# *qHAADF*
for DigitalMicrograph

Quantitative High Angle Annular Dark Field Image Analysis
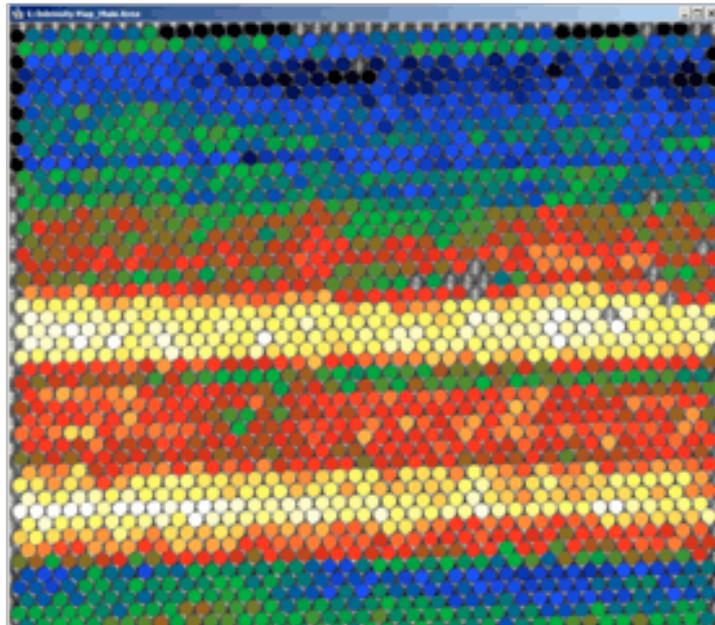
qHAADF User Manual v1.7

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Acknowledgements

The scientific developers of this method (Prof. Sergio I. Molina, Prof. Pedro L. Galindo and Dr. J. Pizarro) would like to acknowledge to all authors of the references cited in this manual for their collaboration in the process of its application to the scientific problems presented in these cited papers.

Copyright Statements

Introduction to Quantitative High Angle Annular Dark Field Image Analysis (qHAADF)

qHAADF stands for Quantitative High Angle Annular Dark Field Image Analysis, the DigitalMicrograph plug-in for atomic column-to-column compositional analysis of materials.

All results obtained by qHAADF are fully compatible with other functions present in DM. For example, compositional maps can be analysed and/or manipulated with functions such as histograms, statistics (mean, standard deviation, min, max etc.), or using the corresponding buttons, such as the Profile utility.

The main references for the algorithm are:

> [1] *Column-by-column compositional mapping by Z-contrast imaging*
> S.I. Molina, D.L. Sales, P.L. Galindo, D. Fuster, Y. González, B. Alén, L. González, M. Varela and S.J. Pennycook
> *Ultramicroscopy* **109** (2009) 172–176
> *doi:10.1016/j.ultramic.2008.10.008*
> *(see also Erratum on Ultramicroscopy 109 (2009) 1315)*

> [2] *Compositional Analysis with Atomic Column Spatial Resolution by 5th-Order Aberration-Corrected Scanning Transmission Electron Microscopy*
> D. Hernández-Maldonado, M. Herrera, P. Alonso-González, Y. González, L. González, J. Gázquez, M. Varela, S. J. Pennycook, M. P. Guerrero-Lebrero, J. Pizarro, P. L. Galindo and S. I. Molina
> *Microscopy & Microanalysis* **17** (2011) 1-4
> *doi: 10.1017/S1431927611000213*

> [3] *Distribution of Bismuth Atoms in GaAsBi Epilayers*
> D. L. Sales, E. Guerrero, J. F. Rodrigo, A. Yáñez, P. L. Galindo, M. Shafi, A. Khatab, M. Henini, S. Novikov, M. F. Chisholm and S. I. Molina
> *Appl. Phys. Lett.* **98** (2011) 101902:1-3
> doi:10.1063/1.3562376

This manual will help you to use of the qHAADF package with some worked examples.

Software requirements

The following is a list of the software requirements necessary to run the qHAADF plug-in:

- – DigitalMicrograph (GATAN^{TM})
- – USB Key Driver
- – HREM Mouse Tool Plug-in (Free-ware downloadable from www.hremresearch.com)
- – IPU Plug-in (Free-ware downloadable from www.hremresearch.com)

Software Installation

Installing USB Key Driver

The user key driver should be installed by following the instructions given by the key driver installer. You can find the key driver installer at the plug-in page on HREM Research web site.

Installing DigitalMicrograph Plug-ins

The DigitalMicrograph Plug-in will be provided as Gatan compiled script file(s) (.gtk) and dynamic link library file(s) (.dll). All these files can be installed by copy-and-paste to the folder "PlugIns." (The PlugIns folder should exist under a normal installation of the DigitalMicrograph).

When the DigitalMicrograph is launched after placing the plug-ins into the PlugIns folder, the PlugIns will appear as a new menu or an addition to the standard tools.

Installing Mouse Tools

All the files relating Mouse tool plug-in can be installed by copy-and-paste to the folder "PlugIns." The Mouse tool will appear as an addition to the standard tools.

Installing IPU Plug-in

The qHAADF plug-in uses some functions based on the Intel' MKL (Math Kernel Library) provided by the IPU plug-in. All the files relating the IPU plug-in can be installed by copy-and-paste copy. The IPU plug-in will appear as under *IPU* menu. Please consult the ReadMe file that comes with the IPU plug-in.

Installing qHAADF

qHAADF.gtk and qHAADF.dll can be installed by copy-and-paste to the folder "PlugIns". The qHAADF plug-in will appear under *qHAADF* menu.
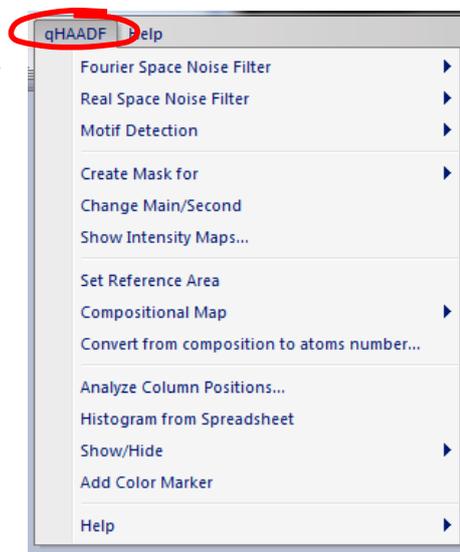
Installing Polygon ROI Tools

The Polygon ROI tool comes with the qHAADF plug-in. This tool will be installed in the same way as the Mouse tool. The Polygon ROI tool will appear as an addition to the standard tools.
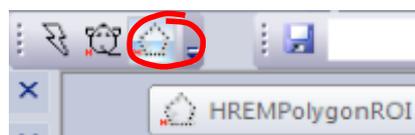
Getting Started

Open the file "Test image.dm3" using the DM command **File…Open**.
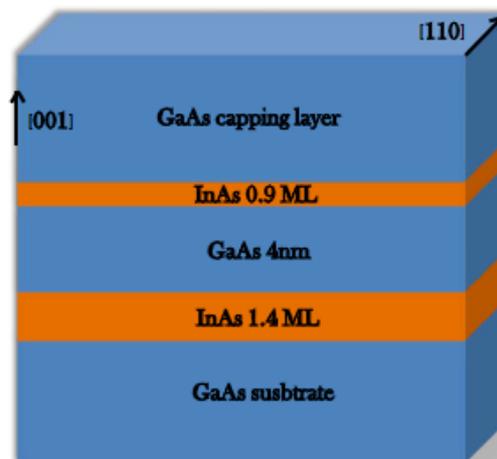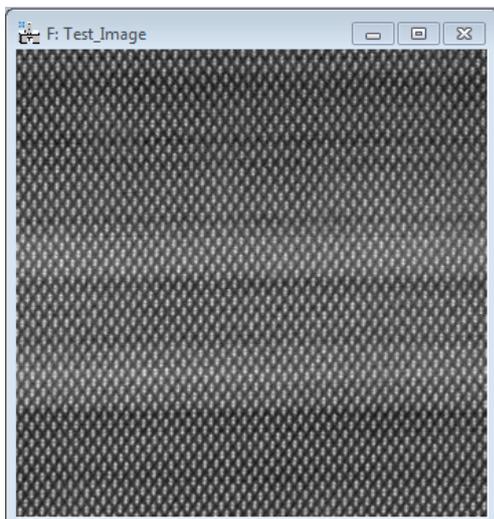
This image was taken from a sample that consists of two InAs layers of 1.4 monolayers (ML) and 0.9 ML of InAs, respectively, grown by molecular beam epitaxy on a GaAs (001) at a substrate temperature of 500ºC. Further growth and sample preparation details can be found elsewhere [1]. The layer structure of this sample is shown above.

In this example, qHAADF package is used to measure atomic column by column the percentage of In and Ga atoms on each cationic column.

All the commands related to qHAADF are located in the menu **qHAADF**.

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[1] Microscopy & Microanalysis 17 (2011) 1-4.

Image pre-processing

Filtering can be used to improve the quality of images with "snow" or other noise resulting from poor reception conditions. There exist two commands to denoise images, Fourier and Real Space Noise Filter. However, it is important to notice that all later calculations leading to compositional determination are done using raw data (from detector black level subtracted original image).

Fourier Space Noise Filter

The first command to be applied to the image is to calculate the *Power Spectrum* of the image:
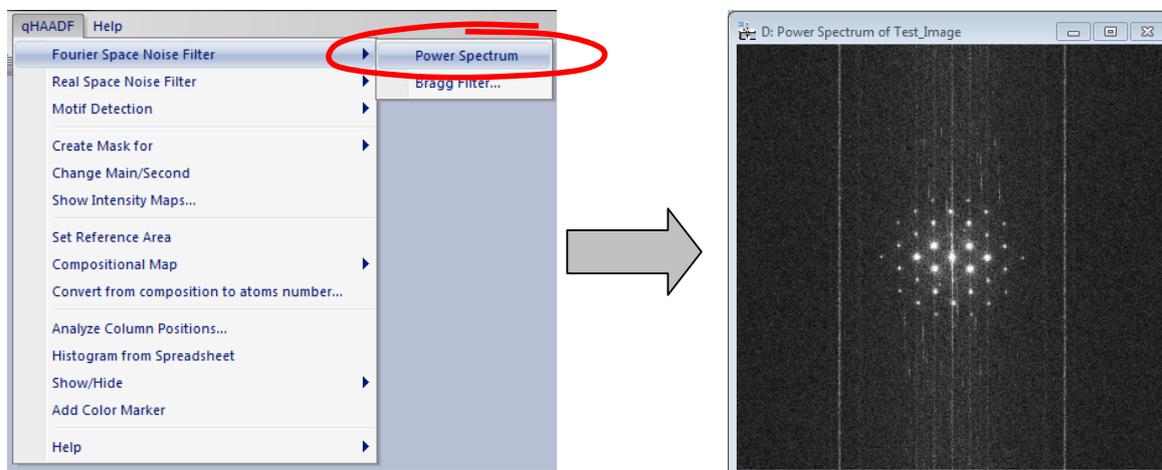
Now, using the **mouse tool,** click on desired spots. The usual choice is to select the brightest spots in the spectrum, but those corresponding to higher harmonics can also be selected:

The user doesn't need to hit the spot exactly, because qHAADF looks for the local maxima near the selected point. Anyway, you can zoom in the spectrum before hitting peaks using the DM **zoom** tool:
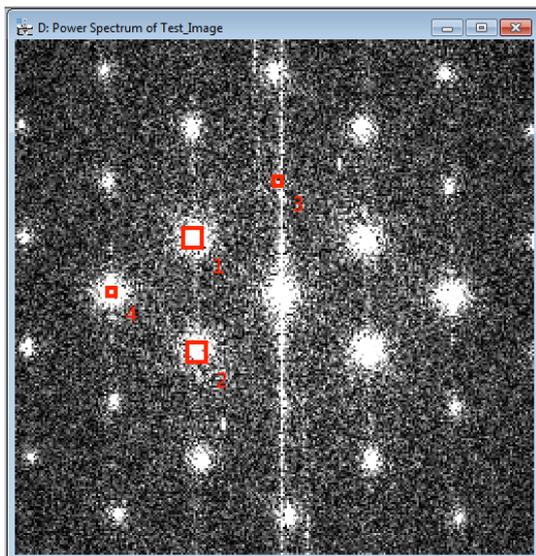
Hint: if you wish to delete any spot, just click on the mouse mark again with the SHIFT key down.

**Hint:** Symmetry in the selection for each spot is assumed.

Don't be surprised if the central spot is not present in the power spectrum. It just indicates that the mean intensity of the image is zero.

We are now ready to apply a Bragg Filter. This process creates an image where the contrast resulting from the ordered regions is clearly distinguishable from the background intensity.
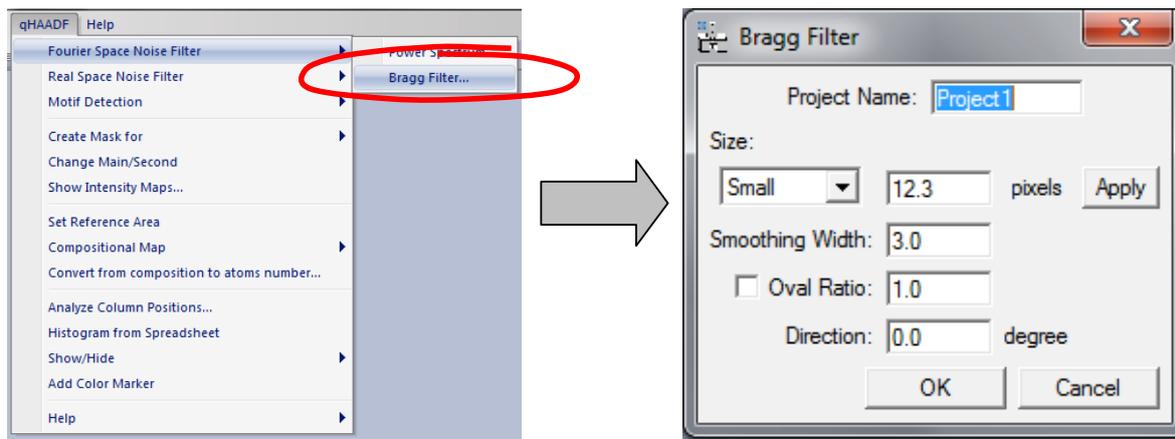

The shape and size of the Bragg filter must be adjusted such that no loss of information occurs. In this dialog box we can determine the size (in pixels), smoothing width (in pixels), oval ratio (height/width) and direction (in degrees) of mask spots.

By pressing the **Apply** button, the mask described by the chosen parameters may be pre-visualized, as it is shown in these two examples:
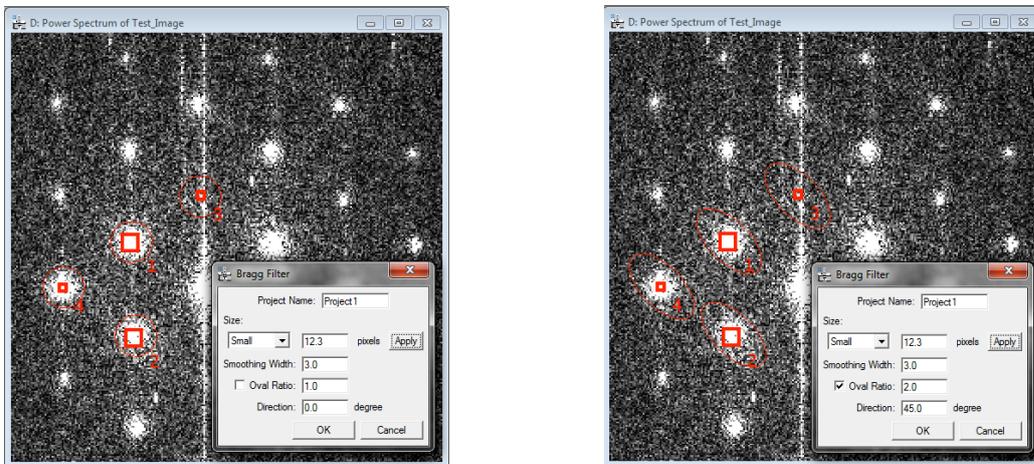
Let us select the first choice by pressing the OK button, and the Bragg filtered image will appear immediately.

If Bragg filter parameters are properly chosen (big masks and a sufficient number of peaks), the resulting filtered image will preserve the location of maxima. The great advantage in using the filtered image is the reduction of noise.
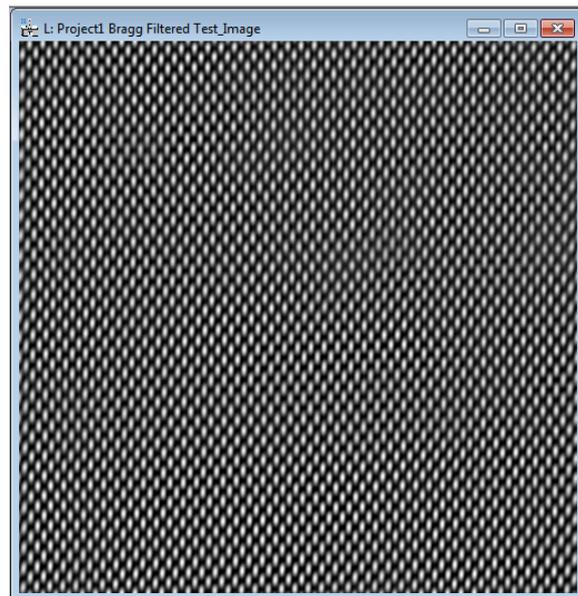
Real Space Noise Filter

qHAADF package offers two different types of Real Space filter:
(i) Wiener Filter
(ii) Low Pass Filter.

Wiener filter:

The Wiener filter is widely used for image restoration and calculates the optimal filter for the removal of noise from a signal which is corrupted by the measuring process itself. It assumes that if noise is present in the system, then it is considered to be additive white Gaussian noise.

After selecting the original image, and applying the Adaptive Wiener Filter in the menu, the user should decide the size of the windows used for calculating the Adaptive Average and the Noise Estimation, as follows:
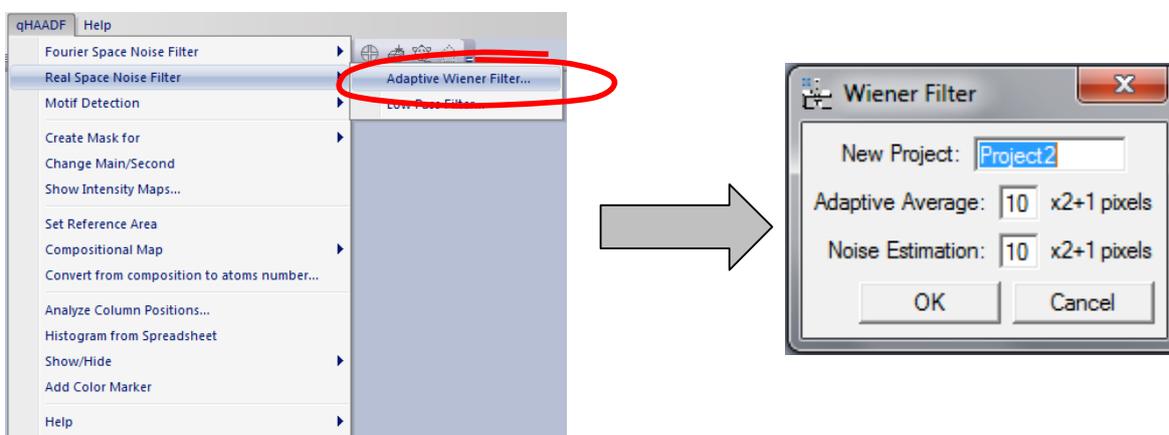

In a typical qHAADF session, if Wiener filtering is desired, it is usually the first operation to be applied to the original image. The result of the Wiener filtering operation on qHAADF *Test* image and respective Power Spectra (Adaptive Average =10, Noise Estimation=10) is depicted below.
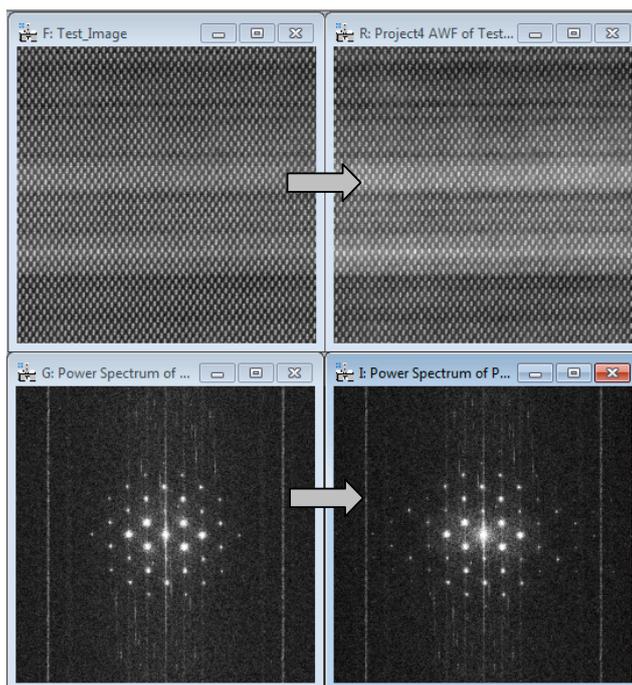
Low Pass Filtering

In order to generate a Low-Pass filtered image, we simply select the input image and use the ***Low Pass Filter*** command in the menu. The strength of the filter is defined by the radius of the mask in pixels (the highest the radius, the strongest the filter):
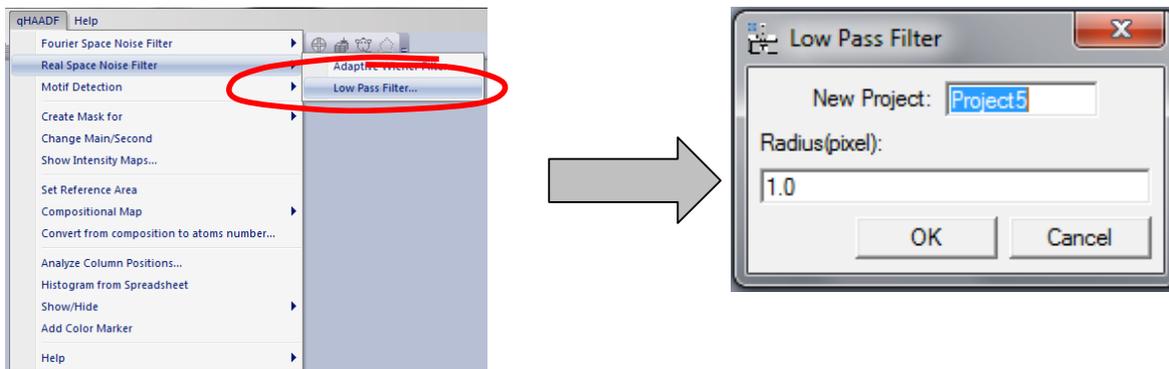
In the following figure, the resulting images after the application of a Low-Pass filter to the *Test* image with different radius are shown:
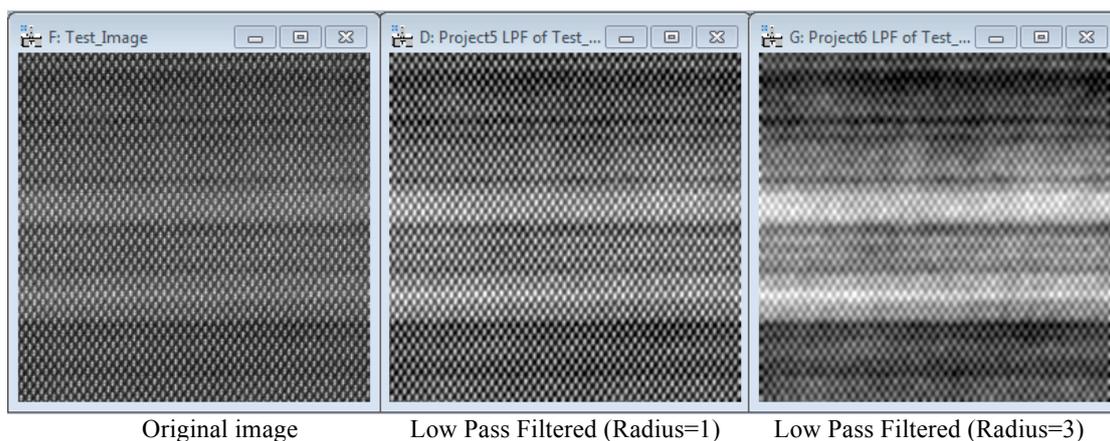
| Original image | Low Pass Filtered (Radius=1) | Low Pass Filtered (Radius=3) |

Motif Detection

Motif Detection focus on locating peaks of intensity in the image.
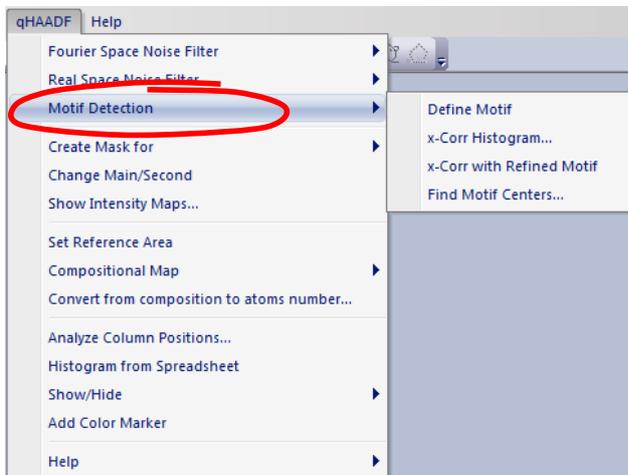

In order to achieve it, three steps must be followed:

Step 1. x-Cross Correlation Histogram

Step 2. x-Cross Correlation with Refined Motif

Step 3. Find Motif Centers

To determine quantitatively the InGaAs composition distribution in the image, cation peaks of intensity will be located.

Step 1 (x-Corr Histogram): Use the **Rectangle ROI** tool and select the motif. You can zoom in the filter image before selecting the motif by using the **Zoom** tool.

If you want to rotate the motif, use the *Define Motif* command (This is optional.). Then, you can rotate the ROI as well as to change the ROI size (see Additional Functions).
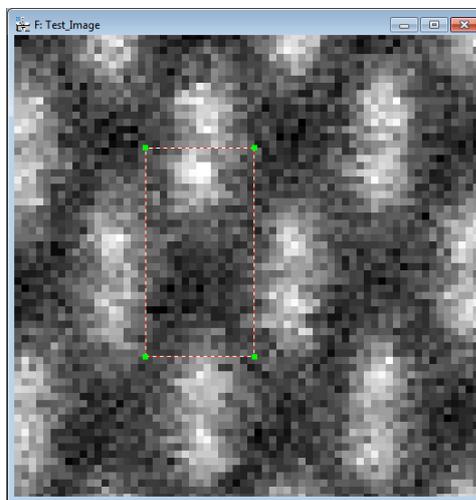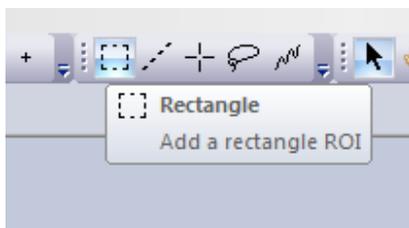

Next, select the *x-Corr Histogram* in the Motif Detection submenu. A dialog shown below will open:
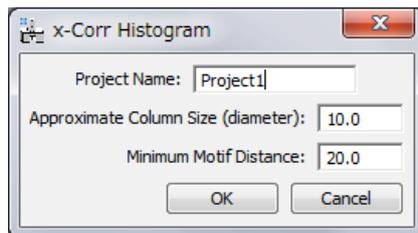
After clicking OK, the HREM Histogram tool shown below and a new window will appear showing the histogram of all maxima found in the Cross-Correlation map, obtained using the *User-Selected* motif and the original image.

HREM Histogram tool
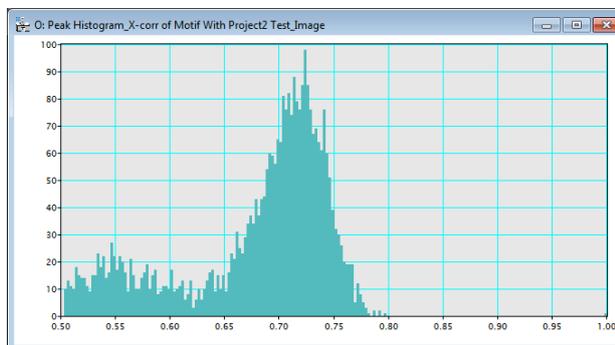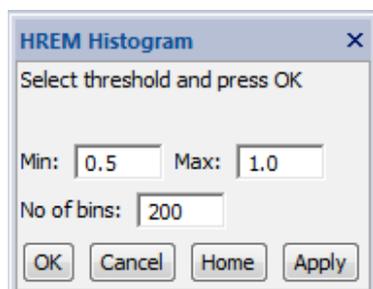
There will be a single point with a unit value (1.0), which corresponds to the self-correlation of the selected motif, and the remaining peaks will correspond to areas in the image quite similar to the selected motif. Its cross-correlation value is a measure of similarity, being possible values in the range from -1 (completely different) to 1 (exactly the same). Usually, peaks have cross-correlation values above 0.5. The default range of the histogram is set to 0.5 to 1.0. If you want, you can change the histogram range as well as the number of bins. When you change these values, push the "Apply" button.

To obtain a refined motif using the patterns in the image, which give high cross-correlation value with the motif, the user should select the range of desired cross-correlation value in the histogram by using the Range ROI (You can set Range ROI using **the Select and Move Objects** tool / Arrow tool).
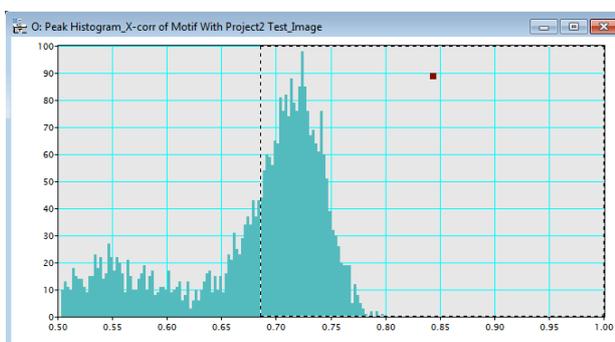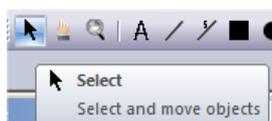

When threshold is defined by the left edge of the Range ROI, the discovered motifs will be classified to red or blue depending on their cross-correlation values: red indicate the motif, whose cross-correlation value is higher than the selected threshold, while blue indicate the motif equal to or lower than the threshold. The peak colour will be dynamically revised by changing the threshold (the left-edge of the Range ROI).
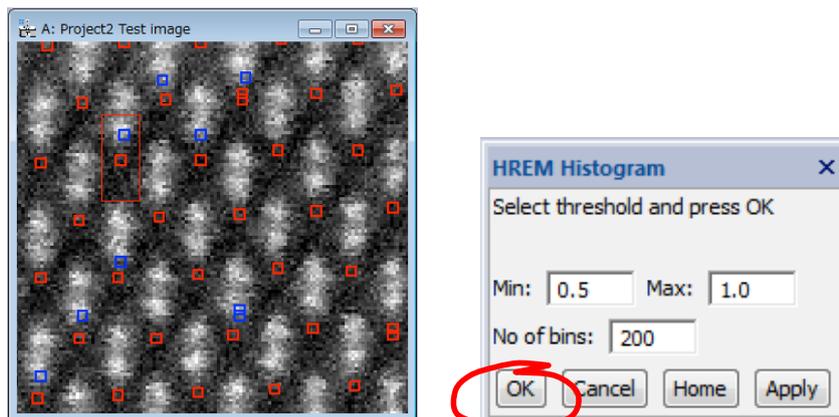
When you satisfy the threshold by looking the motif markers (red or blue), push the "OK" button of the Histogram tool, or the "Cancel" button to stop the process.

If you push the "OK" button, the first refined motif is calculated by averaging all patterns associated to each point in the histogram above the chosen threshold (0.68 in the figure). The average motif is automatically shown:
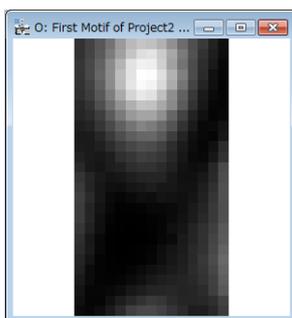

Step 2 (x-Corr with Refined Motif): Select the *x-Corr with Refined Motif* in the Motif Detection submenu.
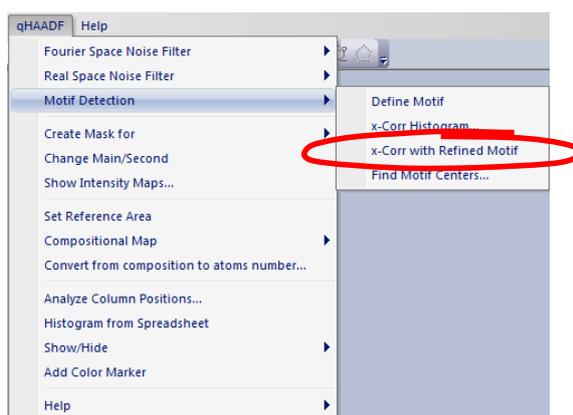

The second operation is the calculation of a new histogram of all maxima found in the Cross-Correlation map between the *Refined* motif and the original image. The HREM Histogram tool and a new histogram window will appear. Usually, the cross-correlation values are in the range 0.7-0.9. If you want, you can change the histogram range as well as the number of bins. When you change these values, push the "Apply" button.

HREM Histogram tool
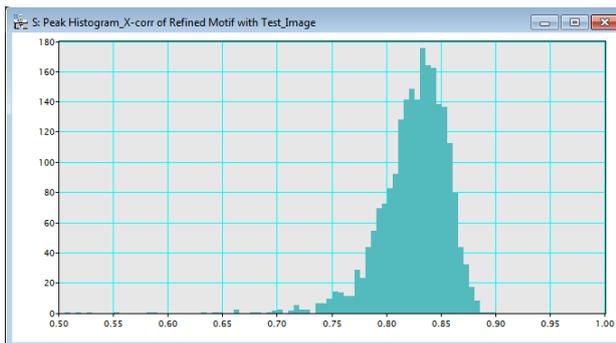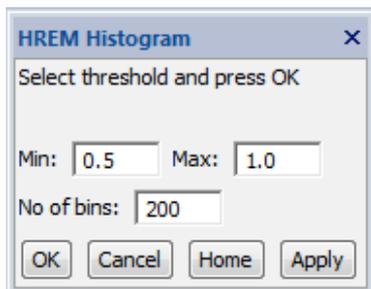
When you select the range of desired cross-correlation value in the histogram by using the Range ROI **(**You can set the Range ROI using **the Select and Move Objects** tool / Arrow tool), the discovered motifs will be classified to red or blue as before. The peak colour will be dynamically revised by changing the threshold (the left edge of the Range ROI).
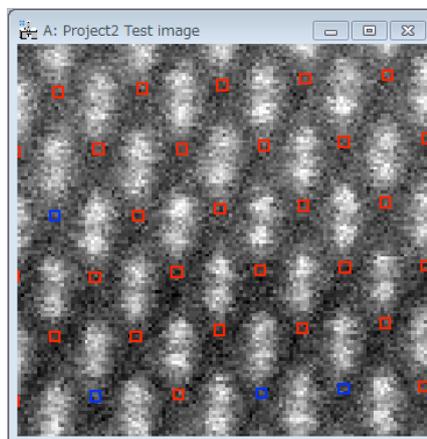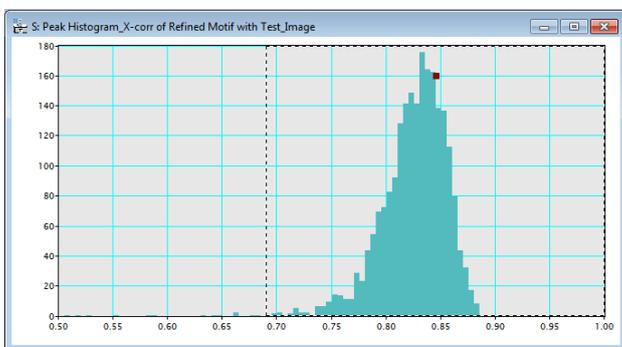

When you satisfied the threshold, push the "OK" button of the Histogram tool, or push the "Cancel" to stop the process.

If you push the "OK" button, the second refined motif is calculated by averaging all patterns associated to each point in the histogram above the chosen threshold (0.69 in the figure). The second refined has the peak position(s) found in the motif as shown here:
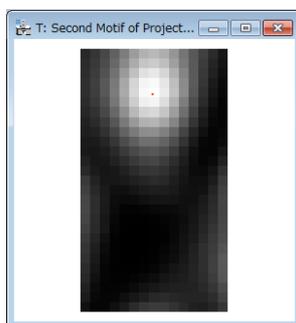
Step 3 (Find Motif Centers): Select the ***Find Motif Centers*** in the Motif Detection submenu.
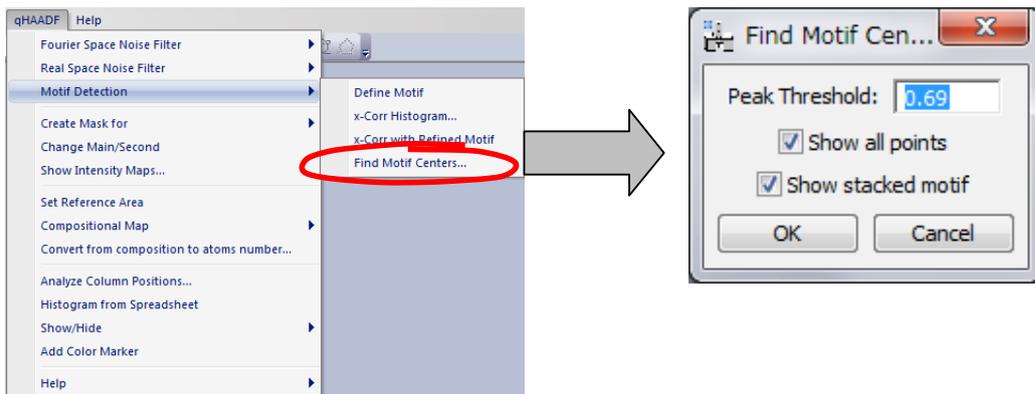
Peak Threshold indicates the minimum cross-correlation value with the refined motif to be considered as a valid peak. This value corresponds to the left-edge of the Range ROI in the histogram. Peaks having cross-correlation values below this threshold will be discarded.

If we want to restrict the distance between the motifs, it is possible to define the Minimum Motif Distance in the first dialog of the Motif Detection.

By pressing OK, the centers of the valid motifs will be shown over the filtered image as shown below:
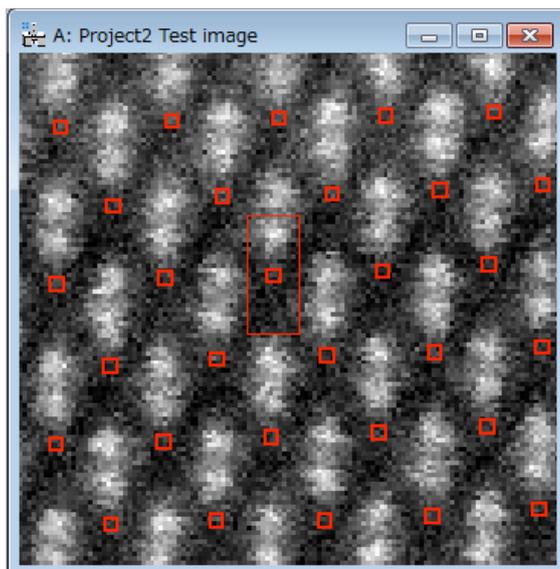
Integration areas definition

qHAADF allows you to define three different Intensity Integration Areas: main, secondary and third integration Area. Main area will be shown using red spots, secondary area using green spots and third integration area using yellow spots.

The **HREMPolygonROI** tool is used to define Integration Areas
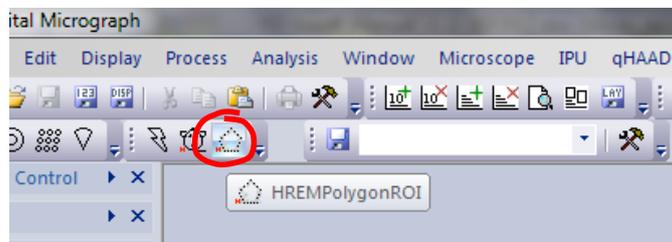
Zoom the filter image and define a polygon by using the HREM Polygon ROI tool. At first select the Polygon ROI, and click the first point, then move the mouse pointer to the next point and click to fix the second point. In this way, you can define the polygon of any number of vertices. Press double click when finished. The polygon will be drawn in green. If you make any error in the polygon definition, you can delete it (*Select* the ROI and press *Delete* key).
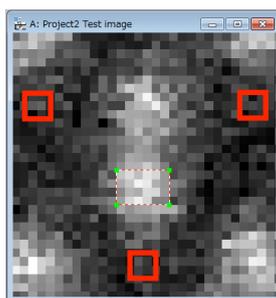

To define Intensity Integration Area select *Create Mask for* in the menu and define the main Area.
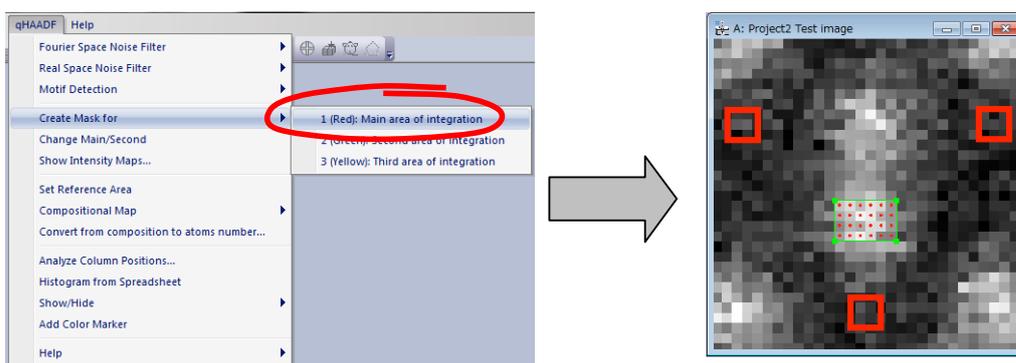
A set of red spots inside the polygon will be shown and they will define the Integration Area. You can add or deleted spots by using the **Polygon ROI** tool: Select the Polygon ROI tool, and click a new pixel to add a point or a selected (red) point to delete the point, when pressing the ALT key.

Repeat the process to define the secondary (Green) and third (Yellow) Integration Area in the same way, if necessary.
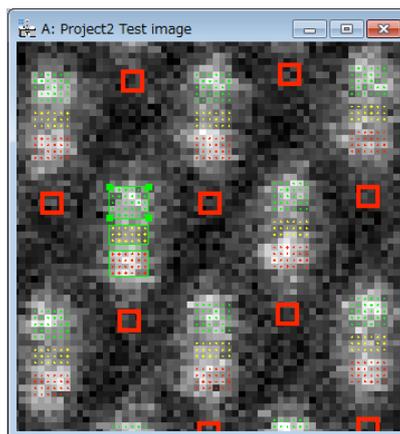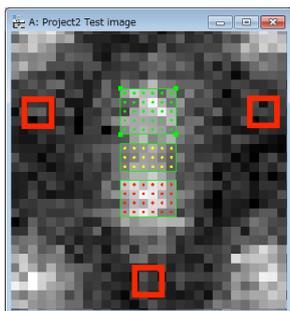
By selecting the option **Show/Hide Intensity Masks** the Integration Areas in the whole image will be shown or hided.

Main and secondary Integration Area can be exchanged by selecting the **Change Main/Second** in the menu.
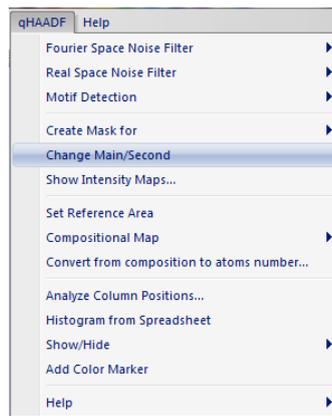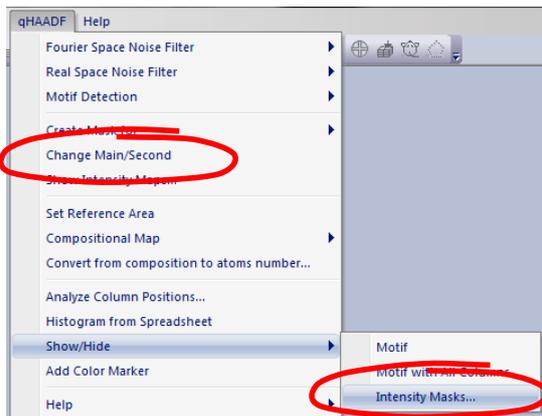

Once the Intensity Integration Areas have been determined, intensity maps can be drawn.
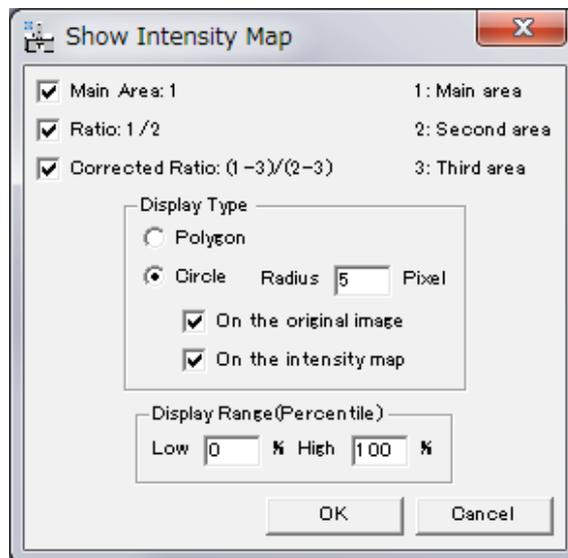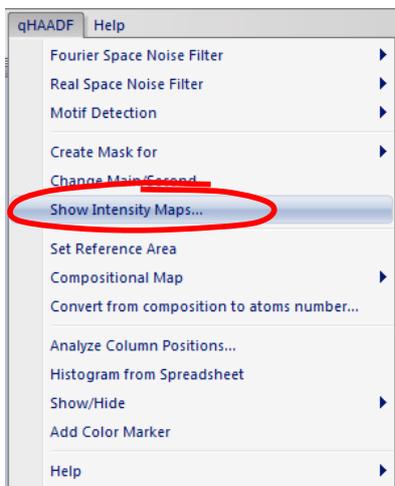
Main Area shows intensity map from the main Integration Area defined. *Ratio* shows intensity map by dividing the first Integration Area by the second one. *Corrected Ratio* shows intensity map by computing the three integration areas as indicated in the window. The display type can be defined as polygon type or circle type at different radius. To show intensity maps at least the main Integration Area must be defined.

The color circles can be shown *on the original image* and/or *on the intensity map*. The latter display is useful for drawing a line profile of the intensity. *The Display Range* is used to modify the colour scale.
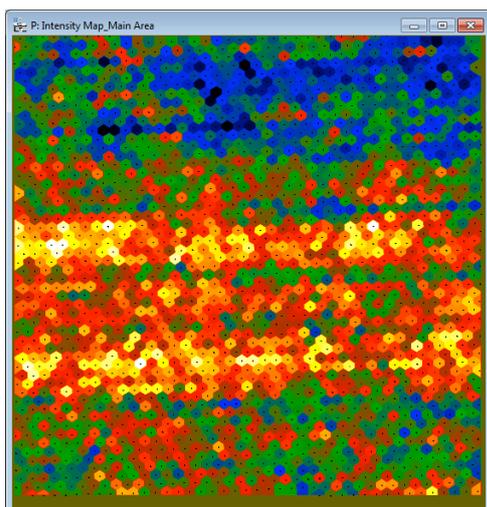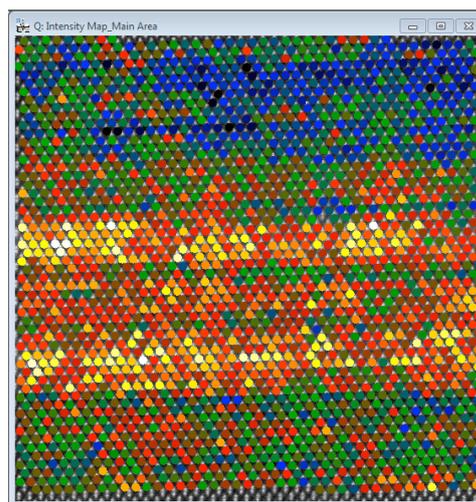
Display type polygon   Display type circle

Compositional Analysis

Once all Integration Areas have been determined, we can proceed to the calculation of compositional maps. Although there are three Integration Areas, the results presented in this section relates to the main Integration Area.

**Step 1: Reference area definition**

A very important step is to define the reference area, that is to say, the area which is considered to correspond to the substrate (with 0% In in this example, that is, GaAs). All values will be referred to this area. Use the **Rectangle ROI tool** (Region Of Interest tool) or **Polygon ROI tool** to select a reference area in the image. Then select *Set Reference Area* in the menu. The Reference Area will be shown in red. If you make any error, you can delete the reference area (*Select* the Reference Area and press *Delete* key) and repeat the process.
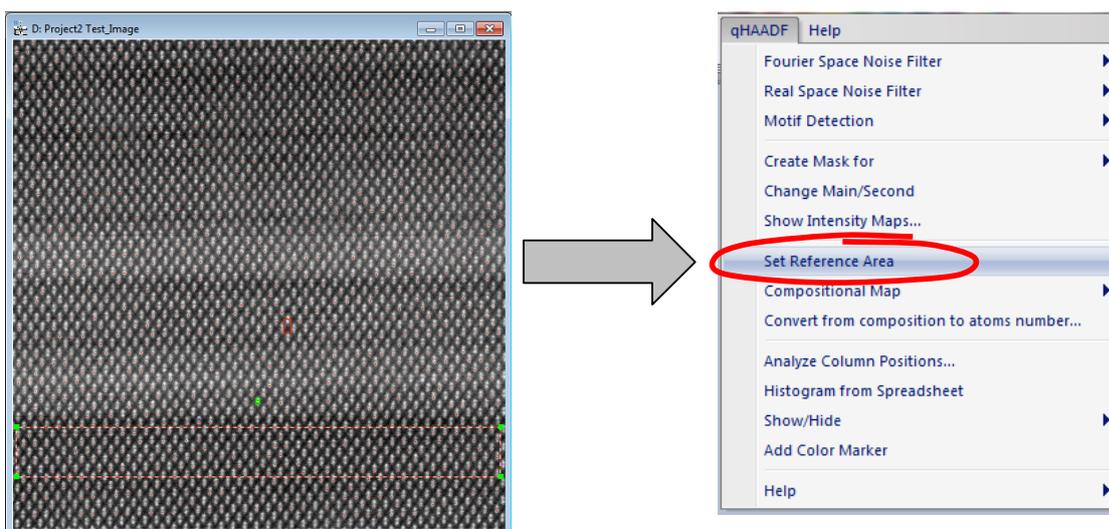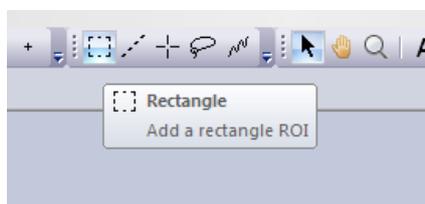
Step 2: Compositional Maps

The ratio R for each atomic column (the In-Ga cationic columns in the present work), defined as the ratio between the intensity integrated around an In_xGa_{1-x} column (in $In_xGa_{1-x}As$) and the intensity integrated around a Ga column (in GaAs) keeps a linear relation with the composition x, as it is expressed in the equation: $R=ax+b$. The R-values are determined from integrated intensities calculated from the HAADF image.

If the linear relation is known:

Select the ***Compositional Map -> with R Factor Coefficients***.
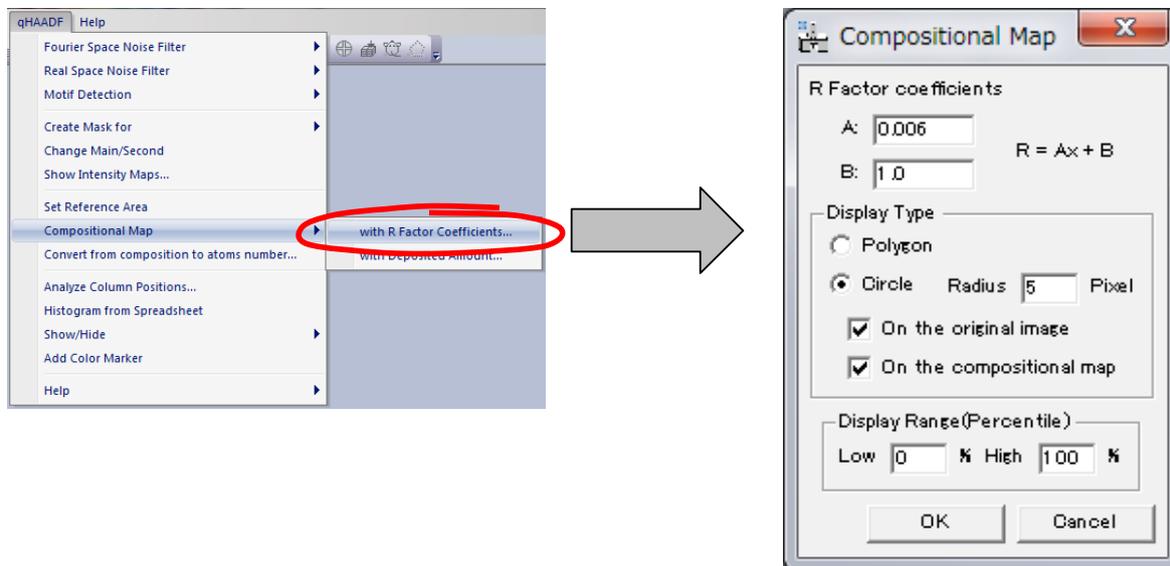
Write the coefficient values A and B and select the display type (Polygon or Circle), then press the *OK* button. The color circles can be shown *on the original image* and/or *on the compositional map*. The latter display is useful for drawing a line profile of the composition. *The Display Range* is used to modify the colour scale.
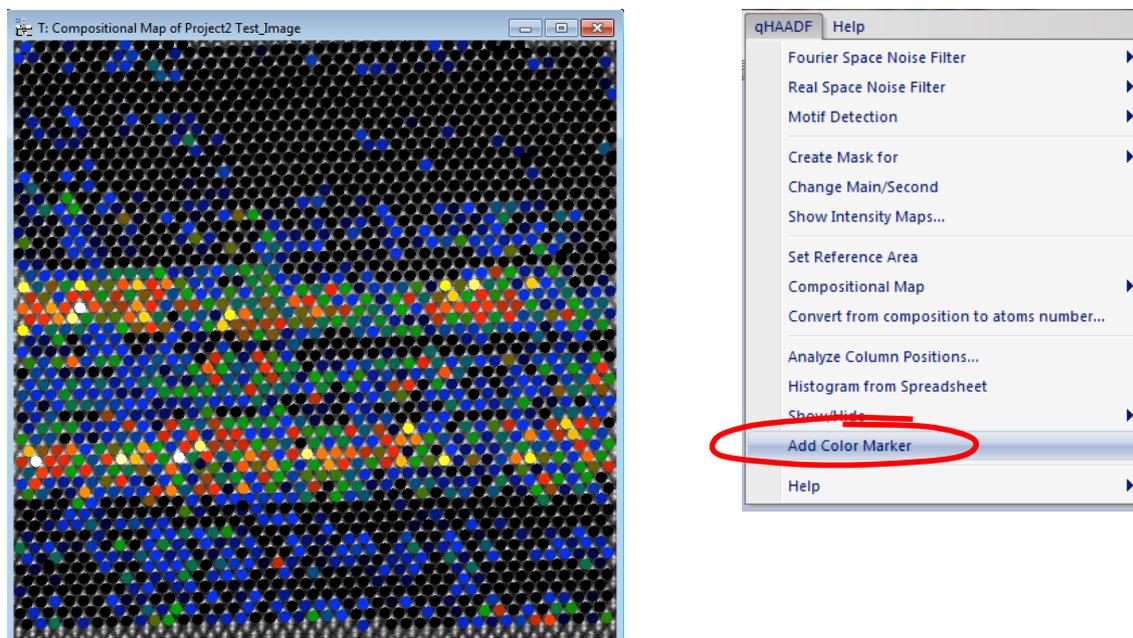
It is possible to draw a color bar by selecting the ***Add Color Marker*** command.

If the linear relation is unknown:

Step 1: Select a region where total deposition amount is known (2.3 monolayers of InAs in GaAs, in this example) by using the **HREMPolygonROI** tool.
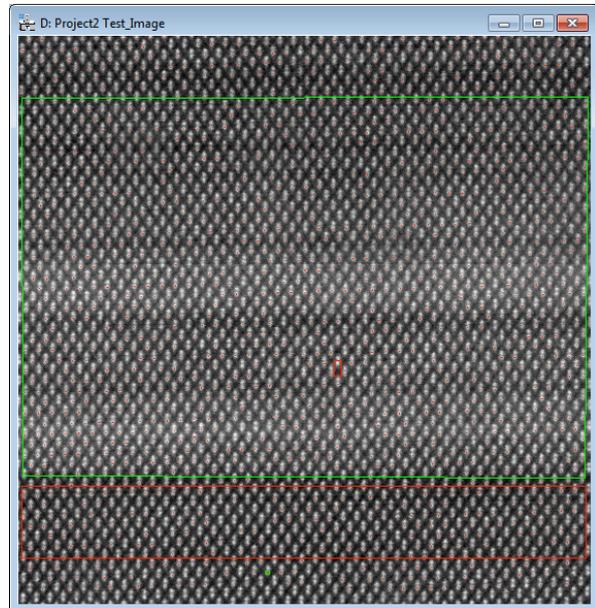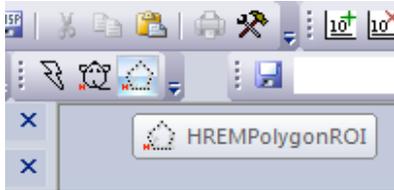
Step 2: Draw a line, which indicates the direction of monolayers by using **Line ROI** tool. Try to draw the line as longer as possible for a better result.

21
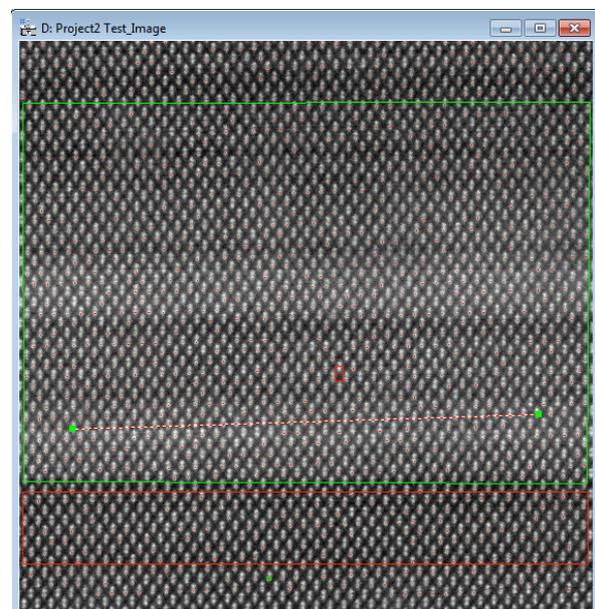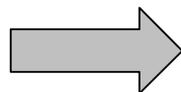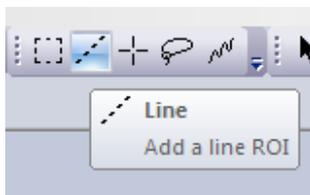
Step 3: Select the ***Compositional Map -> with Deposited Amount* option**.
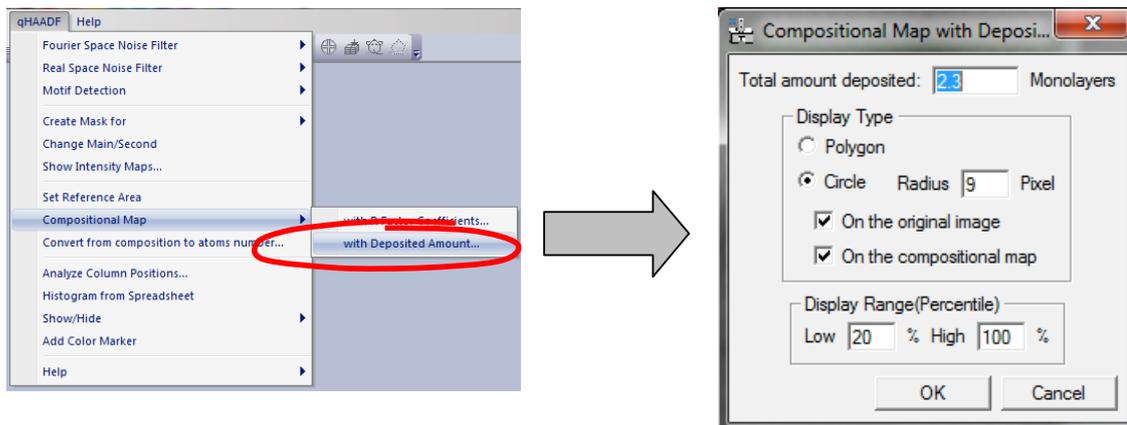
Write the *Total amount deposited* and select the *Display Type* (Polygon or Circle). The color circles can be shown *on the original image* and/or *on the compositional map*. The latter display is useful for drawing a line profile of the composition. *The Display Range* is used to modify the colour scale. The obtained compositional map is shown in this figure:
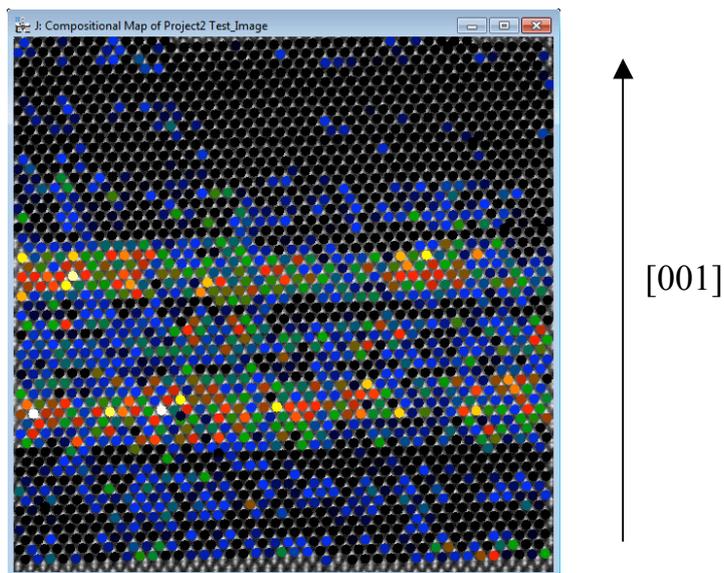

An example of a compositional profile taken from an area with a width of 6 atomic columns is shown below, expressed as In% versus the number of pixels along [001]
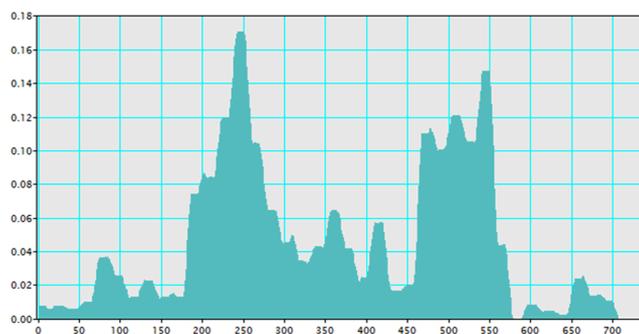
Convert from composition to atoms number

The composition of each column will be converted to a number of atoms in the column, when you know the total number of atoms in the column. To do so, after calculating a composition map, select the ***Convert from composition to atoms number*** command. Then, the following dialog will appear:
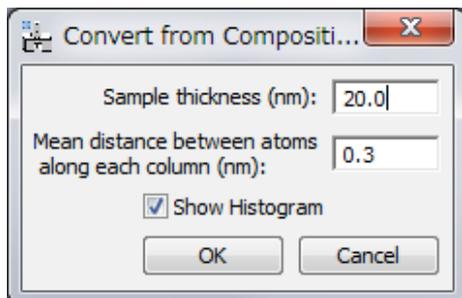
Here, the total number of atoms in the column will be calculated from the sample thickness and a mean distance between atoms. You may note the information obtained here is, in principle, identical to the compositional map. You can change the display range of the Atom Number Map and its Histogram by changing the Contrast Limit of the Image Display Info in usual way.

Additional functions

Analyze column positions

Once Peaks using motif have been located, it is possible to analyze column positions with respect to its relative position within the grid.
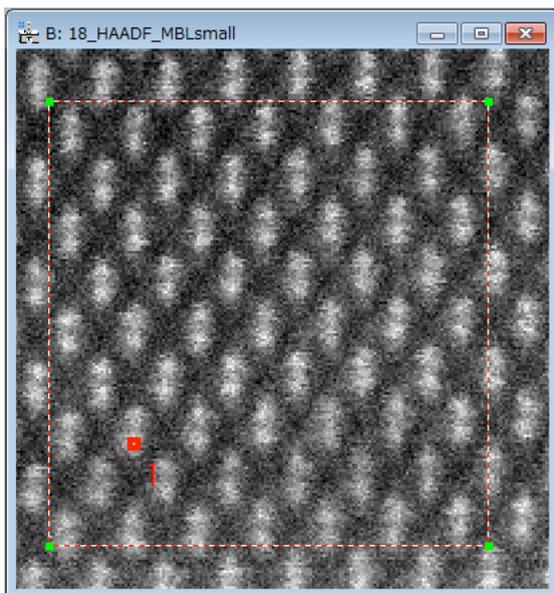
In order to do so, go through the following steps:

- Choose the original image and select the area of interest using the Rectangle ROI tool or Polygon ROI tool.

- Choose atomic column(s) to be analysed in the original image, using the HREM Mouse tool.

- Choose the project image, for which the *Find Columns* command has been applied.

- Apply the ***Analyze Column Positions*** command

Then, the user will have the option to calculate the distances from the checked point to other points (if there more than two points), or the angles subtended by two adjacent points (if there more than three points). The column value may be the integrated intensity or the peak height, and the column coordinates may be based on the image origin or the motif origin (see *Quick Reference Guide*).
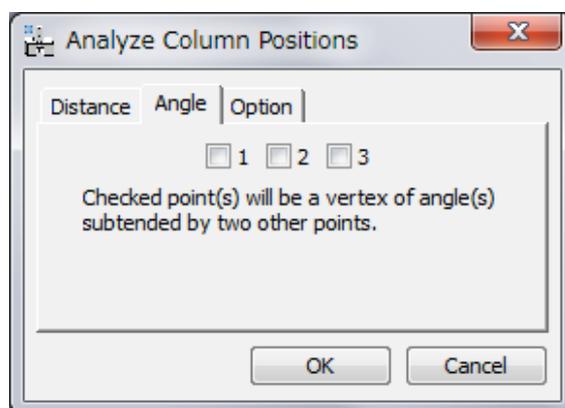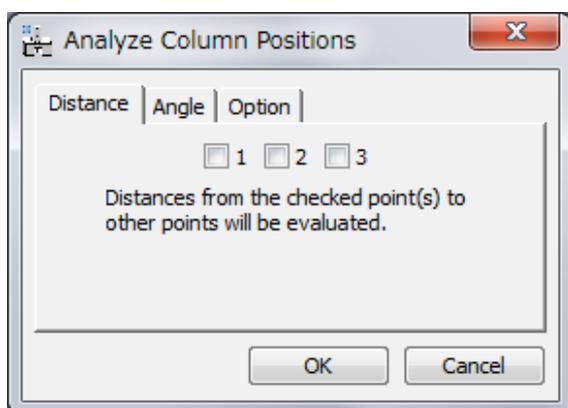
The column positions will be shown in the original image, and the intensity of each point will be stored in a datasheet.
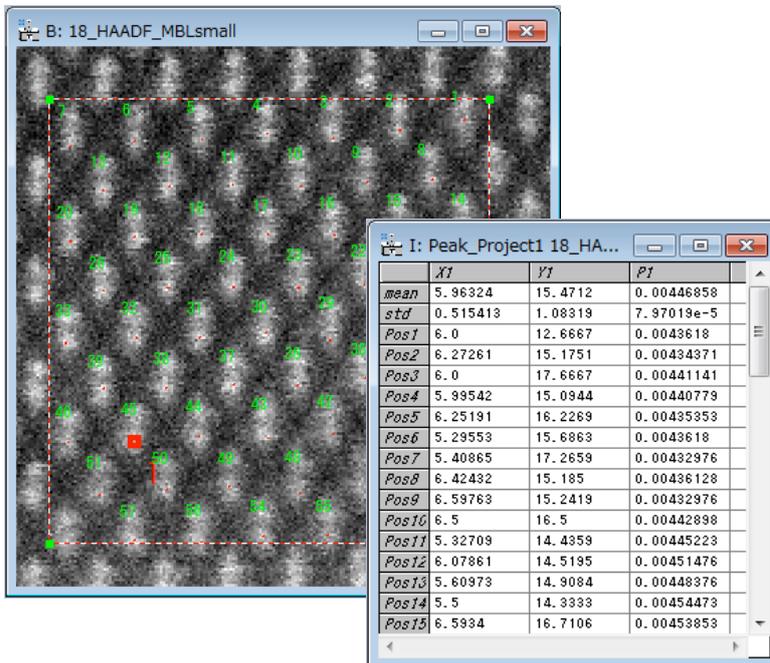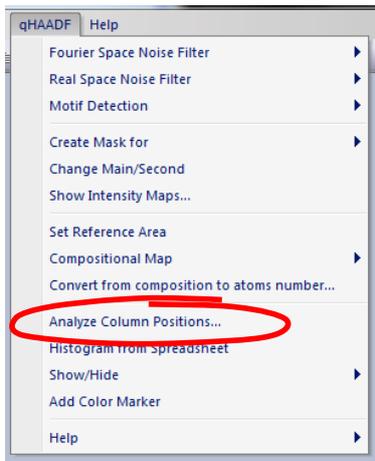
Histogram from spreadsheet

It is also possible to get a histogram from the Spreadsheet by using the ***Histogram from Spreadsheet*** command, thus obtaining a histogram for the column in the spreadsheet.
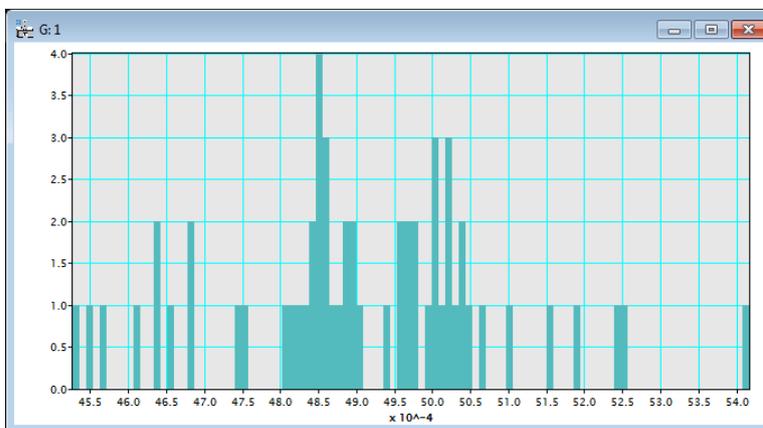
Rotatable ROI
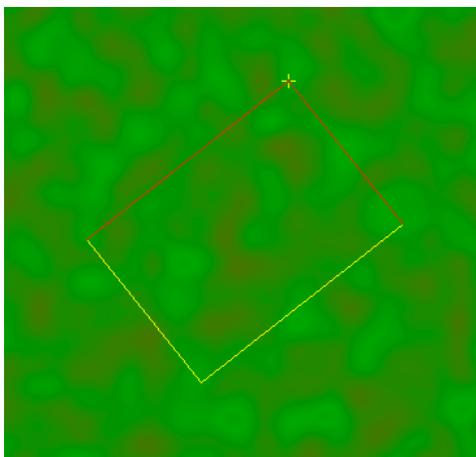
The edge length will be adjusted by one of the yellow edges, and the rotation angle will be adjusted by the yellow cross (+). (You can change the both edge lengths by dragging the yellow cross when pushing the SHIFT key.)

Quick Reference Guide

The qHAADF Main Menu

The commands in the qHAADF menu are described below.

Command	Description
Fourier Space Noise Filter (see *sub menus*)	Noise reduction through a Bragg filter
Real Space Noise Filter (see *sub menus*)	Noise reduction in Real Space Filter
Motif Detection (see *sub menus*)	Peak Detection using a Motif
Create Mask for (see *sub menus*)	Define an Intensity Integration Area
Change Main/Second	Change Integration Area Order (main/second areas)
Show Intensity Maps...	Show maps of Integrated Intensities
Set Reference Area	Define the reference area (usually a pure binary compound; it is usual to choose this reference area from a substrate material in the case of epitaxial materials)
Compositional Map (see *sub menus*)	Computes Compositional map
Convert from composition to atoms number…	Computes the number of atoms of each column from a compositional map

Analyze Column Positions...	Analyzes column positions and intensity and angles
Histogram from Spreadsheet	Calculates a different histogram for each column in the spreadsheet
Show/Hide (see *sub menus*)	Show/Hide Windows
Add Color Marker	Draws a color bar

Fourier Space Noise Filter SubMenu

Power Spectrum

Bragg Filter...

Component	Description
Power Spectrum	Calculates the Fourier transform of the front most image, and displays the power at each frequency (commonly called the Power Spectrum).
Bragg Filter	Calculates Bragg Filter using the spots selected in the Power Spectrum. Shape and size of the mask can be defined by the user in the dialog. Note: spots should be selected previously in the Power Spectrum using the Mouse Tool.

Bragg Filter Dialog

The components of the dialog are described below.

Dialog

Bragg Filter

Project Name: Project1

Size:

Medium ▾   16.3   pixels   Apply

Smoothing Width: 5.0

☐ Oval Ratio: 1.0

Direction: 0.0   degree

OK   Cancel
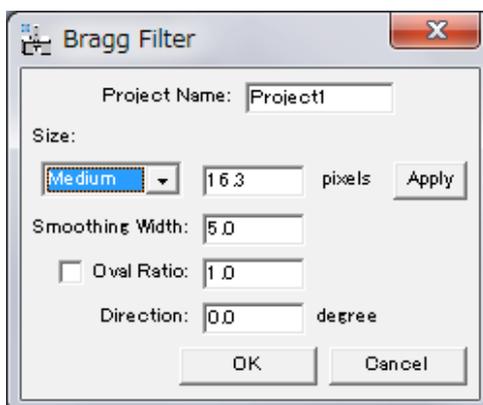
Component	Description
Project Name	Name given to the group of images and results
Size	Defines mask radius in pixels (beyond which values are set to zero).
Smoothing Width	Specifies mask smoothing width in pixels
Oval Ratio	Defines the shape of the oval, as major to minor axis ratio
Direction	Sets the direction of the oval masks angle, in degrees

Real Space Noise Filter SubMenu

Component	Description
Adaptive Wiener Filter...	Remove noise from the image using an adaptive Wiener filter based on a local variance.
Low Pass Filter...	Calculates and applies a Low Pass filter to the image

Adaptive Wiener Filter Dialog

If the local variance is small, the pixel value is replaced by the local average to reduce slat-and-pepper noise. Contrary, the pixel value is retained, when the local variance is large to keep the image sharpness.

Dialog
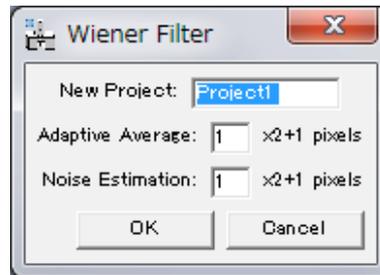
Component	Description
New Project	Name given to the group of images and results
Adaptive Average	Window size [(2N+1)x(2N+1) pixels] to be used in the calculation of local average
Noise Estimation	Window size [(2N+1)x(2N+1) pixels] to be used in the calculation of local variance.

Low Pass Filter Dialog

Dialog
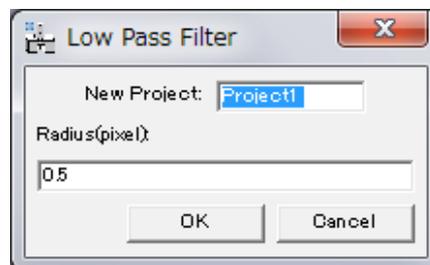
Component	Description
New Project	Name given to the group of images and results
Radius (pixel)	The radius of the mask in pixels

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Motif Detection SubMenu

Component	Description
Define Motif	Define a Rectangle ROI as a Motif, and make it rotatable.
x-Corr Histogram… (see Dialog)	Calculates Cross-Correlation Histogram between the selected reference region (motif) and the original image. Note: The left edge of the selection in the histogram is used as a threshold to obtain the refined motif in the next step.
x-Corr with Refined Motif	Obtains a refined motif, and then calculates Cross-Correlation Histogram between the refined motif and the original image. Note: The left edge of the selection in the histogram is used as a threshold to find good motifs in the next step.
Find Motif Centers... (see Dialog)	Finds the centers of good Motifs in the image.

x-Corr Histogram Dialog

Dialog
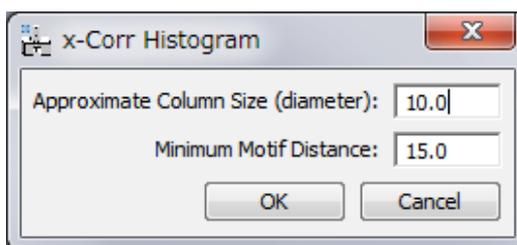
Component	Description
Approximate Column Size (diameter)	Specifies an approximate atom column size (the minimum distance between atom column peaks). (This parameter is used in **x-corr with Refined Motif** to define peaks in the refined motif.)
Minimum Motif Distance	Specifies a minimum distance between allowed motifs. (This parameter is used in **Find Motif Centers…**)

Find Motif Centers Dialog

Dialog
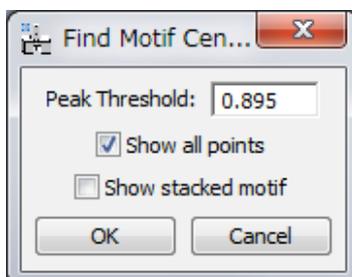
Component	Description
Peak Threshold	Specifies a minimum for the intensity of allowed peaks
Show all points	Shows also the Motif centers in blue that were rejected by the cross-correlation threshold and/or the minimum motif distance criteria. (Namely, all the peak points are displayed in red or blue color.)
Show stacked motif	Make a stacked image from detected motifs.

Create Mask SubMenu

1 (Red): Main area of integration

2 (Green): Second area of integration

3 (Yellow): Third area of integration

Component	Description
1 (Red): Main area of integration	Defines the Intensity Integration Area used in the Compositional Analysis
2 (Green): Second area of integration	Defines an auxiliary Intensity Integration Area
3 (Yellow): Third area of integration	Defines an auxiliary Intensity Integration Area

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Show Intensity Map Dialog

Dialog
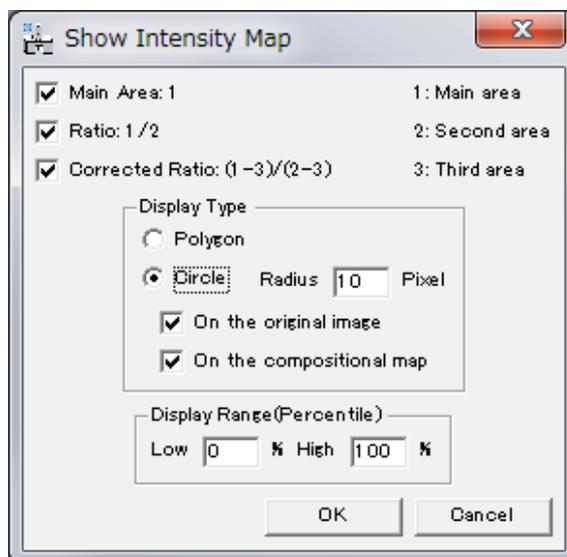
Component	Description
Main Area:1	Shows an Intensity map obtained using the main integration area
Ratio: 1/2	Shows an Intensity map obtained by dividing integrated intensities of the main area by the integrated intensities of the second one
Corrected Ratio (1-3)/(2-3)	Shows an intensity map obtained as (Main-third) / (second-third) integration areas
Display Type	Selects the display type from Polygon and Circle
Circle	
Radius	Defines the circle radius
On the original image	Shows the color circles on the original image
On the compositional map	Shows the color circles on the compositional map
Display Range (Percentile)	Defines minimum (Low) and maximum (High) values of Integrated intensities to be shown

Compositional Map SubMenu
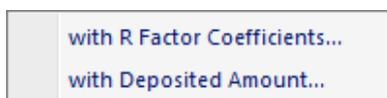
Component	Description
with R Factor Coefficients...	Compositional map determination knowing the R Factor
with Deposited Amount...	Compositional map determination knowing the Deposited Amount in a certain area

Compositional Map with R Factor Coefficients... Dialog

Dialog
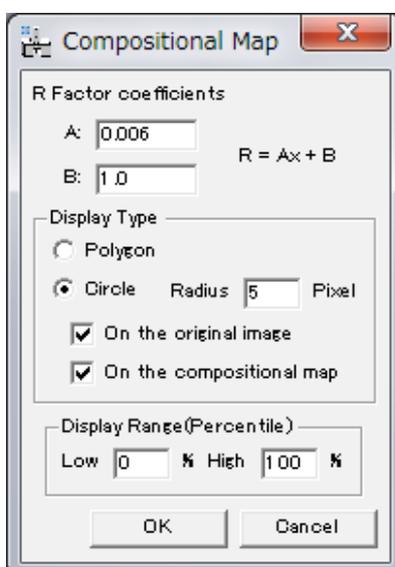
Component	Description
R Factor coefficients	Slope and y-intercept of R(x)= A x + B
Display Type	Selects the display type from Polygon and Circle
Circle	
Radius	Define the circle radius
On the original image	Show the color circles on the original image
On the compositional map	Show the color circles on the compositional image
Display Range (Percentile)	Defines minimum (Low) and maximum (High) values of Integrated intensities to be shown

Compositional Map with Deposited Amount... Dialog

Dialog
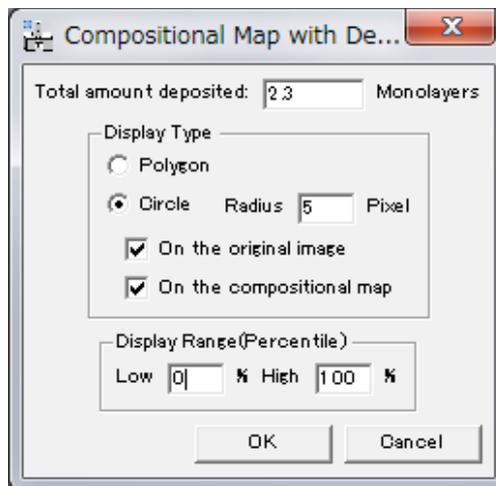
Component	Description
Total amount deposited	Total deposited amount in a defined polygonal area
Display Type	Selects the display type from Polygon and Circle
Circle	
Radius	Defines the circle radius
On the original image	Show the color circles on the original image
On the compositional map	Show the color circles on the compositional image
Display Range (Percentile)	Defines minimum (Low) and maximum (High) values of Integrated intensities to be shown

Convert from composition to atoms number... Dialog

Dialog
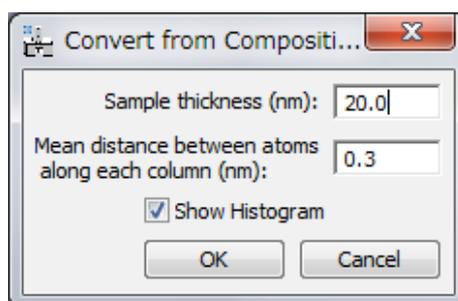
Component	Description
Sample thickness (nm)	Specify the sample thickness in nm.
Mean distance between atoms along each column (nm)	Specify the mean distance between atoms along the column in nm.
Show Histogram	If checked, the histogram of the number of atoms within a ROI (an interested area) will be shown.

Analyze Column Positions Dialog

The user will have the option to decide the distances and/or angles to be evaluated.

Distance Tab
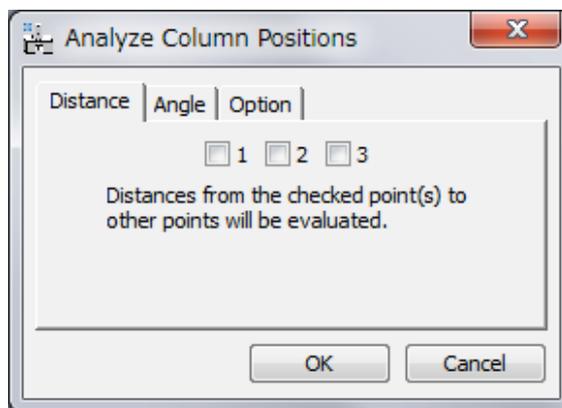
The number of each check box corresponds to the assigned number to the mouse click. All the distance(s) from the checked point to other points will be calculated.

Angle Tab
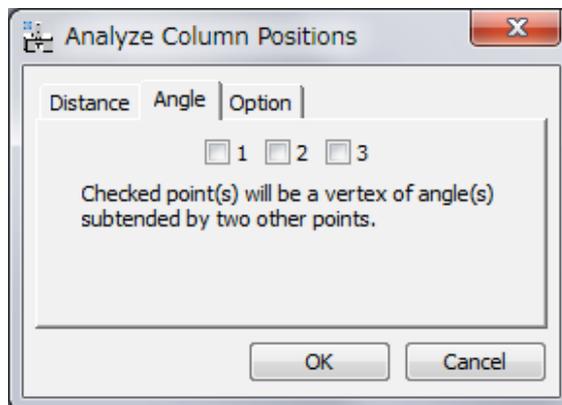
The number of each check box corresponds to the assigned number to the mouse click. All possible angle(s) whose vertex corresponds to the checked point will be calculated.

Option Tab
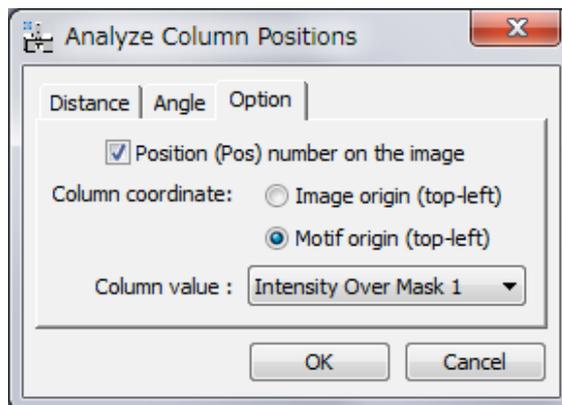
Component	Description
Position (Pos) number on the image	Display position number (Left column of the spread sheet) on original image.
Column coordinates	You can select the origin of column positions from 'Image origin (Top-left)' or 'Motif origin (Top-left)'.
Column value	You can select output column value from averaged 'Intensity over the Mask 1/2/3' or 'Peak Height'.

Show/Hide SubMenu
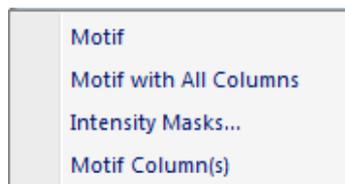
Component	Description
Motif	Shows/hides Motif window
Motif with All Columns	Shows/hides Motif with all columns. You can use this command to show all columns in the motif.
Intensity Masks...	Shows/hides intensity mask
Motif Column(s)	Shows/hides Motif column(s) that is/are close to the HREM Mouse point(s). You can use this command to hide the column(s) or to show the removed column(s). Use this command after you place the mouse point(s)