingFactor(ChannelNumber, isMetric)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file.
If IsMetric is 1, the function returns the scaling factor to convert the LSB data to metric units.
If IsMetric is 0, the function returns the scaling factor to convert the LSB data to volts units.

Output:

factor: Scaling factor

Example:

ZScalingFactorVolt = NSMU.GetScalingFactor(1,0);

GetBufferSize

Returns the buffer size for a specific ChannelNumber

Syntax:

[size] = GetBufferSize(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file.

Output:

size: Buffer size

Example:

BufferSize = NSMU.GetBufferSize(1);

GetSamplesPerLine

Returns the samples per line in an image file.

Syntax:

[samps] = GetSamplesPerLine(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file

Output:

samps: samples per line

Example:

SamplesPerLine = NSMU.GetSamplesPerLine(1);

GetNumberOfLines

Returns the number of lines in an image file

Syntax:

[lines] = GetNumberOfLines(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file

Output:

lines: number of lines

Example:

NumberOfLines = NSMU.GetNumberOfLines(1);

GetImageAspectRatio

Returns the Aspect Ratio in an image file

Syntax:

[AspectRatio] = GetImageAspectRatio(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file

Output:

AspectRatio: Aspect ratio

Example:

AspectRatio = NSMU.GetImageAspectRatio(1);

GetNumberOfForceCurves

Returns the number of force curves in the file

Syntax:

[number] = GetNumberOfForceCurves()

Output:

number: number of force curves

Example:

NumberOfForceCurves = NSMU.GetNumberOfForceCurves();

GetNumberOfPointsPerCurve

Returns the number of points for a specific force curve

Syntax:

[number] = GetNumberOfPointsPerCurve(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file

Output:

number: number of points in the force curve

Example:

NumberOfPoints = NSMU.GetNumberOfPointsPerCurve(1);

GetRampSize

Returns the ramp size of a specific force curve ChannelNumber

Syntax:

[RampSize, RampUnits] = GetRampSize(ChannelNumber, isMetric)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file
If IsMetric is 1, the function returns the RampSize to metric unit
If IsMetric is 0, the function returns the RampSize to volts unit.

Output:

Ramp size and units

Example:

[RampSize, RampUnits] = NSMU.GetRampSize(1, 0);

GetZScaleInSwUnits

Returns the ZScale of a specific force curve ChannelNumber

Syntax:

[ZScale] = GetZScaleInSwUnits(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file

Output:

Z scale in sw units

Example:

SWZScale = NSMU.GetZScaleInSwUnits(ChannelNumber);

GetZScaleInHwUnits

Returns the ZScale of a specific force curve ChannelNumber

Syntax:

[ZScale] = GetZScaleInHwUnits(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file

Output:

Z scale in hw units

Example:

HWZScale = NSMU.GetZScaleInHwUnits(ChannelNumber);

GetNumberOfTracePoints

Returns the number of points in trace

Syntax:

[NumTrace] = GetNumberOfTracePoints(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file

Output:

the number of points in trace curve

Example:

NumTrace = NSMU.GetNumberOfTracePoints(1);

GetNumberOfRetracePoints

Returns the number of points in retrace

Syntax:

[NumRetrace] = GetNumberOfRetracePoints(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file

Output:

the number of points in retrace

Example:

NumRetrace = NSMU.GetNumberOfRetracePoints(1);

GetPoissonRatio

Returns the Poisson ratio from the header file

Syntax:

[Ratio] = GetPoissonRatio()

Output:

Poisson ratio

Example:

PoissonRatio = NSMU.GetPoissonRatio();

GetTipRadius

Returns the Tip radius from the header file

Syntax:

[Radius] = GetTipRadius()

Output:

Tip Radius

Example:

Radius = NSMU.GetTipRadius();

GetForwardRampVelocity

Returns the Forward ramp velocity from the header file

Syntax:

[Velocity] = GetForwardRampVelocity(ChannelNumber, isMetric)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file
IsMetric is 1 or 0

Output:

Forward ramp velocity

Example:

VelocityMetric = NSMU.GetForwardRampVelocity(1,1);

GetReverseRampVelocity

Returns the Reverse ramp velocity from the header file

Syntax:

[Velocity] = GetReverseRampVelocity(ChannelNumber, isMetric)

Input:

IsMetric is 1 or 0
ChannelNumber ranges from 1 to Number of Channels in the file

Output:

Reverse ramp velocity

Example:

VelocityMetric = NSMU.GetReverseRampVelocity(1,1);

GetSpringConstant

Returns the Spring constant

Syntax:

[SpringConst] = GetSpringConstant(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file

Output:

Spring constant

Example:

Springcst = NSMU.GetSpringConstant(1);

GetNumberOfChannels

Returns the Number of Channels in an Image file

Syntax:

[NumberOfChannels] = GetNumberOfChannels()

Output:

Number of Channels in the Image file

Example:

channels = NSMU.GetNumberOfChannels();

GetHsdcRate

Returns the Hsdc rate from the header

Syntax:

[HsdcRate] = GetHsdcRate(ChannelNumber)

Input:

ChannelNumber ranges from 1 to Number of Channels in the file

Output:

Hsdc Rate in Hsdc file

Example:

hsdcRate = NSMU.GetHsdcRate(1);

CreateForceTimePlot

Returns force curve data vs time and their labels.

Syntax:

[xData, yData, xLabel, yLabel] = CreateForceTimePlot(ChannelNumber, UnitType)

Input:

ChannelNumber: ranges from 1 to Number of Channels in the file.
UnitType: this.METRIC, this.VOLTS, this.FORCE, this.RAW

Output:

xData: an array of time data
yData: an array of force data
xLabel: x Label
yLabel: y Label

Example:

[xData, yData, xLabel, yLabel] = NSMU.CreateForceTimePlot(1, NSMU.METRIC);
You may use the output data for other MATLAB functions, e.g. plotting the data:

```
plot(xData, yData);

xlabel(xLabel);

ylabel(yLabel);
```

CreateForceZPlot

Returns force curve data vs Z range and their labels

Syntax:

[xTrace, xRetrace, yTrace, yRetrace, xLabel, yLabel] = CreateForceZPlot(ChannelNumber, UnitType, isSeparation)

Input:

ChannelNumber: ranges from 1 to Number of Channels in the file.
UnitType: this.METRIC, this.VOLTS, this.FORCE, this.RAW
isSeperation: 1 if you want a separation plot

Output:

xTrace: an array of Z data for plotting yTrace
xRetrace: an array of Z data for plotting yRetrace
yTrace: an array of force Trace data
yRetrace: an array of force Retrace data
xLabel: x Label
yLabel: y Label

Example:

```
[xTrace, xRetrace, yTrace, yRetrace, xLabel, yLabel] = NSMU.CreateForceZPlot(1, NSMU.FORCE, 0);

plot the data
plot(xTrace, yTrace);
hold on;
plot(xRetrace, yRetrace);
xlabel(xLabel);
ylabel(yLabel);
```

CreateForceVolumeForceCurveZplot

Returns x, y trace and retrace values and their labels of Force curve Z plot in a Force volume file

Syntax:

[xTrace, xRetrace, yTrace, yRetrace, xLabel, yLabel] = CreateForceVolumeForceCurveZplot(ChannelNumber, UnitType)

Input:

ChannelNumber: ranges from 1 to Number of Channels in the file.
UnitType: this.METRIC, this.VOLTS, this.FORCE, this.RAW

Output:

xTrace: an array of Z data for plotting yTrace
xRetrace: an array of Z data for plotting yRetrace
yTrace: an array of force volume force curve trace data
yRetrace: an array of force volume force curve Retrace data
xLabel: x Label

yLabel: y Label

Example:

[xTrace, xRetrace, yTrace, yRetrace, xLabel, yLabel] = NSMU.CreateForceVolumeForceCurveZplot (1, NSMU.METRIC);

CreateHSDCTimePlot

Returns HSDC data vs. time and their labels

Input:

ChannelNumber: ranges from 1 to Number of Channels in the file.
UnitType: this.METRIC, this.VOLTS, this.RAW

Output:

xData: an array of time data
yData: an array of hsdc data
xLabel: x Label
yLabel: y Label

Example:

[xData, yData, xLabel, yLabel] = NSMU.CreateHSDCTimePlot(1, NSMU.METRIC);

Chapter 8: Time-Based Analysis

Time-Based analysis functions display experimental results as a function of time. Unlike Ramps, ***Time-Based*** analyses work with data sets that do not involve changing a control variable (Z or bias).

The following ***Time-Based Analysis*** commands are available in NanoScope Analysis 1.50:

- QNM Hsdc-ForceCurve-Image
- High Speed Data Capture (HSDC)
- Strip-chart
- Strip-chart Combined Channels

8.1 QNM HSDC Force Curve/Image

8.1.1 Introduction

Real-time PeakForce QNM saves images of processed data like modulus and adhesion. There are times when one would like to compare these processed data images with the associated force curves. For this reason, a PeakForce QNM mode off-line analysis function is included in the NanoScope Analysis package. The main intention of this function is to allow you to view and analyze force curves from areas where material properties are most likely to change. You are given options to export raw force curves that can then be analyzed in the NanoScope Analysis or third party analysis programs.

You should collect an image and then, at a region of interest during the capture, click the ***Capture Line*** button. This ensures capture of the raw high speed data capture (HSDC) in the DSP buffers. Remember that to transfer the data to the computer and into a file, you must click the ***Upload Data*** button in the ***High Speed Data Capture*** interface.

The QNM Force Curve Procedure (page 268) page shows you how to use the NanoScope Analysis package to analyze captured force curves.

The QNM Force Curve Controls and Settings (page 272) page describes the controls and settings used in the PeakForce QNM function.

The Exported Force Curves (page 275) page describes additional functionality available for exported force curves.

8.1.2 QNM Force Curve Procedure

1.  Start the NanoScope Analysis package by double clicking the offline icon on the Windows desktop.

2. Open the PeakForce QNM HSDC file.

3.  Click the QNM-Hsdc Force Curve-Image icon to open the ***QNM Hsdc Force Curve-Image*** window, shown in Figure 8.1a.

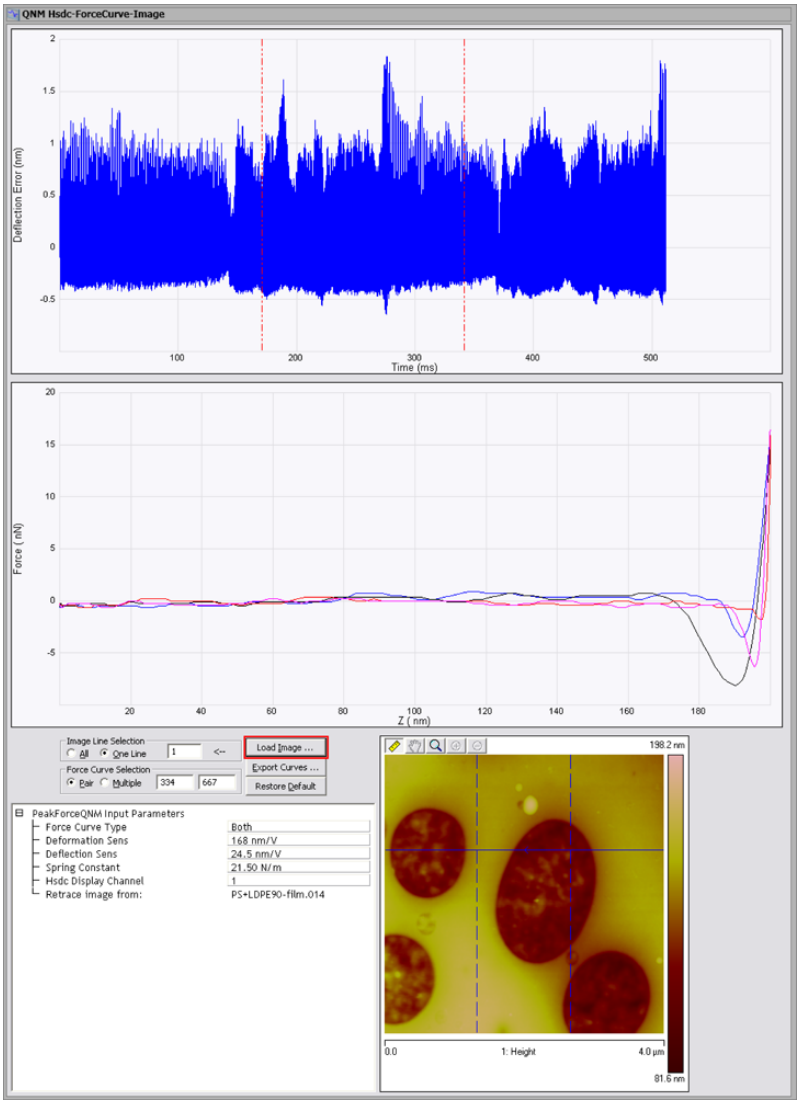


Figure 8.1a: The ***QNM Hsdc Force Curve Image*** window.

4. Click the ***Load Image*** button, circled in Figure 8.1a, and select the image file associated with your high speed data capture file.
5. The solid blue horizontal line, shown in Figure 8.1b, displays the captured line.

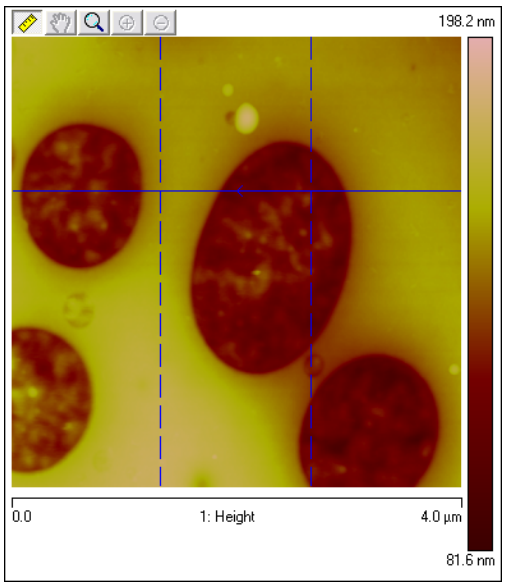


Figure 8.1b: The ***Height*** channel of the image file

6. Two vertical dashed blue cursors, shown in Figure 8.1c, display the X position of the displayed force curves when ***Pair*** is checked in the ***Force Curve Selection*** box. The associated number boxes display the Z piezo tap number. You may move the force position by either dragging the dashed blue cursors in the image, the dashed red cursors (see Step 7) in the time display or entering the numbers in the ***Force Curve Selection*** panel. You may select the channel of the captured image by right-clicking in the image as shown in Figure 8.1c.

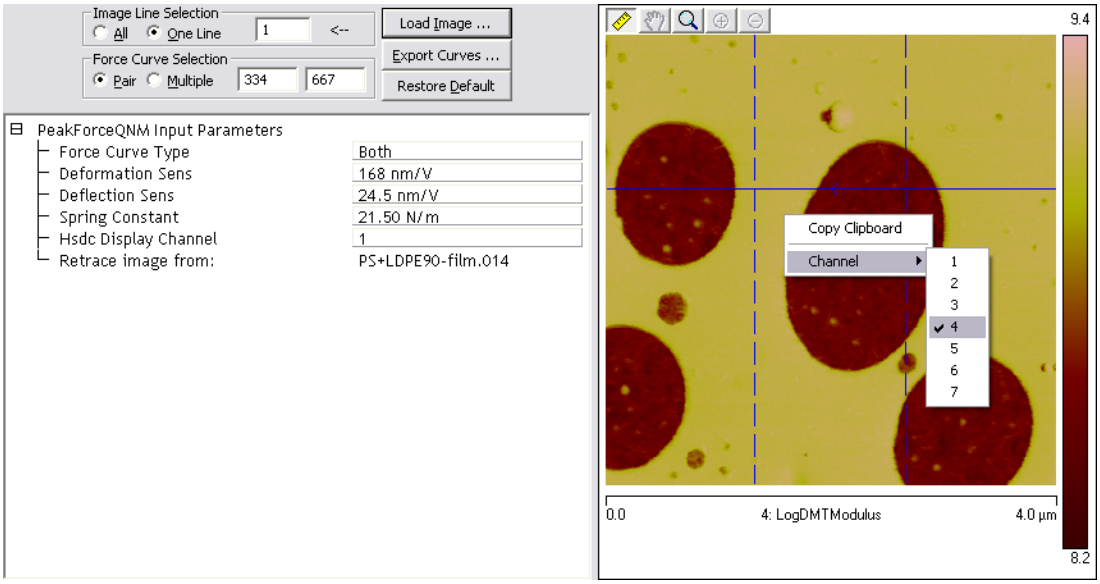


Figure 8.1c: Vertical cursors display X position

7. The position of the force curves is also represented by the red dashed cursors in the ***Deflection Error vs. Time*** display, shown in Figure 8.1d.To Zoom in on an area of interest in the graphs, hold down the Control key and draw a box in the preferred area. To Zoom back out, double-click the image or click the magnifying glass icon in the lower left corner of the plot.

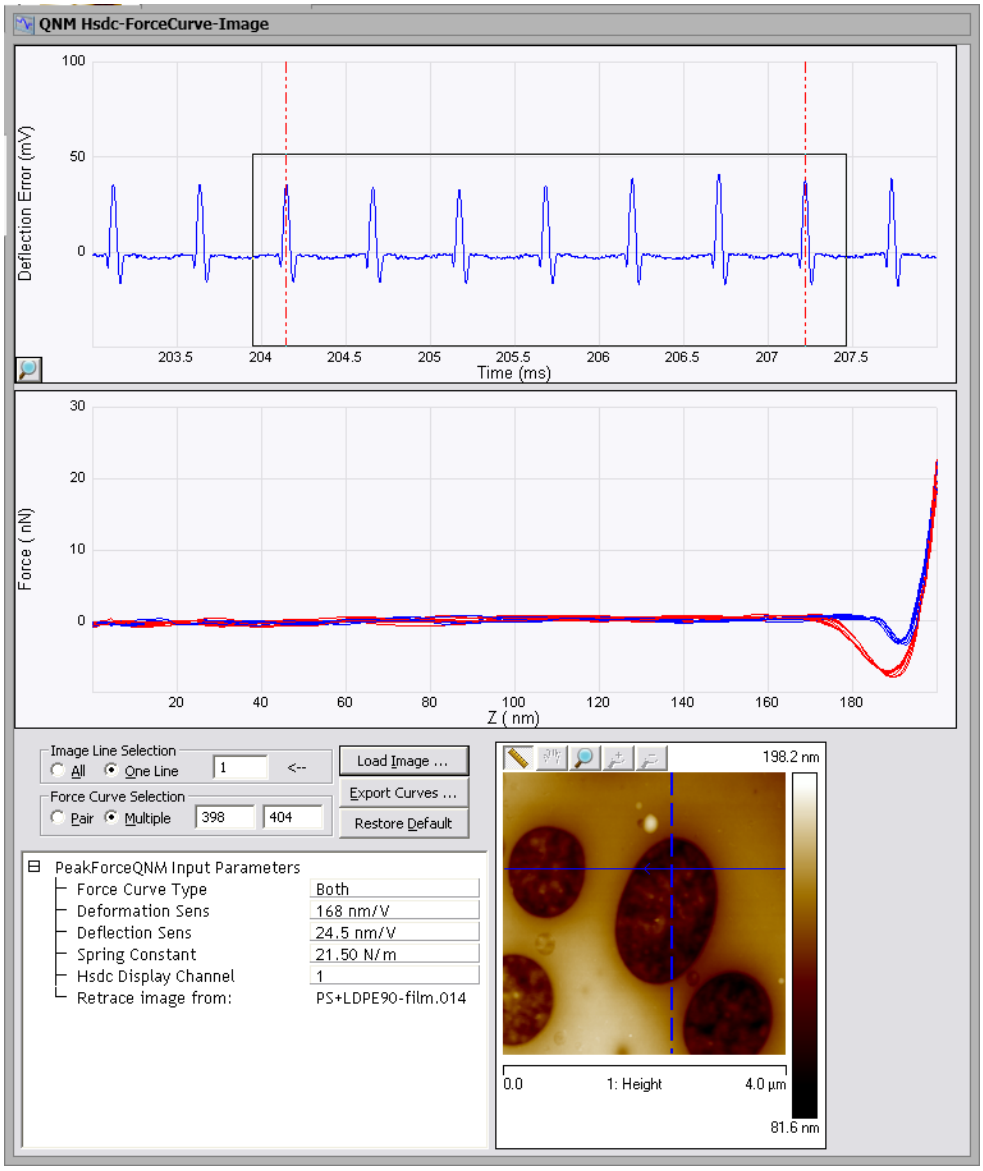


Figure 8.1d: The ***QNM Hsdc Force Curve-Image*** window

8.1.3 QNM Force Curve Controls and Settings

Image Line Selection

Range and Settings::

- ***All***: Displays all captured lines.
- ***One Line***: Displays one captured scan line of taps.
  The arrow in the ***Image Line Selection*** panel and the solid blue line, shown in Figure 8.1b, display the scan direction. The counters are displayed in the ***Force Curve Selection*** panel.

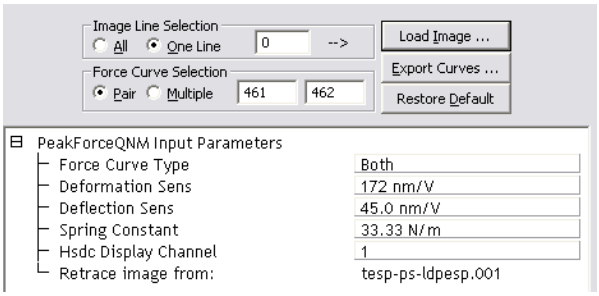


Figure 8.1e: PeakForce QNM Controls

Force Curve Selection

Range and Settings:

- ***Pair***: Displays one force curve for each cursor. See Figure 8.1d (in QNM Force Curve Procedure (page 268)) for an example. The red cursors snap to the closest peak in the Deflection Error vs. Time plot. The exported force curves encompass a full cycle around the selected peaks. Force curve number 1 will be the first curve that has a full cycle. This may be the second peak in the time plot. The location of the pair of force curves can be controlled by moving either the dashed blue cursors in the image, the dashed red cursors (see Step 7 in the QNM Force Curve Procedure (page 268)) in the time display or entering the numbers in the ***Force Curve Selection*** panel.

NOTE: You may select one (rather than two) curve by entering the same curve number in both fields.

- ***Multiple***: Displays all the force curves between the vertical cursors. The location of the force curves can be controlled by dragging either the dashed blue cursors in the image, the dashed red cursors (see Step 7 in the QNM Force Curve Procedure (page 268) page) in the time display or entering the numbers in the ***Force Curve Selection*** panel. See Figure 8.1f.

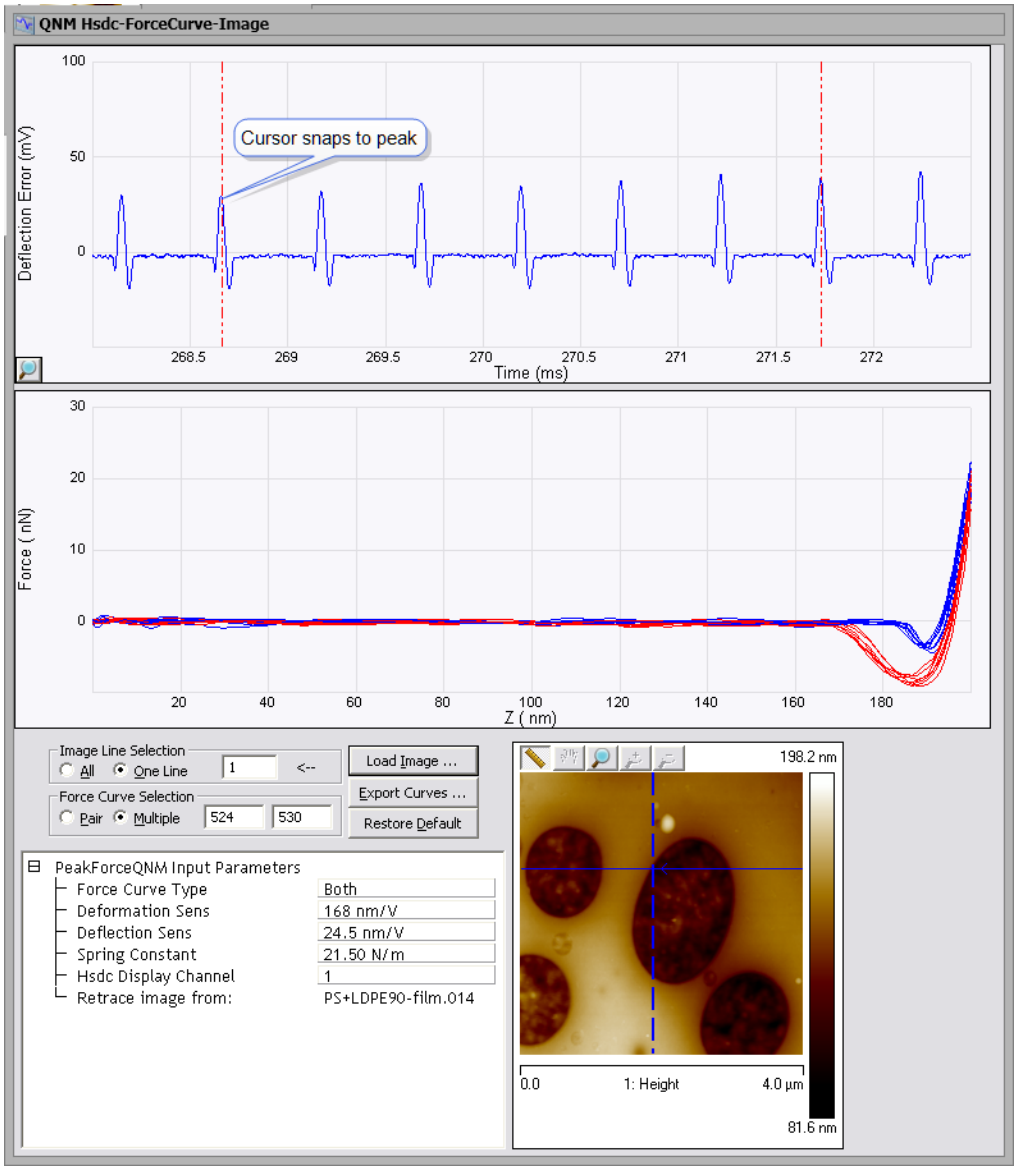


Figure 8.1f: Multiple Force Curve Selection

Force Curve Type

Range and Settings:

- ***Both***: Display both the extend and retract portions of the Z piezo ramp.
- ***Trace***: Displays the extend portion of the Z piezo ramp.
- ***Retrace***: Displays the retract portion of the Z piezo ramp.

Exporting Force Curves

Click the ***Export Curves*** button to export either

- a ***Pair*** of force curves. One force curve will be exported for each vertical cursor. The red cursors snap to the closest peak in the Deflection Error vs. Time plot. The exported force curves encompass a full cycle

around the selected peaks.

NOTE: You may select one (rather than two) curve by entering the same curve number in both fields.

- or ***Multiple*** curves in a directory FrcExport.
  One file will be created for each force curve. This binary file (header is ASCII) can be opened by the NanoScope Analysis package.

Because off-line plots (either NanoScope or NanoScope Analysis) feature more display options for exported curves (FrcExport) than HSDC files, you may wish to export your curves and then open the FrcExport files. See the Exported Force Curves (page 275) section for details.

PeakForce QNM Input Parameters

The parameters appearing in the PeakForce QNM Input Parameters window have been collected in real-time but may be modified for off-line analysis here.

- Deformation Sensitivity
- Deflection Sensitivity
- Spring Constant
- Hsdc Display Channel

8.1.4 Exported Force Curves

Exported force curves (file names begin with FrcExport) can be viewed in NanoScope software or NanoScope Analysis software. Off-line plots feature more display options for exported curves than are available for HSDC files. These additional options are listed below.

Time Domain Plots

Change the ***X Data Type*** from ***Z Height*** to ***Time*** to transform the original force curve, shown in Figure 8.1g, to a Force vs. Time plot (a.k.a. heartbeat), shown in Figure 8.1h

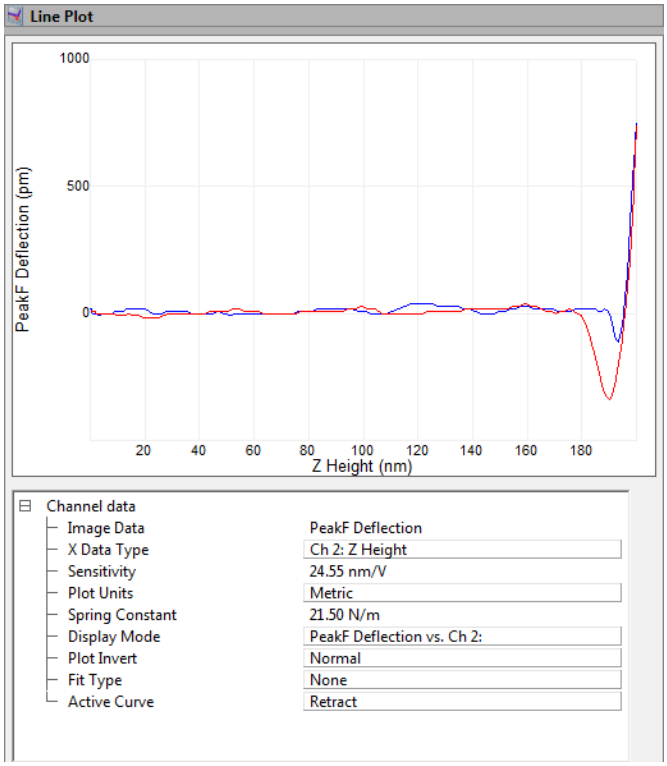


Figure 8.1g: Exported force curve.

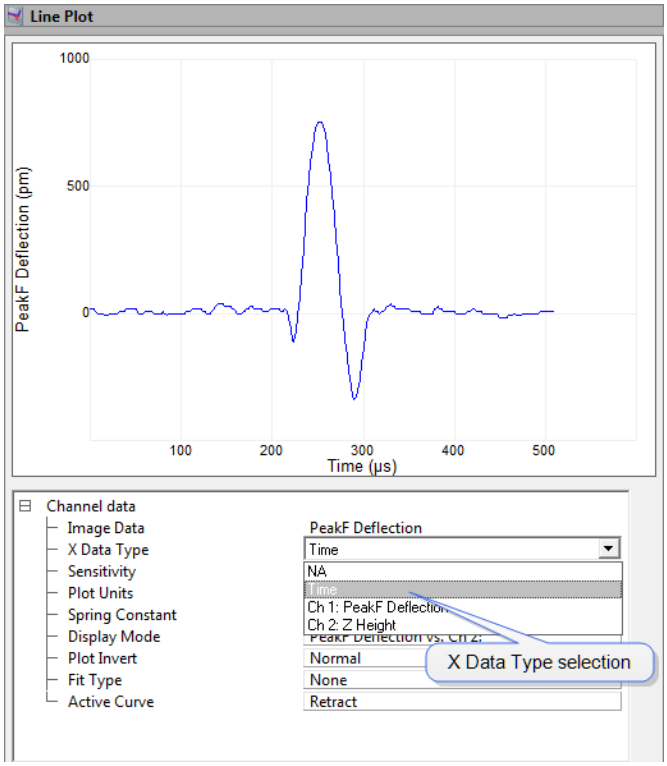


Figure 8.1h: Force vs. time.

Plot Units

The Y axis can be displayed as ***Volts*** (Deflection), ***Metric*** (distance in nanometers) or ***Force*** (nano Newtons).

Display Mode

Change the ***Display Mode*** to ***PeakF Deflection vs. Sep***, shown in Figure 8.1i, to plot your data vs. separation.

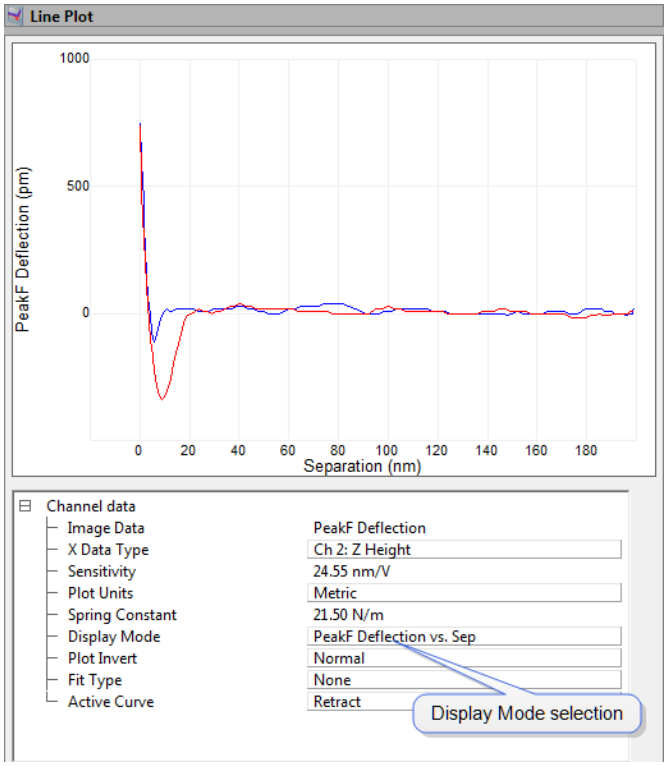


Figure 8.1i: Force vs. separation.

8.2 High Speed Data Capture (HSDC)

High Speed Data Capture files allow for the capturing and storing of many signals.

8.2.1 HSDC Procedure

To open a ***HSDC*** file in NanoScope Analysis, double click on a NanoScope ***HSDC*** file in the ***Browse Files*** view or navigate to the preferred ***HSDC*** file from the ***Open File*** icon . If the file is indeed an ***HSDC*** file, it will be opened in the ***HSDC*** window automatically.

When the ***HSDC*** image is opened it should look similar to the image shown in Figure 8.2a. The data for ***Marker Pair 2*** is non-existent as that marker has not yet been added to the ***HSDC*** image.

To add markers to the ***HSDC*** image, position the mouse in the ***Force Curve*** graph area to the left of the Y axis. The standard cursor will change to a *double-headed arrow cursor*. When the *double-headed cursor* appears, left-click the mouse, and drag the cursor to the desired position on the ***Force Curve***. The data for the position is automatically updated in the ***Marker Pair Results*** 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***.

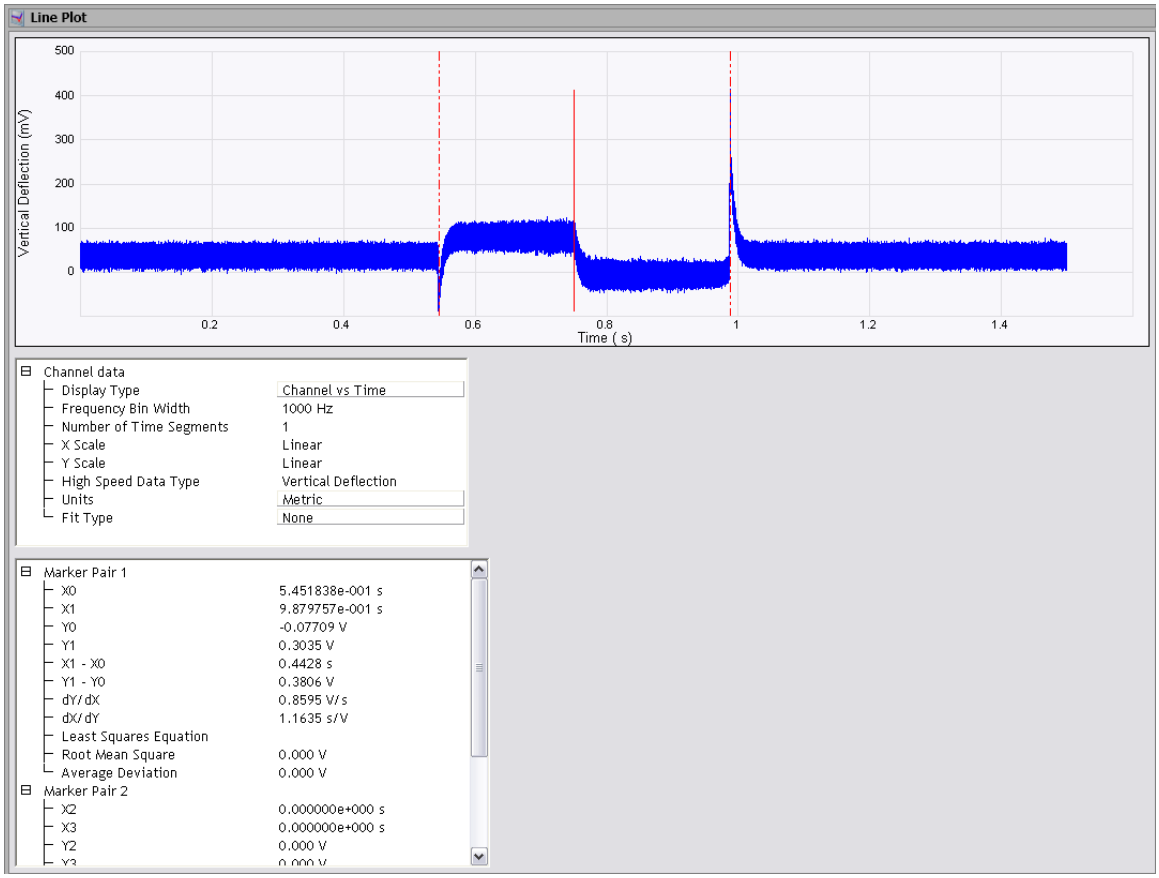


Figure 8.2a: HSDC Window

8.2.2 HSDC Interface

Parameter	Description
Display Type	Choose: -Channel vs Time or -Amplitude vs Frequency
Frequency Bin Width	Automatically determined
Number of Time Segments	Automatically determined
X scale	Automatically determined
Y scale	Automatically determined
High Speed Data Type	Automatically determined
Units	Choose: Metric or Volts
Fit Type	Choose: None or Line

Table: 8.0bd *Channel Data* Parameters

Parameter	Description
Marker Pair 1:	
X0	Z position of first marker, Marker Pair 1
X1	Z position of second marker, Marker Pair 1
Y0	Deflection/oscillation position of first marker, Marker Pair 1
Y1	Deflection/oscillation position of second marker, Marker Pair 1
X1 - X0	Z distance between markers in Marker Pair 1
Y1 - Y0	Deflection/oscillation space between markers in Marker Pair 1
dY/dX	Slope of Marker Pair 1
dX/dY	1/Slope of Marker Pair 1
Least Squares Equation	
Root Mean Square	
Average Deviation	
Marker Pair 2:	
X2	Z position of first marker, Marker Pair 2
X3	Z position of second marker, Marker Pair 2
Y2	Deflection/oscillation position of first marker, Marker Pair 2
Y3	Deflection/oscillation position of second marker, Marker Pair 2
X3 - X2	Z distance between markers in Marker Pair 2
Y3 - Y2	Deflection/oscillation space between markers in Marker Pair 2
dY/dX	Slope of Market Pair 2
dX/dY	1/Slope of Marker Pair 2
Least Squares Equation	
Root Mean Square	
Average Deviation	

Table: 8.0be *Marker Pair* Results

8.3 Strip-chart

A Strip-chart file plots a channel versus time.

8.3.1 Strip-chart Procedure

1. To open a ***Strip-chart*** file in NanoScope Analysis, double click on the file in the ***Browse Files*** view or navigate to the preferred file from the ***Open File*** icon . If the file is indeed a ***Strip-chart*** file, it will be opened in the ***Strip-chart*** window automatically. When the image is opened it should look similar to the image below.
2. To add markers to the image, position the mouse in the graph area to the left of the Y axis. The standard cursor will change to a double-headed arrow cursor. When the double-headed cursor appears, left-click the mouse, and drag the cursor to the desired position on the graph. The data for the position is automatically updated in the ***Marker Pair Results*** area.

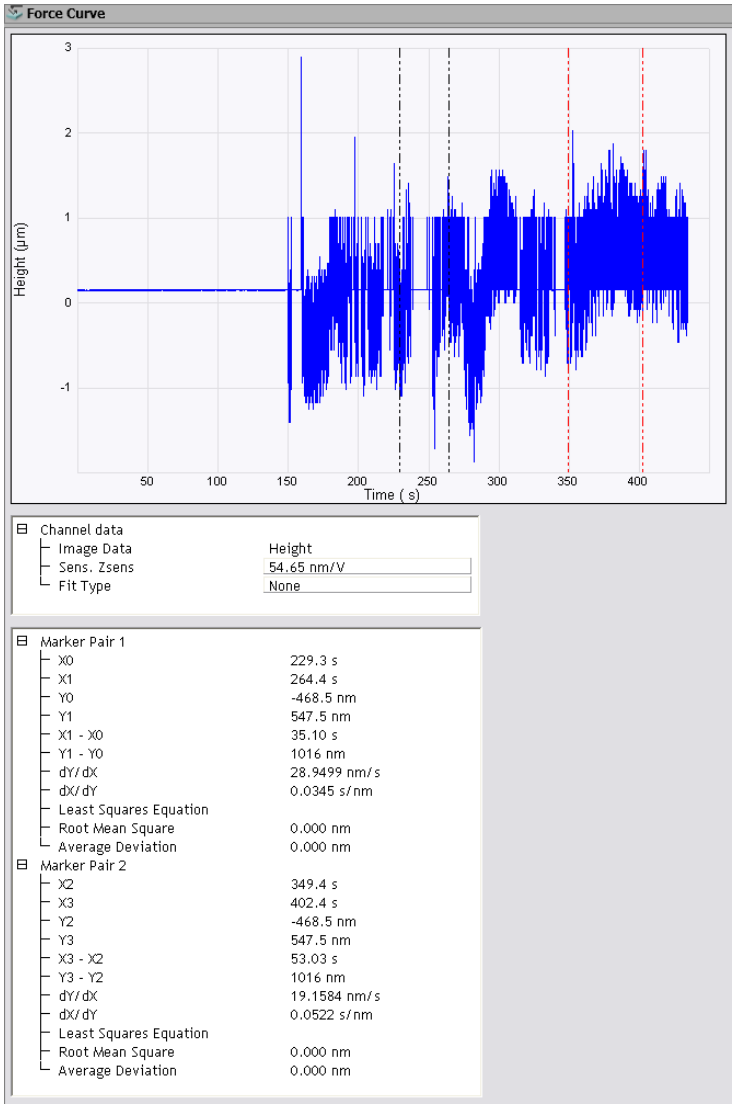


Figure 8.3a: Strip-chart Window

8.3.2 Strip-chart Interface

Parameter	Description
Image Data	Determined by original data
Sens. Zsens	
Fit Type	Choose: None, Line, Hertzian, WLC

Table: 8.0bf *Channel Data* Input Parameters

Parameter	Description
Marker Pair 1:	
X0	Z position of first marker, Marker Pair 1

Parameter	Description
X1	Z position of second marker, Marker Pair 1
Y0	Deflection/oscillation position of first marker, Marker Pair 1
Y1	Deflection/oscillation position of second marker, Marker Pair 1
X1 - X0	Z distance between markers in Marker Pair 1
Y1 - Y0	Deflection/oscillation space between markers in Marker Pair 1
dY/dX	Slope of Marker Pair 1
dX/dY	1/Slope of Marker Pair 1
Least Squares Equation	
Root Mean Square	
Average Deviation	
Marker Pair 2:	
X2	Z position of first marker, Marker Pair 2
X3	Z position of second marker, Marker Pair 2
Y2	Deflection/oscillation position of first marker, Marker Pair 2
Y3	Deflection/oscillation position of second marker, Marker Pair 2
X3 - X2	Z distance between markers in Marker Pair 2
Y3 - Y2	Deflection/oscillation space between markers in Marker Pair 2
dY/dX	Slope of Market Pair 2
dX/dY	1/Slope of Marker Pair 2
Least Squares Equation	
Root Mean Square	
Average Deviation	

Table: 8.0bg *Marker Pair* Results

8.4 Strip-chart Combined Channels

The ***Strip-chart Combined*** plots a channel versus time and two different channels versus each other. By comparing the two different charts it is possible to correlate multiple channels against time.

8.4.1 Strip-chart Combined Procedure

1. To open a ***Strip-chart*** file in NanoScope Analysis, double click on a NanoScope ***Timed*** file in the ***Browse Files*** view or navigate to the preferred ***Timed*** file from the Open File icon  . If the file is indeed a ***Timed*** file, it will be opened in the ***Strip-chart*** window automatically. When the image is opened it should look similar to the image below. The data for ***Marker Pair 2*** is non-existent, as that marker has not yet been added to the ***Strip-chart*** image.
2. Now, to open the ***Strip-chart Combined*** window, click on the Strip-chart Combined icon from the ***Icon*** toolbar. The ***Strip-chart Combined*** window will open.
3. To add markers to the image, position the mouse in the graph area to the left of the Y axis. The standard cursor will change to a *double-headed arrow cursor*. When the *double-headed cursor* appears, left-click the mouse, and drag the cursor to the desired position on the graph. The data for the position is automatically updated in the ***Marker Pair Results*** area.

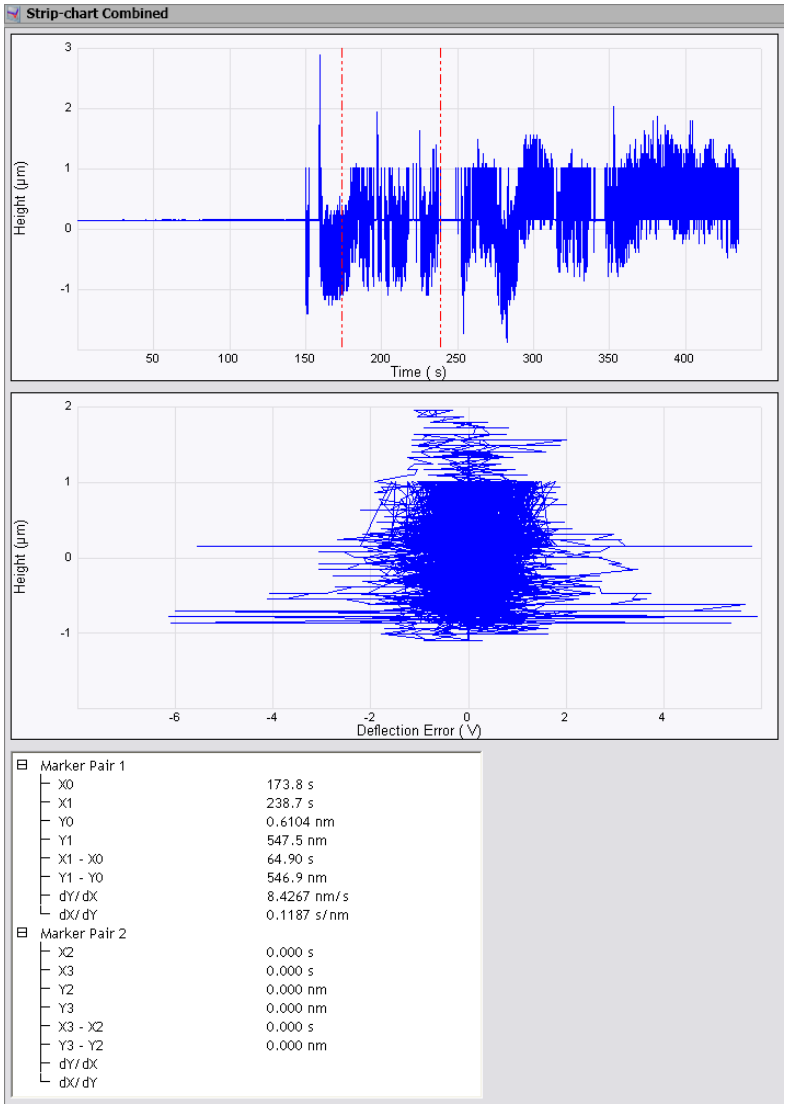


Figure 8.4a: ***Strip-chart Combined*** Window

8.4.2 Strip-chart Combined Interface

Parameter	Description
Marker Pair 1:	
X0	Z position of first marker, Marker Pair 1
X1	Z position of second marker, Marker Pair 1
Y0	Deflection/oscillation position of first marker, Marker Pair 1
Y1	Deflection/oscillation position of second marker, Marker Pair 1
X1 - X0	Z distance between markers in Marker Pair 1
Y1 - Y0	Deflection/oscillation space between markers in Marker Pair 1
dY/dX	Slope of Marker Pair 1

Parameter	Description
dX/dY	1/Slope of Marker Pair 1
Marker Pair 2:	
X2	Z position of first marker, Marker Pair 2
X3	Z position of second marker, Marker Pair 2
Y2	Deflection/oscillation position of first marker, Marker Pair 2
Y3	Deflection/oscillation position of second marker, Marker Pair 2
X3 - X2	Z distance between markers in Marker Pair 2
Y3 - Y2	Deflection/oscillation space between markers in Marker Pair 2
dY/dX	Slope of Market Pair 2
dX/dY	1/Slope of Marker Pair 2

Table: 8.0bh *Marker Pair* Results

8.5 Electrochemical SPM

The electrochemical display environment, shown in Figure 8.5a, displays one channel of the image, three plots and a plot control panel.

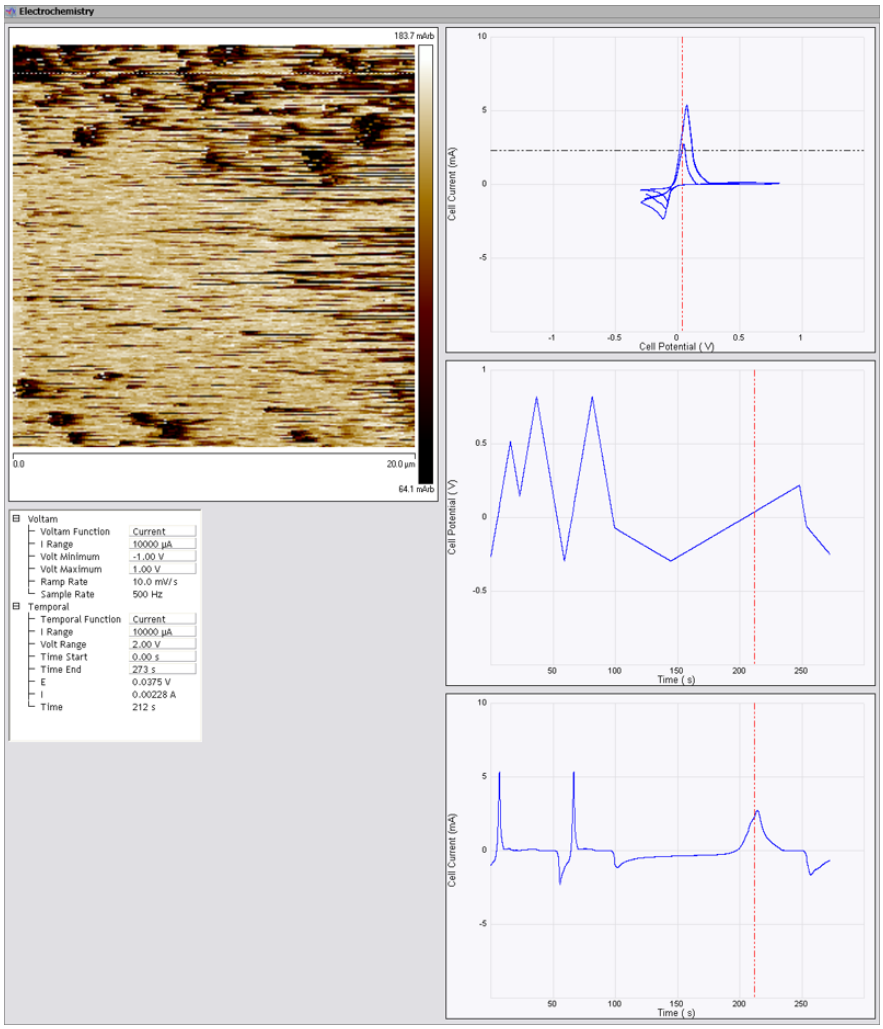


Figure 8.5a: The NanoScope Analysis Electrochemistry display window showing a PeakForce DMT modulus image

The ***Voltammogram*** (top plot) plots current along the vertical axis versus potential along the horizontal axis. This can be ***Itip*** vs. ***Etip*** (STM) or ***I*** vs. ***E*** or one of the calculated values, current density, charge, etc. vs., ***E***.

NOTE: The calculated values are all based on the electrochemical cell current, ***I***, and *not* on STM tip current, ***Itip***.

In the ***Temporal*** (bottom two) plots, the horizontal axis is always time. A voltage (top) and a current (bottom) are plotted versus time. The voltage can be the electrochemical cell potential, ***E***, or the potential of the STM tip, ***Etip***. The current can be electrochemical cell current, ***I***, one of its derivative quantities; e.g., charge, current density, etc., or it can be the current flowing through the STM tip, ***Itip***.

The time scale on the ***Temporal*** graph does not necessarily correspond to the time required to capture an SPM image for the following reasons:

1. The total number of data points is limited to 62,254. Hence, the product of the ***Sample Rate*** and ***Time*** range is limited to 62,254. For example, when one attempts to collect 1000 seconds of data, the maximum ***Sample Rate*** is 62 Hz.
2. If the time to capture an image exceeds the time to record the maximum of the 62,254 electrochemical data points that can be stored, only the last 62,254 data points are saved. The data points prior to the last 62,254 data points are lost. Time zero on the ***Temporal*** graph reflects the start of the last 62,254 data points.
3. To display on the ***Temporal*** graph only a portion of the stored data points, for example, the last 30,000 of 62,254 data points recorded using a ***Sample Rate*** of 100 Hz, define ***Time Start*** equal 300 seconds (roughly one-half of the maximum of 623 seconds for this case) and ***Time End*** equal 623 seconds in the plot controls dialog box for the NanoScope Analysis software. In this case, time zero on the ***Temporal*** graph would actually be the first data point after the 300-second marker.

Cursors

A mouse click-and-hold-and-drag may be used in the ***Temporal*** plot windows to display data at any point in the experiment.

The markers in all three plots will follow the position of the cursor as the mouse is dragged (click and hold) in the plot. The electrochemical cell data (***E***, ***I***, ***Time***) at the position of the marker is displayed in the ***Temporal*** panel of the plot controls dialog box in the lower left of the EC window.

A marker on the ***Voltammogram*** will indicate the corresponding data as potential vs. current. The vertical line in the ***Temporal*** plot indicates, in time, when the first line of the SPM image was captured. As the ***Temporal*** marker is moved, a horizontal line on the SPM image will move to the scan line that was captured at approximately the same time. See Figure 8.5a. In addition, the mouse may drag (click-and-hold) the line on the image to any scan line, and this will move the ***Temporal*** and ***Voltammogram*** markers to the appropriate positions and update the electrochemical cell data display.

Note that it is possible to have data displayed in the ***Temporal*** plot across such a time window that it does not correspond to any of the data in the SPM image. This is because when an SPM image is captured, the last 62,254 electrochemical data points are also recorded in the file, and only a portion of the electrochemical data recorded may correspond to the time required to capture the SPM image; i.e., the image may have taken less time to capture than the last 62,254 electrochemical data points.

A mouse Ctrl-click-and-hold-and-drag may be used in the plot windows to zoom in on a portion of the data. Clicking the magnifying glass in the lower left corner of the plot window resets the plot.

Plot Controls Dialog Box

The parameters in the plot controls dialog box, shown in Figure 8.5b and described in Table: 8.0bi, allow you to scale and clip the electrochemical data.

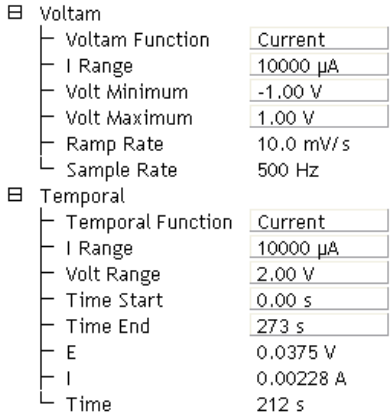


Figure 8.5b: The electrochemistry plot control dialog box

Parameter Group	Parameter	Description
Voltam	***Voltam Function***	Indicates the quantities plotted along horizontal and vertical axes of the voltammogram. *Settings:* • Charge • Chrg Dens • Current • Cur Dens • Log Cur • Lg Cur Dens • Tip Current When this parameter is ***Itip***, the current through STM tip is plotted vs. ***Etip***. All other settings (e.g., current, charge) have the electrochemical cell parameter plotted vs. ***E***.
	I Range	Controls the vertical scale of the ***Voltammogram*** graph.
	Volt Minimum	Voltage corresponding to left edge of ***Voltammogram*** graph.
	Volt Maximum	Voltage corresponding to the right edge of the ***Voltammogram*** graph.
	Ramp Rate	Indicates the ramp rate at the time of capture.
	Sample Rate	The rate of electrochemical data recording at the time of capture.
	Tip Reference	STM only. Indicates whether the STM tip potential, ***Etip***, or tip bias, ***Ebias***, is kept constant during ramping.
	Ramp Electrode	Indicates which electrode (working or STM tip) was ramped at time of capture.
Temporal	***Temporal Function***	Indicates what parameter is plotted along the vertical axis vs. time along horizontal axis. *Settings:* • Charge • Chrg Dens • Current • Cur Dens • Log Cur • Lg Cur Dens • Tip Current
	I Range	Controls the current scale of the ***Temporal*** graph.

Parameter Group	Parameter	Description
	V Range	Controls the voltage scale of the ***Temporal*** graph.
	Time Start	Start time of displayed data (left edge of plot).
	Time End	End time of displayed data (right edge of plot). **NOTE:** The system will record the current and voltage vs. time data starting from time = 0 in the Temporal graph. The current is integrated starting at time = 0 of the Temporal graph. Any data that fits into the Temporal graph will be displayed. Voltammogram will display data within the time range of the Temporal graph.
	E	Cell potential at marker position.
	Etip	STM only. Potential of the tip relative to the reference electrode.
	Ebias	STM only. Voltage difference between tip and sample, ***Etip*** - ***E***.
	I	Cell current at marker position.
	Time	Time at marker position relative to start of ***Temporal*** plot. The data is normally displayed using the ***Temporal*** Time range at the time of capture.

Table: 8.0bi Plot Controls parameters

Chapter 9: MIRO

Bruker's Microscope Image Registration and Overlay (MIRO) software integrates AFM imaging with optical microscopy. This optional software allows the user to automatically import and rescale light microscope images, which can then be used to direct the location of AFM imaging and force measurements. Correlated datasets can be captured and analyzed with the powerful offline functionality.

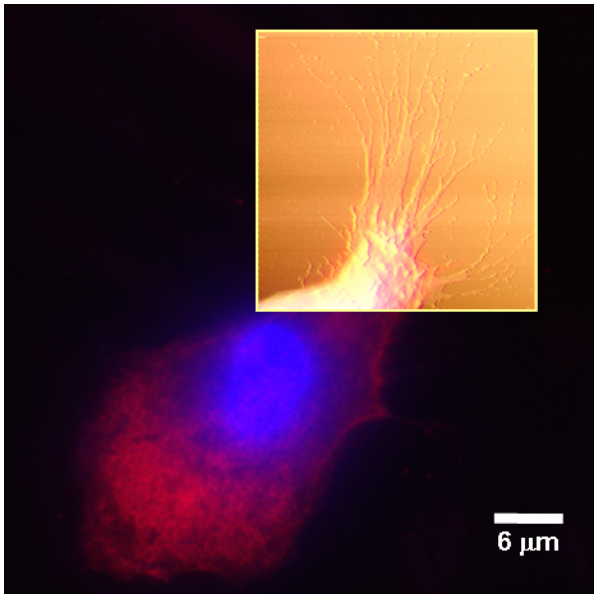


Figure 9.0a: Fixed macrophage cell labeled with Alexa Fluor phalloidin (red) and DAPI (blue) with AFM inset. Image courtesey of Peter Hanley, Institute fro Physiology II, University of Muenster, Germany.

If you would like more information or would like to purchase MIRO, please contact Bruker.

MIRO™ (Microscope Image Registration and Overlay) user-guided interactive software allows you to do the following:

- Register optical and AFM images
- Import and overlay multiple optical and AFM images
- Adjust and fine-tune the registration parameters of both optical and AFM images
- Store and restore profiles for different system configurations (e.g. multiple objective lenses)
- Adjust image color, transparency and overlay options—individually for each channel
- Export overlaid images
- Save each overlay and associated image parameters for further analysis in offline mode
- MIRO 2.0 adds multiple **Region of Interest** views which allow you to more easily compare overlaid images

Refer to the following sections for information about MIRO:

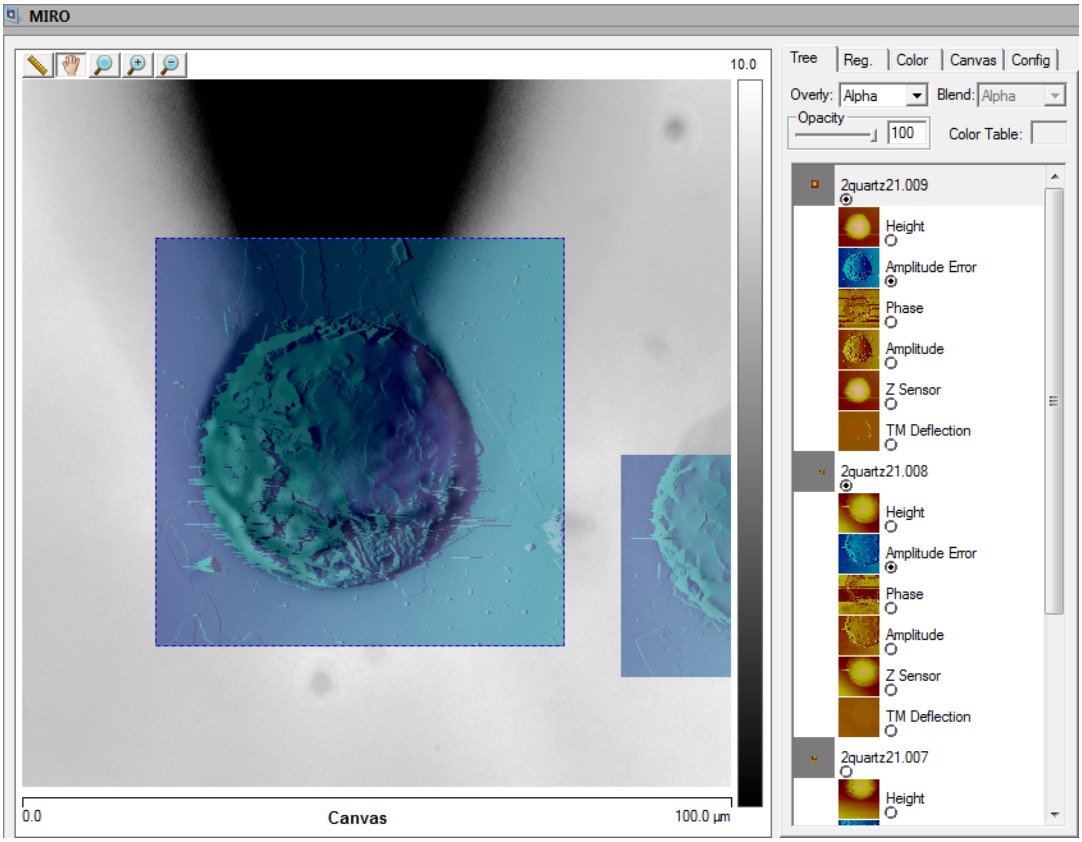
9.1 MIRO Files

MIRO files are xml (ASCII) files that contain all MIRO information: tree structure, import settings, canvas settings, ROI settings, etc. MIRO files are saved as *.iro files.

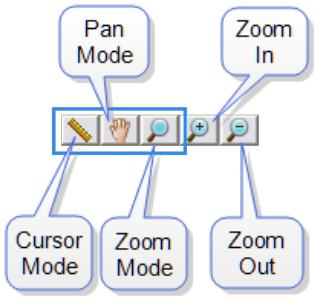
- Double-click an *.iro file in the NanoScope Analysis ***Browse*** window to open it in MIRO.

9.2 The MIRO Canvas

Double-click an *.iro file to open the MIRO canvas.



The NanoScope Analysis image buttons available in MIRO:



The first three buttons represent "modes" in which you will be able to interact differently with the image showing on the canvas:

Cursor Mode: Allows the user to draw a box, line, or place a marker to obtain measurements from the image displayed in the canvas.

- With the **Cursor Mode** button selected, click the right mouse button to select **Box**, **Rotating line**, or **Cross.**
- Left-click and drag on the image to draw the box, line, or cross on the element you wish to measure.
- Information about the box dimensions or line length and angle will appear in a tool tip at the bottom left-hand-side of the canvas.

Pan Mode: From a zoomed canvas, allows the user to drag other areas of the canvas into view.

- With the **Pan Mode** button selected, click the left mouse button and drag the canvas around as desired.

Zoom Mode: Allows the user to draw a zoom in box on the canvas.

- With the **Zoom Mode** button selected, click the left mouse button and drag to create a zoom box.
- Note that the box will be drawn from the center (click point) outward.

Additional buttons and mouse functions control other interactions with the image:

- **Zoom In:** Button is active for one click only; zooms in by 40%, relative to the current screen center.
- **Zoom Out:** Button is active for one click only; zooms out by 40%, relative to the current screen center.
- **Mouse Wheel:** Turn the mouse wheel to zoom in (roll away from yourself) or zoom out (roll towards yourself) in 20% increments.
  - Current position of the mouse cursor (arrow) is used as the anchor point of the zoom when using the mouse wheel
  - Enabled regardless of the active mode in the canvas (Cursor Mode, Pan Mode, or Zoom Mode)
- **Mouse Double Click:** Centers the view on the clicked spot.
  - Does *not* zoom in or out
  - Enabled regardless of the active mode in the canvas (Cursor Mode, Pan Mode, or Zoom Mode)

The MIRO Toolbar (page 309), which appears in the NanoScope main window when MIRO is active, offers additional imaging options.

The MIRO canvas contains all of the following tabs, each with its respective functionality:

- The Tree Tab (page 296)
- The Registration Tab (page 298)

- The Color Tab (page 299)
- The Canvas Tab (page 308)
- The Configuration Tab (page 308)

9.2.1 The Tree Tab

The **Tree** tab allows you to select the AFM and optical channels to be overlaid, change their tree structure, adjust their overlay and blend properties, color, and opacity.

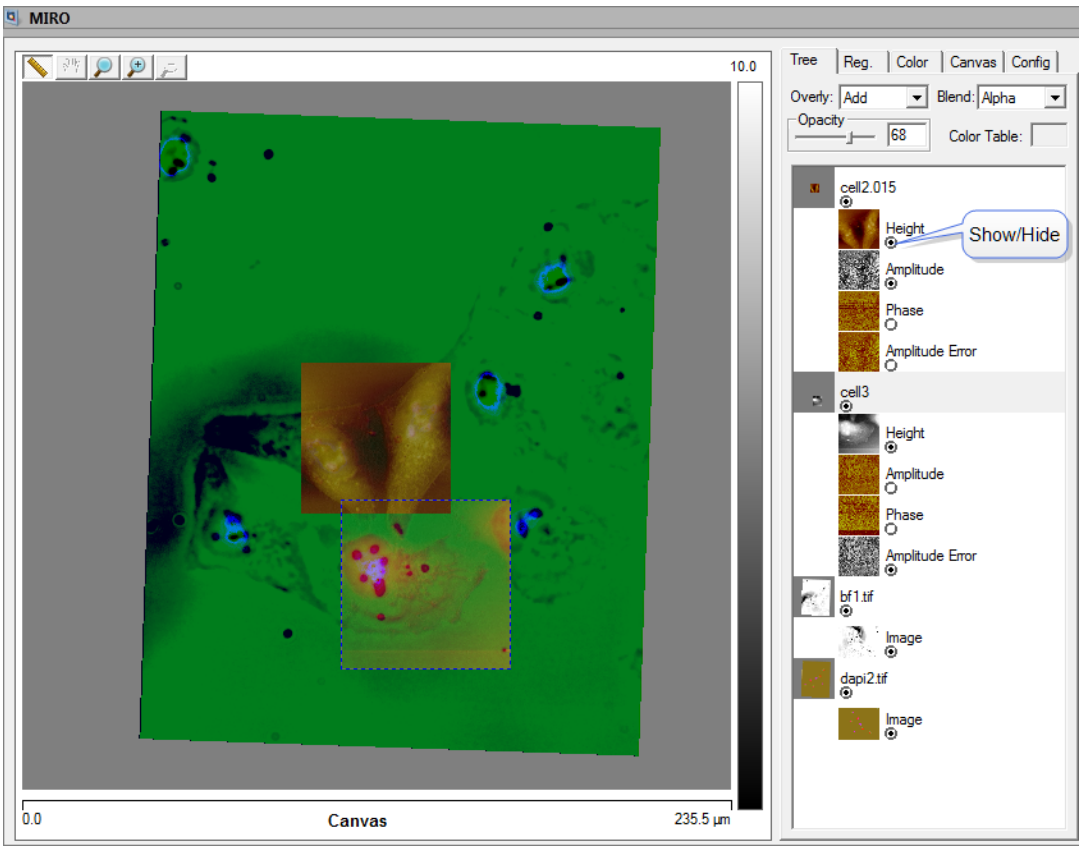


Figure 9.2a: MIRO Canvas with Lines and Buttons selected

Functions Performed on a Selected Image:

- **Show/Hide**: Click the radio button below the image name to show/hide the image (as demonstrated in Figure 9.2a).
- **Change Order in tree:** Drag the image to change its order in the tree. The order of images in the tree determines the overlay order on the canvas.
- **Overlay:** Specifies the overlay method for the images. Define α as the opacity and "n" as the layer number.

  Settings:

  - Alpha: $Color_n = Color_{nOriginal} * \alpha_n + Color_{n-1} * (1-\alpha n)$
  - Add: $Color_n = Color_{nOriginal} * \alpha_n + Color_{n-1}$
  - Max: $Max[Color_{nOriginal} * \alpha_n, Color_{n-1}]$

- **Blend:** Specifies the overlay method for the channels. Define n as the layer number with n = 1 the bottom layer and α_n as the opacity of the n^{th} layer.

  Settings:

  - **Alpha:** $Color_n = Color_{nOriginal} * \alpha_n + Color_{n-1} * (1-\alpha_n)$
  - **Add:** $Color_n = Color_{nOriginal} * \alpha_n + Color_{n-1}$
  - **Max:** $Max[Color_{nOriginal} * \alpha_n, Color_{n-1}]$
- **Opacity:** Move the **Opacity** slider, enter a number or use the arrow keys to change the opacity of an image. This function aids image alignment.
- **Color Table:** Selects the color table. See List of Color Tables.

Canvas Formatting Functions:

Right-click the Tree on the right-hand side of the canvas to access most of the Tree Tab functions:

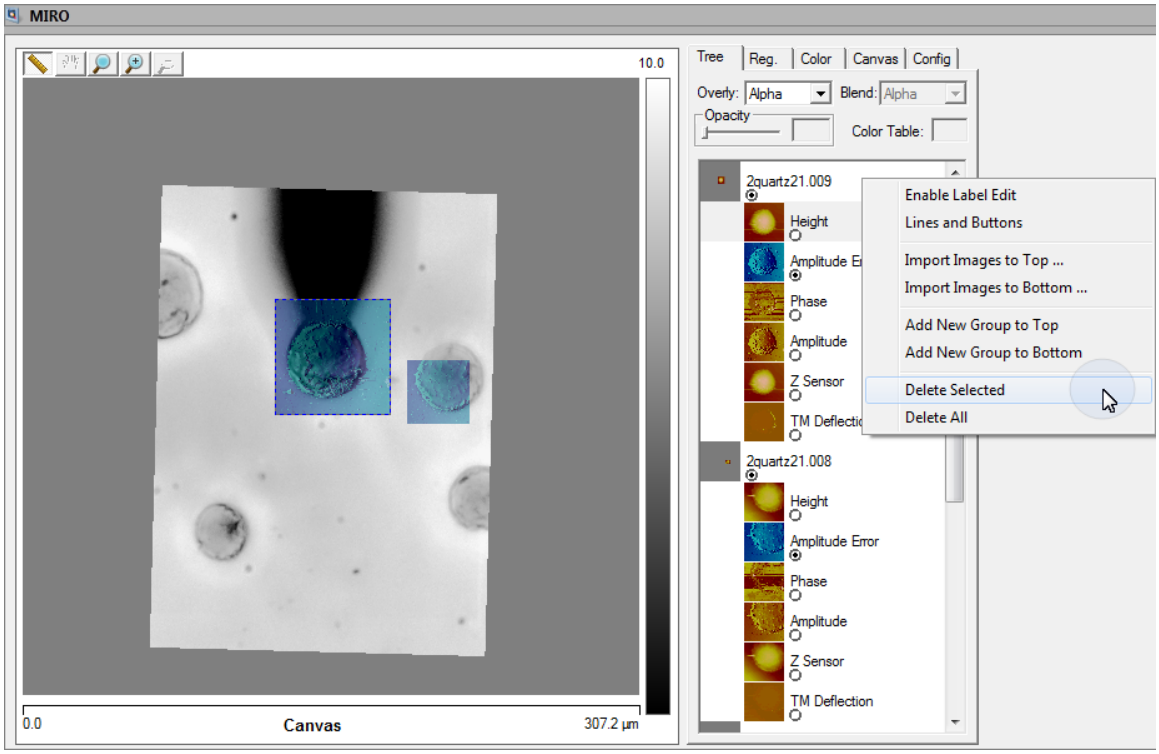


Figure 9.2b: Example of function options available by right-clicking on the tree

- **Enable Label Edit:** When selected, allows the user to change the image label
- **Lines and Buttons:** The Lines and Buttons function, shown in Figure 9.2a, displays the image tree structure. Clicking a button collapses that portion of the tree.
- **Import Images to Top:** Sets default to import an image to the top of the selected image
- **Import Images to Bottom:** Sets default to import an image to the bottom of the selected image
- **Add new Group to Top:** Adds a new group to the top of the selected image
- **Add new Group to Bottom:** Adds a new group to the bottom of the selected image
- **Delete Selected:** Deletes the selected image from MIRO
- **Delete All:** Deletes all images from MIRO

9.2.2 The Registration Tab

The **Registration** tab is used to adjust the registration overlay.

Once the initial registration process has been performed, you can expand, shrink, translate or rotate a selected image so that it more accurately overlaps a correlating area of an AFM image.

> **CAUTION:** Adjustments to the registration are usually done on optical images. AFM images always import according to their registration-associated scan information.

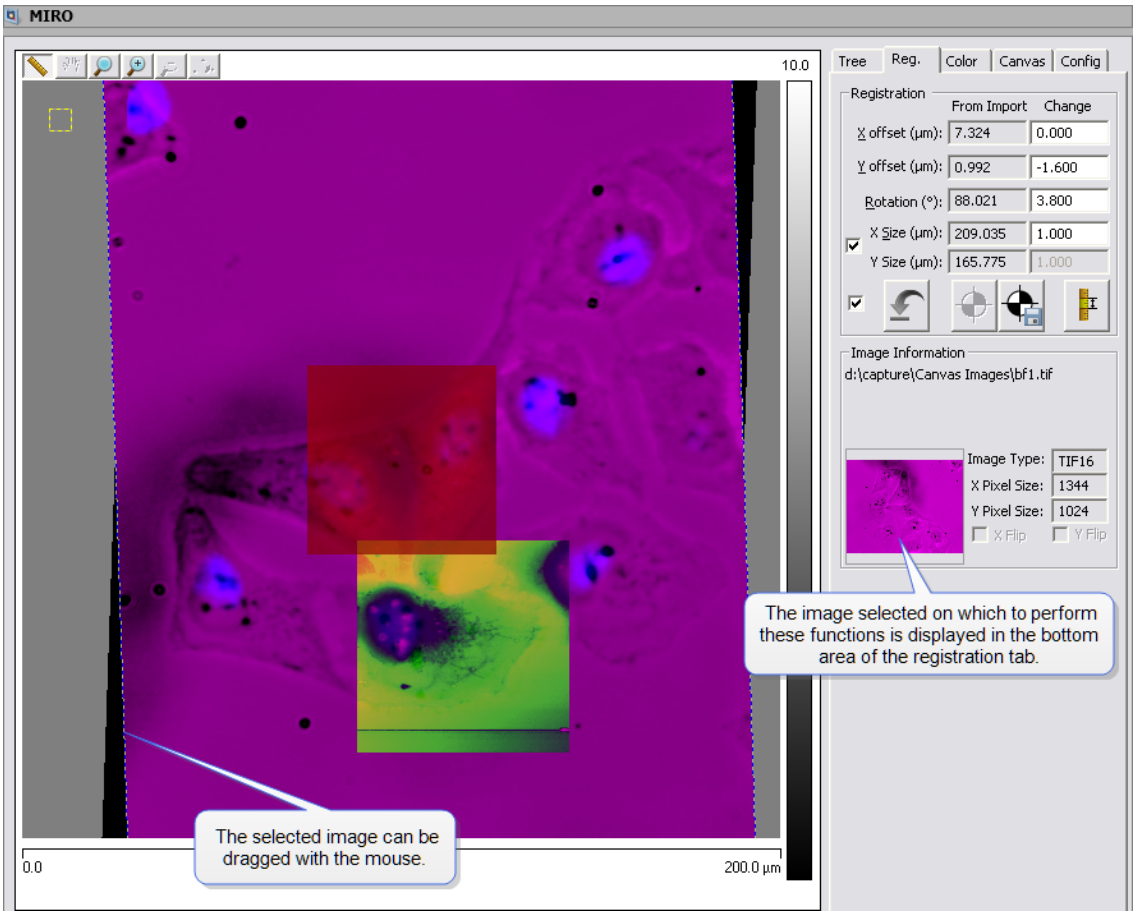


Figure 9.2c: The Registration tab in the MIRO window

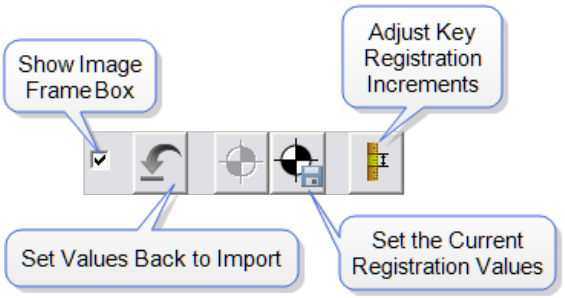


Figure 9.2d: Registration buttons

NOTE: Registration adjustments affect the image selected in the Tree tab.

Refer to Adjusting the Image (page 321) for information about adjusting registration.

9.2.3 The Color Tab

The **Color** tab is used to modify the color, contrast, and color offset of the image.

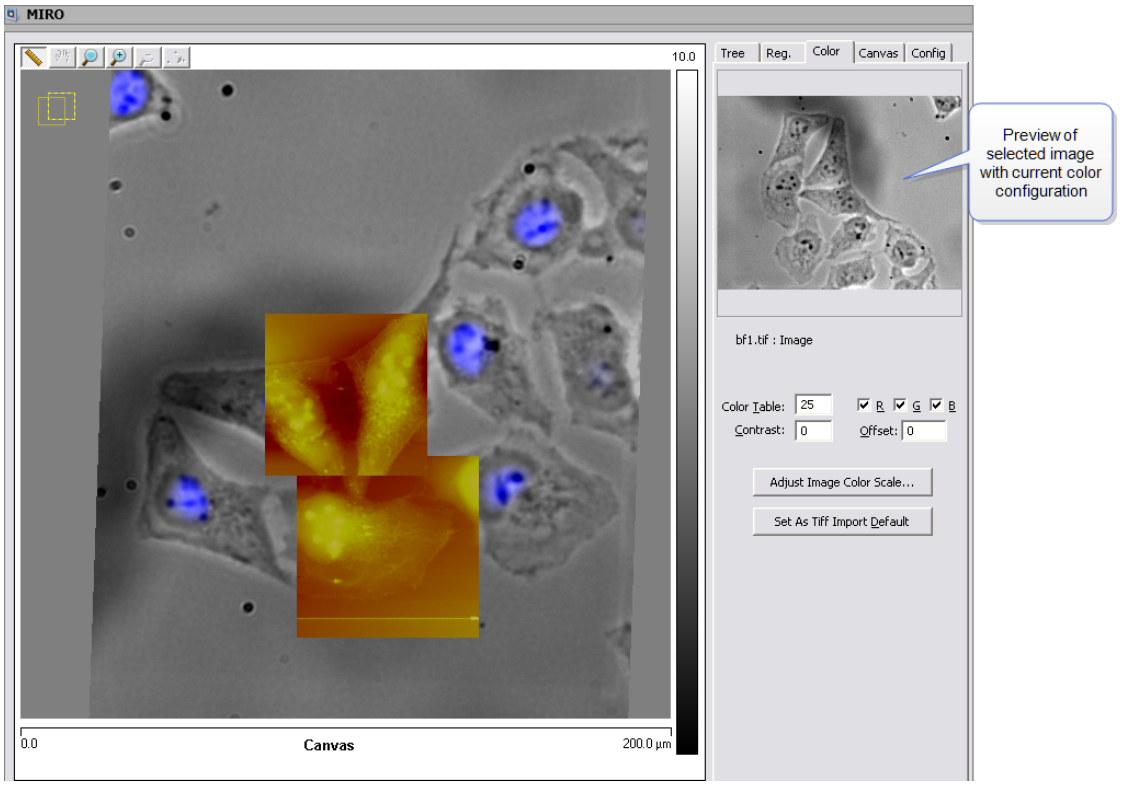


Figure 9.2e: The Color Tab in the MIRO window

You may change the **Color Table**, **Contrast** and **Offset** by adjusting their values. You may also change the color by checking or un-checking the **R** (red), **G** (green) or **B** (blue) check boxes.

NOTE: Color adjustments affect the image selected in the **Tree** tab.

Color Tab Parameters

Color Table

Choose among the standard NanoScope color tables

Range and Settings: 0 to 25 (see List of Color Tables).

RGB

Turns On/Off Red, Green and Blue in the image (see Figure 9.2f, Figure 9.2g, Figure 9.2h, and Figure 9.2i, below for examples).

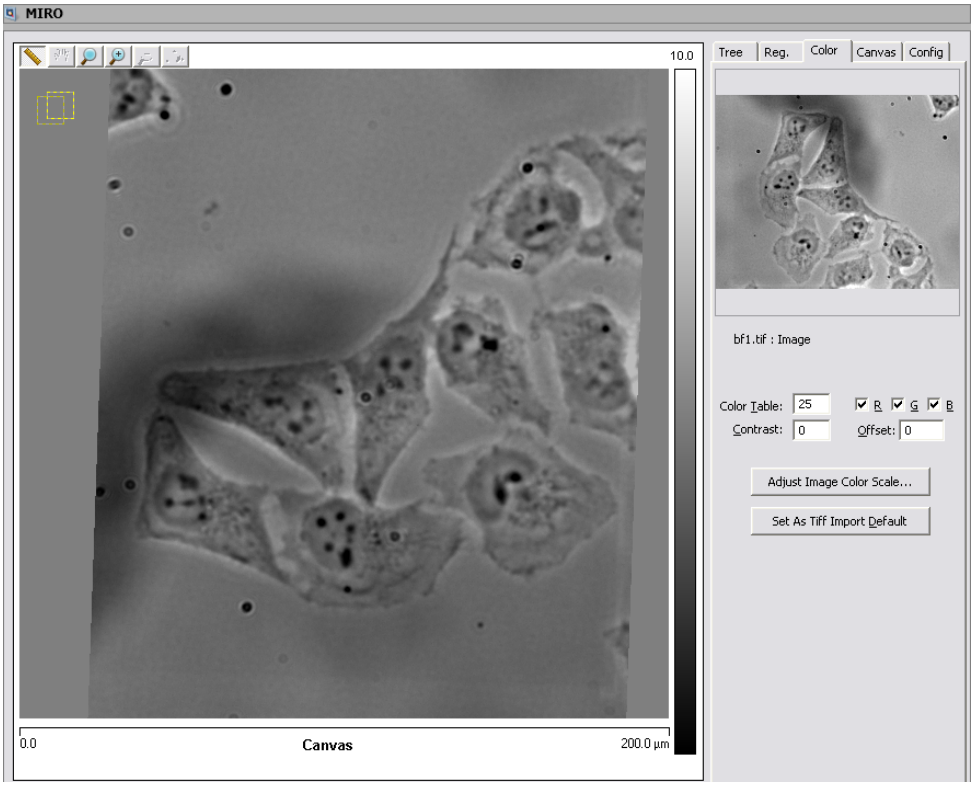


Figure 9.2f: Original Image in Color Table 25

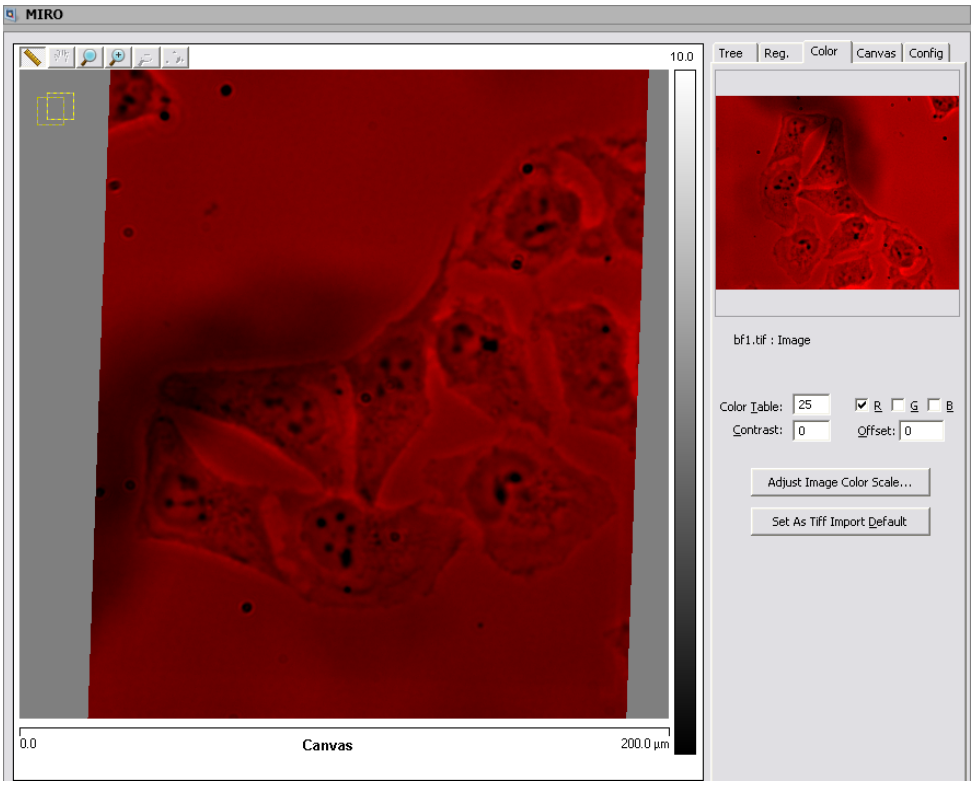


Figure 9.2g: Image of Figure 9.2f with only R (Red) selected

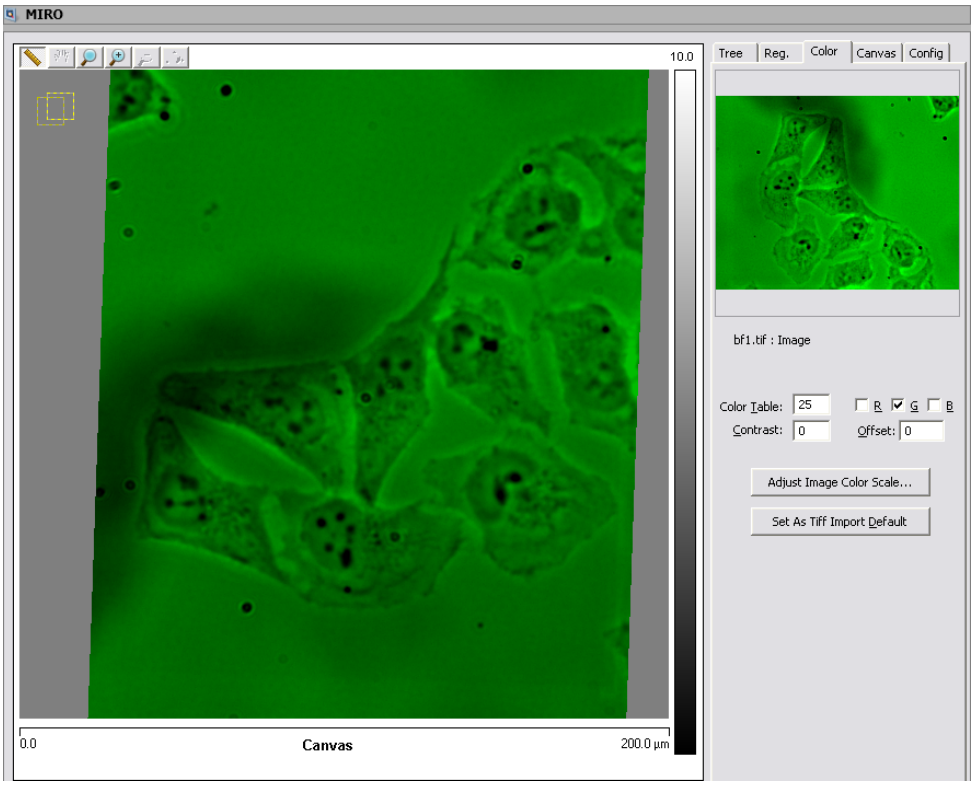


Figure 9.2h: Image of Figure 9.2f with only G (Green) selected

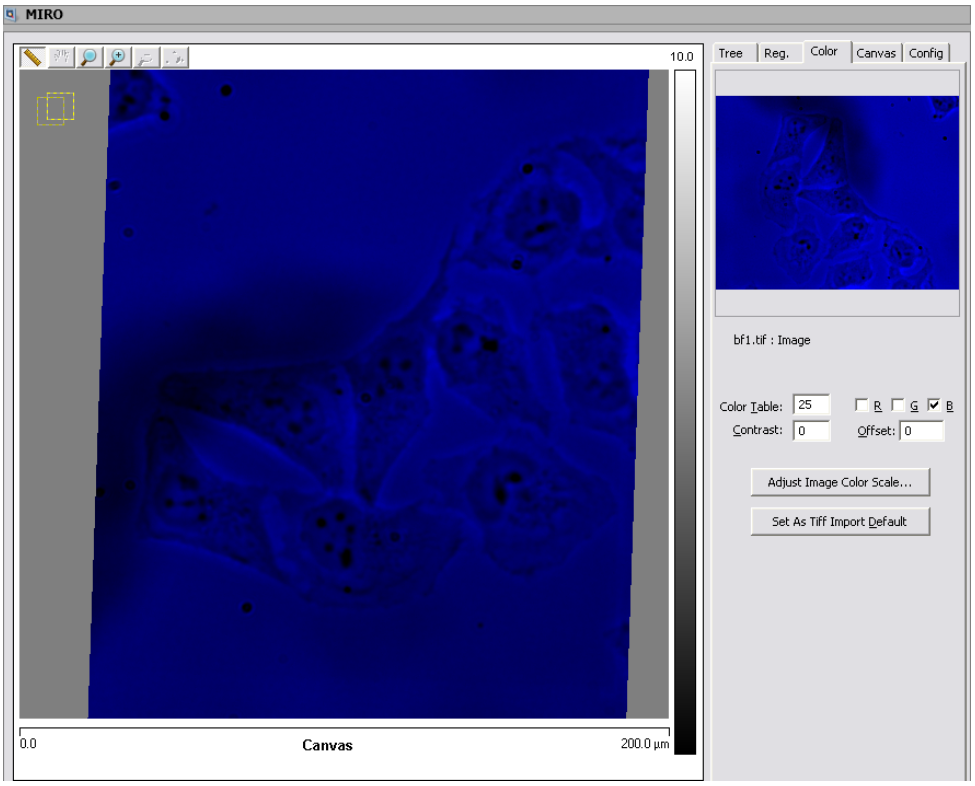


Figure 9.2i: Image of Figure 9.2f with only B (Blue) selected

Contrast

Adjusts image contrast

Range and Settings: –10 to +10. See below for examples and for a plot of the respective image intensity levels.

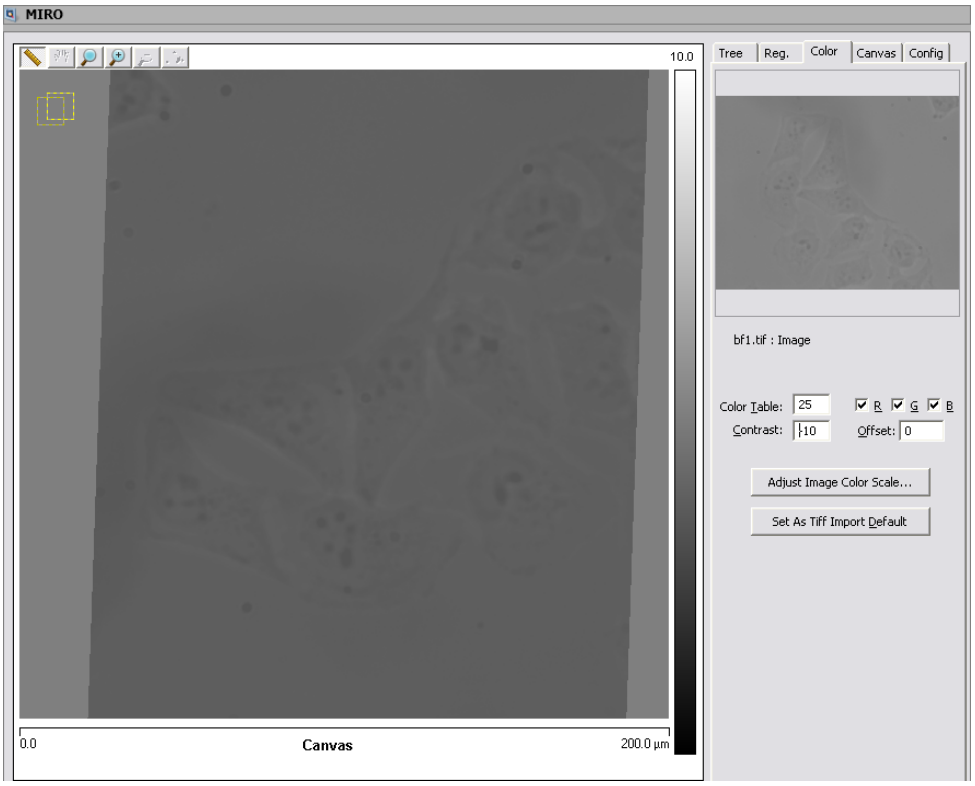


Figure 9.2j: Contrast set to –10

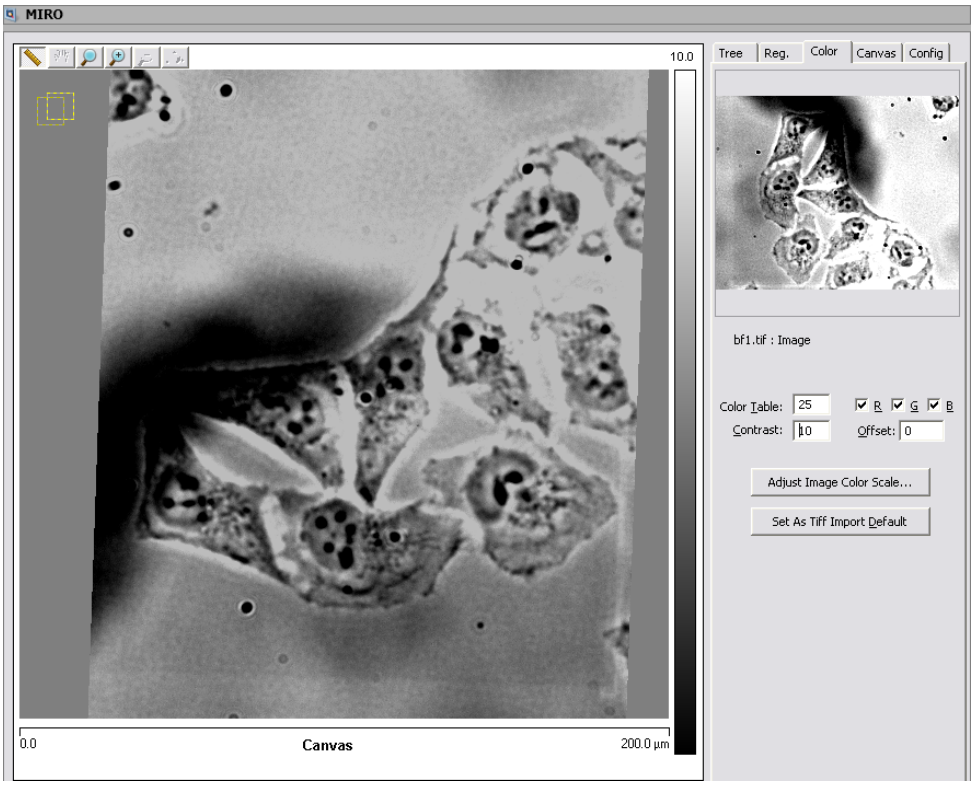


Figure 9.2k: Contrast set to +10

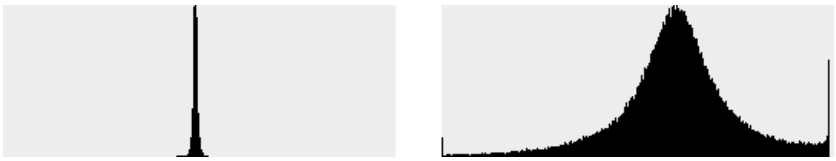


Figure 9.2l: Plots of image intensity from Figure 5 (left) and Figure 6 (right)

Offset

Adds or subtracts a constant offset from each color table index, shifting the color scale up or down.

Offset effectively changes the color value around which the color scale is mapped.

Range and Settings: –128 to +128. See below for examples and a plot of the respective image intensity levels.

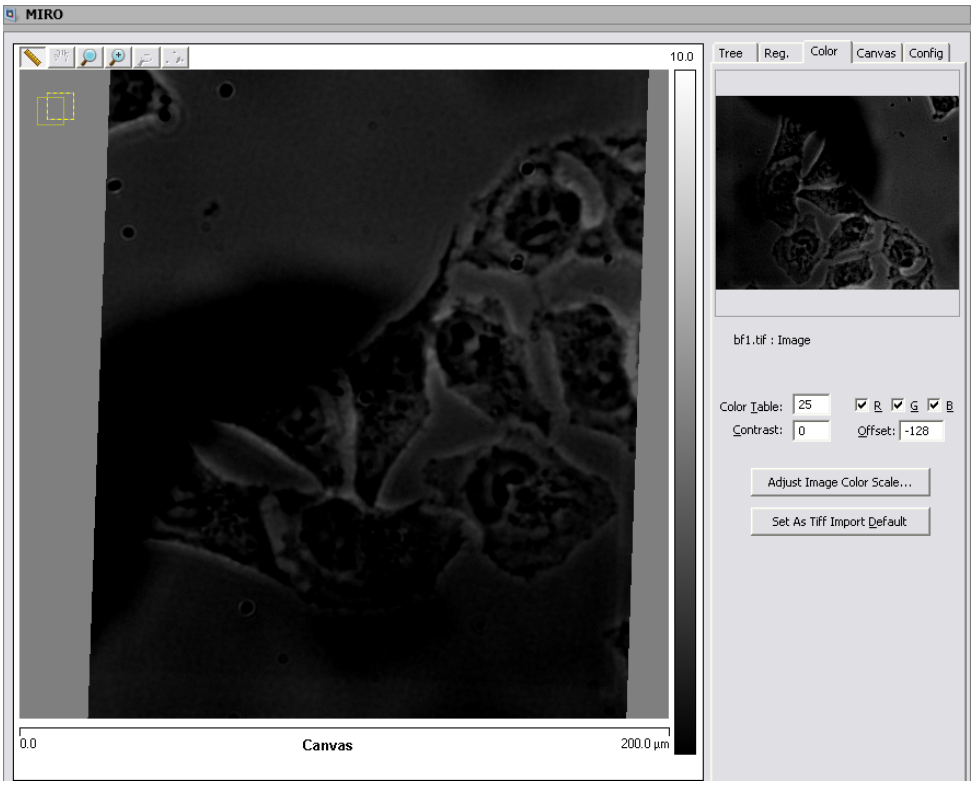


Figure 9.2m: Offset set to –128

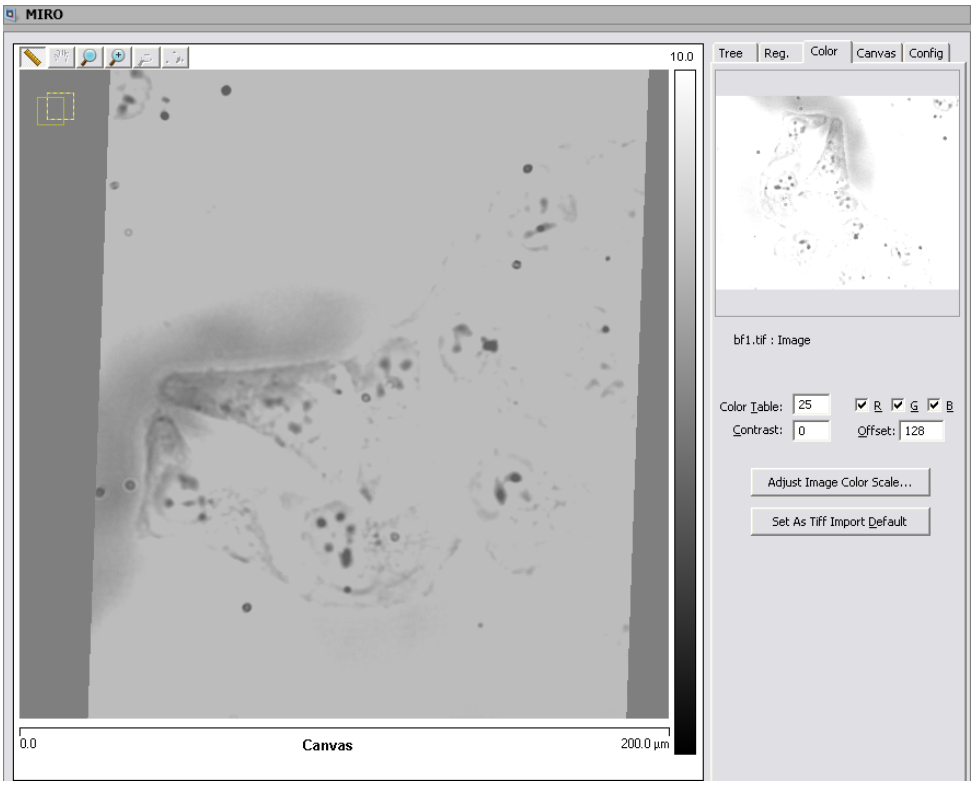


Figure 9.2n: Offset set to +128

Figure 9.2o: Plots of image intensity in Figure 8 (left) and Figure 9 (right)

Adjust Image Color Scale

Opens the Color Scale (page 29) function.

Set As Tiff Import Default

Sets the above parameters as the default tiff image import parameters.

> **NOTE:** This function is available only when you import a tiff image.

9.2.4 The Canvas Tab

The **Canvas** tab is used to adjust the canvas size, location and angle.

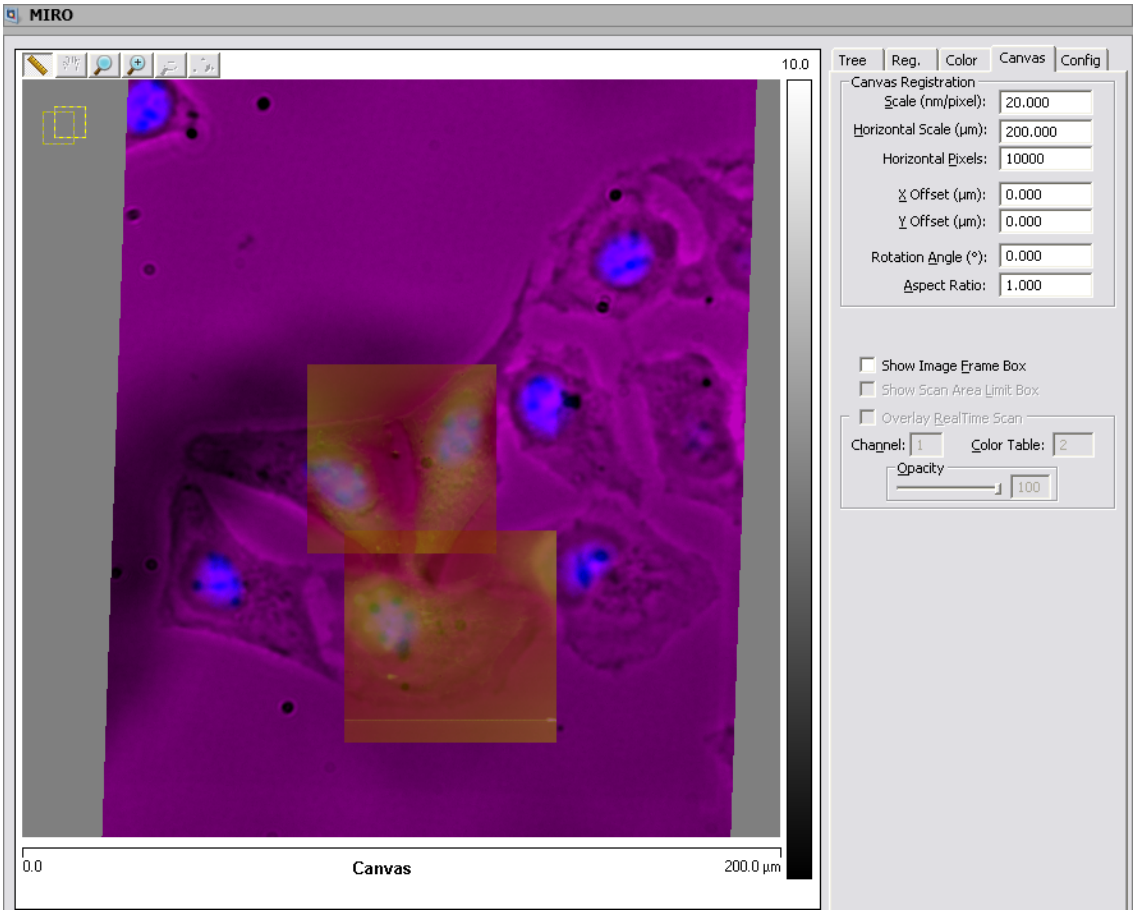


Figure 9.2p: The Canvas Tab in the MIRO window

Canvas Controls

Show Image Frame Box: Indicates, using a blue dashed line, which image is selected and can be manipulated. If this option is not selected, adjustments to the images can not be made using the mouse.

9.2.5 The Configuration Tab

The **Configuration** tab is used to select the camera and overlay methods as well as set up defaults for the import of images.

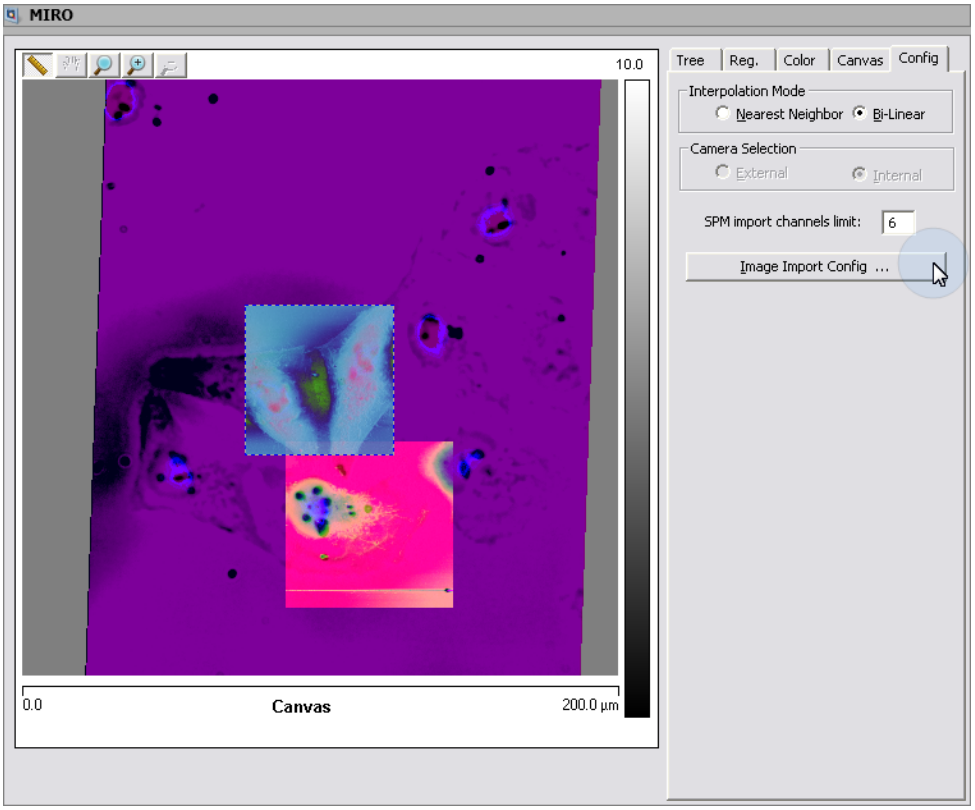


Figure 9.2q: The Configuration Tab in the MIRO window

Configuration Controls

Interpolation Mode

Settings:

- **Nearest Neighbor**—Selects the value of the nearest point
- **Bi-Linear**—Two dimensional linear interpolation

SPM import channels limit:

Limits the maximum number of channels that can be imported in one image.

Range: 1 - 8

Image Import Config

Allows setting defaults for importing images such as registration profiles, etc.

9.2.6 The MIRO Toolbar

The MIRO toolbar appears when MIRO is active. The following functions are available through the MIRO toolbar:

Import images. When optical images are imported, you will be prompted to select a registration profile to use from the Image Import Configuration window. See Importing Images (page 313) for more information.

Export From the Canvas View (page 331)

Create Region Of Interest (page 318)

Refresh Region Of Interest (page 318)

Configure Region Of Interest (page 318)

Undo Image Change:
See Undo/Redo (page 328) for a discussion of the **Undo** function.

Redo Image Change:
See Undo/Redo (page 328) for a discussion of the **Redo** function.

9.3 MIRO Operation

There are several helpful topics for MIRO camera operations:

- Introduction to Optical Image Registration (page 310)
- Placing Images on the MIRO Canvas (page 313)
  - Importing Images (page 313)
- Region Of Interest (page 318)
- Adjusting the Image (page 321)
- Moving Images (page 322)
- Undo/Redo (page 328)
- Export From the Canvas View (page 331)
- MIRO Import/Export (page 329)

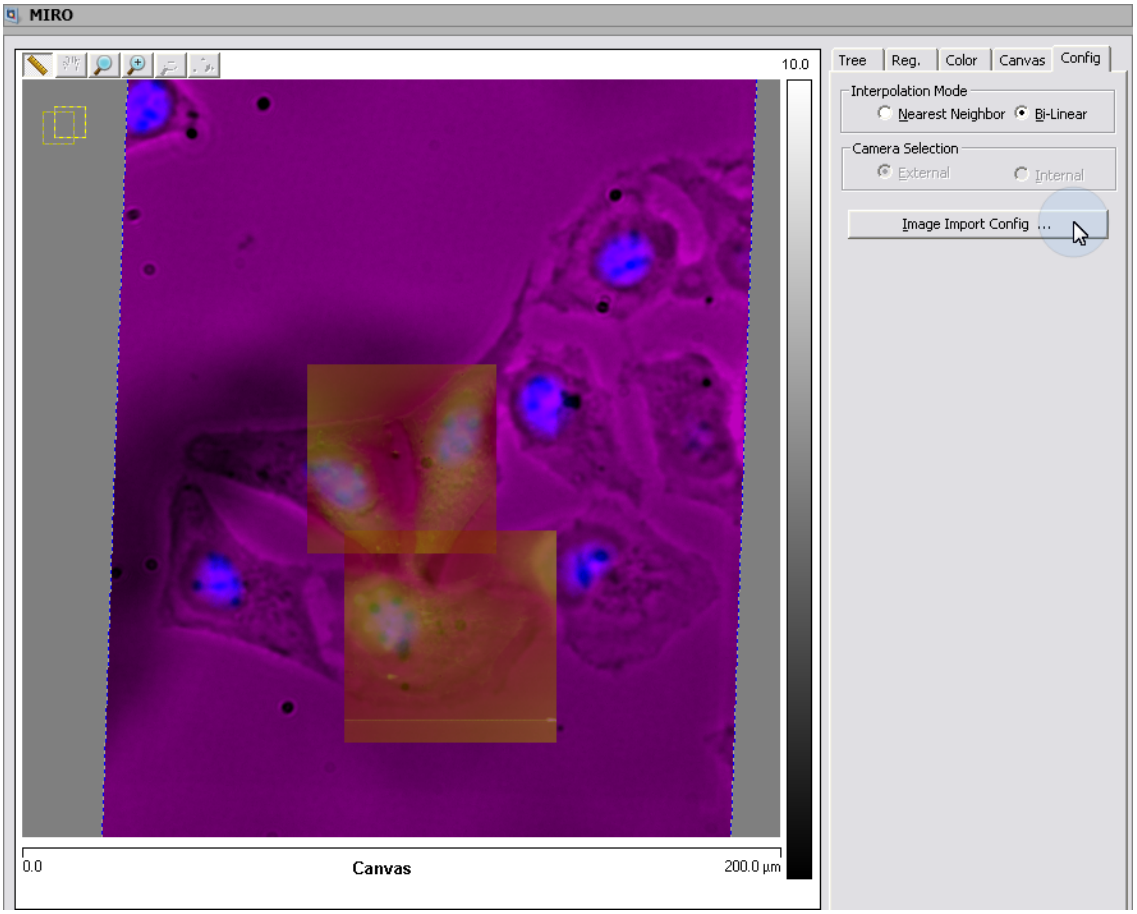
9.3.1 Introduction to Optical Image Registration

In order to import and overlay an optical image to the MIRO canvas, the following information is needed:

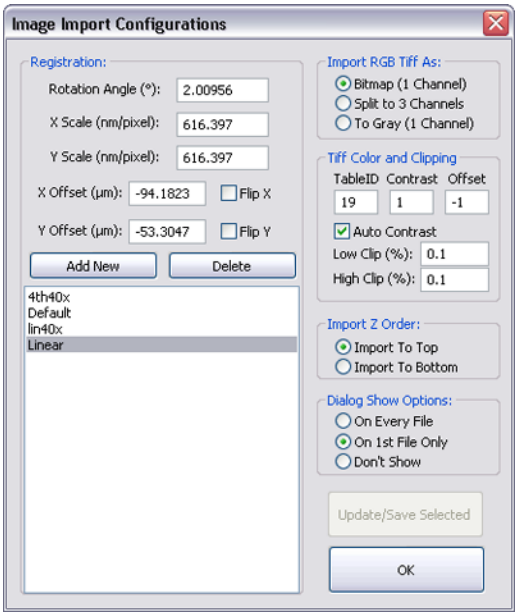
- Rotation Angle
- X Scale
- Y Scale
- X Offset
- Y Offset
- Image Flips
- Non-linear correction data

MIRO saves this data as *.irc files in the Mirc directory. When an optical image is imported, the data in the selected *.irc file is used.

You can view, edit, create and delete these *.irc files using the Image Import Configurations window. To access the Image Import Configurations window, click the **Image Import Config** button in the ***Config*** tab:



The ***Image Import Configurations*** window will open:



There are several ways to create or modify the registration *.irc file:

1. Estimate or calculate the registration data and enter it in the Image Import Configurations Window.
2. After the optical image is “tweaked” (see Adjusting the Image (page 321)) the registration data can be set/saved (*.irc file) by clicking the **Set the current values as import registration** icon on The Registration Tab (page 298).

The ***Image Import Configurations*** window is also used to configure **Import Z Order** and **Dialog Show Options**:

Import Z Order Parameters

- **Import To Top**: Imports selected images to the top of the image tree.
- **Import To Bottom**: Imports selected images to the bottom of the image tree. Imported images may not be visible if they are beneath another image with high opacity.

Dialog Show Options

- **On Every File:** Opens the Configurations for Import window (see Importing Images (page 313)) each time a file is opened.
- **On 1st File Only:** Opens the Configurations for Import window for the first file when multiple optical images are selected (select multiple images by holding down the CTRL key while clicking each file name).
- **Don’t Show:** Does not open the Configurations for Import window when optical images are imported.

NOTE: If you have turned the **Don’t Show** option "On" and wish to display the Configurations for Import window, you will have to access it through the **Image Import Config.** button in the ***Config*** tab.

9.3.2 Placing Images on the MIRO Canvas

Several methods are available for placing images on the MIRO canvas:

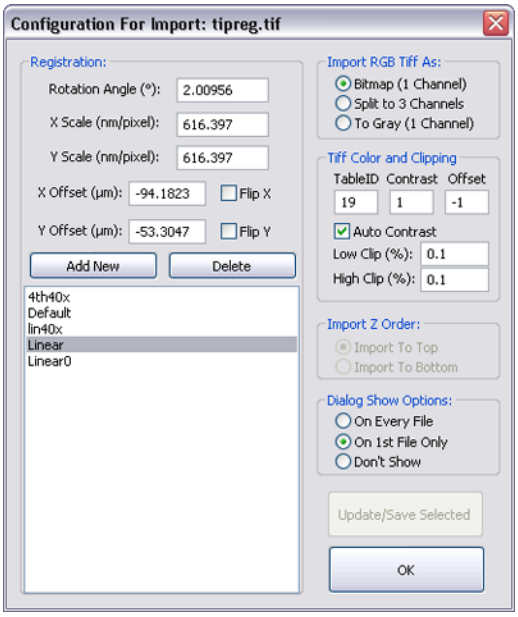
- Importing Images (page 313)
    - Both saved AFM and optical images may be imported.
- Load Canvas File; see MIRO Import/Export (page 329)

Importing Images

1. Click the **Import Images** icon to open the MS Explorer Open window.
2. Browse for the image(s) you wish to view—multiple images can be selected—and click **Open**.

   You can select and load an image for calibration using this method.

    - If an AFM image is selected, the system knows the scan size and offsets and assumes that you have not moved the stage.
    - If an optical image is selected, the system uses the image import configuration settings set in the Configuration For Import window:



> **NOTE:** This window may open automatically, depending on the selection in the Dialog Show Options panel. It will not open if you have selected the **Don't Show** radio button selected. To open the window, click the Image Import Config button on The Configuration Tab (page 308). When using the internal (µEye) camera, it is not necessary to view this dialog and the Don't show button should be enabled.

4. From the list, select a registration file that corresponds to the objective used to capture the image (see XY Calibration) and click **OK**.

You may also adjust various Registration parameters in this window:

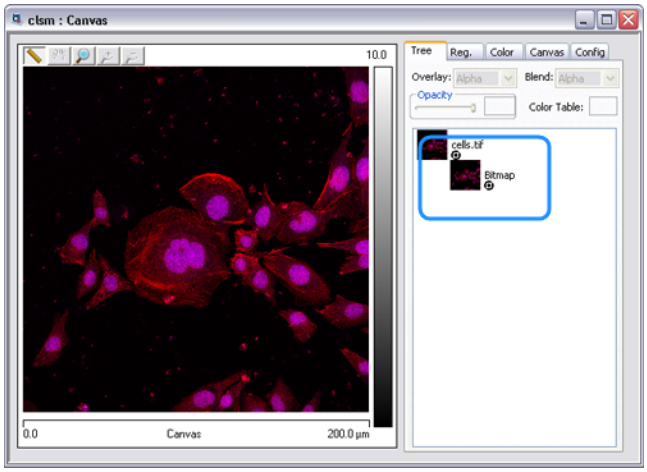
- Rotation Angle
- X Scale
- Y Scale
- X Offset
- Flip X
- Y Offset
- Flip Y

NOTE: If you adjust any of these parameters, you must click **Update/Save Selected** to update the selected image registration file (*.irc) or **Add New** and enter a new file name to create a new image registration file.

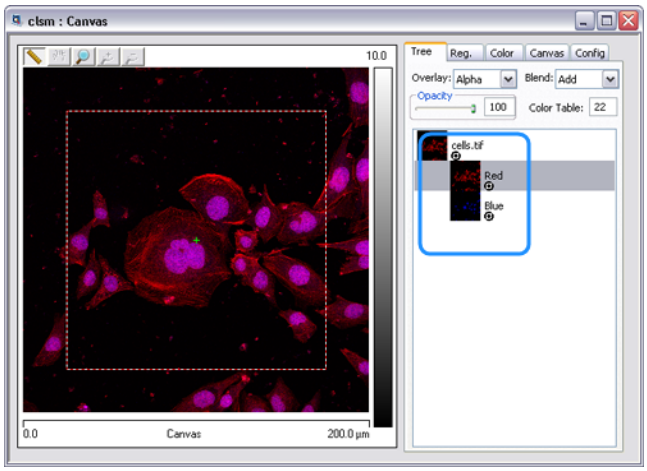
Other Import Configuration Controls

Import RGB Tiff Parameters

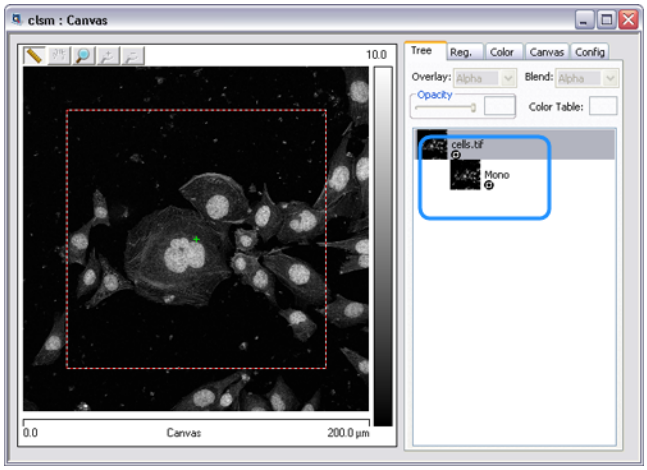
- **Bitmap:** Imports the tiff image as a bitmap.



- **Split to 3 Channels:** Splits RGB tiff optical images to Red, Green and Blue channels, allowing you to adjust them independently (the example below has only 2 channels).



- **To Gray:** Imports the tiff image as a 16 bit gray-scale image.



Tiff Color and Clipping Parameters

NOTE: These parameters, with the exception of Auto Contrast, can be pre-set using the **Set As Tiff Import Default** button in the Color tab (see Color Tab Parameters (page 300) for more information).

- **Color Table ID:** Chose a standard NanoScope color table.
  - *Range and Settings*: 0 to 25.
  - See List of Color Tables
- **Contrast:** Image contrast.
  - *Range and Settings*: –10 to +10.
  - See Contrast (page 303) for more information and examples.
- **Offset:** Adds or subtracts a constant offset from each color table index, shifting the color scale up or down. Offset effectively changes the color value around which the color scale is mapped.
  - *Range and Settings*: –128 to +128.
  - See Offset (page 305) for more information and examples.

- **Auto Contrast:** Auto Contrast automatically adjusts the image contrast by first clipping a small, user-adjustable, number of pixels, Low Clip and High Clip, to accommodate long tails in the contrast distribution. Auto Contrast is turned on if checked.

  Figure 9.3a shows the original tiff image and Figure 9.3b shows a graph of its intensity (long tails are circled):

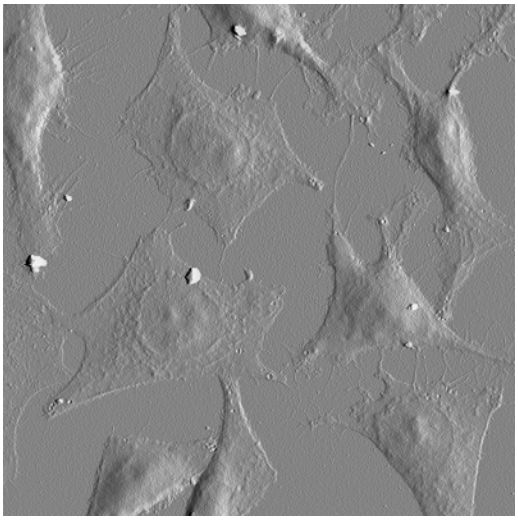


Figure 9.3a: Original Tiff Image

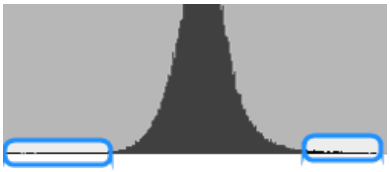


Figure 9.3b: Graph of Image Intensity of image in Figure 1 showing the tails in the distribution

Auto Contrast removes the long tails in the distribution then adjusts the dynamic range to fill the range.

Figure 9.3c shows the original tiff image before import and Figure 9.3d shows a graph of the corresponding image intensity:

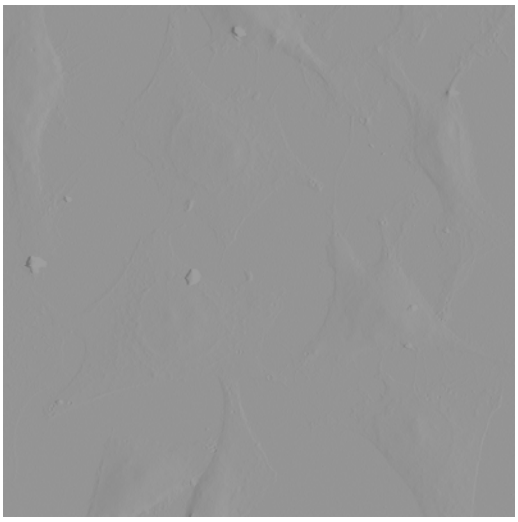


Figure 9.3c: Original Tiff Image Before Import

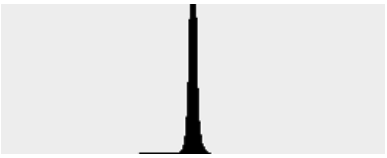


Figure 9.3d: Graph of Image Intensity of image in Figure 3

Figure 9.3e shows the same tiff image after Auto Contrast adjustment, and Figure 9.3f shows a graph of the corresponding image intensity:

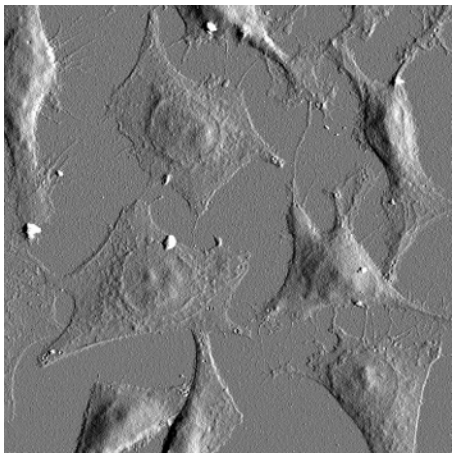


Figure 9.3e: Image After Import with Auto Contrast On

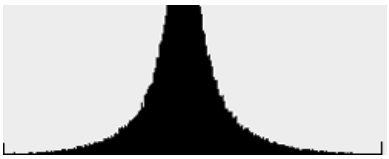


Figure 9.3f: Graph of Image Intensity of image in Figure 5

9.3.3 Region Of Interest

You may define multiple Regions of Interest (ROI) to allow you to more easily compare overlaid AFM and optical images and produce publication-ready images.

Create a Region of Interest

1. Using the ruler tool, draw a box on the MIRO canvas.

2. Click the **Create a Region of Interest View** icon to open an ROI window that displays up to 8 layers in that box plus the overlaid image.

The number of layers in the ROI is controlled by the ***Layer Limit*** parameter in the **Configure ROI View Settings** window:

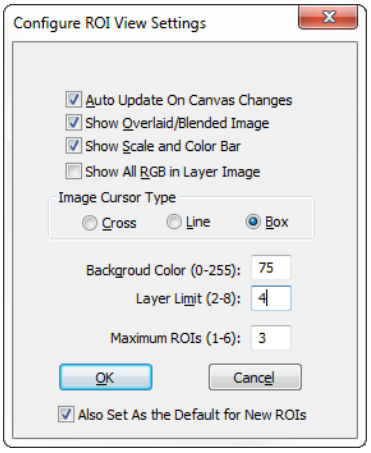
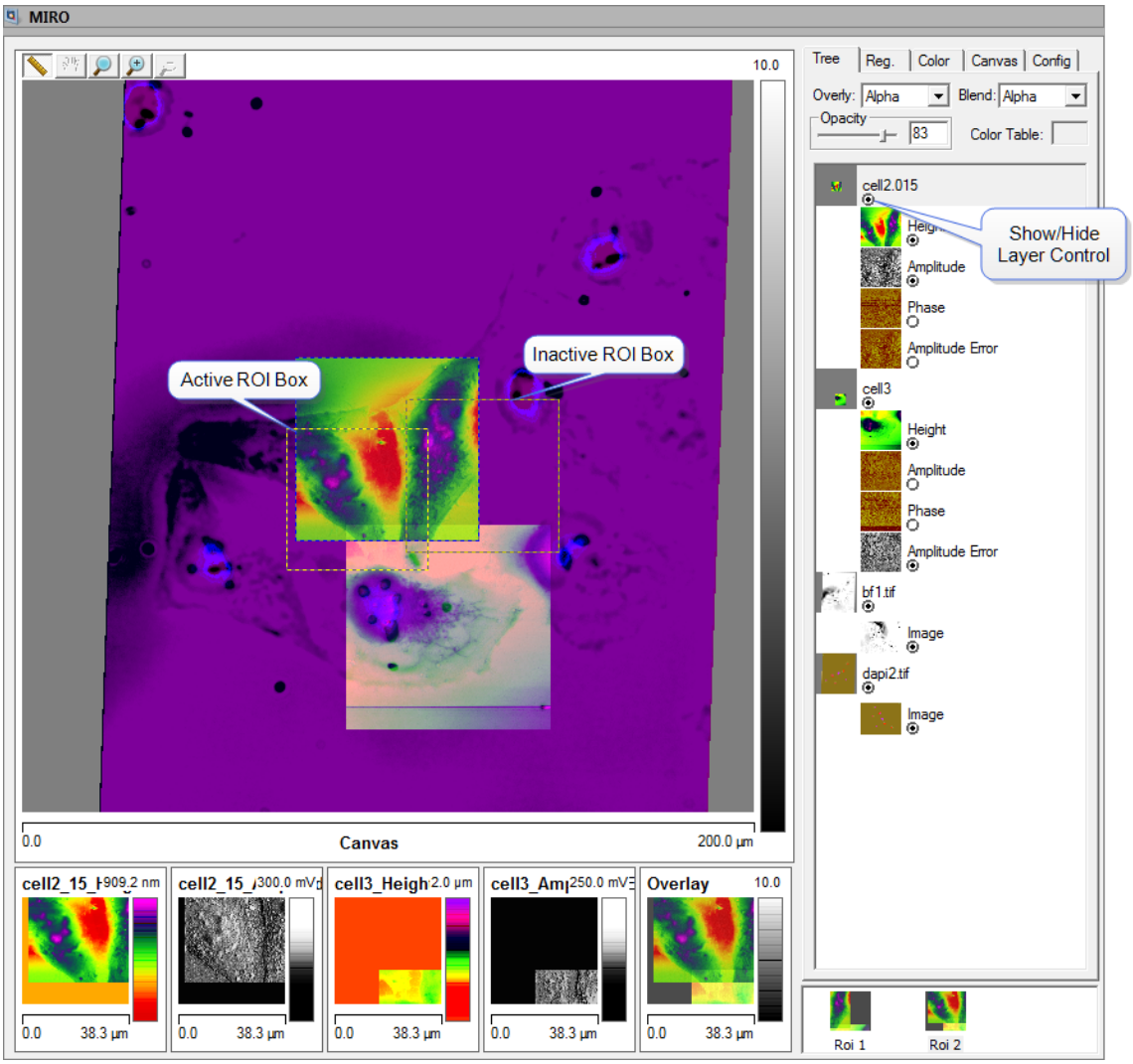


Figure 9.3g: The **Configure ROI View Settings** window

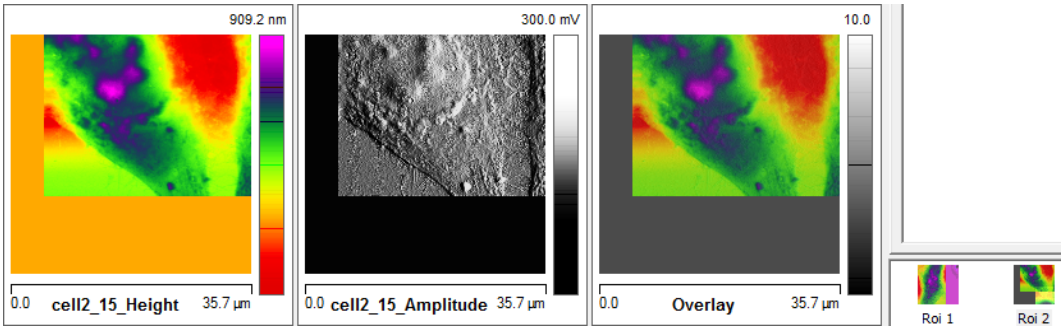
The layers displayed in an **ROI** view are controlled by selecting the **Show/Hide** button in the MIRO ***Tree*** tab.

The default Maximum Number of ROIs is 1. You may open up to 6 ROI views. The active ROI will be displayed in the MIRO ***Canvas*** window as a dashed yellow box while the inactive ROIs will be shown as dashed white boxes.

NOTE: If ***Maximum ROIs*** is set to 1, the default, creating a second ROI will destroy the first ROI.



The default ROI window displays 2 layers plus the overlaid image:

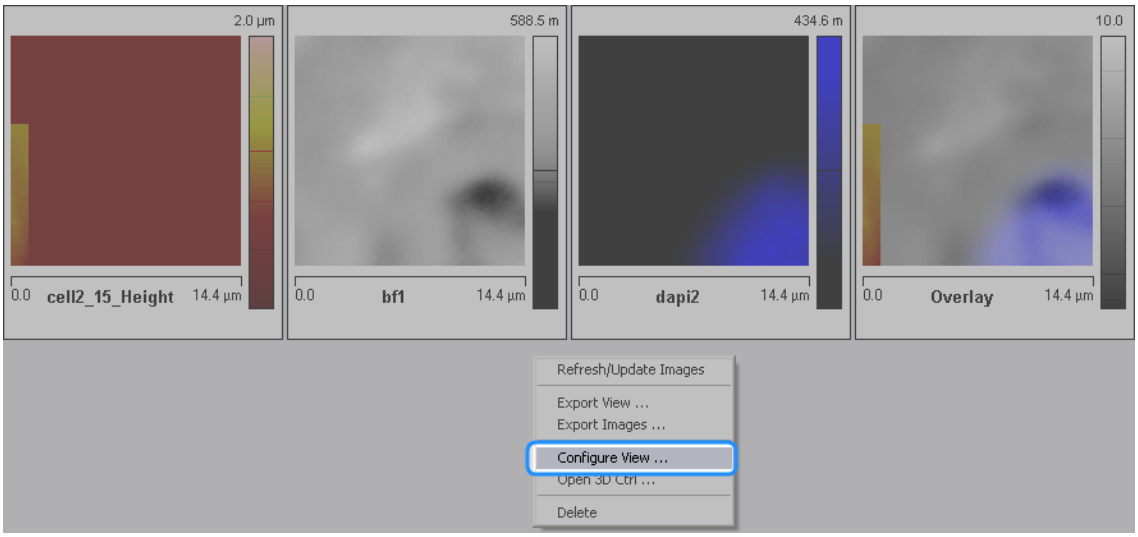


NOTE: Regions of interest are square. If you draw a rectangle, the narrowest side will be used to define the square.

Configure the Region of Interest

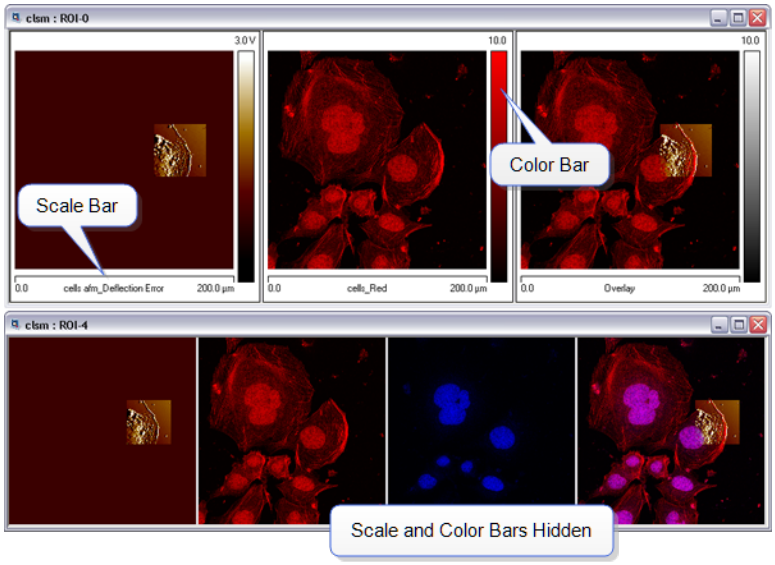
You can change the size of the active panel to resize or reformat the ROI area.

Configure the ROI window by either clicking the **Configure the ROI** icon or right-click in the blank area the adjacent to the ROI thumbnails and select **Configure View**. This opens the ***Configure ROI View Settings*** window.



Configure ROI View Controls:

- **Auto Update On Canvas Change:** Automatically updates the ROI view when a change is made to the MIRO Canvas, e.g. showing or hiding a layer. Unchecking this box will freeze the ROI view. You may want to use this feature if you are changing the MIRO canvas but want to keep the ROI view from changing. You may manually refresh the ROI view by either clicking the **Refresh the ROI** icon or by right-clicking in the blank area adjacent to the ROI thumbnails and clicking **Refresh/Update Images**.
- **Show Overlaid/Blended Image:** Displays, as the final panel, the overlaid and blended image as shown in the MIRO Canvas window.
- **Show Scale and Color Bar:** Shows the layer label, ROI dimensions, and vertical scale:



- **Show All RGB in Layer Image:** Shows Red (R), Green (G) and Blue (B) regardless of the settings in the Color tab.
- **Image Cursor Type:** May be a Cross, Line or Box (default). The same cursor will appear in all images in that ROI window.
- **Background Color:** The intensity of the areas of the ROI that have no image with 0 being the darkest and 255 the lightest.
- ***Layer Limit:*** The number of layers displayed is set in the **Layer Limit** box. You may display up to 8 layers in an ROI window.
- ***Maximum ROIs***: The maximum number of ROIs.
- ***Also Set As the Default for New ROIs***: Sets new ROI default to these values.

Click **OK** to accept your changes or **Cancel** to return to the unchanged ROI window.

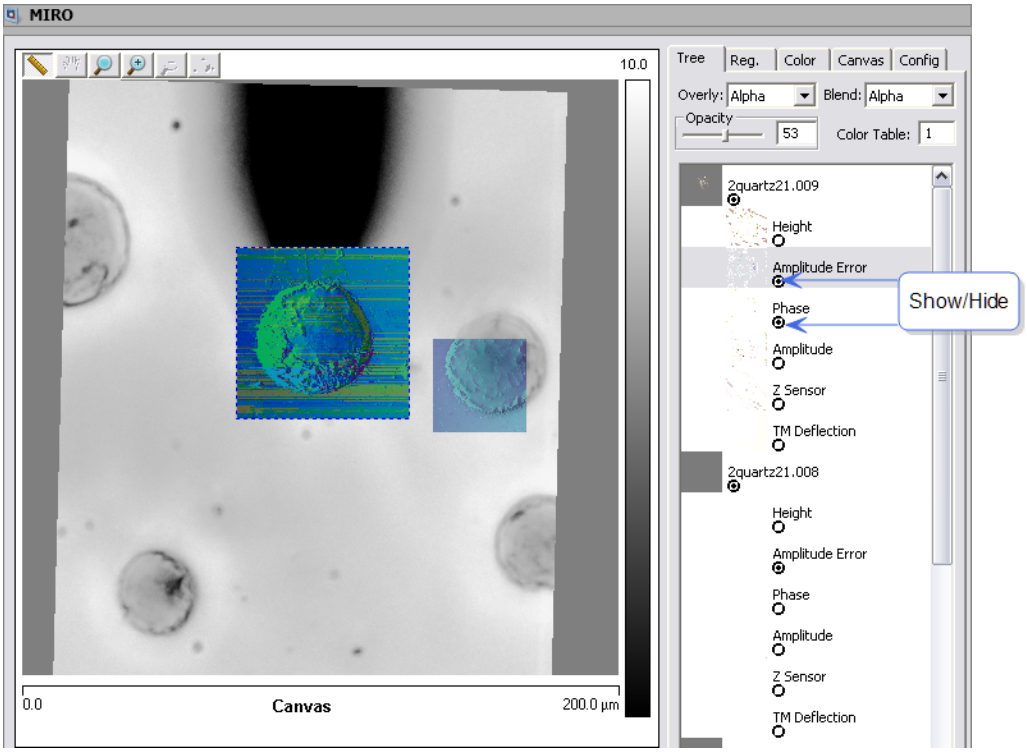
Regions of interest are saved when you save MIRO (*.iro) files. The Regions of Interest will open when you open the saved MIRO file.

9.3.4 Adjusting the Image

The MIRO canvas offers a wide range of options in terms of image contrast, color, opacity… Beyond the aesthetic aspect, it can be very useful to check if the AFM and optical images exactly overlap each other, by selecting an AFM channel—deflection or amplitude usually gives the best contrast—and setting the opacity parameter to zero. Then progressively increase this value to see the AFM image appear.

Save the registration file once the optical images have been adjusted for optimal registration.

Another helpful option is to select two AFM channels (for instance Amplitude Error and Phase) and use this function to alternately switch from one channel to the other.



Several methods are available to obtain good overlay accuracy between AFM images and optical images:

- You can adjust the numerical parameters in the Registration tab to make the AFM images fit the optical images.
- You can drag, resize and rotate the selected image box on the Canvas by using the mouse (in **Cursor** mode; see Moving Images (page 322)).

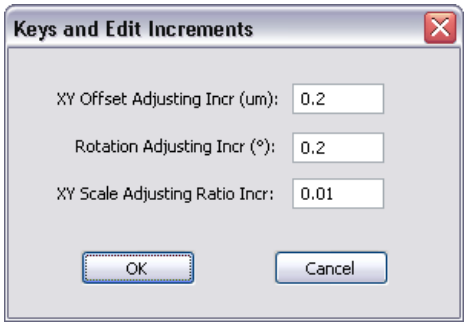
NOTE: To "tweak" the registration, adjust the optical images, not the AFM images.

9.3.5 Moving Images

You may Rotate (page 325), Translate (page 325), Stretch (page 326) or Shrink (page 328) any selected image using keyboard shortcuts or the cursor.

NOTE: Image movement using the cursor is possible only in The Registration Tab (page 298). If any portion of the image is outside the MIRO canvas boundaries, movement of the image using the cursor is not possible but keyboard shortcuts will still function. The image frame in the Registration Tab changes from blue dashes to blue-white dashes when part of the image is outside the MIRO canvas.

Adjust the registration increments by clicking the **Adjust the Registration Key Increments** icon in the Registration window. This opens the ***Keys and Edit Increments*** window:

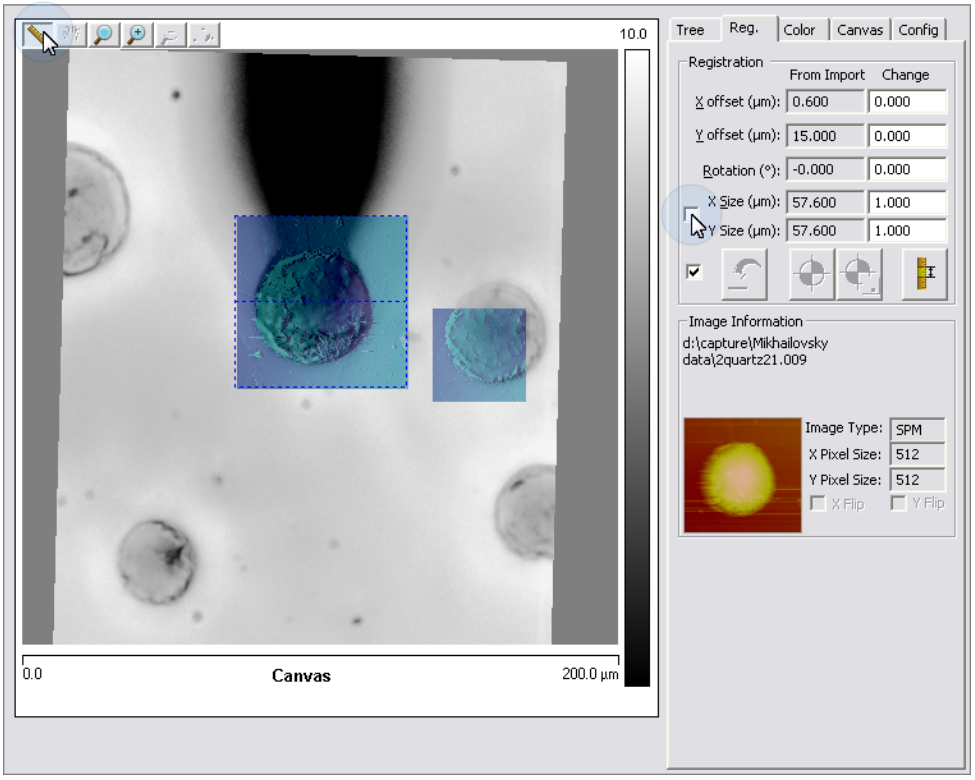


Change the **XY Offset Adjusting Increment**, the **Rotation Adjusting Increment** and/or the **XY Scale Adjusting Ratio Increment** and click **OK**.

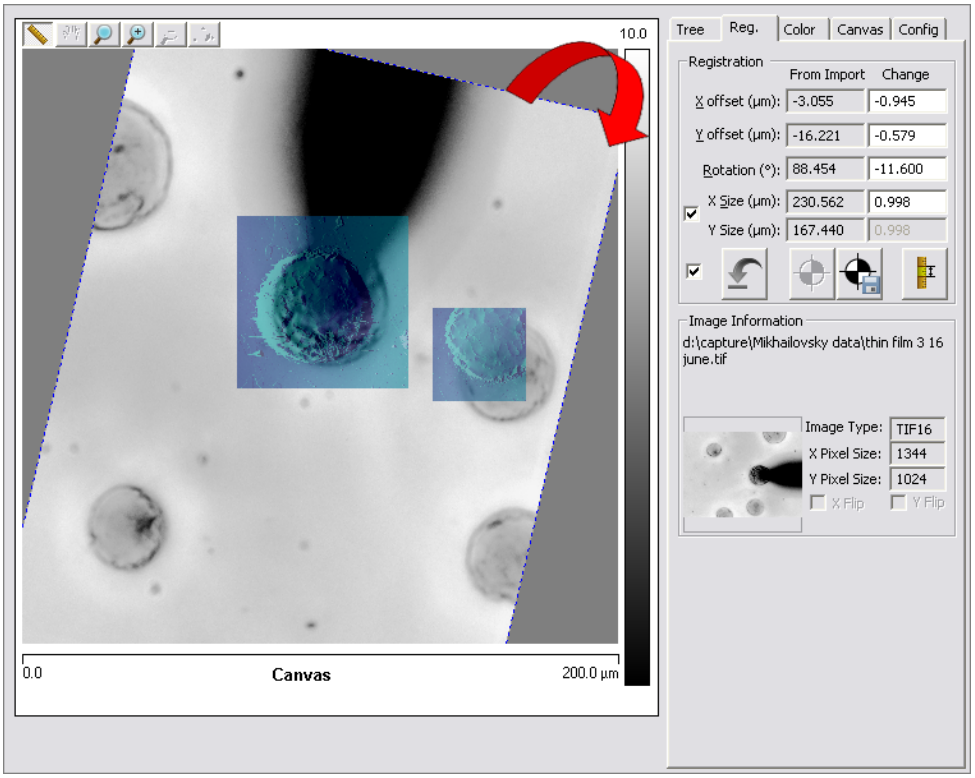
Select the image you wish to manipulate in the **Tree Tab**. A blue-white dashed line will surround and bisect the active image. Then select the **Registration Tab** to modify the registration image.

NOTE: If you wish to use the mouse, ensure that you are in **Cursor** mode and in the Registration Tab. The mouse cannot be used for Rotate, Translate, Shrink, and Stretch operations in **Zoom** mode.

NOTE: To adjust X and Y independently, uncheck the **X-Y Size** check box, shown in the Registration Tab. If the X-Y check box remains checked, the image will stretch proportionately in X and Y.


10.0
0.0
Canvas
200.0 µm
Tree
Reg.
Color
Canvas
Config
Registration
From Import
Change
X offset (µm):
0.600
0.000
Y offset (µm):
15.000
0.000
Rotation (°):
-0.000
0.000
X Size (µm):
57.600
1.000
Y Size (µm):
57.600
1.000
Image Information
d:\capture\Mikhailovsky data\2quartz21.009
Image Type:
SPM
X Pixel Size:
512
Y Pixel Size:
512
X Flip
Y Flip

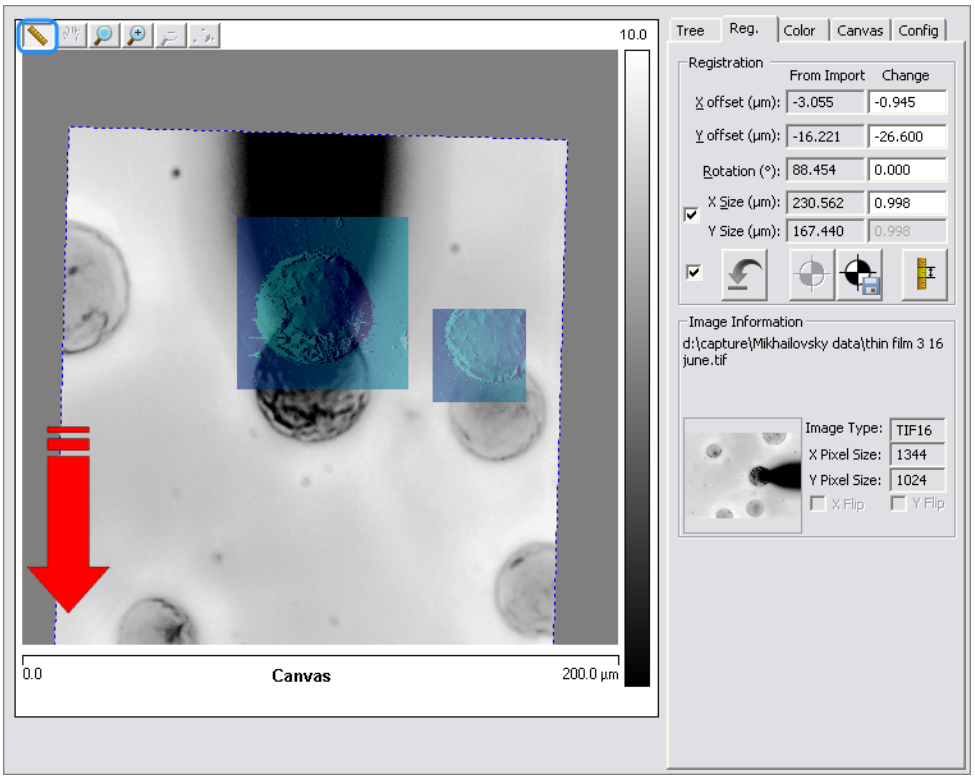
Rotate



- Click [Shift] + [left mouse button] and “grab” a corner of the active layer to rotate the active layer.

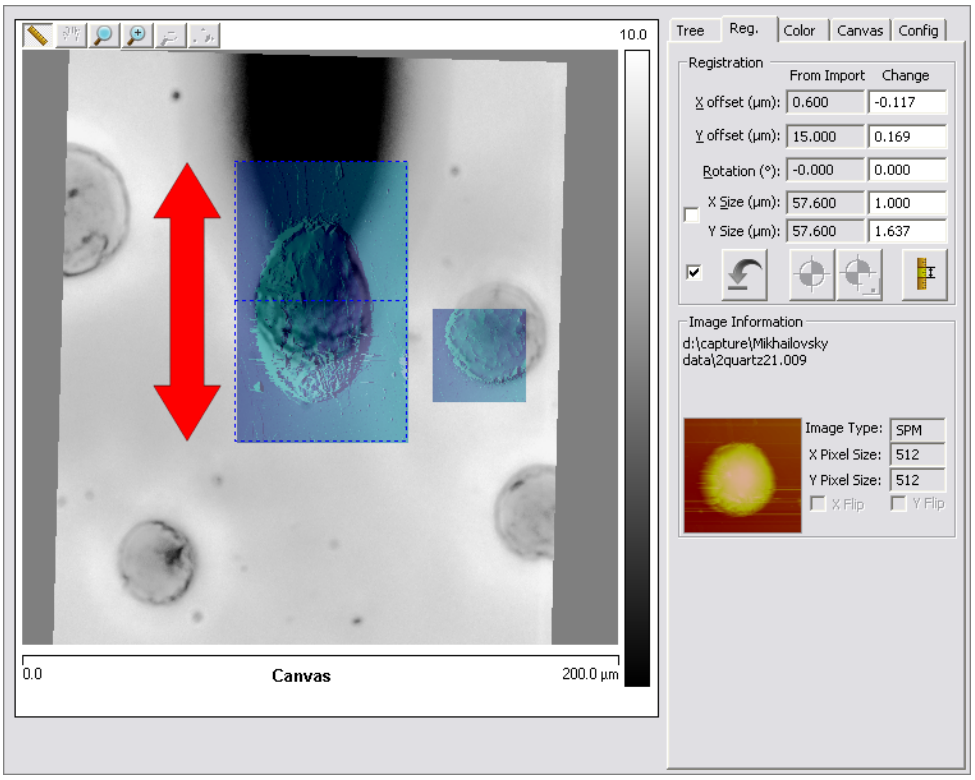
Translate

- Click the left mouse button and drag the active layer.

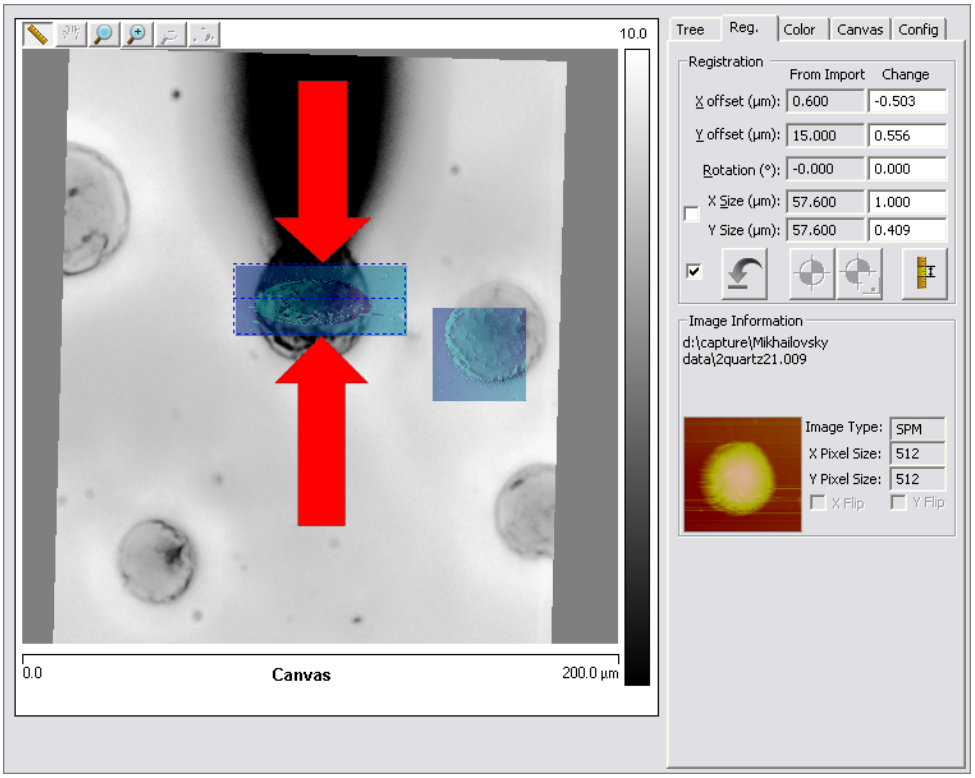


Stretch

- Click the left mouse button and grab the appropriate edge to stretch or shrink the active layer in that direction.


10.0
0.0
Canvas
200.0 µm
Tree
Reg.
Color
Canvas
Config
Registration
From Import
Change
X offset (µm):
0.600
-0.117
Y offset (µm):
15.000
0.169
Rotation (°):
-0.000
0.000
X Size (µm):
57.600
1.000
Y Size (µm):
57.600
1.637
Image Information
d:\capture\Mikhailovsky data\2quartz21.009
Image Type:
SPM
X Pixel Size:
512
Y Pixel Size:
512
X Flip
Y Flip

Shrink

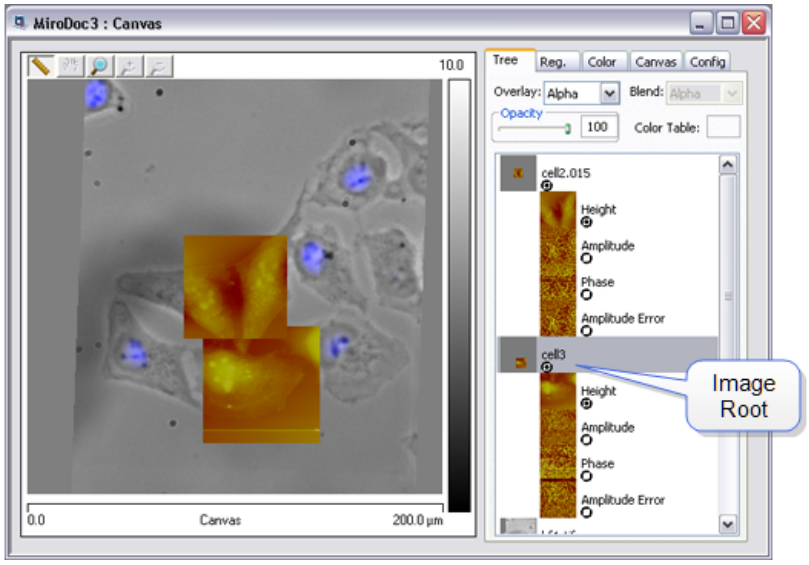


- Click the left mouse button and grab an edge to stretch or shrink the active layer.

9.3.6 Undo/Redo

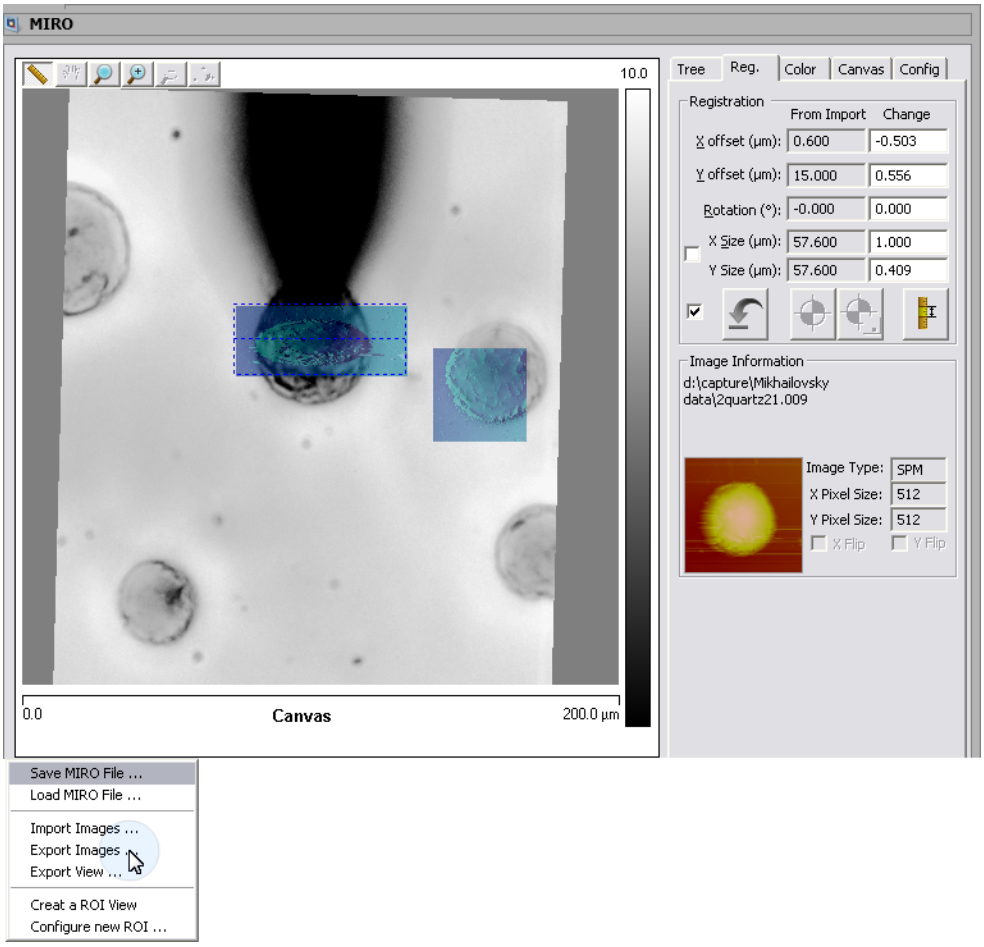
The **Undo** and **Redo** functions allow unlimited undo and redo of the following operations within an image (where the image is defined as the root of a tree):

- Image registration changes: offset, size, rotation, translation, X-Y linking.
- Color table, overlay and blend types, opacity, contrast, offset, RGB.
- Layer (channel) selection changes.



9.3.7 MIRO Import/Export

Right-click in the border of the MIRO window to open a GUI with options to **Save/Load the MIRO File** (*.iro) or **Export the MIRO View**.



Save MIRO File saves the image tree as an *.iro file that can be retrieved later using the **Load MIRO File** command or by double-clicking on the .iro file in the NanoScope browse window.

> **NOTE:** The image registration file (*.irc) is embedded in the saved *.iro file.

Import Images: refer to Placing Images on the MIRO Canvas (page 313) for details.

Export Images: refer to Export From the ROI View (page 332) for details.

Export View saves a JPEG image of the entire MIRO Canvas window. This is the same as the **Export the View** button in the Export Images from Canvas View window.

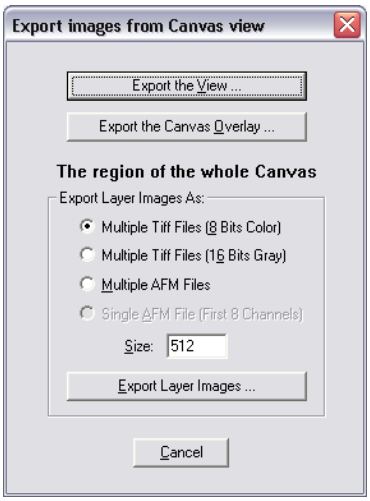
> **NOTE:** When closing the canvas, the system will prompt you to save the current MIRO configuration.

> **NOTE:** Clicking the **Save** icon with MIRO in focus will also save the .iro file.

For other Export options see Export From the Canvas View (page 331) and Export From the ROI View (page 332).

Export From the Canvas View

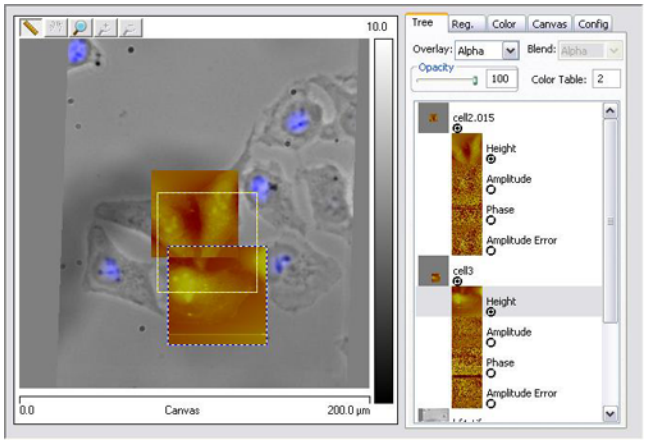
 Click the **Export images** button to open the **Export Images from Canvas View** window:



Three Export images options are available:

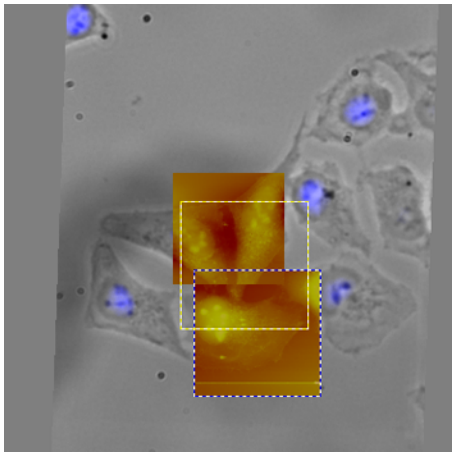
1. Export the View

Saves the *whole* MIRO window as a JPEG image file:



2. Export the Canvas Overlay

Saves the image in the MIRO canvas window as a single layer Tiff, BMP, JPG, PNG or GIF image at its original size:



3. Export Layer Images

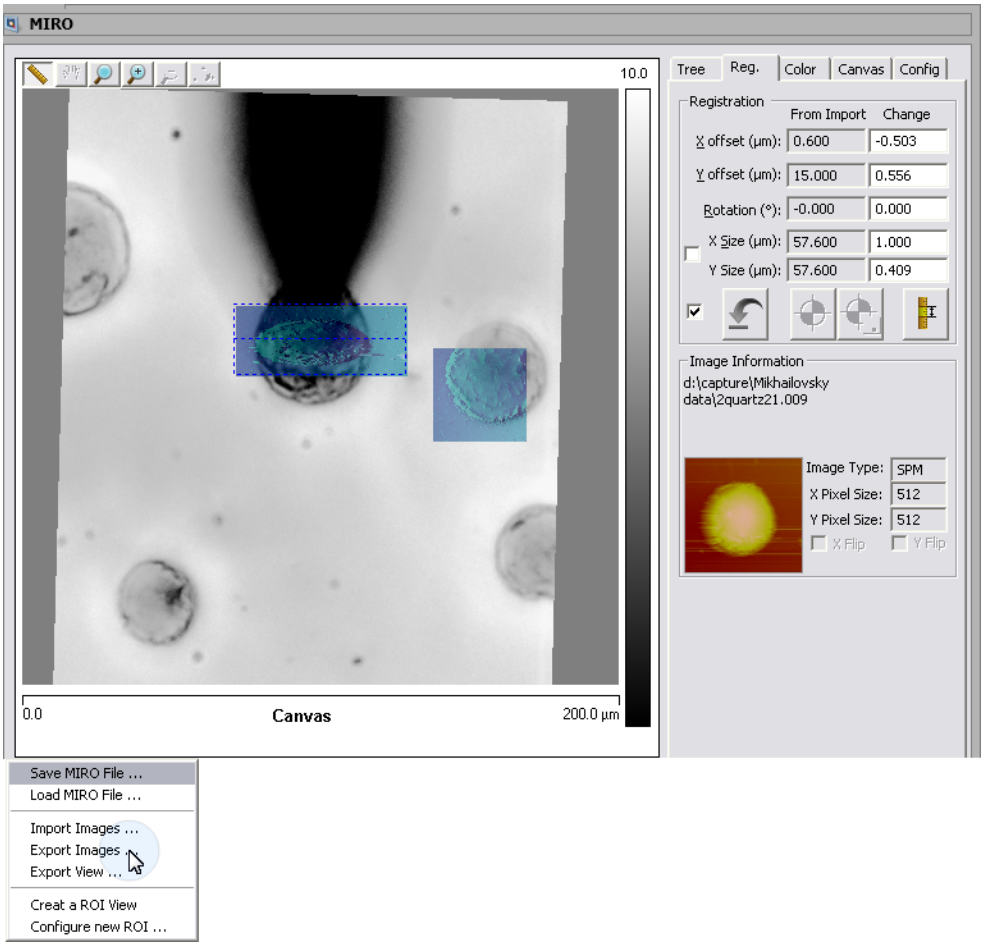
Exports, in order of priority, selected layers in either the region inside the select box, the zoomed region or the entire MIRO canvas.

Use the **Show/Hide** button to control which layers will be exported. You may also adjust the exported image size by changing the **Size** parameter (in the **Export Layer Images As** section of the Export Images From the Canvas View window, above). The image interpolation mode is determined by the Interpolation Mode setting in The Configuration Tab (page 308). Several export options are available:

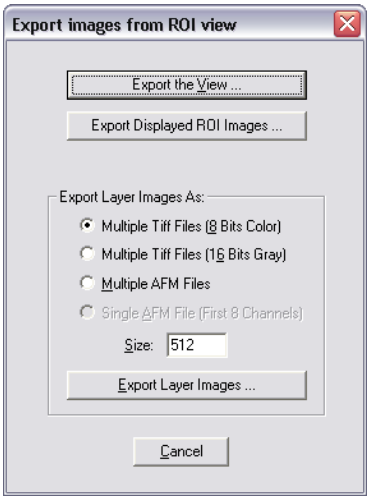
- Individual layers are exported as 8-bit RGB uncompressed tiff files.
- Individual layers are exported as 16-bit gray-scale uncompressed tiff files.
- Individual layers, including optical images, are exported as *.spm files.

Export From the ROI View

It is possible to export images from an ROI view by either clicking the **Export images** icon when the ROI window is active, or by right-clicking in the border and selecting **Export Images**:



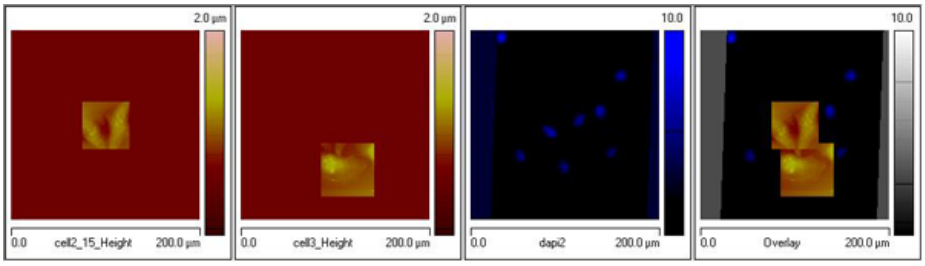
Both methods will open the **Export Images from ROI View** window:



Three Export ROI options are available:

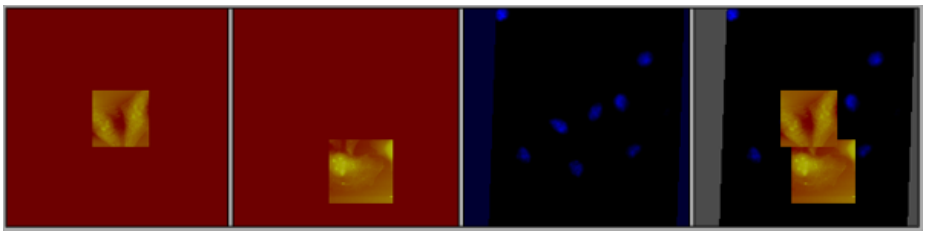
1. Export the View

Saves the *whole* ROI window as a JPEG image file:



2. Export Displayed ROI Images

Saves the ROI images as single layer Tiff, BMP, JPG, PNG, or GIF images at their original size:



3. Export Layer Images

Exports ROI images with preserved layers. Layers are either exported to separate files or a single mult-channel file is created.

You may adjust the exported image size by changing the **Size** parameter (in the **Export Layer Images As** section of the Export Images From the ROI View window, above). The image interpolation mode is determined by the Interpolation Mode setting in The Configuration Tab (page 308). Several export options are available:

- Individual layers are exported as 8-bit RGB uncompressed tiff files.
- Individual layers are exported as 16-bit gray-scale uncompressed tiff files.
- Individual layers, including optical images, are exported as *.spm files.

9.4 MIRO Feature Summary

Import

The following file types may be imported:

- Tiff
- BMP
- JPG (JPEG)
- PNG
- GIF

Canvas

The Canvas view allows the following functions:

- Zoom
- Pan
- Resize
- Scale
- Rotate
- Offset
- Pixel size
- File tree

Overlay and Color Control

- Check box of the tree nodes to toggle show/hide
- Drag and drop tree nodes to change the overlay order
- Change image or channel opacity to affect overlay and blend
- Manipulate color by color table, contrast and offset
- Individual red, green, blue On/Off controls
- Two interpolation methods: Bi-Linear and Nearest Neighbor

Position and Scale Re-registration

- Drag, resize and rotate the image (in **Cursor** mode only)
- Registration tab with edit-box registration, undo and use information
- Update or save the selected non-AFM image registration as Import Registration

Export

- Export the Canvas window as a single layer Tiff, BMP, JPG, PNG or GIF image
- Export selected channel image files into a new directory
- Export the Canvas view

Region of Interest

- Up to 5 ROI views
- Re-sizable
- Auto update and frozen options
- Scale and color bar show/no show options
- Configurable background color
- Synchronized cursors
- Show the ROI boxes in the Canvas view, with the active ROI solid line

ROI Export

- Export as jpeg
- Export as 8 bit color tiff
- Export as 16 bit gray tiff
- Export as the shown size and color
- Export as multiple AFM images

Undo/Redo

- Unlimited image level changes
- Image registration changes: offset, size, rotation, translation, X-Y linking.
- Color table, overlay and blend types, opacity, contrast, offset, RGB.
- Layer (channel) selection changes.

Chapter 10: Technical Support at Bruker

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

Click **Help > Technical Support** for Bruker SPM technical support contact information.

10.1 Regional Technical Support

Select your geographic region for the nearest service and support locations and contact information:

10.2 Web-Based Technical Support Resources

- http://www.bruker-axs.com/nano_surfaces_support.html
- http://www.bruker.com
- http://www.brukerafmprobes.com
- http://nanoscaleworld.bruker-axs.com

10.3 Asia-Pacific

Select your country or region to obtain local technical support contact information:

World Wide Web

- http://www.bruker-axs.com/nano_surfaces_support.html
- http://www.bruker.com
- http://www.brukerafmprobes.com
- http://nanoscaleworld.bruker-axs.com

Asia-Pacific (APAC)

Bruker AXS Pte Ltd

- **Address:**

  11 Biopolis Way #10-05/08

  The Helios

  SINGAPORE 138667

- **Telephone:** +65 6773 9688
- **Fax:** +65 6773 9662

Australia/New Zealand

NewSpec PTY. LTD.

- **Address:**

  134 Gilbert Street

  Adelaide, SA 5000

  AUSTRALIA

- **Telephone:** +61 8 8273 3040

India

M/s Icon Analytical Equipment Pvt. Ltd.

- **Address:**

  554, G.M.Bhosale Marg, Worli

  Mumbai 400 018

  INDIA

- **Telephone:** +91 22 6663 3911
- **Fax:** +91 22 6663 3914

Malaysia

Bruker Malaysia SDN Bhd

- **Address:**

  303 Block A, Menatari Business Park No2

  Jalan PJS 8/5

  Dataran Mentari 46150 Petaling Jaya

  46150 Selangor

  MALAYSIA

- **Telephone:** +603 5621 8303
- **Fax:** +603 5621 9303

Pakistan

Noor (Private) Limited

- **Address:**

  2nd Floor, Naqi Market

75-Shahrah-e-Quaid-e-Azam

Lahore 54000

PAKISTAN

- **Telephone:** +92 42 3636 2211
- **Fax:** +92 42 3637 3320

PR China

Bruker Beijing (Rep Office of KHE)

- **Address:**

  Suite A329

  First No. 8 Guanghua Road

  Chaoyang Distric, Beijing 100026

  China

- **Telephone:** +86 10 8251 2606
- **Fax:** +86 10 6581 6755

Bruker Shanghai

- **Address:**

  Suite 505, Building 7

  1888 Xinjinqiao Road

  Shanghai, 201206

  China

- **Telephone:** +(86) 21 5531 8005
- **Fax:** +(86) 21 3872 0056

South Korea

Bruker BioSciences Korea Co. Ltd. (AAFM)

- **Address:**

  Bundang-gu, Seongnam-si

  KINS Tower 15F, 25-1 Jeongja-dong

  Gyeonggi-do 463-847

  SOUTH KOREA

TecSco (AFMI & SOM)

- **Address:**

#1811 Gwanghwamun Officia

163 Sinmunno1ga Jongnogu

Seoul, 110-999

SOUTH KOREA

- **Telephone:** +82 2 3276 3660 1
- **Fax:** +82 2 3276 3662

Taiwan

Bruker Taiwan Co., Ltd.

- **Address:**

  3F-5, No.5 Taiyuan 1st St.

  Zhubei City

  Hsinchu County 302

  TAIWAN R.O.C.

- **Telephone:** +886 2 869 81212

Thailand

Bruker Biospin AG

- **Address:**

  41 Soi Lertpanya

  Sri Ayuthaya Rd. - Lertpanya Bldg. Suite 1407

  Bangkok 10400

  THAILAND

- **Telephone:** +66 2 642 6900
- **Fax:** +66 2 642 6901

Lite-Tech International Co. LTD

- **Address:**

  10 Ruamchitt Road, Tanonnakornchaisri

  Dusit Bangkok 10300

  THAILAND

- **Telephone:** +662 667 45019
- **Fax:** +662 667 4506

10.4 Japan

Select your country or region to obtain local technical support contact information:

World Wide Web

- http://www.bruker-axs.com/nano_surfaces_support.html
- http://www.bruker.com
- http://www.brukerafmprobes.com
- http://nanoscaleworld.bruker-axs.com

Bruker AXS K.K.

- **Address:**

  Bancho M Building

  2-8 Rokubancho

  Chiyoda-ku

  Tokyo, 102-0085

  JAPAN

- **Telephone:** +81 3 3265 1190
- **Fax:** +81 3 3265 1198

10.5 Europe, Africa, and the Middle East

Select your country or region to obtain local technical support contact information:

World Wide Web

- http://www.bruker-axs.com/nano_surfaces_support.html
- http://www.bruker.com
- http://www.brukerafmprobes.com
- http://nanoscaleworld.bruker-axs.com

Belarus, Kazakhstan, Kyrgyzstan, Russia, Tajikistan, Ukraine, Uzbekistan, Turkmenistan, Georgia, Moldova, & Armenia

OPTEC

- **Address:**

  Department of Nanotechnology Systems & Electron Microscopy (NTS)

  Denisovski per., 26

  105005 Moscow

  RUSSIA

- **Telephone:** +7 495 933 5151
- http://optec.zeiss.ru

BENELUX (Belgium, Denmark, Finland, Luxembourg, Netherlands, Norway, Sweden)

Bruker Nederlands BV

- **Address:**

  Bruynvisweg 16-18

  1531AZ Wormer

  THE NETHERLANDS
- **Telephone:** +31 75 628 5251
- **Fax:** +31 75 628 9771
- **Mailing Address:**

  P.O. Box 88

  NL 1530AB Wormer

  THE NETHERLANDS

Bosnia, Bulgaria, Croatia, Hungary, Serbia, & Slovenia

LABCO

- **Address:**

  Vadgalamb u.1

  H-3519 Miskolc

  HUNGARY
- **Telephone:** +36 4656 2466

Czech Republic & Slovakia

Measurement Technic Moravia Ltd.

- **Address:**

  Nádražní 267,

  66441, Omice

  CZECH REPUBLIC
- **Telephone:** +420 733 727 920
- www.mt-m.eu/

Estonia & Latvia

Bruker Baltic OÜ

- **Address:**

  Pärnu mnt. 141

  11314 Tallinn

  ESTONIA

- **Telephone:** +372 689 9000
- www.bruker.com/lv.html

France & Switzerland

Bruker AXS S.A.S.

- **Address:**

  7, rue de la Croix Martre

  91120 PALAISEAU

  FRANCE

- **Telephone:** +33 1 72 86 61 00
- **Fax:** +33 1 72 86 61 20

Germany & Switzerland

Bruker Nano GmbH

- **Address:**

  Östliche Rheinbrückenstraße 49

  76187 Karlsruhe

  GERMANY

- **Telephone:** +49 (0721) 50997 5950
- **Fax:** +49 (0721) 50997 5952

Greece

Analytical Instruments

- **Address:**

  9, Tzavella St.

  Chalandri 152 31

  Athens

GREECE

- **Telephone:** +30 210 674 8973
- www.analytical.gr/en/

Israel

New Technology R.K. Ltd.

- **Address:**

  11 Tuval Street, 7th floor

  Ramat Gan 52522

  ISRAEL

- **Telephone:** +972 3 679 2000
- www.newtech.co.il/

Ireland & United Kingdom

Bruker UK Limited

- **Address:**

  Nanotech House, Anderson Road

  Buckingway Business Park

  Swavesey, Cambridge CB24 4UQ

  UNITED KINGDOM

- **Telephone:** +44 1954 233 900
- **Fax:** +44 1954 231 300

Italy

2M Strumenti SRL

- **Address:**

  Via G. Pontano, 9

  Roma, I-00141

  ITALY

- **Telephone:** +39 06 8689 5319
- www.2mstrumenti.com

Lithuania

Linea Libera

- **Address:**

  Akademijos str. 2

  Vilnius LT-08412

  LITHUANIA

- **Telephone:** + 370 52 63 8748
- www.linealibera.lt

North Africa, Algeria, Morocco, & Tunisia

Opexcel

- **Address:**

  3 rue Ruhmkorff

  75 017 Paris

  FRANCE

- **Telephone:** +33 144 83 0221

Poland

LabSoft

- **Address:**

  ul. Bażancia 45A

  02-892 Warszawa

  POLAND

- **Telephone:** +48 22 644 9750
- www.labsoft.pl/

Romania

Ronexprim SRL

- **Address:**

  5 Cotiturii Street

  010855 Bucharest-1

  ROMANIA

- **Telephone:** +40 21 314 3599
- www.ronexprim.com

Saudi Arabia, United Arab Emirates, Qatar, Bahrain

Naizak Labsystems

- **Address:**

  PO Box 57792

  Al Sulaimaniya District

  Prince Musaid Bin Abdul Aziz Road

  11584 Riyadh

  SAUDI ARABIA

- **Telephone:** +966 1 479 0484
- www.naizak.com

South Africa

Carl Zeiss (Pty) Limited

- **Address:**

  363 Oak Avenue, Ferndale

  Randburg, 2194

  REPUBLIC OF SOUTH AFRICA

- **Telephone:** +27 11 886 9510
- www.zeiss.co.za

Spain, Portugal

TELSTAR Instrumat, S.L.

- **Address:**

  Avda. Alcalde Barnils, 70 - PTA. 3

  08190 Sant Cugat del Valles

  SPAIN

- **Telephone:** +34 93 544 2320
- www.telstar-instrumat.com/

Turkey

Ceyhun Atuf Kansu Caddesi

- **Address:**

  No: 112, Kat: 4, Daire: 26

  06520 Balgat - Cankaya / Ankara

  TURKEY
- **Telephone:** +90 312 472 6108
- www.anatek.com.tr

10.6 North America

Technical Support for North America is located at the factory where the Bruker SPMs are designed and manufactured. Customers outside of North America are also welcome to contact the factory for service or support inquiries.

- **Phone:**
  - 1-800-873-9750
  - 1-805-967-1400
- **Fax:** 1-805-967-7717
- **E-mail:** sbotechsupport@bruker-nano.com

Mailing Address

Technical Documents, Technical Support or Bug Reports at Bruker

Bruker Inc.

112 Robin Hill Rd.

Santa Barbara, CA 93117

World Wide Web

- http://www.bruker-axs.com/nano_surfaces_support.html
- http://www.bruker.com
- http://www.brukerafmprobes.com
- http://nanoscaleworld.bruker-axs.com

10.7 Latin America

Select your country or region to obtain local technical support contact information:

World Wide Web

- http://www.bruker-axs.com/nano_surfaces_support.html
- http://www.bruker.com
- http://www.brukerafmprobes.com
- http://nanoscaleworld.bruker-axs.com

Argentina

Bio Analitica Argentina S.A

- **Address:**

  Florida 835, 1º piso Of. 104A

  C1005AAQ Buenos Aires

  ARGENTINA

- **Telephone:** +54 11 4515 0117
- **Fax:** +54 11 4515 0142

Brazil

Altmann S.A. Importação e Comércio

- **Address:**

  Ave das Nacoes Unidad 13.771

  Bloco 1, 7th Floor

  Sao Paulo, SP 04794-000

  BRAZIL

- **Telephone:** +55 11 2198 7198
- **Fax:** +55 11 5507 4196

Chile

Arquimed S.A.

- **Address:**

  Arturo Prat 828,

  Santiago de Chile

  CHILE

- **Telephone:** +56 (2) 674 30 14
- **Fax:** +56 (2) 634 46 33

IGMO Ltda

- **Address:**

  Santo Domingo 1083 Of. 1114

  52612 Santiago

  CHILE

- **Telephone:** +56 (9) 9 895 3089

Columbia

Arotec Colombiana S.A.

- **Address:**

  Cra. 16, No 35-56

  Bogota

  COLUMBIA
- **Telephone:** +57 (1) 288 7799
- **Fax:** +57 (1) 285 3604

Equador

Ing. Jose M. Jalil Haas

- **Address:**

  Fray Joaquín Auz # 181 (E7-08) y Últimas Noticias

  Quito

  ECUADOR
- **Telephone:** +593 (2) 244 2388

Mexico

Alta Tecnologia en Laboratorios

- **Address:**

  Comoporis #43

  Col. El Caracol

  Del. Coyoacan

  04739 Mexico D.F.

  MEXICO
- **Telephone:** +52 (55) 5606 7525

Peru

Science and Technology Training EIRL

- **Address:**

  Calle Independencia 521

  Urbanizacion Pando 7ma Etapa

San Miguel, Lima32

PERU

- **Telephone:** +51 1628 1840
- **Fax:** +51 1628 1841

Uruguay

Labimed S.A.

- **Address:**

  La Cumparsita 1373 Of 803

  11200 Montevideo

  URUGUAY

- **Telephone:** +59829032902
- **Fax:** +59829031772

Venezuela

Business Electronics International C.A.

- **Address:**

  Av. La Salle c/c Lima

  Torre Phelps, Piso 18 Oficina 18-B

  Caracas 1050

  VENEZUELA

- **Telephone:** +58 2127931496

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