XEI

Powerful Image Processing Tool for SPM Data

Software Manual

Version 1.8.0

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Preface

This document is an instruction manual for XEI, an Image Processing Program for SPM data developed by Park Systems. XEI, developed in Java, can be run on any machine that supports Java Virtual Machine (JVM). This manual discusses in detail the software features of the XEI program.

This manual explains the image analysis features in accordance with the standard analyzing features useful for handling SPM data. This document describes, in detail, every item that is displayed in XEI's user interface, and offers a wealth of information regarding the use of a variety of analyzing tools and image processing modes to produce enhanced images. It is quite important to make good use of the XEI image processing program, just as it is important to collect the best possible data utilizing the XEP data acquisition program. The XEI software will allow you to maximize the system's potential, however, by providing the ability to remove certain artifacts from scan data and by allowing you to extract more information from the sample surface by utilizing various analysis tools.

The contents of this manual are organized as follows. First, an overview of the main categories in the XEI is provided so that you may browse for items of interest. Then, the main processing and analyzing tools are more elaborately discussed in each chapter. This software manual pays attention to all available modes and toolbars and discusses their basic functions so that you can apply them to your data with ease.

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Chapter 1. Overview of XEI

XEI is an excellent software program that provides user-friendly and dynamic tools for image processing, quantitative analysis and statistics, and export and printing of processed images and measurement results. This chapter provides an overview of the features and controls in the XEI program so that you can be more familiar with its layout and capabilities.

1-1. Overall Features in XEI

To open the XEI program, double click the XEI icon  on your computer's desktop. Figure 1-1-1 shows the XEI screen appearance that is displayed when starting up the XEI program.

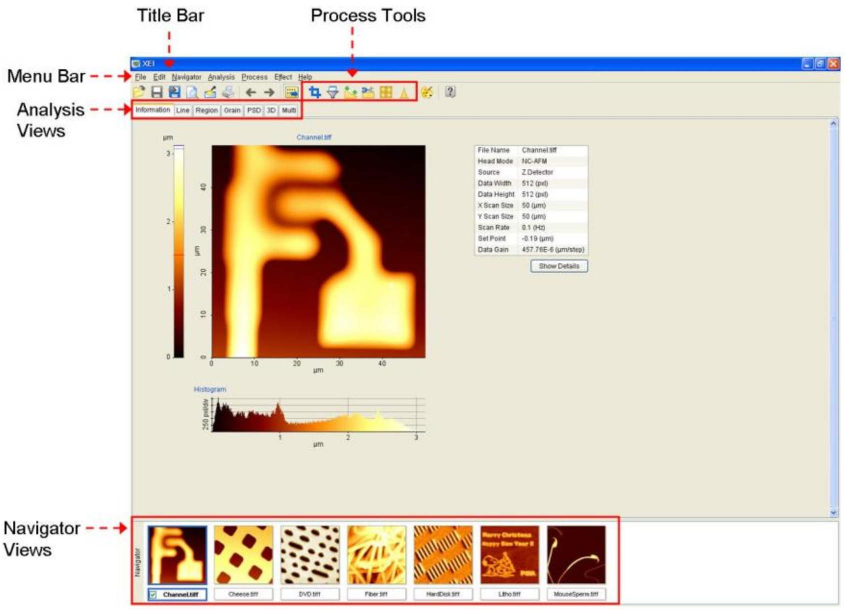


Figure 1-1-1. XEI - Image Processing Program

1-1-1. Title Bar

The Title bar displays the title of the image processing program, XEI. Also, in the preview screen, it indicates the Analysis view type (Information, Line, Region, 3D, and Multi) you want to preview. For example, in Figure 1-1-2, the Title bar indicates that the screen is displaying the preview of the Line view of the selected image.

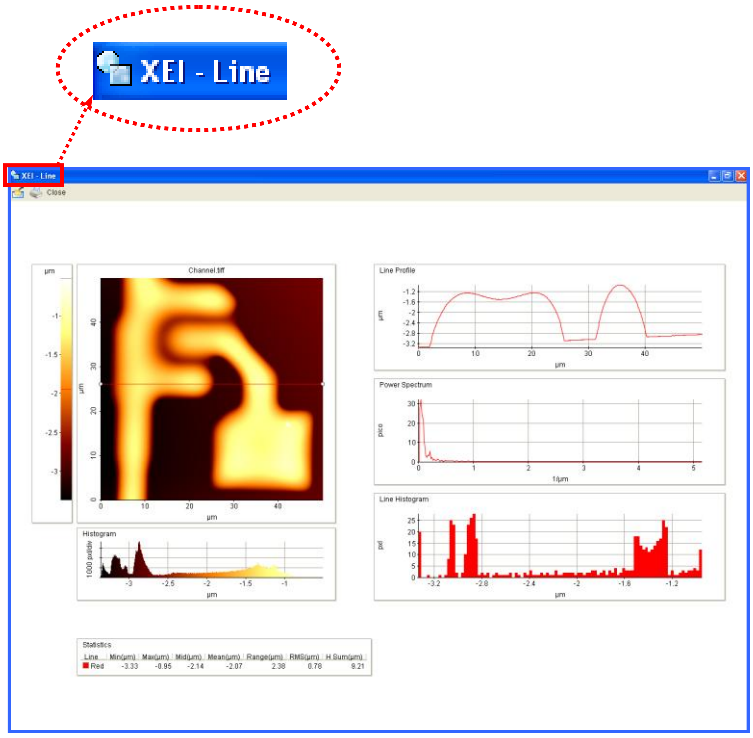


Figure 1-1-2. Title bar in a preview screen

1-1-2. Menu Bar

The Menu bar includes several groups of menu items that are available for working with SPM images. A more detailed explanation is provided in Chapter 2. "Menus & Toolbar". Figure 1-1-3 shows menus, menu items and related icons.

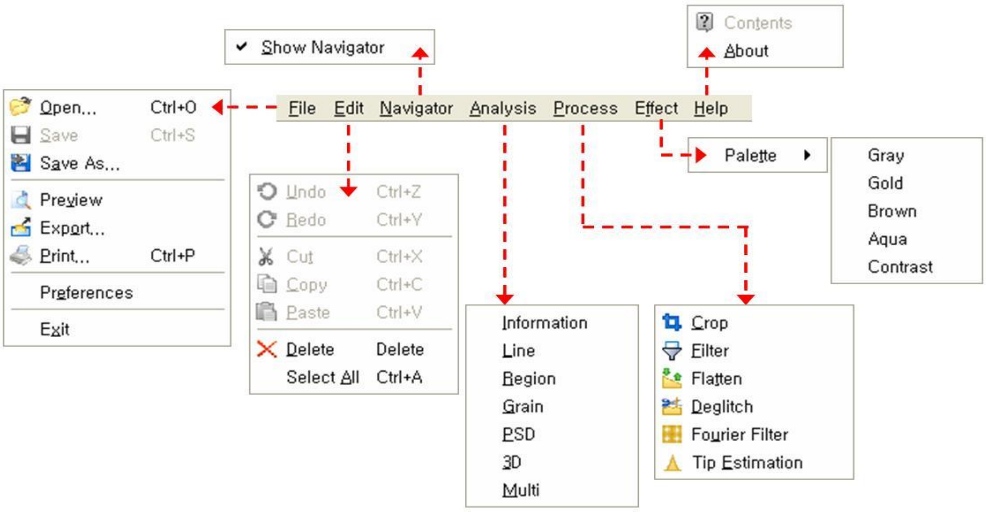


Figure 1-1-3. Menu bar

1-1-3. Toolbar

The Toolbar, shown in Figure 1-1-4, offers many icons for direct access to the most frequently used basic functions. A more detailed description of the Toolbar is also provided in Chapter 2. “Menus & Tool bar”

Figure 1-1-4. Toolbar

1-1-4. Analysis View

The Analysis view is a worktable that allows you to work with the selected image and to perform image processing and quantitative analysis on an image. As shown in Figure 1-5-1, the Analysis view of the XEI has three parts: Analysis view tabs, Image display panel and Analysis result & parameters display panel.

Above the Analysis view, there are seven tabs for opening the analysis view: Information, Line, Region, Grain, PSD, 3D, and Multi. When you click each tab, the Analysis view will be switched to the view you selected.

At the left side of the Analysis view, is the Image display panel that displays an image with the palette panel and Histogram panel. You can display the image that you want to process and analyze in the Image display. To bring an image file into the Image display panel, double-click the image from the Navigator view.

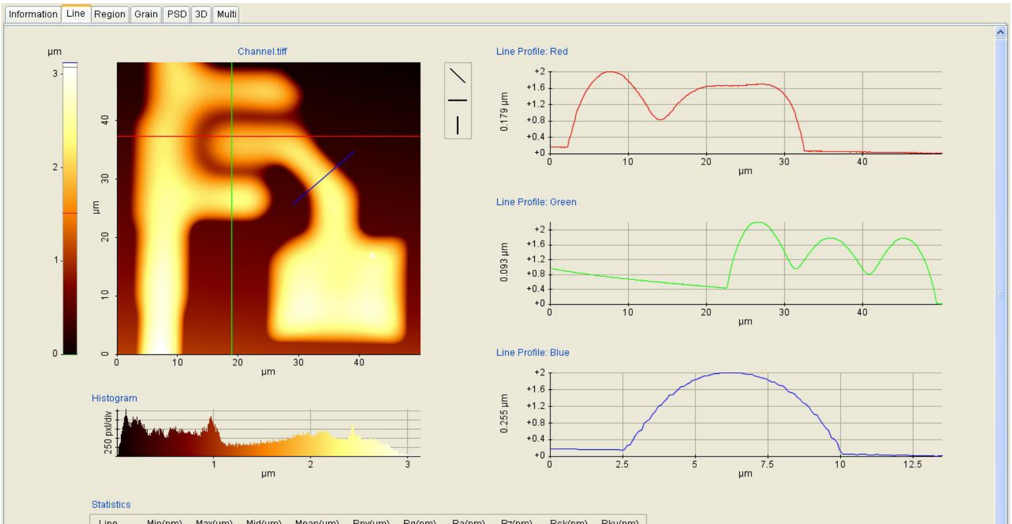
WARNING!

The contrast color in an image that was generated in the older version XEP program (XEP 1.0) may be reversed. The darker color represents a higher height and the brighter color represents a lower height value. Please, reset the contrast settings so that the brighter color should be the higher height.

In the Image display panel, you can do the following things:

- Load an image from your hard disk into the Image display panel via the Navigator view
- Adjust the color scale of an image with the palette panel
- Preview and print an image in the Image display panel

The right panel of the Analysis view varies according to the selected Analysis view. That is, it displays an information table in the Information view; several data plots in the Line or Region view; and 3D rendering parameters in the 3D view. Also, in the Multi view, the Analysis view displays multiple images at one time. Figure 1-5-1 shows the Analysis view of the Information view. Each Analysis view is described further in each related chapter.



Line	Min(nm)	Max(µm)	Mid(µm)	Mean(µm)	Rpv(µm)	Rq(nm)	Ra(nm)	Rz(nm)	Rsk(pm)	Rku(pm)
Red	178.986	2.189	1.184	1.079	2.010	753.741	705.060	210.325	-25.705	583.893
Green	92.926	2.309	1.201	1.179	2.216	537.062	468.322	41.435	199.422	954.127
Blue	254.974	2.265	1.260	1.077	2.010	784.263	731.421	366.939	160.603	640.313

Figure 1-1-5. Analysis View (in Line view)

1-1-5. Navigator View

The Navigator view serves as a buffer for the images that you have already opened in XEI. You can view basic information of each images in the navigator view by placing mouse pointer over an image. (see the box in Figure 1-1-6)

To load a certain image from the ‘Navigator View’ to the ‘Analysis View’, double click the image you want to load and then click ‘Yes’ to the warning message saying that *“This will initialize all the analysis views. Do you want to continue?”*

Only one image can be loaded at a time. The loaded image is outlined in blue color and check box beside its name is checked. Figure 1-6-1 shows the Navigator view.

WARNING!

> When the new image is loaded, the analysis results of the previously loaded image (line profile, statistics table, histogram, etc.) in all the analysis views (Grain, PSD, 3D…) and any changes made by imageprocessing will be removed as all the analysis view is initialized. Therefore you should save all the necessary analysis results and changes made to the image before you load new image to the analysis view from the navigator view.

Figure 1-1-6. Navigator view

There are three ways to bring images into the Navigator view:

- Drag and drop the selected images from your image directory into the Navigator view (Figure 1-1-7).
- Select the ‘Open’ option in the File menu or click the ‘open data file’ icon to find an image you want to load (Figure 2-1-2).
- Use Send to XEI menu in the buffer window of the XEP.

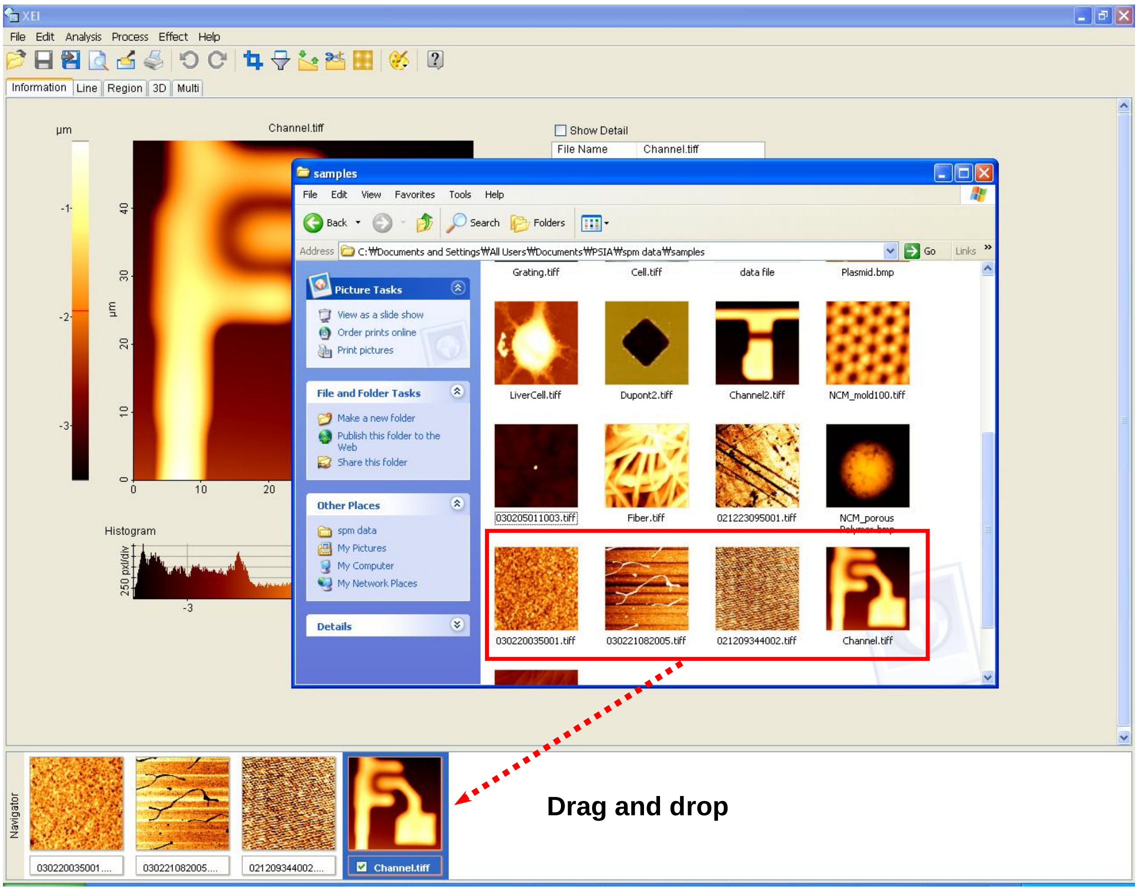


Figure 1-1-7. Drag and drop images into the Navigator view

When you right-click the cursor on an image in the Navigator view, a context menu as shown in Figure 1-1-8 is generated allowing you to execute the following actions: Load, Reopen, Delete, and Delete All.

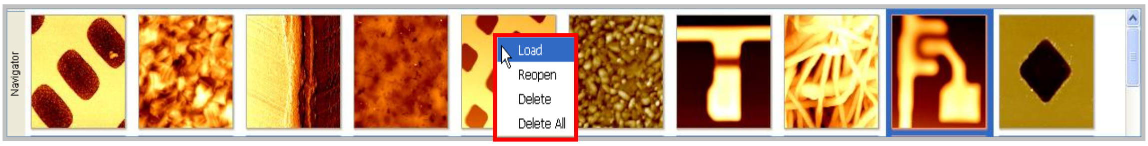


Figure 1-1-8. Context menu in the Navigator view

■ Load

You can load the selected image into the Analysis view for image processing and quantitative analysis.

■ **Reopen**

You can reopen the original image again in the Analysis view for a new session or to refresh the image in order to perform image processing and analysis again.

■ **Delete**

Removes the selected images from the Navigator view.

■ **Delete All**

Removes all images from the Navigator view.

1-2. Installation of Park Systems XEI' Software

The XEI software program for XE systems can be run properly in : **Windows XP Service Pack 2 or Windows 7(32bit) and Java SE Runtime Environment 6 or higher**. The Java Runtime Environment must be installed prior to installing 'Park Systems XEI' software.

1-2-1. Uninstallation of the old version 'Park Systems XEI' program

1. Remove old 'PSIA XEI or Park Systems XEI' program by using 'Add or Remove Program' in the Control panel.

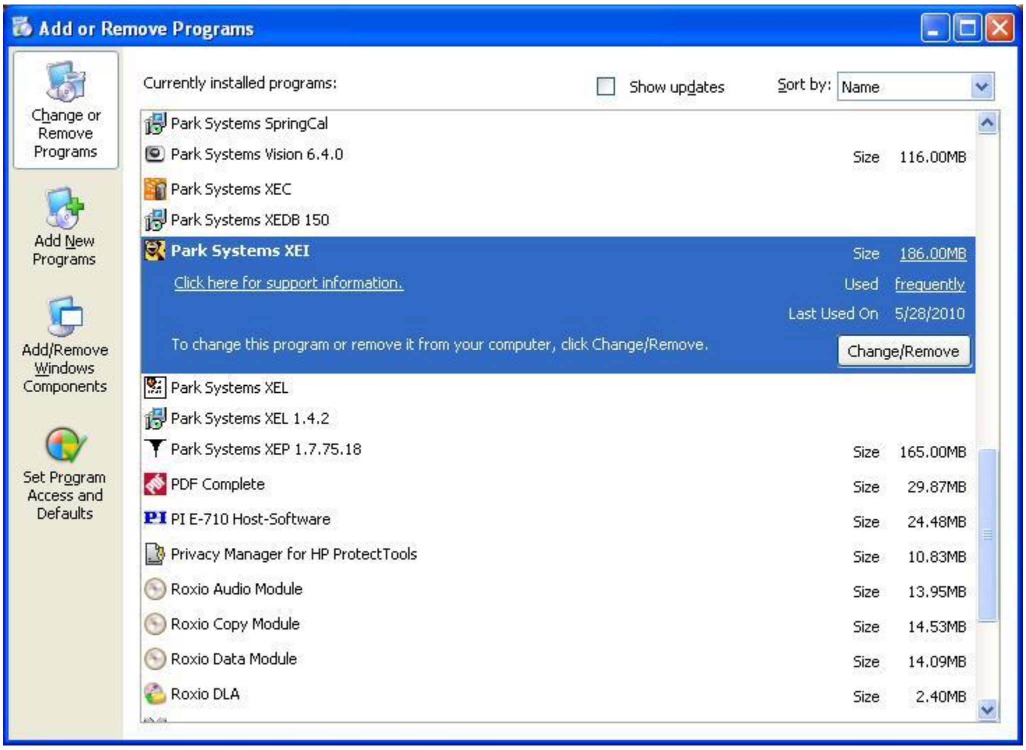


Figure 1-2-1. 'Add and Remove Program' window

2. The 'Uninstall Shield Wizard' dialog will be opened. When 'Confirm Uninstall' message box asks you again if you want to completely remove this 'PSIA XEI or Park Systems XEI' program, click 'OK' to proceed uninstallation.

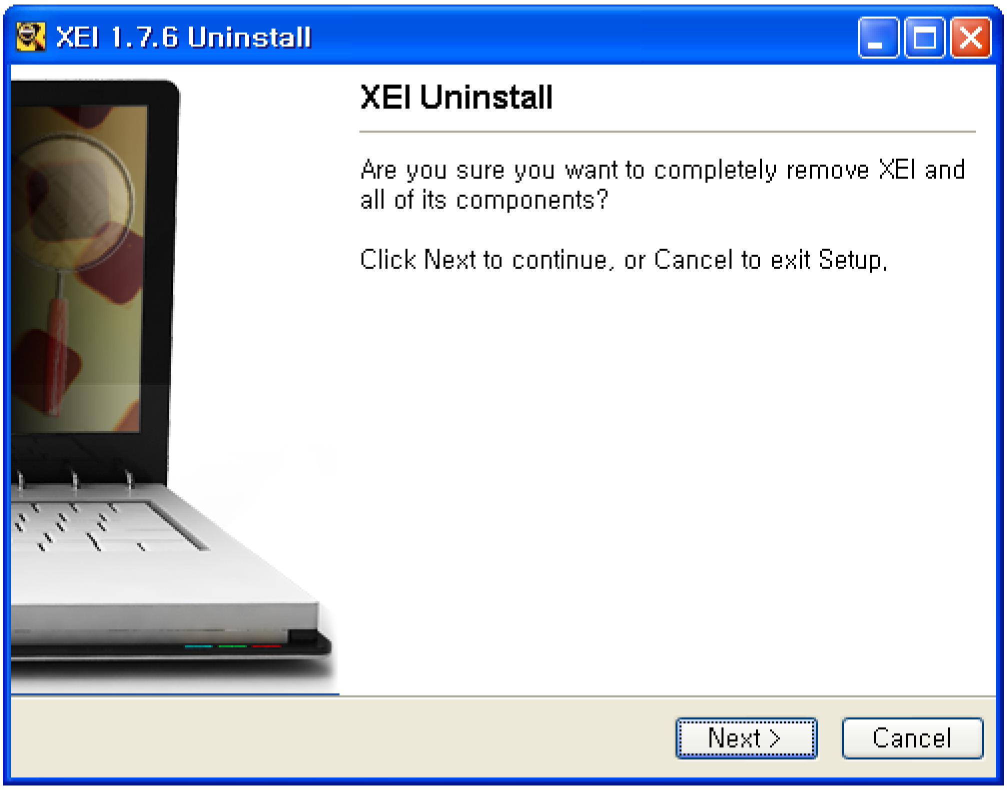


Figure 1-2-2. Confirm Uninstall Message

3. The figure below will be shown when uninstallation is successfully done.

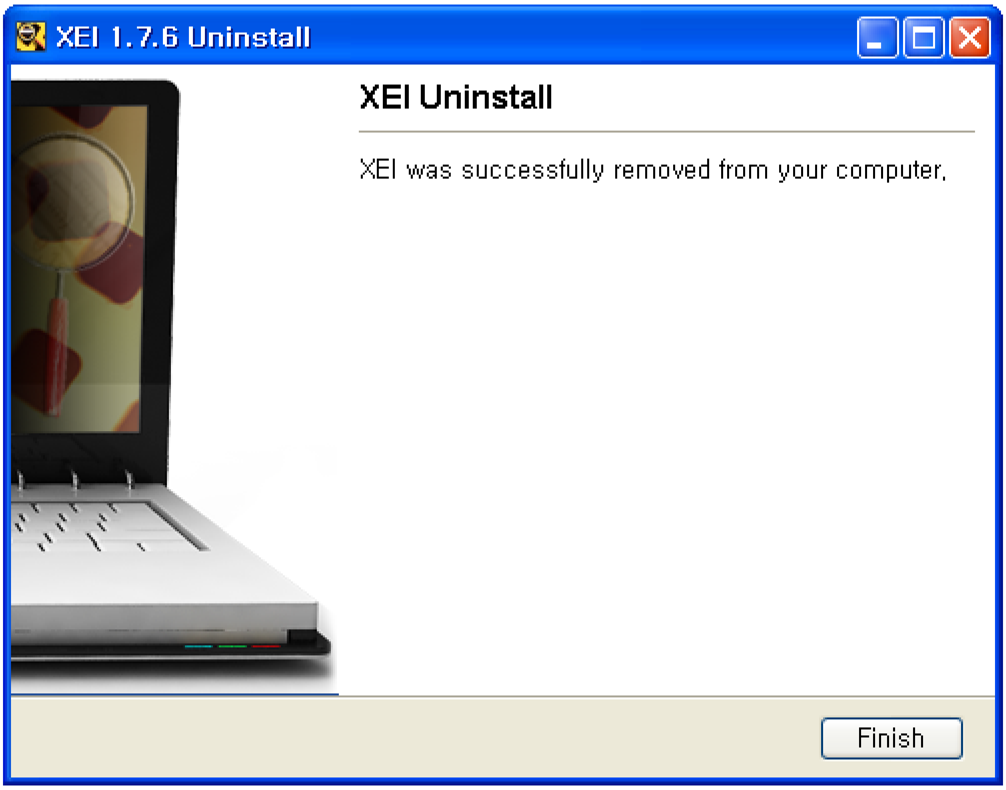


Figure 1-2-3. Confirm Uninstall Message

1-2-2. Installation of the new version 'Park Systems XEI' program

The procedure to install the new version 'Park Systems XEI' is as follows:

1. Insert the Unified XE-Software Installer CD and Installation Dialog will be opened as seen in Figure 1-2-4.

Figure 1-2-4. Installation Dialog of Unified XE-Software Installer CD

2. The XEI software is run properly in Java SE Runtime Environment 6 or higher. If necessary, install java program included in CD by clicking ‘JRE Install’.

3. Clicking ‘XEI Install’ opens following dialog.

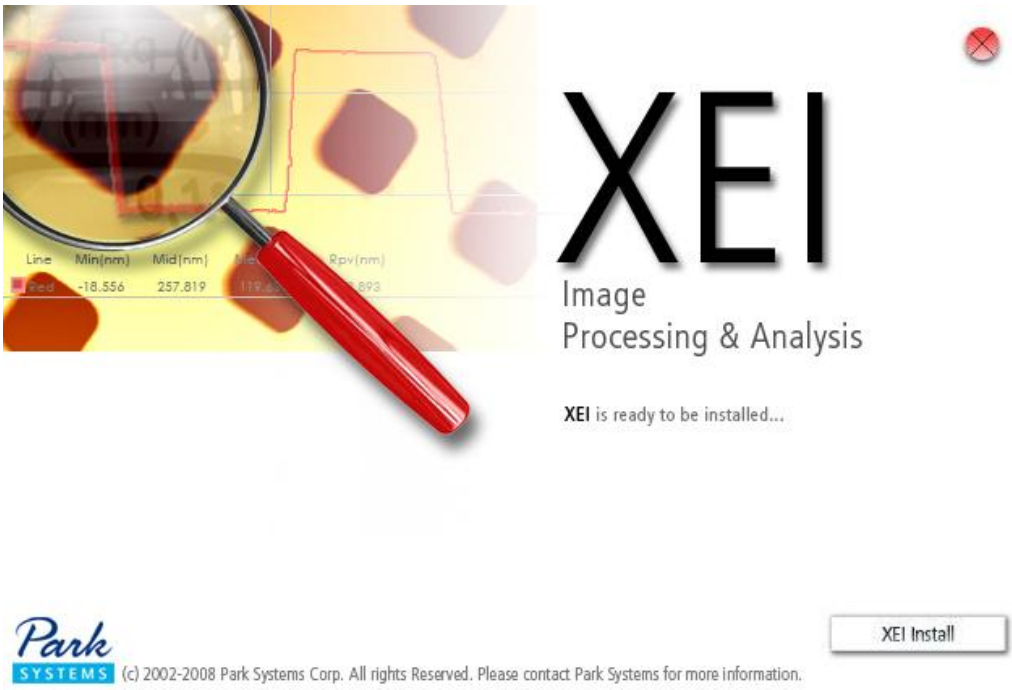


Figure 1-2-5. Installation Dialog of XEI

4. Click 'XEI Install' to Install XEI program by following the steps below.

   Step1: **Preparing to Install** - Installation will start as shown as in Figure 1-2-6.

   Step2: **Installer Language –** Choose the installer language in Figure 1-2-7.

   Step3**: Welcome to the XEI Setup Wizard** - Click the 'Next' button to continue the install setup as shown in Figure 1-2-7.

   Step4: **License Agreement** – Read the License Agreement. You must accept this agreement before continuing with the installation by checking 'I accept the agreement' and click the 'Next' button to continue the install setup as shown in Figure 1-2-7.

   Step5: **Select Destination Directory** - The 'Park Systems' folder is made in the C directory by this installation procedure. This is the base directory of XE software. You may also select other destination in your computer by selecting

‘Browse’. Click the ‘Next’ button as shown in Figure 1-2-7.

Step6: **Select Start Menu Folder** – Select the Start Menu folder in which you would like Setup to create the program's shortcuts, then click ‘Next’ button as shown in Figure 1-2-7.

Step7: **Select File Associations** – Select file association you want to creat e and click ‘Next’ button when you are ready to continue as shown in Figure 1-2-7.

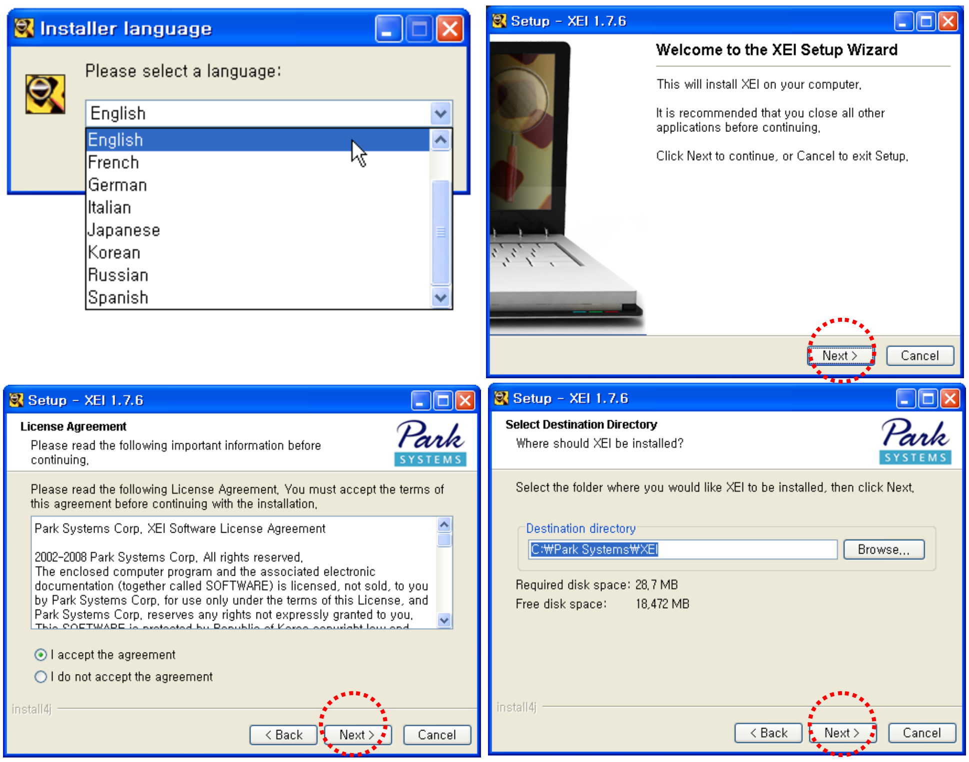
Step8: **Select Graphic Option** – Select the graphic type according to your graphics driver. If not selected correctly, the XEI program will not open properly. The most common graphic type will be ‘OpenGL’.

<u>NOTE!</u>

If you select the wrong graphic type, the XEI program will not open properly. To correct this problem, you must uninstall XEI completely and reinstall the program again.

Step9: **Select Additional Tasks** – Check if you want to create a desktop icon and click ‘Next’ button as shown in Figure 1-2-7.

Figure 1-2-6. Setup the 'Park Systems XEI' program



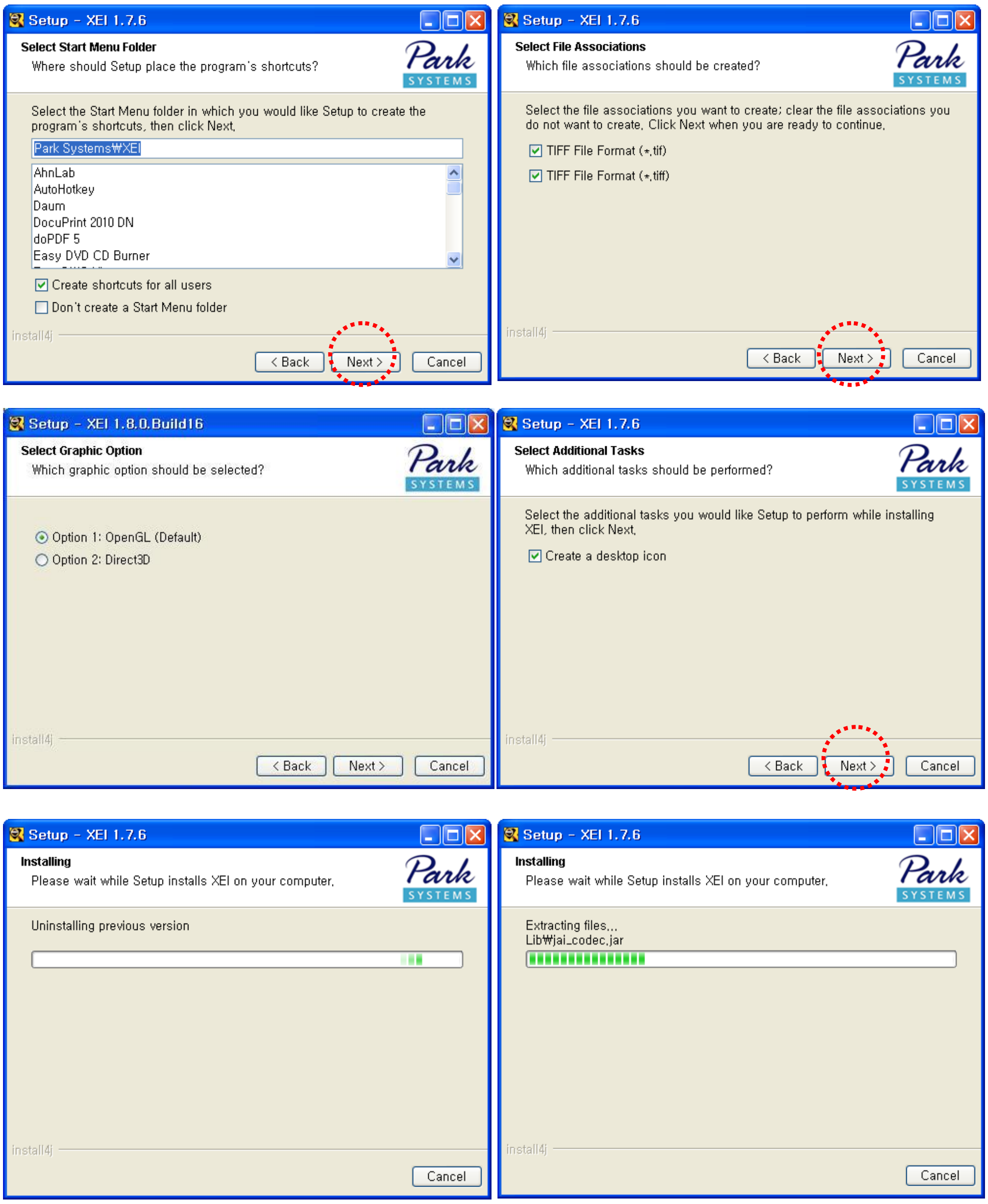


Figure 1-2-7. Procedure to install the 'Park Systems XEI' program

When the setup is completed, the 'Completing the XEI Setup Wizard' window appears, click the 'Finish' button as shown in Figure 1-2-8.

When you have finished the XEI installation procedure, XEI folder is created in the 'Park Systems' folder as a subfolder. Its shortcut will be automatically created in your desktop and the 'Park Systems XEI' program will be made.

Figure 1-2-8. 'Completing the XEI Setup Wizard' dialog

Chapter 2. Menus & Toolbar

The Menu bar contains a list of all available menus from which you can access the basic functions of the XEI image analysis program. Also, the most frequently used menu items are provided as icons on the Toolbar. Figure 2-1 shows the several menu items and the related icons.

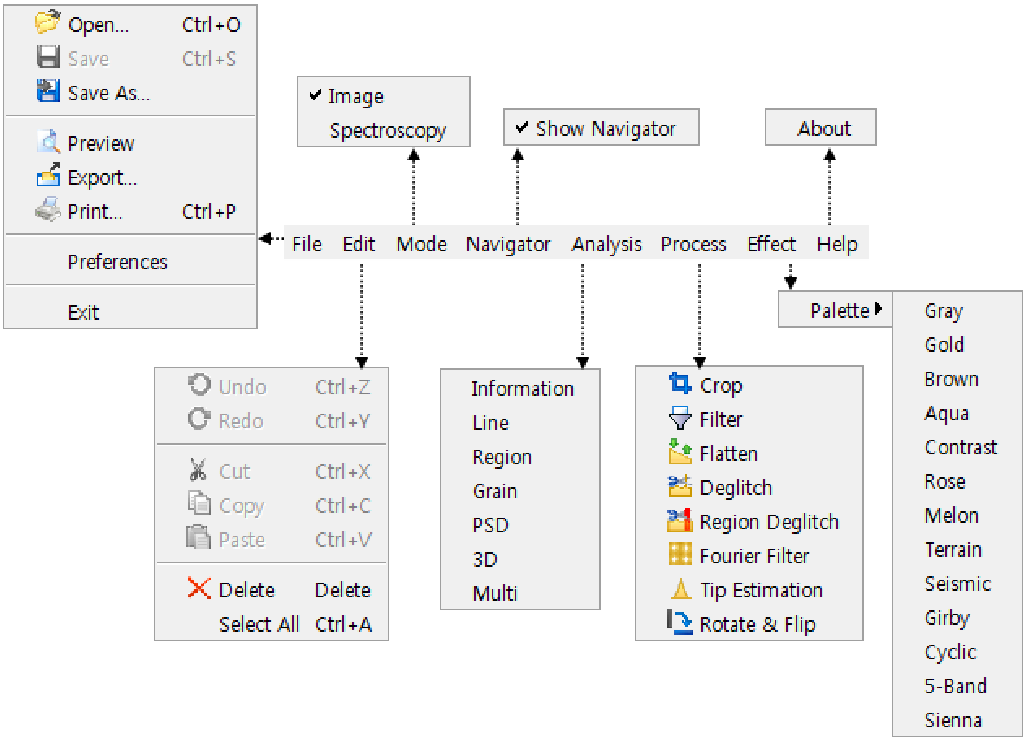


Figure 2-1. Menu bar

2-1. File

Contains several menu items that allow you to Open, Save, Save As, Preview, Export, Batch Export and Print image data files as shown in Figure 2-1-1.

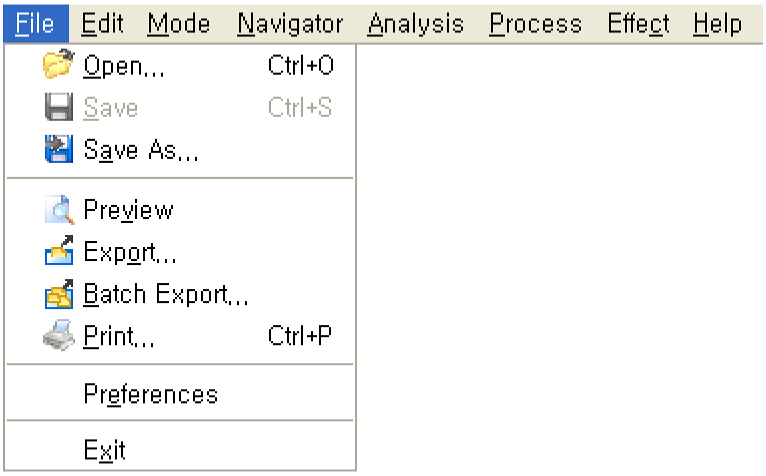


Figure 2-1-1. File menu

2-1-1. Open 

Opens the 'Open' dialog as shown in Figure 2-1-2. In order to bring an image into the Analysis view, select the 'File>Open' in the Menu or click the 'Open' icon . Then, select the image file you want to analyze in the Open dialog. This image file is loaded into the Navigator view. If the image file is the first file loaded into the Navigator view, it is automatically loaded into the Analysis view of the Information view. Otherwise, double clicking the image in the Navigator view loads the image into the current analysis view.

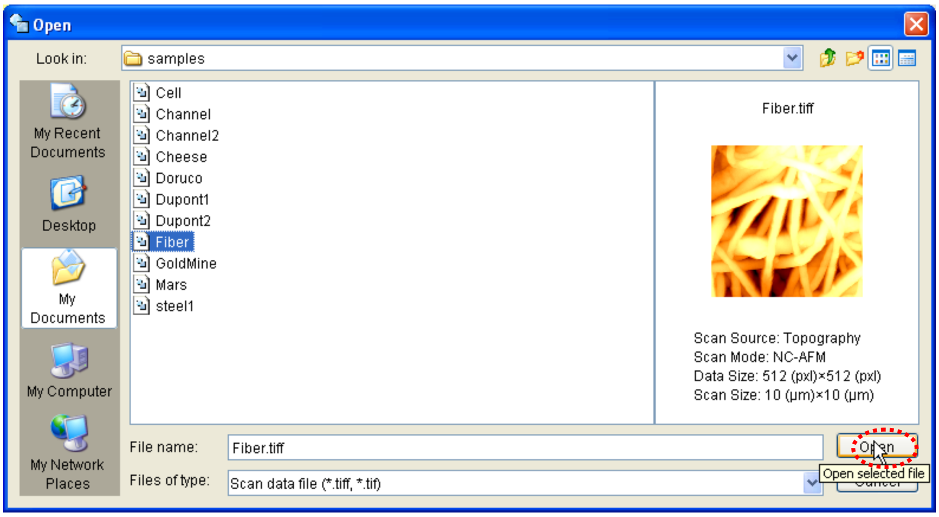
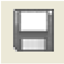


Figure 2-1-2. Open dialog

2-1-2. Save 

Allows you to save the processed image or result in the Image display panel to the original image data file, overwriting the original data. When you select the 'Save' menu, the 'Save' warning message box as seen in Figure 2-1-3 appears to remind you that this command may replace the original image file.

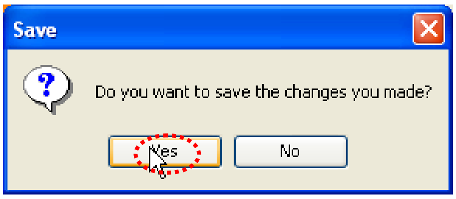


Figure 2-1-3. 'Save' warning message box

2-1-3. Save As 

Opens the 'Save As' dialog as shown in Figure 2-1-4. In this dialog, you can save the transformed image or statistics data as a new image data file. Unlike the 'Save' menu, it does not overwrite the data in the original data file but create another data file.

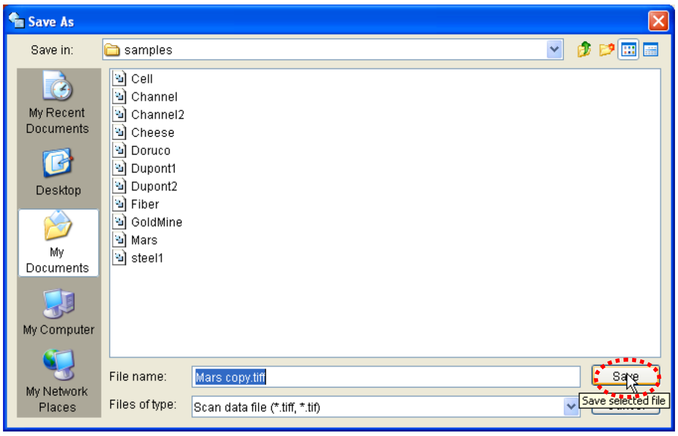


Figure 2-1-4. Save As dialog

2-1-4. Preview 

Allows you to preview the processed image with its analysis data. You can export and print this result in the preview mode. As an example of the preview screen, Figure 2-1-5 shows the preview screen of the selected image in the Line view.

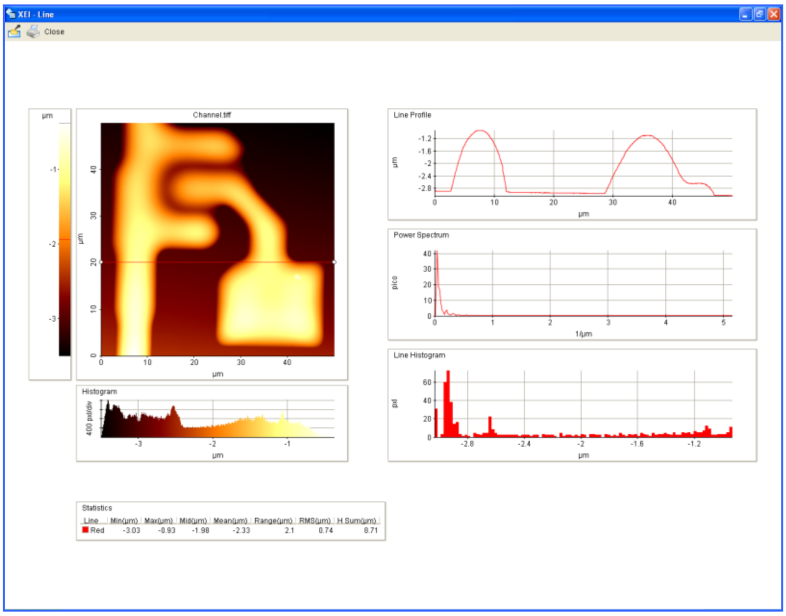
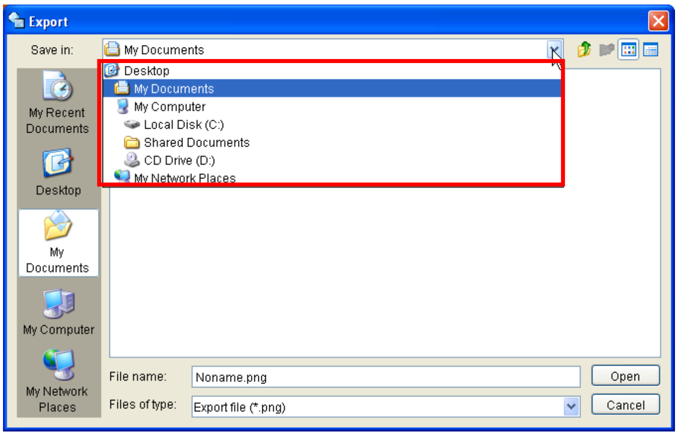


Figure 2-1-5. Preview screen

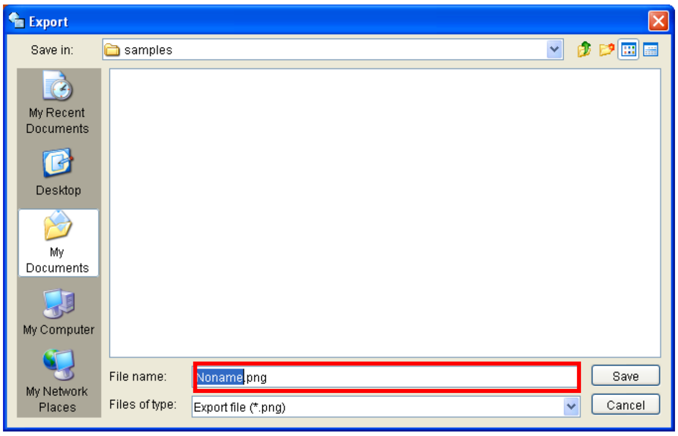
2-1-5. Export 

Allows you to export the data file as a Portable Network Graphics(PNG) file, a Bitmap Image(BMP) file and a Joint Photography Experts Groups(JPEG) file. This 'export' file format is selected by default considering the images' quality and size. In order to export the data file, select click the 'Export' option in the File menu or clicking the 'Export' icon  and find the directory you want to export the data file. Then, save this file as a new file name. Figure 2-1-6 shows the procedure to export your data file in the 'Export' dialog.

(a)



(b)



(c)

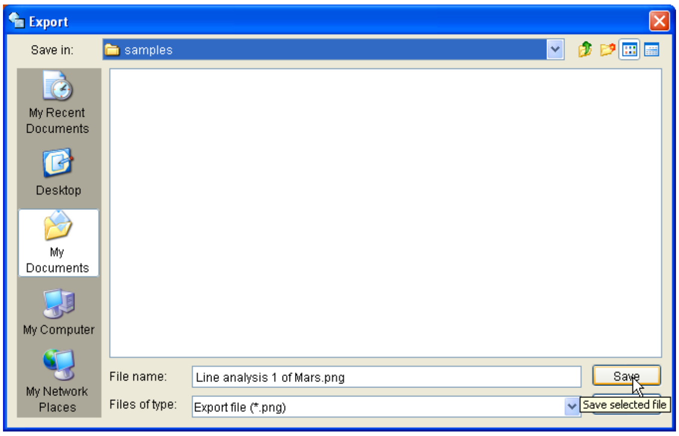


Figure 2-1-6. Export dialog

2-1-6. Print

Allows you to print the selected view. Before printing, you can preview the newly processed image or analysis data in the preview screen. This preview can be printed by selecting the ‘File>Print’ or clicking the print icon .

2-1-7. Preferences

Through the ‘preferences’ menu, you can change several settings in accordance with your preferences.

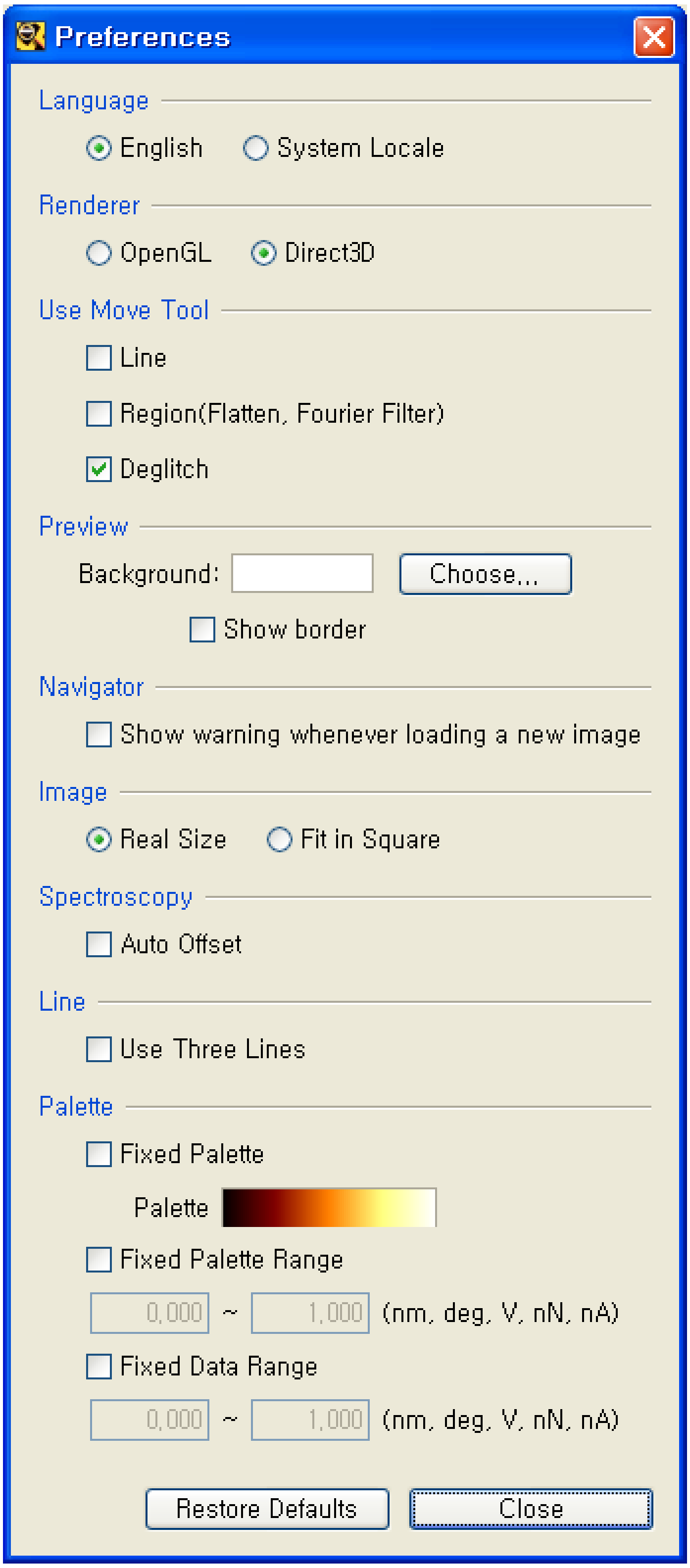


Figure 2-1-7. Preferences Dialog

The settings that can be changed from the 'Preferences' window are

- Language for the XEI software. English or language of your computer system OS (Currently Korean and Japanese are supported)
- The type of 3D Renderer(OpenGL, Direct3D) suitable for your system.
- The type of Move Tool you wish to use
- Background color and border settings of the image data files that are created when the analysis view is exported
- Notify the user when a new image is being loaded for analysis
- Preserve the original image's dimensions, or fit them into a square
- Add a constant value to Spectroscopy data for normalization
- Use multiple (up to 3) lines for analysis in Line View(As default, it is not unchecked and you can use two lines).
- Change original condition of palette(color of palette, palette range, palette data range).

2-1-8. Exit

You can close the XEI program by selecting the 'File>Exit' menu. Then, the 'Exit' confirmation message box appears as seen in Figure 2-1-8.

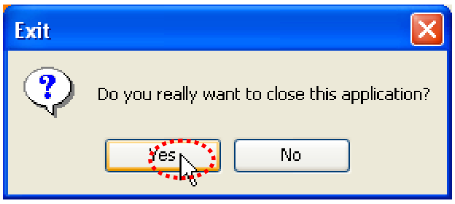
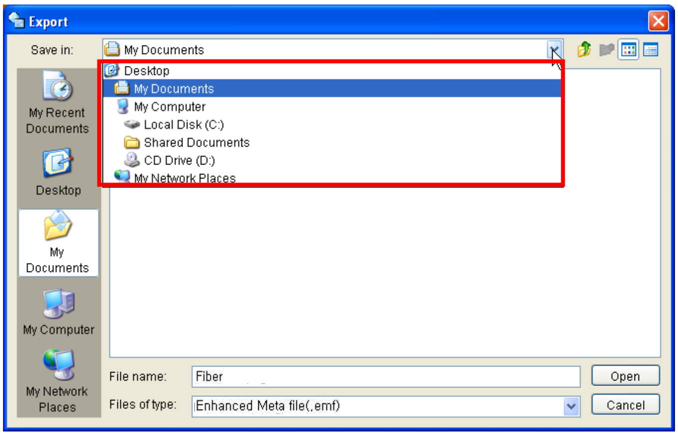


Figure 2-1-8. 'Exit' confirmation message box

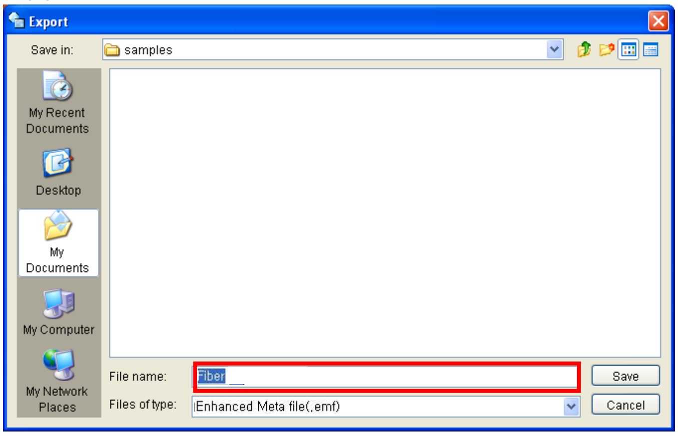
2-1-9. Batch Export 

Batch Export icon will allow users to export the screen or displaying image, as an "Enhanced Meta" file or ".emf" file (one of the vector file formats). Vector file format contains each shape's geometric information, and displays the best resolution of screen image, whereas previous versions of XEI, the saving file resolution depended on size of screen display. Hence, when saving the screen display files as an "*.emf" file, the resolution quality will maintain its visual quality. This image file separates information for line, shape, and color's graphic components. In order to export the screen display image as an ".emf" file, select the 'Batch Export' option in the File menu or click the 'Batch Export' icon  and locate the directory where data will be saved. Then save the file with a new file name. Figure 2-1-9 shows the procedure to export data file in the 'Batch Export' dialog.

(a)



(b)



(c)

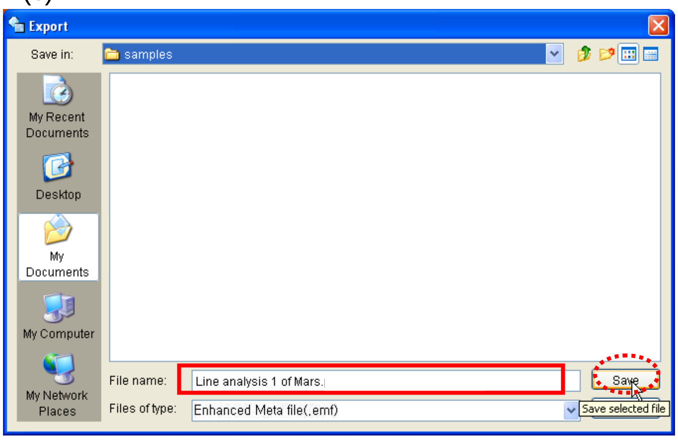


Figure 2-1-9. Batch Export dialog

2-2. Edit

Has common function necessary to edit the image for processing and analysis. Figure 2-2-1 shows several Edit menu items.

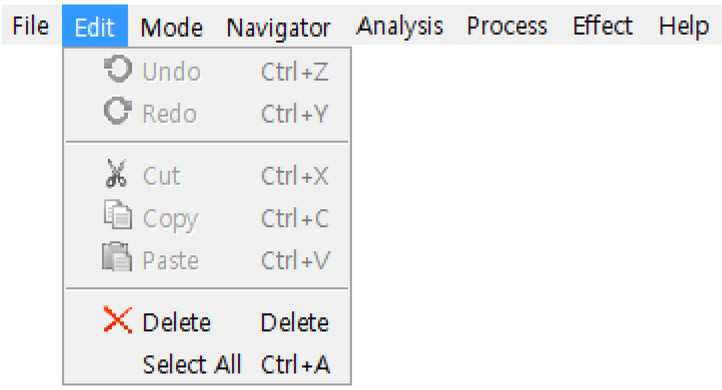


Figure 2-2-1. Edit menu

2-2-1. Undo

Undoes the previous command.

2-2-2. Redo

Redoes the previous command.

2-2-3. Cut

Cuts the selected line or region related to analysis of the image.

2-2-4. Copy

Copies the selected line or region in the image.

2-2-5. Paste

Allows you to paste the cut or copied ‘line or region’ to the location of your choice

2-2-6. Delete

Deletes the selected line or region of the image in the Analysis view.

2-2-7. Select All

Selects all lines or regions in the image.

2-3. Mode

Used for switching between Image and Spectroscopy modes.

2-3-1. Image

This item enters Image Mode. Except for Chapter 18, Spectroscopy Mode, this manual assumes that XEI is being used in Image mode.

2-3-2. Spectroscopy

This item enters Spectroscopy Mode. Used for analysis of F/D and I/V spectroscopy curves, Spectroscopy Mode is explained in further detail in Chapter 18, Spectroscopy Mode.

2-4 Navigator

2-4-1. Show Navigator

User can choose to show or hide the Navigator View through this command.

2-5. Analysis

The Analysis menu provides you direct access to carry out quantitative analysis of the selected line, region, grain and PSD of an image and to view the 3D rendered image. As shown in Figure 2-5-1, the Analysis menu has seven items: Information, Line, Region, Grain, PSD, Surface, Fractal, 3D, and Multi. You can start any one of these analysis by selecting the option in the Analysis menu or by clicking the corresponding tab below the Toolbar.

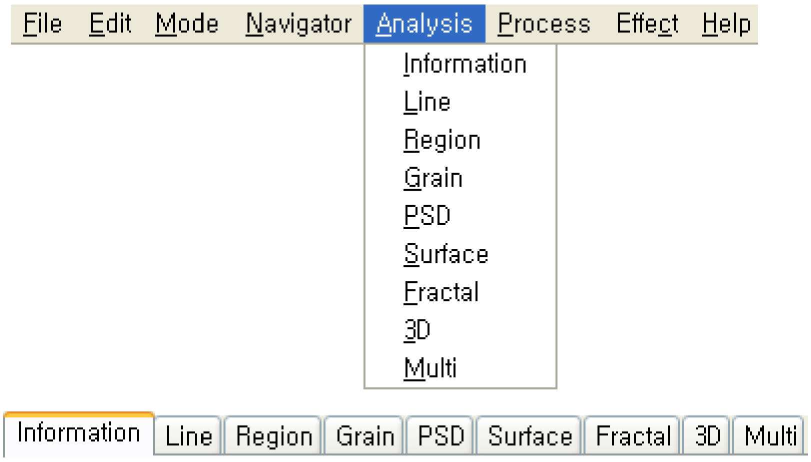


Figure 2-5-1. Analysis menu and tabs

2-5-1. Information

In the Information view, you can display the 2D image with basic information of the image that you selected from the Navigator view or loaded by using the 'Open' dialog. The Information view shows the original image and much of the scan information associated with the image data. Figure 2-5-2 shows the Information view of the selected image. The Information view is described further in Chapter 3. "Information View".

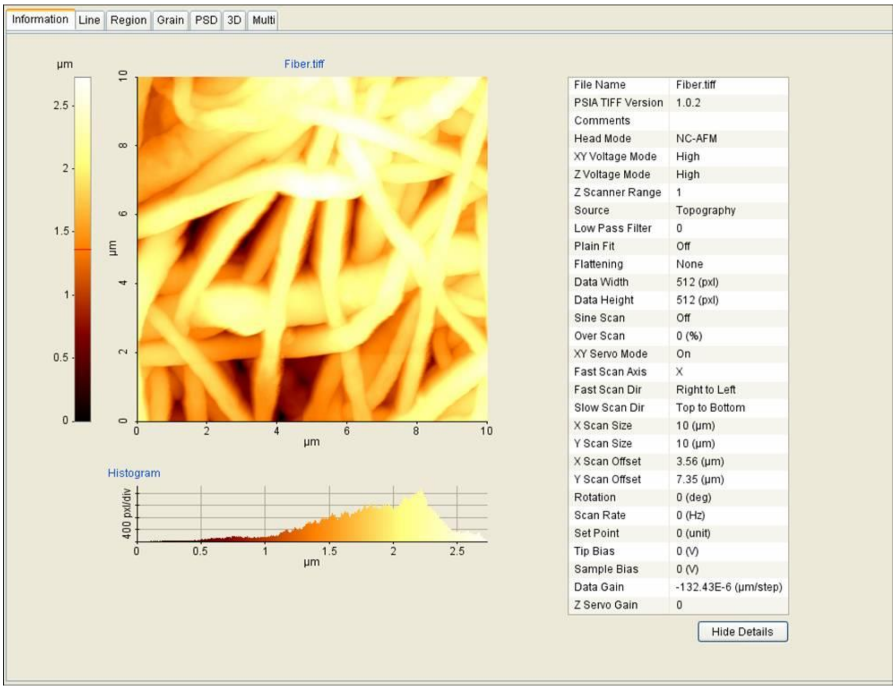


Figure 2-5-2. Information view

2-5-2. Line

In the Line view, you can get information about the cross section or height profile of the surface in the selected image. You can see a Line Profile, a Power Spectrum, and a Line Histogram of a selected line, all at one time. Also, the surface statistics table of the selected line is displayed. Figure 2-5-3 shows the Line view of the analyzed image. A more detailed description of the Line view is offered in Chapter 4. “Line View”.

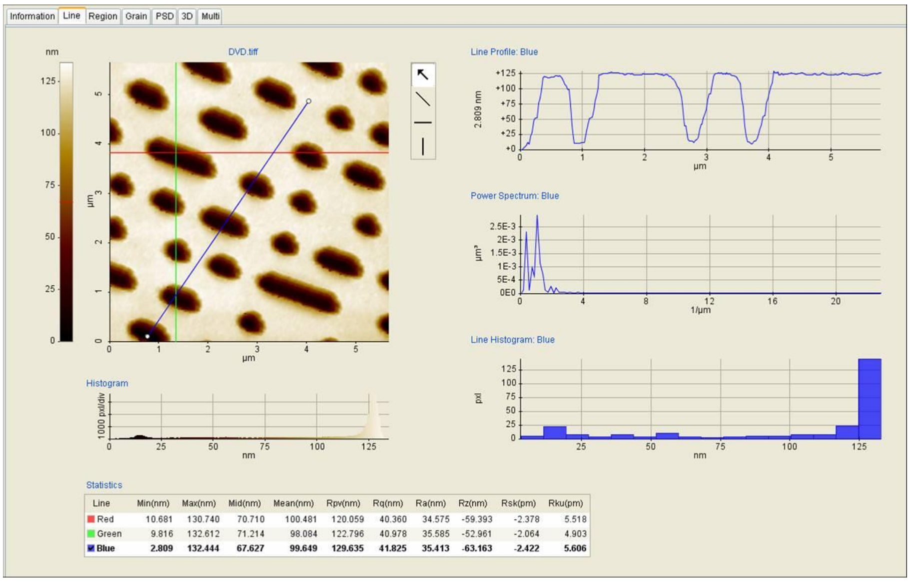


Figure 2-5-3. Line view

2-5-3. Region

In the Region view, you can get information about a region of the sample surface in the selected image. You can see a Region Histogram of the selected region as well as a surface Statistics table such as the maximum and minimum height value, mean height and RMS roughness. Figure 2-5-4 shows the Region view of an analyzed image. A more detailed description of the Region view is offered in Chapter 5. "Region View".

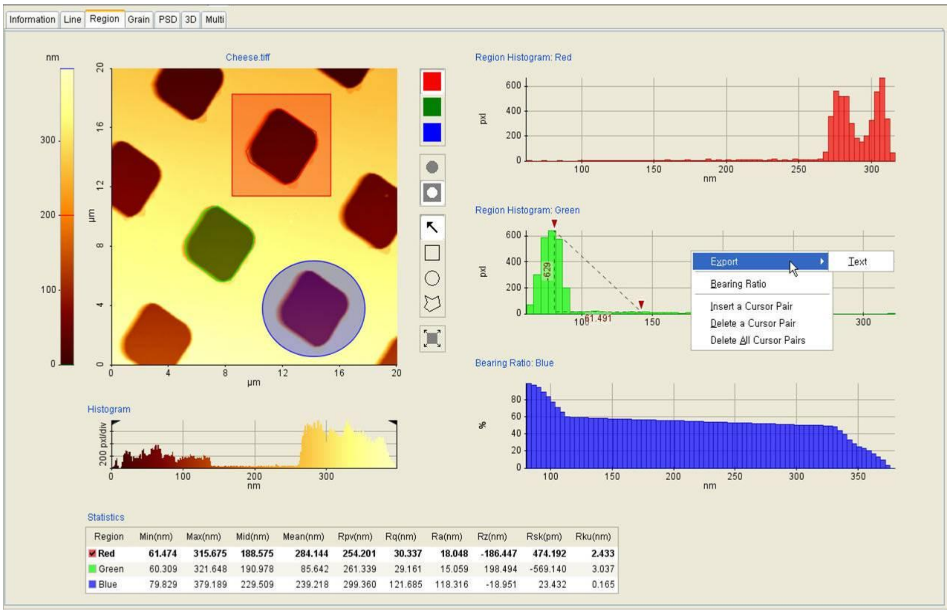


Figure 2-5-4. Region view

2-5-4. Grain

In the Grain view, user can perform grain analysis on the loaded image. System automatically detects grains in the image, calculates important surface profile parameters of each detected grain, and displays the distribution of surface parameters among detected grains   Figure 2-5-5 shows the Grain view of an analyzed image. A more detailed description of the Region view is offered in Chapter 6. “Grain view”.

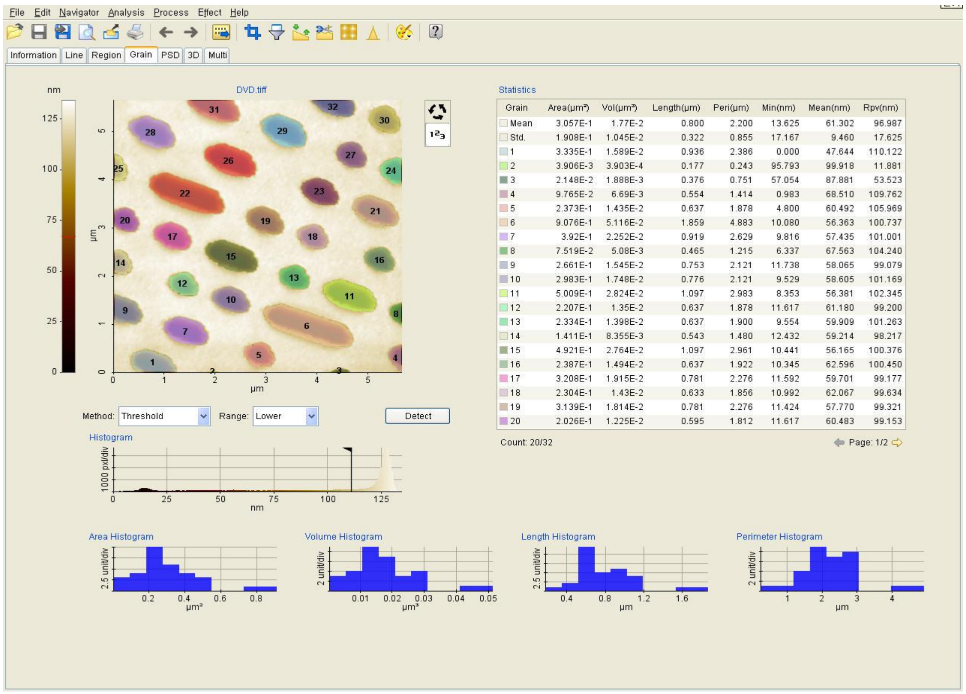


Figure 2-5-5. Grain view

2-5-5 PSD

In the PSD view, user can analyze roughness of the sample surface through PSD graph of the loaded image and obtain relevant data. Figure 2-5-6 shows the PSD view of an analyzed image. A more detailed description of the Region view is offered in Chapter 7. “PSD View”.

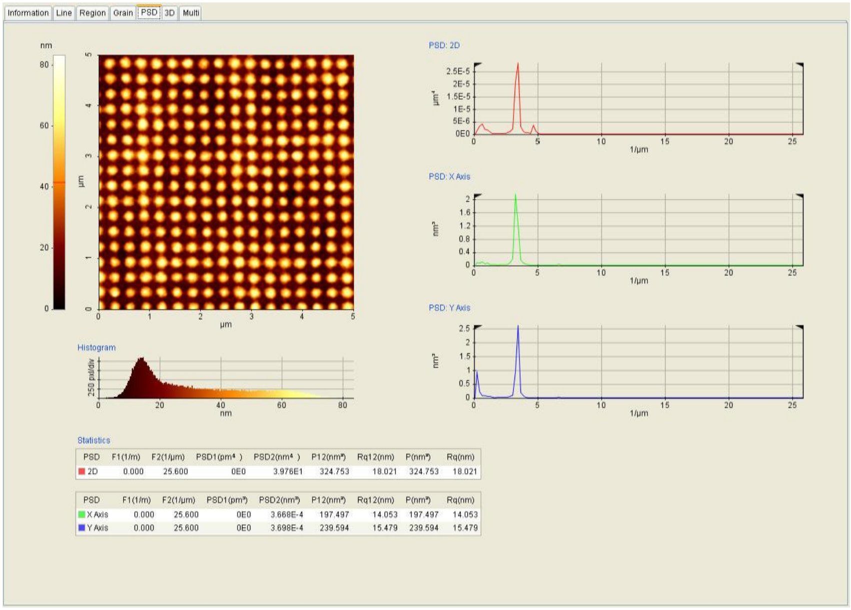


Figure 2-5-6. PSD view

2-5-6. Fractal

In the Fractal view, user can analyze fractal dimension of the sample surface through fractal graph of the loaded image. Figure 2-5-7 shows the Fractal view of an analyzed image. A more detailed description of the Fractal view is offered in Chapter 8.

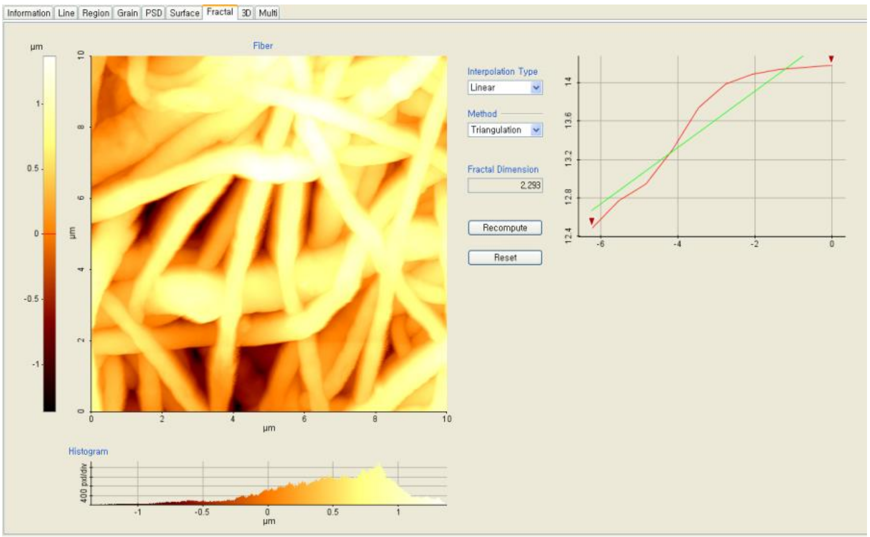


Figure 2-5-7. Fractal view

2-5-7. Surface

In the Surface view, user can analyze surface area of the sample image in the selected image. You can collect surface statistics such as geometric area, surface area and surface area ratio. Figure 2-5-8 shows the Surface view of an analyzed image. A more detailed description of the Surface view is offered in Chapter 23.

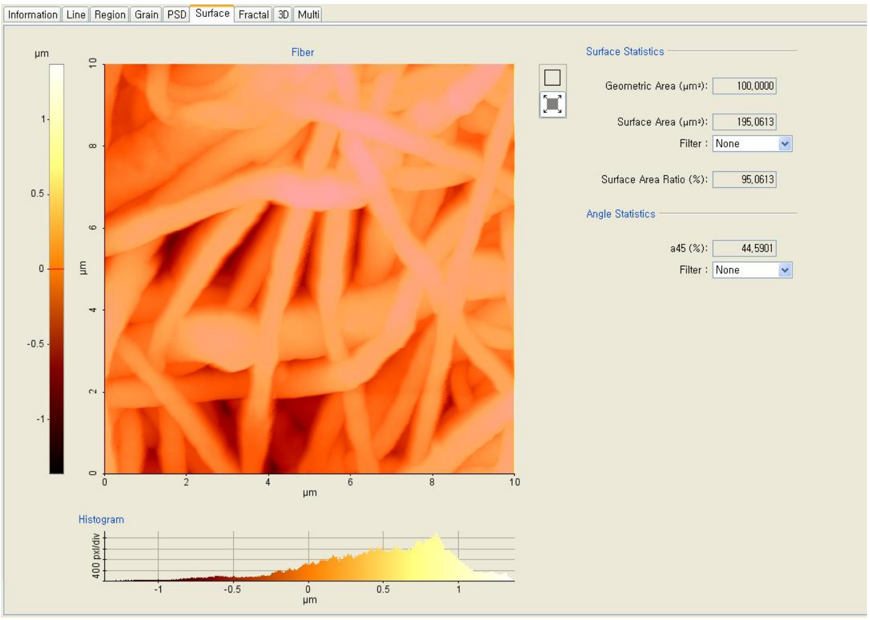


Figure 2-5-8. Surface view

2-5-8. 3D

In 3D view, you can view and generate 3D rendered images using many display parameters. The 3D view helps you to see the features of the image and the relationships between those features more clearly. Figure 2-5-9 shows the 3D view of a 3D rendered image. The 3D view is discussed more in Chapter 9.

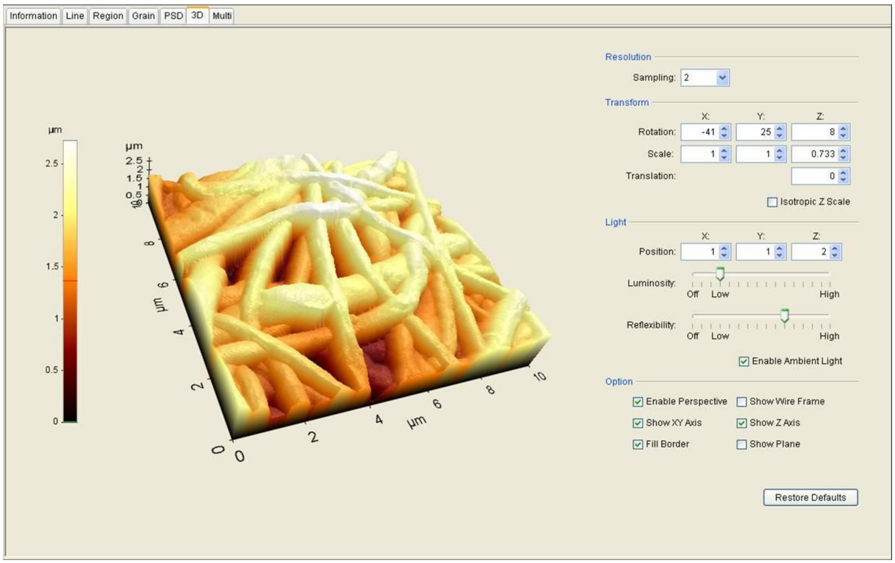


Figure 2-5-9. 3D view

2-5-9. Multi

In Multi view, you can display and print out several images, up to 6 at a time, with their file name and the palette panel for the contrast and adjustment of the images. You can load multiple images into the empty display panel. Figure 2-5-8 shows the Multi view of the selected images from the Navigator view. A further detailed description is provided in Chapter 10. "Multi View".

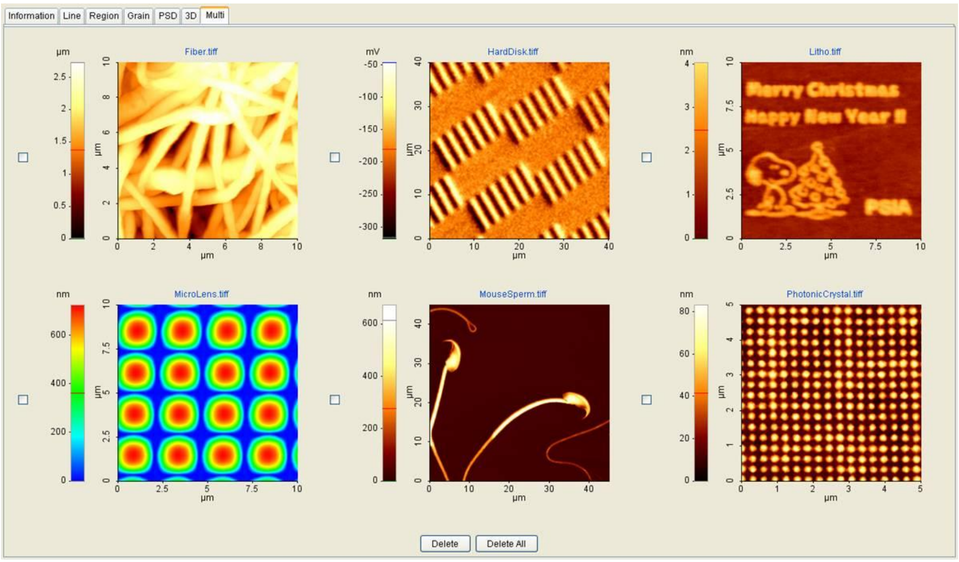


Figure 2-5-10. Multi view

2-6. Process

The Process menu offers you eleven image processing tools: Crop, Filter, Flatten, Deglitch, Region Deglitch, Fourier Filter, Tip Estimation, Rotate & Flip, Pixel Manipulation, Unary Arithmetic, Binary Arithmetic and Stitch as shown in Figure 2-6-1. Commonly, this Process menu provides several controls for improving image resolution or removing artifacts such as high or low frequency noise, curvature, tip effect and glitches from an image without modifying the actual surface features. Several process dialogs are implemented. You can use one of them from the Process menu or click the icon from the toolbar. .

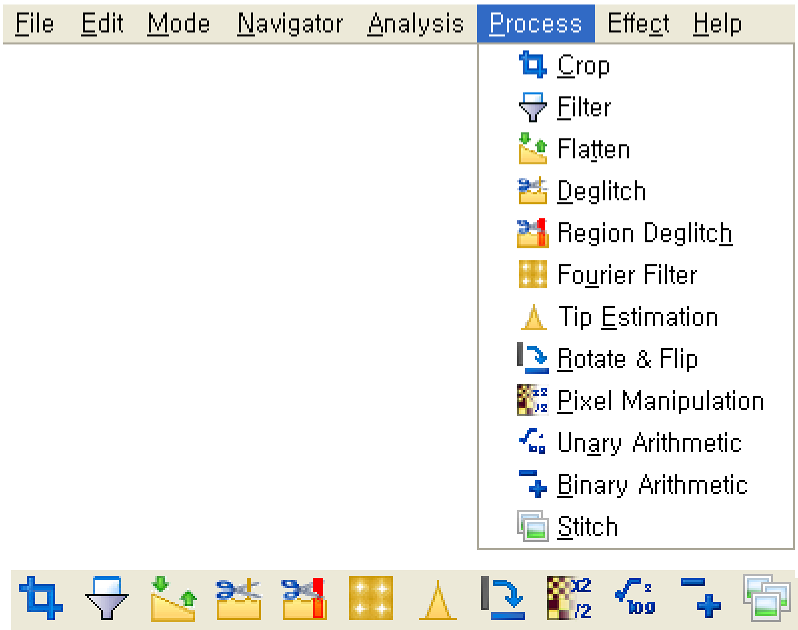


Figure 2-6-1. Process menu and Toolbar

2-6-1. Crop 

In the Crop process dialog, you can crop a part of an image which is a region of interest. Figure 2-6-2 shows the Crop process dialog. The Crop menu is described more in Chapter 11. "Crop".

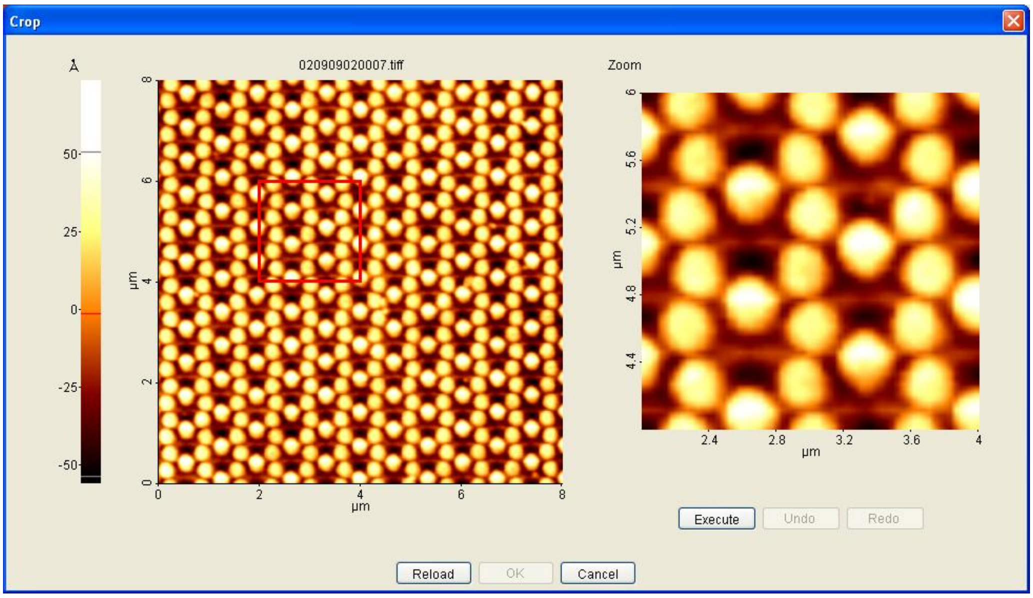


Figure 2-6-2. Crop process dialog

2-6-2. Filter

Using the Filter process dialog, you can remove some artifacts from the sample surface that are not real data. Figure 2-6-3 shows the Filter process dialog. A further detailed description is offered in Chapter 12. "Arithmetic Filter".

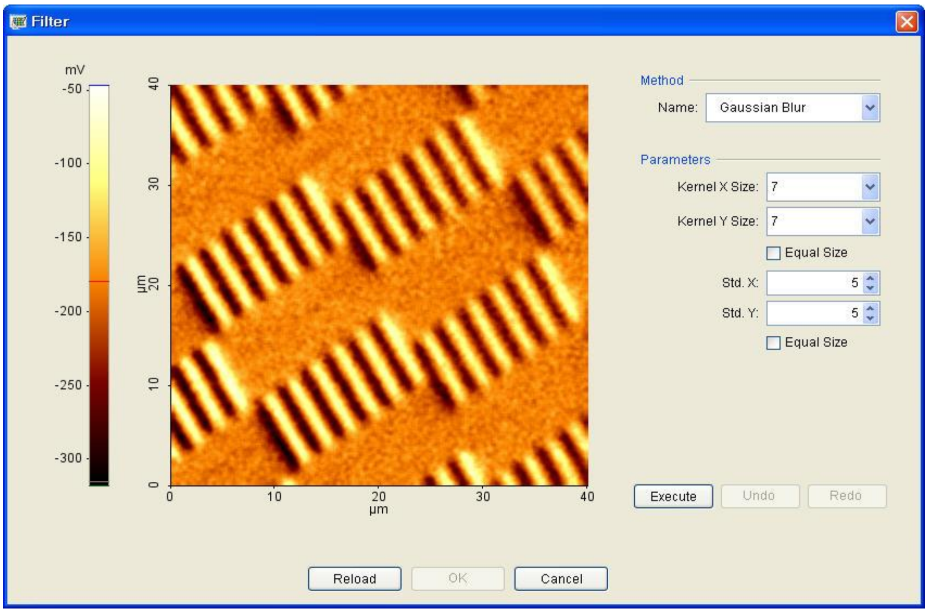


Figure 2-6-3. Filter process dialog

2-6-3. Flatten

In the Flatten process dialog, you can remove curvatures and slopes from your image data. For more information about the Flatten processing feature, you can refer to Chapter 13. “Flatten” in this document. Figure 2-6-4 shows the Flatten process dialog.

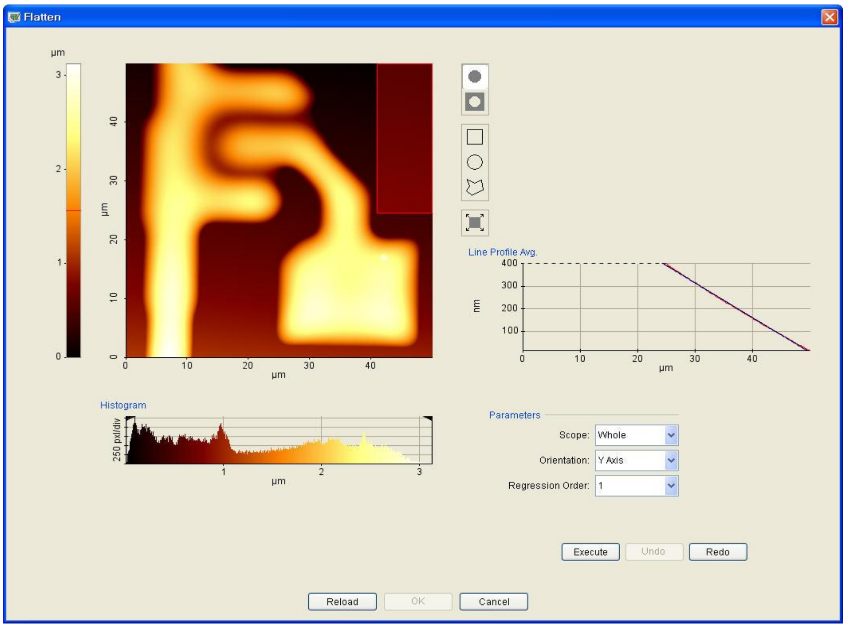


Figure 2-6-4. Flatten process dialog

2-6-4. Deglitch

In the Deglitch process dialog, you can remove small glitches or vertical and horizontal streaks in an image. Figure 2-6-5 shows the Deglitch process dialog. Deglitch is described further in Chapter 14. “Deglitch”.

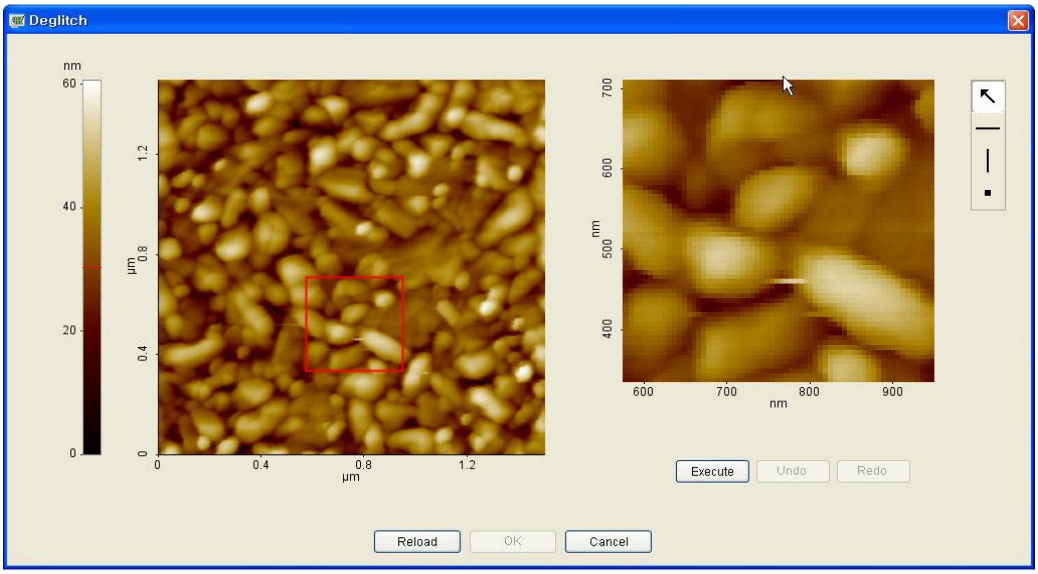


Figure 2-6-5. Deglitch process dialog

2-6-5. Fourier Filter

In the Fourier Filter process dialog, you can use the Fourier Filter to remove unwanted frequency components from your data. About the Fourier Filter, consult Chapter 16. "Fourier Filter". Figure 2-6-6 shown below is the Fourier Filter process dialog.

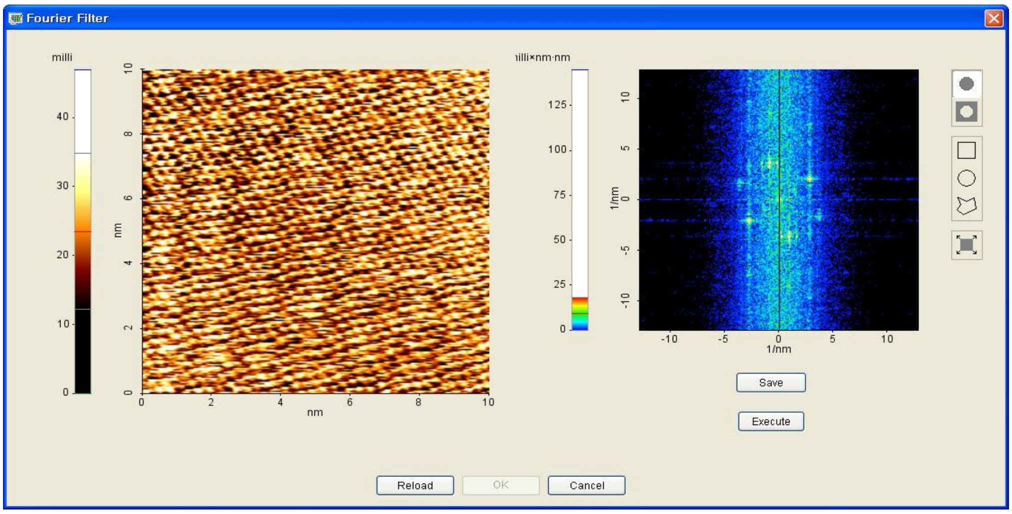


Figure 2-6-6. Fourier Filter process dialog

2-6-6. Tip Estimation

In the Tip Estimation process dialog, you can estimate the shape of the tip used to obtain the image and remove the artifacts generated by tip shape (known as 'Tip Convolution') from the loaded image to obtain more accurate image. Consult Chapter 17 for more information on Tip Estimation. Figure 2-6-7 shows the Tip Estimation process dialog.

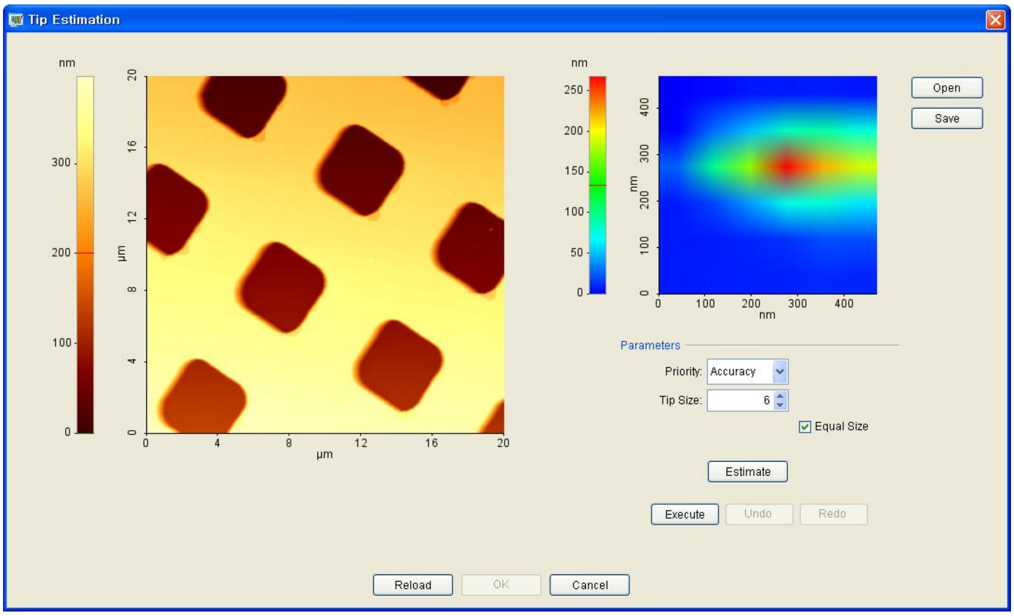


Figure 2-6-7. Fourier Filter process dialog

2-6-7. Region Deglitch

In the Region Deglitch process dialog, you can remove small artifact in an image that does not represent the true surface topography to obtain more accurate image. Consult Chapter 15 for more information on Region Deglitch. Figure 2-6-8 shows the Region Deglitch process dialog.

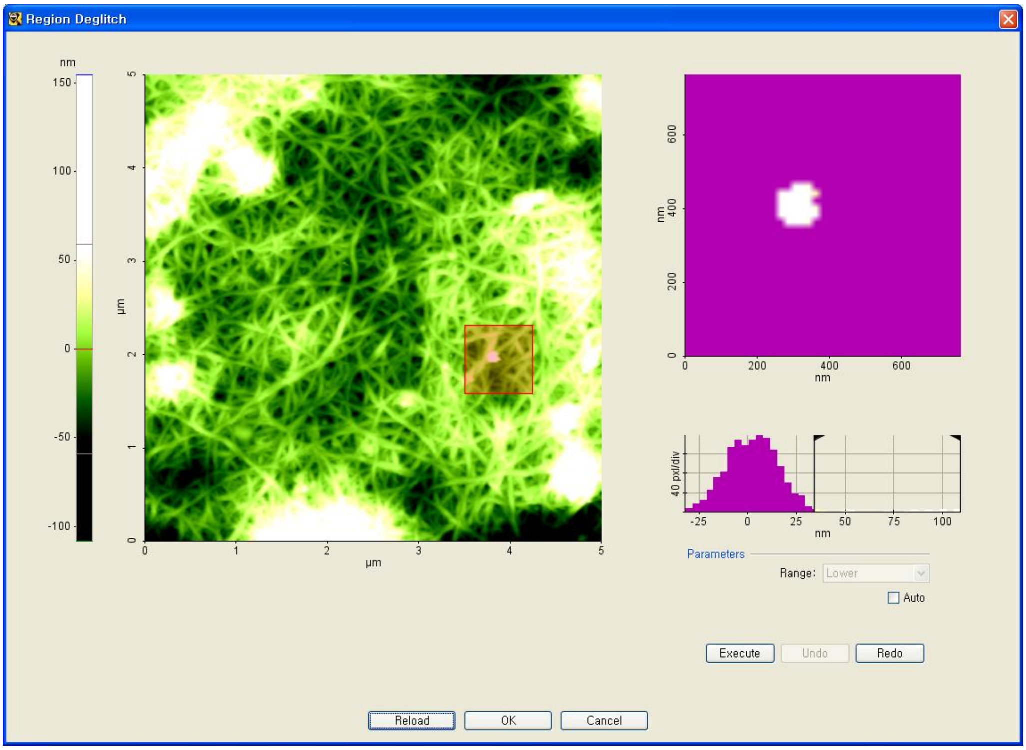


Figure 2-6-8. Fourier Filter process dialog

2-6-8. Rotate & Flip 

In the Rotate & Flip process dialog, you can change the orientation of the obtained image. It may be helpful comparison of images taken at different orientations. Consult Chapter 18 for more information on Rotate & Flip. Figure 2-6-9 shows the Rotate & Flip process dialog.

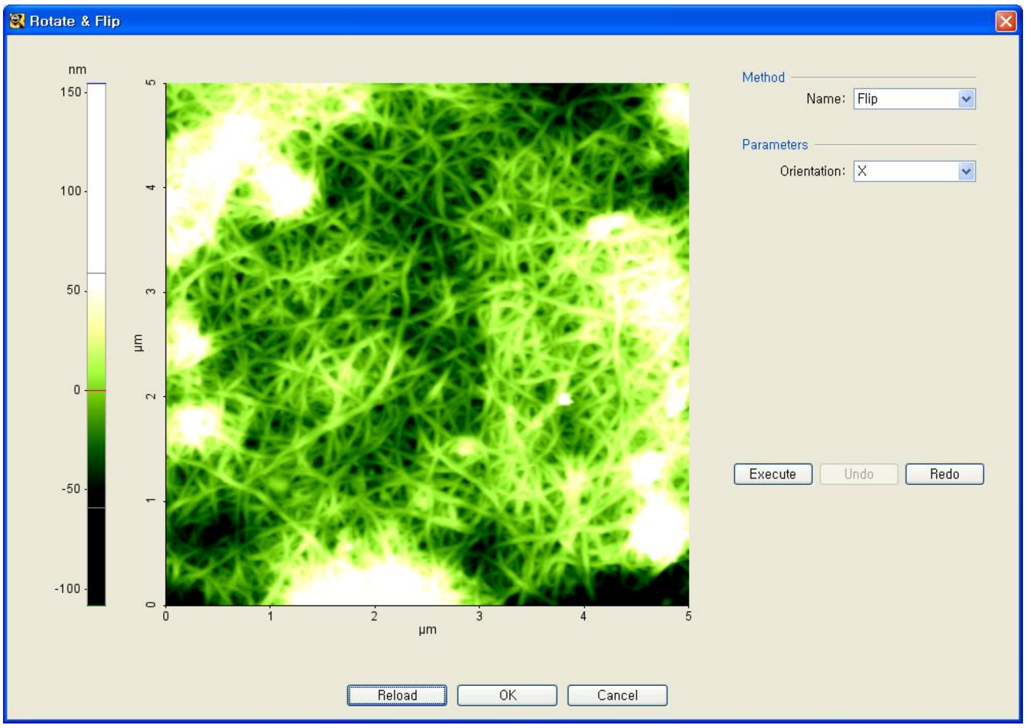


Figure 2-6-9. Rotate & Flip process dialog

2-6-9. Pixel Manipulation 

In the Pixel Manipulation process dialog, you can increase or decrease the number of pixels in the obtained image. This is useful when comparing images of differing resolutions. Consult Chapter 19 for more information on Rotate & Flip. Figure 2-6-10 shows the Pixel Manipulation process dialog.

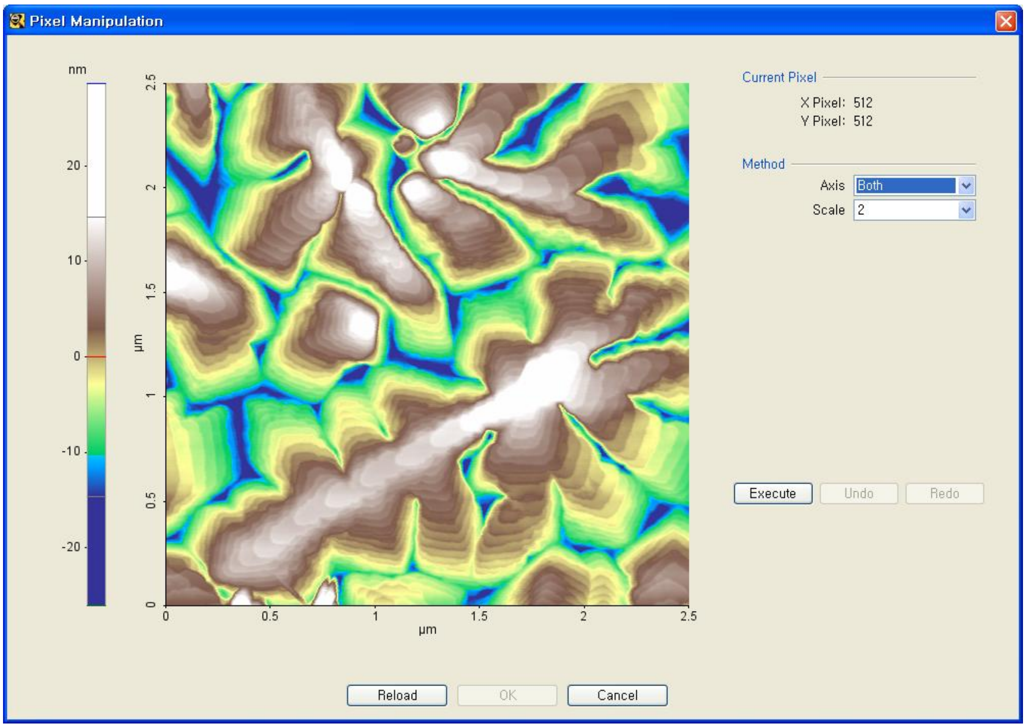


Figure 2-6-10. Pixel Manipulation process dialog

2-6-10. Unary Arithmetic 

In the Unary Arithmetic process dialog, you can perform arithmetic operation on image such as invert, square and square root. Consult Chapter 20 for more information on Unary Arithmetic. Figure 2-6-11 shows the Unary Arithmetic process dialog.

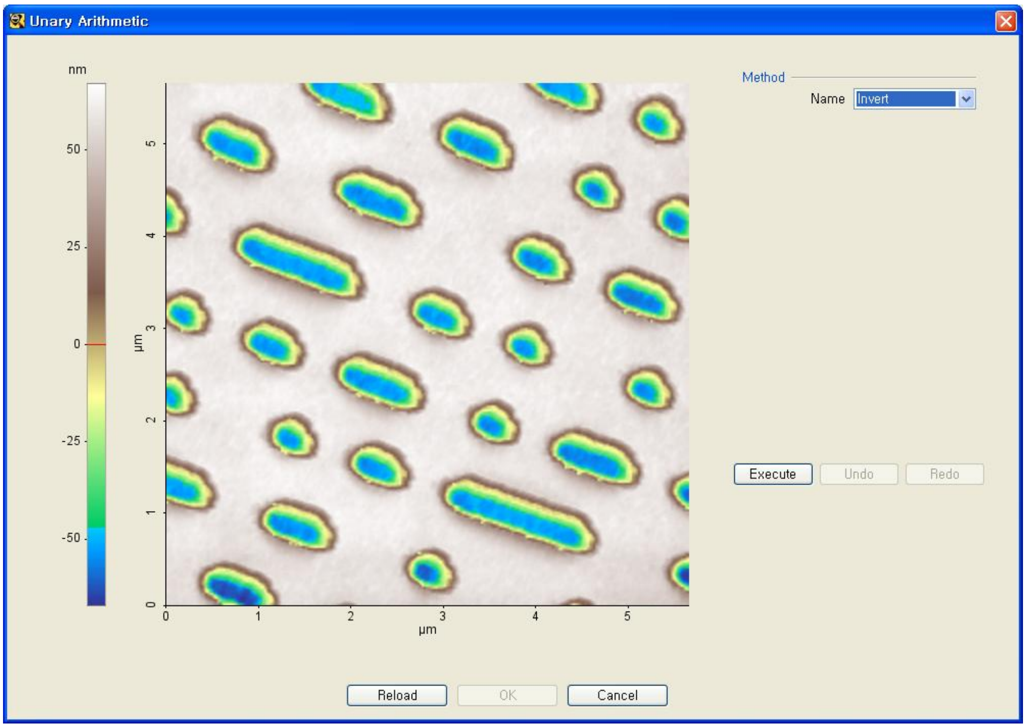


Figure 2-6-11. Unary Arithmetic process dialog

2-6-11. Binary Arithmetic 

In the Binary Arithmetic process dialog, you can perform arithmetic operation on two images such as +/-. It may be useful for the direct comparison of two images. Consult Chapter 21 for more information on Binary Arithmetic. Figure 2-6-12 shows the Binary Arithmetic process dialog.

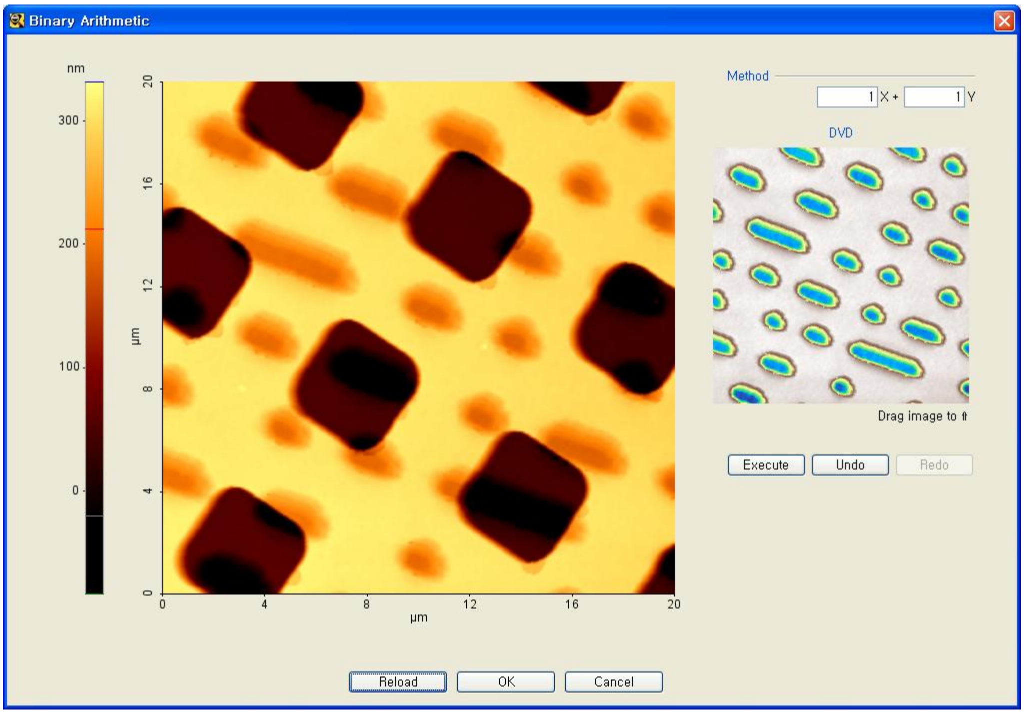


Figure 2-6-12. Binary Arithmetic process dialog

2-6-12. Stitch

In the Stitch process dialog, you can stitch several images together and make an image. It may be useful that you want to get a bigger sized image than the obtain image. Consult Chapter 24 for more information on Stitch. Figure 2-6-13 shows the Stitch process dialog.

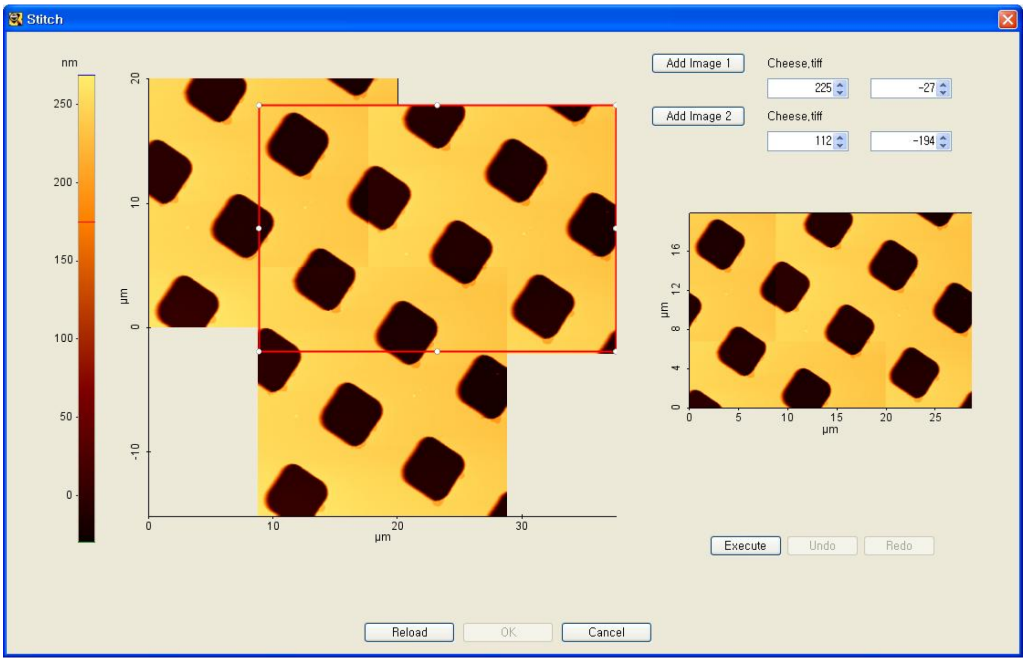


Figure 2-6-13. Stitch process dialog

2-7. Effect

2-7-1. Palette

You can select the palette that is to be used for the contrast adjustment in the 'Effect>Palette' menu or by clicking the 'Palette' icon .

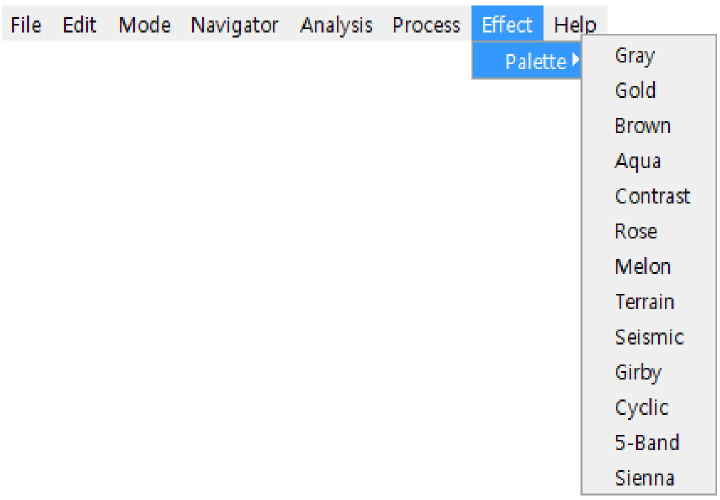


Figure 2-7-1. Effect menu

2-8. Help

2-8-1. About

This item opens a dialog with information(Version and build data) on this program.

Figure 2-8-1. About dialog

Chapter 3. Information View

In the Information view, the loaded image and its essential information, such as the scan conditions and parameters that were used in acquiring data, are displayed on the XEI screen. You can preview the original image and data through the Information view before performing an image processing or analysis.

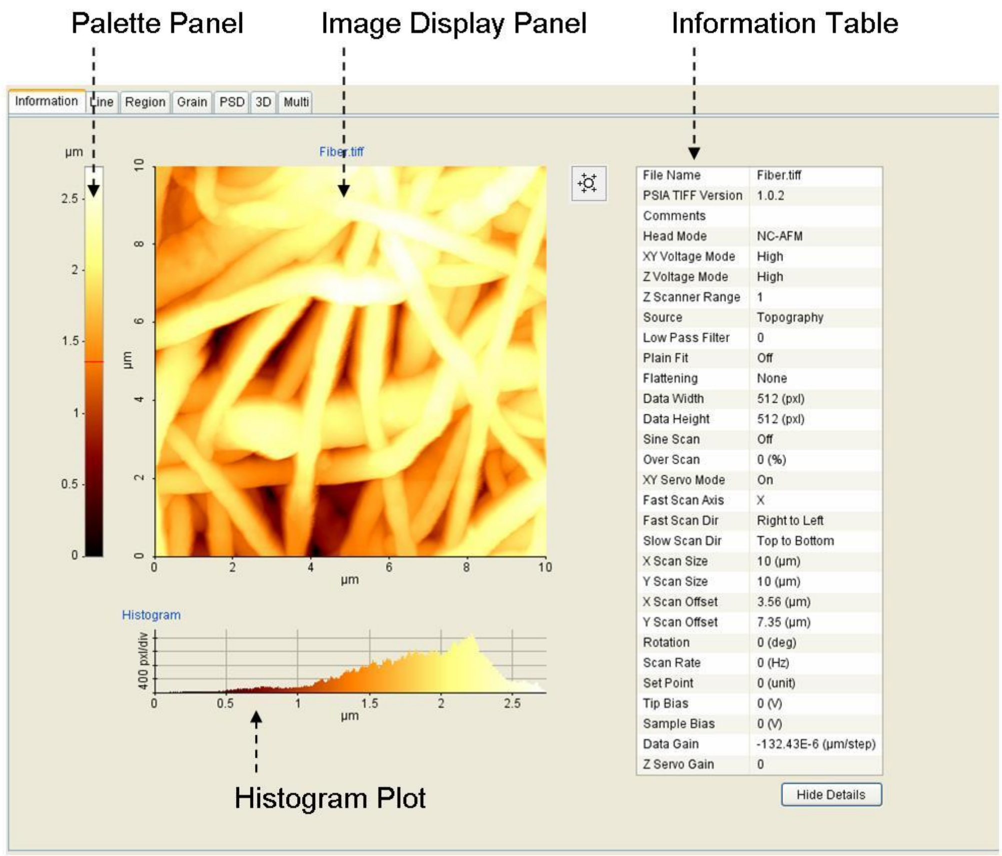


Figure 3-1-1. Information view

3-1. Information View

The Information view is automatically enabled when you execute the XEI program, but you can switch to the Information view from other views by selecting 'Analysis>Information' in the Menu or by clicking the Information view tab below the menu bar. Figure 3-1-1 shows the layout of the Information view.

3-2. Palette Panel

The Palette Panel is used to adjust the contrast level range of an image. The Palette panel displays the range of the image data values of the measured signal. Also, the Palette panel shows the relationship between the color of the pixel in the image and corresponding data values of the measured signal. Different colors or shades in the Palette panel represent different height values of the data in the image. The default palette is based on gold color palette scale in which darker colors indicate lower heights and the brighter colors indicate higher height values. As shown in the Figure 3-2-1, there are 3 cursors in the scale bar that indicates the level and range of the scale bar and can be adjusted.

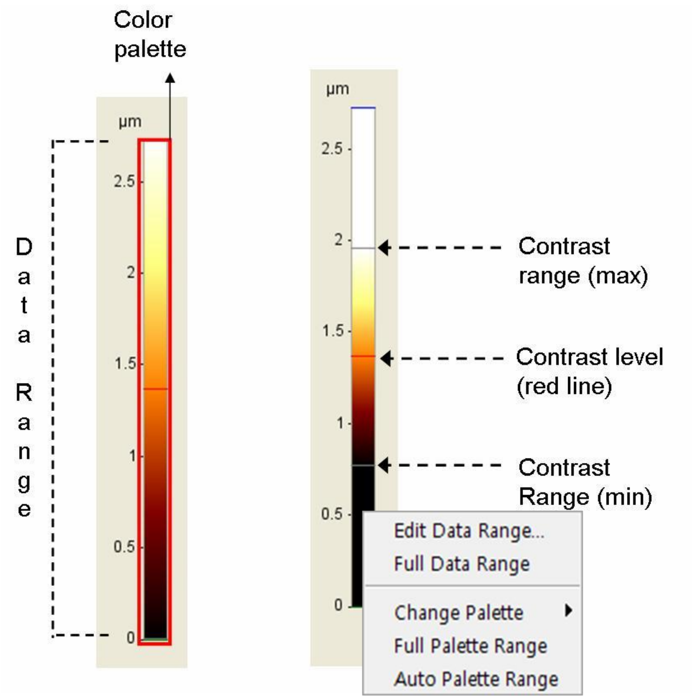


Figure 3-2-1. Palette Panel

3-2-1. Data Range Adjustment

On the left side of the Palette panel, the vertical data scale indicates the height range of the image. By default, maximum (minimum) value of the data range corresponds to the maximum (minimum) data of the pixel data. This data range can be edited manually by 'Edit Data Range' command in the context menu of the palette panel.

■ Full data range

Full data range command automatically sets maximum (minimum) value of the data range to the maximum value of the pixel data.

3-2-2. Contrast Range Adjustment

There are two cursors in the palette panel that helps users to change the contrast range. They are Contrast Max and Min cursors. The contrast range is set by adjusting the vertical length of the color palette by dragging these two cursors. Also contrast range can be adjusted by 'Full Palette range' command in the context menu of the palette panel.

■ Contrast Max cursor

'Contrast max' cursor indicates the data value on the data scale that corresponds to the brightest color of the current color palette (generally white). Any pixels with the data value that exceeds the value indicated by 'Contrast range max' will be displayed in brightest color of the color palette (generally white) regardless of their value.

■ Contrast Min cursor

'Contrast min' cursor indicates the data value on the data scale that corresponds to the darkest color of the current color palette (generally black). Any pixels with the data value that is under the value indicated by 'Contrast range min' will be displayed in darkest color of the color palette (generally black) regardless of their value.

■ Full Palette Range

Full palette range command automatically brings ‘Contrast Max’ cursor to the maximum value of the data range and ‘Contrast in’ cursor to the minimum value of the data range. Therefore, Full palette range command adjusts contrast range such that the contrast range matches the full range of the data range. Thus, the scale maximum corresponds to the data maximum and the scale minimum corresponds to the data minimum.

Adjusting contrast range is useful when you are interested in a specific height range in an image. You can narrow the contrast range so that it covers smaller features in an image (Figure 3-2-2). In this way, you can scale up a specific height range in an image to see smaller features in greater detail.

■ Auto palette range

The contrast range can be automatically determined by the XEI program. Double click on the contrast bar to set the contrast range with this feature.

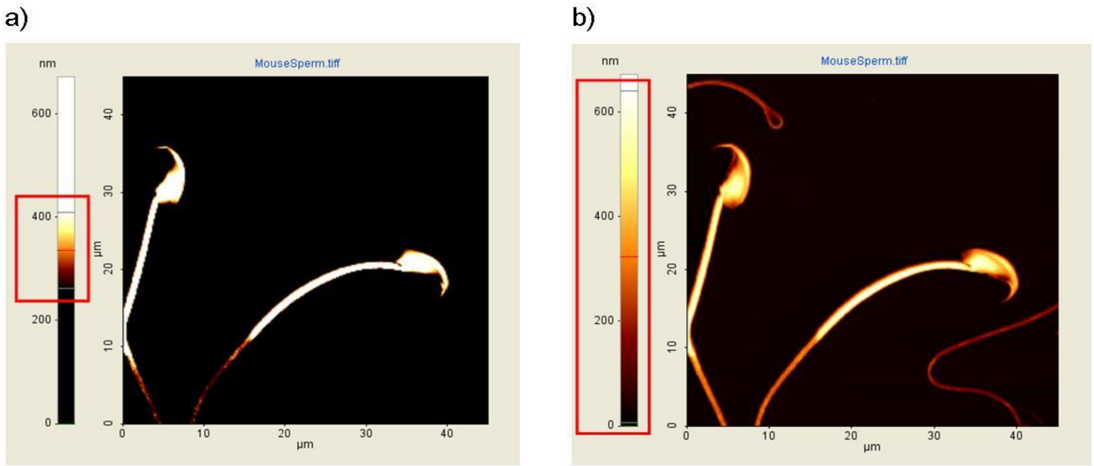


Figure 3-2-2. Contrast range adjustment

3-2-3. Contrast Level Adjustment

‘Contrast level marker’ is a red line on the palette panel. ‘Contrast level marker’ indicates the data value on the data scale that corresponds to the middle of the current color palette. As shown in Figure 3-2-3, the contrast level is adjusted by click and dragging the 'Contrast level marker' on the palette panel.

a) b)

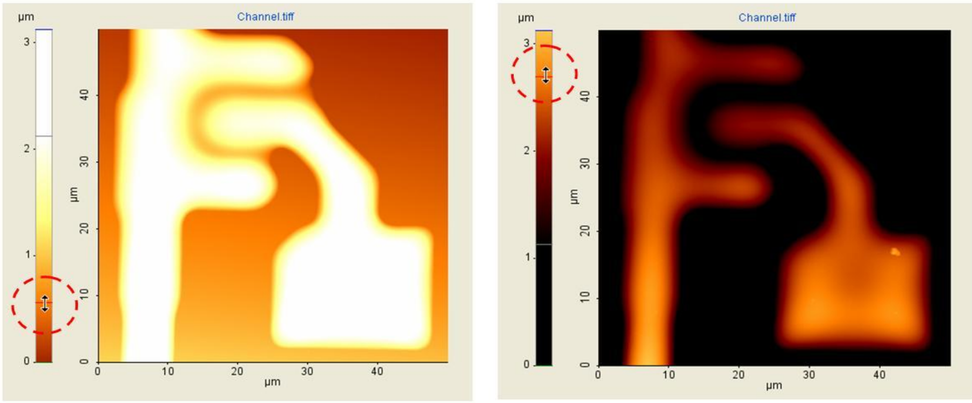
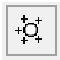


Figure 3-2-3. Contrast level adjustment

3-2-4. Palette Change

You can change the palette for the contrast adjustment by selecting the 'Palette' option in the Effect menu (see Figure 2-6-1).

3-2-5. Enhanced Color 

The Enhanced Color button changes the way colors are displayed. In the Enhanced Color scheme, the color of a pixel is determined by how much of a change it has compared to its neighbors. Therefore, it is not linearly representative of the data. You can toggle Enhanced Color using the  button. Enhanced Color also has its own palette, accessible by right-clicking the Enhanced Color button.

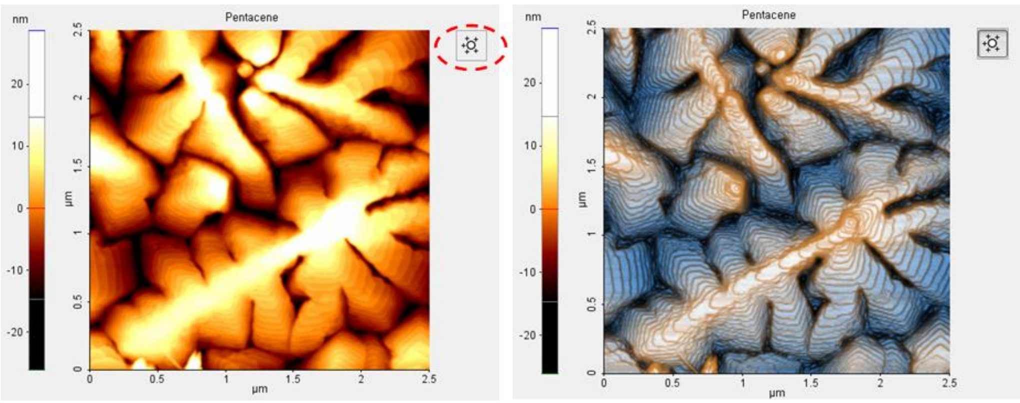


Figure 3-2-4. Enhanced Color

3-2-6. Zoom In/Out 

Loaded images can be zoomed in by clicking the  icon and can be zoomed out by clicking the  icon. Adjusting the mouse wheel can also be used to increase or decrease the zoom percentage. The zoom percentage of the original image size is set to 100%, this is the minimum percentage that the image can be zoomed out to. The zoom percentage is displayed at the upper right corner of image display panel. The image resulting from the zoom in or out will be displayed within scan image display. Due to the size of the display, some of the image area will not be visible. The panning tool can be used to change the available visible area by adjusting the image offset.

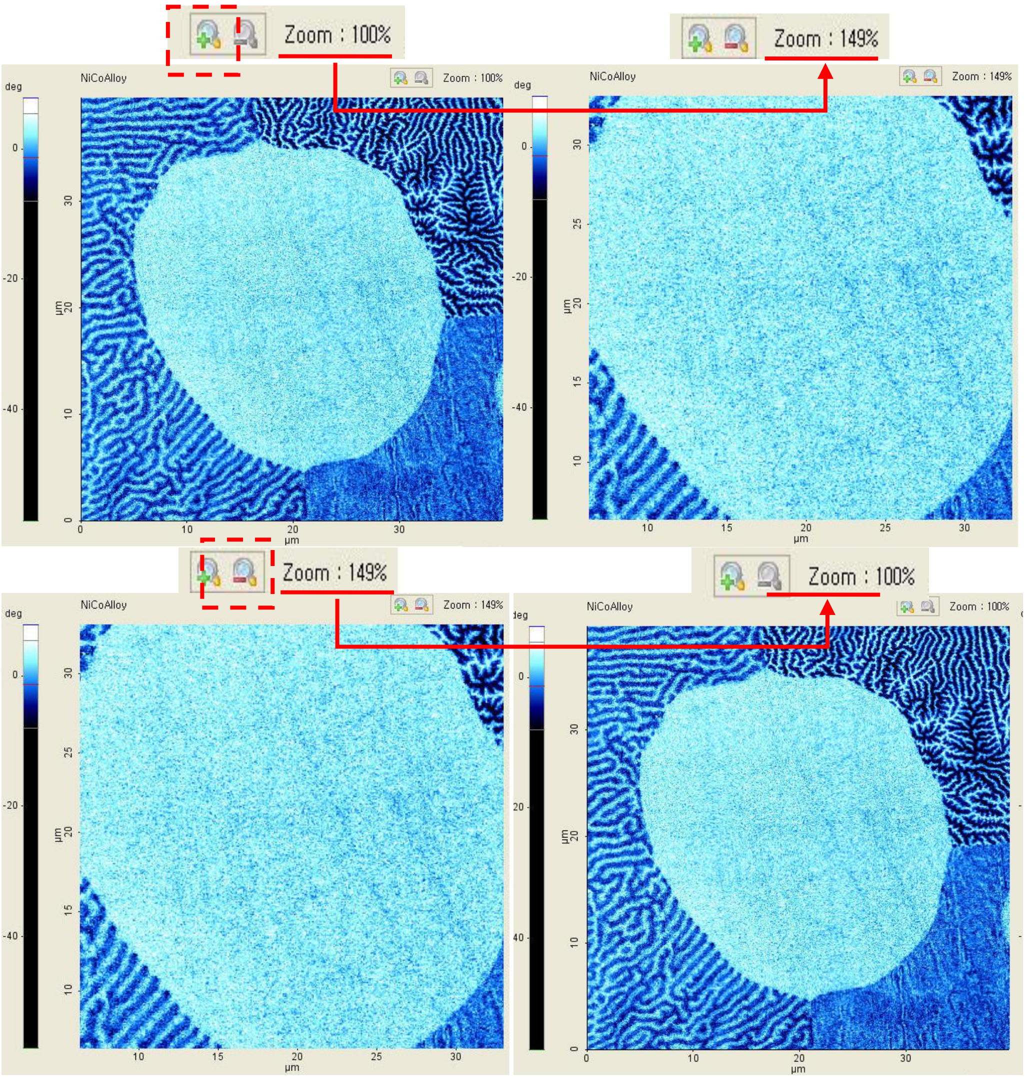


Figure 3-2-5. (Upper) Zoom In, (Down) Zoom Out

To bring up the panning tool, click the wheel button after putting the cursor on the image, and the  icon will be appear. At this time, drag a location on the image to a different position.

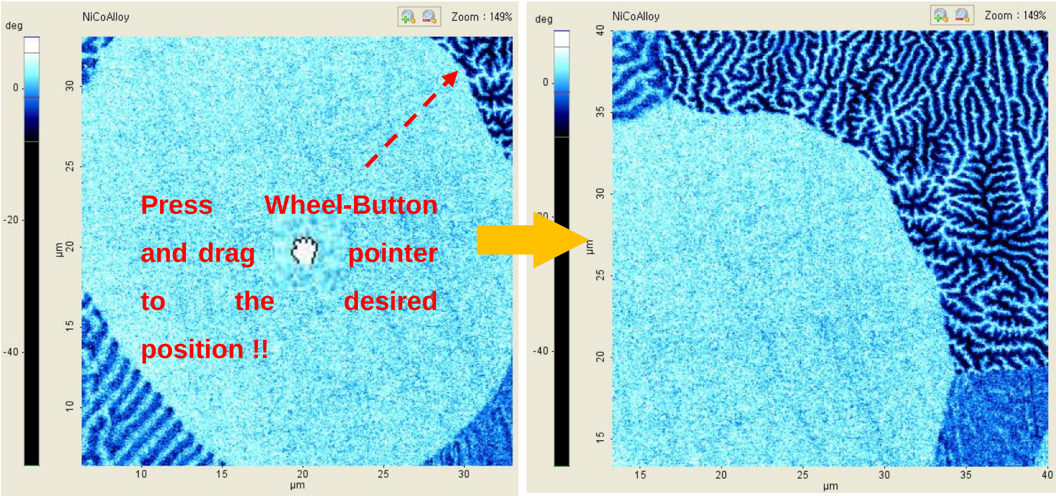


Figure 3-2-6. Pan

3-3. Image Display Panel

As shown in Figure 3-3-1, the Image display panel shows the 2D image you selected in the Navigator view.

3-3-1 Loading Image to the Image Display Panel

When you want to change the image in this panel, you can double-click another image in the Navigator view. At this time, you can see the ‘Load’ confirmation message box which asks if you want to initialize the selected image (Figure 3-3-2).

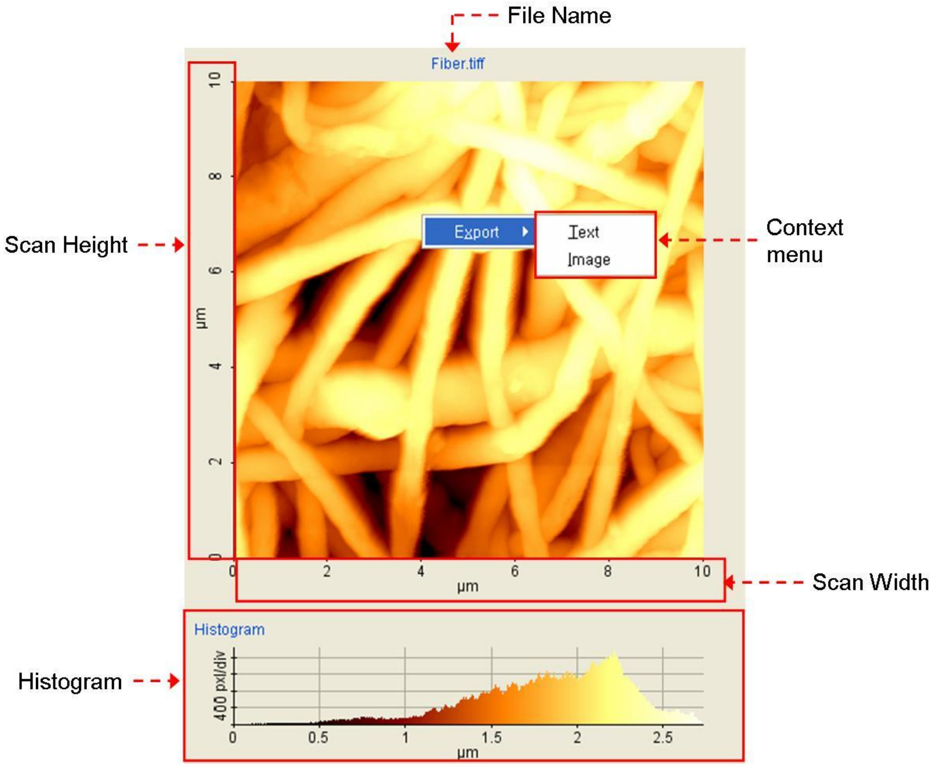


Figure 3-3-1. Image display panel of the Information view

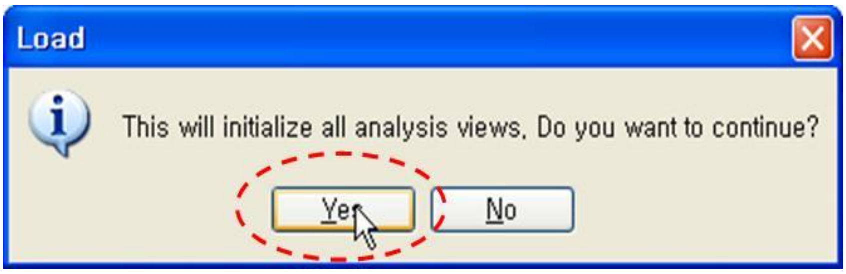


Figure 3-3-2. 'Load' confirmation message box

3-3-2 Export

Tiff files, loaded in XEI, can be exported in the form of a text file or an image file (jpg, png, bmp, and emf) from the 'Export' command in the context menu of the Image display panel. The raw tiff file consists of two parts, the scan data and the image. When the tiff file is exported as a text file, the file will contain basic information about the tiff file and the data array of the scan data. On the other hand, when the tiff file is exported as an image file, the exported image file only includes the image of the tiff file but not the scan data within it; the image will not include any dimensional information.

3-3-3 Copy to Clipboard

This command copies the scan data onto the clipboard as a text file or an image. Text files will contain basic image information and the data array. The command will copy an image file to the clipboard. Right click on the image to open the context menu in the Image display panel. From the 'Copy to Clipboard' command in the context menu, choose text or image, then paste the copied data in the corresponding document file by clicking [Ctrl+V] button.

3-3-4 Histogram

The Histogram shown below (Figure 3-3-3) is a bar graph that shows the distribution of heights along a height profile. When you load an image, a histogram is automatically displayed.

The x axis represents the height of data points in the sample surface and its unit can be Å, nm, µm and so on. The width of a bar depends on the overall height range of the sample and the number of data points of the line profile. The y axis is the number of data points with the same height values and its unit is pixel.

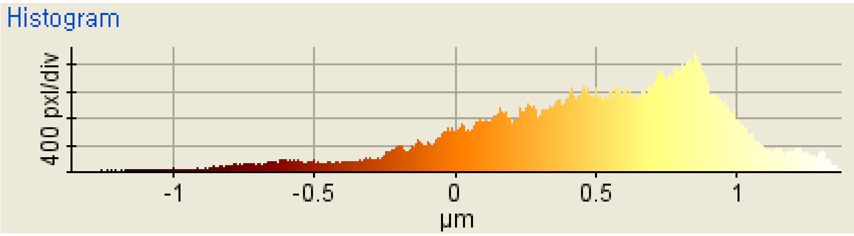


Figure 3-3-3. Histogram

When right click on Histogram, menu will pop-up. Below is context of menu.

- **Use Gaussian Fitting**

It displays a Gaussian Fitting curve of height distribution, according to the function below, on histogram chart. Gaussian Fitting curve contains;

a: Number of pixels according to m,

m: Average,

σ: Average deviation.

Gaussian curves can be useful for acquiring height data from the image Histogram.

$$f(x) = a\,e^{-\frac{(x-m)^2}{2\sigma^2}}$$

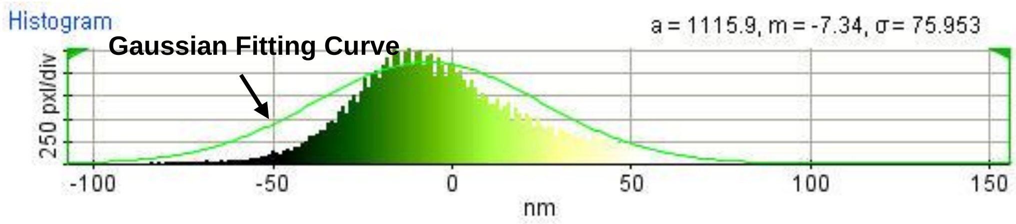


Figure 3-3-4. Cursors on Histogram

Cursors can be placed on the Histogram to acquire single point data. Paired cursors can be placed on the Histogram to acquire distances between two areas of the Gaussian function. After adding the cursor(s), the cursors can be dragged to different positions on the Histogram.

■ Export

Same as Export feature in Image Display panel. Refer to Section 3-3-2.

■ Copy to Clipboard

Copies the histogram data to the clipboard as a text file (txt) or an image file. Open the context menu by right clicking on the histogram, choose the 'Copy to Clipboard' command in the context menu and paste the data in the corresponding document file by clicking [Ctrl+V] button.

■ Insert a Cursor

Insert a single cursor on the histogram, similar to Line Profile panel. Up to three single cursors can be added. In figure 3-3-5, below, two single cursors are shown on the histogram. Numbers in the rectangle indicate each single cursor's X, Y position. Red single cursor indicates (22.116nm, 38.841pxl).

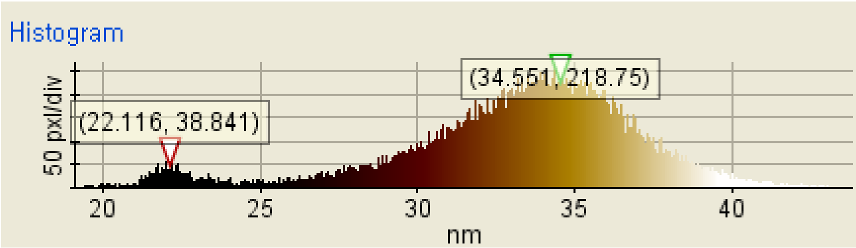


Figure 3-3-5. Cursors on Histogram

■ Delete a Cursor

Deletes a selected cursor, similar to Line Profile panel.

■ Delete all Cursors

Deletes all of the added cursors, similar to Line Profile panel.

■ Insert a Cursor Pair

Inserts a cursor pair, similar to Line Profile panel. Currently, three cursor pairs can be added. Figure 3-3-6 below is shown with one cursor pair inserted in the histogram. The numbers in the rectangle indicates the difference between the cursor pair. The X and Y differences are 113.026nm and 3362pxl respectively.

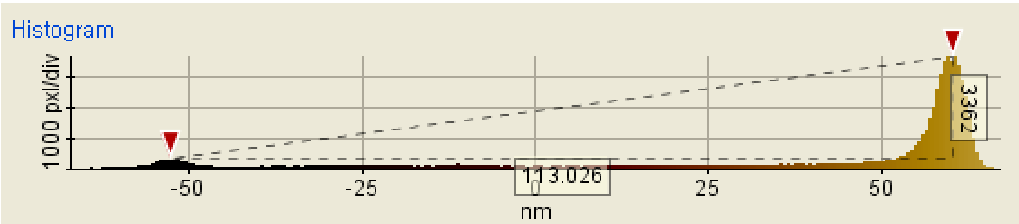


Figure 3-3-6. Cursors on Histogram

■ Delete a Cursor Pair

Deletes a selected cursor pair, similar to Line Profile panel.

■ **Delete all Cursor Pairs**

Deletes all added cursor pairs, similar to Line Profile panel.

3-4. Information Table

When scan image file is generated from XEP software, various information and scan parameters used to obtain image is saved along with the image itself. As shown in Figure 3-4-1, these can be viewed through the Information table. Clicking 'Show Details' button will display every information and parameters saved with the image. Click 'Hide Details' button to view only the important information and parameters, summarized. Meaning of the each items found in the Information table is given in the Table 3-1 .

File Name	08um.tiff
Head Mode	NC-AFM
Source	Topography
Data Width	512 (pxl)
Data Height	512 (pxl)
X Scan Size	9.04 (µm)
Y Scan Size	9.04 (µm)
Scan Rate	0 (Hz)
Set Point	0 (unit)
Data Gain	-145.67E-6 (µm/step)

Figure 3-4-1. Information table (Hide Details)

Table 3-2. Items in the detailed Information table

Item	Meaning
File Name	Indicates the file name of the generated image that was saved after scanning.
Version	Indicates the version of Park Systems software that created the image file. XEI 1.8.0 supports tiff file below 1.0.2
Date Time	Shows the time and date at which this file was created.
Comments	Shows the comments you edited in the Image Information dialog of the XEP or XEI.
Head Mode	Indicates the Head mode such as AFM, NC AFM, MFM, LFM, EFM, FMM and so on. It was selected in the XEP Part Selection dialog.

XY Range Mode	Indicates the scan range mode of the XY scanner (Large, Medium or Small) during imaging. This parameter is set in the Part Config dialog box of XEP.
Z Range Mode	Indicates the scan range mode of the Z scanner (Large or Small) during imaging. This parameter is set in the Part Config dialog box of XEP.
Z scanner range	Indicates the range of Z scanner (0 to 1 corresponding to 0 to 12um range of the Z scanner) during imaging. This parameter is set from the Part Config dialog box in XEP
Source	Indicates the input signal source that was used to acquire an image. This Source was selected in the Input Configuration dialog of the XEP image acquisition software.
Low Pass Filter	Indicates the time interval used to generate the averaged data pixel so that high frequency noise can be eliminated. The higher value of the LPF means that a longer time interval is permitted to generate each pixel. This parameter was adjusted in the Input Configuration dialog in XEP.
Plain Fit	When turned On, Plain fit keeps the average level of each line of data constant so that the contrast scale does not saturate while an image is being generated. This parameter was selected in the Input Configuration dialog.
Flattening	Shows the type of flattening applied to the image during data acquisition process, if any flattening was selected from the Input Configuration dialog.
Data Width	Indicates the pixel size of an image in the x direction. This parameter was selected in the Scan Configuration dialog.
Data Height	Indicates the pixel size of an image in the y direction. This parameter was selected in the Scan Configuration dialog.
Sine Scan	When it is On, indicates that the sine scan was applied to an image while scanning. This parameter was selected in the Scan Configuration dialog.
Over Scan	Indicates the percentage that an over scan was applied to an image while scanning. This parameter was selected in the Scan Configuration dialog.
Fast Scan Axis	Indicates the scan direction that was selected to acquire

each line of data in compiling the image. This parameter was selected in the X, Y check box in the Scan control window of XEP.

Fast Scan Dir If the fast scan axis is X, indicates that the fast scan direction is from left to right or from right to left.

Slow Scan Dir If the fast scan axis is X, indicates that the slow scan direction is from bottom to top or from top to bottom.

X Scan Size Indicates the scan size of an image in the x direction. This value was set in the Scan control window of XEP.

Y Scan Size Indicates the scan size of an image in the y direction. This value was set in the Scan control window of XEP.

X Scan Offset Indicates the X offset coordinate relative to the scanner midpoint (0, 0) that was used to define the scan area. This value was set in the Scan control window of XEP.

Y Scan Offset Indicates the X offset coordinate relative to the scanner midpoint (0, 0) that was used to define the scan area. This value was set in the Scan control window of XEP.

Rotation Indicates the degree of rotation that the fast scan direction was rotated relative to the X axis or the Y axis while an image was generated. This parameter was adjusted in the Scan control window of XEP.

Scan Rate Indicates the frequency that the scanner is rastering back and forth across the sample surface. This parameter was adjusted in the Scan control window of XEP.

Set Point Indicates the set point value adjusted in the Scan control window or Frequency Sweep dialog. Depending on the scan mode, the meaning of this value may differ for different scan modes.

Amplitude The amplitude at which the cantilever was modulated during NC-AFM mode images.

Sel Freq. The frequency at which the cantilever was modulated during NC-AFM mode images.

Tip Bias Indicates the voltage that was applied to the tip with the sample being grounded to investigate the interaction between the tip and sample while scanning. Depending on your instrument, either a tip bias or a sample bias can be applied. This can be adjusted in the Scan control window of XEP.

Sample Bias Indicates the voltage that was applied to the sample with the tip being grounded to investigate the interaction between the tip and sample while scanning. Depending on your instrument, either a tip bias or a sample bias can be applied. This can be adjusted in the Scan control window of XEP.

Data Gain The real data is obtained by multiplying the raw data and data gain itself.

Z servo gain Indicates the value of Z servo gain set during the imaging process.

Chapter 4. Line View

In the Line view , you can measure and analyze several characteristics of an image along selected line profiles. Select the line type (for example, vertical, horizontal, or slanted), and generate the line (up to 3 if 'Use Three Lines' is selected in 'File>Preferences') on the image across the profile you want to measure and analyze. You can make quantitative measurements of surface features and collect surface statistical data along the cross section. The Line view provides a Line Profile, a Power Spectrum, and a Histogram of the line profile.

In general, you can analyze the selected lines in your image in the Line view through the following steps:

1. Select an image you want to analyze in the Navigator view.
2. Enable the Line view
3. Click the desired line type button on the line selection toolbar that is at the higher right side of the displayed image.
4. To draw a line, drag the mouse across the profile you wish to analyze.
5. The measurement results will appear in several panels and a statistics table.
6. Save and print your Line view results if desired.

Figure 4-1 shows the summarized procedure to analyze the selected line in an image.

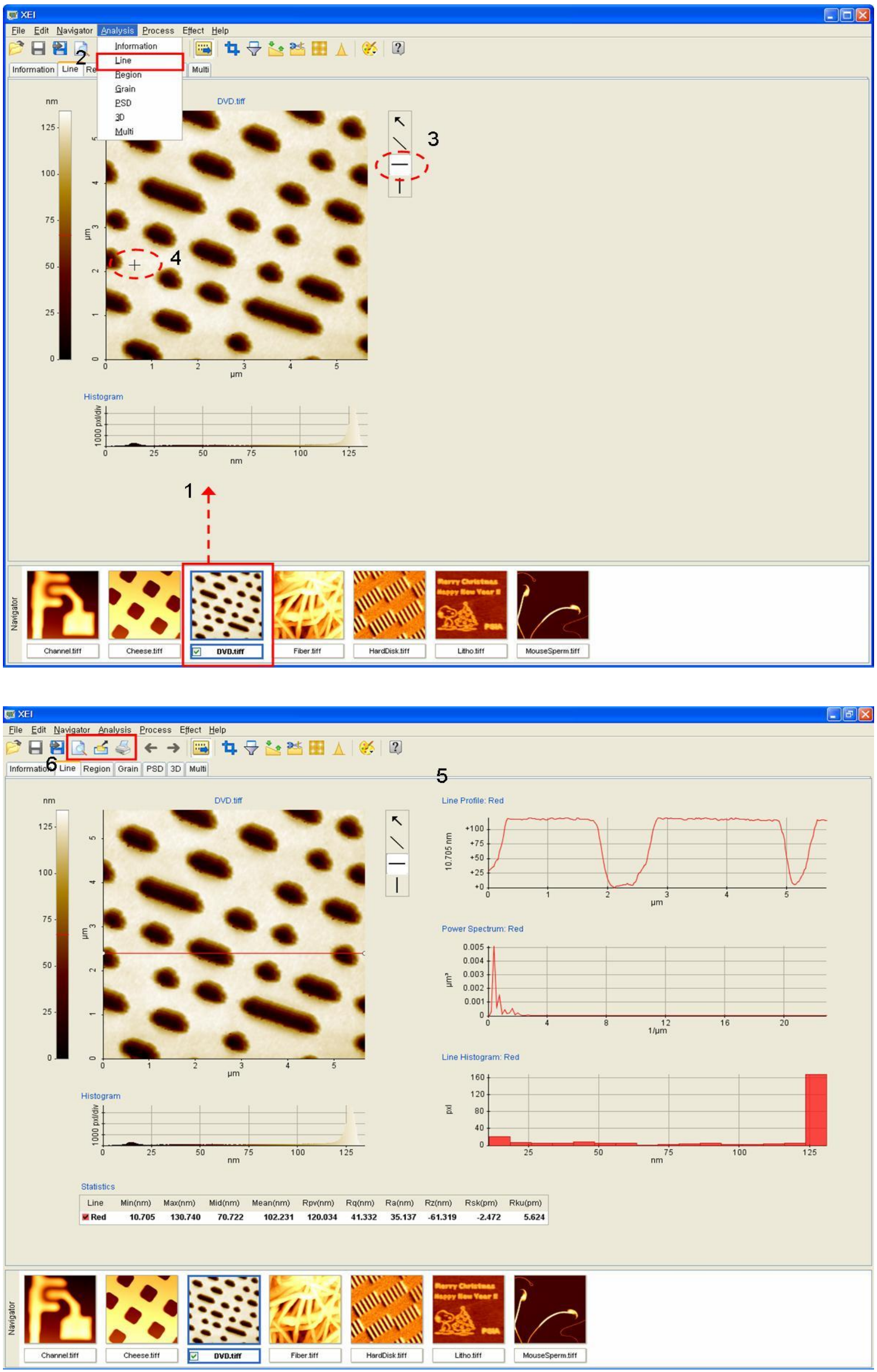


Figure 4-1. Procedure for Line view

4-1. Line View

To enable the Line view, select 'Analysis>Line' from the menu bar or click the Line analysis tab below the Toolbar. The layout of the Line view is divided into three main regions; Image display panel, Analysis plots panel, and Statistics table. Figure 4-1-1 shows the Line view of the horizontal line in the image.

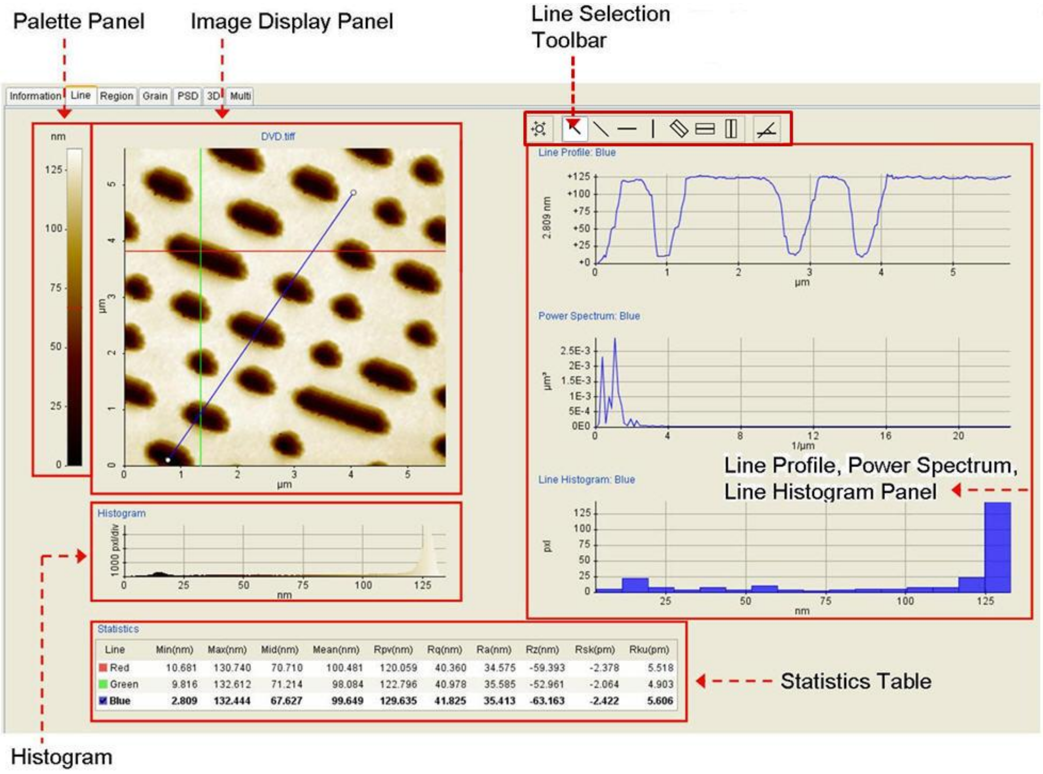


Figure 4-1-1. Line view

4-1-1 Palette Panel, Image Display Panel and Histogram

Just as in other Analysis views, the image you want to analyze can be displayed in the Image display panel with the Palette Panel. It is the same Palette Panel and Image Display Panel that appears in all the analysis views of XEI. Please refer to Chapter 3-2 and 3-3 for details. Also the histogram of the entire image surface is displayed on the bottom of the Image Display Panel as in the other analysis views. Please refer to Section 3-3 for details.

4-1-2 Line Selection toolbar

Line selection toolbar, where the Tools for selecting line for the analysis are gathered, is at the right side of the image Display Panel.

4-1-3 Line Profile, Power Spectrum and Line Histogram Panel

Line Profile, Power Spectrum, and Line Histogram is generated immediately on the separate panel after you create a line across the image for line analysis. These plots are automatically updated whenever you select the line and move the selected line in the image. Detailed features of these three panels are explained in section 4-3, 4 & 6 respectively.

4-1-4 Line Statistics Table

In the Line Statistics Table, the statistics table of the quantitative measurements up to three selected lines (classified by different colors: red, green, and blue) is displayed. The related values of the selected lines are changed in accordance with the change in position of the cross section. Detailed features of the Line Statistics Table are explained in section 4-5.

4-2. Selecting Lines for Line Analysis

To get reasonable information of line profile of the sample, it is important to select specific lines for analysis. Line selection toolbar contains various tools that help you to select precise lines for line data analysis. The process of selecting line for analysis is done in three steps.

Step 1. Select Type of the Line 

You can create up to three lines for line profile analysis on the image (see Figure 4-2-1): vertical, horizontal and/or arbitrarily sloped lines are possible. Each line you create is indicated by a different color (red, green, and blue in order) in the Image display panel as well as in the analysis plots. The Selected line will display end points of an arrow to easily identify the selected line.

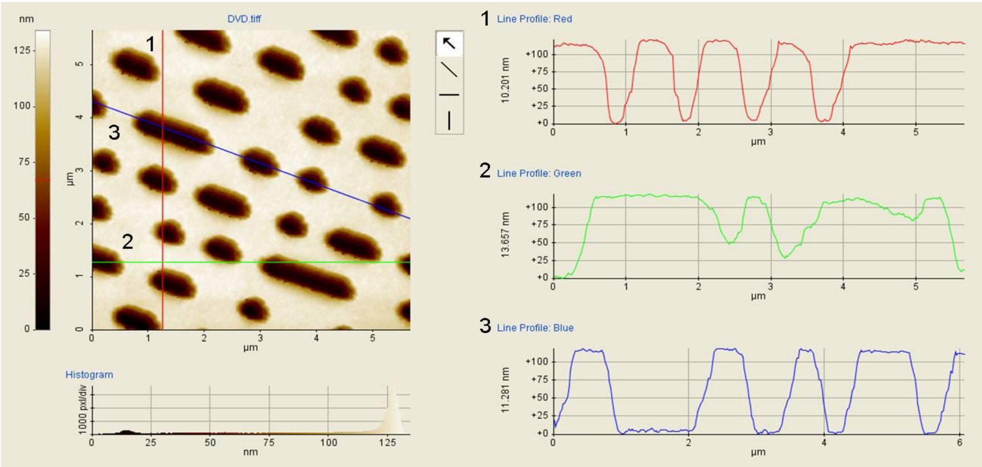


Figure 4-2-1. Line selection toolbar

Step 2. Create the Line 

- **X or Y axis line** 

Click the X or Y axis line button on the line selection toolbar to generate a horizontal or vertical line to be analyzed as a cross section of the sample surface. Then, click the cursor at any location on the image where you would like to analyze the height profile. The colored horizontal or vertical line will appear in the image. You can easily move the line for analysis anywhere in the image by dragging and dropping the line again and again. Figure 4-2-2 shows an example of moving a X axis line for analyzing different image cross sections.

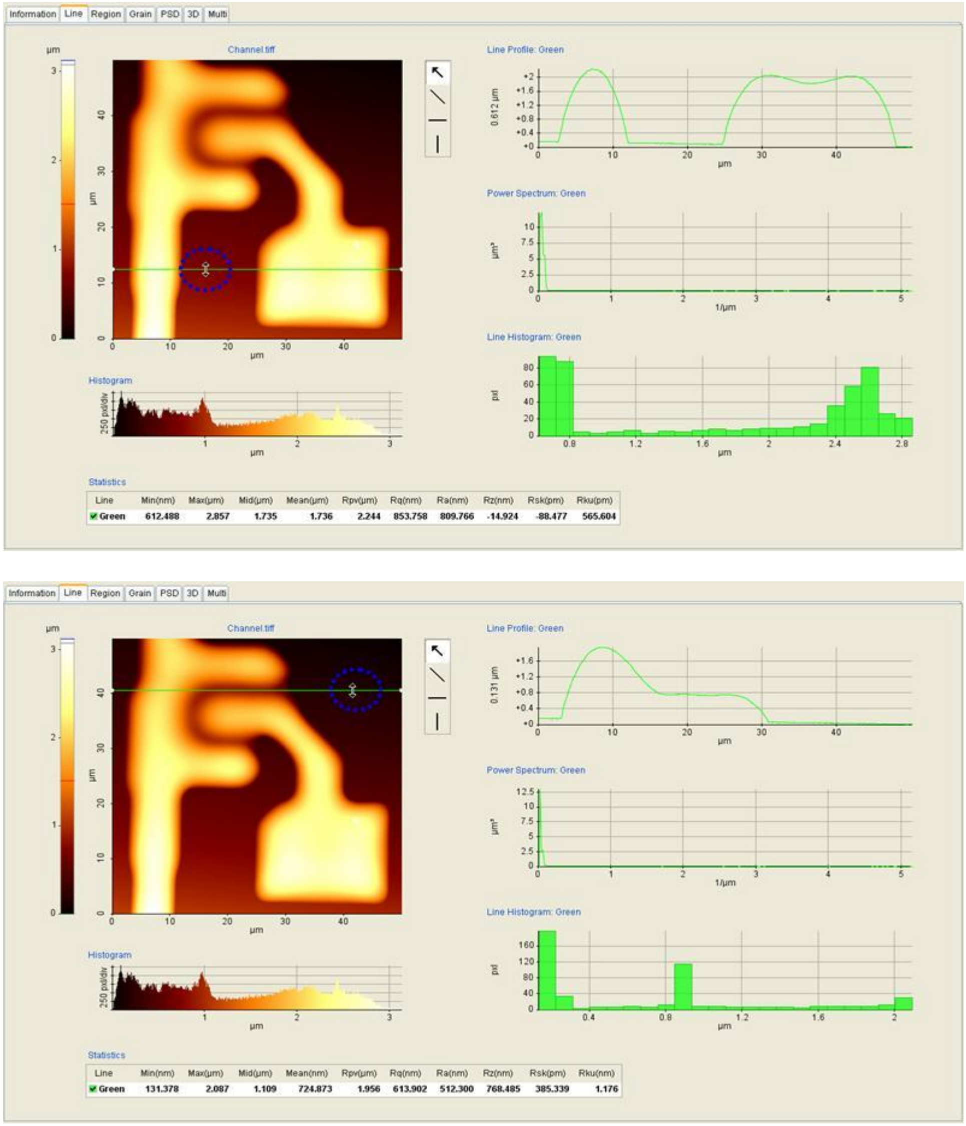


Figure 4-2-2. Move a line for Line view

■ Slanted line 

As shown in Figure 4-2-3, after clicking the slanted line button, press the cursor onto any location where you would like to start the arbitrary slanted line. Drag and drop the cursor onto the end point of this line. To change the location of the line, follow the same procedure as for a vertical or horizontal line. Furthermore, you can resize the line by clicking the line to display trackers at the two end points of the line. Then, drag and drop these trackers.

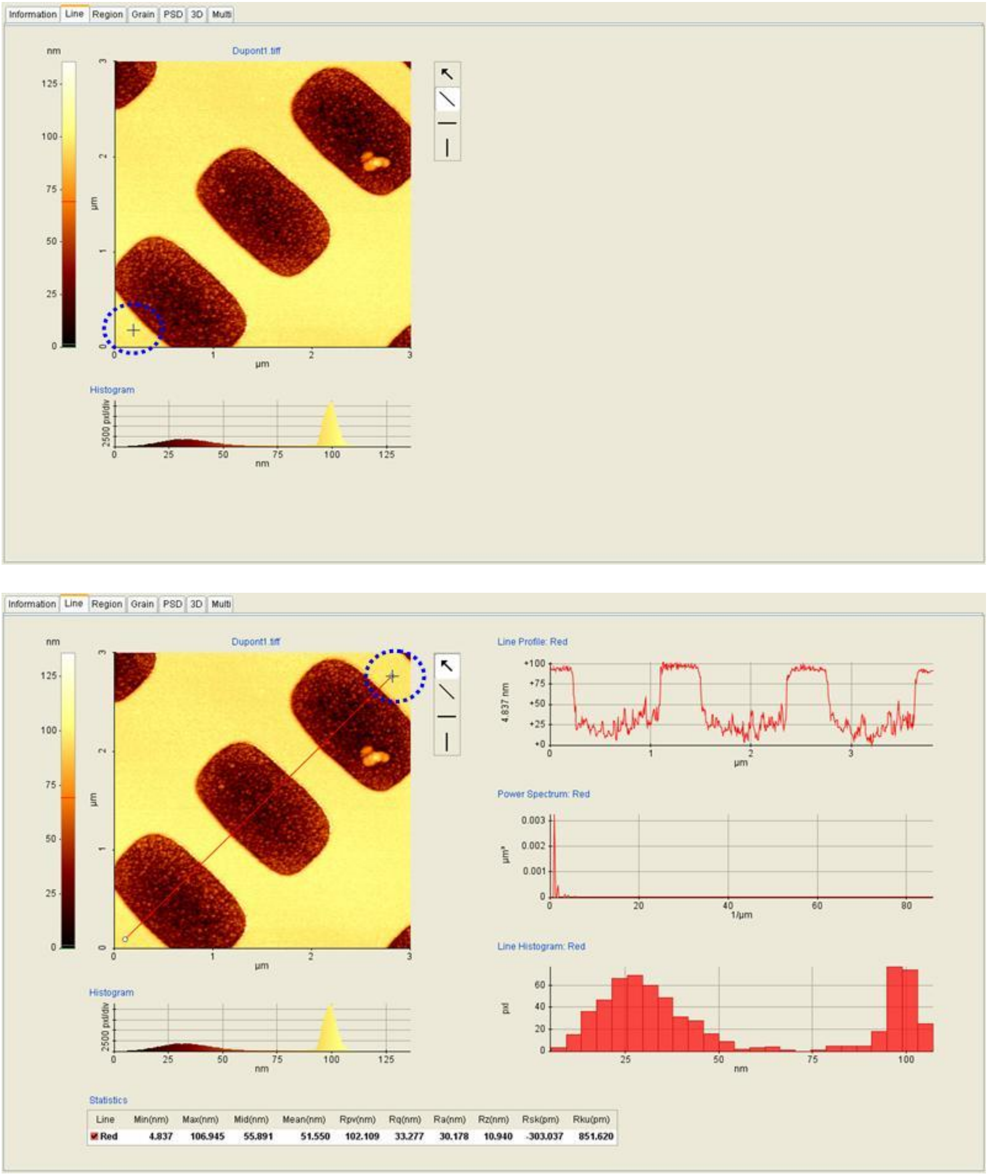
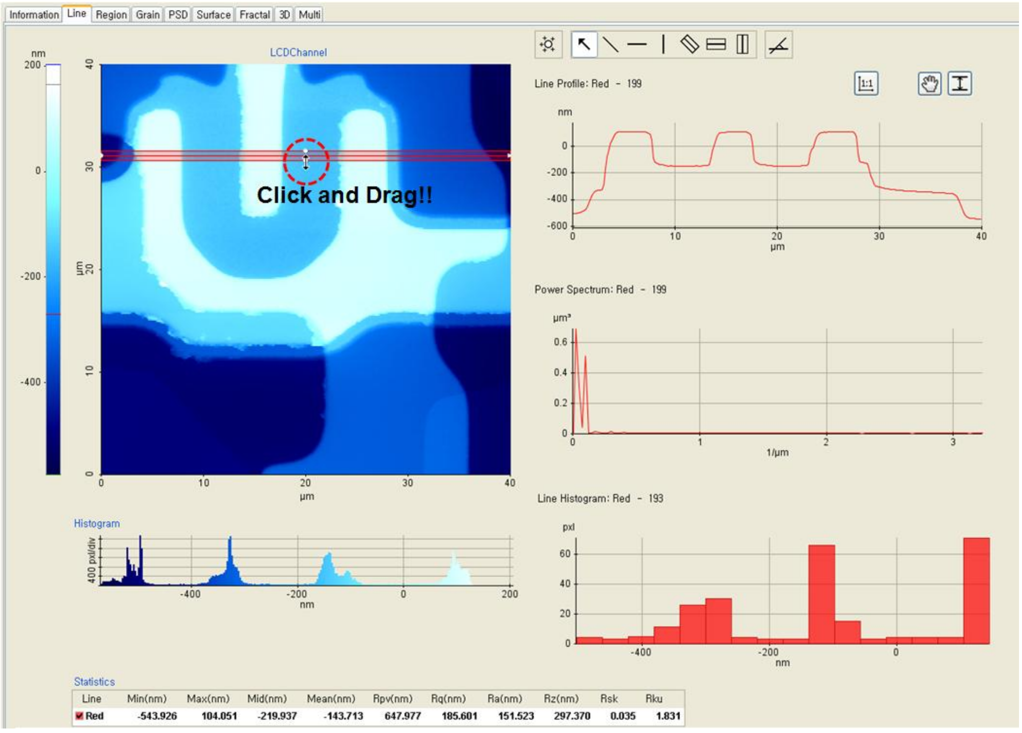


Figure 4-2-3. Create a slanted line

■ Average line 

For each X, Y and Slanted lines, there are also Average lines. The process for creating an Average line is the same as creating a single line. When an Average line is created, it is colored from center line towards each side. The selected average area will display in the Line Profile panel as a single Line Profile. Average Lines can be resized by clicking the circular tracker and dragging to desired area. Figure 4-2-4 shows Average X axis Line.



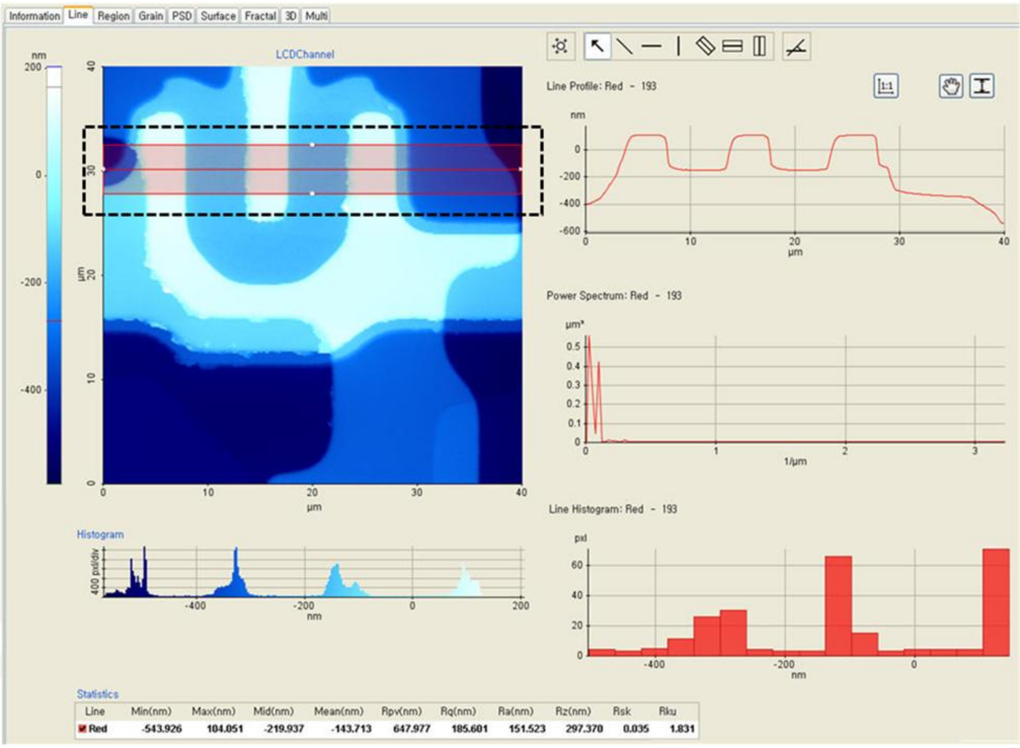
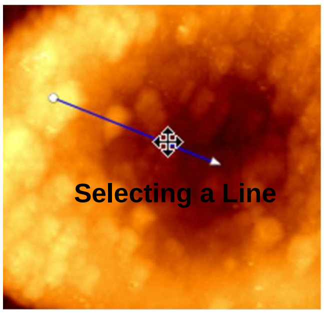


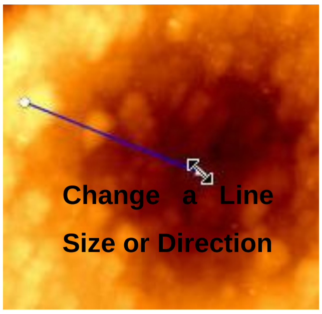
Figure 4-2-4. Control an Average Line Region

Step 3. Edit the created Line

You can move, delete, and resize the line created in step 2 with the help of the 'Move tool'. The Move tool will only appear on the toolbar if you have checked the 'Line' check box in the 'Use Move Tool' option of the 'Preferences Window'.

//When the 'Use Move Tool' option for the 'Line' is checked, the mouse pointer stays in 'line selection' (cross hair mouse pointer) mode so that user can continuously create lines for analysis without reselecting the line button on the toolbar for each line. The mouse pointer will stay in 'line selection' mode unless you deselect the 'Move Tool' button to exit 'line selection' (cross hair mouse pointer) mode and switch to 'line editing' (arrow mouse pointer) mode.





On the other hand, when the 'Use Move Tool' option for the 'Line' is not checked, the mouse pointer will automatically switch from 'line selection' (cross hair) to 'line editing' (arrow) mode each time you create a line.

■ Selecting

First, select the line corresponding to the line shape you would like to edit. Next, click 'Move tool' to enable line editing. Click on the line you would like to move to select it. You can also select multiple lines by pressing 'Ctrl' key as you click the lines. To select all the lines, press Ctrl+A, or select 'Select All' in the context menu.

■ Moving

To move an object, move the mouse cursor over the object until it becomes a four-arrow cursor and the circular tracker appears (circle and arrow at endpoints) on the line. You can move the selected line by dragging it.

■ Deleting

To delete the selected line, right click to bring up the context menu and select the delete command or press delete button on the keyboard.

■ Changing Shape

For slanted lines, you can resize the line by clicking the line to display circular trackers (circle and arrow) at the two end points of the line. Then, drag and drop these trackers.

■ Measuring Angle between Lines 

As shown in Figure 4-2-5, when clicking the ‘Show Angle’  icon, the angle value between two lines will be displayed on Image Display panel. ‘Show Angle’ icon can be selected under the line selection toolbar.

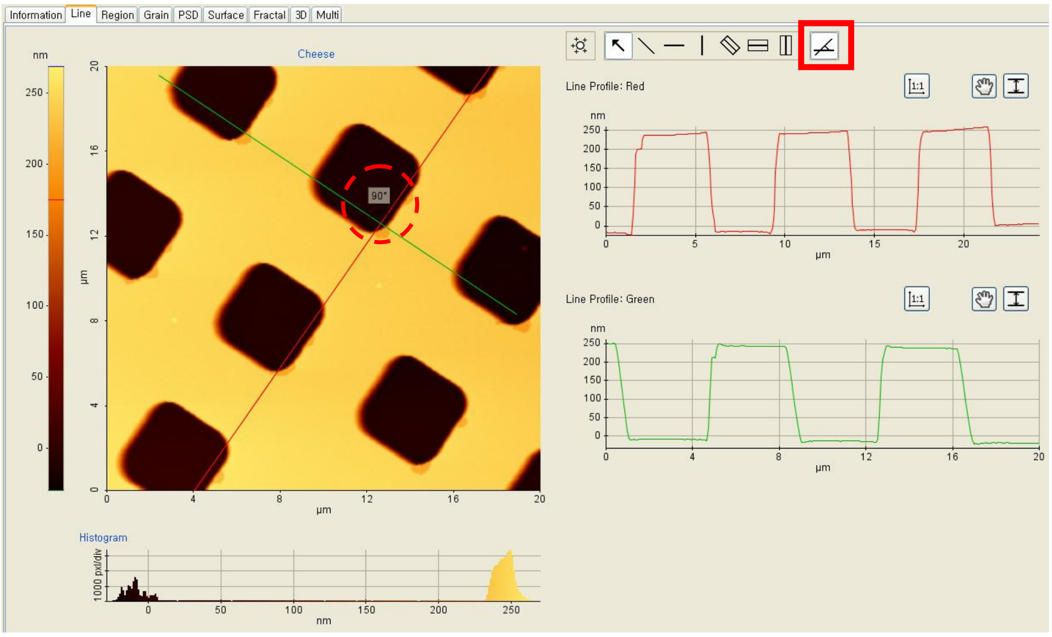


Figure 4-2-5. Show angle between two lines

■ Change Image Color(Use Enhanced Color)

For effective line analysis, enhanced color can be used in the Image Display panel. Clicking the ‘Use Enhanced Color’  icon, will activate the feature. Please refer Section 3-2-5 for more detail.

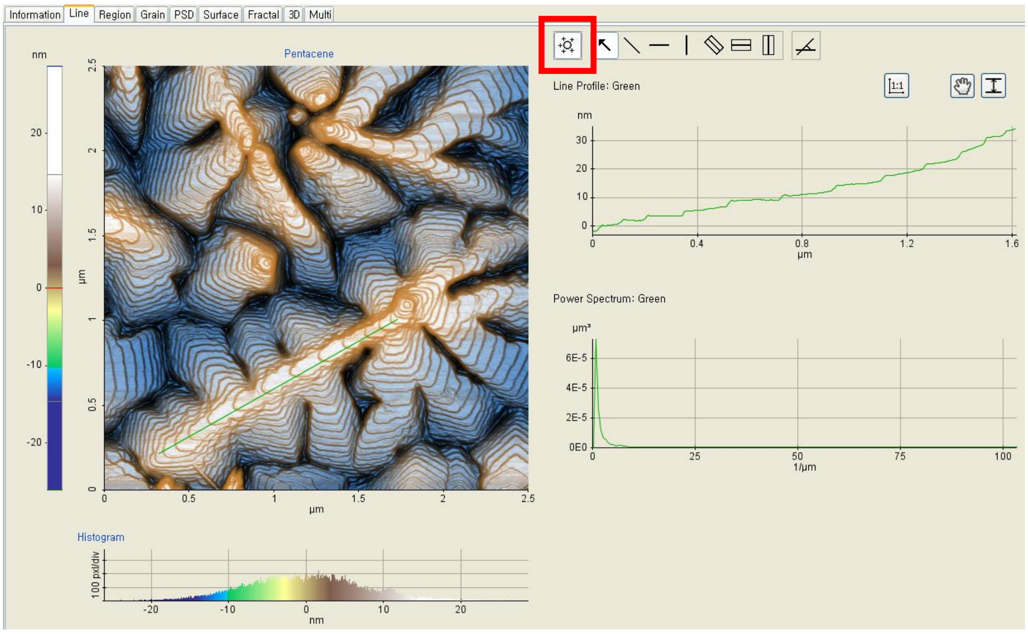


Figure 4-2-6. Use Enhanced Color

4-3. Line Profile Panel

The Line Profile panel displays the cross-sectional height profile of the image along the line created by user. The unit of x axis is usually µm or nm and that of y axis is variable depending on the collected signal to generate its image for example, µm, nm, mV, V and so on.

- **1:1 Visual Ratio**

Displays ratio between the X and Y's line profile as 1:1 ratio. This feature can be useful for enlarging the Y axis' line profile.

- **Move**

Selecting this icon will allow to the user to scroll the viewable area by clicking and dragging the image.

- **Zoom Out**

When selected, the line profile is automatically scaled in the Line Profile panel by clicking icon.

A context menu (see the outlined box in Figure 4-3-1) is generated when you right-click the cursor in the Line Profile panel. The items of the context menus are described below.

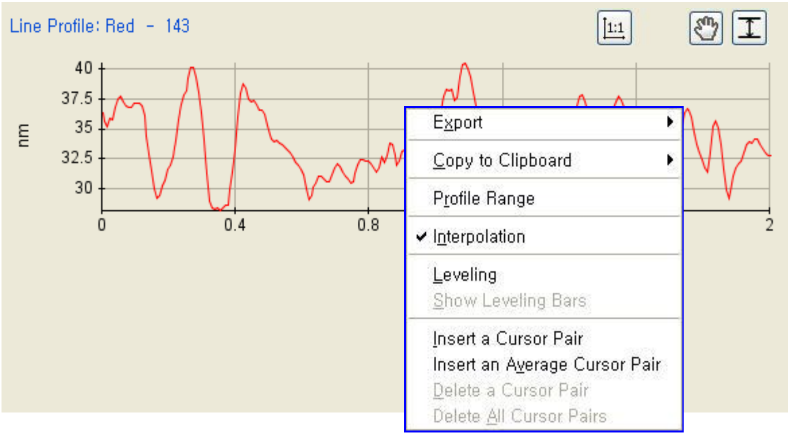


Figure 4-3-1. Context menu in the line profile

4-3-1 Export

Through the 'Export' command in the context menu of Line view, you can export the data of the Line Profile as a text file and save it individually. This text file can be used for analysis in other software program.

4-3-2 Insert (Delete) a Cursor Pair

To measure an exact height difference and distance between two data points in the Line profile, you can insert a cursor pair on the Line Profile by selecting 'Insert a Cursor Pair' command in the context menu. You can insert up to three cursor pairs per profile.

When the cursor pair is inserted, two triangular shaped cursors appear on two arbitrary points on the Line profile and the corresponding points on the image in the image display panel as well. Along with the cursor pair, '∆X', '∆Y', 'Angle' information is displayed in the Cursor Statistics table as default (Figure 4-3-2 and Figure 4-3-3).

Also, you can select the cursor pair parameters to be displayed on the table from the 'Show Items' command in the context menu of the Cursor Statistics table as well. The cursor information parameters that can be displayed in the Cursor Statics table are described below.

ΔX	The horizontal distance between the two points marked by the cursors
ΔY	The vertical distance between the two points marked by the cursors
Angle	The angle between the points. This is determined by dividing the vertical difference by the horizontal difference.
Left X	The horizontal coordinate for the left cursor.
Left Y	The vertical coordinate for the left cursor.
Right X	The horizontal coordinate for the right cursor.
Right Y	The vertical coordinate for the right cursor.

The context menu in the Cursor Statistics table is generated by right clicking on the table. These menu functions are similar to those in region statics table except for the items under the 'Show Items' command. Refer to Section 4-3.

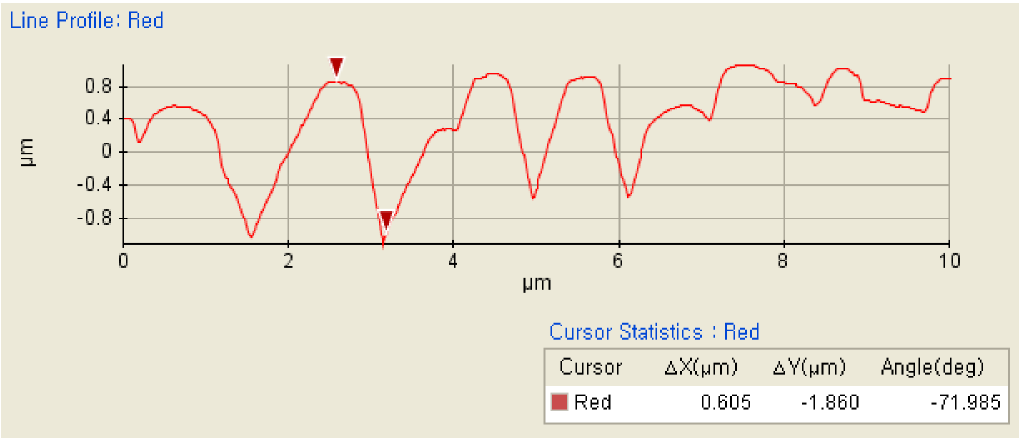


Figure 4-3-2. Cursor pair and displayed information

You can adjust the location of the cursors by dragging and dropping individual triangular cursors either from the line profile or from the image in the image display panel. You can also move the cursors with pixel precision by clicking on a cursor, then pressing the → and ← keys on your keyboard. The displayed cursor information is automatically updated whenever you change the position of the cursor pair. Figure 4-3-3 shows an example of using the cursor pair.

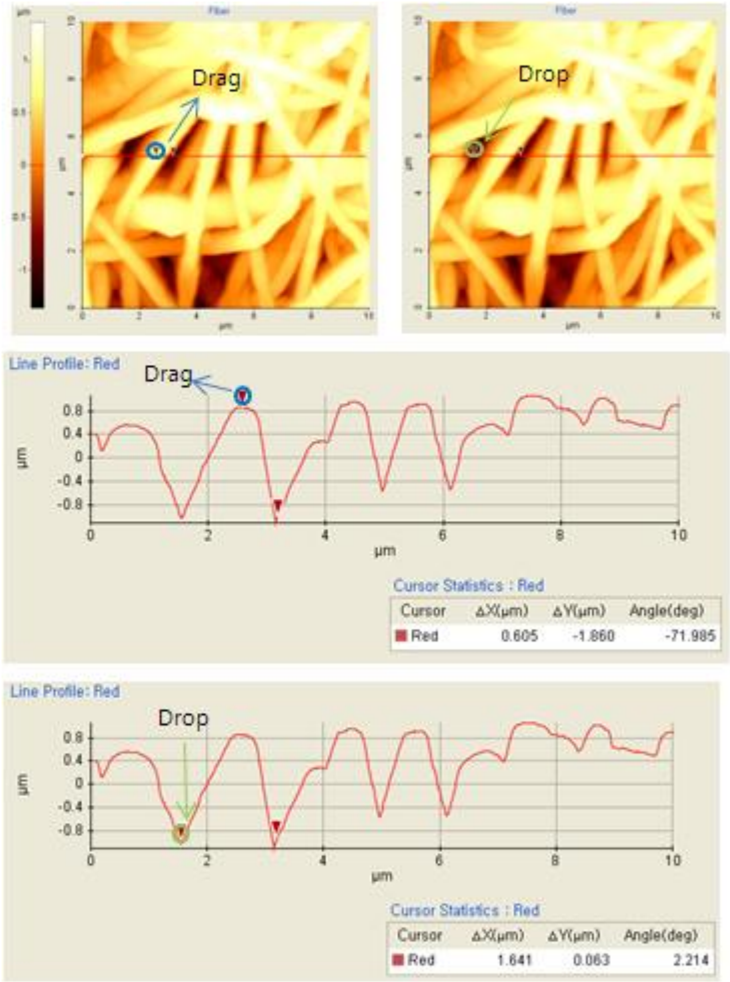


Figure 4-3-3. Moving cursors by mouse

To delete the cursor pair from the line profile, click the cursor pair which you want to delete and select 'Delete a cursor pair' command from the context menu or use the 'Delete' button on your keyboard. This command deletes the selected cursor pair from the Line Profile. To delete all of the cursor pairs from the Line Profile, select 'Delete all cursor pairs' command from the context menu.

4-3-3 Interpolation

This function allows smooth shifting between pixels by adding another point in between two points. If this function is disabled, it will only move as pixels.

4-3-4 Leveling

After you select ‘Leveling’, you will see two white bars in the line profile. You can use these bars to easily subtract the background slope. Point your mouse at each bar and the cursor will change to a left-right arrow. Drag each bar to two different points you believe to be at the same height. The slope of the line profile will change accordingly so that the two different points are brought to the same level. After leveling, the white bars can be disappeared by deselecting ‘Show leveling bars’.

4-3-5 Profile Range

Selecting ‘Profile Range’ will appear Profile Range dialog. Line profile range can be adjusted in this dialog.

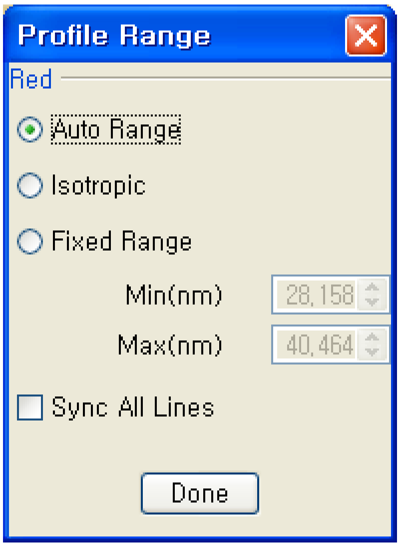


Figure 4-3-4. Profile Range

- **Color**

  Displays a selected line profile color

- **Auto Range**

  When selected, automatically adjusts the range of the display so that the whole line profile is visible on the graph.

- **Isotropic**

  Fits the Y scale to the maximum scale of X. Consequently, you will see a height that is similar to the real line profile.

- **Fixed Range**

The vertical scale indicates the height range of the line profile. By default, maximum (minimum) value of the data range corresponds to the maximum (minimum) data of a line profile. This data range can be edited by changing the 'Max (Min)' text field in 'Fixed Range' of 'Profile Range' dialog.

- **Sync All Lines**

When selected, the vertical data range scale of all the lines will be matched.

4-3-6 Copy to Clipboard

Through the 'Copy to Clipboard' command in the context menu of Line view, you can copy the line profile data to clipboard as text or image file and paste [Ctrl+V] button on the corresponding document file.

4-4. Power Spectrum Panel

When you select a line in an image, its power spectrum is displayed in the Power Spectrum panel. Figure 4-4-1 shows the power spectrum of the selected line in the Line view. A power spectrum shows the contribution of each spatial frequency to the line profile versus frequency. It is generally used to examine spatial periodicities in an image and to measure noise characteristics. When you select a line in an image, a power spectrum is automatically displayed.

The Power Spectrum, shown below, is related to the 1-dimensional Fourier transformation of the selected line in the Line Profile. In a Power Spectrum, peaks represent the intensities of frequency components in the selected line. The x axis is the frequency of the selected line and its unit is 1/µm. The y axis is the intensity of the frequency component and its unit can be Å×µm, µm×µm, V×µm and so on. The front unit is varied by on the unit of the selected input signal and z scale within the selected line and the next unit is varied by the length of the line.

A context menu is generated when you right-click the cursor in the Line Power

Spectrum panel. Currently, ‘Export’, ‘Copy to Clipboard’ and ‘Show Pair Cursor Pair’ menu are available commands. For more information, refer to Section 4-3.

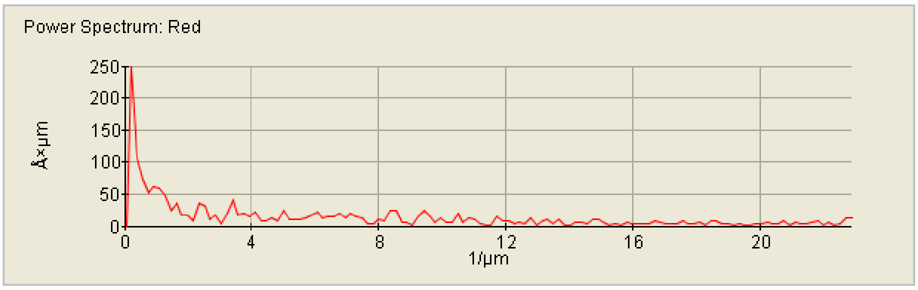
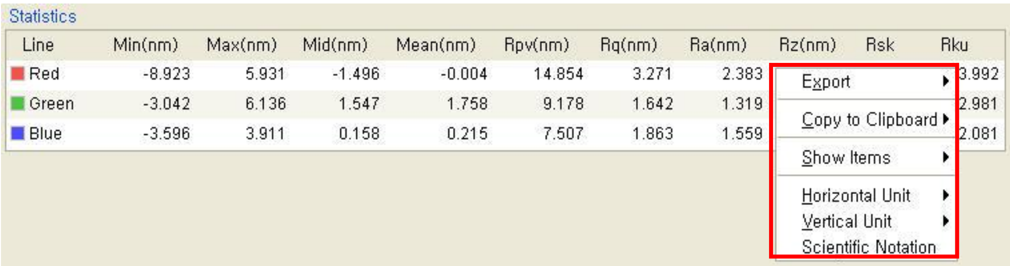


Figure 4-4-1 Power spectrum panel

4-5. Line Statistics Table

The Line Statistics table, shown in Figure 4-5-1, shows several statistics of the line profile. Each line is related to one row of the table. The results of the statistics on the selected line are updated automatically when you move the selected line to different locations in an image. The context menu (see the outlined box in Figure 4-5-1) is generated when you right-click the cursor in the Line Profile panel. Through the context menu, the statistics table can be rearranged as desired. These menu items are described as Figure 4-5-1.



Statistics

Line	Min(nm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(nm)	Rsk	Rku
Red	-8.923	5.931	-1.496	-0.004	14.854	3.271	2.383			3.992
Green	-3.042	6.136	1.547	1.758	9.178	1.642	1.319			2.981
Blue	-3.596	3.911	0.158	0.215	7.507	1.863	1.559			2.081

Figure 4-5-1. Line statistics table

■ Export

Export the statistics data as image or text file.

■ Copy to Clipboard

Copy the statistics data as image or text file to clipboard and you can paste the corresponding document file.

■ Show Items

Select the line profile parameters to be displayed on the statistics table.

■ Horizontal Unit

In the Statistics table, sets the scale units of the horizontal axis. As default, each parameter scale uses the ‘Auto Unit’ feature. The horizontal (X) axis for all parameters can be manually set to the same single unit (fm, pm, nm, µm, mm, and m).

■ Vertical Unit

In the Statistics table, sets the scale units of the vertical axis. As default, each parameter scale uses the ‘Auto Unit’ feature. The vertical (Y) axis for all parameters can be manually set to the same single unit (fm, pm, nm, µm, mm, and m).

■ Scientific Notation

Line profile parameter values in the Statistics table will be displayed in Scientific Notation (Exponential Notation). The values are displayed to three decimal places. Due to limited space in the Statistics table, this feature is useful when displaying multiple parameters.

The meanings of the surface profile parameters displayed in the Line Statistics Table are defined as follows.

Table 4-5-1. Line Profile Parameters

Parameter Name	Meanings
Min	Min is the minimum, or smallest, value in the line profile.
Max	Max is the maximum, or largest, value in the line profile.
Mid	Mid is the arithmetic average between the minimum and maximum values. That is, Mid = (Max + Min) / 2.
Mean	Mean is the arithmetic mean value of the line profile. It is the sum of the height of each point divided by the number of points.
Rpv	Rpv is the peak-to-valley of the line. It is the difference between minimum and maximum, that is, (Max – Min).
Rq	Rq is the root-mean-squared roughness.
Ra	Ra is the roughness average. The average roughness is the area between the roughness profile and its mean line.
Rz	Rz is the ten point average roughness. It is the arithmetic average of the five highest peaks and five lowest valleys in the line.
Rsk	Rsk is the skewness of the line.
Rku	Rku is the kurtosis of the line. It indicates the “spikiness” of the sample surface along that line.

4-6. Line Histogram Panel

The Line Histogram panel provides information about the distribution of heights of the pixels within the selected line. Corresponding to the three selectable line groups, up to three Line Histograms (R, G, B) can be generated. Figure 4-6-1 shows the Line Histogram panel. The x axis represents the height of data points in the line. The y axis represents the number of pixels in the selected line. Several features that helps user to perform further analysis of the Line Histogram can be accessed through the context menu. You can see the context menu in the Line Histogram panel right the mouse with the pointer on the table.

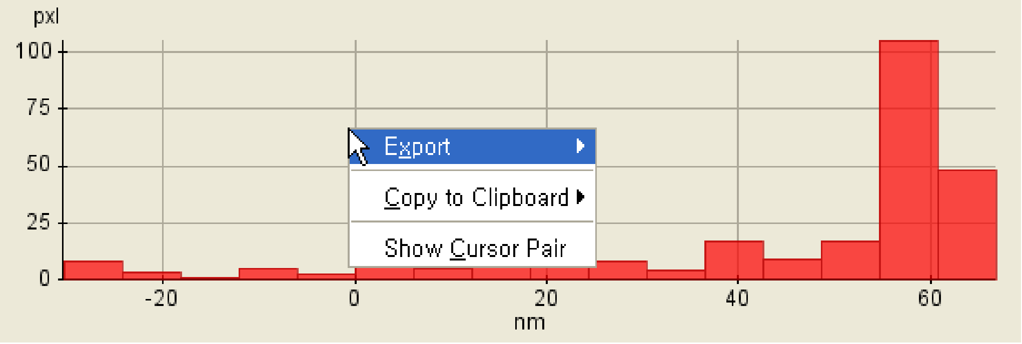


Figure 4-6-1. Line Histogram Panel

Chapter 5. Region View

In the Region view, you can measure and analyze surface regions of an image. You can make quantitative measurements of surface features in the selected regions and collect surface statistics such as surface roughness, average height. These statistical values are displayed in the table and plotted in the Region Histogram panels. Up to three particular regions can be selected to include regions for analysis. Furthermore, you can select regions to exclude certain features from analysis.

In general, you can go through the following steps in Region view:

1. Load an image you want to analyze into the Analysis view from the Navigator view.
2. Enable the Region view.
3. Select regions of the image to include or exclude for Region view.
4. Once selecting region group, both the region histogram plot and statistics table are generated with results and updated whenever the change of the selected region group occurs.
5. Save and print your Region view results

Figure 5-1 shows the summarized procedure to analyze the region of an image.

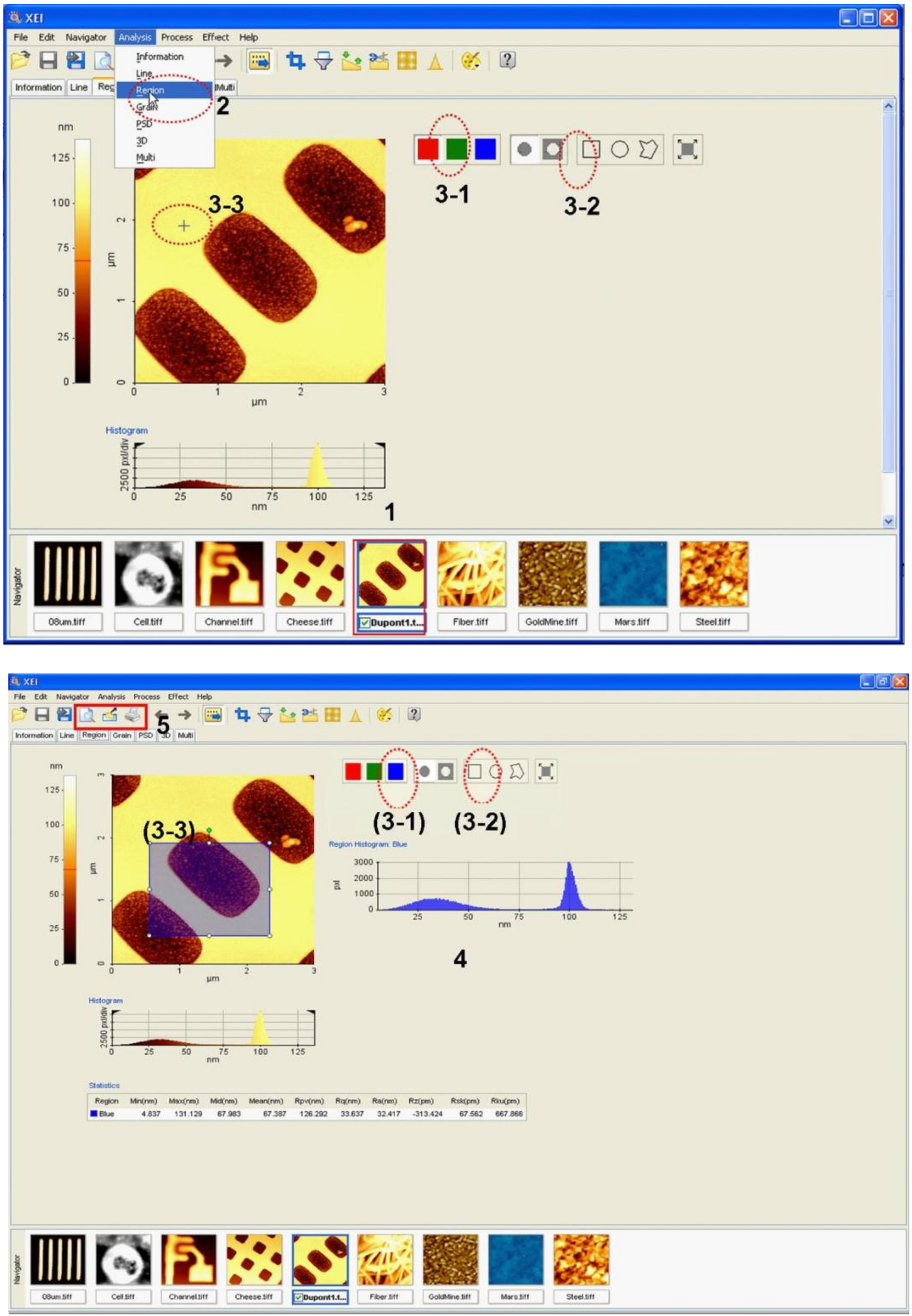


Figure 5-1. Procedure for Region view

5-1. Layout

To enable the Region view, select ‘Analysis>Region’ menu or click the Region analysis tab below the Toolbar.　The Region view consists of the Palette Panel, Image Display Panel, Region Selection Toolbar, Region Histogram Panel, Histogram and the Statistics table. Figure 5-1-1 shows the Region view that is divided into several parts.

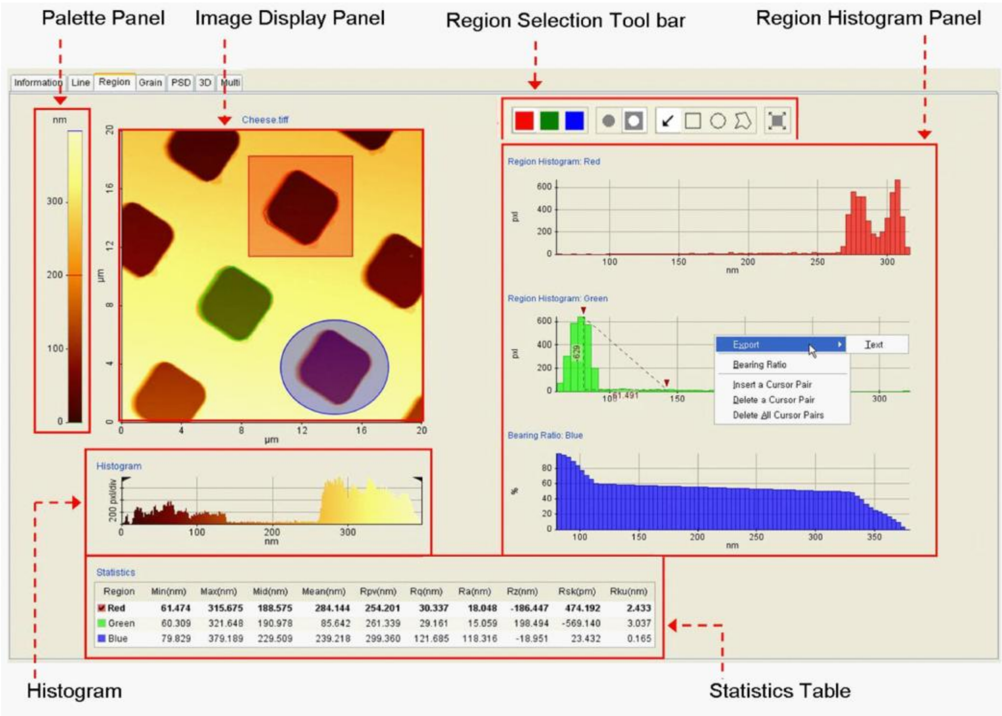


Figure 5-1-1. Region view

5-1-1 Palette Panel, Image Display Panel and Histogram

Just as in other Analysis views, the image you want to analyze can be displayed in the Image display panel with the Palette Panel.　It is the same Palette Panel and Image Display Panel that appears in all the analysis views of XEI.　Please refer to Chapter 3-2 and 3-3 for details.

Also the histogram of the entire image surface is displayed on the bottom of the Image Display Panel as in the other analysis views.　However, Histogram in the Region View has special ‘Height Restriction Markers’ to select pixels within certain height range.　Detailed features of the Region Selection Toolbar are explained in section 5-2.

5-1-2 Region Selection toolbar

Region selection toolbar, where the Tools for selecting region for the analysis are gathered, is at the right side of the image Display Panel.

5-1-3 Region Histogram Panel

Three Region Histograms, corresponding to three different user-selected Region groups (Red, Green and Blue), are generated automatically at the right side of the Image display panel. Detailed features of the Region Histogram Panel are explained in section 5-4.

5-1-4 Region Statistics Table

In the Region View, below the Image display panel, the Region Statistics table will be generated. Detailed features of the Region Statistics Table are explained in section 5-5.

5-2 Selecting Region for Region Analysis

To get reasonable information of surface statistics, it is important to select specific regions including or excluding the data for analysis. Region selection toolbar contains various tools that help you to select precise region for region data analysis. The process of selecting region for analysis is done in four steps.

Step 1. Select Region Group 

Region Group is the group of the 'selected area' for the region statistical analysis. Each region group is made of single or multiple 'selected area'. XEI allows user to create and edit up to three Region Groups, Red, Green and Blue for region analysis. The 'selected area' that belong to different Region Groups are discriminated by their color. Before you create or edit 'selected area' on the image for the region analysis, you should decide to which region group the 'selected area' will belong by clicking one of the Region Group Select button.

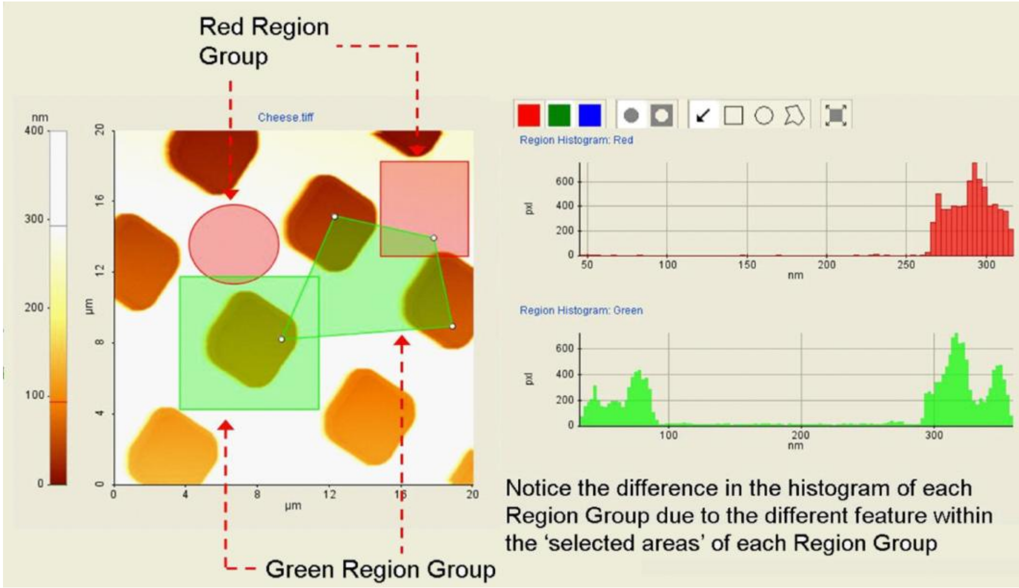
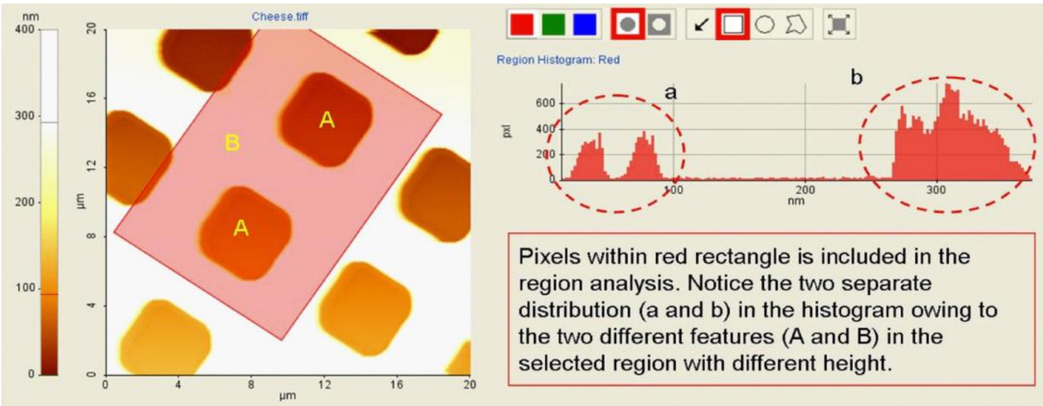


Figure 5-2-1. Region Group

Step 2. Select Inclusion or Exclusion 

You should decide whether the pixels within the 'selected area' you create to be included or excluded by clicking either Inclusion or Exclusion before you create a 'selected area'. Figure 5-2-2 shows effect of selecting Inclusion and Exclusion on region analysis result. Be aware that the selecting area as 'Exclusion' is effective only if the area selected as 'Exclusion' is part of the area that has been selected as 'Inclusion'.



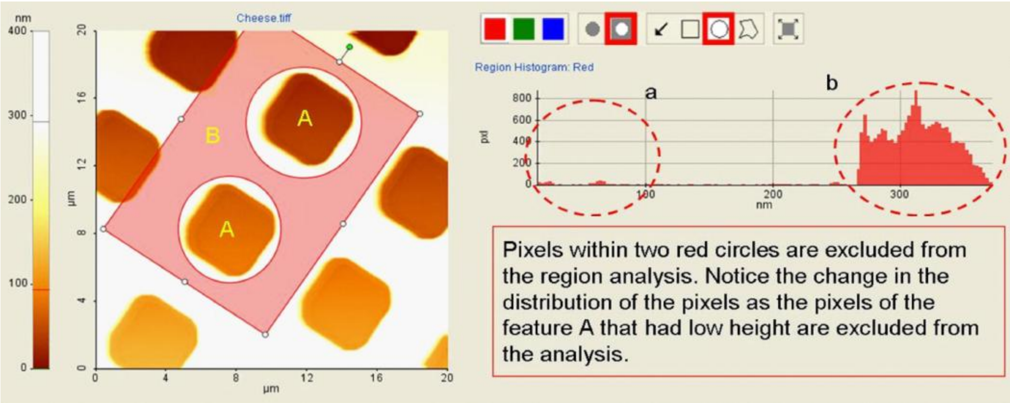


Figure 5-2-2. Region view

Step 3. Create 'selected area'

You can create 'selected area' of different shapes by using Rectangle, Ellipse and Polygon button. Also you can designate entire image as a 'selected area'. 'Selected area' for Inclusion will be painted in red, green, and blue while the 'Selected area' for Exclusion will be only outlined in red, green and blue depending on the color of the region group to which selected area' belongs to.

■ Rectangle & Ellipse

To create rectangle or ellipse shaped 'selected area', click the 'Rectangle' or 'Ellipse' button, respectively. Then, press the cursor at the point you want to create the top-left corner of a 'selected area', and drag the mouse pointer at the point you want to create bottom-right corner of a 'selected area'.

■ Polygon

To create polygon shaped 'selected area', click the polygon button and click the cursor onto the point you want to create a starting point of a polygon. Move and click the cursor at each point of the polygon region. Double-click at the point you would like to make the end point.

■ Entire Region

To set the entire image as 'selected area', click the 'Entire Region' button. It is set as default when you select 'Region View'.

Step 4. Edit the 'selected area'

You can move, delete and resize the 'selected area' created in step 3 with the help of the 'Move tool'. Move tool only appears on the toolbar only if you have checked 'region' check box from the 'Use Move Tool' option in the 'Preferences Window'.

When the 'Use Move Tool' option for the 'region' is checked, mouse pointer stays in 'region selection' (cross hair mouse pointer) mode so that user can continuously create 'selected area' for region analysis one after another. Mouse pointer will stay in 'region selection' mode unless you click 'Move Tool' button to exit 'region selection' (cross hair mouse pointer) mode and switch to 'region edition' (arrow mouse pointer) mode. On the other hand, when the 'Use Move Tool' option for the 'Region' is not checked, the mouse pointer will automatically switch from 'region selection' (cross hair) to 'region edition' (arrow) mode each time you create a line.

- **Selecting**

First, select the region group (R, G, B) corresponding to the region shape you would like to edit. Next, click 'Move tool' to enable the region shape edit. Click on the region shape you would like to move to select it. You can also select multiple region shape by pressing 'Ctrl' key as you click multiple region shape. To select all the region shape of the region group, press Ctrl+A or select 'Select All' in the context menu.

- **Moving**

The mouse cursor changes to four arrow cursor and selected region shape is marked by circular tracker around it. You can move the selected region by dragging it.

- **Deleting**

To delete the selected region shape, select delete command from the context menu or press delete button.

- **Changing Shape**

In case of rectangle and ellipse, you can also extend or shrink the selected region by dragging a small circular tracker that appears when you click the region.

You can also rotate a rectangle and ellipse by dragging a green circular tracker. In case of polygon, you can change the shape of the already made polygonal region by dragging each circular tracker of it. However, the number of points cannot be changed.

5-3. Height Restriction Markers

Below the Image display panel, histogram of the loaded image is displayed. Height restriction markers are two flags that appear when the Region Histogram is displayed. Height Restriction Markers are used to exclude the pixels within certain height range from the region analysis.

There are two Height Restriction Markers, Lower and Upper. Drag these two 'Height restriction Markers' on the each side of the histogram to set the lower and upper value of the pixels to be selected. Pixels with the height lower than the 'Lower Height restriction Marker' or higher than the 'Upper Height restriction Marker' will be excluded from the region analysis. Pixels that are excluded from the analysis are marked in violet color at Palette bar.

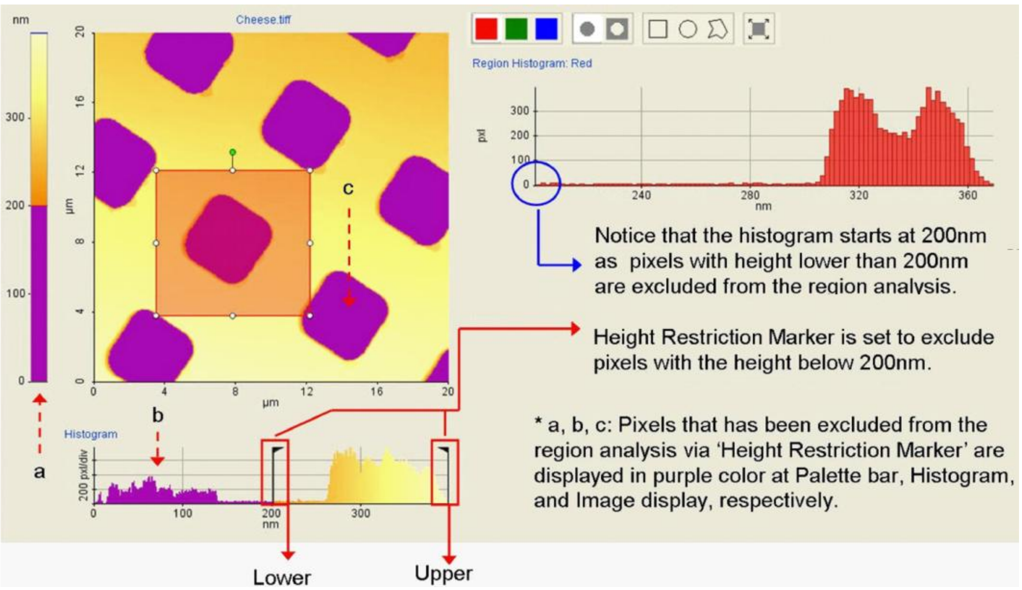


Figure 5-3-1. Region view

5-4. Region Histogram Panel

The Region Histogram panel provides information about the distribution of heights of the pixels within the selected region. Corresponding to the three selectable region groups, up to three Region Histograms (R, G, B) can be generated.

Figure 5-4-1 shows the Region Histogram panel. The x axis represents the height of data points in the sample. The y axis represents the number of pixels (or bearing ratio) in the selected region group. Several features that helps user to perform further analysis of the Region Histogram can be accessed through the context menu.

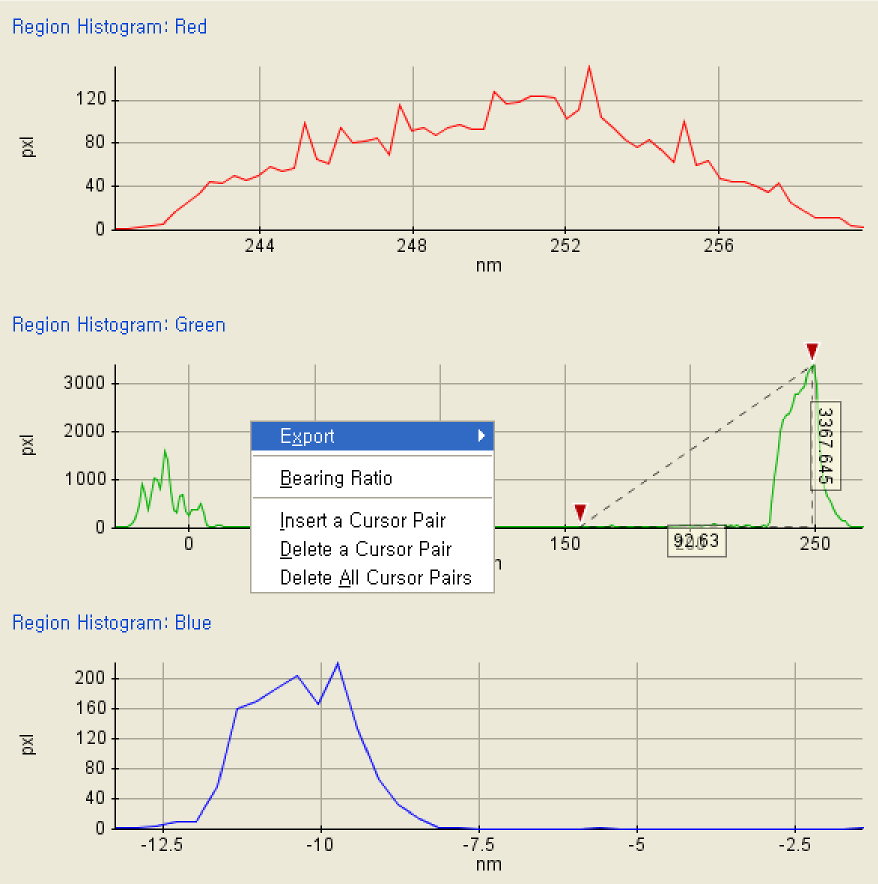


Figure 5-4-1. Region histogram panel

5-4-1 Export

Through the 'Export' command in the context menu of Line view, you can export the data of the Region Histogram as a text file or an image file and save it individually. This file can be used for analysis in other software program.

5-4-2 Bearing Ratio

Bearing ratio at arbitrary representative value in histogram is defined as follows.

Bearing ratio

= 100% - percentage of the pixels whose values are below the current representative value.

In default display, the y axis of the Region Histogram panel represents the number of pixels in the selected region group. User can choose to display ‘Bearing Ratio’ instead of the number of pixels by selecting ‘Bearing Ratio’ command in the context menu.

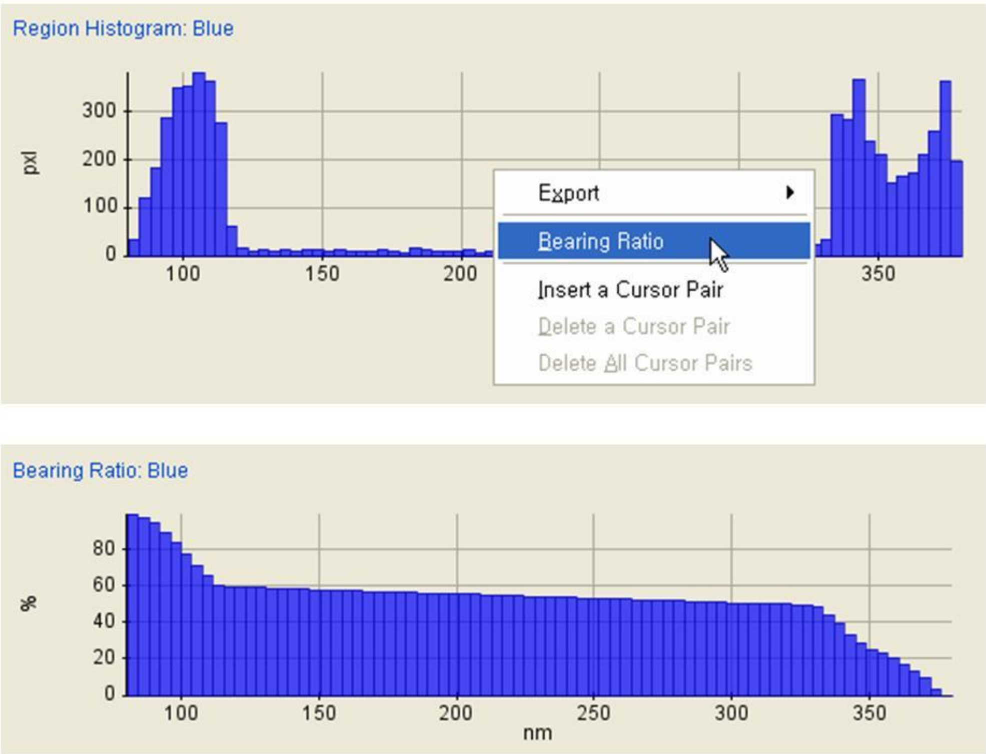


Figure 5-4-2. Bearing Ratio display

5-4-3 Insert (Delete) a Cursor Pair

Cursor pair can be inserted into a Region Histogram as it can be done in the Line Profile Panel (See section 4-3-2) to measure a difference between the number of pixels (or bearing ratio) and the representative value of two columns in the histogram. You can insert a cursor pair on the Line Profile by selecting 'Insert a Cursor Pair' command in the context menu. You can insert up to three cursor pairs per profile. Figure 5-4-3 shows a cursor pair inserted in the Region Histogram.

When the cursor pair is inserted, two triangular shaped cursors appear on two arbitrary columns on the Region Histogram. Along with the cursor pair, additional information is displayed (Figure 5-4-3).

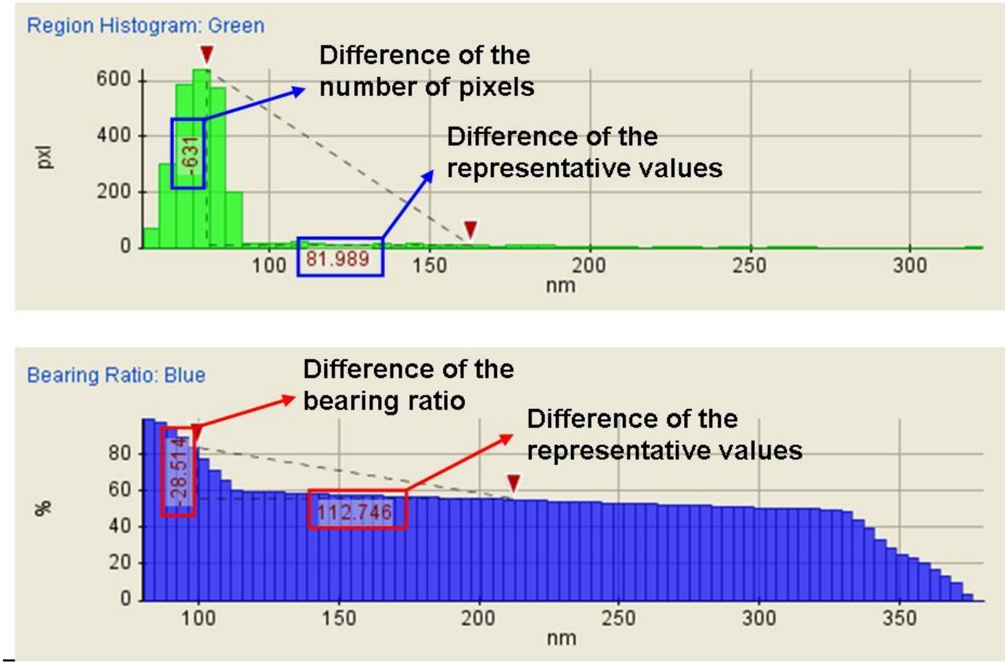


Figure 5-4-3. Cursor pair and displayed information

You can adjust the location of the cursors by dragging and dropping individual triangular cursors either from Region Histogram.   The information displayed with the cursor are automatically updated whenever you change the position of the cursor pair.

To delete the cursor pair from the Region Histogram, select 'Delete a cursor pair' command from the context menu.   This command deletes selected cursor pair from the Region Histogram.   To delete all the cursor pair from the Region Histogram, select 'Delete all cursor pairs' command from the context menu.

5-5. Region Statistics Table

The Region Statistics table, shown in Figure 5-5-1, displays the statistics of the all data points in the selected region group. Each region group is related to one row of the table. The results of the statistics on the selected region are updated automatically when you change the selected region group by resizing or moving the region selector.

The context menu (see the outlined box in Figure 5-5-1) is generated when you right-click the cursor in the Region Statics table. The menu items are same as one in Line Profile Statics table. Refer to Section 4-5.

Figure 5-5-1. Line statistics table

The meanings of the surface profile parameters displayed in the Region Statistics Table are defined as follows:

■ Min

Min is the minimum height value of the region.

■ Max

Max is the maximum height value of the region.

■ Mid

Mid is the arithmetic average between the minimum and maximum height value within the selected region. That is Mid = (Min + Max) / 2.

■ Mean

Mean is the arithmetic mean height value of the region. It is the sum of the height of each point divided by the number of points in the selected region.

■ Rpv

Rpv is the peak-to-valley of the selected region. It is the difference between minimum and maximum, that is, (Max – Min).

■ Rq

Rq is the root-mean-squared roughness. It is the standard deviation of the height value in the selected region.

■ Ra

Ra is the average roughness. The average roughness is the area between the roughness and its mean.

■ Rz

Rz is the ten point average roughness. It is the arithmetic average of the five highest peaks and five lowest valleys in the selected region.

■ Rsk

Rsk is the skewness of the selected region.

■ Rku

Rku is the kurtosis of the selected region. It indicates the “spikiness” of the selected sample surface.

Chapter 6. Grain View

In the 'Grain View' user can perform grain analysis on the loaded image. System automatically

1. Detects grains in the image
2. Marks each detected grain with different colors and numbers
3. Calculates important surface profile parameters of each detected grain and displays them in table,
4. Displays Distribution of surface parameters among detected grains will be displayed in the histograms.

Basically, you can perform grain analysis on the loaded image through the following procedure.

1. Bring an image file into the Analysis view from the Navigator view.
2. Enable the Grain View and select between two grain detection methods, Threshold or Watershed.
3. Set appropriate parameters for the selected grain detection method (Threshold: Range, Watershed: Filter level). Run the automatic grain detection process.
4. Each detected grain will be marked with different colors and numbers on the loaded image. Surface profile parameter of each detected grain will be displayed in the table. Distribution of surface parameters among detected grains will be displayed in the histograms. Export table, image and histogram as image or text file if desired.

6-1. Grain Detection Method

User can select between two different grain detection methods to use for automatic grain detection process. These two detection methods are 'Threshold' and 'Watershed'.

6-1-1 Threshold method

■ Algorithm

In the algorithm of 'Threshold' grain detection method, group of pixels surrounded by the other pixels whose values are larger (or smaller) than the upper (or lower) 'Threshold' value are recognized as grain. Figure 6-1-1 shows a simplified 1D example showing how 'Threshold grain detection algorithm'' works.

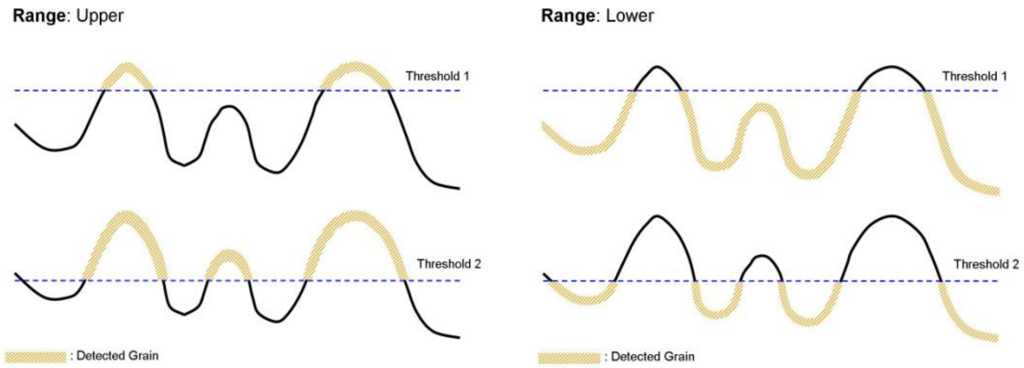


Figure 6-1-1. Threshold Grain detection

As can be seen from Figure 6-1-1, grain detection result differs according to the range setting and threshold value setting. XEI allows users to select between 'lower' and 'upper' for range and set the value of threshold by moving 'Height restriction marker' in the histogram of loaded image. The area of 'Height restriction marker' can be reset by clicking 'Reset Bounds' on Histogram Context menu (right clicking histogram will pop-up).

■ Upper

When the range is set to 'Upper', the 'Height restriction marker' appears on the left side of the histogram. User can set the 'upper threshold value' by moving the ‘height restriction marker’. The pixels corresponding to the left side of the upper threshold markers are colored in purple to indicate their values are smaller than the threshold value selected by the marker. Group of pixels surrounded by the other pixels whose values are smaller than the ‘Threshold’ value (i.e. pixels that are not colored in purple) are recognized as grain.

■ **Lower**

When the range is set to ‘Lower’, the ‘Height restriction marker’ appears on the right side of the histogram. User can set the ‘lower threshold value’ by moving the ‘height restriction marker’. The pixels corresponding to the right side of the lower threshold markers are colored in purple to indicate their values are larger than the threshold value selected by the marker. Group of pixels surrounded by the other pixels whose values are larger than the ‘Threshold’ value (i.e. pixels that are not colored in purple) are recognized as grain. Figure 6-1-2 shows the example of ‘Threshold’ grain detection process.

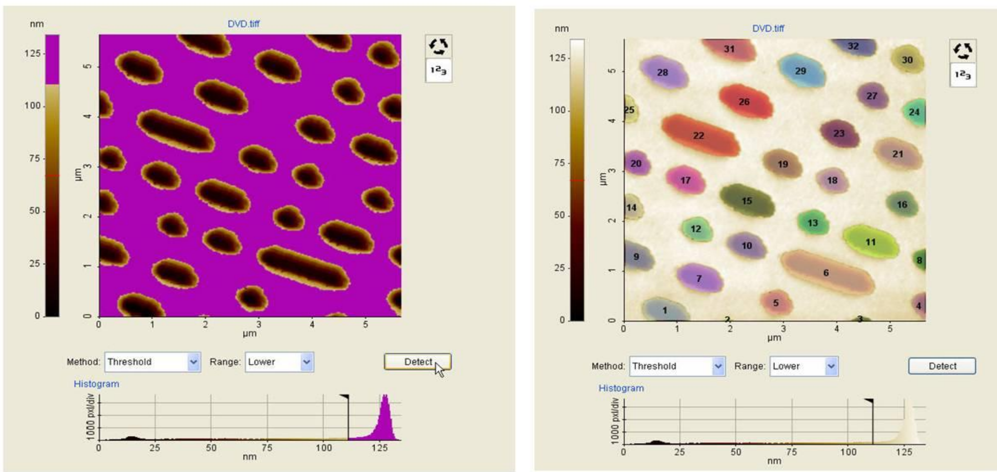


Figure 6-1-2. Threshold Grain Detection Process

6-1-2 Watershed method

■ **Algorithm**

To understand the algorithm of ‘Watershed’ grain detection method, let’s look at the 1D example in the Figure 6-1-3.

Now, let’s imagine that we pour water over this surface. Water will first fill the lowest point of the surface. The region that water starts to fill in is recognized as a single grain. As the level of water increases, water starts to fill more region of the surface and thus more grains are detected. Then when the level of water reaches certain value, water filling one grain will start to overflow to other neighboring grains. Algorithm recognizes this point and sets the grain boundary.

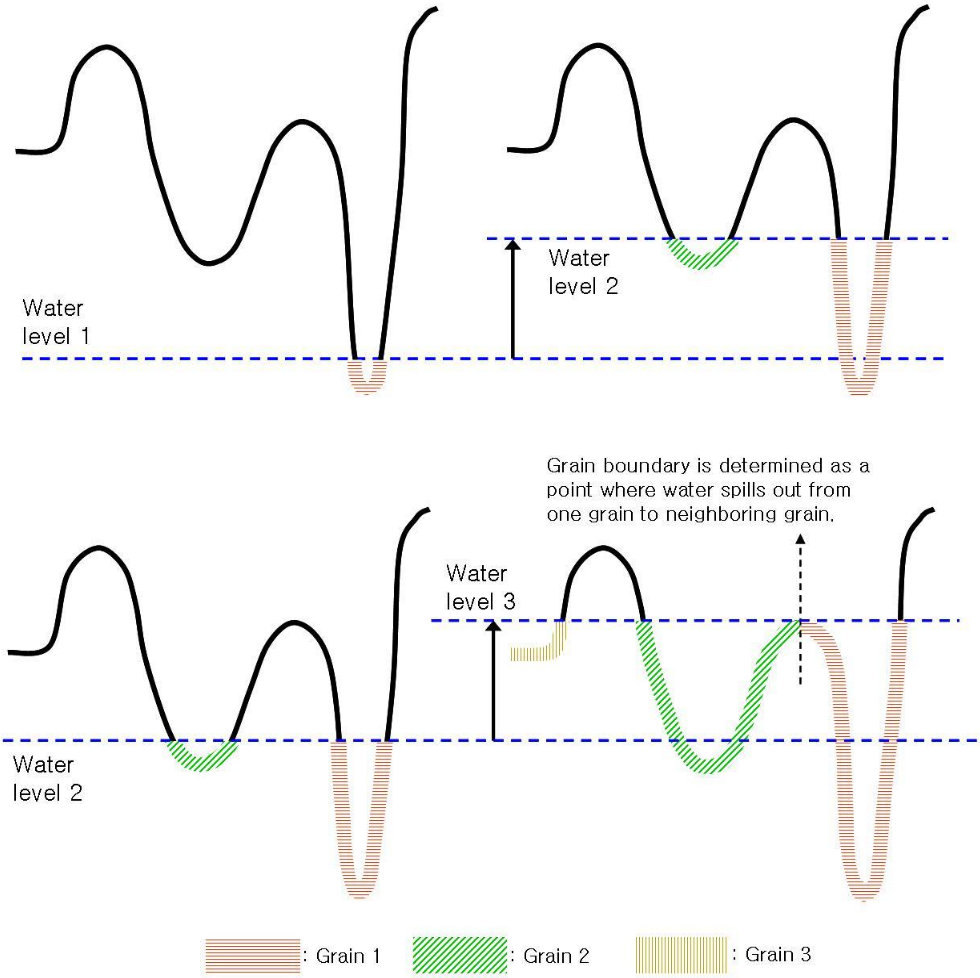


Figure 6-1-3. Watershed Grain Detection Process

■ Parameter settings in 'Watershed' grain detection

As it can be expected from the algorithm of the 'Watershed' grain detection method, surface roughness affects the number of detected grains, or the 'sensitivity' in the watershed grain detection method. See Figure 6-1-4. In some cases, ripples in the images can be detected as a grain via watershed algorithm, resulting in a single grain to be divided in to many 'unwanted' grains.

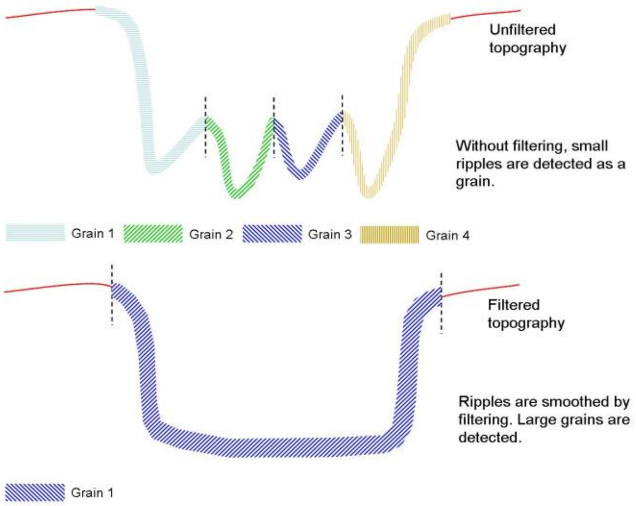


Figure 6-1-4. Effect of filtering on 'Watershed' grain detection

To control the surface roughness and thus the detection sensitivity of the method, it is desirable to apply 'smoothing' filter to the image before the detection algorithm starts. 'Filter level' parameter is the level of filter that is applied to the image before the 'Watershed' grain detection starts. The higher the filter level, the more the image will be smoothed before grain detection to remove 'grains' created by noise. Filter level acts to control the sensitivity of the grain detection as shown in Figure 6-1-5. Notice the difference in the number of total detected grain displayed in right corner and how the grains circled in dotted line differ according to the filter level.

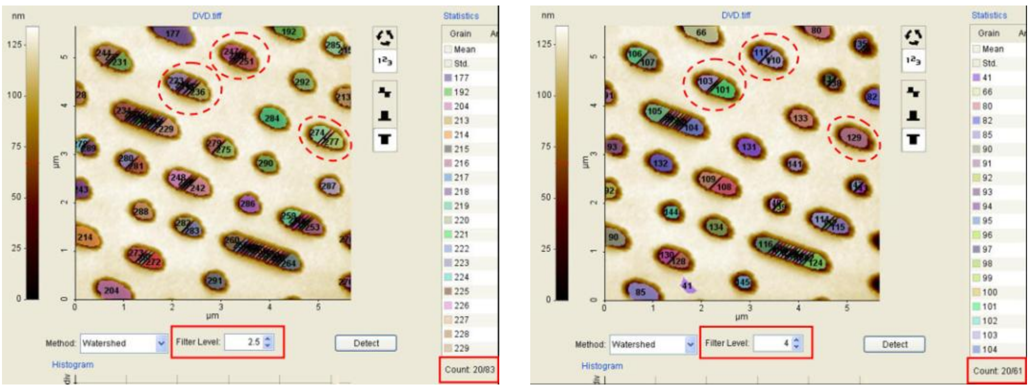


Figure 6-1-5. Effect of filter level on grain detection. Grain detection results with Filter level 4 (left) and filter level 2.5 (right).

6-2. Grain Display Panel

When the grain detection process is complete, XEI will mark each detected grain with a different color and number. The number for each grain is allocated in the order that it was detected. The color of each grain is randomly generated from XEI in order to prevent any grains being marked with same color. (Each colored grain is best seen if you view the original image in ‘Gray scale’.)

6-2-1 Selecting and deleting the detected grains

Each detected grain can be selected and deleted. This function is useful for picking out the ‘unwanted’ grains. Just click on any detected grain to select it. Then the boundaries of selected grains will be dotted with white circles. To delete the selected grains press ‘Delete’ button. You can also select multiple grains. There are two ways.

1. Hold down ‘Ctrl’ button of your keyboard as you click multiple grains.
2. Click and drag to select grains in the region of your interest (Figure 6-2-1).

To select all the detected grains in the loaded image, click any where on the image and then press ‘Ctrl+A’ or select ‘Select All’ from the context menu which appears when you right click on the image (Figure 6-2-1).

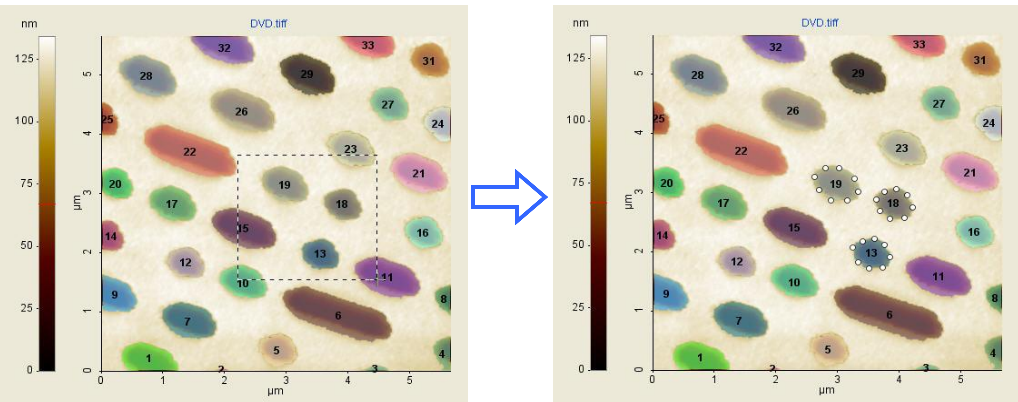


Figure 6-2-1. Multiple grain selection

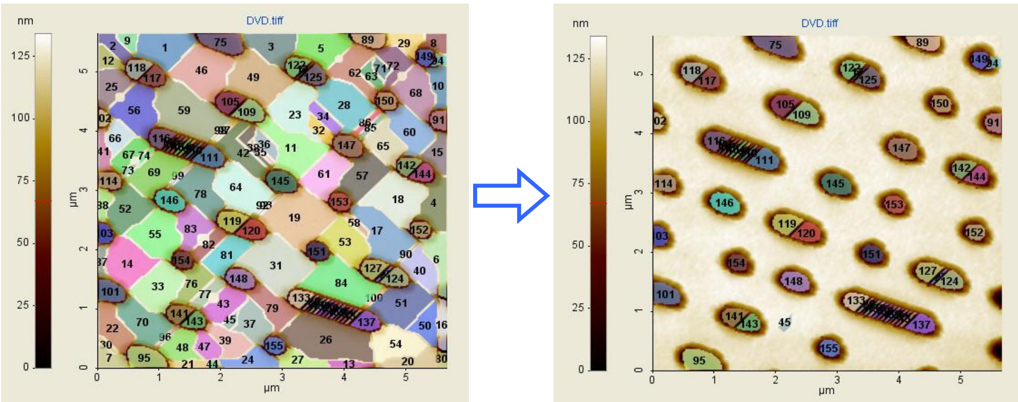
6-2-2. Show Number and Restore Grain Button

■ **Restore Grain Button** 

Click this button to restore the deleted grains by reloading the initially detected grains.

■ **Show Number Button** 

Click this button to display or hide the numbered label on each detected grains.



Show All **Show Valley**

Figure 6-2-2. Show All and Show Valley

■ **Show All (only in watershed mode)** 

Clicking this button displays all the grains detected by 'watershed' grain detection method.

■ **Show Hills Only (only in watershed mode)** 

Clicking this button displays only the 'hills' among the grains detected by 'watershed' grain detection method. In the algorithm of the 'watershed' grain detection, hills are defined as a grain whose average value of the pixels within exceeds the average of the pixels on the boundary.

■ **Show Valleys Only (only in watershed mode)** 

Clicking this button displays only the 'valleys' among the grains detected by 'watershed' grain detection method. In the algorithm of the 'watershed' grain detection, valleys are defined as a grain whose average value of the pixels within does not exceed the average of the pixels on the boundary.

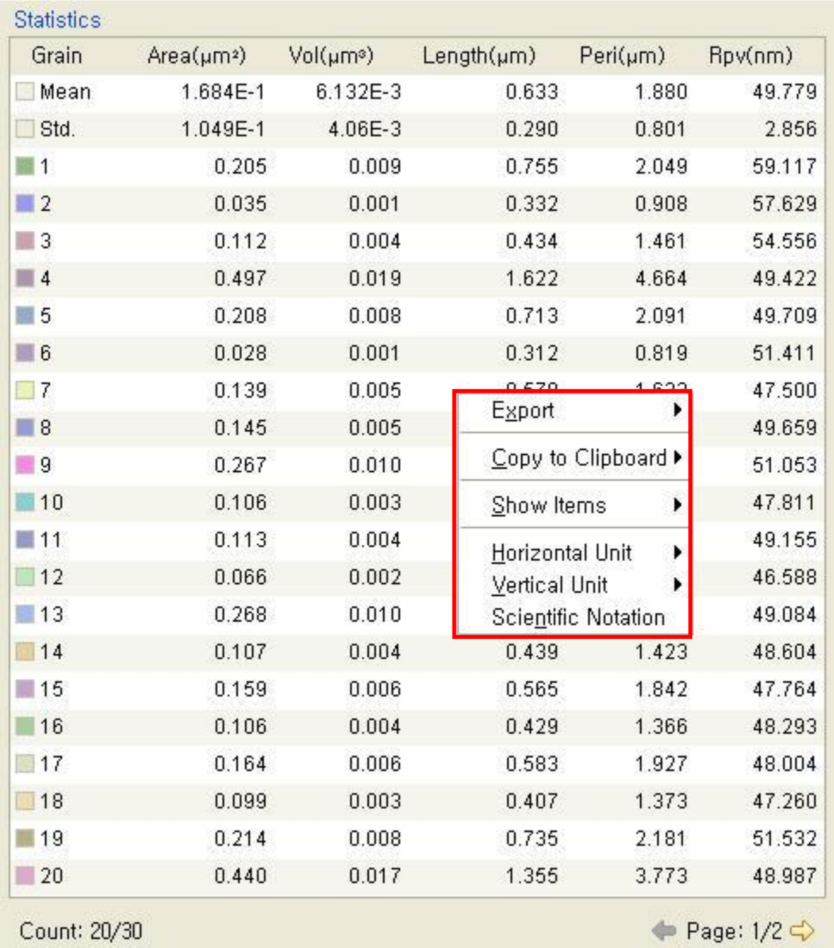
6-3. Statistics Table

After automatic grain detection, XEI calculates important surface profile parameters of each detected grain. These parameters are displayed in the statistic table. The meanings of the parameters are given in the table below.

Area	Area is the projected area of the detected grain.
Volume	Volume is the volume of the detected grain.
Length	Length is the distance between the two farthest points within the projected area of the grain.
Peri	Peri is the perimeter of the projected area.
Rpv	Rpv is the peak-to-valley of the line. It is the difference between minimum and maximum, that is, (Max-Min).

Table 6-3-1. Grain statistics parameters

In the 'Statistic Table', the surface profile parameters of the detected grains are arranged in numerical order. If more than 20 grains are detected system will display 20 grains at each page. You can jump from pages to pages through the arrow at the bottom right of the table. When the user selects grains from the image, surface profile parameters of the selected grains are displayed in the top of the table in bold letter. Moreover, when multiple grains are selected, mean value and standard deviation of each parameter are displayed in Mean and Std row. Table can be exported as a table or text file from the context menu which is shown when you right click the mouse with the pointer on the table. Currently, the context menu has 'Export', 'Copy to Clipboard', 'Show Items', 'Horizontal Unit', 'Vertical Unit' and 'Scientific Notation' items. For the information, please refer to the Section 4-5.



Statistics

Grain	Area(µm²)	Vol(µm³)	Length(µm)	Peri(µm)	Rpv(nm)
Mean	1.684E-1	6.132E-3	0.633	1.880	49.779
Std.	1.049E-1	4.06E-3	0.290	0.801	2.856
1	0.205	0.009	0.755	2.049	59.117
2	0.035	0.001	0.332	0.908	57.629
3	0.112	0.004	0.434	1.461	54.556
4	0.497	0.019	1.622	4.664	49.422
5	0.208	0.008	0.713	2.091	49.709
6	0.028	0.001	0.312	0.819	51.411
7	0.139	0.005	[illegible]	[illegible]	47.500
8	0.145	0.005			49.659
9	0.267	0.010			51.053
10	0.106	0.003			47.811
11	0.113	0.004			49.155
12	0.066	0.002			46.588
13	0.268	0.010			49.084
14	0.107	0.004	0.439	1.423	48.604
15	0.159	0.006	0.565	1.842	47.764
16	0.106	0.004	0.429	1.366	48.293
17	0.164	0.006	0.583	1.927	48.004
18	0.099	0.003	0.407	1.373	47.260
19	0.214	0.008	0.735	2.181	51.532
20	0.440	0.017	1.355	3.773	48.987

Count: 20/30 Page: 1/2

Figure 6-3-1. Statistics Table

6-4. Histogram Panel

The distribution of the certain surface profile parameters related to the grain size analysis, (i.e. area, volume, surface, perimeter) is plotted as a histogram in the histogram panel.

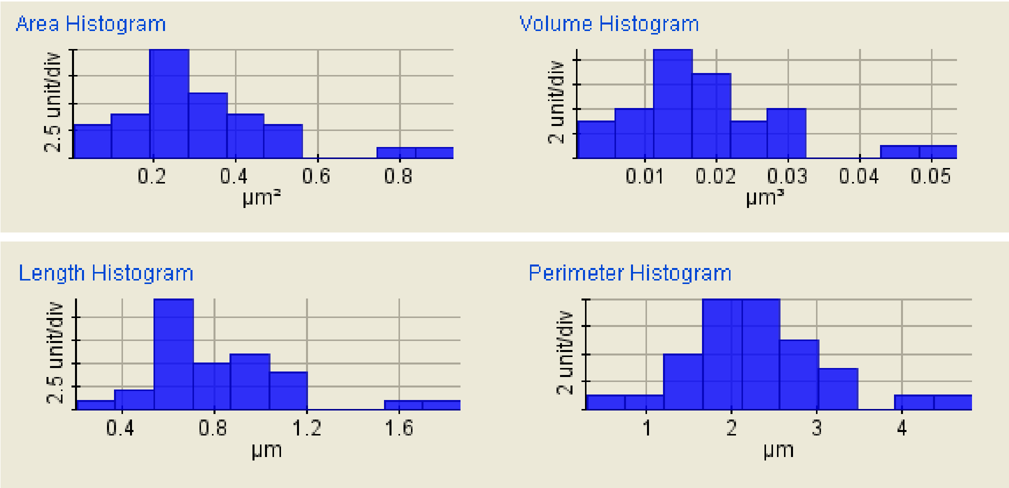


Figure 6-4-1. Statistics Table

Chapter 7. PSD View

In the ‘PSD View’ user can view PSD graph of the loaded image and obtain relevant data. PSD view is useful for surface roughness analysis.

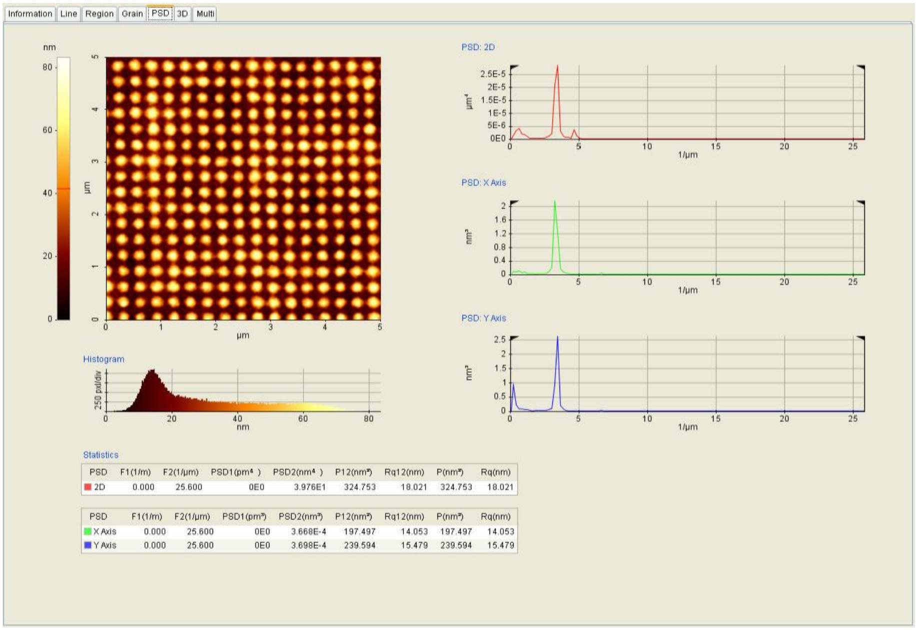


Figure 7-1. PSD View

7-1. What is PSD?

PSD is an abbreviation of “Power Spectrum Density.” PSD of the loaded image is obtained from Fourier Transform (FT) of the image and reflects the RMS roughness of the sample surface. PSD, FT, and RMS roughness are related as follows.

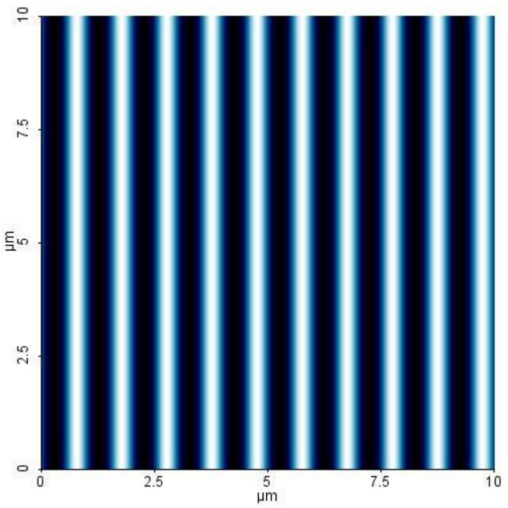
$$\mathbf{PSD = FT^2 = RMS^2}$$

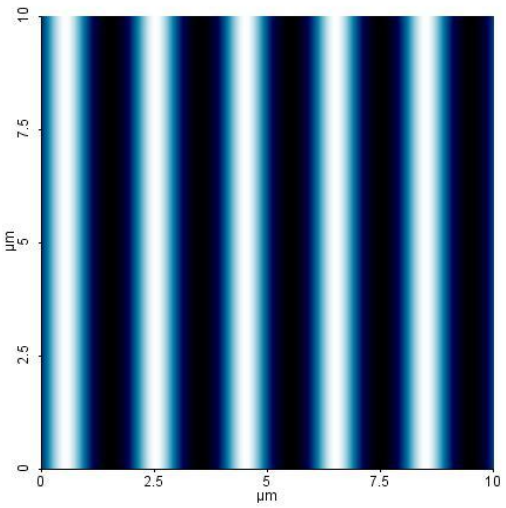
The power spectral density (PSD) of a surface is equal to square of its Fourier Transform (FT) and RMS roughness value squared.

7-1-1 Meaning of PSD

PSD is one of many parameters that are used to represent the surface roughness of the sample. PSD has advantages over the other surface roughness parameters such as RMS roughness because PSD contains the information how each frequency components contributes to the total roughness of the surface.

The example below shows the advantage of PSD as a surface roughness parameter. The images 'sinepi.tiff' and 'sine2pi.tiff' in Figure 7-1-1a are synthetic images generated from two sine functions with same amplitude but different frequency.





sinepi.tiff **sine2pi.tiff**

Roughness parameters of 'sinepi.tiff'

Statistics

Region	Min(pm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(pm)	Rsk(pm)	Rku(pm)
Red	0.000	447.391	223.695	223.709	447.391	157.978	141.909	-26.673	-0.001	205.645

Roughness parameters of 'sine2pi.tiff'

Statistics

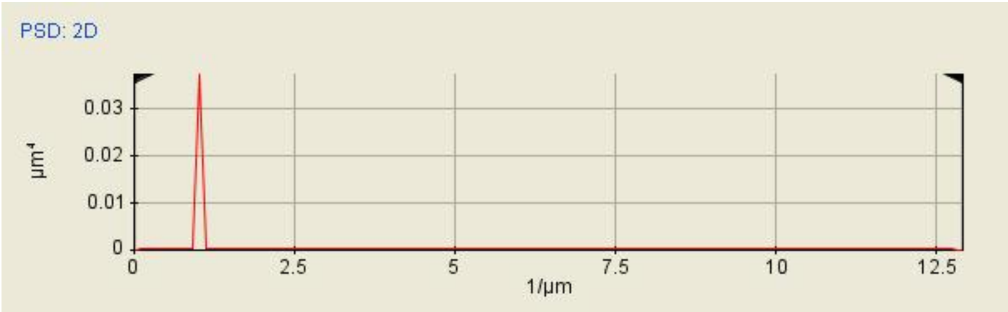
Region	Min(pm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(pm)	Rsk(pm)	Rku(pm)
Green	0.000	447.391	223.695	223.709	447.391	157.978	141.909	-26.673	-0.001	205.645

Figure 7-1-1a. Two synthetic images of same roughness

As a result, their roughness parameters (Rpv, Rq, Ra, Rz, Rsk, Rku) are same despite eminent differences between their surface profile. These images are also included in sample image folder of XEI (C:\Park Systems\XEI\Samples). You can verify that they have the same roughness.

However, PSD graph which contains not only roughness information but also the contribution of each frequency components to the roughness can discriminate the difference of roughness between two images.

2D PSD of 'sinepi.tiff'



2D PSD of 'sine2pi.tiff'

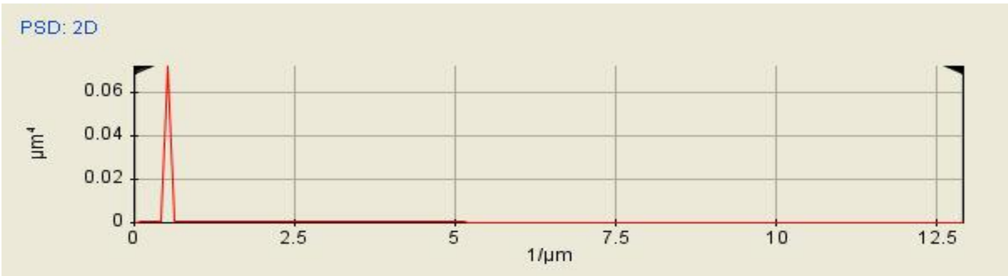


Figure 7-1-1b. PSD of two synthetic images of same roughness

7-2. PSD Graphs

XEI calculates and plots three different types of PSD for the loaded image; PSD X, PSD Y and PSD 2D. The X axis of the PSD X and PSD Y graph is the 'spatial frequency (cycle/μm)' of the image. For PSD 2D graph, the unit of the 'spatial frequency' is different (cycle/μm^2) as the range of power spectrum is 2 dimensional area.

The Y axis of the PSD graph is 'Power Spectrum Density', which is Power spectrum (μm^2) corresponding to each spatial spectrum (cycle/μm) value. Thus the unit for the Power Spectrum Density is μm^2 / (cycle/μm) = μm^3.

For each PSD graphs, there are two cursor(F1, F2) that slides along the X axis to mark point of interest on the PSD graph.

7-2-1 PSD 2D

PSD 2D graph is generated from 2 dimensional Power spectrum of the image. Power corresponding to the area of same 'spatial frequency' (represented as concentric circle in 2D power spectrum of the image)

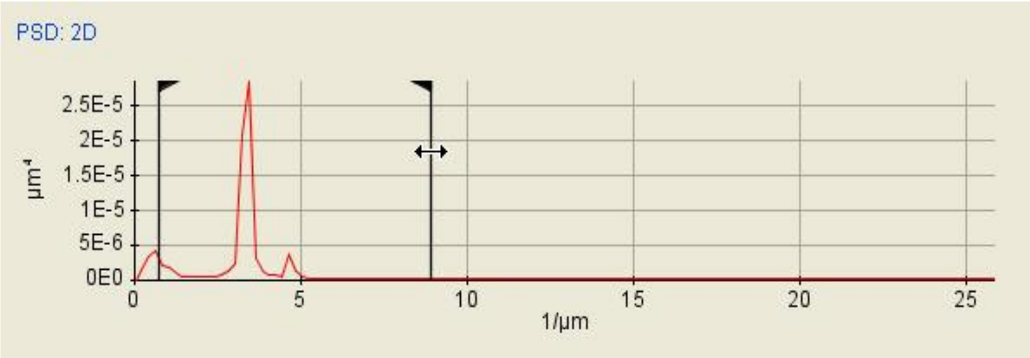


Figure 7-2-1a. PSD 2D

7-2-2 PSD X(Y)

PSD X(Y) is an average of the power spectrums for each line of the image parallel to X(Y) axis

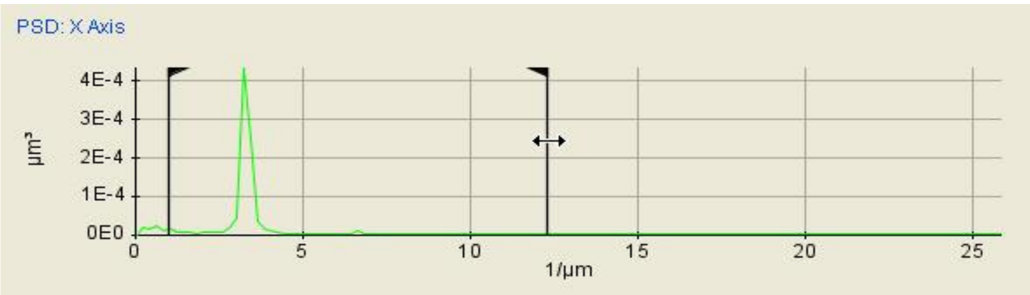


Figure 7-2-1b. PSD X axis

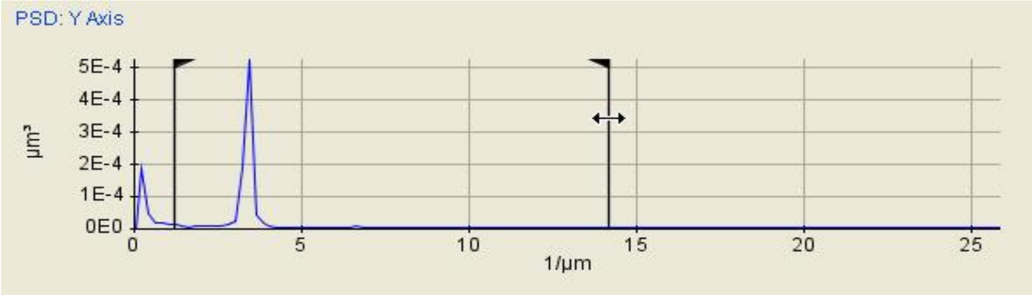


Figure 7-2-1c. PSD Y axis

7-2-3 PSD Context Menu

Right clicking on the graph will appear menu window as Figure 7-2-2d.

Figure 7-2-2d. PSD Context Menu

- **Export**

PSD graphs can be exported to 'text' or 'image' file for further analysis through other data processing software.

- **Copy to Clipboard**

PSD graphs can be copied to clipboard and pasted to the corresponding document program.

- **Show Cursor Pair**

For each PSD graphs, you can show two cursors that slide along the X axis to mark point of interest on the PSD graph.

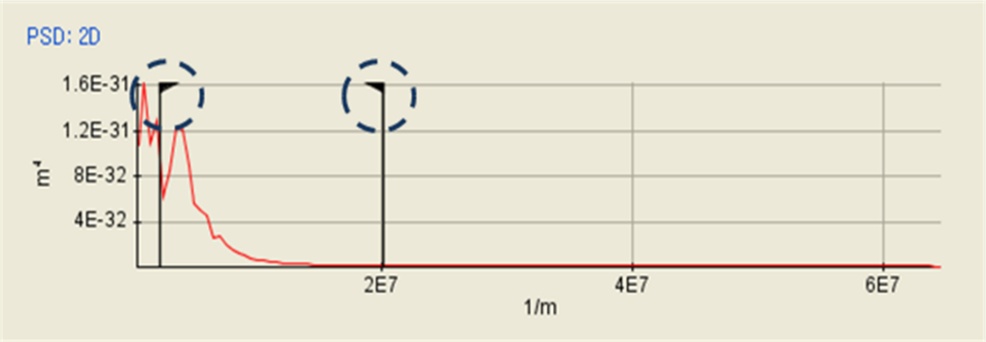


Figure 7-2-2e. PSD Show Cursor Pair

- ## Axis Options

Graph scale and range can be adjusted in 'Axis Options' dialog which is popped up when choosing 'Axis Options' menu. Data Range/Scale can be appointed on each axis.

Linear Scale: Display selected axis' data range as linear scale.

Log Scale: Display selected axis' data range as log scale.

Auto Range: Display full data range in a selected axis.

Fixed Range: Display selected axis' inserted Min/Max values. To select big or small value, base and exponent are separated.

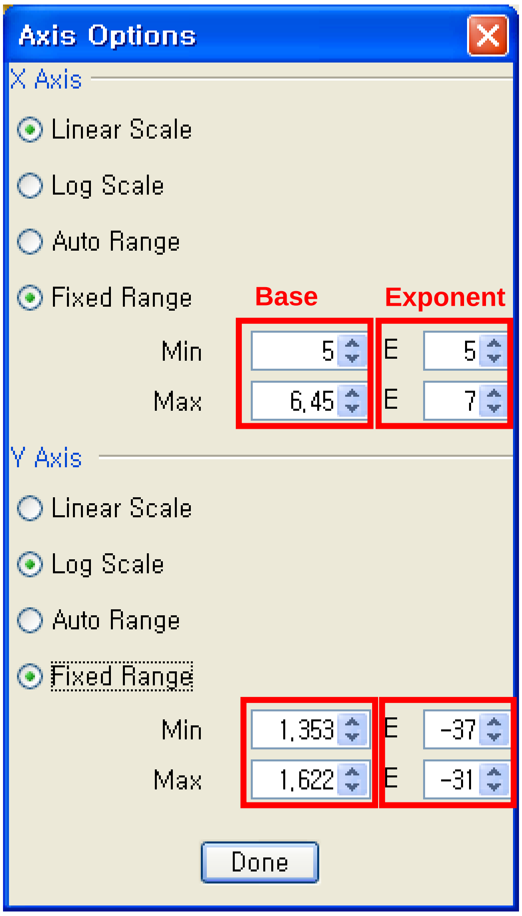
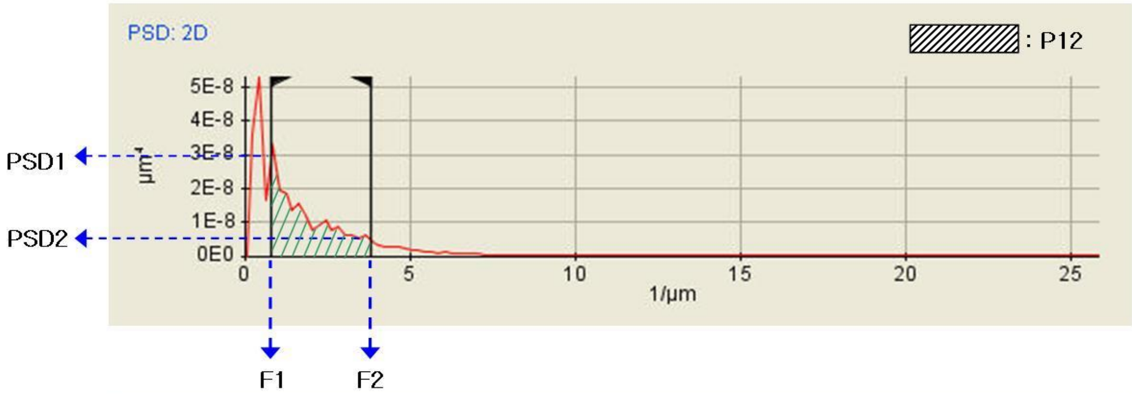


Figure 7-2-2f. PSD Axis Options

7-3 PSD Statistics Histogram

Various statistical analysis results of the PSD graph is displayed in this Histogram Panel. Below the Histogram panel, PSD Statistics table is shown at the same time. When you right click the mouse with the pointer on the table, you can see the context menu. Currently, the context menu has ‘Export’, ‘Copy to Clipboard’, ‘Show Items’, ‘Horizontal Unit’, ‘Vertical Unit’ and ‘Scientific Notation’ items. For the information, please refer to the Section 4-5.



Statistics

PSD	F1(1/mm)	F2(1/μm)	PSD1(μm^4)	PSD2(μm^4)	P12(nm^2)	Rq12(nm)	P(nm^2)	Rq(nm)
2D	600.000	8.800	4.114E-6	1.86E-8	311.735	17.656	324.753	18.021

PSD	F1(1/μm)	F2(1/μm)	PSD1(μm^3)	PSD2(nm^3)	P12(nm^2)	Rq12(nm)	P(nm^2)	Rq(nm)
X Axis	0.800	12.200	1.049E-5	2.619E2	183.196	13.535	197.497	14.053
Y Axis	1.000	14.000	1.028E-5	2.339E2	184.046	13.566	239.594	15.479

Figure 7-3-1. PSD Statistics & Histogram

- **F1(2)**

  Spatial frequency of the cursor 1(2)'s position.

- **PSD1(2)**

  Power Spectrum Density at the cursor 1(2)'s position.

- **P12**

  Area under the graph bounded by the cursor 1 and 2.

- **Rq12**

  RMS roughness between the cursor 1 and 2. Square root of the P12.

- **P**

  Total area under the graph.

- **Rq**

  Total RMS roughness of the image. Square root of the P.

Chapter 8. Fractal View

In fractal geometry, objects can have non-integer (fractional) dimensions. Fractal analysis allows calculation of the dimension of sample topographies using the triangulation, cube counting, and partitioning methods.

To see how an object can have a non-integer dimension, consider a continental coastline. If one measures the coastline with a 100km-length ruler, a certain measurement will result. Then, if one took multiple 10km-length rulers, a larger measurement will result, as more of the curves will be counted. As the length of the rulers used approaches 0, the measured coastline length approaches infinity. The slope of this length-of-ruler to length-of-coast curve can be said to be the dimension of the coastline. For a topographic image, one counts area or volume instead of length.

As shown in Figure 8-1, the Fractal Analysis View consists of Image Display Panel, the Fractal Analysis Control Panel, and the Fractal Graph.

The following procedure can be used for estimating D:

1. Bring an image file into the Analysis view from the Navigator view.
2. Select Fractal View.
3. Adjust the parameters in the Fractal Control Panel.
4. Adjust the cursors in the Fractal Graph.
5. Click the Recalculate button.

Figure 8-1 shows some of these steps.

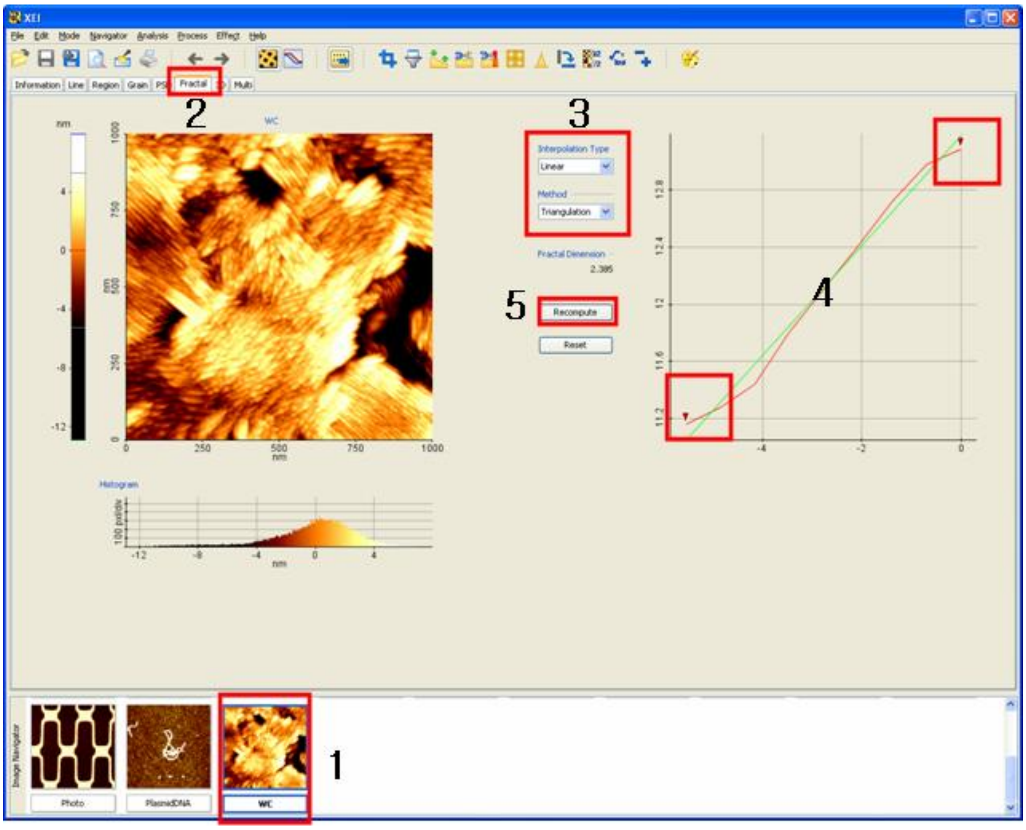


Figure 8-1. Procedure for Fractal view

8-1. Fractal View

To open the Fractal view, select the 'Analysis>Fractal' menu or click the Fractal view tab below the Menu bar.

The Fractal view consists of three main regions (see Figure 8-1-1): On the left is the Image Display Panel, which shows the image being analyzed. In the center is the Fractal Control Panel, which accepts parameters from the user and displays the analysis results. On the right is the Fractal Graph, which displays the curve relevant to the selected analysis method, and allows the user to select the region to be used in fractal analysis.

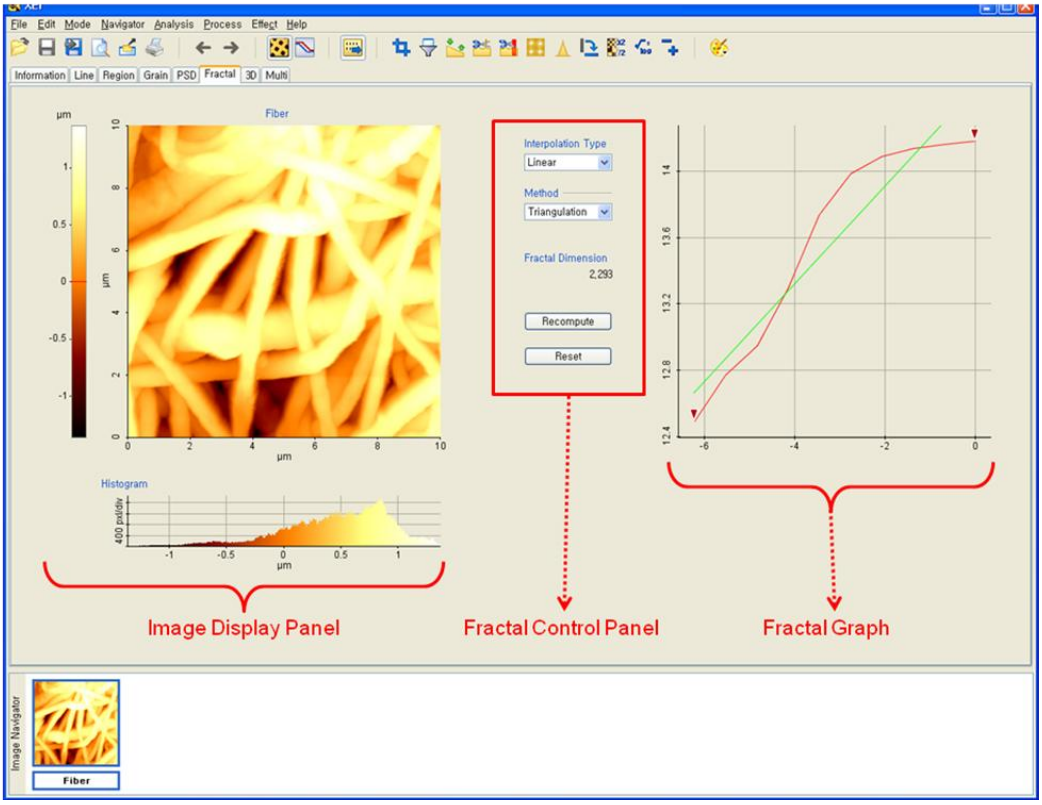


Figure 8-1-1. Layout of Fractal View

8-2. Fractal Control Panel

There are several items in the control panel that can be controlled for estimating D, the fractal dimension value, and for displaying the results of the estimation.

8-2-1. Interpolation Type

When computing the fractal dimension, it is useful to increase the effective resolution by estimating, or interpolating, values in between pixels. Currently, only linear interpolation is available.

Linear interpolation simply takes the arithmetic mean of the two pixels.

8-2-2. Method

There are several methods by which to calculate D.

■ **Triangulation**

In the Triangulation method, the surface of the image is "coated" with triangular plates. As the triangles become more numerous and smaller, their collective surface area increases. This relationship is the basis of the triangulation method.

■ **Box Counting**

In the Box Counting method, the image is imagined to be enclosed in a cubic area. As the cube is increasingly split into smaller pieces, some of the resulting cubes are no longer required to completely overlap the sample, and thus the collective volume of the cubes decreases as their size decreases.

■ **Partitioning**

Similar to the Box Counting method, the image is separated into prisms. However, the value measured is not the combined volume of these prisms, but rather the difference in height between the prism and the sample surface. As these prisms become smaller, the sum of these differences, or variance, can be expected to decrease. When the slope between the number of cubes and the variance is β, the fractal dimension is equal to $3 - \beta/2$.

8-2-3. Fractional Dimension

This label displays the estimated value for D with the current parameters.

8-2-4. Control Buttons

The Recompute button causes a new estimation to be performed with the current settings.

The Reset button reverts all of the parameters to the default values.

8-3. Fractal Graph Panel

The Graph Panel plots the number of subdivisions to the relevant value, depending on the method described in 8-2-2. Two cursors are used to select the domain to be used in estimating the fractal dimension. Simply click and drag the cursors to move them, or select one and use the right and left keys to move them with pixel precision.

Chapter 9. 3D View

In the 3D view, you can see both the features of the image and the relationships between those features in a 3D rendered view. Different from other microscopic techniques such as SEM or TEM, the 3D view is unique to SPM. The scanning probe microscope scans the sample surface horizontally (x, y) line by line while collecting the vertical (z) direction profile of the sample surface. As a result, the scanning probe microscope collects truly 3-dimensional (x, y, z) information from the surface and this 3-dimensional data represents true surface topography.

Basically, you can create the 3-diemnsional perspective of an image through the following procedure.

1. Bring an image file into the Analysis view from the Navigator view.
2. Enable the 3D view to generate an initial 3D rendering of the image.
3. Adjust several 3D rendering parameters to obtain the best 3D view
4. Export and print out the 3D image if desired.

Figure 9-1 shows the summarized procedure for 3D rendering of an image.

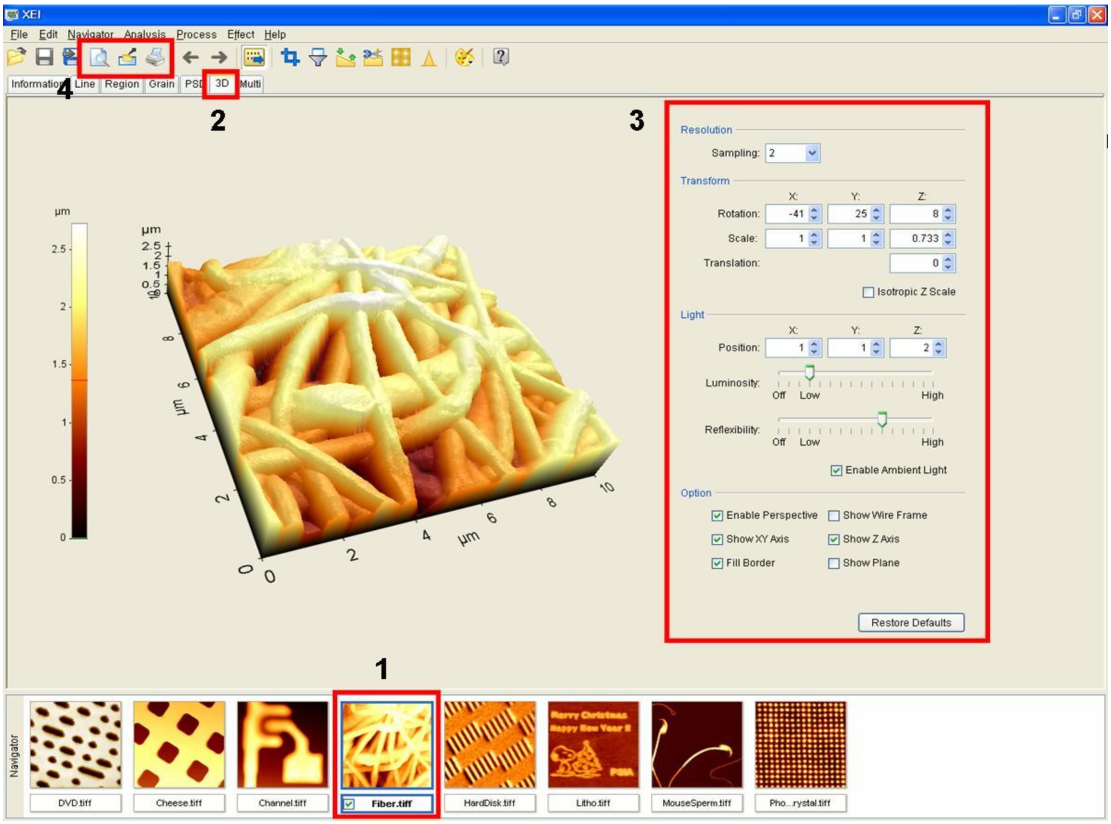


Figure 9-1. Procedure for 3D view

9-1. 3D View

To open the 3D view, select the 'Analysis>3D' menu or click the 3D view tab below the Menu bar.

The 3D view consists of two main regions (see Figure 9-1-1): One is the 3D Image display panel that is placed to the left side in the Analysis view. The other is the 3D rendering parameters panel to the right side. These are going to be described in detail in the next section.

In the 3D view, you can change the following characteristics of the image:

- The presented resolution of the image
- The rotation angle of the image
- The size of the image
- The height magnification
- The position of the simulated light source

- The color and intensity of the simulated light source
- The color of the image and background

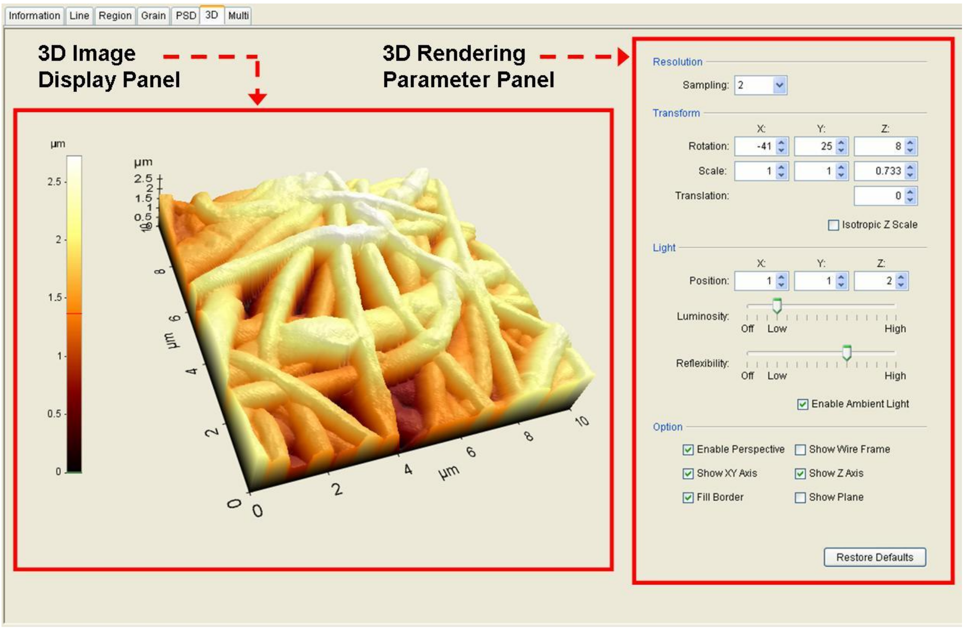


Figure 9-1-1. Layout of 3D View

9-2. 3D Image Display Panel

In the 3D Image display panel, the 3-dimensional perspective of an image is displayed and updated immediately after you adjust anything of the available 3D rendering parameters. The 3D image is held within a frame and presented on a virtual plane. Dragging the cursor within the frame allows you to rotate the image in the 3D Image display panel.

Using the 3-dimensional (x, y, z) data set, the individual lines will be stacked to generate the 3-dimensional perspective and then this view may be adjusted by simulating the reflection of light from the surface. Surface features that would be illuminated from above appear bright, and features that would be illuminated from an oblique view appear dark. You can vary the direction of illumination by changing the position of an artificial light source. You can also rotate the image to vary your viewing angle. Figure 9-2-1 shows the general 3D Image display panel

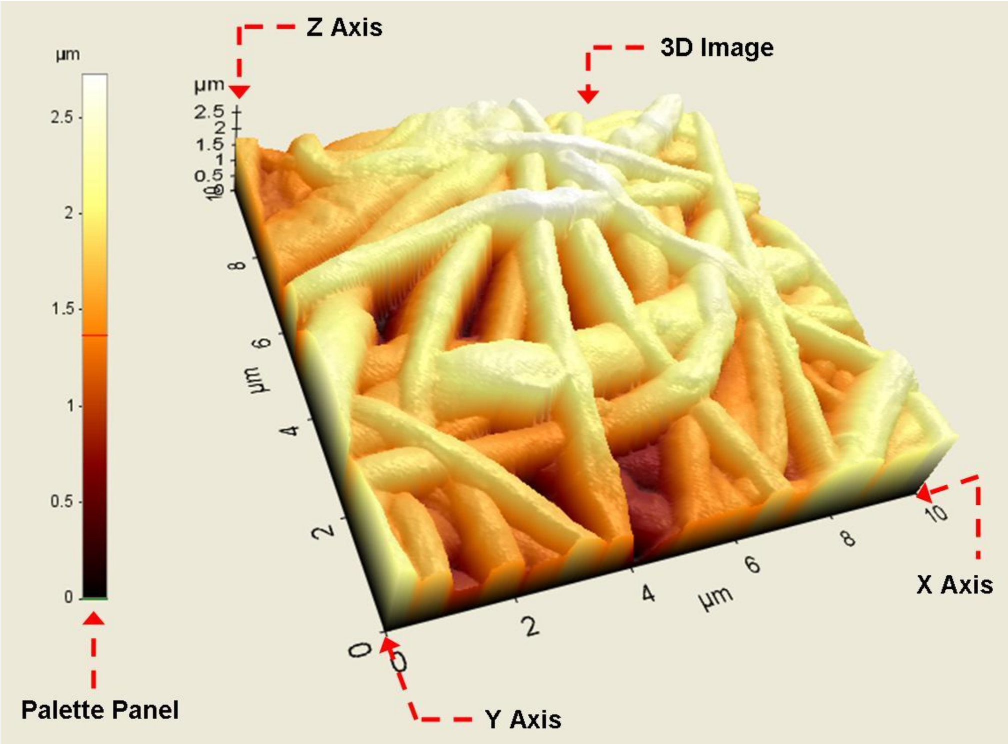


Figure 9-2-1. 3D Image display panel

9-3. 3D Rendering Parameters

The 3D rendering parameters can be adjusted to get the best 3-dimmensional view of the sample surface. Whenever you adjust these parameters, they are automatically applied to the 3-dimensional image in the 3D Image display panel. These 3D rendering parameters, as shown in Figure 9-3-1, are described further below.

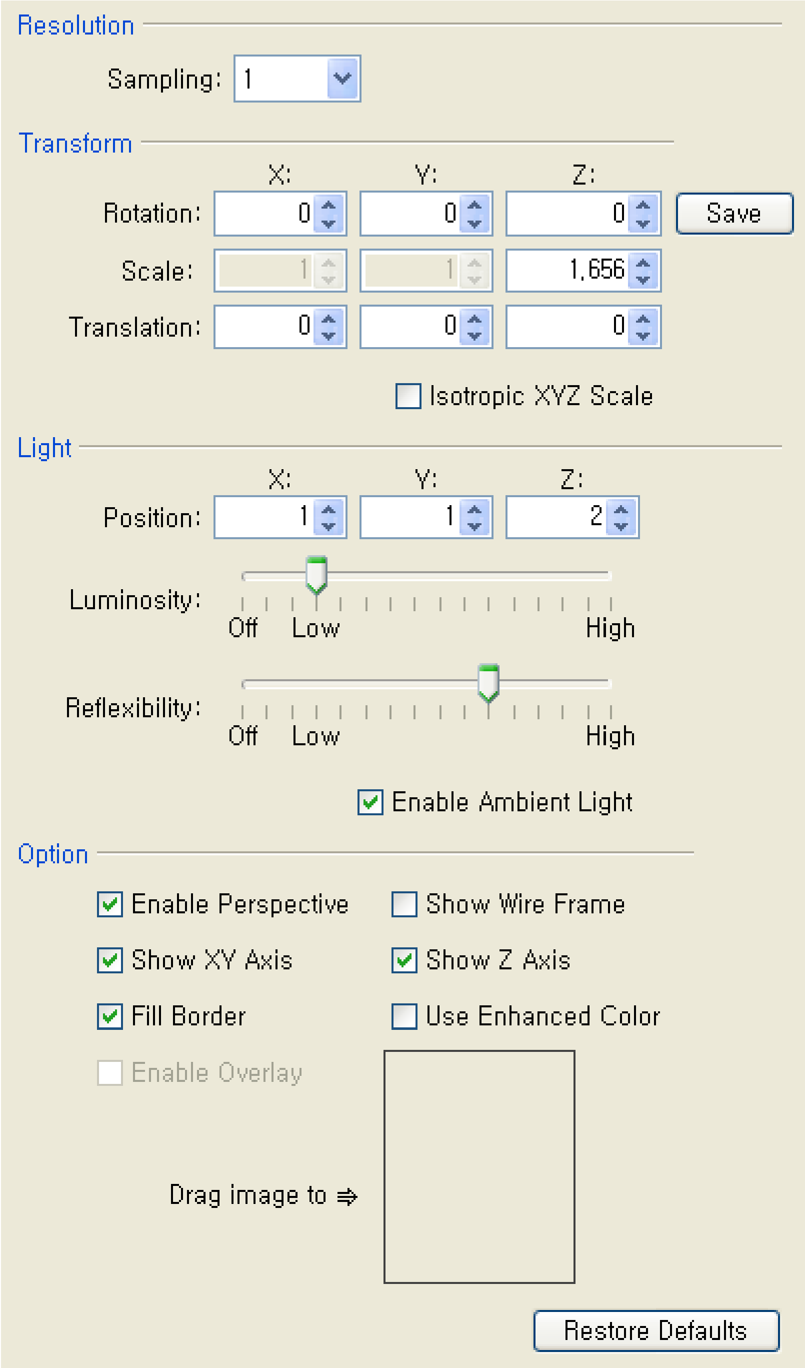


Figure 9-3-1. 3D rendering parameters

9-3-1. Resolution

Allows you to vary the resolution of the displayed 3D image. You can select the number of sampling data points in the Sampling combo box. By default, the image pixel size is set to be 256×256. So the number of sampling data points is automatically changed to be displayed at this default resolution. However, when the pixel size of the original image is more than 256×256 (512, 1024, 2048, and 4096), you can enhance the resolution of the 3D view by selecting the appropriate sampling number (1, 2, 4, 8, or 16; see Figure 9-3-2). However, increment of the image pixel size is less effective since this may need larger memory but cannot show remarkable enhancement of the image's resolution.

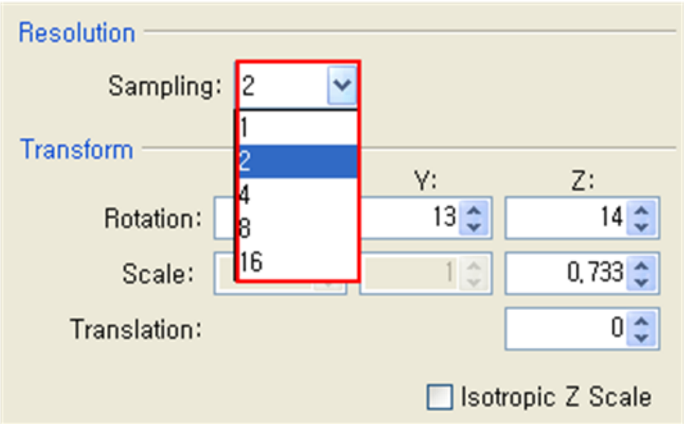


Figure 9-3-2. Sampling numbers

■ Sampling Number

Changes the number of sampling data points in the line. Sampling number is automatically set to as follows: the number of data points ÷ sampling number =256.

Sometimes the number of data points collected for a line exceeds the number of pixels on the 3D Image display panel. In this case, you should select the reasonable sampling number (see Figure 9-3-2) to enhance the resolution of the 3D displayed image. When you open a new image, the sampling is selected automatically to display 256 data points for a line. To adjust the display for higher resolution images, you should set the sampling numbers manually. For example, when the pixel size of the original image is 1024, the sampling number is automatically converted to 4 (in order to reduce its pixel size to 256×256 1024 should be divided by 4), but you can enhance the resolution of the 3D image by selecting a smaller number for sampling the data (when the number is 1 or 2, the image pixel size is 1024 or 512).

9-3-2. Transform

Allows you to alter the viewing angle and the scale of the 3D image. Also, you can translate the 3D rendered image in the z direction. Figure 9-3-3 shows the 3D image view that the Transform functions are applied to the 3D rendition of an image.

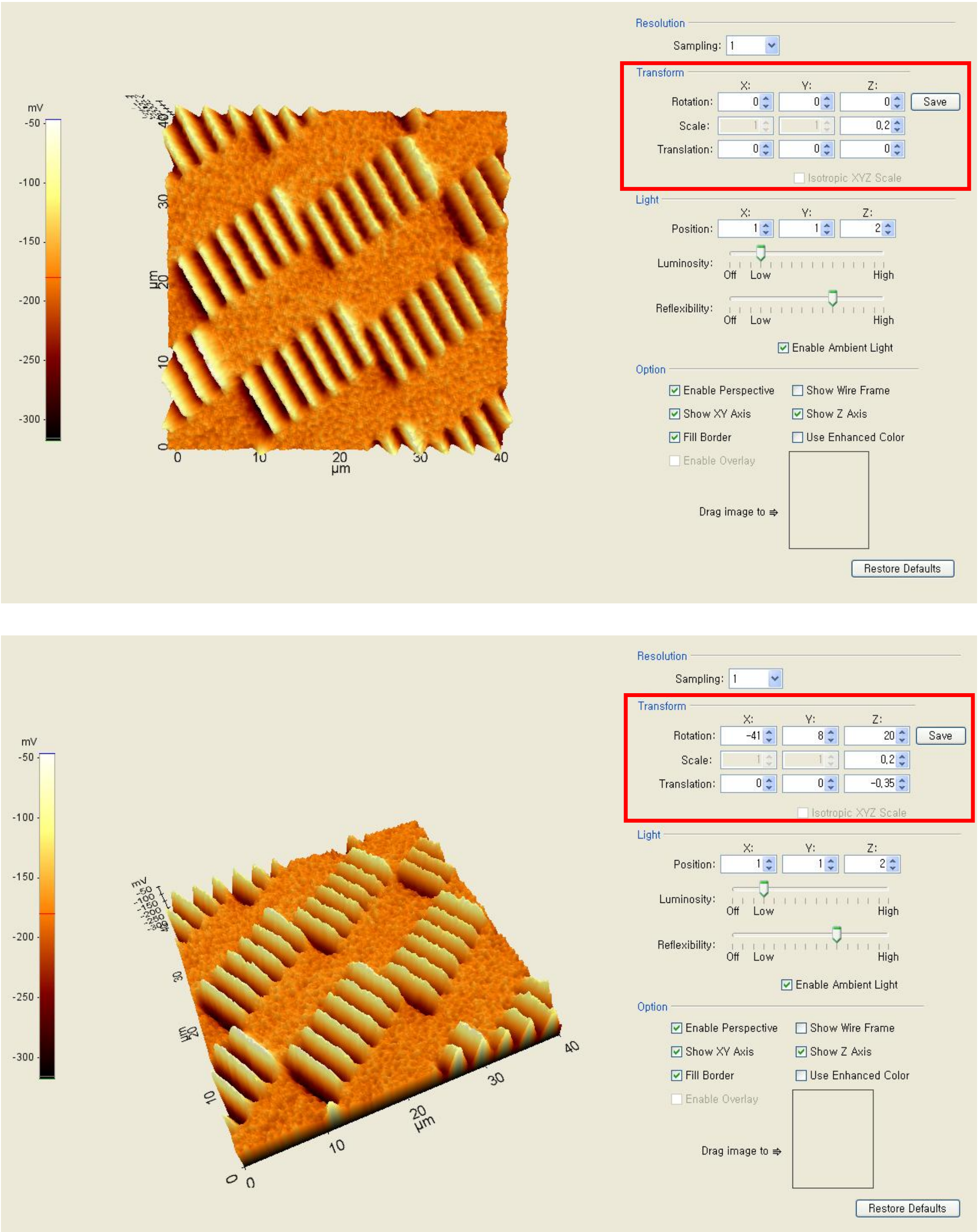


Figure 9-3-3. Transformed 3D image

■ Rotation

Changes the viewing angle of the image by rotating the 3D image. You can rotate the image plane around the x, y and z axis by entering the rotation degrees or by using the spin buttons next to the Rotation text fields for X, Y and Z respectively. You can change the viewing angle from -180 to 180 in x, y and z direction. The Rotation angle can be saved by clicking 'Save' button in Transform Panel. After save, all the images that opens in 3D Analysis View will be based on previous saved value. When clicking 'Restore Defaults' button, all the values will be set as default value. You must click 'Save' button if these values need to be saved.

- X: changes the viewing angle of the image in the x direction
- Y: changes the viewing angle of the image in the y direction
- Z: changes the viewing angle of the image in the z direction

■ Scale

You can alter the scale of the 3D rendered image in the horizontal (x, y) and the vertical (z) directions. Also, you can manipulate the scale by rolling the mouse wheel. When adjusting the scale using the mouse wheel, the ratio between X, Y, and Z axis on the image will be preserved. The 'Isotropic Z scale' check box fits the z scale to the maximum scale of x, y. Consequently, you will see an image that is similar to the real surface.

- X: alters the scale of the 3D image in the x direction
- Y: alters the scale of the 3D image in the y direction
- Z: alters the scale of the 3D image in the z direction

■ Translation

You can change the position of the 3D image in XYZ direction. Also, you can change in XY direction with dragging mouse and control key on keyboard.

9-3-3. Light

Changes the position of the simulated light source. By default, an ‘Ambient Light’ is turned on when you enable the 3D view. The ‘Ambient Light’ is the default light that commonly exists everywhere, similar to sunlight. It is used to minimize the variation of light effects among various shaped images.

In addition to an ambient light, there is another light source that may be adjusted by the user. You can change the position of the light source by specifying the position in x, y, and z direction.

- **Position**
  - X: moves the position of the simulated light source in the x direction
  - Y: moves the position of the simulated light source in the y direction
  - Z: moves the position of the simulated light source in the z direction

- **Luminosity**

You can increase or decrease the luminosity of a 3D rendered image by adjusting the slider from Low to High.

- **Reflexibility**

You can increase or decrease the reflexibility of a 3D rendered image by adjusting the slider from Low to High.

- **Enable Ambient Light**

You can turn on or off the ’Ambient light’ by selecting or deselecting it in the ‘Ambient light’ check box, respectively.

9-3-4. Option

■ Enable Perspective

Enables the perspective 3D display. Figure 9-3-4 shows two images selected (above) and deselected (below) the 'Enable Perspective' option in the 3D view.

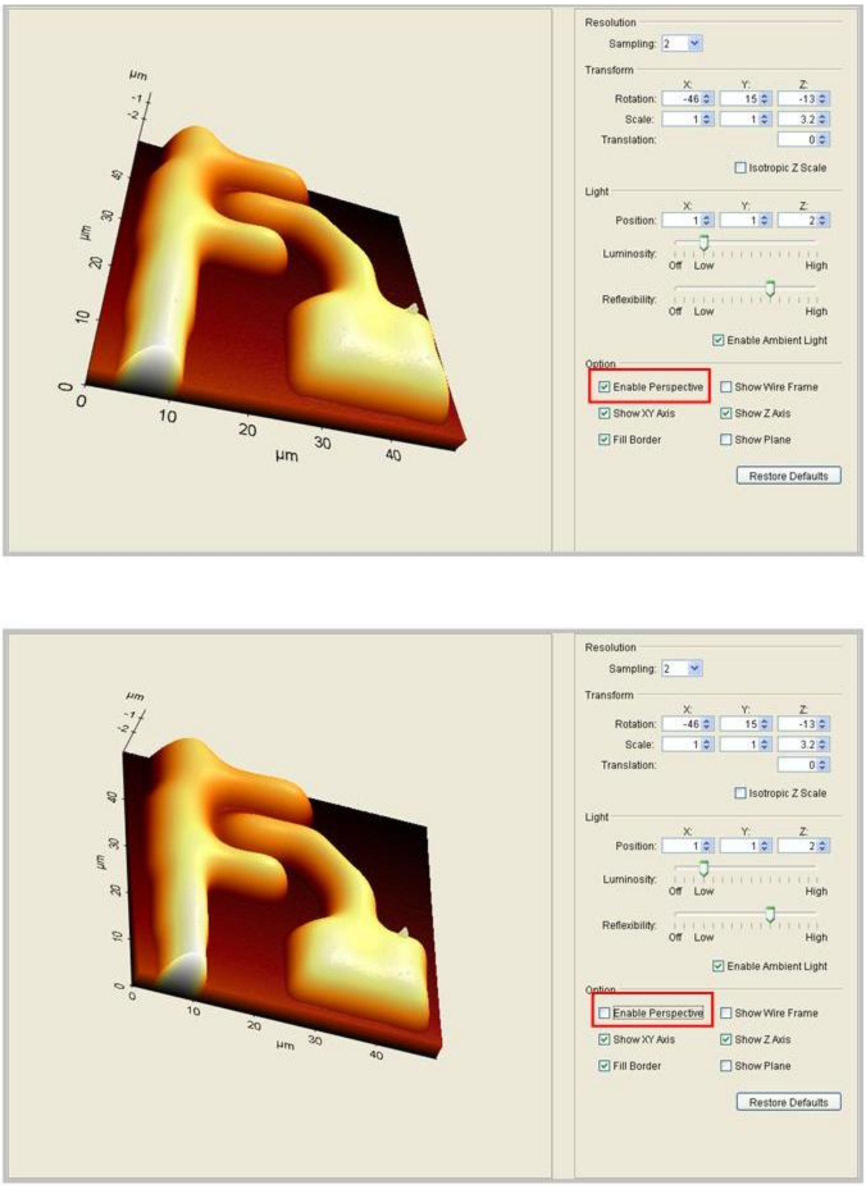
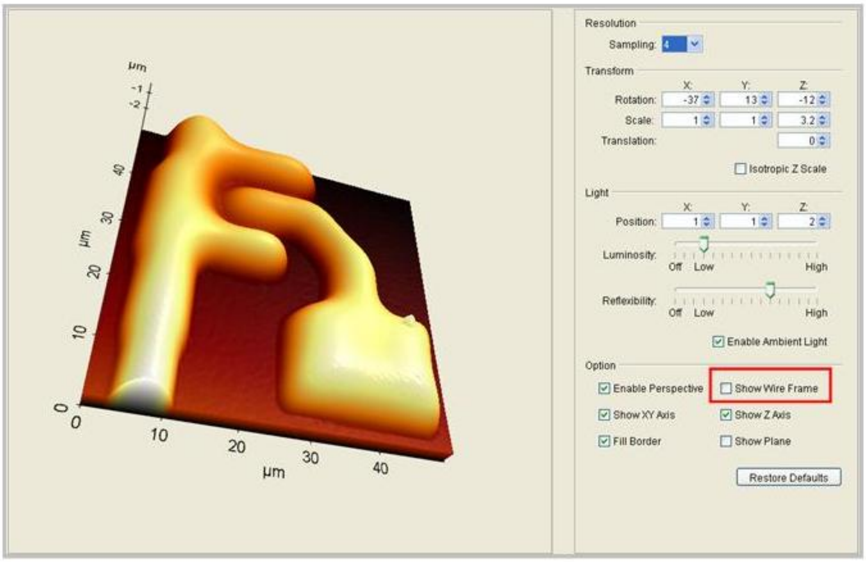


Figure 9-3-4. Enable Perspective

■ Show Wire Frame

Shows the wire frame display of the image.   Figure 9-3-5 shows two images deselected (above) and selected (below) the 'Show Wire Frame' option in the 3D view.



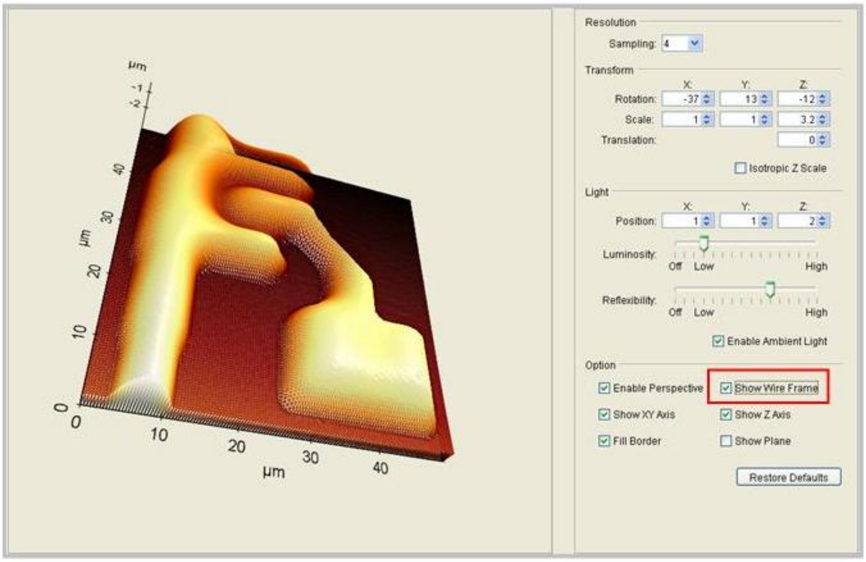


Figure 9-3-5. Show Wire Frame

■ Show XY Axis

Shows the X and Y axes. Figure 9-3-6 shows two images selected (above) and deselected (below) the 'Show XY Axis' option in the 3D view.

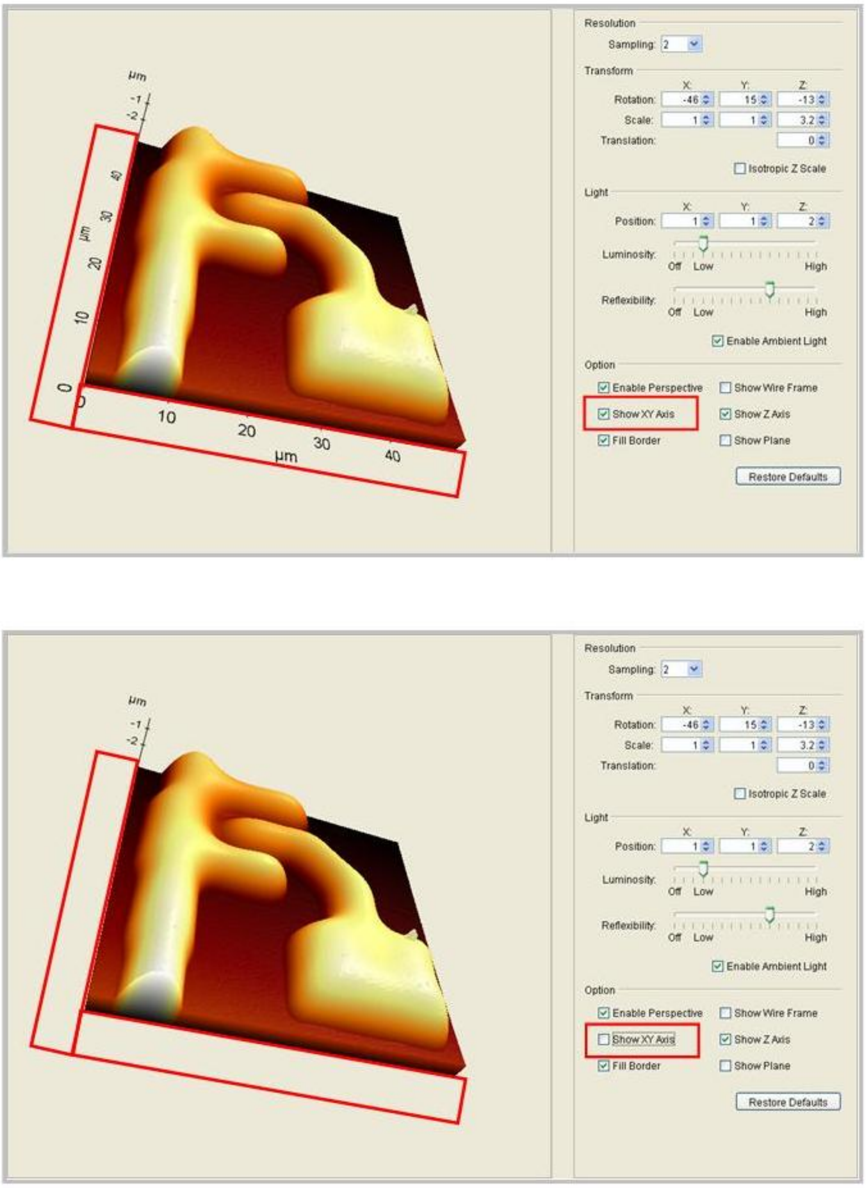


Figure 9-3-6. Show XY Axis

■ Show Z Axis

Shows the Z axis. Figure 9-3-7 shows two images selected (above) and deselected (below) the 'Show Z Axis' option in the 3D view.

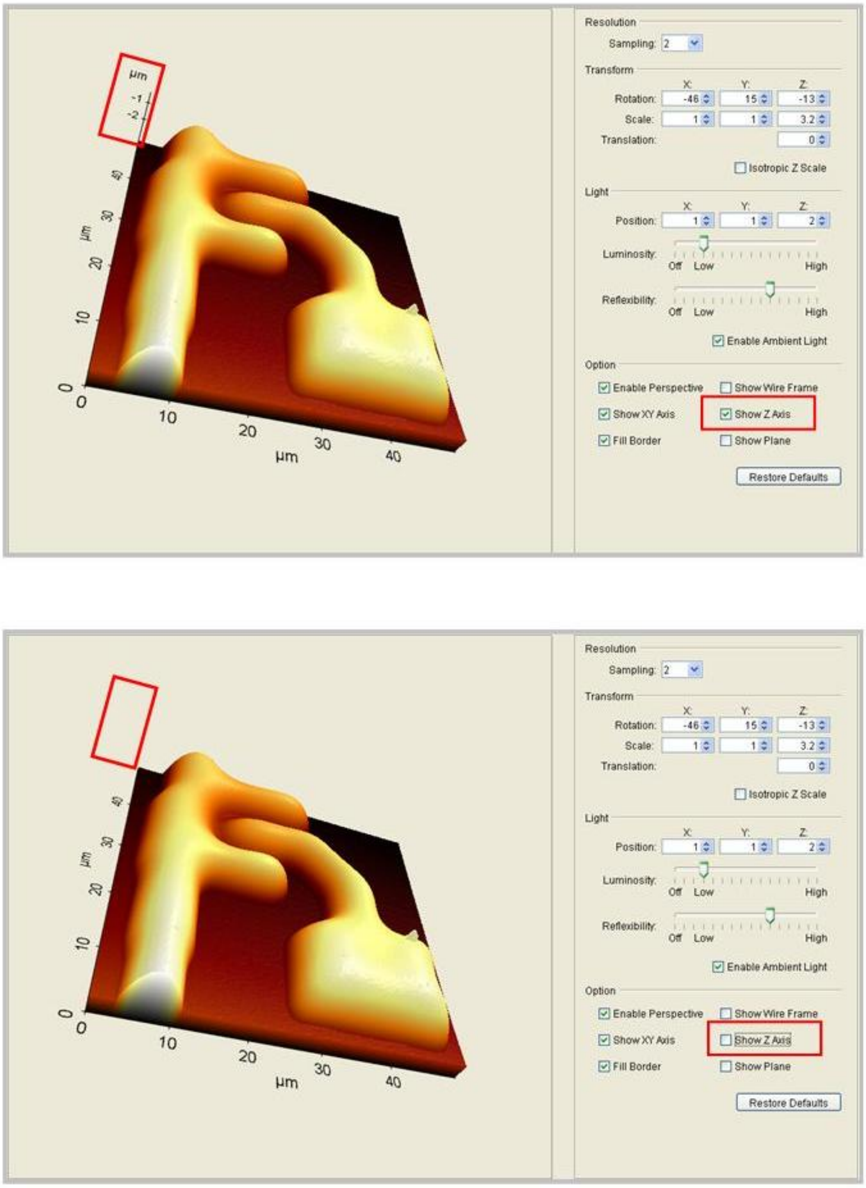
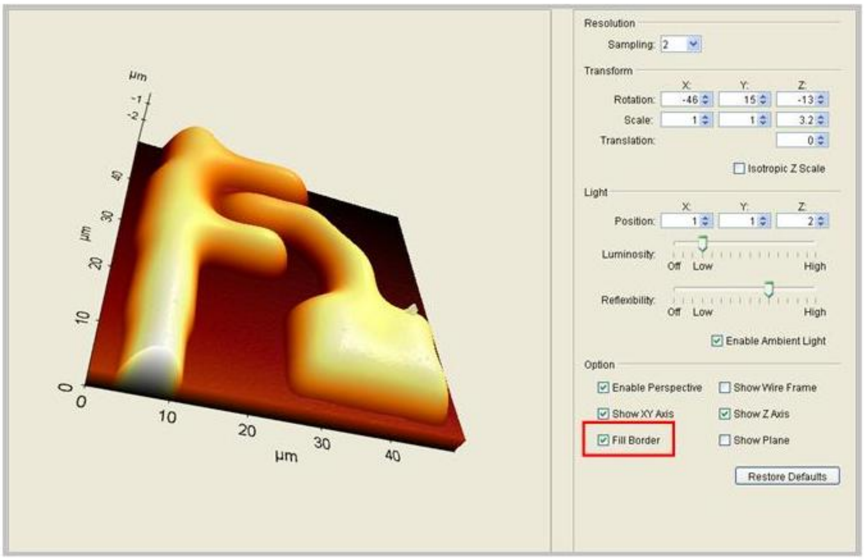


Figure 9-3-7. Show Z Axis

■ **Fill Border**

Fills the border of the image. Figure 9-3-8 shows two images selected (above) and deselected (below) the ‘Fill Border’ option in the 3D view.



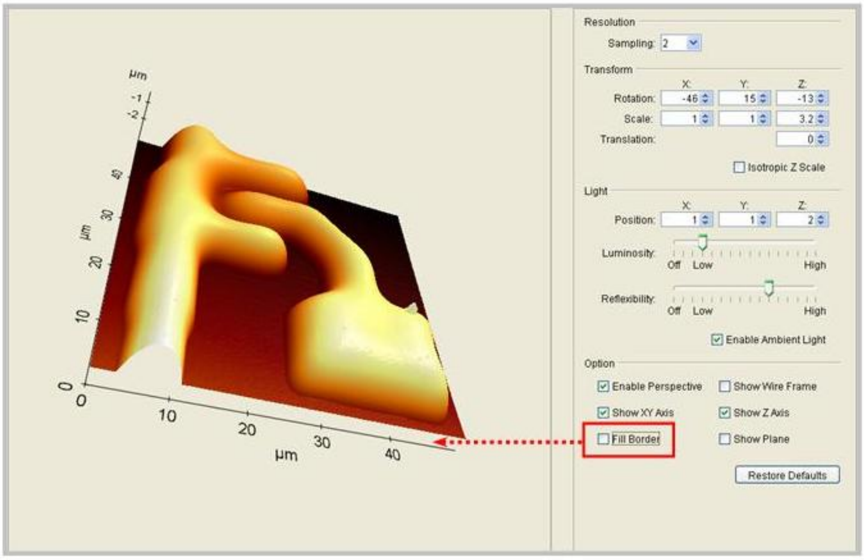


Figure 9-3-8. Fill Border

■ **Use Enhanced Color**

Changes the coloring scheme to Enhanced Color. Enhanced color uses the change of a pixel relative to its neighbors instead of its absolute value. Figure 9-3-9 shows an image with enhanced color on.

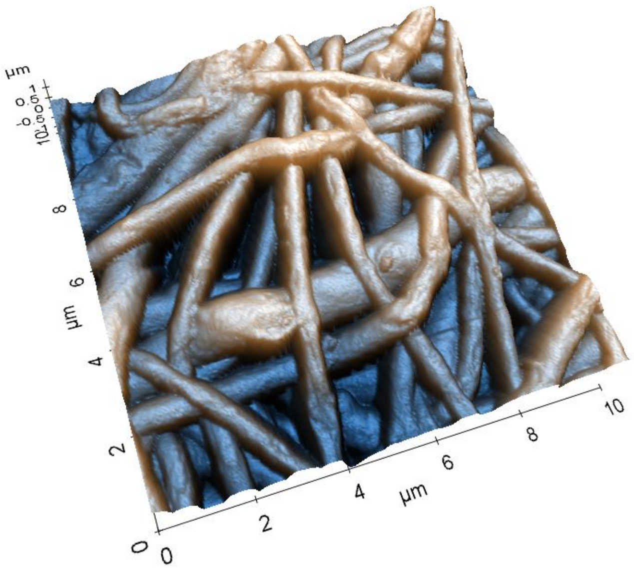


Figure 9-3-9. Use Enhanced Color

■ **Enable Overlay**

You can overlay another image on to the currently opened one. Click and drag an image from the navigator to the box indicated in Figure 9-3-10. This will change the coloring of the rendered image to reflect the overlaid image.

The images must be of matching sizes for this feature to work properly.

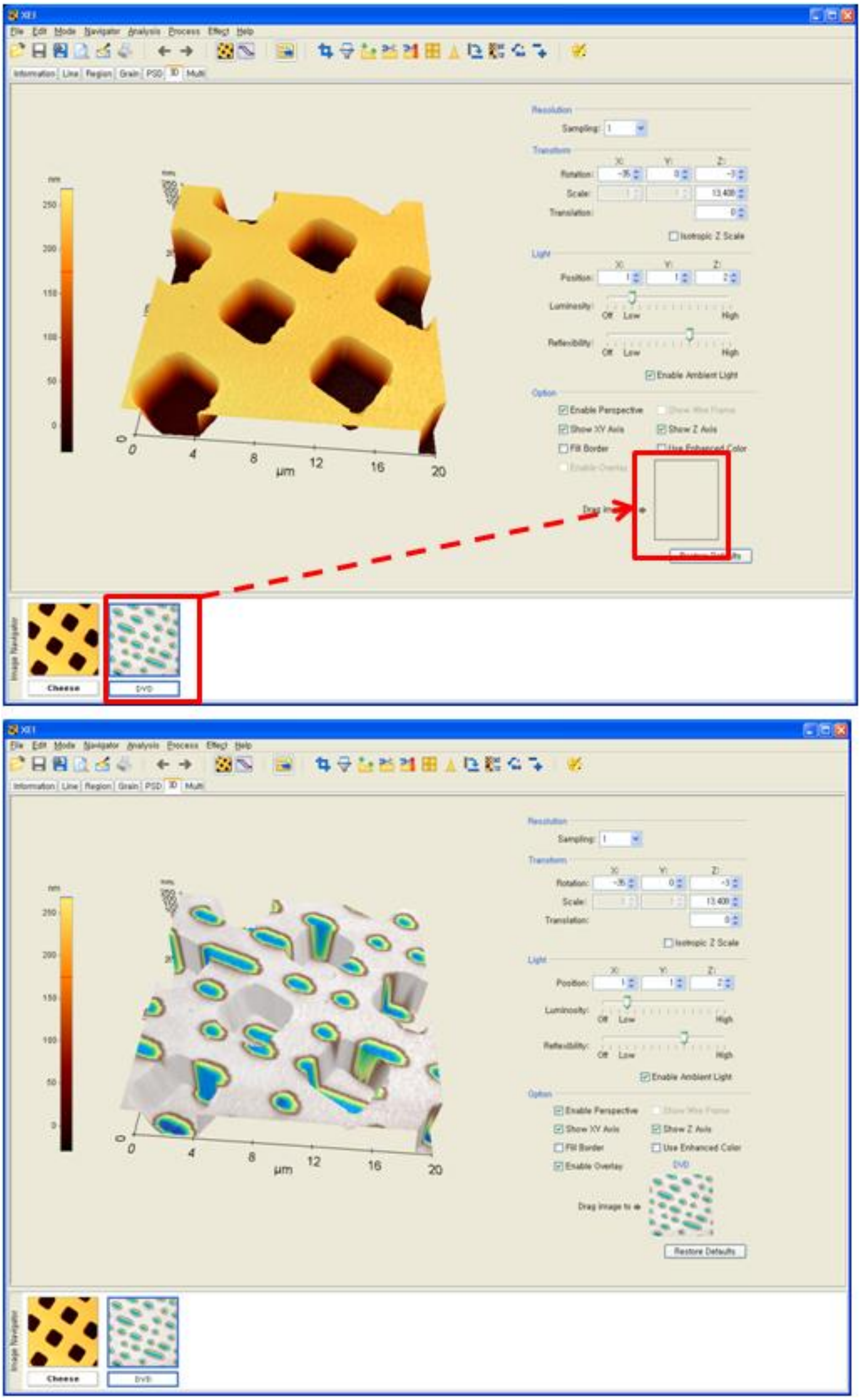


Figure 9-3-10. Image Overlay

9-3-5. Restore Defaults

Restores parameter values to the original default settings provided with the software. Figure 9-3-9 shows two images before (above) and after (below) click the 'Restore Defaults' button in the 3D view.

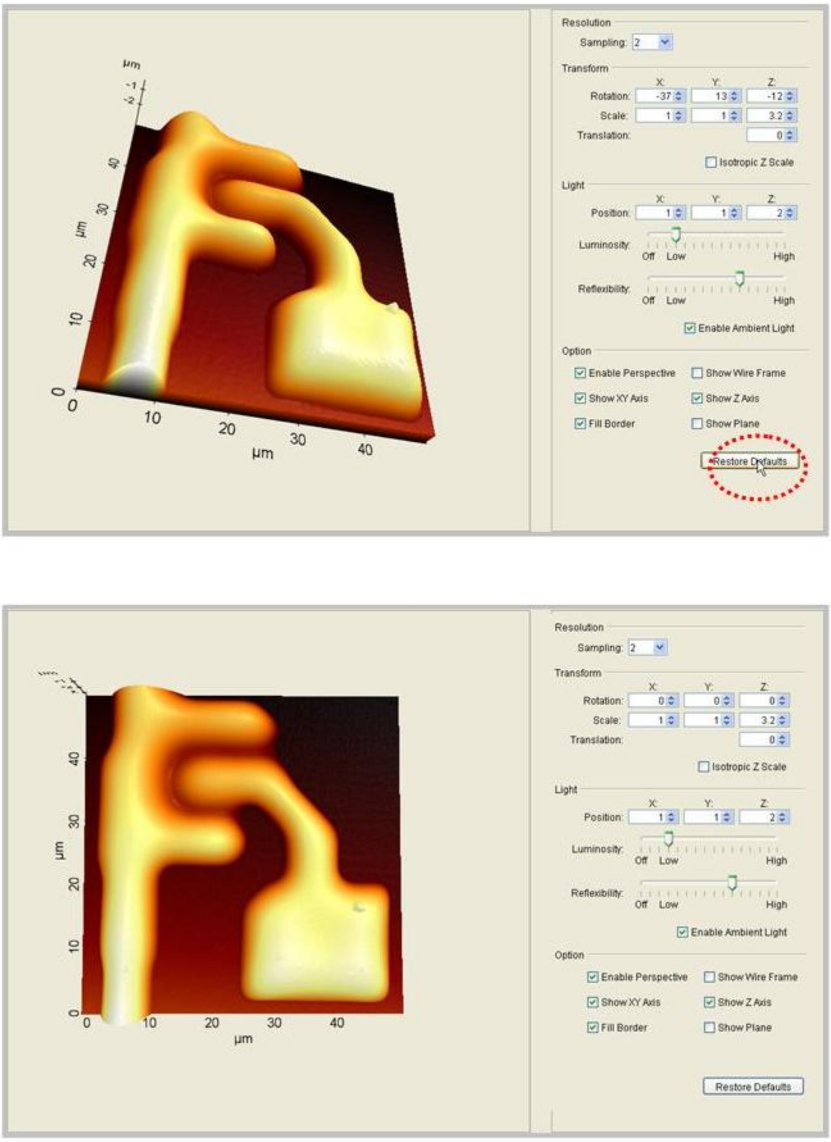


Figure 9-3-11. Restore Defaults

Chapter 10. Multi View

In the Multi view, you can display and export or print out several images simultaneously. All images will include a file name and a palette panel indicating the contrast level and data range. Up to 6 images can be displayed at once for a multi image report. You can arrange several images in the Multi view using the following procedure:

1. Load multiple images into the Navigator view from your image directory.
2. Enable the Multi view.
3. Drag and drop images from the Navigator view to the Multi view.
4. Individually adjust the contrast level and range using the palette panel of the selected image.
5. Print and Export the multi images if desired

Figure 10-1 shows the procedure to generate multi images report in the Multi view.

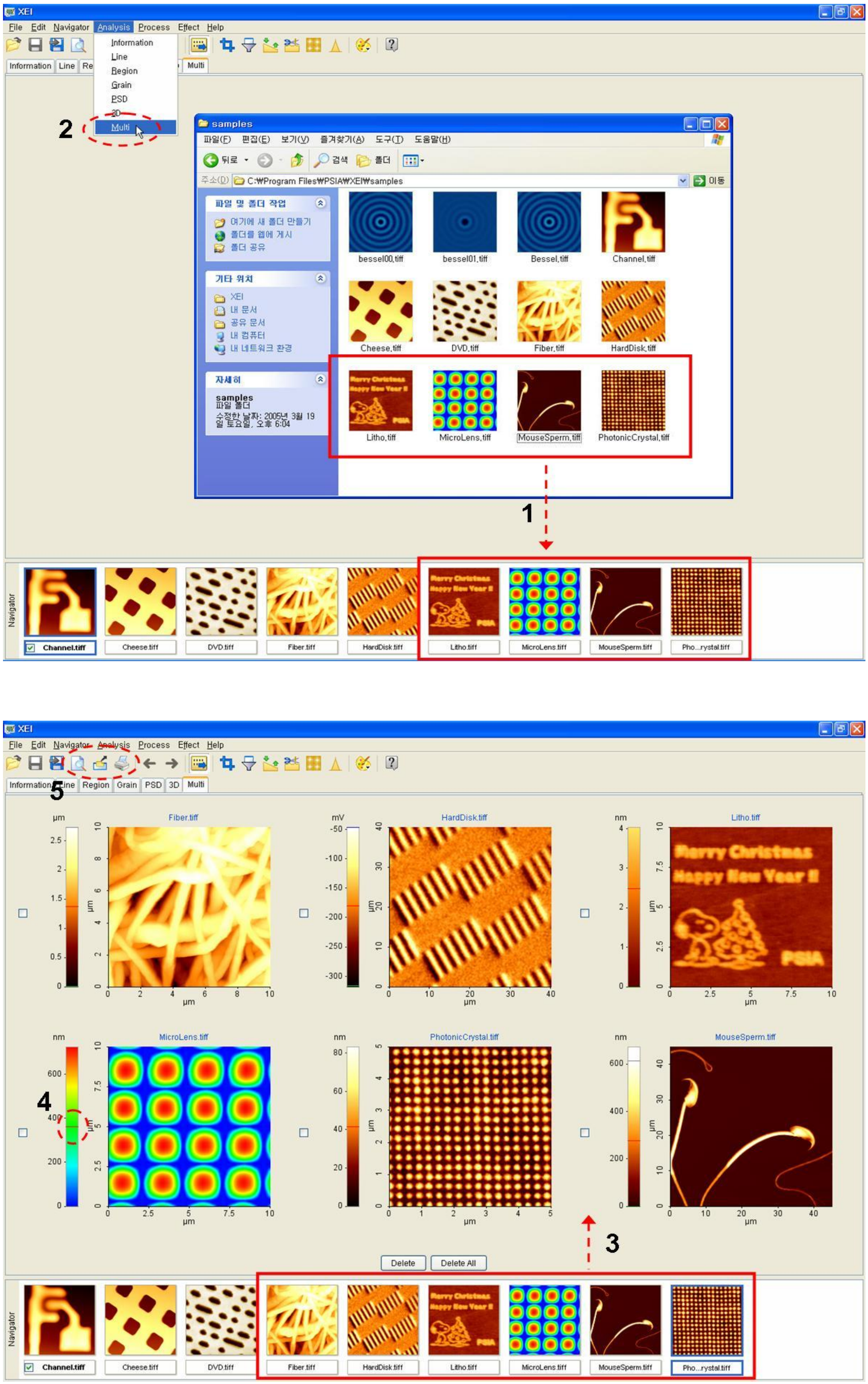


Figure 10-1. Procedure to generate multi images

10-1. Multi View

To enable the Multi view, select the 'Analysis>Multi' in the Menu or click the Multi tab below the menu bar. You can display up to 6 images at once in the Multi view. When you want to eliminate displayed images from the Multi view, click the 'Delete All ' button that is positioned at the bottom of Multi View.

Figure 10-1-1 shows the Multi view which shows the initial screen, two images loaded view, four imaged loaded view and six images loaded view. You can see that as the images are added into the multi view, their size become smaller.

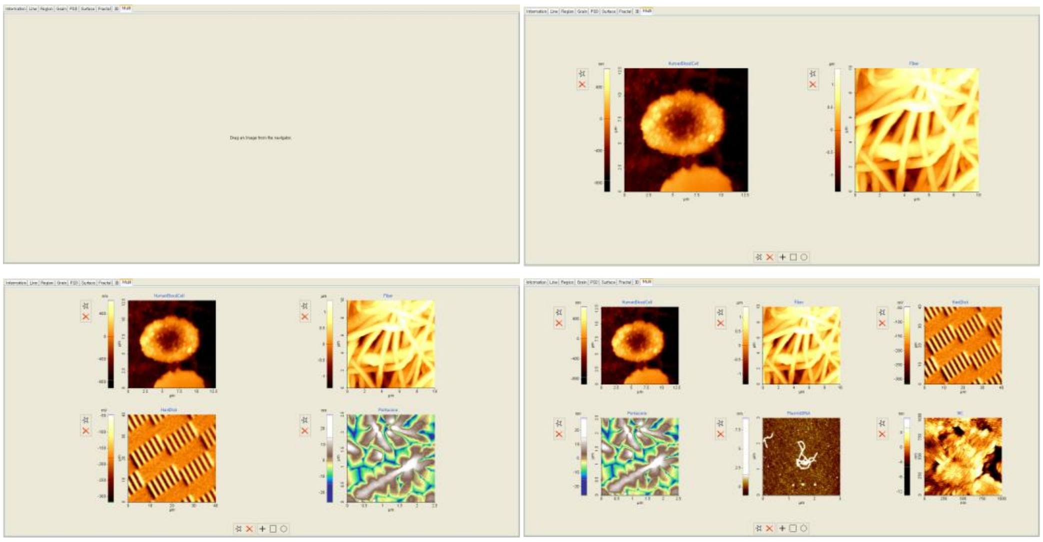


Figure 10-1-1. Multi View with different numbers of images loaded.

10-2. Bring Images into the Multi View

It is simple for you to bring images for Multi view. Only you have to do is to drag and drop images from the Navigator view into the Multi view (see Figure 10-1). One image can be loaded into the Multi view at one time. Up to 6 images can be loaded into the Multi view. The more images in the Multi view, the smaller size of the images. If you want to delete an image, click the 'Delete Selected One ' button on the left top of the individual image. If you want to delete all images, click the 'Delete All ' button on the bottom of Multi view.

10-3. Adjust the Contrast Level and Range

You can adjust the contrast range and level using the individual palette pane or 'Use Enhanced Color' for each image in the Multi view. How to adjust the contrast level or range is like that of other analysis views. Please refer Section 3-2. Palette Panel, for more information about changing the contrast range and level. Also, if you want to use enhanced color for all displayed images, click the 'Use Enhanced Color All' button on the bottom of the Multi view.

10-4. Compare Images

A figure such as a Cross, Rectangle, or Ellipse, can be inserted in an image to help analyze the image in Multi View. On the bottom of the Multi View Image display panel, click the desired figure icon, and then click the desired location of the image and drag the figure to the appropriate size.

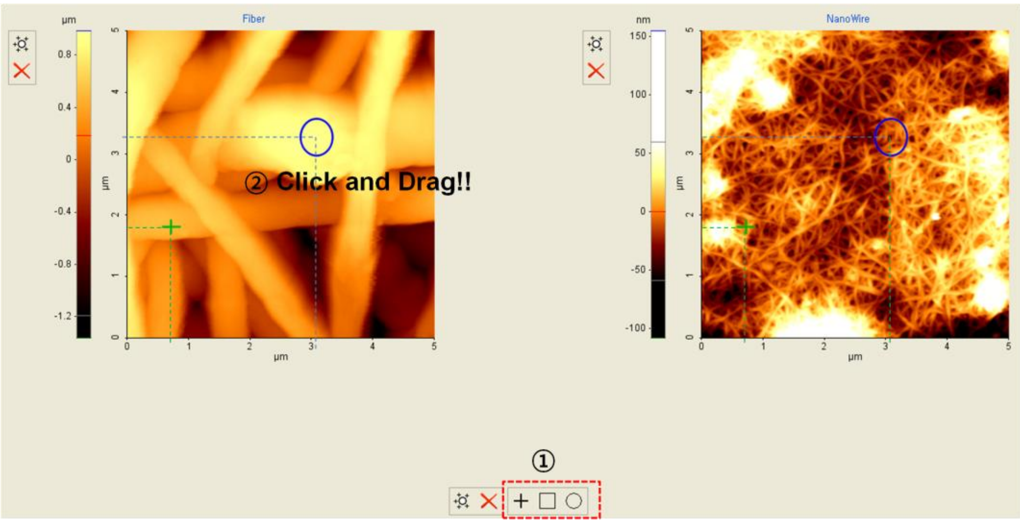


Figure 10-4-1. Compare Images using figures

■ Changing Shape

When the figure's size needs adjustment, click the figure on image, then click the circular tracker and drag the figure to the appropriate size. When the figure's angle needs adjustment, click the figure on image then click the green rotation handle and drag it to the appropriate direction.

■ Deleting

Select the desired figure to delete then press the [Delete] key on the keyboard.

■ Moving

Select the desired figure to move then click and drag.

Chapter 11. Crop

In the Crop process, you can select several parts of an image that you are interested in. The Crop processing tool allows you to eliminate "bad data" from an image file, thus making it easier to selectively process the true or reliable data in the same file.

11-1. Crop Process Dialog

To open the Crop process dialog, select 'Process>Crop' in the Menu or click the 'Crop' icon  in the Toolbar. As shown in Figure 11-1-1, the Crop process dialog is composed of two panels, the Image display panel and the Zoom Image display panel.

In the Image display panel, on the left side of the Crop Process dialog, you will see a red outlined rectangle. You can use this rectangle to select the region you want to crop. You can control the size of the region to be cropped and move it to the desired area. To magnify and reduce the selected region, drag and drop the cursor which is generated at any of the rectangle's four corners. When the selected region needs to be rotated, click the green rotation handle and drag it to the desired rotation direction. Alternatively, you can enter numbers into the X/Y Size and angle fields.

Too move the rectangle, drag and drop the four-arrow cursor that appears when the cursor is positioned within it.

The Zoomed Image display panel to the right of the Image Display Panel shows the enlarged image of the selected region (red bordered box in the image). You can preview a newly cropped region in this Image display panel.

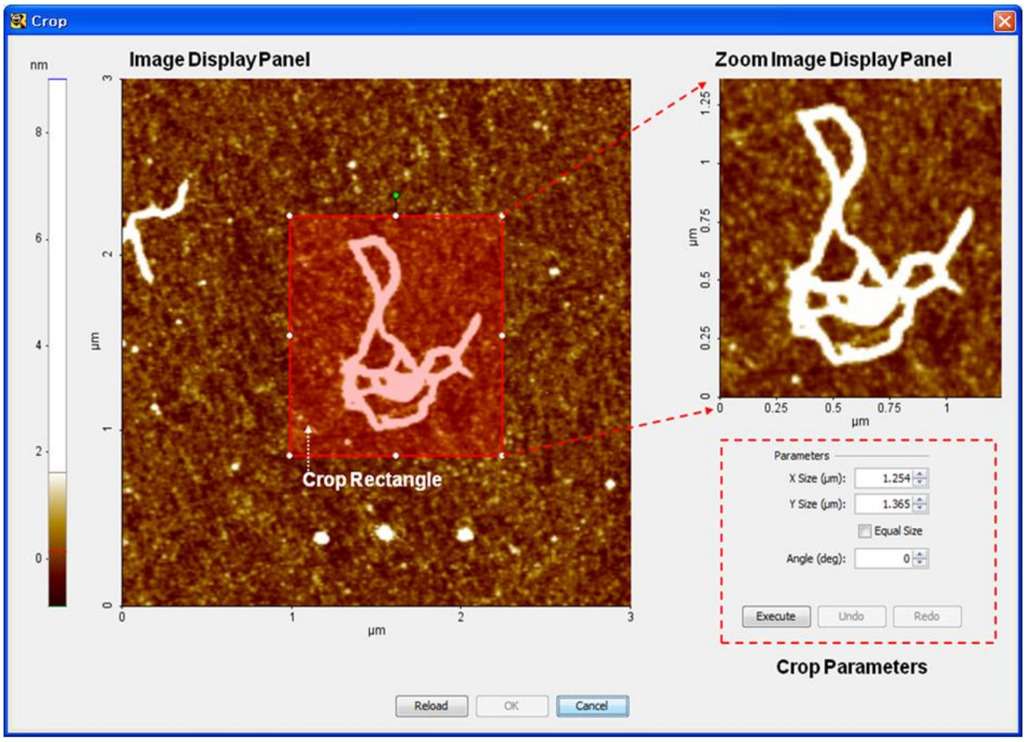


Figure 11-1-1. Crop process dialog

11-2. Crop an Image

In general, follow these steps to crop an image (see Figure 11-2-1):

1. Load an image file into the Analysis view from the Navigator view.
2. Select 'Process>Crop' or click the 'Crop' icon  in the Toolbar to display the Crop process dialog.
3. Move the crop rectangle over the region to be cropped. Increase or decrease the size of the selected region and/or rotate the region as desired.
4. Once you are satisfied with the new area displayed in Zoom Image Display panel, click the 'Execute' and 'OK' button to create a newly cropped image in the Navigator view. The image will be generated with a default name of 'original name+cropped.tiff'. The image will be automatically displayed in the image display panel.
5. Save the cropped image as another file name for further image

processing and analysis.

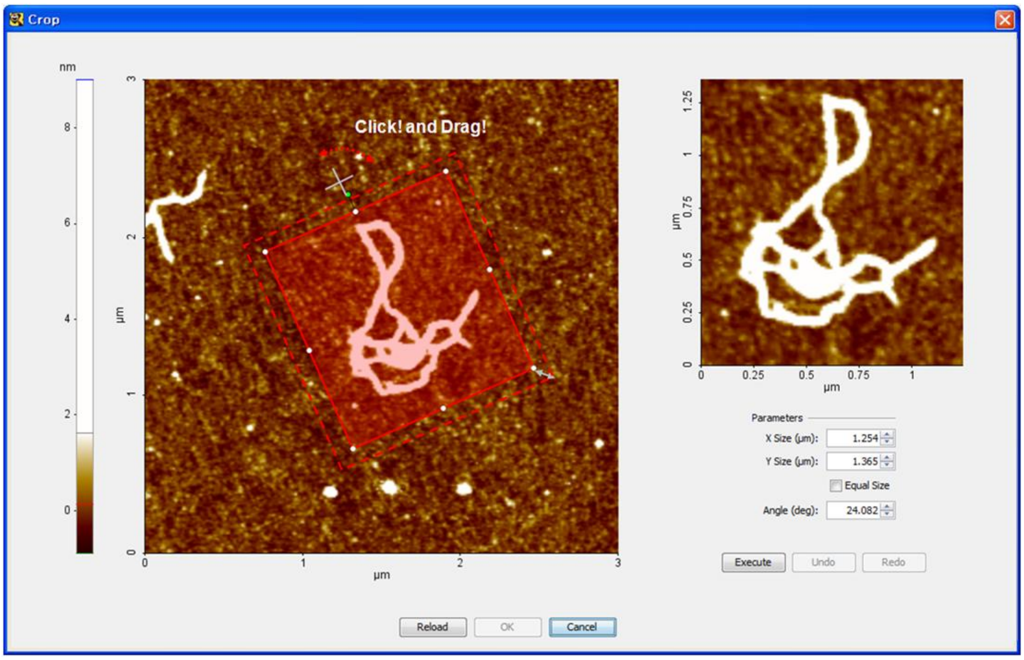


Figure 11-1-2. Rotation

NOTE!

Cropping a local region of an image produces a new, processed image that can be saved to your hard disk or printed. Cropping an image does not affect the original data unless you press the Save button.

NOTE!

The Cropping procedure is only possible with image in the Image Display panel.

NOTE!

After rotation, the image is produced with a 2D Bi-linear interpolation algorithm.

■ **X/Y Size**

Crops Rectangle's X/Y size

■ **Equal Size Check Box**

When this box is checked, X/Y Size input text-field will be one. Any input in this text-field will adjust both X/Y size.

■ **Angle**

Rotates the Crop Rectangle. Crop rectangle will rotate counter-clockwise as the Angle increases in the positive direction. Values between 0 ~ 359.9° can be used in the input box.

■ **Execute**

Crops the selected region and displays the new image in the Image Display panel.

■ **Undo/Redo**

Undo/Redo previous action.

■ **OK**

Saves cropped image in Image Display panel and closes Crop process dialog.

■ **Cancel**

Cancels Crop process and closes Crop process dialog.

■ **Reload**

Loads the original image in Crop process dialog.

Chapter 12. Arithmetic Filter

In order to get better presentations and the best measurement results, the Arithmetic Filters are used to reduce various noisy features in the image. The Arithmetic Filter processing techniques in XEI are divided into four classes: Smoothing, Sharpening, Edge Enhancement, and Custom. This chapter describes the functions under each of these four classes.

Most of the filters use an *n x m* filtering kernel matrix, where *n* and *m* are odd integers so that there is a unique center of the kernel matrix. A filter places this kernel on a matrix of image pixels and uses the values of neighboring pixels to determine the new value for the center pixel.

12-1. Filter Process Dialog

To open the Filter process dialog, select the ‘Process>Filter’ menu or click the ‘Filter’ icon  in the Toolbar. As shown in Figure 12-1-1, the Filter list box has four groups of filters. Those groups are ‘Smoothing’, ‘Sharpening’, ‘Edge Enhancement’, and ‘Custom’. Each filter group has several different types of filters. After you select the desired filter, set the kernel width and height. The meaning of each item in the Filter process dialog is described in detail below.

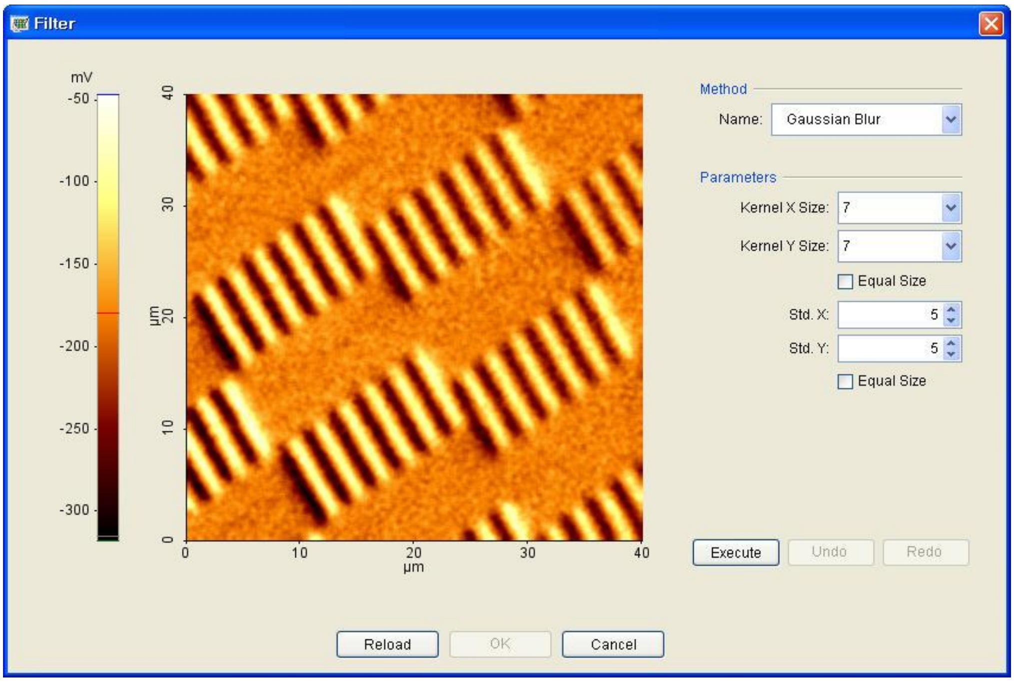


Figure 12-1-1. Filter process dialog

12-2. Smoothing

The smoothing processes reduce sharp edges and small variations. This effectively removes glitches and is useful therefore.

12-2-1 Mean

The Mean Filter's characteristics are determined by the kernel height and width. A larger kernel size results in more blurring. Therefore, an excessive kernel size may produce unexpected effects on your data.

After the filter calculates the average of the pixels bounded in the kernel matrix, the average is set to be a new pixel value located at the center of the kernel. If you use a 3 by 5 kernel, for example, this filter places this kernel on an image and then calculates the average of 15 (= 3 × 5) image pixels bounded in the kernel to substitute each pixel value to the average.

12-2-2 Gaussian Blur

The Gaussian Blur Filter's characteristics are determined by the kernel height and width, and the standard deviation. These can be varied with separate values for the X and Y dimensions. The pixel is set to the center value of the Gaussian curve that best fits the data points.

12-2-3 Median

The Median filter is an effective method for removing outliers or shot noise in an image. At first, the Median filter sorts the pixel data to find the median of the pixels bounded in the kernel matrix. Then, the median value is used to replace the value of a pixel that is over the acceptable range. If you use a 3 by 5 kernel, for example, this filter places this kernel on an image and calculates the median of 15 (= 3 × 5) image pixels bounded in the kernel. The calculated median is set as a new pixel value located at the center of the kernel.

The median filtering is more reliable than the average filtering in the cases such as the one in the following example:

When one value deviates extremely from the others and shifts the mean as in this set "1, 3, 4, 5, 9, **10**, 200, 14, 15, 17, 19", the median is 10 and the average of this set is 297/11=27. If the out of range value is considered to be a bad data point and is then excluded from the calculation of the average, the more accurate average would now be closer to the median: (297-200)/10=9.7.

12-2-4 Low Pass

The Low Pass filter has a fixed kernel size of 3x3. The value "Weighting Factor" is represented in the kernel by n. The term $1/(n+2)^2$ can be factored out, so the kernel can also be represented as the product of $(n+2)^{-2}$ and the values in the following table.

$1/(n+2)^2$	$n/(n+2)^2$	$1/(n+2)^2$
$n/(n+2)^2$	$n^2/(n+2)^2$	$n/(n+2)^2$
$1/(n+2)^2$	$n/(n+2)^2$	$1/(n+2)^2$

1	n	1
n	n^2	n
1	n	1

12-2-5 Conservative

The Conservative filter removes extreme points. For a given pixel, the surrounding pixels are considered. The number of neighboring pixels is determined by the Kernel Size parameter.

If the pixel is the highest point within the kernel, its value is lowered to the next-highest value within the kernel. If it is the lowest point, then its value is increased to the second-lowest value within the kernel.

This operation is performed simultaneously on all of the pixels, with the effect of removing extreme points and maintaining the same median value.

12-3. Sharpening

Sharpening filters are used to make smaller features more noticeable. They increase the difference between neighboring pixels.

12-3-1 High Pass

High Pass is the first of the Sharpening filters. Its kernel size is variable but must be a square. The center pixel is multiplied by the square of the length of the square; all other pixels are given a weight of -1.

12-3-2 Laplacian of Gaussian

The Laplacian of Gaussian allows the user to perform both the Gaussian Blur, then the Laplacian Edge Enhancement on an image in one go. However, the X and Y kernel size and standard deviation values for the Gaussian blur are equal.

12-4. Edge Enhancement

Edge Enhancement function create images of the gradient between pixels. This allows the user to better distinguish edges of sample features.

12-4-1 Roberts

The Roberts filter can be applied in the four cardinal directions, denoted as "East," "West," "North," and "South." This filter sets the value of each point as the difference between the point and the point adjacent to it in the direction of application. For example, if one chose East, pixel (5,5,10) with a neighbor (4,5,8) would now have the value of (5,5,11-8). One can also say that the value of a pixel is set to be the sum of itself and its neighbors when they are multiplied by the following kernel (for the East direction):

0	0	0
-1	1	0
0	0	0

12-4-2 Sobel

The Sobel filter differs from the Roberts filter in that it weighs the neighboring pixels differently. Instead of finding the difference between the actual pixel and one neighbor, it finds the difference between pixels on opposing sides:

-1	0	1
-2	0	2
-1	0	1

12-4-3 Laplacian

A Laplacian filter is different from a Roberts or Sobel filter in that it finds the differential between a pixel and its neighbors in the four cardinal directions. Its kernel is as follows:

0	-1	0
-1	4	-1
0	-1	0

12-5. Custom

Custom filters can be applied to images. User-defined kernels are limited to a size of 3x3.

12-5-1 3x3 Convolution

The user may decide what weight is given to each pixel in the kernel which has a 3x3 size.

NOTE!

Applying the Arithmetic Filter process to an image produces a new, processed image that can be saved or printed as a new file. Filtering does not change the original data unless you click the Save button.

Chapter 13. Flatten

The Flattening processing tool removes artifacts that result from the slope and curvature produced by the scanning process. These artifacts can affect the height data of the image and make the image difficult to interpret.

Slope results from the fact that the sample surface will always be tilted to some extent relative to the plane of the XY scanner. Also slope can be caused by the XY scanner not moving in a plane perpendicular to the Z scanning direction. Curvature is mainly caused by the out-of-plane motion of the XY scanner while scanning the sample.

During the flattening process, XEI first obtains the 'fitting curve' for each scan lines in the image. 'Fitting curve' is an estimation of the 'slope' or 'curvature' introduced in the image. Then, from each scan line in the image, XEI 'subtracts' the corresponding fitting curve. As a result, the 'offset' between the each point on the scan line and the each corresponding point on the fitting curve is obtained. This 'offset' is assigned as a new data for the each point. Figure 13-1 shows short example showing flattening applied to a single line.

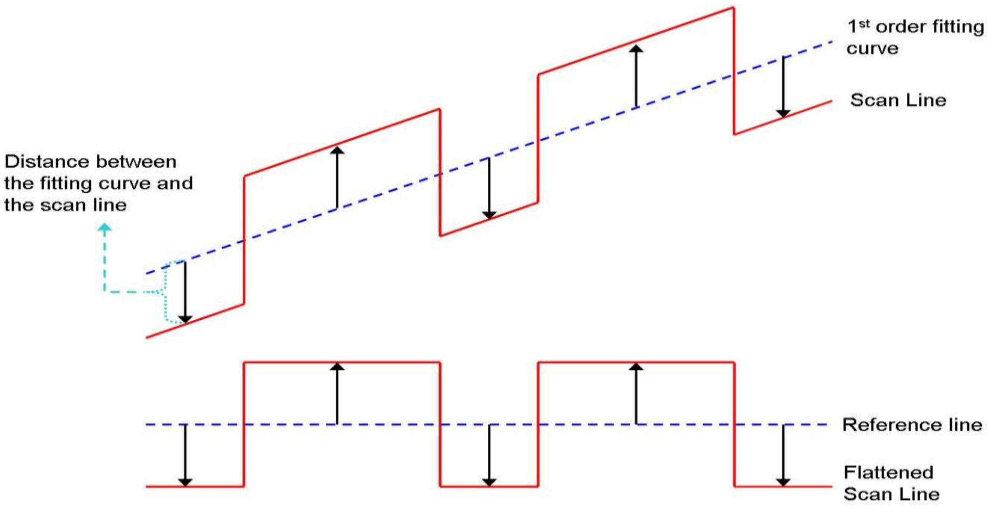


Figure 13-1. 1D example of the flattening

13-1. Flatten Process Dialog

To display the Flatten process dialog, select ‘Process>Flatten’ in the Menu or click the ‘Flatten’ icon  in the Toolbar. Figure 13-1-1 shows the Flatten process dialog which is composed of several parts. The Image display panel shows the original image and the processed image. At the upper-right side of the Image display panel is the Region selection toolbar composed of several buttons that include and exclude regions for flattening. At the lower-right side of the Image display panel are several parameters used to flatten an image. At the right side of the Image display panel is the Line Profile panel which displays the average height profile and the fitting curve for flattening an image. Below the Image display panel is the Histogram of the entire image for height restriction.

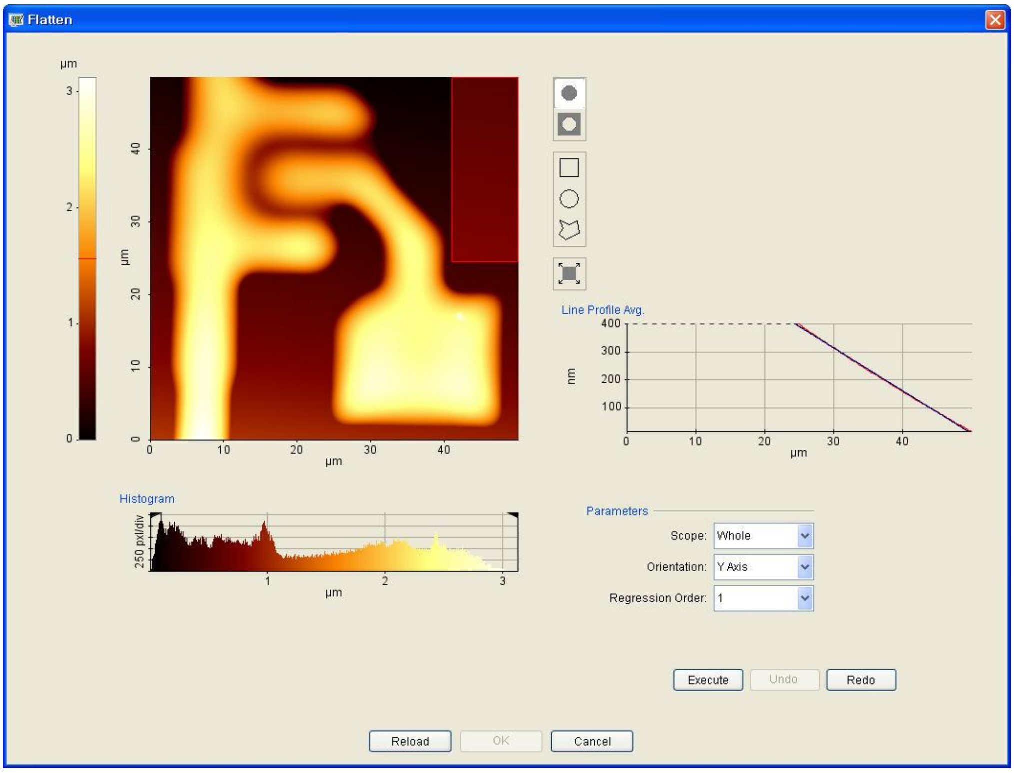


Figure 13-1-1. Flatten process dialog

The Flatten process dialog provides some parameters that are useful for applying different flattening techniques. These are described further in the following section.

13-1-1. Image Display Panel

The Image display panel displays an original image and a flattened image. After adding regions, it also shows the regions as partially transparent shapes. If the Scope is set to ‘Line’, you will see a movable line locator in the Image Panel (for example, the red horizontal line with the two-arrow cursor in an image of Figure 13-1-1).

13-1-2. Region Selection Toolbar

The Region selection toolbar is composed of several buttons that include or exclude any regions in an image. Data points that are in the included regions are collected to calculate fitting curves and data points that are in the excluded regions are not used. The function of the region selection toolbar is summarized below.

- Inclusion - Sets selected regions to be included in the fitting curve
- Exclusion - Sets selected regions to be excluded from the fitting curve
- Rectangle - Selects a rectangular region
- Ellipse - Selects an elliptical region
- Polygon - Selects a polygonal region
- Entire region - Selects entire image

■ To select a region type

To specify the features of the image to be included and excluded, select the region type (rectangle, ellipse, and polygon) and create the regions in the image that will be included or excluded areas of the image. The shape and size of the selected region can be adjusted by dragging each small round tracker which is generated when you click any location within the selected region.

Especially, in the case of the polygonal region, after selecting the polygon in the Region selection toolbar, click the cursor onto any place where you want to create the region and then, move and click once onto each point of the polygon. Changing the shape and size of the polygon region is performed by the same steps described in the Region Analysis section. In addition, to move the selected region you have already created, click the cursor in the selected region and drag the four-way arrow to reposition the region.

After selecting and grouping regions to be included and excluded for flattening, the Line profile automatically calculates and displays the average height profile and the fitting curve.

13-1-3. Histogram Panel

As shown in Figure 13-1-2, the Histogram panel shows a bar graph showing the distribution of heights in the image. The x axis is the height of data points in the sample surface, and the y axis is the number of data points. The Histogram panel has a pair of height restriction markers that restrict height range of data. One marker that has a flag directing right represents a lower limit and the other marker that has a flag directing left represents an upper limit. You can drag these markers to determine the height range to be included. Data points that have heights in the restricted height range are included and that have heights out of the range are excluded when calculating fitting curves. Included heights are painted with the original palette and excluded heights are painted with violet in the Palette panel, Image display panel, and the Histogram panel.

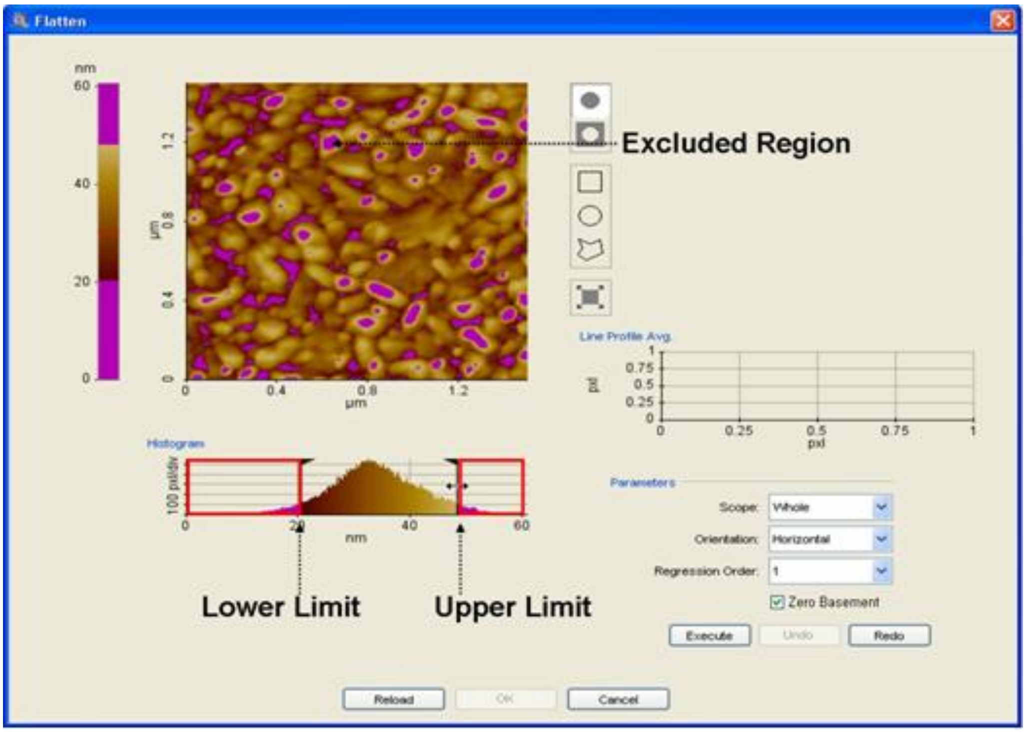


Figure 13-1-2. Height restriction markers in the histogram

13-1-4. Flattening Parameters

■ Scope

The Scope is a range for collecting data and calculating a fitting curve that will be used for flattening. The flattening process collects data in the scope to calculate a fitting curve. The calculated fitting curve will be subtracted from the original image during flattening. There are two scopes: Whole and Line.

If the 'Whole' scope is selected, included data are used to calculate an average line profile and its fitting curve. The average line profile shows overall features of the image and the fitting curve calculated from this average line profile shows an overall distortion of the image. The fitting curve is subtracted from the entire image. The Line Profile panel displays this average line profile and its fitting curve.

If the 'Line' scope is selected, included data are used only to calculate a fitting curve for each line profile. Each fitting curve is subtracted from each line profile. In this scope, a movable line locator appears on the Image display so that you can examine a line profile at the locator and see its fitting curve in the Line Profile panel.

You can move this line locator easily by dragging it. Whenever you move the line locator, the line profile is automatically updated.

The 'Difference' scope takes the first derivative of the data, and uses this data for flattening. This helps to reduce deviations in height offset between adjacent lines.

■ Orientation

Orientation indicates the direction of the flattening process. If the ‘Horizontal’ orientation is selected, a horizontal slope and curvature will be removed. The same manner is applied for the ‘Vertical’ orientation.

In the ‘Whole’ scope, all line profiles of the selected orientation are averaged to calculate a fitting curve for an overall image. In the ‘Line’ scope, a movable line locator that lies in the selected orientation appears on the Image display panel. You can examine a line profile of the selected orientation as well as the corresponding fitting curve.

In general, you may need to flatten an image both in the horizontal and vertical directions to eliminate all directional slope and curvature components from the image.

■ Regression Order

The Regression order is the order of a regression polynomial selected for flattening. A fitting curve is calculated by polynomial regression. There are four possible regression orders: the zeroth, first, second, and the third. Each is denoted by 0, 1, 2, and 3. The zeroth order subtracts a constant from each line. The first order is used to remove a slope caused by a slanted scan plane relative to the sample plane. The second order is used to remove curvature caused by a bending motion of the XY scanner. The third order is for eliminating more complex distortions, but is rarely used.

■ Zero Basement

The Zero Basement parameter will add a constant value to every pixel so that the average value of the data is 0.

13-1-4. Line Profile Panel

The Line profile panel displays both the line profile (red curve) and the fitting curve (blue curve) for flattening this Line Profile panel. In the Whole scope, this profile is an overall line profile. In the Line scope, this profile is a line profile located by a line locator in the Image display panel. The red curve is the line profile only for the included data and dashed lines are displayed for excluded data. A blue curve displayed simultaneously with the red curve is a fitting curve for flattening. The fitting curve is calculated only with the included data. Figure 13-1-3 shows two images before (left) and after (right) flattening. You can confirm whether the flattening process is executed well to see that the fitting curve becomes “flat” after executing the process.

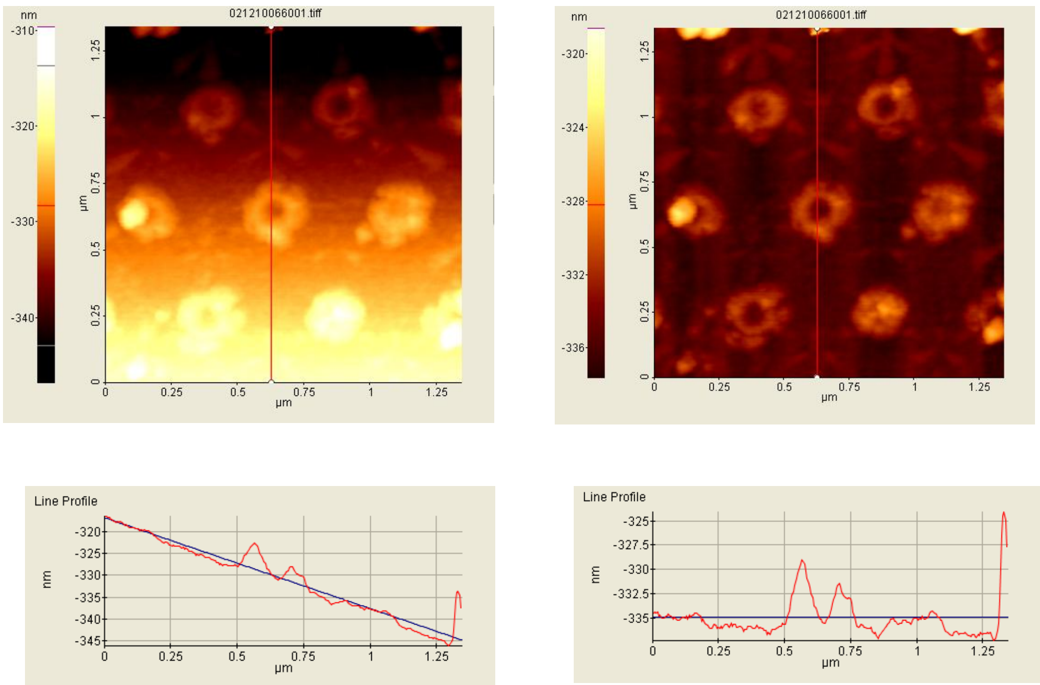


Figure 13-1-3. Line profiles with fitting curves

13-2. Flatten an Image

Flattening is carried out through three processes. As soon as you open the Flatten process dialog, the software determines automatically the average curvature and slope of the image. Then, the software calculates a set of values that will compensate for the slope and curvature. Finally, you can have the software subtract the compensating values from the data points of the image.

You can follow this general steps for eliminating the slope and curvature of the image (see Figure 13-2-1):

1. Load the image you want to flatten into the Image display panel.
2. Select the Flatten menu or click the 'Flatten' icon  to open the Flatten process dialog.
3. Select the Orientation for flattening, appropriate Scope.
4. Create regions of the image to be included and/or excluded from the calculation of the fitting curve. If necessary, restricts heights using height restriction makers in the Histogram panel.
5. Select the Regression order, which determines the type of slope or curvature to be eliminated.
6. Adjust some parameters to get desirable fitting curves and click the 'Execute' button if desired.
7. Save, export or print this image for further processing and analysis if desired.

It may be necessary to flatten an image in both the horizontal and vertical directions and also to execute the image flattening using more than one regression order in subsequent steps to remove both curvature and slope from an image.

<u>NOTE!</u>

Applying the Flattening process to an image produces a new, processed image that can be saved or printed as a new file. Flattening does not change the original data unless you click the Save button..

Figure 13-2-1 shows the summarized procedure to flatten the selected region in an image.

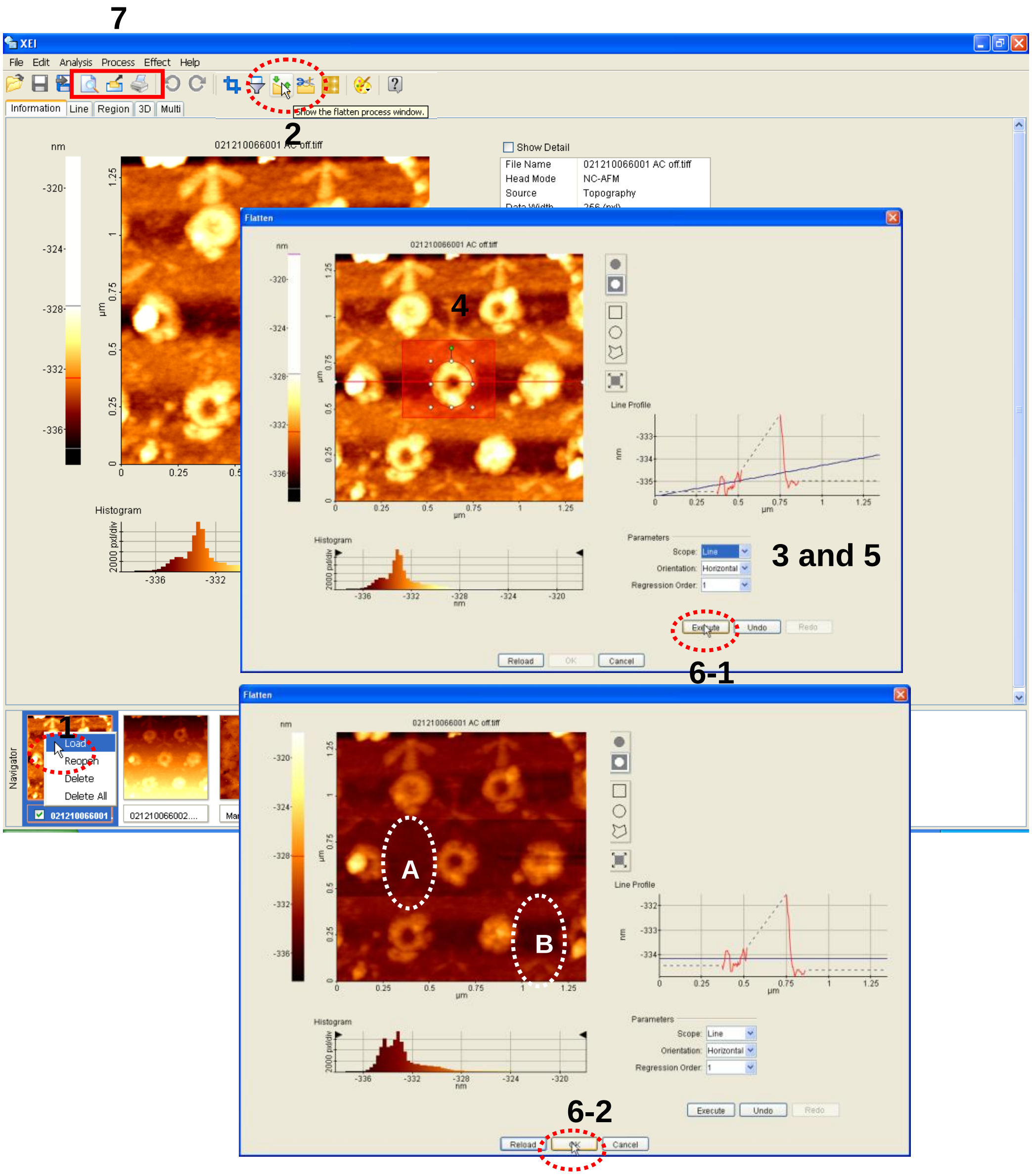


Figure 13-2-1. Procedure to flatten an image

Chapter 14. Deglitch

Deglitching is used to remove glitches from an image. A glitch is a small artifact in an image that does not represent the true surface topography. You can apply deglitching in both the horizontal and vertical directions.

Usually, glitches occur in the fast scan direction and appear as discontinuities or streaks in an image. Long glitches are sometimes caused by loose, unidentified particles on the surface that are dragged by the tip.

14-1. Deglitch Process Dialog

To open the Deglitch process dialog, select 'Process>Deglitch' in the Menu or click the 'Deglitch' icon  in the Toolbar.

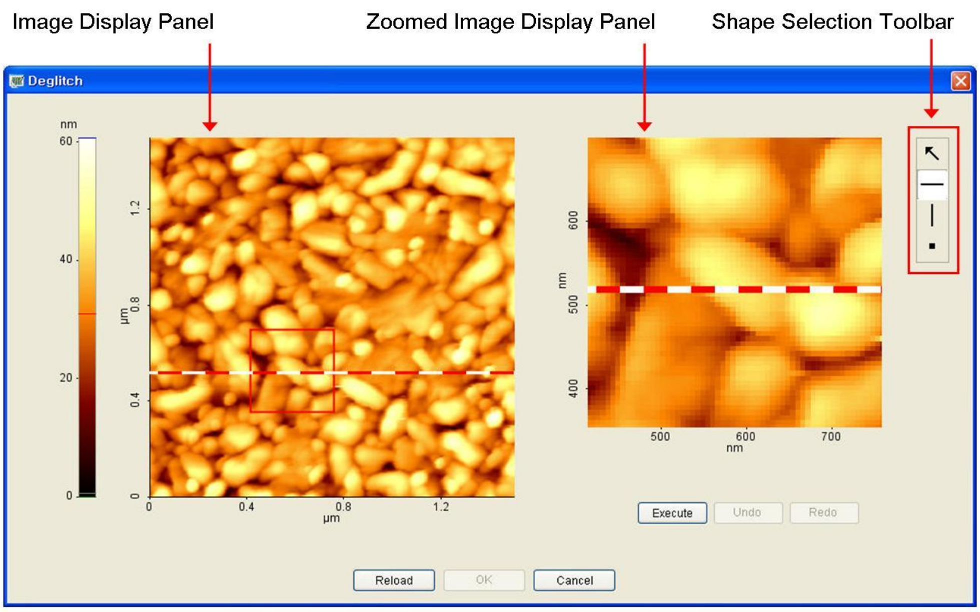


Figure 14-1-1. Deglitch process dialog

As shown in Figure 14-1-1, the Deglitch process dialog is composed of two main parts; Image display panel and Zoomed Image display panel. At the left side, the Image display panel shows the original or processed image. At the right side, there is the Zoomed Image display panel with a Shape selection toolbar that is used to perform the glitch removal. Horizontal and vertical lines may be used as well as points.

14-1-1. Image Display Panel

The Image display panel displays an original image and a deglitched image. There is a red outlined square that indicates a zoomed region. After adding lines or points for deglitching, they will be displayed as dashed lines (Figure 14-1-1).

14-1-2. Zoomed Image Display Panel

The Zoomed Image display panel displays the magnified image of the zooming square. The Zoomed Image display panel magnifies the image dynamically while the zooming square is moved. Figure 14-1-2 shows that some glitch (see white outlined circles) disappear in the image after deglitching it in the Deglitch process dialog.

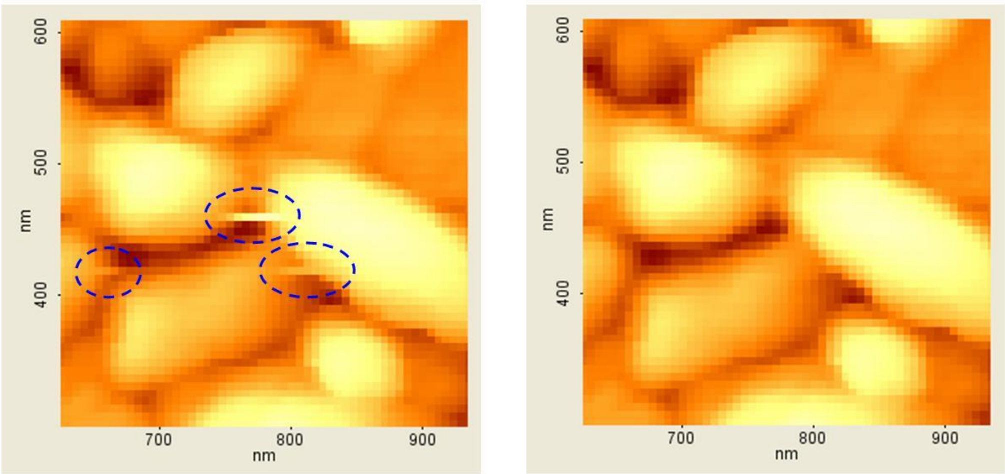


Figure 14-1-2. Deglitched image

14-1-3. Shape Selection Toolbar 

The Shape selection toolbar has both a horizontal and a vertical line button and a point. If you select the horizontal or vertical line button, you can generate related lines in the Zoomed Image display panel pixel by pixel (dashed line as shown in Figure 14-1-1). The drawn lines are also displayed in the Image display panel. You can deglitch the lines or points that you selected by clicking the 'Execute' button.

14-2. Deglitch an Image

Deglitching is processed according to the rule that glitches are replaced by the lines of pixels through the average filter. For deglitching a horizontal line, every pixel in the line you select is substituted by the average of its top neighbor and its bottom neighbor. A line can be selected that extends across the entire image. For deglitching a vertical line, every pixel in the line you select is substituted by the average of its left and its right neighbor. Points are deglitched by getting the average of four neighbor pixels, one from each cardinal direction.

The procedure to deglitch an image is as follows (see Figure 14-2-1):

1. Load the image you want to deglitch into the Analysis view.
2. Select 'Process>Deglitch' in the Menu or click the 'Deglitch' icon  in the toolbar to display the Deglitch process dialog.
3. Move the zooming square to where you want to deglitch in the image.
4. Decide what shape (line or point) to deglitch with. Place the cursor in the Zoomed Image display panel and click the cursor onto glitches.
5. Preview the changes in the Image display panel after clicking the 'Execute' button executing the deglitching process. Update the deglitched image into the Analysis view if desired.
6. Save, export, or print this processed image for further analysis and processing

<u>NOTE!</u>

Applying the Deglitching process to an image produces a new, processed image that can be saved or printed as a new file. Glitch removal does not change the original data unless you click the Save button.

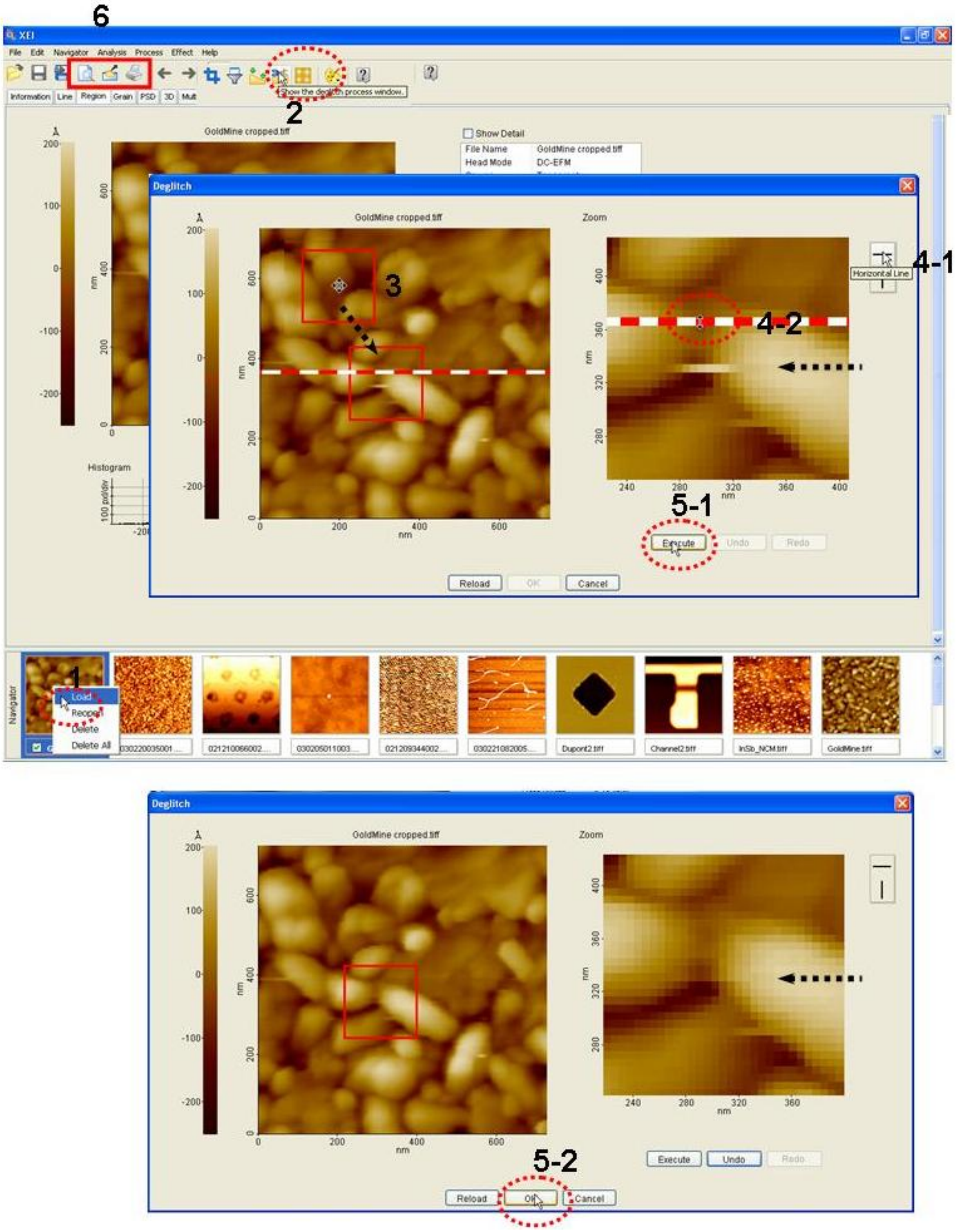


Figure 14-2-1. Procedure to deglitch an image

Chapter 15. Region Deglitch

Region Deglitching is used to remove glitches from an image. A glitch is a small artifact in an image that does not represent the true surface topography. The Region Deglitch process allows you to remove glitches in the horizontal and vertical directions. The Region Deglitch process allows removal of artifacts in larger areas, or removal of multiple artifacts in one go.

15-1. Region Deglitch Process Dialog

To open the Region Deglitch process dialog, select ‘Process>Region Deglitch’ in the Menu or click the ‘Region Deglitch’ icon in the Toolbar.

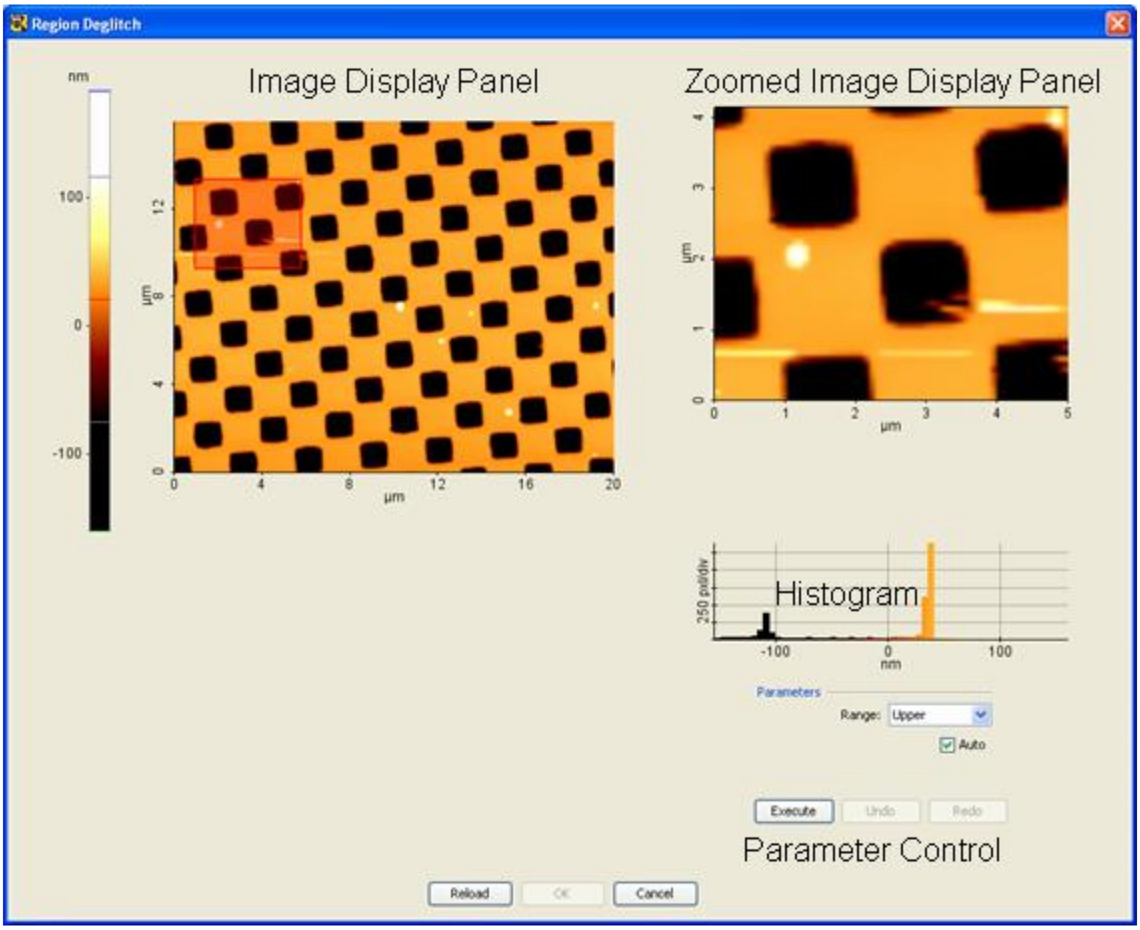


Figure 15-1-1. Region Deglitch process dialog

As shown in Figure 15-1-1, the Region Deglitch process dialog is composed of four main parts; Image display panel, Zoomed Image display panel, Histogram, and Parameter Control. At the left side, the Image display panel shows the whole image. At the right side, there is the Zoomed Image display panel that shows the region that is being deglitched.

15-1-1. Image Display Panel

The Image display panel displays the whole image that is currently being processed. There is a red rectangle that indicates the selected and zoomed region. The zooming rectangle can be moved by clicking dragging it, and resized by clicking and dragging one of its corners.

15-1-2. Zoomed Image Display Panel

The Zoomed Image display panel displays the magnified image of the zooming square. The Zoomed Image display panel magnifies the image dynamically while the zooming square is moved. In Region Deglitch, this area also represents the region that is being deglitched.

15-1-3. Histogram

The deglitch can be performed to remove artifacts that result in apparent low or apparent high values in the image. When these are determined manually, the histogram is used to set these upper or lower bounds.

15-1-4. Parameter Control

There are two settings that can be adjusted in Region Deglitch.

- Auto
  When this is selected, the software automatically fits a Gaussian curve to the histogram and considers points that are above or below the main curve to be due to artifacts. When unselected, the Histogram is used to manually determine the upper and lower bounds.

- Upper, Lower, Both
  When in Auto mode, you can decide to only consider points on the upper or lower extreme to be artifacts. If Both is selected, both upper and lower extremes will be considered artifacts.

15-2. Region Deglitch an Image

Region Deglitching is based on the assumption that within the selected region, pixels above or below a certain threshold are caused by noise, and that their actual value can be more accurately represented by interpolating a value from the surrounding data. Within the region defined by the zooming square, every point that is considered too high or too low is given a new value based on its closest non-artifact neighbors in the four cardinal directions.

The following procedure can be used to perform Region Deglitch on an image with the Auto setting.

1. Open the file, and enter the Region Deglitch process.
2. Select the area you wish to deglitch.
3. Select the threshold type (Upper, Lower, or Both).
4. Click the 'Execute' button.

Figure 1-2-1 shows this process, and Figure 1-2-2 shows a deglitched image.

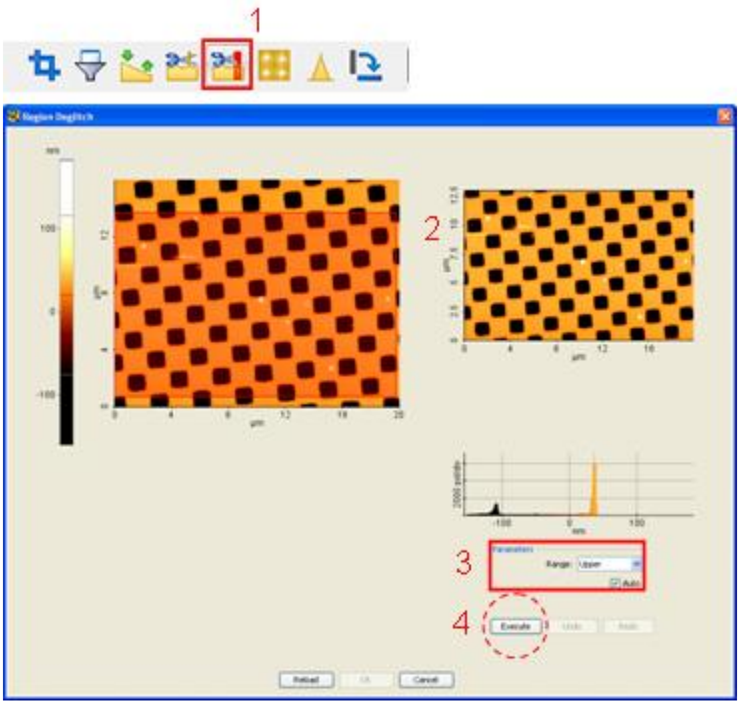


Figure 15-2-1. Auto Region Deglitch

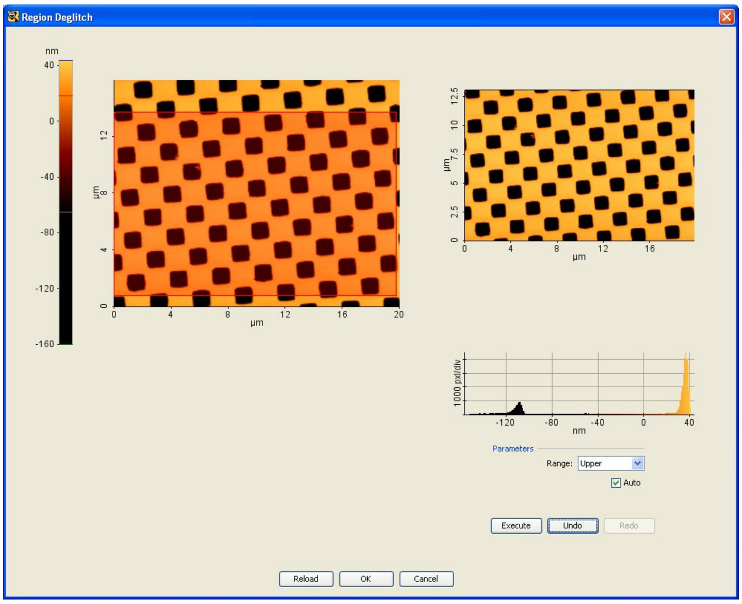


Figure 15-2-2. Auto Deglitched Image

The following procedure can be used for manual selection of the thresholds.

1. Open the file, and enter the Region Deglitch process.
2. Select the area to region deglitch.
3. Deselect Auto, and move the Histogram cursors to limit the points to the glitches. Excluded points will be shown in purple.
4. Click the Execute button.

NOTE!

Applying the Region Deglitching process to an image produces a new, processed image that can be saved or printed as a new file. Glitch removal does not change the original data unless you click the Save button.

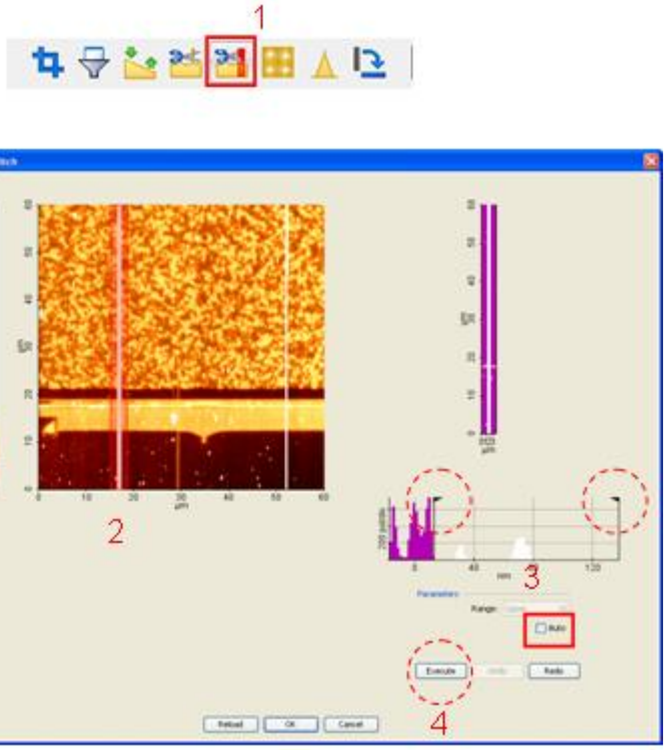


Figure 15-2-3. Manual Region Deglitch

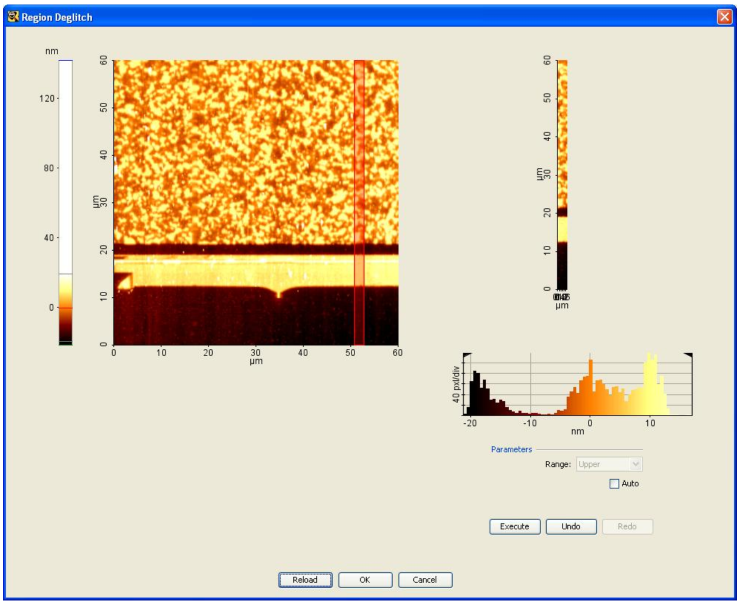


Figure 15-2-4. Manual Deglitched Image

Chapter 16. Fourier Filter

You can use the Fourier Filter to remove unwanted frequency components from your data. A Fourier Filter is most commonly used to remove periodic noise that appears in an image, for instance, due to electrical noise or mechanical vibrations. A 2-dimensinal power spectrum of an image may be used to identify periodic noise. In the power spectrum, periodic noise will appear as a vertical band running through the center of the power spectrum. This noise can be removed by applying a Fourier Filter. Also, a Fourier Filter may be used to remove a selective frequency component from actual surface data. This technique is often applied in presenting atomic lattice data. In this case, a Fourier Filter is applied that includes only the frequencies that represent the symmetry of the atomic lattice.

16-1. Fourier Filter Process Dialog

To open the Fourier Filter process dialog, select the 'Process>Fourier Filter' option in the Menu or click the 'Fourier Filter' icon  in the Toolbar.

As shown in Figure 16-1-1, the Fourier Filter dialog consists of an Image display panel and a 2D power spectrum display. On the left side, there is the Image display panel which shows the original image to which the Fourier Filter will be applied and will also show the transformed image after you have applied the Fourier Filter. At the right side of the Image display panel is a 2-dimensional power spectrum which includes a palette panel as well as tools used to either include or exclude regions (rectangle, ellipse, polygon or entire region) to be filtered.

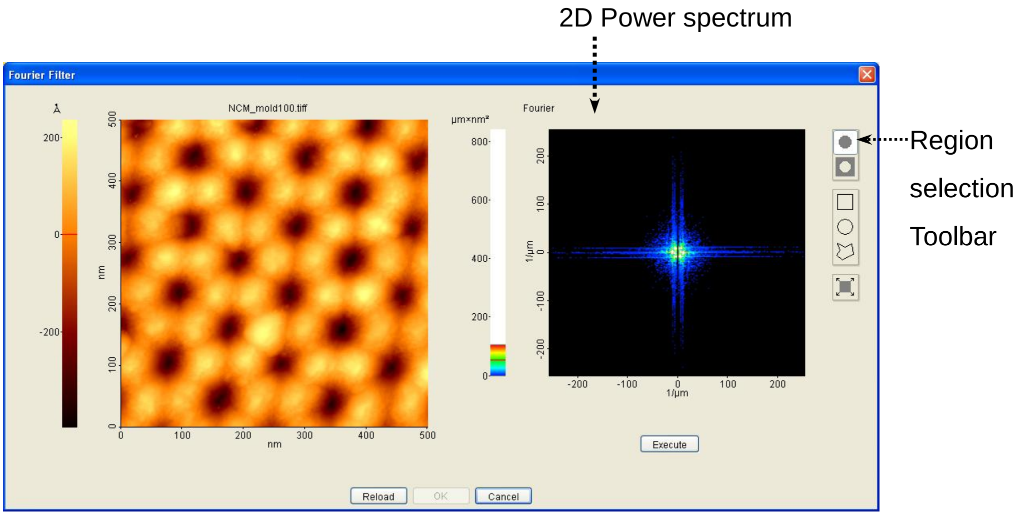


Figure 16-1-1. Fourier Filter process dialog

16-2. 2D Power Spectrum

When you open the Fourier Filter process dialog, the Fourier transform of the selected image is automatically calculated. The resulting power spectrum is displayed in a different color. Figure 16-2-1 shows the general 2D power spectrum which all height data in the spatial domain are converted to the frequency domain after Fourier transform. Peaks in the power spectrum appear bright on a dark background, and also, different colors are displayed in different intensities of frequency components in the data. You can adjust this scale using the palette panel to see various peaks in the power spectrum more clearly.

The unit of the z scale in the power spectrum is displayed at the left side of the palette panel as Å×μm^2, µm ×μm^2, V×μm^2, Å×nm^2, nm ×μm^2, V× $Å^2$ and so on that depending on the unit you selected as an input signal in the Input configuration dialog when the image was initially acquired. The units of x and y in the power spectrum are 1/µm, that is, the reciprocal of each unit of x and y in the image.

In a power spectrum, the x scan direction is displayed horizontally and the y scan direction is displayed vertically. Lower frequencies are near the origin and higher frequencies are further from the origin. Peaks in the power spectrum are symmetric about the origin.

Each spatial frequency in the real spatial image is represented by a peak in the power spectrum. Peaks can be due to actual surface periodicities such as the spacing between lines on a grating of a standard sample or the spacing between rows of atoms on a graphite surface. Peaks may also result from periodic noise. To apply the Fourier Filter to unwanted frequency components, remove or reduce the intensities of the unwanted peaks in the power spectrum.

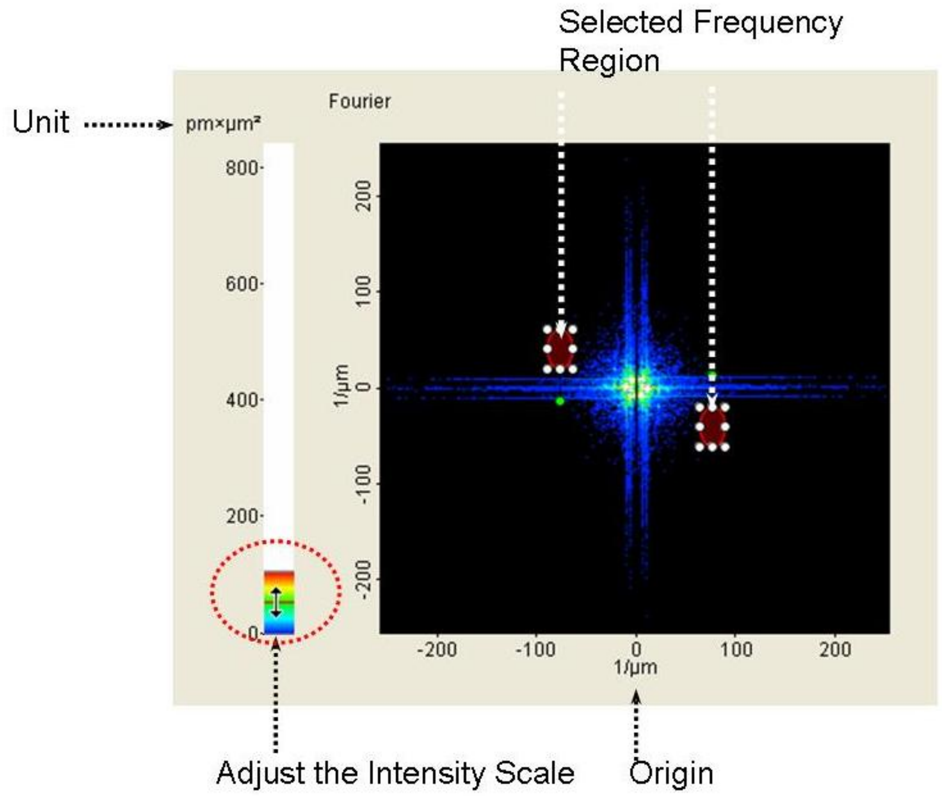


Figure 16-2-1. 2D power spectrum

16-3. Apply the Fourier Filter to an Image

A selective Fourier filter allows you to remove specific frequency components from the power spectrum of an image. This process is commonly used to remove peaks attributed to periodic noise. Furthermore, it can be useful when you wish to take an image with only chosen periodicities by including only those peaks in which you are interested.

In Fourier filtering, you select a region type to be used for including or excluding frequency components in the power spectrum. You can remove all periodic noise by excluding frequency components within the included region.

Since peaks in the power spectrum are reflected across the origin, both a selected region and its reflected region will be generated together.

You can apply the Fourier filter to an image by following these general steps (see Figure 16-3-1):

1. Load the image you want to apply Fourier Filter into the Analysis view.
2. Open the Fourier Filter process dialog by selecting 'Process>Fourier Filter' in the Menu or by clicking the 'Fourier Filter' icon  on the Toolbar. When you open the Fourier Filter process dialog, the entire power spectrum is automatically displayed.
3. Select a region type (rectangle, ellipse, polygon or entire region) you wish to use to include or exclude selected frequencies, and draw it around the desired spectral features in the power spectrum.
4. Click the 'Execute' button to preview the effect of the Fourier Filter. Update the image in the Analysis view by selecting the 'OK' button if desired.
5. Save, export, process or analyze the filtered real spatial image.

Figure 16-3-1 shows the general procedure to apply the selective Fourier Filter and also, you can see a comparison of an original image and a Fourier filtered image. Furthermore, Figure 16-3-2 shown below is the atomic lattice image which the selective frequency components were passed through the Fourier Filter.

NOTE!

Applying the Fourier Filter to an image produces a new, processed image that can be saved or printed as a new file. This application does not change the original data unless you click the Save button.

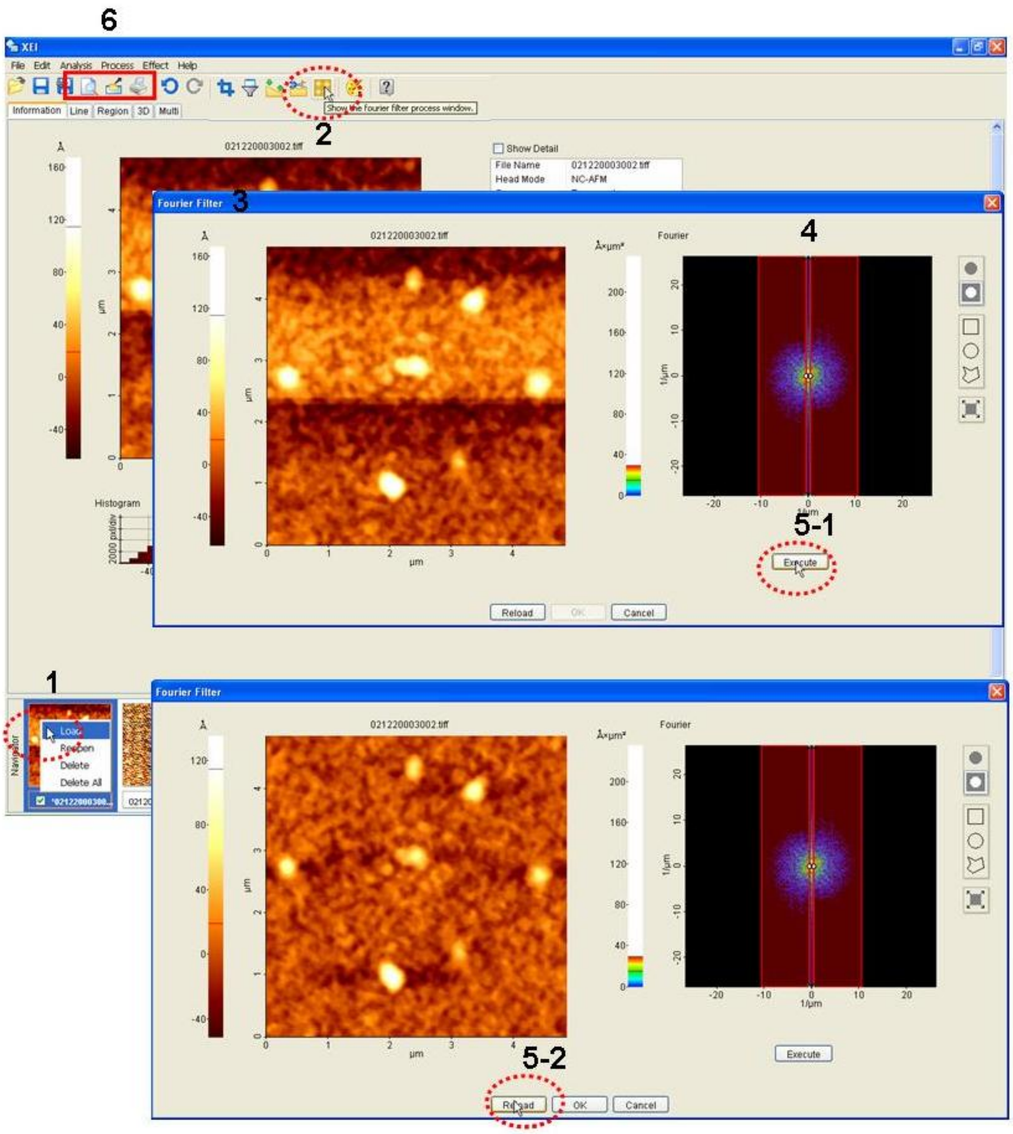


Figure 16-3-1. Procedure to apply the Fourier Filter to an image

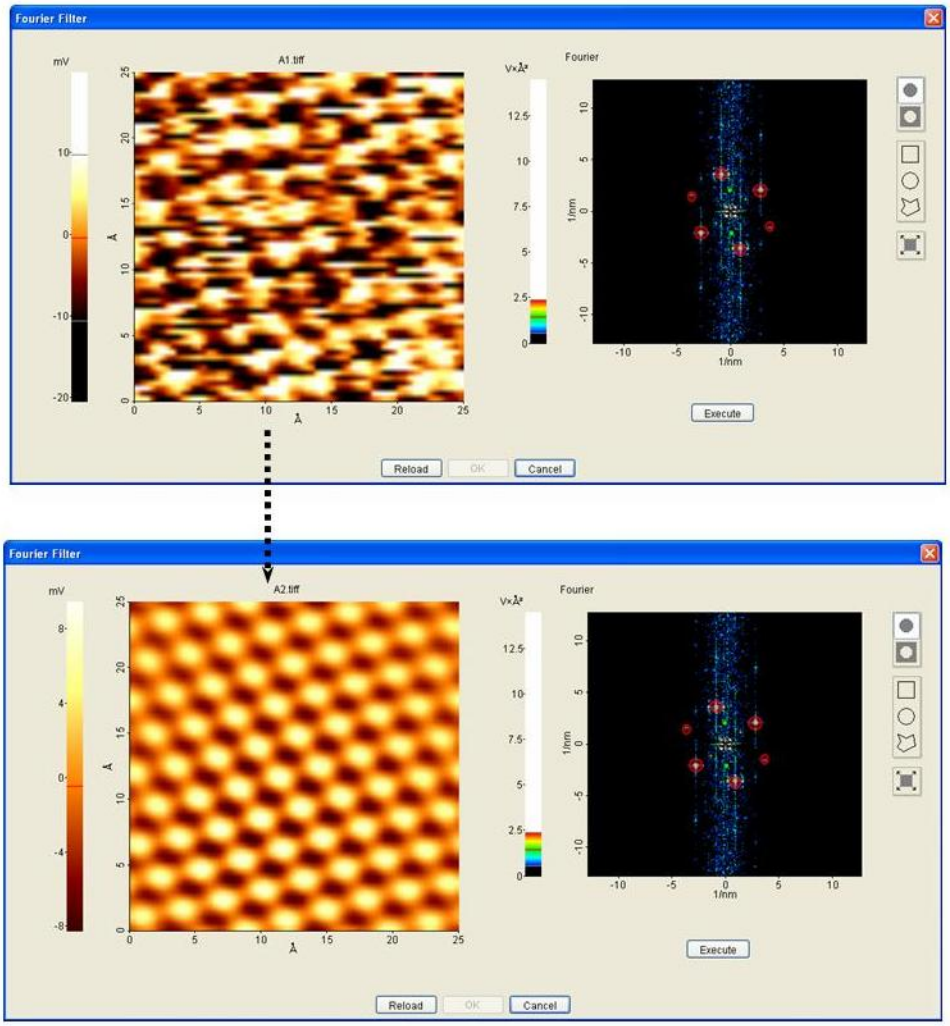


Figure 16-3-2. Fourier Filter applied to Atomic lattice image

Chapter 17. Tip Estimation

As the size of the tip is finite, the images obtained by the SPM are affected by the shape of tip. In professional words, image of the tip is 'convoluted' to the image of the sample surface obtained with the tip (i.e. Tip Convolution). Tip Convolution generates error in the dimensions of the sample surface measured with the SPM. Figure 17-1 shows simple example how shape of the tip affects the dimensions of the hills and trenches measured with the SPM.

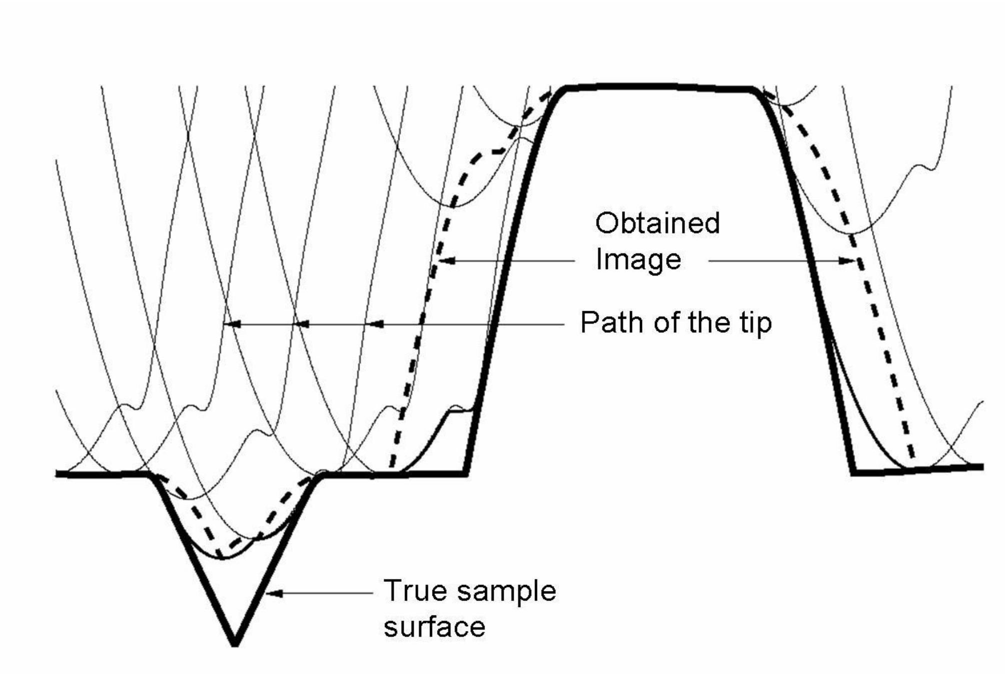


Figure 17-1. Example of tip convoltion

To remove such an affect of the 'tip convolution', XEI offers 'Tip Estimation' process. During the 'Tip Estimation' process, XEI first 'estimates' the shape of the tip used to obtain the image. Then, XEI calculates the artifacts caused by tip and removes them from the loaded image. (Tip de-convolution)

This part of the manual is mainly focused on how to use the 'Tip Estimation' function of the XEI. For detailed information regarding the algorithm of the ‘Tip Estimation’ process, please refer to *“Algorithms for Scanned Probe Microscope Image Simulation, Surface Reconstruction, and Tip Estimation”* by *J. S. Villarrubia*. (‘Volume 102, Number 4, July–August 1997 Journal of Research of the National Institute of Standards and Technology)

17-1. Tip Estimation Process Dialog

To open the Tip Estimation process dialog, select the item from the Process menu or click the ‘Tip Estimation’ icon in the Toolbar.

As shown in Figure 17-1-1, the Tip Estimation dialog consists of two image display panel, one for the loaded image (Image Display Panel) and the other for the estimated tip shape (Tip Image Display Panel), and Parameters panel.

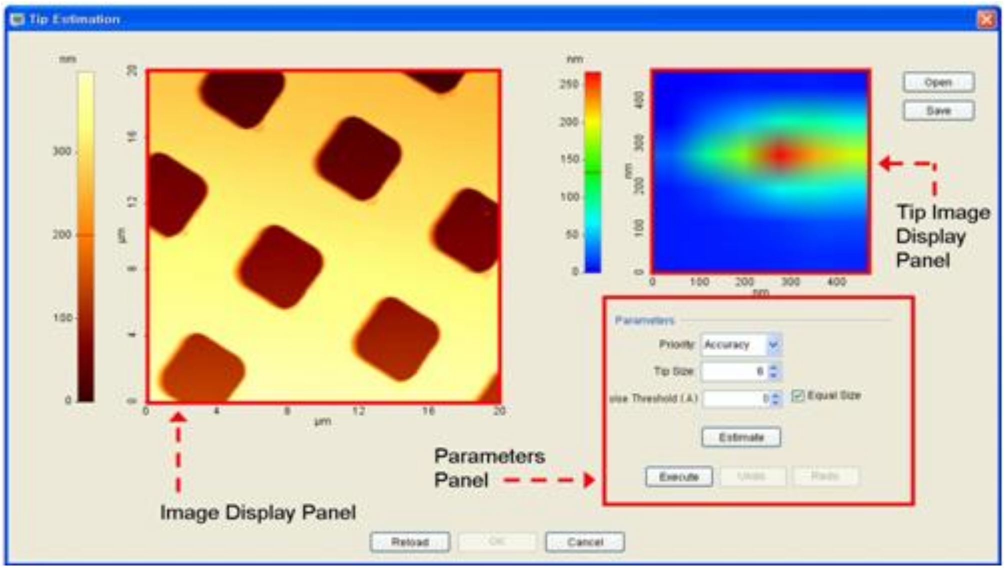


Figure 17-1-1. Tip Estimation process dialog

17-1-1 Image Display Panel

The Image display panel is on the left side shows the original image to which the tip deconvolution will be applied and will also show the transformed image after you have applied the deconvolution. Image before and after tip deconvolution is displayed in the Image Display Panel.

17-1-2 Tip Image Display Panel

2 dimensional representation of the estimated tip shape is displayed on 'Tip Image Display Panel'. Also, the estimated tip shape can be saved and loaded for further analysis.

■ Opening & Saving the Estimated Tip Shape

Estimated tip shape can be saved as a tiff file by clicking 'Save' button. The tiff file of the estimated tip shape will be saved under the same directory where the image loaded for "Tip Estimation' process is saved. The file name of the saved tip shape will be in forms of '*File name of the image loaded for tip estimation process*_tip.tiff'.

Saved tip shape can be loaded to the 'Tip Image Display Panel' later on and used as an estimated tip shape for other samples as well. To load the saved tip shape, click 'Open' button and browse to find the saved tip shape. Figure 17-1-2 shows a tiff file of the saved tip shape loaded in 3D view of the XEI.

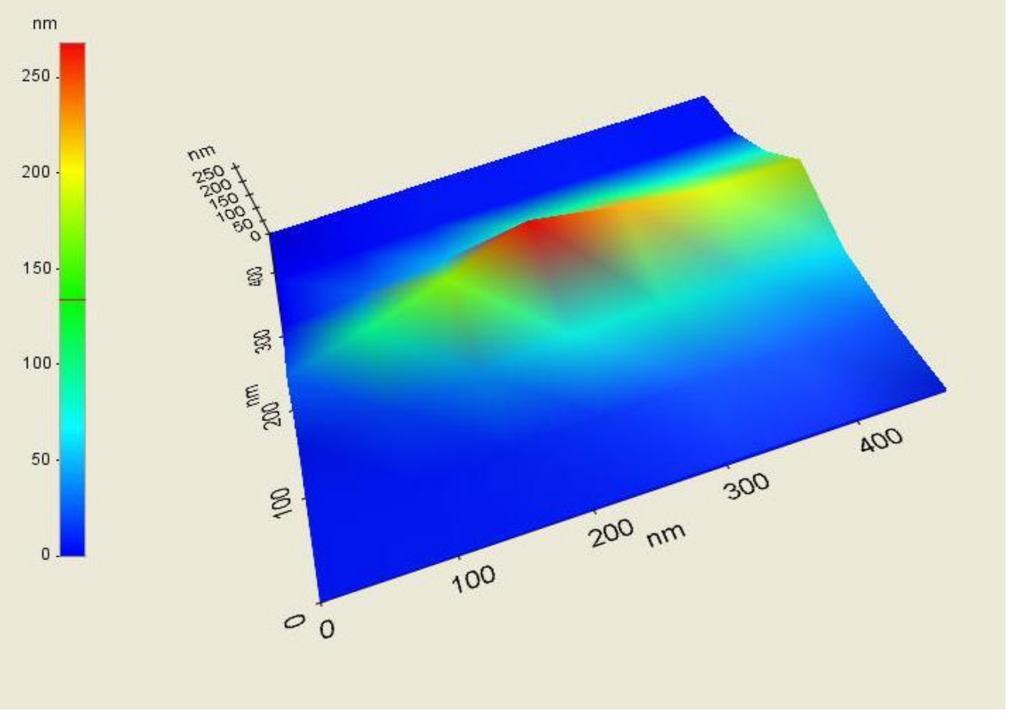


Figure 17-1-2. Estimated tip shape saved as tiff file

Saving and loading the tip shape can be useful if you have more than 2 images that have been obtained using the same tip. You can save the tip shape estimated from one sample and load it to deconvolute other images that have been obtained with same tip without repeating tip estimation process.

17-1-3 Parameters Panel

Parameters related to optimization of tip estimation and deconvolution process are controlled through this panel.

- **Priority**

User can select to give priority of tip estimation and deconvolution algorithm to either 'Speed' or 'Accuracy'. When the 'Priority' is given to 'Speed', XEI uses partial estimation algorithm to perform fast tip estimation and when the 'Priority' is given to 'Accuracy', XEI uses full estimation algorithm to perform more accurate tip estimation.

- **Tip size**

Tip size can be set in units of the 'pixels'. Selecting an appropriate tip size is important for good tip estimation results. Typical tip size that gives accurate estimation result is 0.04 to 0.2 of the image size. For example, if the size of the loaded image is 20um with 256 pixel size, typical tip size that will give good estimation result will be 10.24 to 51.2.

- **Noise Threshold**

Variations that are smaller than this value are ignored during the tip estimation process as contributed by noise. Typical values range from 2Å to 5Å.

17-2. Applying Tip Estimation process to the Image

The tip shape will be automatically calculated when the dialog window is initialized. You can recalculate the tip shape if you have better knowledge of the actual tip size. Put the size (height and width) of the tip into the appropriate fields and click the Estimate button. A new estimation will be made.

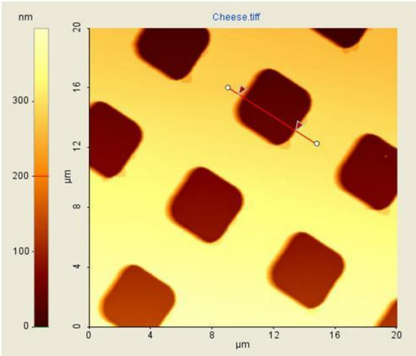
Once a good approximation of the tip shape has been made, it can be applied to the image to remove artifacts created by the tip. This can be helpful for images including sheer slopes. Tip deconvolution is applied to the whole image. You can estimate the tip shape and apply the estimation to an image by following these general steps:

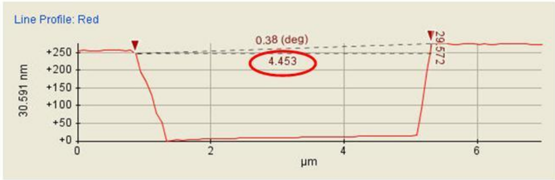
1. Load the image to which you want to apply tip deconvolution into the Analysis view.
2. Select Tip Estimation from the Process menu or click the 'Tip Estimation' icon  in the Toolbar.
3. Input the size of the tip, select priority, and then click 'Estimate' to calculate the shape of the tip. If you had estimated the shape of the tip that was used to obtain the loaded image.
4. Click the 'Execute' button to preview the effect of the tip deconvolution. Update the image in the Analysis view by selecting the 'OK' button if desired.
5. Save, export, process or analyze the new image.

NOTE!

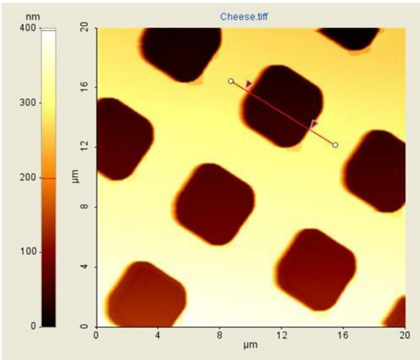
Applying the Tip Estimation process to an image produces a new, processed image that can be saved or printed as a new file. This application does not change the original data unless you click Save button.

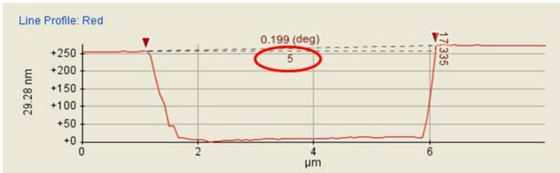
Figure 17-2-1 shows the resulting image when the estimated tip shape is applied to the original data.





Before Deconvolution – measured width of trench (4.5um) is smaller than its known width 5um due to the effect of tip convolution.





After Deconvolution – Tip shape is deconvoluted from the image and now the measured width of trench (5um) matches the known width 5um.

Figure 17-2-1. Application of Tip Estimation

In actual experiments, there is special sample designed for tip shape estimation. Accurate tip shape can be obtained when the tip shape is estimated from the image of this sample. Then, the estimated tip shape can be loaded for tip deconvolution of other images measured with same tip.

Chapter 18. Rotate & Flip

It may be desirable to change the orientation of an image. The Rotate & Flip process can be used to rotate SPM images left or right, or flip the image across one of its axes. This may be helpful for comparison of images taken at different orientations.

18-1. Rotate & Flip Process Dialog

To open the Rotation & Flip process dialog, select 'Process>Rotate & Flip' in the Menu or click the 'Rotate & Flip' icon  in the Toolbar.

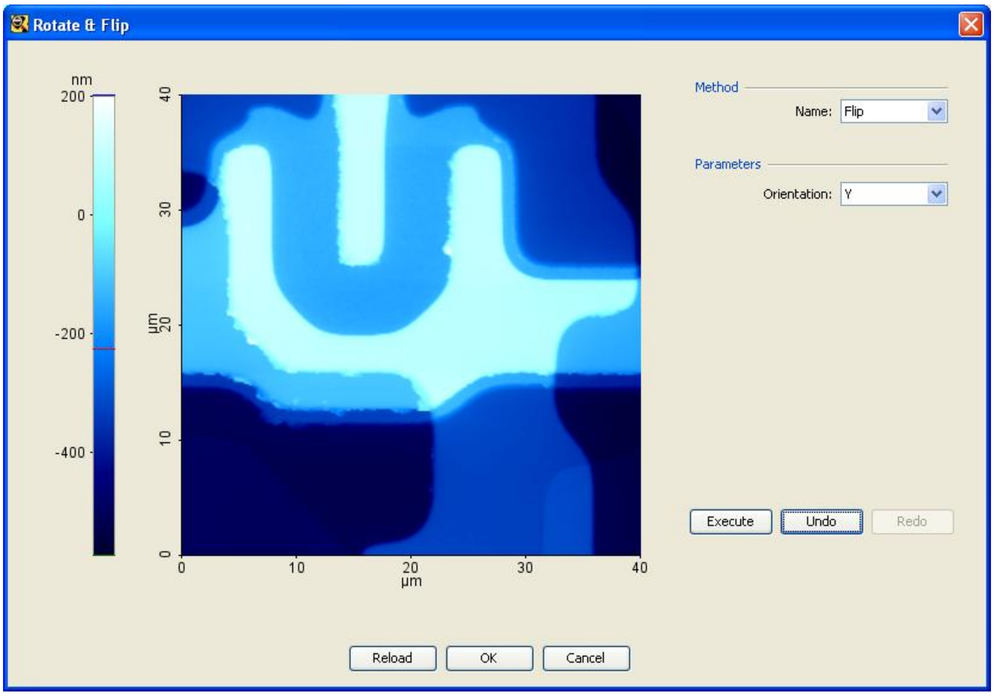
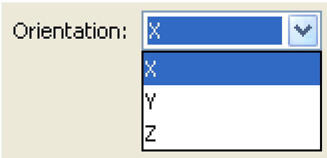


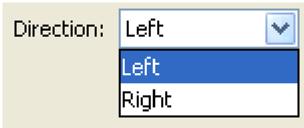
Figure 18-1-1. Rotate & Flip process dialog

As shown in Figure 18-1-1, the Rotate & Flip dialog has two settings that can be modified.

18-1-1. Method

You can choose to flip the image or to rotate the image with this option. Flipping around an axis will invert the value of that axis for every pixel in the image. Rotating will swap the X and Y axes with different signs.





18-1-2. Parameters

The parameter options allow you to select, for the Flip method, X, Y, or Z. This determines which axis the image is flipped around. For Rotate, the field changes to Left or Right, which determines whether the image is rotated counter-clockwise or clockwise, respectively.

18-2. Rotate & Flip an Image

To rotate or flip an image, perform the following steps:

1. Open the file, and enter the Flip & Rotate process.
2. Select the Method and Parameters for the operation.
3. Click the ‘Execute’ button.

Figure 18-2-1 shows this process for flipping an image around its Y axis.

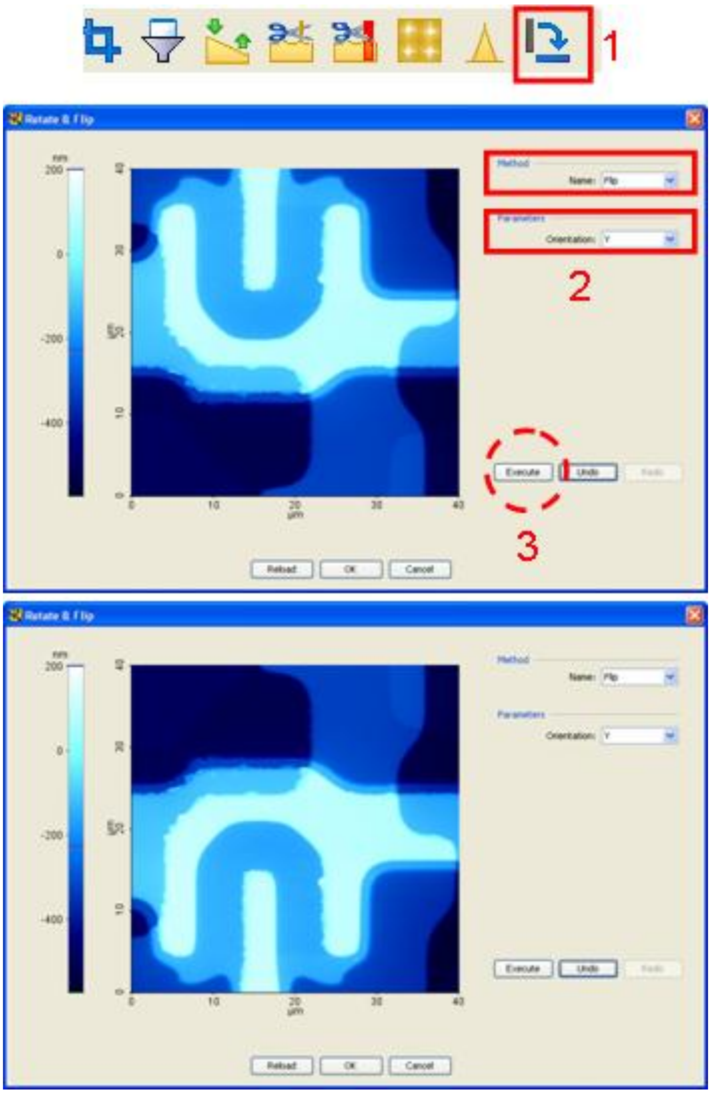


Figure 18-2-1. Perform Y Axis Flip

Chapter 19.　Pixel Manipulation

The Pixel Manipulation Process resamples the image to increase or decrease the number of pixels in the file.　This is particularly useful when comparing images of differing resolutions, as some operations can only work on images of the same resolution.

19-1. Pixel Manipulation Process Dialog

To open the Pixel Manipulation process dialog, select 'Process>Pixel Manipulation' in the Menu or click the 'Pixel Manipulation'' icon  in the Toolbar.

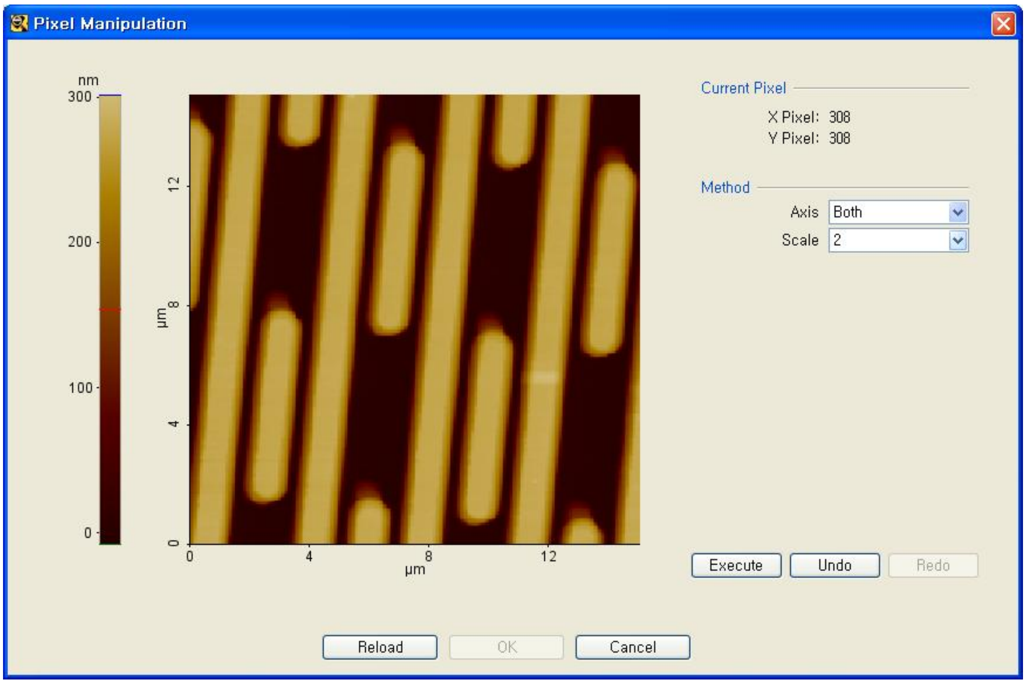


Figure 19-1-1. Pixel Manipulation process dialog

19-1-1. Current Pixel

The current resolution of the file is shown in number of pixels for the X and Y axes.

19-1-2. Method

You can select which axis to change using the 'Axis' drop-down menu: X, Y, or Both.

The amount by which the selected axis is changed is determined by the 'Scale' drop-down menu: Halve the number of pixels, or double them.

19-2. Applying Pixel Manipulation

To apply Pixel Manipulation to an image, perform the following steps:

1. Open the file, and enter the Pixel Manipulation process.
2. Select the Method.
3. Click the ‘Execute’ button.

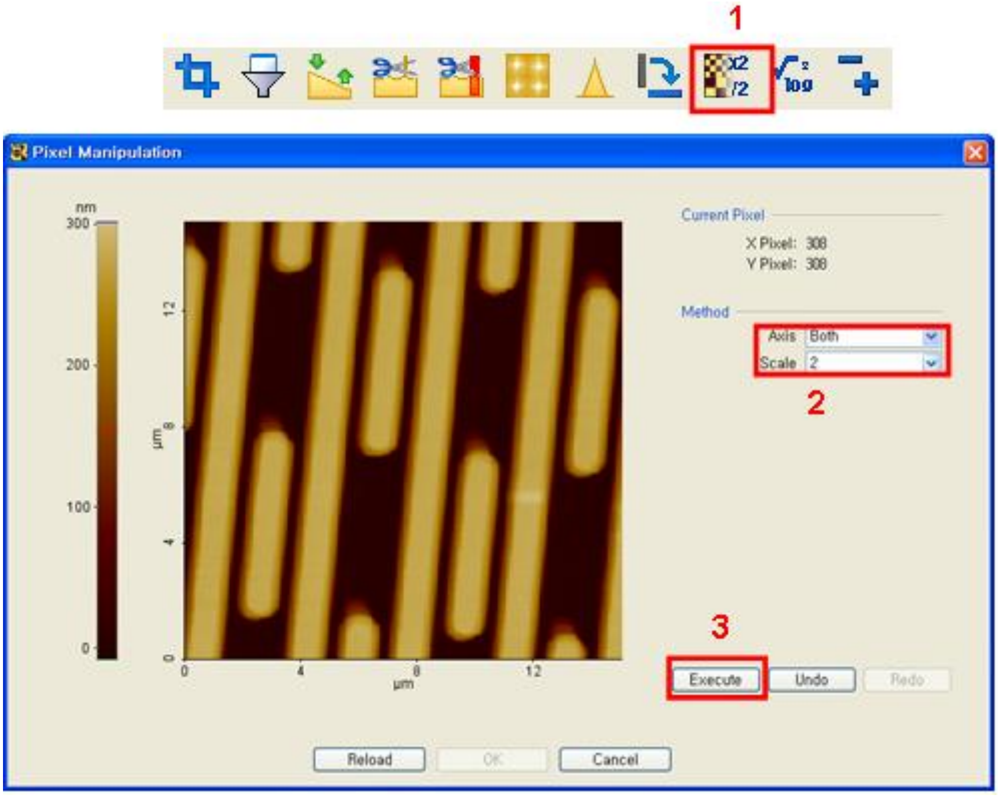


Figure 19-2-1. Perform Pixel Manipulation

Chapter 20. Unary Arithmetic

The Unary Arithmetic Process can perform several arithmetic operations on an image.

20-1. Unary Arithmetic Process Dialog

To open the Unary Arithmetic process dialog, select ‘Process> Unary Arithmetic’ in the Menu or click the ‘Unary Arithmetic’ icon  in the Toolbar.

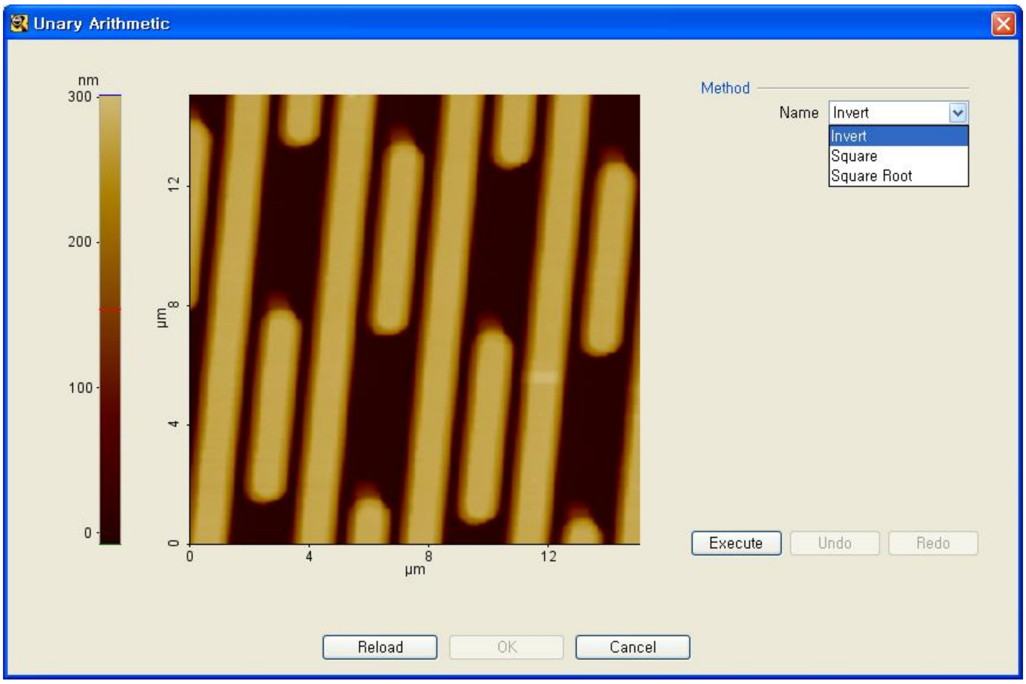


Figure 20-1-1. Unary Arithmetic process dialog

As shown in Figure 11-1-1, the Unary Arithmetic process has one parameter.

20-1-1. Method

The methods available are Invert, Square, and Square Root.

- Invert
  Every pixel is multiplied by -1 in the Z direction.

- Square
  Every pixel is squared.

- Square Root
  The square of every pixel is taken.

20-2. Applying Unary Arithmetic

To apply Unary Arithmetic to an image, perform the following steps:

1. Open the file, and enter the Unary Arithmetic process.
2. Select the Method.
3. Click the ‘Execute’ button.

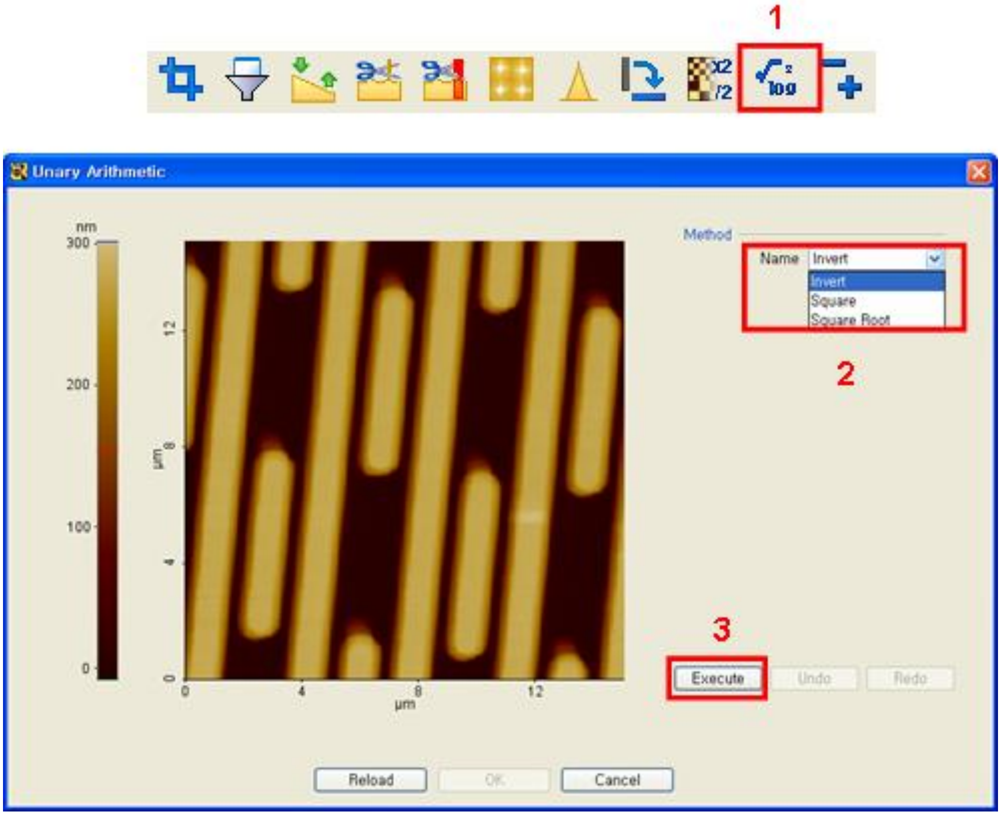


Figure 20-2-1. Apply Unary Arithmetic

Chapter 21.   Binary Arithmetic

The Binary Arithmetic process is used mostly for the direct comparison of two images.

21-1. Binary Arithmetic Process Dialog

To open the Binary Arithmetic process dialog, select 'Process> Binary Arithmetic' in the Menu or click the 'Binary Arithmetic' icon in the Toolbar.

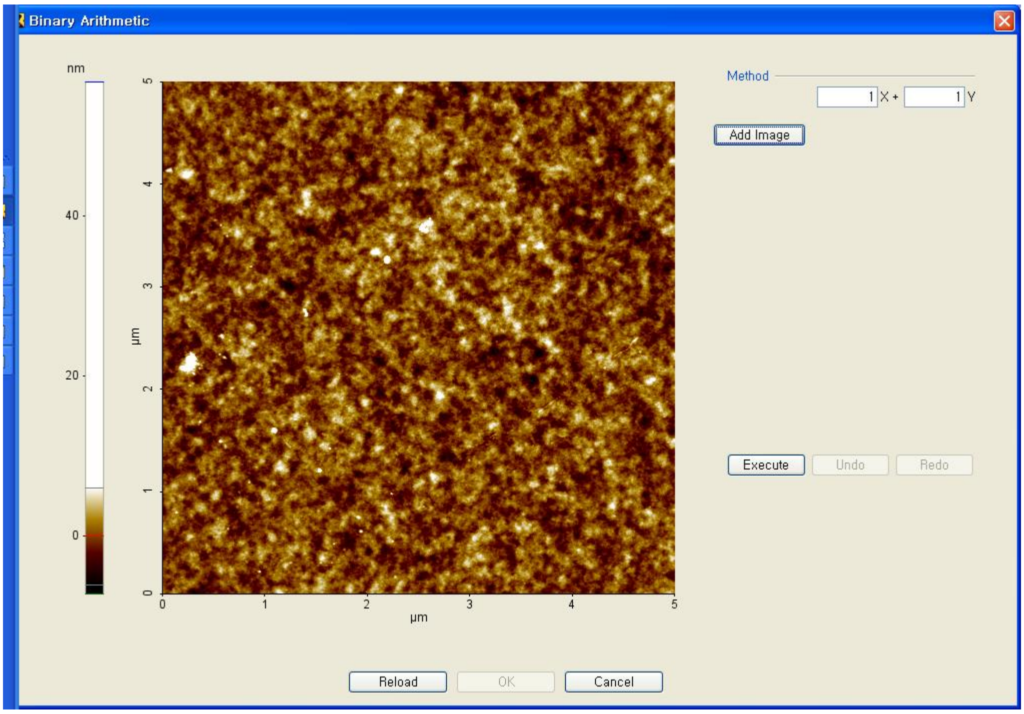


Figure 21-1-1. Binary Arithmetic process dialog

As shown in Figure 21-1-1, the Binary Arithmetic dialog has two parameters, X and Y.

18-1-1. Method

The X and Y fields denote the left and right images. The currently loaded image is shown on the left, and the second image which is to be added to the opened image is shown on the right.

The values in the X and Y fields determine their weight in the result. As the type of data can differ between images, such as with Topography and Error images, a trial and error approach is recommended to find satisfactory values for these fields.

21-2. Applying Binary Arithmetic

To apply Binary Arithmetic to an image, perform the following steps. In this example, the MFM data of a hard drive is added to the Topography signal.

1. Open the file, and enter the Binary Arithmetic process.

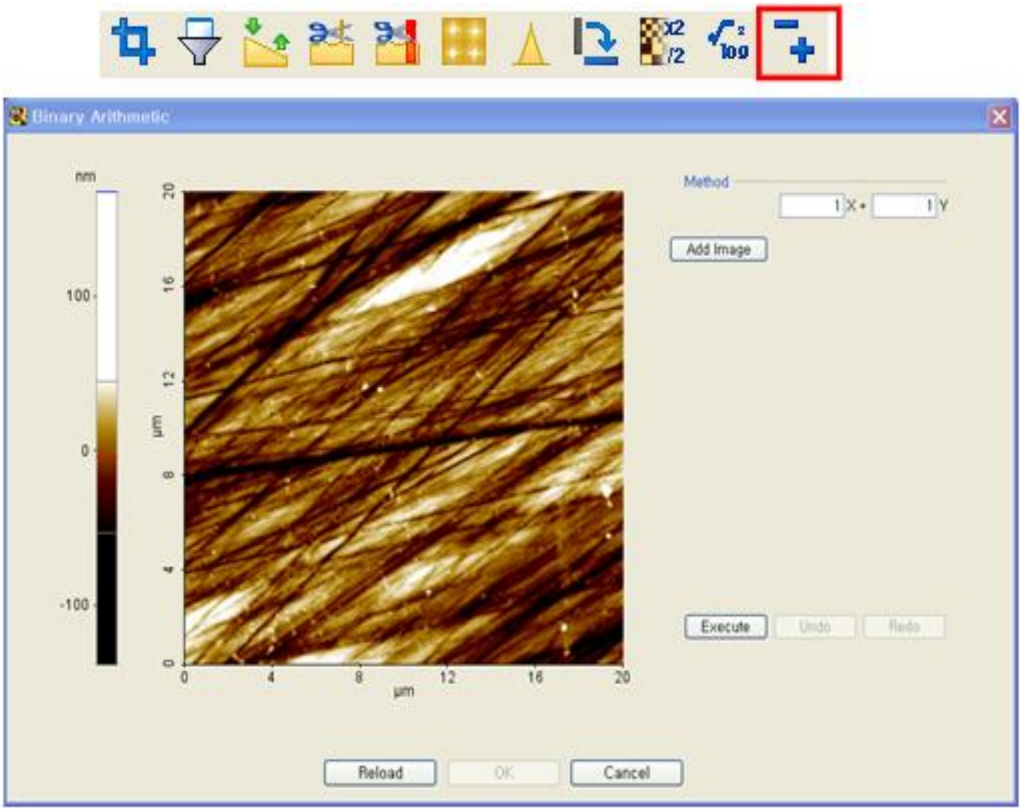


Figure 21-2-1. Start Binary Arithmetic

2. Click [Add Image] button and select the desired image. Then click [Open] button. The selected image will be shown additionally in the Zoom Image Display panel.

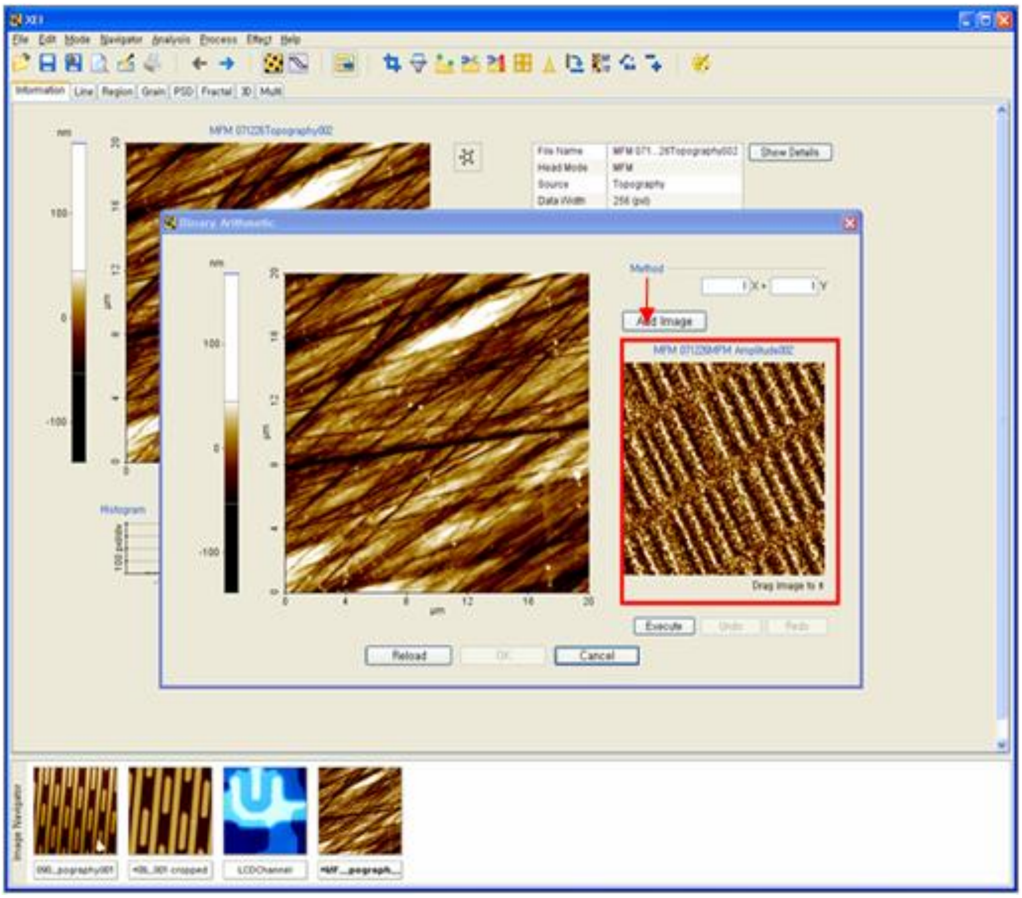


Figure 21-2-2. Select Second Image

3. Specify values for the X and Y weights.
4. Click the [Execute] button.

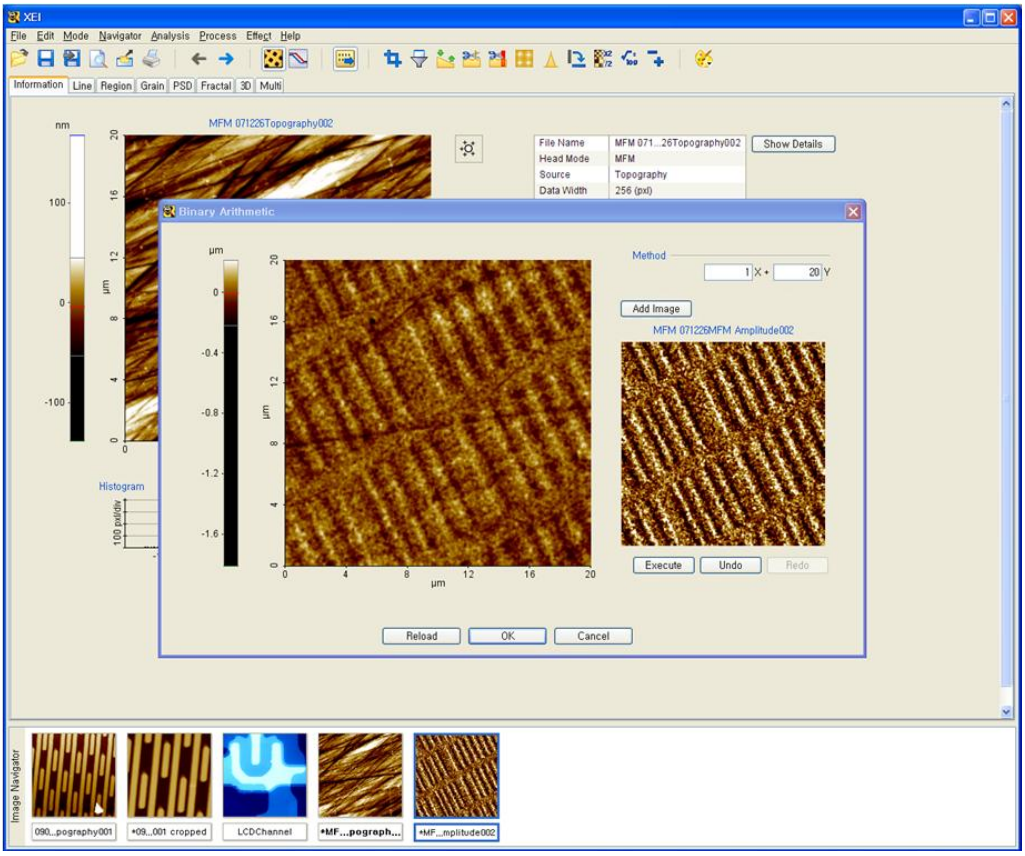


Figure 21-2-3. Binary Arithmetic Result

Chapter 22.　Spectroscopy Mode

Spectroscopy Mode is used for analysis of Force-Distance (F/D) curves, Nano-Indentation curves, Current-Voltage (I/V) curves and Photo Current curves. Spectroscopy Mode can be enabled by clicking the "Spectroscopy Mode" button  in the toolbar, or by selecting the "Spectroscopy" item in the Mode menu.

22-1. Views

Spectroscopy Mode is composed of three Views.　Information View displays information on the reference image and spectroscopy curves.　Batch View allows for the analysis of a set of curves.　Multi View is used for the direct comparison of two curves.　For F/D and Nano-Indentation curves, a Young's Modulus view is added.

22-1-1. Information View

Information View displays basic metadata.　It consists of an image display panel and an information table.　The Information View can be selected by selecting the Information tab, and is identical to the Information View for Image Mode.

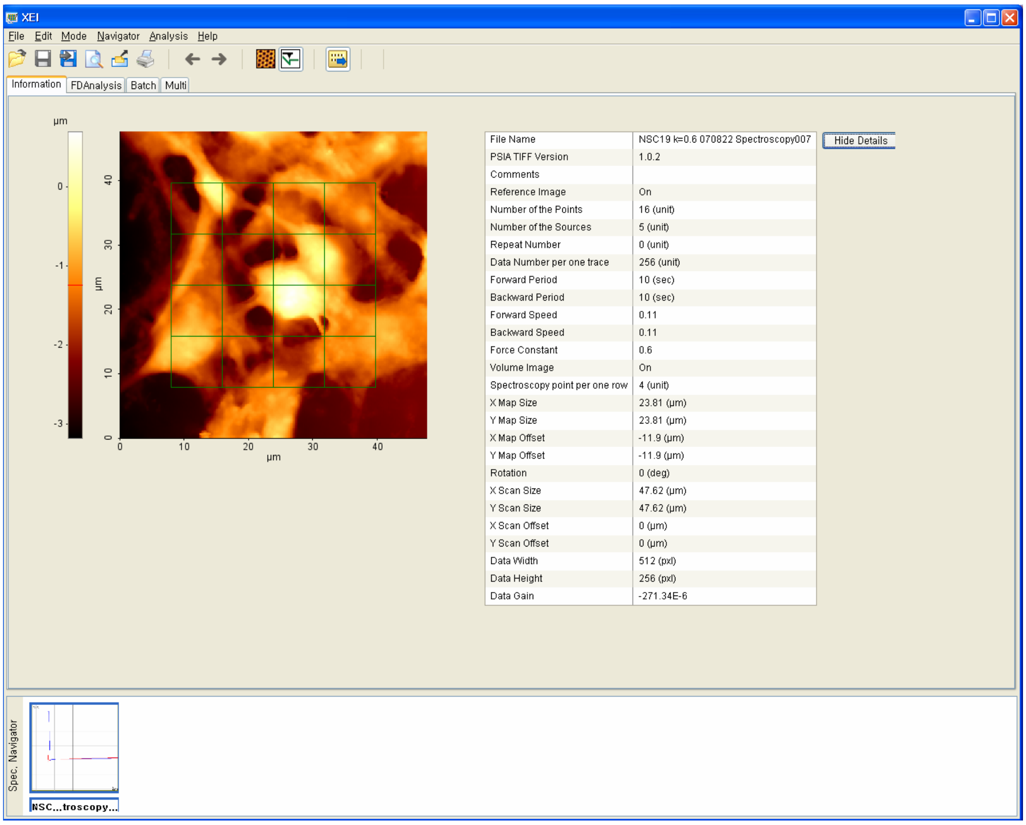


Figure 22-1-1. Information View

22-1-2. Batch View

Batch View can be enabled by clicking the Batch tab when Spectroscopy Mode is enabled. Batch View is designed to assist processing of multiple spectroscopy curves, and export the processed data for further analysis. The Batch View is consists of several components, as shown in Figure 22-1-2.

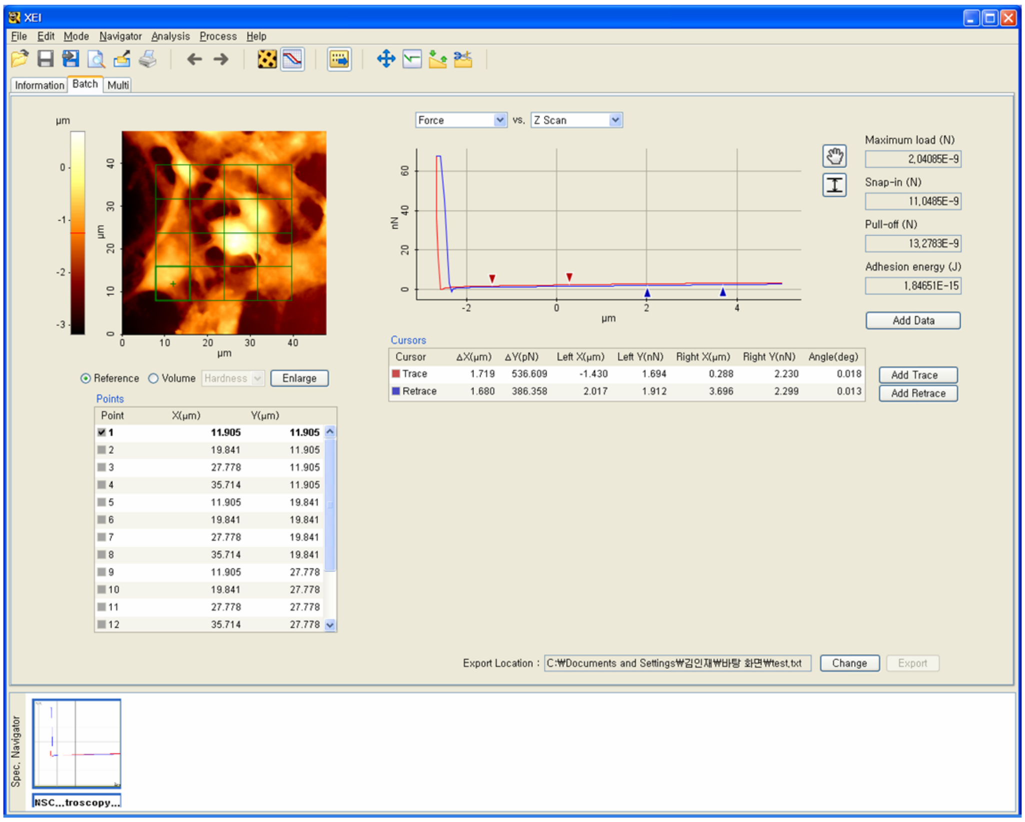


Figure 22-1-2. Batch View Figure

22-1-2-1. Image Display Panel

The Image Display Panel shows a representation of the sample surface, overlaid with a green grid to show the spectroscopy locations.

The Reference and Volume buttons will switch the display between showing the Reference image and image derived from the Spectroscopy measurements.

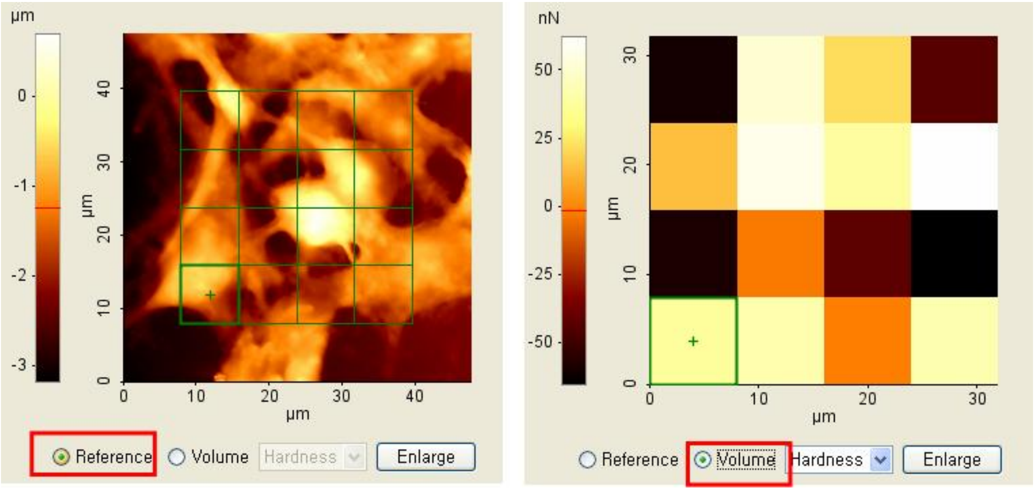


Figure 22-1-3. Reference and Volume

While the Volume option is selected, what it represents can be changed using the activated down arrow button. Volume image can be exported as tiff, text and image file by clicking on the right click on image.

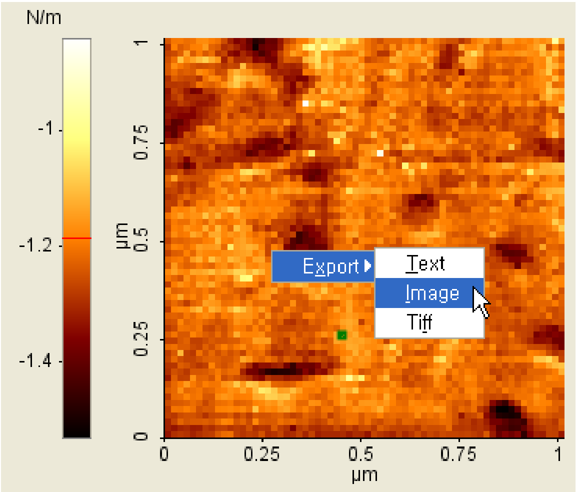


Figure 22-1-4. Volume Image Export

This volume option is only shown for measurement which got from mapping.

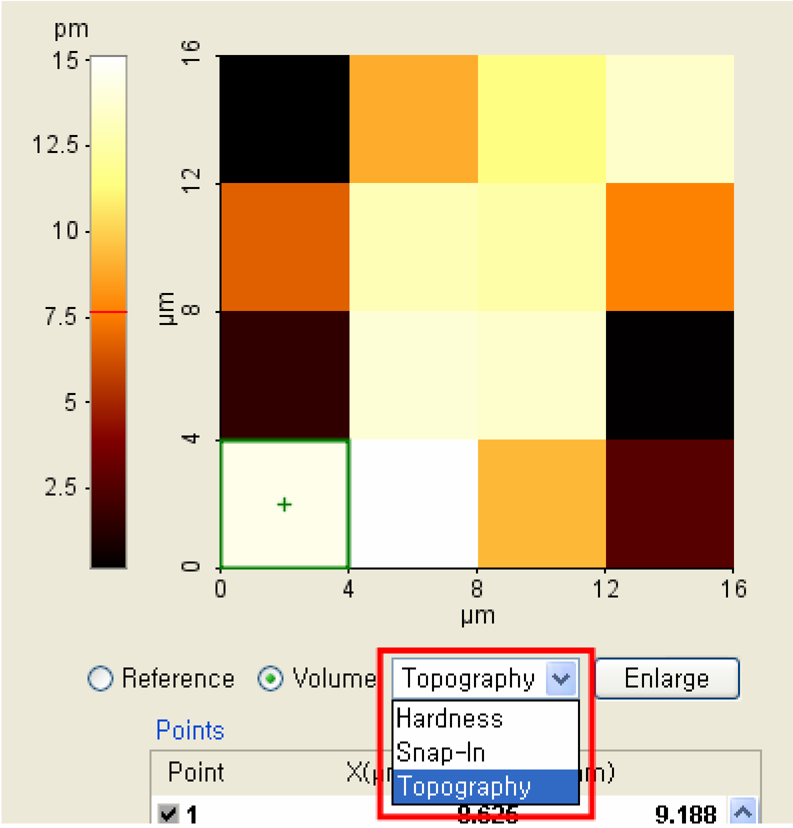


Figure 22-1-5. Volume Option

The Enlarge button will maximize the Image Display Panel. Figure 22-1-6 shows the display with this button enabled. When in this state, the Enlarge button is changed to “Shrink”, which when pressed will revert the view to the previous state.

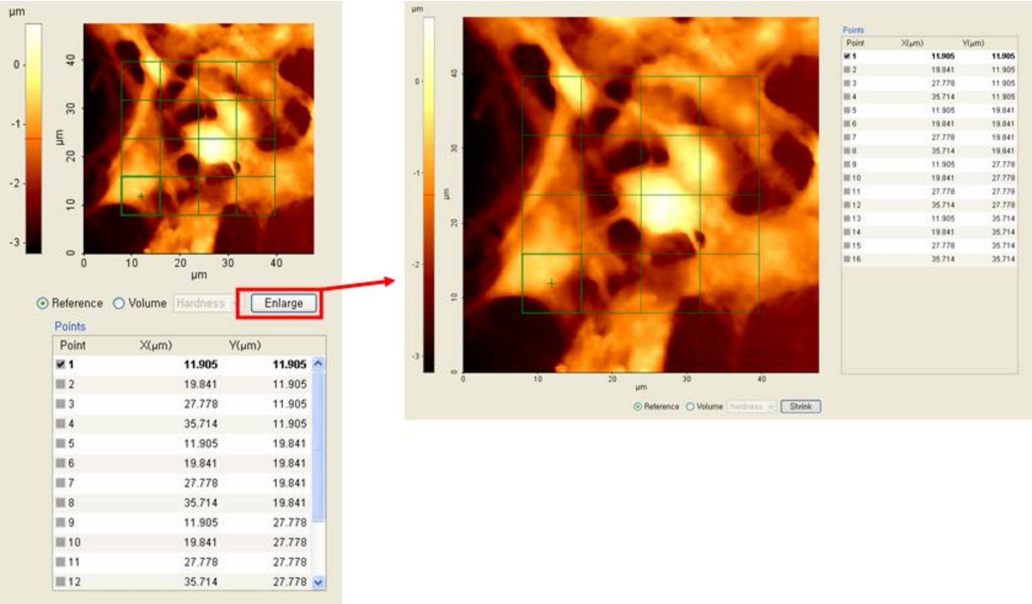


Figure 22-1-6. Image Display Panel (enlarged and normal view)

22-1-2-2. Points Table

The Points Table lists the points taken in the current batch of data, along with their X and Y positions within the image. These are also visually represented in the Image Display Panel. You can select which of the curves to analyze by checking the box in the Point column.

The points selected in this table will be loaded for analysis. Also, you can export them by notepad or spread sheet by clicking on the right of mouse. You can select and export multi points if you click other point after clicking 'Shift' button on the keyboard. In this case, 'info' file which has position information, is also created together with spectroscopy measurement file for each point.

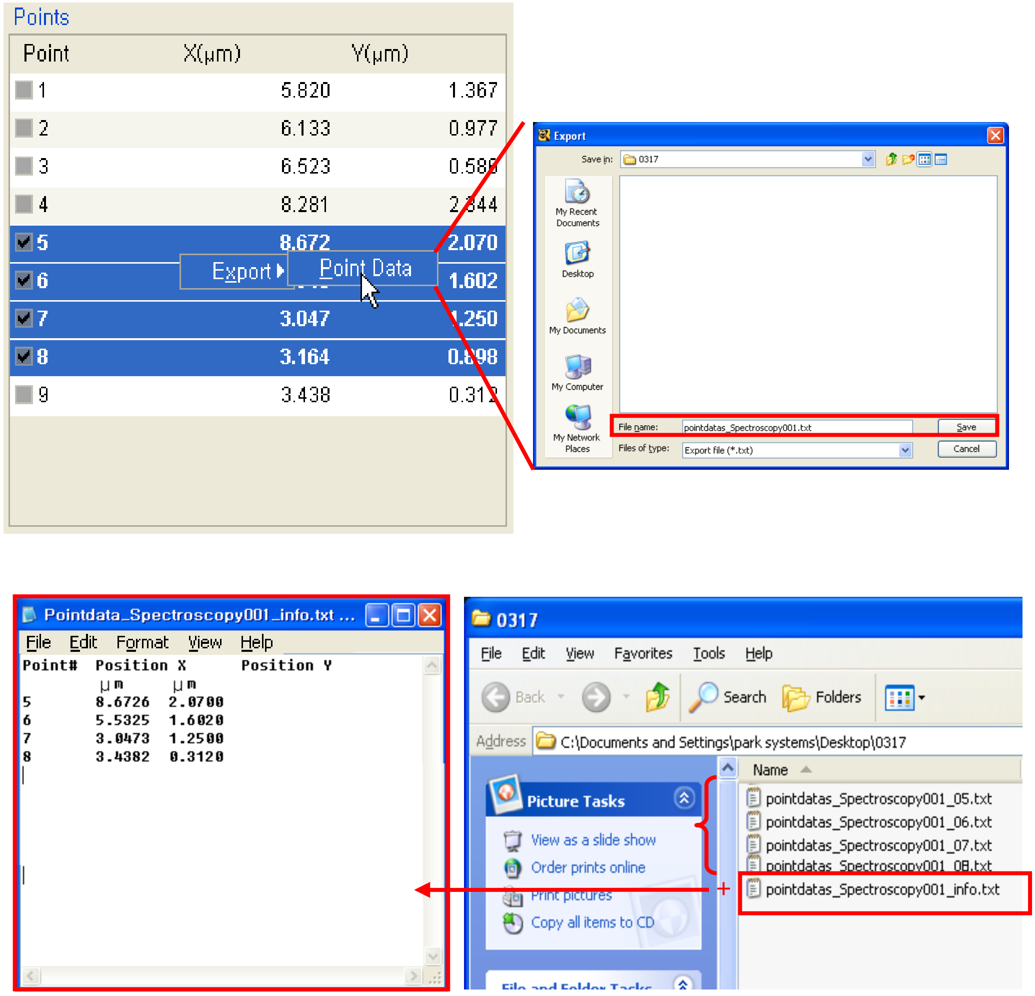


Figure 22-1-7. Points Table

22-1-2-3. Line Display Panel

The Line Display Panel displays the selected curve. The forwards direction is drawn in red, and the backwards direction is drawn in blue.

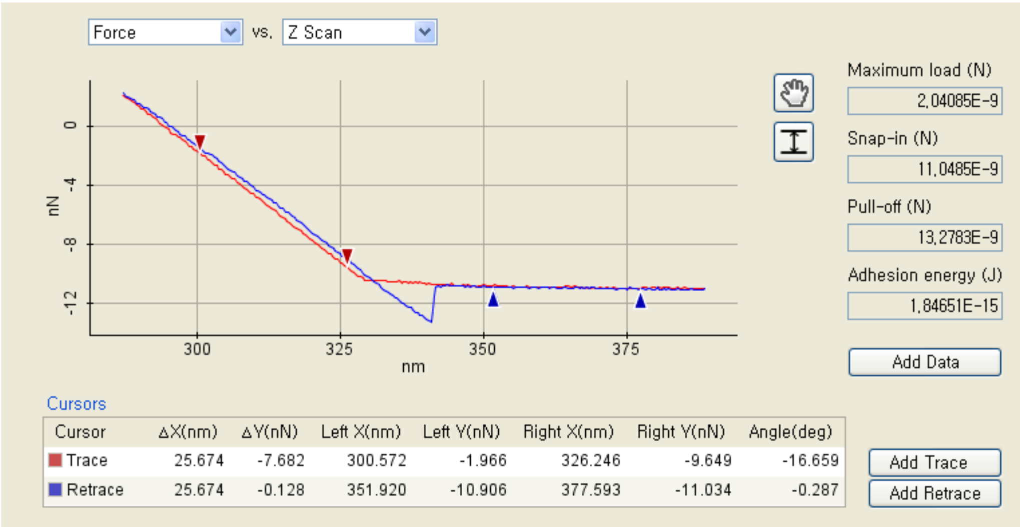


Figure 22-1-8. Line Display Panel

You can change the range of the display with the mouse scroll button. The zoom can be changed by clicking and dragging over an area. To reset the zoom and offset to the default field of view, double-click on the display panel.

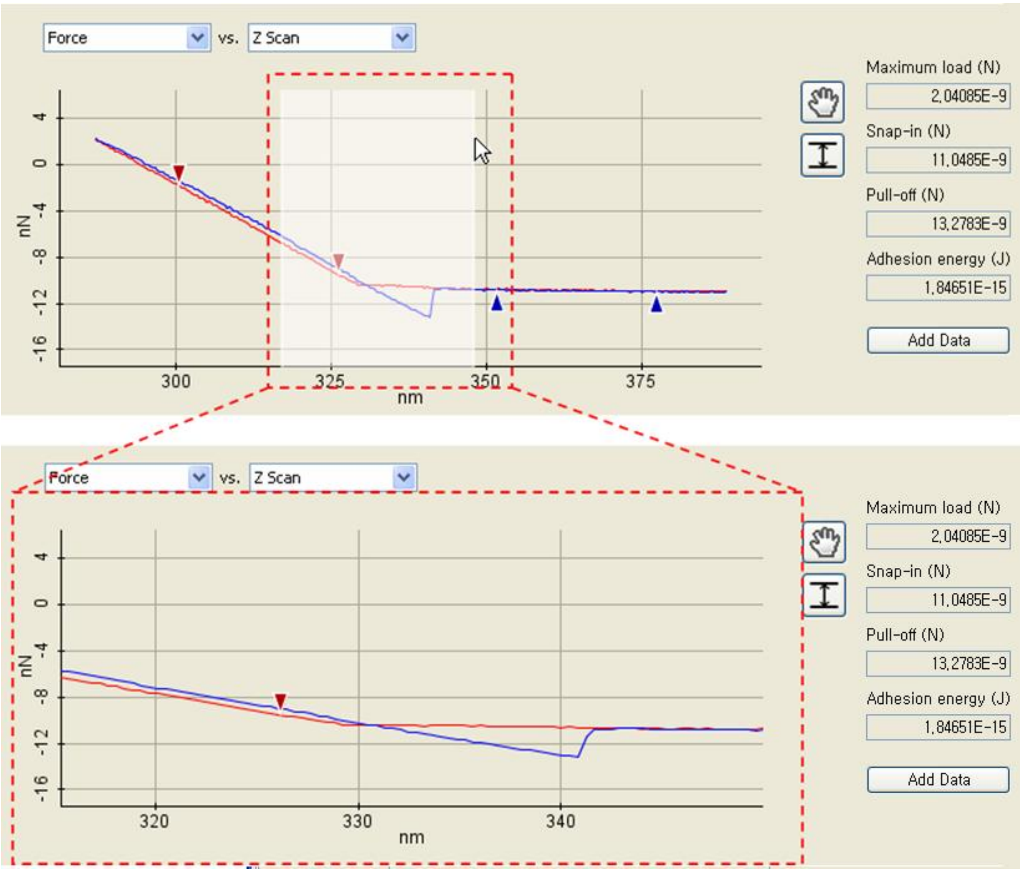


Figure 22-1-9. Zoom in

There are two pairs of cursors, color-coded for their lines. As these cursors are moved, the cursor information table (Section 22-1-2-4) changes to reflect the new locations. The cursors can be clicked and dragged, or moved with pixel precision with the ← and → keys on the keyboard.

Right-clicking on the Line Display will open a context menu.

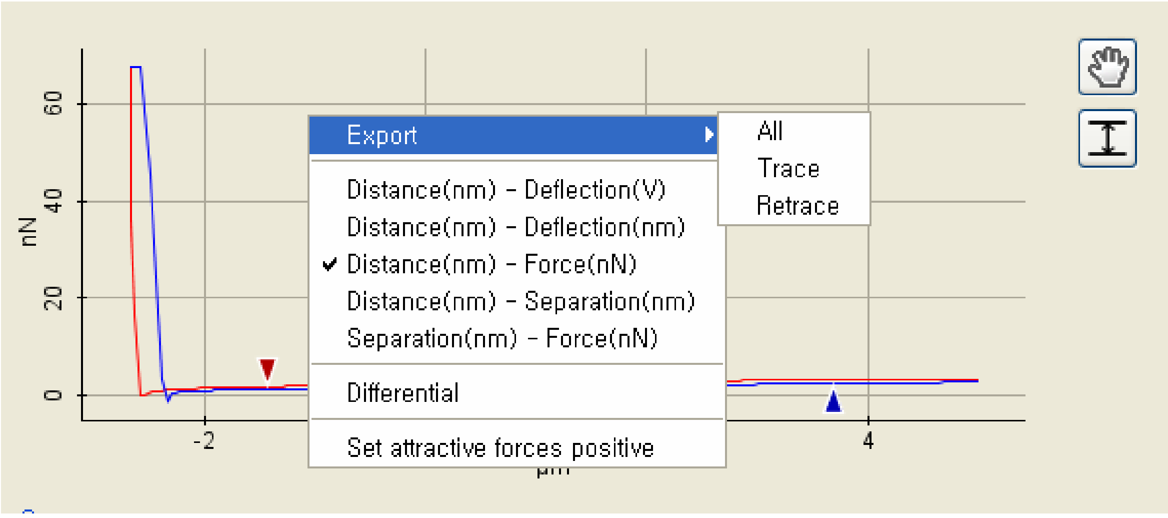


Figure 22-1-10. Line Display context menu

- **Export**

  You can export the trace, retrace, or both trace and retrace lines currently shown.

- **Signal**

  The line can be changed to show different signals. This can also be accomplished by changing the signal in the Signal Selection box.

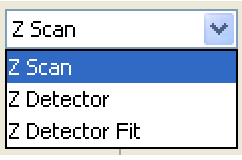
- **Differential**

  Checking this option will change the display to show the first-order differential of the line.

- **Set attractive forces positive**

  This option negates the Y axis for F/D curve analysis.

There are several other useful objects in the Line Display panel.



- **Signal Selection boxes**

  The signal that is represented by the X and Y axes may be changed using these boxes. The options are dependent on the signals saved during acquisition.

- **Panning tool** 

  When this is selected, the mouse cursor changes to a hand. You can click and drag the line display to change its offset. Alternatively, you can middle-click and drag for the same effect without this tool selected.

- **Zoom Out** 

  When clicked, the display's zoom and offset are reset so that the whole curve is visible.

- **Maximum Load field**

  When an F/D curve is loaded in Batch view, the maximum force in the curve is calculated and displayed in this field. For detail information, please see XE user's manual.

- **Snap-in field**

  When an F/D curve is loaded in Batch view, the snap-in force is calculated and displayed in this field. For detail information, please see XE user's manual.

- **Pull-off field**

  When an F/D curve is loaded in Batch view, the pull-off force is calculated and displayed in this field. For detail information, please see XE user's manual.

- **Adhesion energy field**

  When an F/D curve is loaded in Batch view, the adhesion energy is calculated and displayed in this field. For detail information, please see XE user's manual.

- **Add Data button** Add Data

This button will load the calculated values for Maximum Load, Snap-in, and Pull-off to the Basic Information panel (Section 22-1-2-7).

22-1-2-4. Cursor Statistics Table

The Cursor Statistics Table displays information on the cursors shown in the Line Display. The individual items in this table are defined as follows.

Cursors

Cursor	ΔX(nm)	ΔY(nN)	Left X(nm)	Left Y(nN)	Right X(nm)	Right Y(nN)	Angle(deg)
Trace	25.674	-7.682	300.572	-1.966	326.246	-9.649	-16.659
Retrace	30.806	-0.140	346.787	-10.894	377.593	-11.034	-0.260

Add Trace
Add Retrace

Figure 22-1-11. Cursor Statistics Table

- **ΔX**

This item displays the difference in X position between the cursors, or |Left X – Right X|.

- **ΔY**

This item displays the difference in Y position between the cursors, or |Left Y – Right Y|.

- **Left and Right coordinates**

The Left and Right cursors' X and Y values are shown in these fields.

- **Angle**

This item shows the angle between the two cursors.

The two buttons to the right of the Cursor Information Table, Add Trace and Add Retrace are used to add the forward and backward data to the Point Data Table.

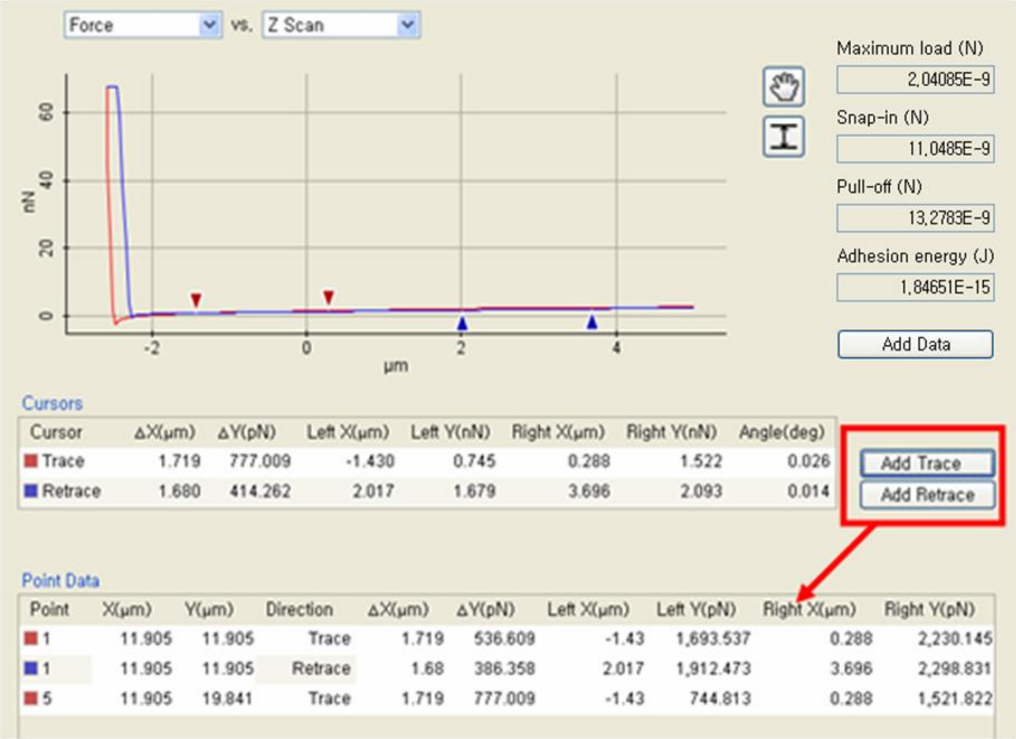
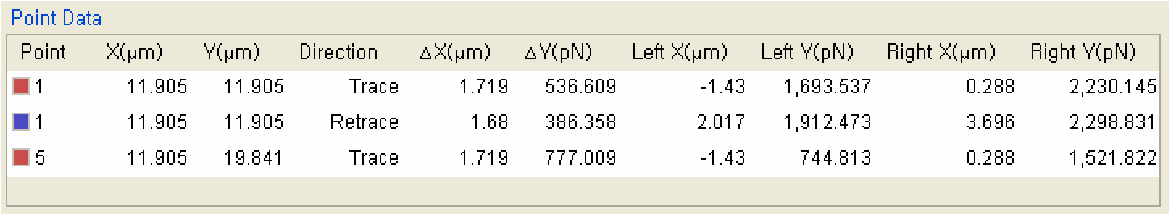


Figure 22-1-12. Addding Trace Lines to Point Data

22-1-2-5. Point Data Table

The Point Data Table displays information about the points selected in the Points Table (Section 22-1-2). The individual items in this table are defined as follows.



Point Data

Point	X(μm)	Y(μm)	Direction	ΔX(μm)	ΔY(pN)	Left X(μm)	Left Y(pN)	Right X(μm)	Right Y(pN)
1	11.905	11.905	Trace	1.719	536.609	-1.43	1,693.537	0.288	2,230.145
1	11.905	11.905	Retrace	1.68	386.358	2.017	1,912.473	3.696	2,298.831
5	11.905	19.841	Trace	1.719	777.009	-1.43	744.813	0.288	1,521.822

Figure 22-1-13. Point Data table

- **X and Y coordinates**

  These fields show the XY scanner's position when this measurement was taken.

- **Direction**

  The Direction indicates whether this line was acquired in the trace direction (Z scanner extension) or the retrace direction (Z scanner retraction).

The rest of the items in the Point Data Table are the same as those in the Cursor Statistics Table (Section 22-1-2-4).

22-1-2-6. Export Panel

The Export Panel allows for the conversion of the data in the Point Data Table into a text (.txt) format.

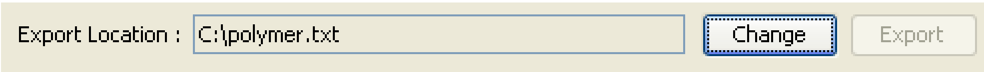


Figure 22-1-14. Export Panel

The Export Panel has three items: the file path field, which shows the name and location of the export file, the Change button, which allows the user to change this name and location, and the Export button, which executes the export.

22-1-2-7. Basic Information Panel

This holds the information selected by clicking the Add Data button in the Image Display panel. It has its own Export panel.

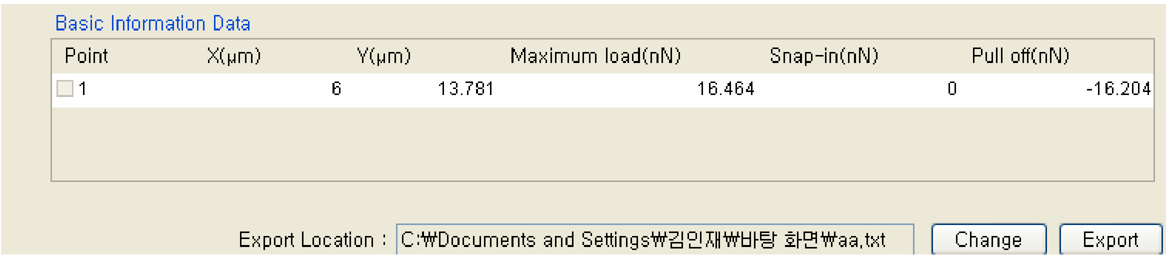


Figure 22-1-15. Basic Information panel

22-1-3. Multi View

Multi View is used for the direct comparison of two curves. It consists of an Image Display panel, Points table, two Line Display panels, and two Cursor Statistics tables.

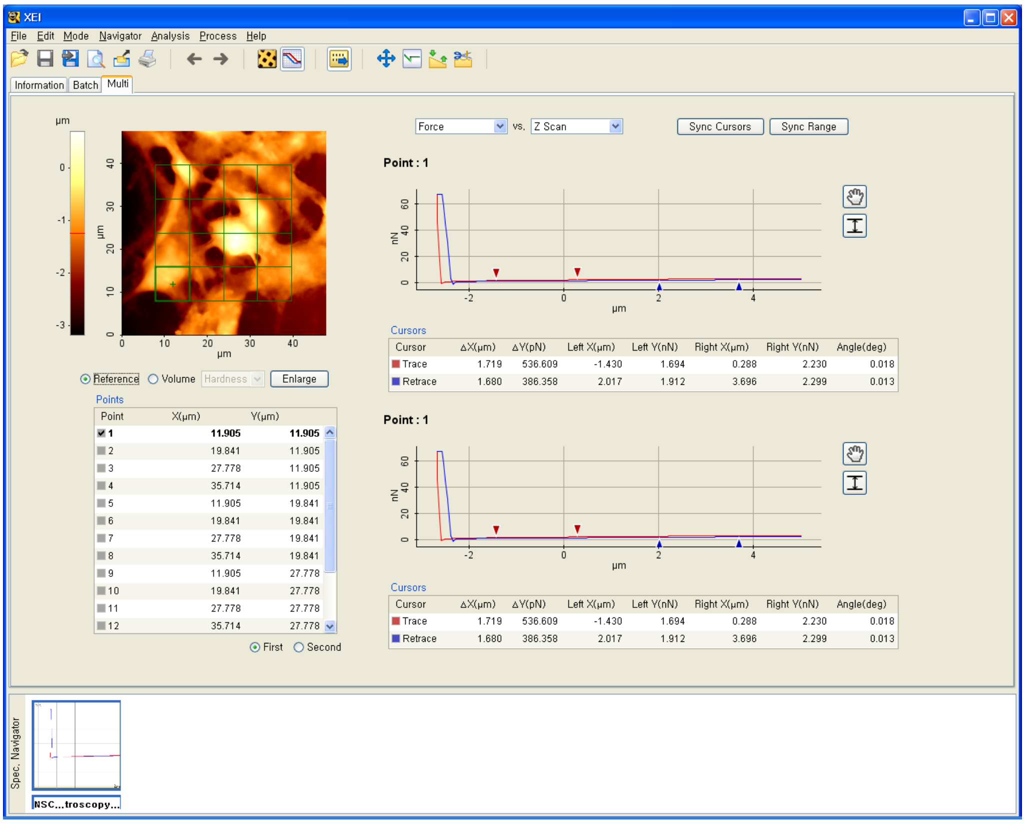


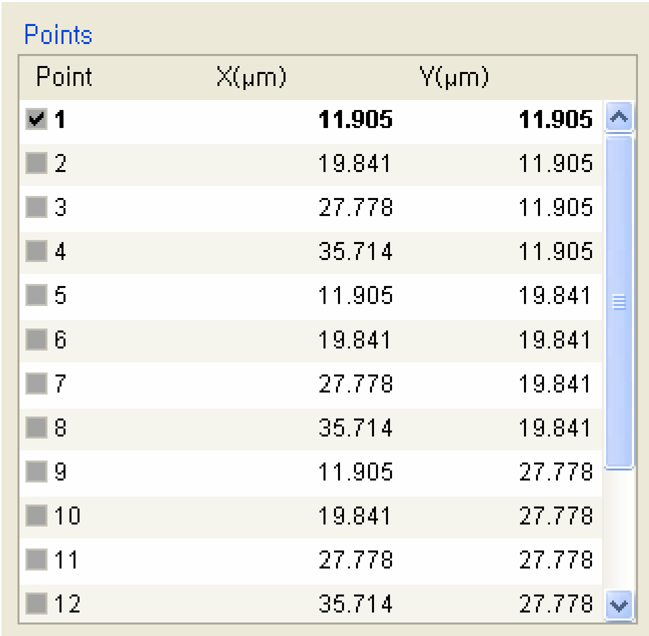
Figure 22-1-16. Multi View

22-1-3-1. Image Display Panel

The Image Display panel shows the reference image taken together with the spectroscopy measurements, if there was one, and the relative locations of the measurements. It is identical to the one in Batch View (Section 22-1-2-1).

22-1-3-2. Points Table

The points table lists all of the spectroscopy measurement points in the currently opened file, as well as their X and Y locations in relation to the XY scanner. Selecting a point in the table will load it to a Line Display panel.


Points

Point	X(µm)	Y(µm)
1	**11.905**	**11.905**
2	19.841	11.905
3	27.778	11.905
4	35.714	11.905
5	11.905	19.841
6	19.841	19.841
7	27.778	19.841
8	35.714	19.841
9	11.905	27.778
10	19.841	27.778
11	27.778	27.778
12	35.714	27.778

Figure 22-1-17. Points Table

- ### Point field

The spectroscopy curve's number is displayed in this field. If multiple measurements were saved to the same .tiff file, their order in the Point field indicates the order in which they were taken.

- ### X and Y fields

The X and Y fields show the XY stage's position when the measurements were taken.

- ### First and Second buttons

The selected point's curve is displayed on either the first or the second Line Display panel (Section 22-1-3-3), depending on which of these is selected.

22-1-3-3. Line Display Panel

There are two Line Display panels. They are identical to the Line Display panel for Batch View (Section 22-1-2-3).

In Multi View, there are two additional buttons in the first Line Display panel.

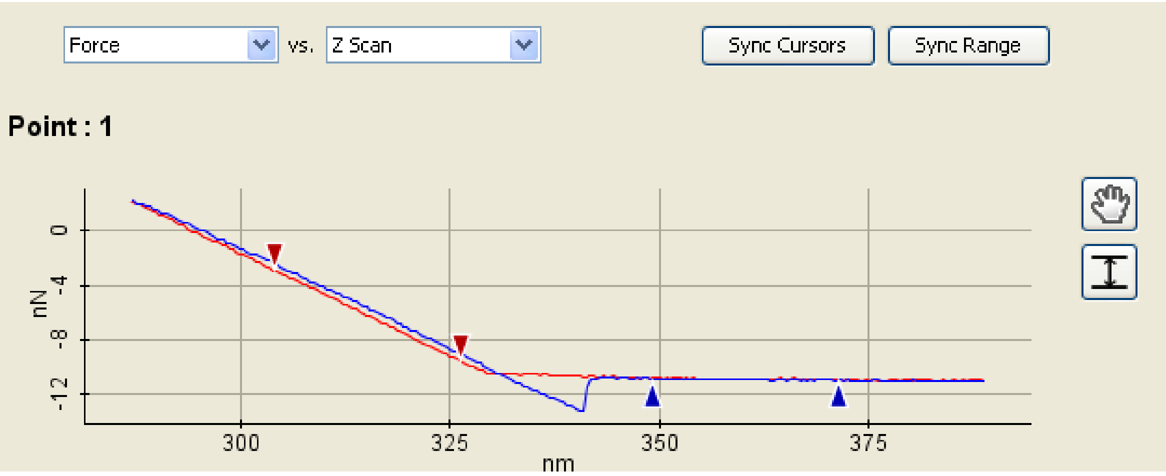


Figure 22-1-18. Line Display panel

- ### Sync Cursors

  When selected, the positions of the cursors in the two Line Display panels will be matched. Moving a cursor when Sync Cursors is selected will move its corresponding cursor in the other Line Display panel.

- ### Sync Range

  When selected, the field of view of the two Line Display panels will be matched, and changing one will change the other by the same amount.

22-1-3-4. Cursor Statistics Table

Cursors

Cursor	ΔX(nm)	ΔY(nN)	Left X(nm)	Left Y(nN)	Right X(nm)	Right Y(nN)	Angle(deg)
Trace	22.311	-6.706	304.092	-2.977	326.403	-9.683	-16.730
Retrace	22.311	-0.097	349.168	-10.895	371.479	-10.992	-0.249

Figure 22-1-19. Cursor Statistics table

There are two Cursor Statistics tables. These tables are identical to the one in Batch View (Section 22-1-2-4).

22-1-4. Young's Modulus View

Young's Modulus View is enabled by clicking the Young's Modulus tab when Spectroscopy Mode is enabled. Young's Modulus View is designed to support the analysis of F/D and Nano-Indentation curves from XEP. XEI software uses the Hertz and Oliver & Pharr methods to calculate the Young's Modulus. Please select the proper method according to the sample to calculate the Young's Modulus.

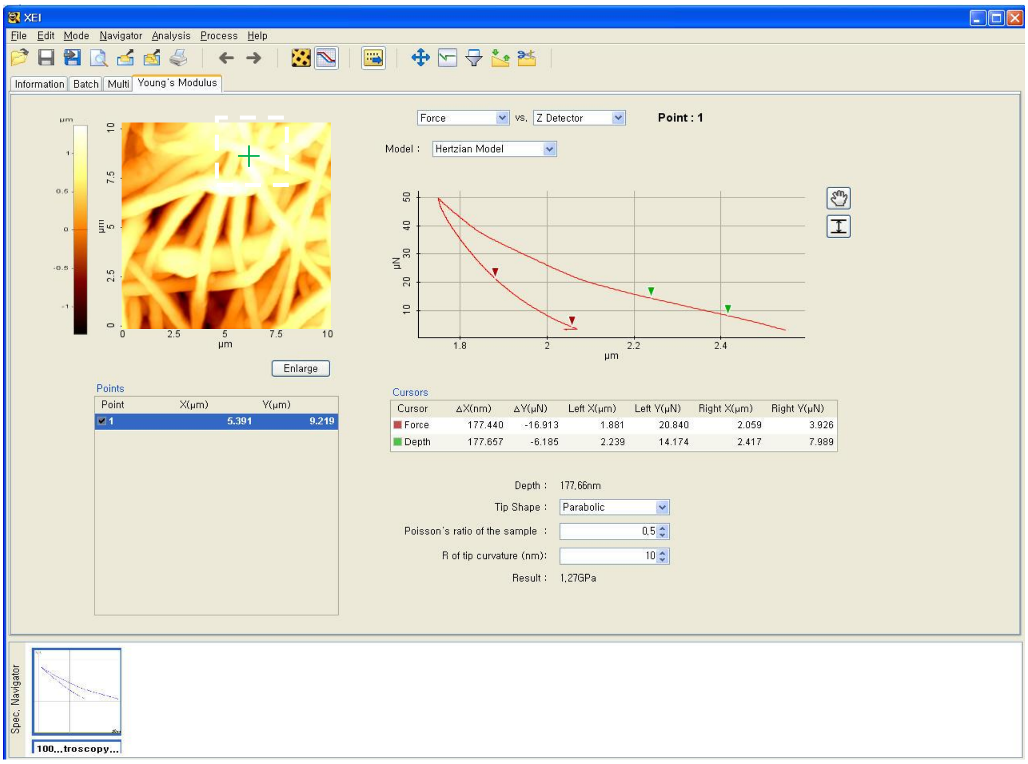
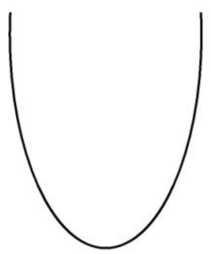
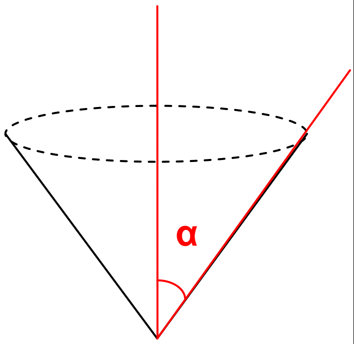
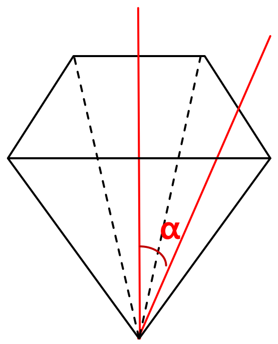


Figure 22-1-20. Young's Modulus View

22-1-4-1. Methods

- **Hertzian Method**

Hertzian method views the half space for sample/tip as an isotropic, linear elastic solid. On the words, the method assumes no other interaction other than elasticity and therefore no plastic deformation between sample/tip. It will calculate Young's Modulus of the sample E = F (Loading force, Indentation depth). This equation is influenced by the Indenter tip geometries. Below are equations for E using different tip geometries.

Parabolic	Conical	Four-sided pyramid
		
$F = \frac{4}{3}\frac{E}{1-v^2}\sqrt{R}\delta^{3/2}$	$F = \frac{2\tan\alpha}{\pi}\frac{E}{1-v^2}\delta^2$	$F = \frac{E}{1-v^2}\frac{\tan\alpha}{\sqrt{2}}\delta^2$

R, δ, α and ν represent the radius of tip curvature, indentation depth, face angle with respect to vertical direction and poisson's ratio of sample respectively. When sample is soft, such as rubber, ν will be set to 0.5. Hence, when acquiring Force-Z displacement curve plot through F/D or Nano-Indentation, the value for E will be calculated. When there are changes on Force-Z displacement, the cantilever will deflect to the opposite direction as tip contacts sample. Hence, in addition to indentation depth, F/k (k=Cantilever Spring Constant) changes must be considered. The revised plot of the cantilever deflection in XEI will transform to display a Force-Separation curve (F, (Z-F/k)), and this will be used for calculating the value for E. For an accurate revision, the cantilever's spring constant (K), and A-B sensitivity (changes on A-B through Z Displacement) must be calibrated prior to the analysis.

- **Oliver-Pharr Method**

Oliver-Pharr Method follows Sneddon's assumption that any deformation occurring during unloading is totally due to elasticity. At this point, the relationship between tip and sample can be calculated with the modulus of elasticity.

$$\frac{1}{E_{eff}} = \frac{1-\nu_s^2}{E_s} + \frac{1-\nu_i^2}{E_i}$$

E_s: sample's modulus of elasticity

E_i: Tip's modulus of elasticity

(Material for Berkovich tip is diamond, in this case, Ei=1141Gpa, Vi=0.07)

ν_s: Poisson's ratio of sample

E_{eff} represents the converted modulus of elasticity, related to the sample's and tip's modulus of elasticity. Under assumption of Sneddon, the tip is assumed as a rigid solid, and the sample is assumed as homogeneous isotropic elastic half space. The function below explains this contact with E_{eff} and contact stiffness. S, A and β representing the contact stiffness, contact area and tip's shape intercept factor. Contact area is under the influence of the tip geometry. The tip shape intercept factor is 1.034 for a Berkovich tip shape.

$$S = \frac{dF}{dh} = 2\beta E_{eff}\sqrt{\frac{A}{\pi}},$$

According to Sneddon's assumption, when elastic contact is influenced by the tip geometry, Oliver-Pharr acquires the maximum load contact area, and decides contact depth as below function.

$$h_c = h_{max} - h_s = h_{max} - \varepsilon\frac{F_{max}}{S}$$

ε represents the tip's intercept factor, for a Berkovich tip, the factor is 0.75, and for a cone shape tip, the value is 0.72 (current XEI version supports Young's modulus auto calibration only for the Berkovich shape tip). Contact stiffness is acquired after fitting the unloading curve. After the contact depth (h_c) is acquired, the Young's modulus (E_s) for the sample can be acquired. At this point, the indentation hardness (H) can be obtained as '$H=F_{max}/A$' (where the contact area is a function of the tip shape, $A=f(h_c)$) and contact depth (h_c).

NOTE!

> The indentation hardness acquired is not a conventional material hardness! To acqurie conventional hardness requires different test proccedures.

To calculate the Young's Modulus, XEI uses the difference in the Force (Red) cursor pair, ∆X, to determine the value for $h_{max.}$ The difference in the Depth (Green) curor pair, ∆Y, is used to determine the Maximum Load. Stiffness data is calculated from the slope of data between Slope (Green) Cursor Pair after fitting.

Below is schematic diagram of this analysis.

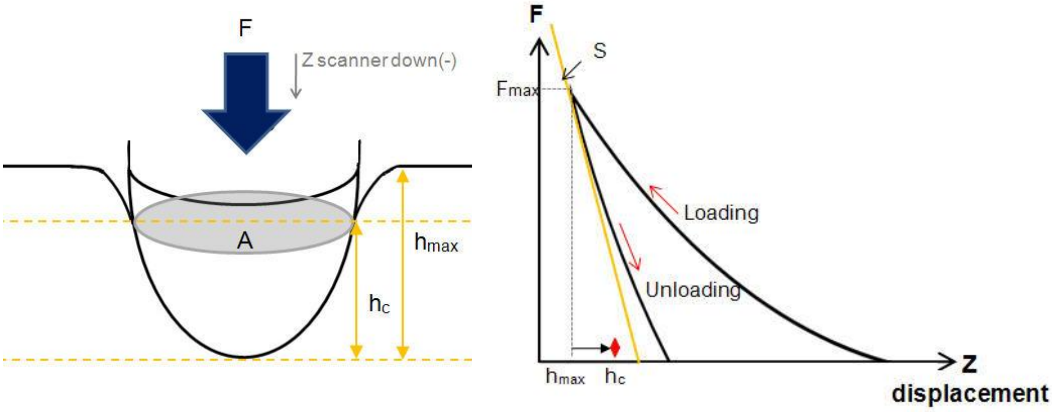


Figure 22-1-21. Calculating Young's Modulus and Hardness(Oliver & Pharr)

22-1-4-2. Acquiring Young's Modulus

To get the Young's Modulus from Spectroscopy data, perform the following steps before Cantilever's Spring Constant (K), A-B Sensitivity (A-B changes according to Z displacement) calibration.

- **Hertzian Method**
  1. Place the Force (Red) Cursor Pair at Min/Max positions of the Loading Force.
  2. Choose the depth position (Loading curve's contact point (right) and end point (left)) by moving the Depth (Green) Cursor Pair.
  3. Input parameters (Tip Shape, Poisson's Ratio of sample, Radius of Tip Curvature)
  4. The Young's Modulus (E) is calculated automatically.

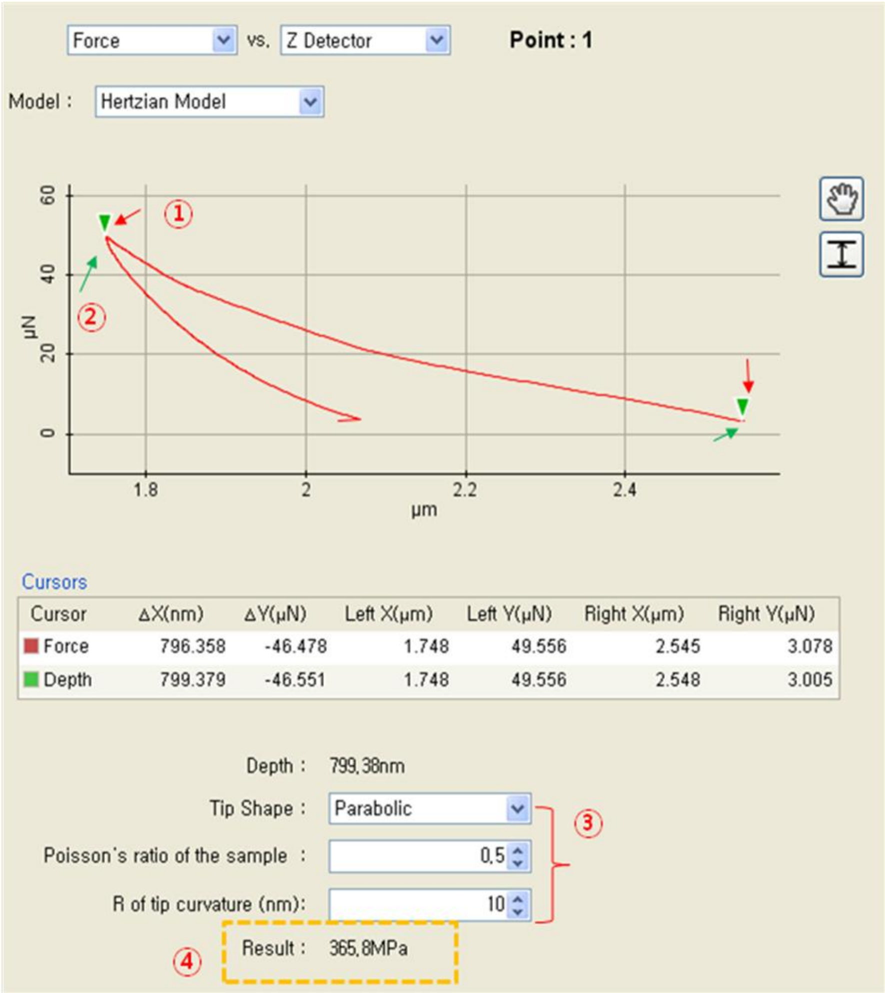


Figure 22-1-22. Acquiring Young's Modulus and Hardness(Hertzian)

■ Oliver and Pharr Method

1. Place Force (Red) Cursor Pair at Min/Max position of Loading Force.
2. Place Slope (Green) Cursor Pair at max position of unloading force on Unloading Curve.
3. Input the Poisson's ratio of the sample.
4. The Young's Modulus (E) and Hardness (H) are calculated automatically.

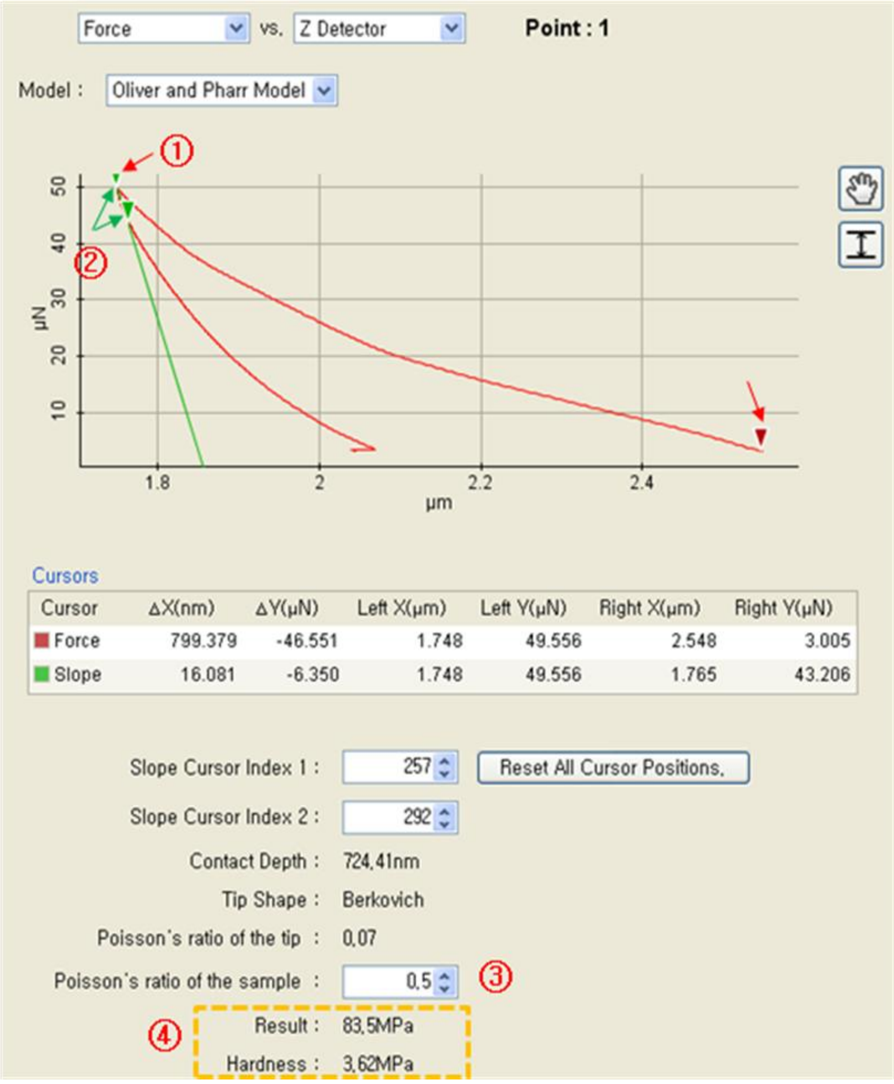


Figure 22-1-23. Acquiring Young's Modulus and Hardness (Oliver and Pharr)

22-2. Processes

Spectroscopy Mode in XEI provides data processing tools specific to spectroscopy data. These processes may be accessed by clicking on their respective icons in the toolbar, or by selecting them from the Process menu.

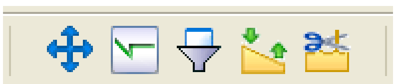


Figure 22-2-1. Process Tool Bar

22-2-1. Offset Adjust

The Offset Adjust process is used to improve correlation between two data sets in Multi View. One can adjust the X and Y offsets by clicking on the + and – buttons. Each click will increment or decrement the offset by the value in the Offset fields. The current total offset is displayed above the control panel.

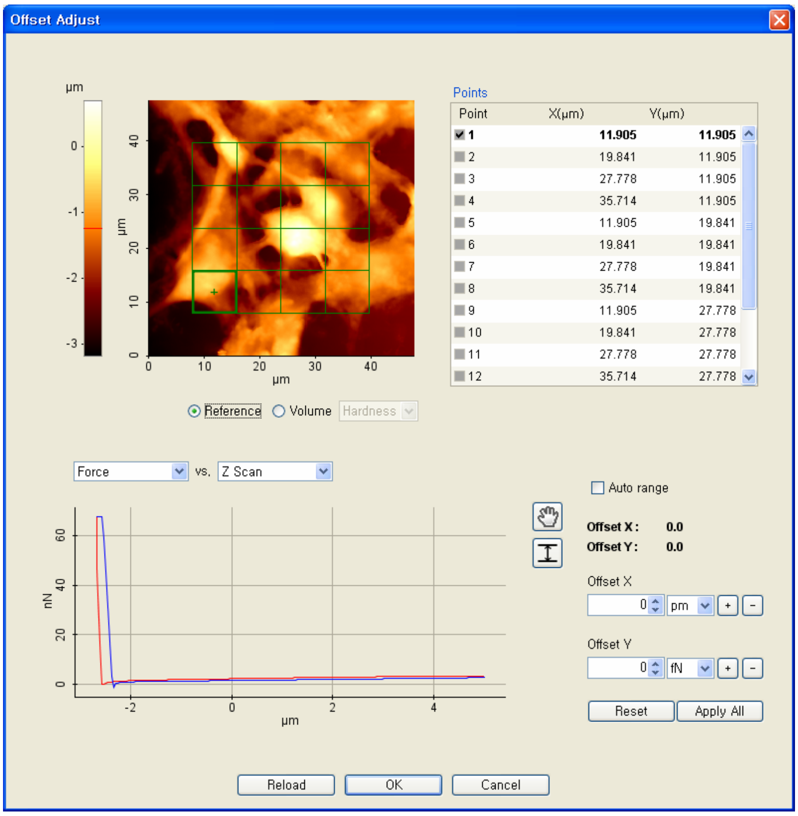


Figure 22-2-2. Offset Process dialog

- **Auto Range**

  When selected, automatically adjusts the range of the display so that the whole curve is visible.

- **Offset X and Y labels**

  The Offset X and Y labels show the current total offset. These change as the + and – buttons are pressed.

- **Offset X and Y fields**

The amount that the + and – buttons increment and decrement from the offset per click is determined by these fields.

- **+ and - buttons**

Every click of the + button increments the offset, and each click of the – button decrements the offset.

- **Reset**

Reverts the Offset X and Y to 0.

- **Apply All**

Applies the Offset X and Y to every point in the tiff file.

Clicking the Apply All and OK buttons will permanently change your data.

22-2-2. Force Constant

The Force Constant dialog is used to calculate the force constant of the cantilever from the data.

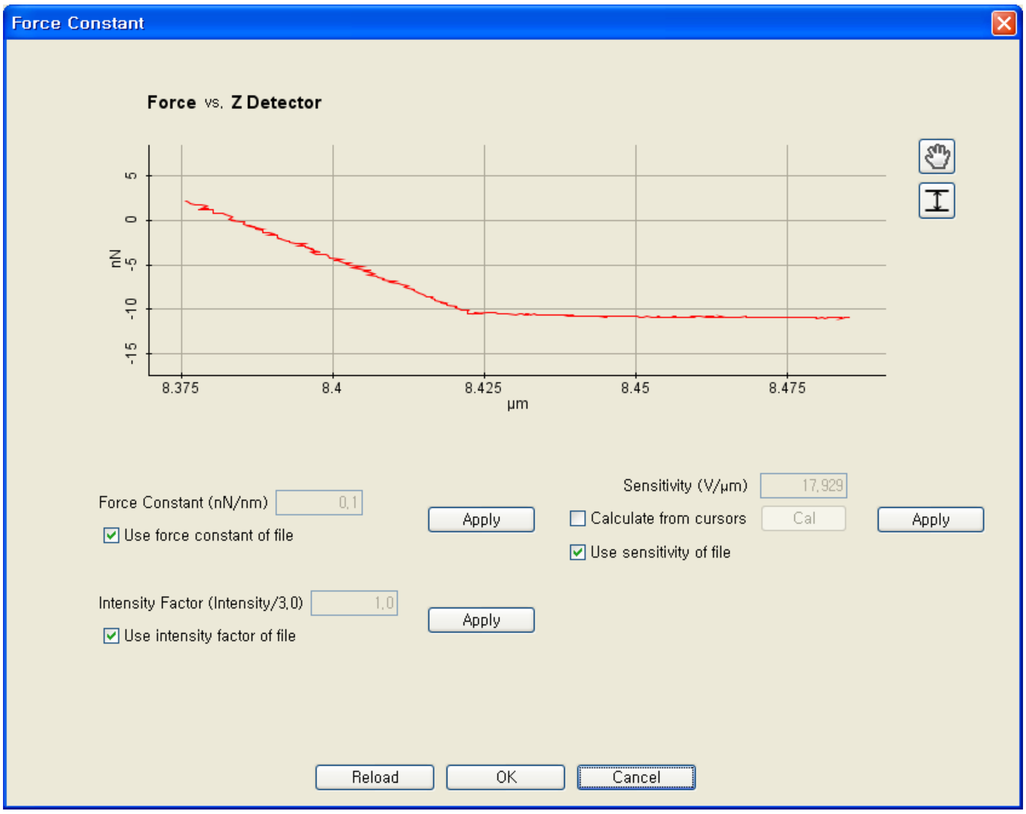


Figure 22-2-3. Force Constant Process dialog

There are three values that can be changed by this process.

22-2-2-1. Force Constant

If the 'Use force constant of file' checkbox is selected, the force constant used when acquiring the image is applied. Deselecting this checkbox will enable the Force constant field, in which the user can input a new value. Clicking the Apply button will save these changes.

22-2-2-2. Sensitivity

The 'Use sensitivity of file' option will apply the sensitivity value that was saved during imaging. Selecting 'Calculate from cursors' will display 2 cursors on the Line Display panel. After moving these cursors, clicking the 'Cal' button will update the sensitivity. Clicking the 'Apply' button will use this new value for measurement analysis.

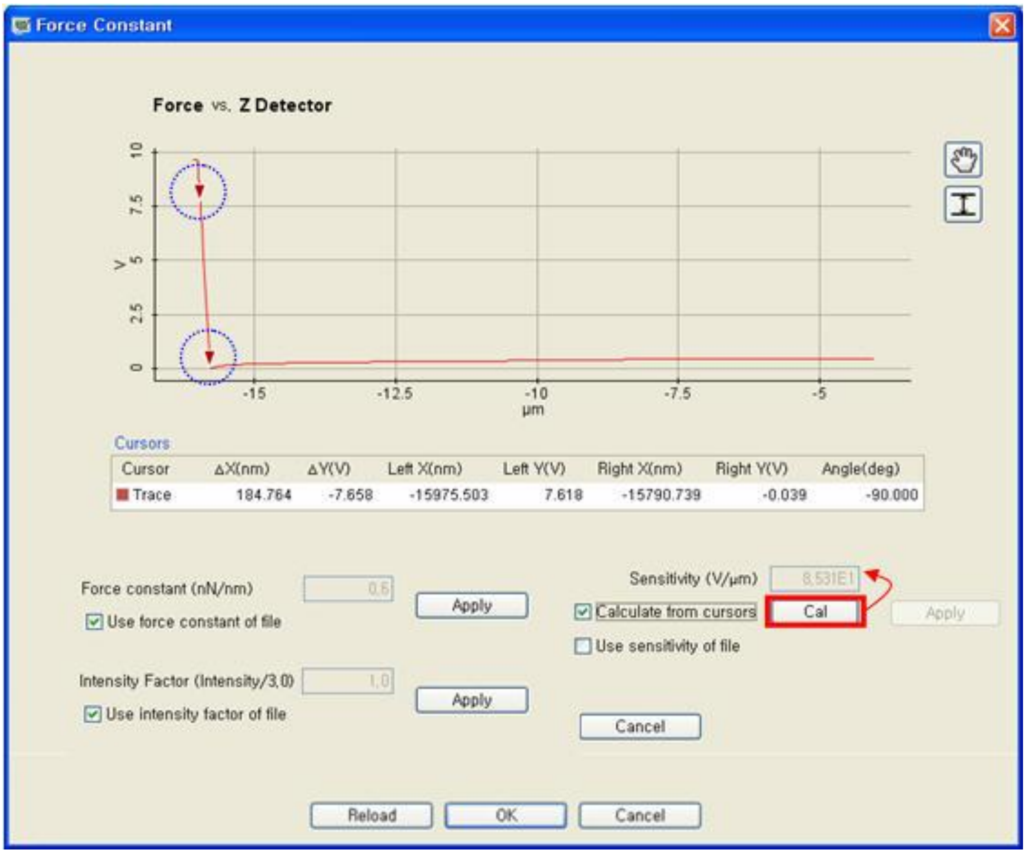


Figure 22-2-4. Sensitivity Calibration

22-2-2-3. Intensity factor

(A-B) DC value is influenced by the PSPD beam intensity. Hence, the XE-AFM calculates the force using a beam intensity normalization factor following the function below:

Force= (A-B)DC x 3.0 (Volt) / (A+B)

1 / Intensity Factor

The beam intensity factor for normalized as (A+B) / 3.0 (Volt) since XE software assumes that the A+B, beam intensity is 3 Volts. This value is automatically applied to the force calculation.

NOTE!

The intensity factor is properly calculated and saved in the file obtained by the F/D and NanoIndentation Spectroscopy only after the image file is acquired.

If you want to change this value manually, please deselect 'Use intensity factor of file' check box and input the desired value on the activated text field above. Clicking the [Apply] button will use this new value for measurement analysis.

22-2-3. Filter

Filtering can be applied to remove noise from the data.

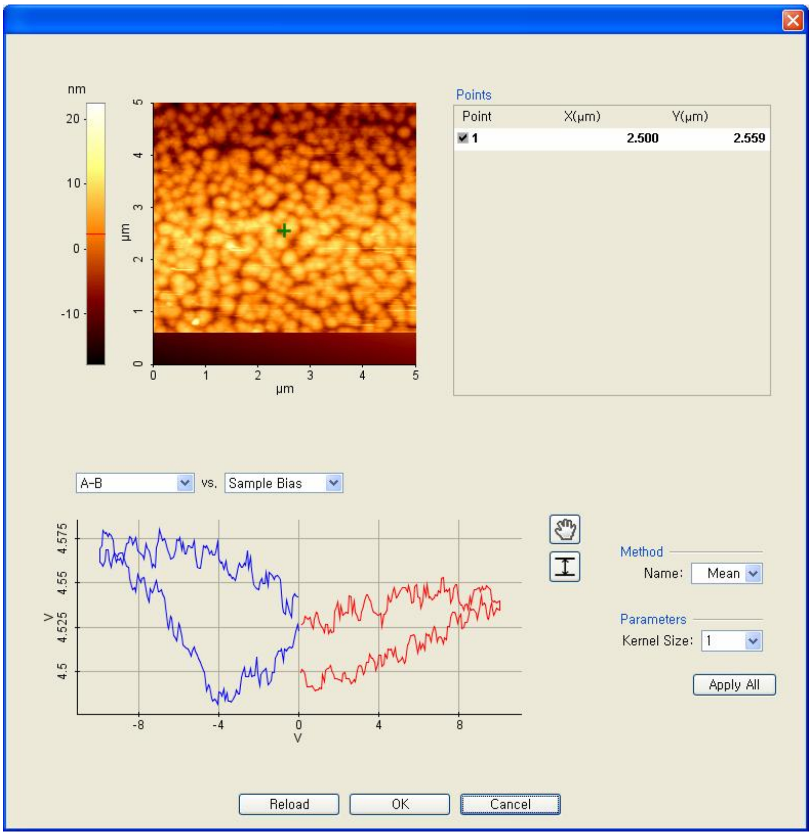


Figure 22-2-5. Filter Process Dialog

As spectroscopy data is two-dimensional, removing noise is performed by taking the average of a data point's neighbors, and assigning that number as the pixel's new value.

- **Method Name**

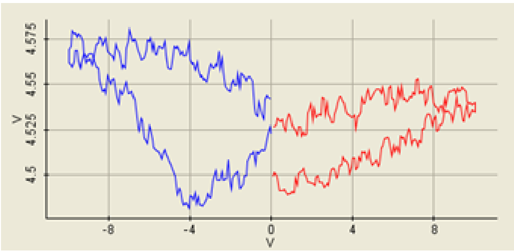
  This parameter decides how the average is calculated. The two options are Mean and Median.

- **Kernel Size**

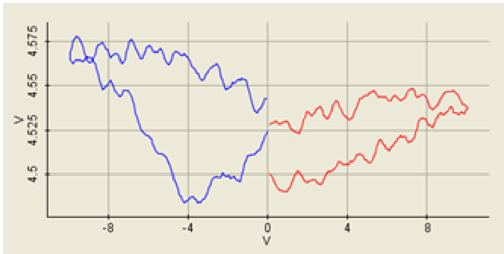
  The number of neighboring data points to consider is determined by this number. A higher value will result in a smoother curve, but may result in loss of actual data.

- **Apply All**

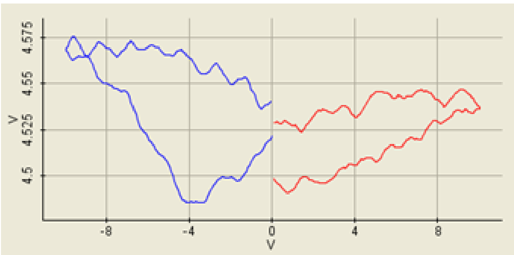
  Applies the filter to every curve selected in the Points table.



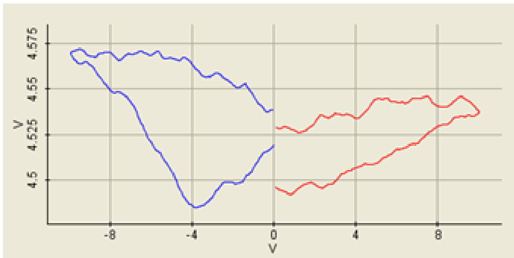
Kernel Size : 1



Kernel Size : 5



Kernel Size : 9



Kernel Size : 13

Figure 22-2-6. Filtering with Various Kernel Sizes

22-2-4. Flatten

This function is used for the reference image, if there is one. It is identical to the Flatten process for images (Section 2-5-3).

22-2-5. Deglitch

This function is used for the reference image, if there is one.　It is identical to the Deglitch process for images (Section 2-5-4).

Chapter 23. Surface Analysis

In the Surface view, you can measure and analyze surface area of an image. You can make quantitative measurements of surface features in the selected regions and collect surface statistics such as geometric area, surface area and surface area ratio. These statistical values are displayed on the right of image.

In general, you can go through the following steps in Surface Analysis View:

1. Load an image you want to analyze into the Analysis view from the Navigator view.
2. Select the Surface view.
3. Select region of the image like Region Analysis view(Entire area or rectangle).
4. Once selecting region, the statistical values are generated with results and updated whenever the change of the selected region occurs.
5. Filter if needed.
6. Save and print your Surface view results

Figure 23-1 shows the summarized procedure to analyze the region of an image.

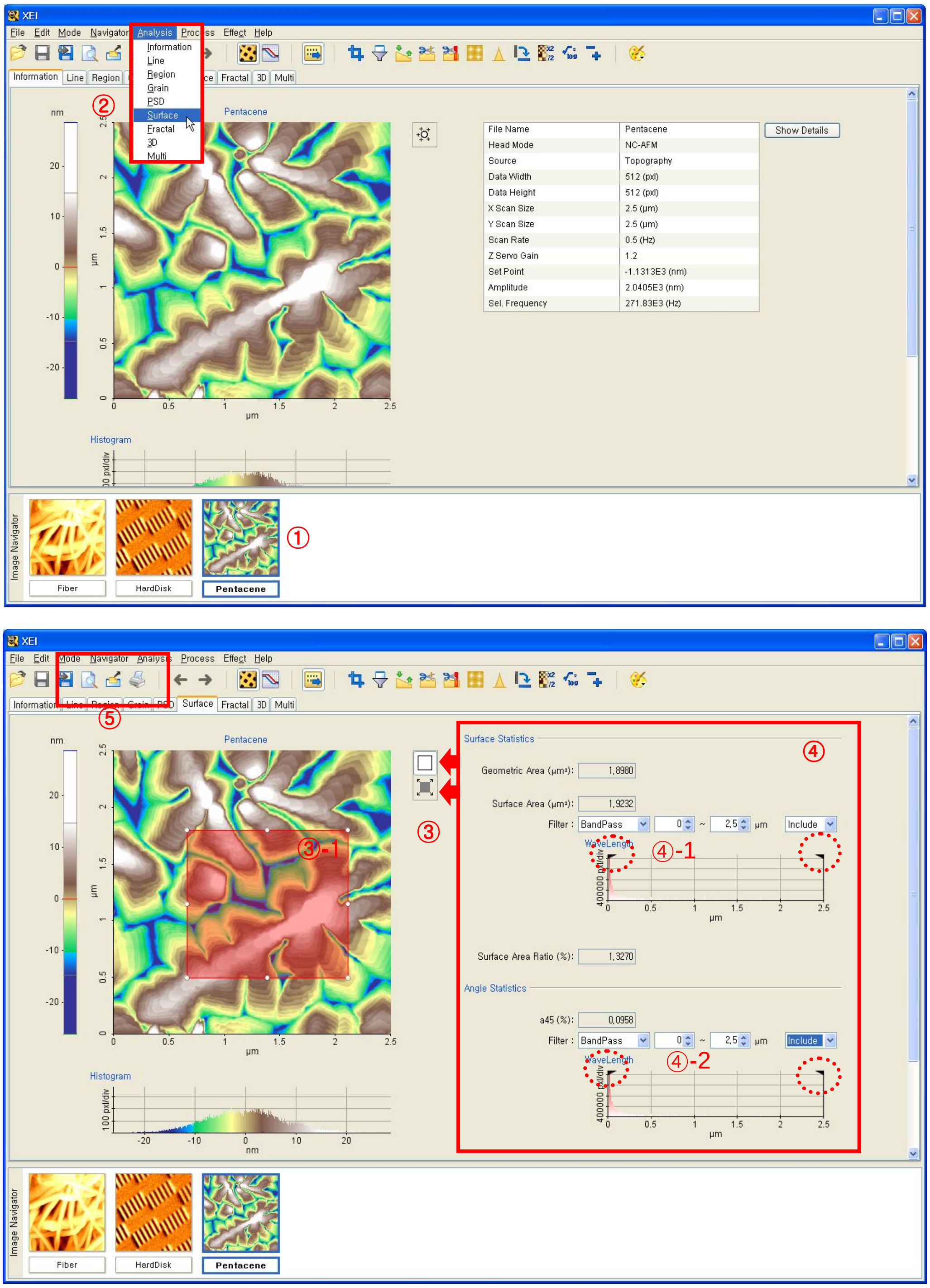


Figure 23-1. Procedure for Region view

To enable the Surface view, select ‘Analysis>Surface’ menu or click the Surface tab below the Toolbar. The Surface view consists of the Palette Panel, Image Display Panel, Region Selection Toolbar, Region Histogram, Surface Statistics

Panel and Angle Statistics Panel. Figure 23-2 shows the Surface view that is divided into several parts.

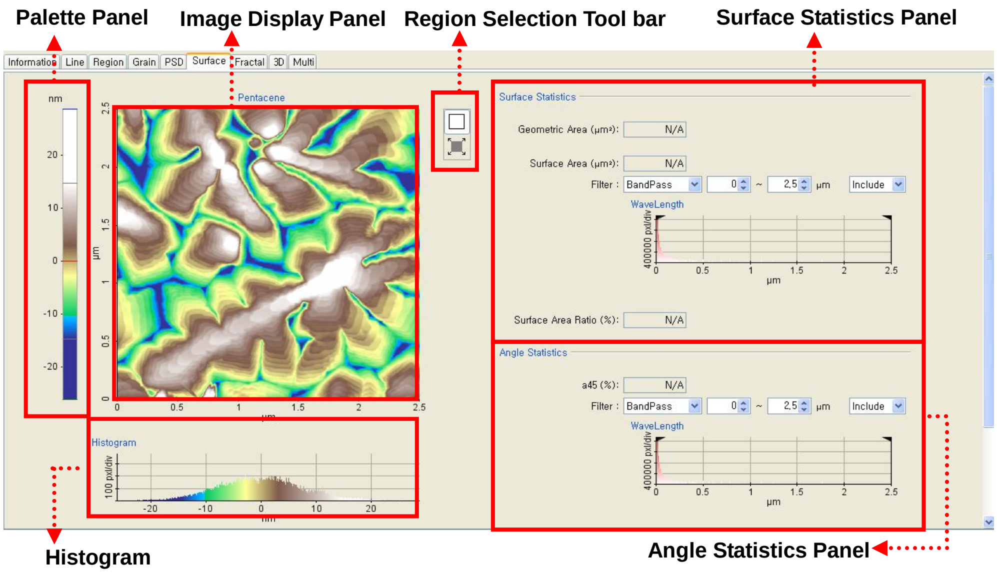


Figure 23-2. Surface view

23-1. Palette Panel, Image Display Panel and Histogram

Just as in other Analysis views, the image you want to analyze can be displayed in the Image display panel with the Palette Panel. It is the same Palette Panel and Image Display Panel that appears in all the analysis views of XEI. Please refer to Chapter 3-2 and 3-3 for details.

Also the histogram of the entire image surface is displayed on the bottom of the Image Display Panel as in the other analysis views.

23-2 Region Selection toolbar

Region selection toolbar, where the Tools for selecting region for the analysis are gathered, is at the right side of the Image Display Panel.

- **Rectangle** □

Currently, you can create a specific place by using 'Rectangle' □ button.

Then press the cursor at the point you want to create the top-left corner of a 'selected area', and drag the mouse pointer at the point you want to create bottom-right corner of a 'selected area'.

- **Entire Region** 

  To set the entire image as 'selected area', click the 'Entire Region' button.

23-3 Surface Statistics Panel

On the right of the Image Display Panel, the Surface Statistics Panel is shown. The Surface Statistics Panel, shown in Figure 23-2, displays the surface statistics of the all data points in the selected region. The results of the statistics on the selected region are updated automatically when you change the selected region by resizing or moving the region selector. Values are related to surface, hence those data that uses metric unite of X, Y, and Z, which are topography, and Z detector data.

- **Geometric Area (μm^2)**

  Area of selected region (plane)

- **Surface Area (μm^2)**

Suppose surface area as 1 by 1pixel. 1 by 1pixel is an area composed with four different points. As shown in Figure 23-3-1, each point' height values are named as Z1, Z2, Z3, and Z4. Z5 is calculated as average high value from Z1 to Z4 and located in the middle of them. Now, there are four surface (A1, A2, A3, and A4), which adds up for area of 1 by 1 pixel. This is how surface area is calculated.

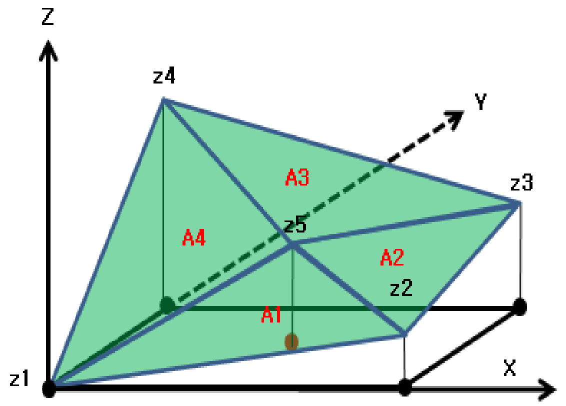


Figure 23-3-1. 1 by 1 pixel surface area

■ Surface Area Ratio(%)

100(%) x (Geometric Area – Surface Area) / (Geometric Area)

■ Filter

Histogram of surface area is displayed when selecting bandpass filter. In Histogram, X axis indicates wavelength of surface area, and Y axis indicates magnitude of normal vector on wavelength. Within 'Height restriction markers', there are two flags (as lower and upper) displayed, using them, wavelength can be exclude/include in selected area for filtering.

For example, click on down arrow button then select 'Exclude', drag these two 'Height restriction Markers' on the each side of the histogram to set the lower and upper value of the pixels to be selected. Pixels with the wavelength lower than the 'Lower Height restriction Marker' or higher than the 'Upper Height restriction Marker' will be excluded from the surface area analysis. Pixels that are excluded from the analysis are marked in violet color at Palette bar. The 'Height restriction marker' is located on top of Histogram. If 'Filter' option is not desired, 'None' can be selected.

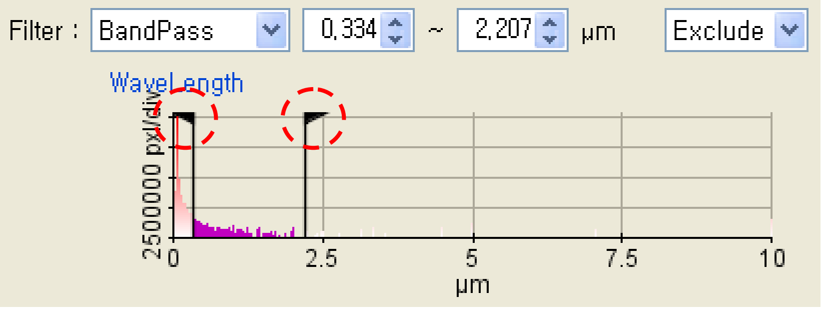


Figure 23-3-2. Filter

23-4 Angle Statistics Panel

On the right of the Image display panel, the Angle Statistics panel is shown. The Angle Statistics panel, shown in Figure 23-2, displays the angle statistics of the all data points in the selected region. The results of the statistics on the selected region are updated automatically when you change the selected region by resizing or moving the region selector. Values are related to surface angle, hence those data that uses Metric unite of X, Y, and Z, which are topography, and Z detector data.

■ a45(%)

Suppose surface area as four points of 1 by 1pixel. Green triangle, made of three points' (one datum point and two adjacent points) height, goes exceeds over 45°. It represents the ratio between number of 1 by 1pixel area and green triangle, made of three points' (one datum point and two adjacent points) height, where exceeds over 45° per white plane. With this function, level of roughness in surface area can be distinguished.

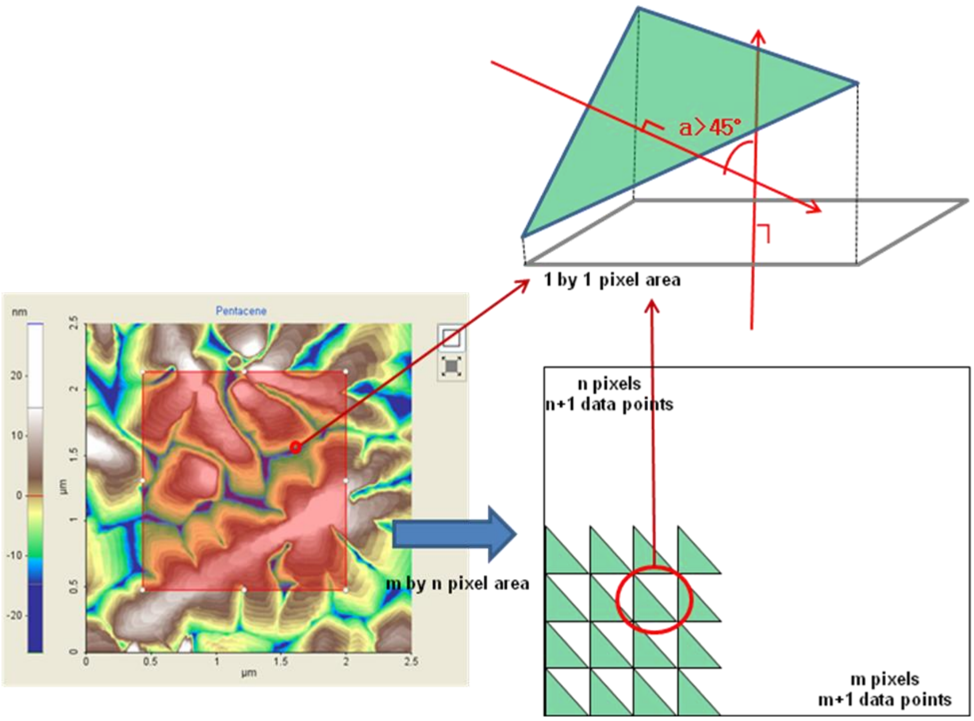


Figure 23-3-3. a45

■ Filter

Filter for ‘a45’ value is selectable. Bandpass filter is supported. It is same option in surface area. Therefore, for detail information, please see Section 23-3.

Chapter 24. Stitch

Using the Stitch Processing tool, images can be stitched together.

24-1. Stitch Process Dialog

To open the Stitch process dialog, select [Process>Stitch] in the Menu or click the  icon in the Toolbar. The Stitch process dialog is composed of two panels, the Image display panel and the Zoom Image Display panel, this is similar to the Crop process dialog. Figure 11-1-1 shows the Stitch process dialog.

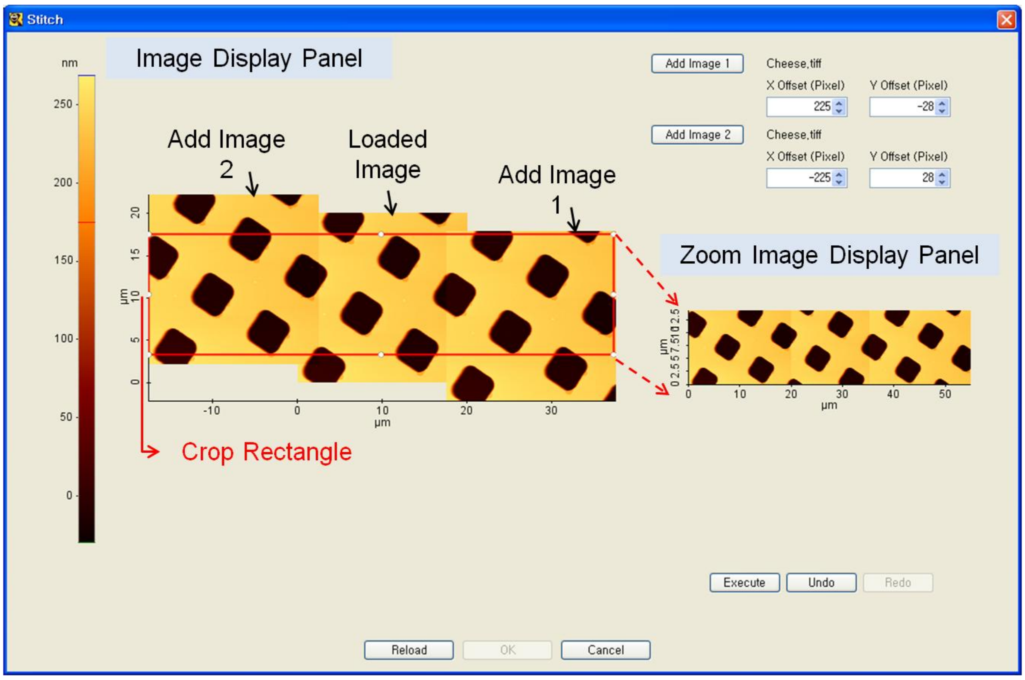


Figure 24-1-1. Stitch process dialog

- **Add Image 1(2)**

Opens a dialog box where you can choose the desired data files. Images will be displayed in Image Display Panel and its' file name will appear on the right. The selected file can be moved by inputting offset values for X/Y pixel. For example, in Figure 24-1-1, the initial loaded image is 256x256 pixels and pixel offsets of Image 1 is 225, -28 and for Image 2 is -225, 28.

- **Execute**

Crops the selected region (crop rectangle) and displays the image in the Image Display panel.

- **Undo**

Undo the previous command.

- **Redo**

Redo the previous command.

- **Reload**

Initializes the Stitch Process Dialog.

- **Okay**

Saves the Cropped image and closes the Stitch Process Dialog.

- **Cancel**

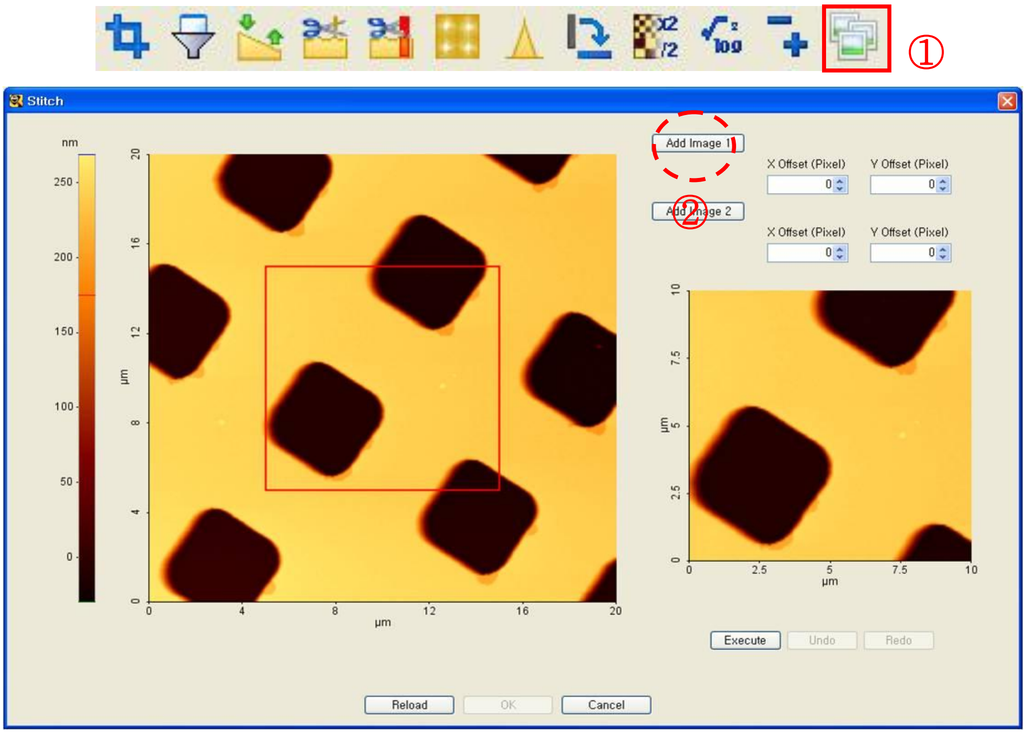
Stops Stitch Process and closes the window.

20-2. Stitching Images

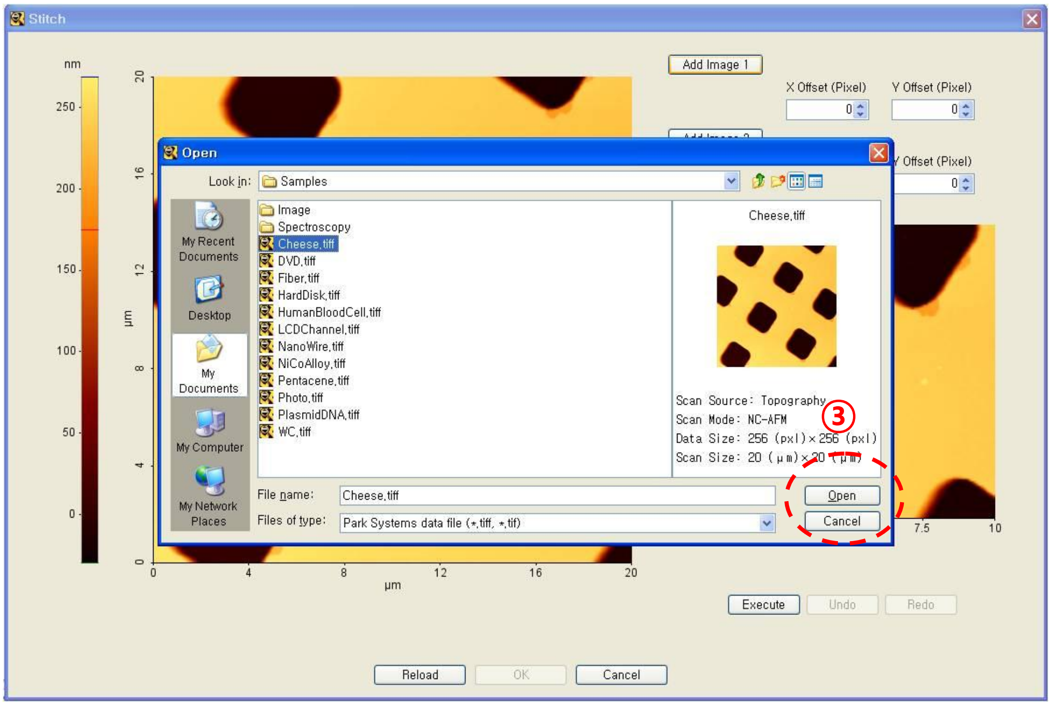
Loads an image file into the Analysis view from the Image Navigator view. To stitch images together, perform the following steps:

1. Open the stitching dialog by clicking [process->stitch] or by clicking the  icon in the Toolbar.

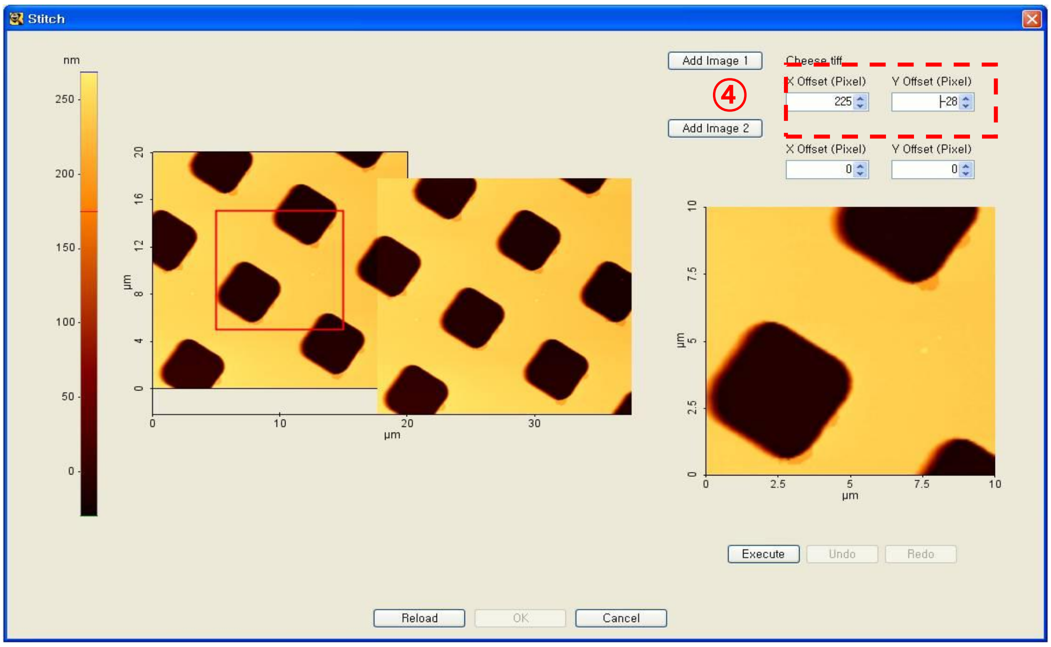
2. Add the image file by clicking the [Add Image 1(2)] button.



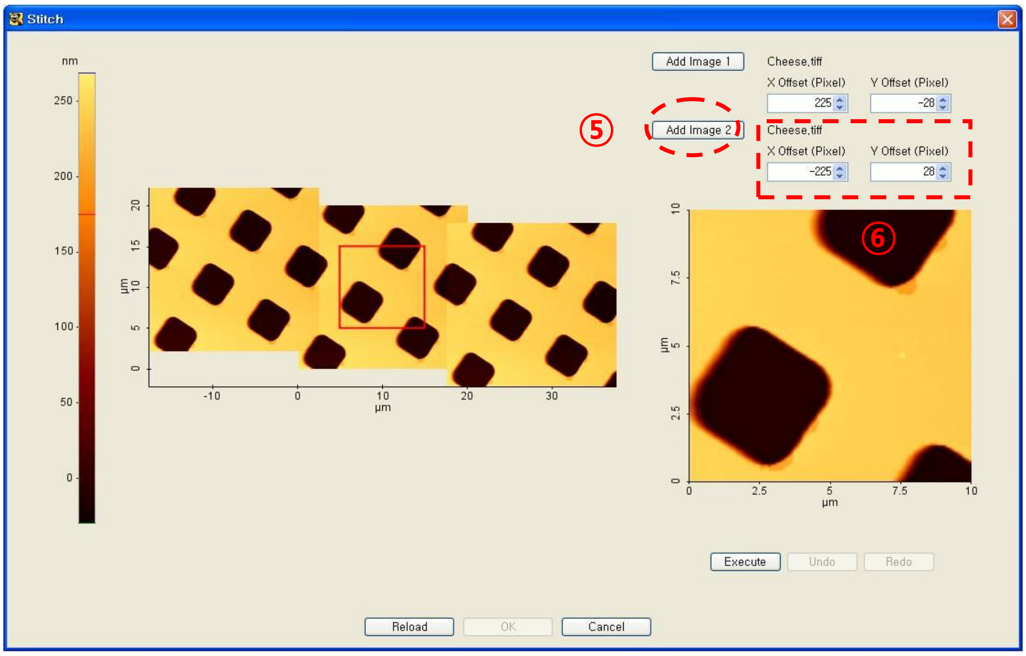
3. Select the desired image and click the [Open] button. Then, the selected image will be shown in the Image Display panel.



4. Adjust the image position by adding X,Y pixel offsets in the text field of added image file as desired.

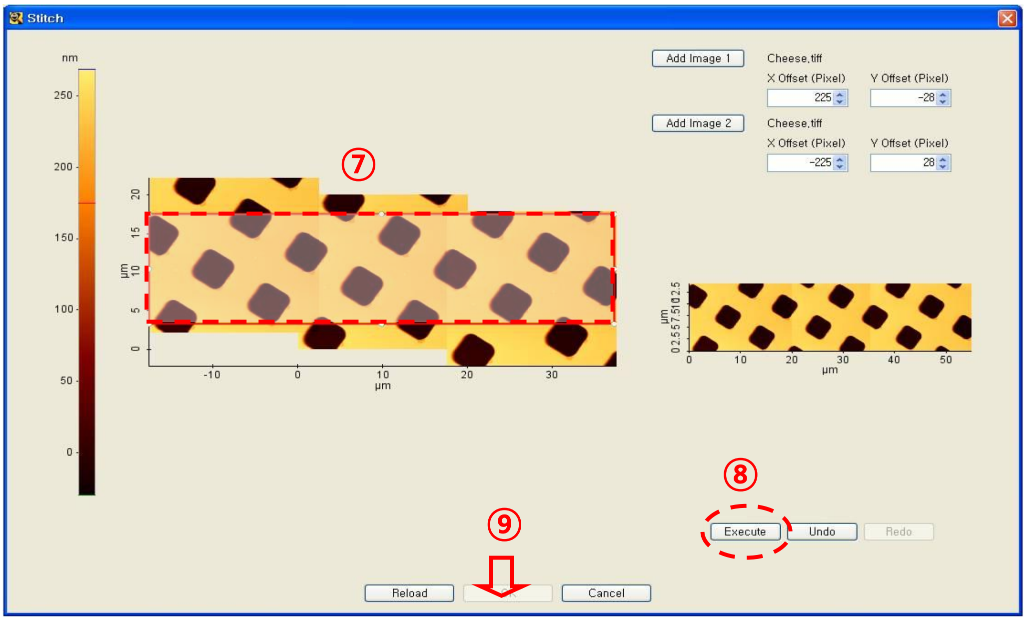


You can stitch up to 2 images together in one process step. To stitch more than 2 images together, repeat steps 2~4. See example below.



5. Move the crop rectangle over the region to be cropped.

6. Once you are satisfied with the new area in Zoom Image Display panel, click the [Execute] button and the [OK] button to create a newly cropped image that will be generated with a default name of 'original name + stitched.tiff' in the Image Navigator view. The cropped image will automatically be displayed in the Image Display panel.
7. Save the cropped stitched image as another file name for further image processing and analysis.



Appendix A. XEI Keyboard Shortcut

For each window in XEI, a keyboard shortcut is available. Please refer to the table below.

Shortcut	Menu window	Function
ESC	All Process View	Cancel
Right and Left arrow ← / →	- Region Analysis View >Region Histogram View -Line Analysis View>Line Profile View	Selected cursor can be moved
	Line Analysis View>Line Profile View	Selected line will move by pixel.
	Image Navigator Panel	Move images to choose
Ctrl + A	-Line Analysis View, Region Analysis View, Flatten Process View>Image View -Multi View	Select all shapes
Delete	-Line Analysis View, Region Analysis View, Flatten Process View>Image View -Multi View	Delete selected shape
	Line Analysis View>Line Profile View	Delete selected cursor
Enter	Image Navigator Panel	Load selected image

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