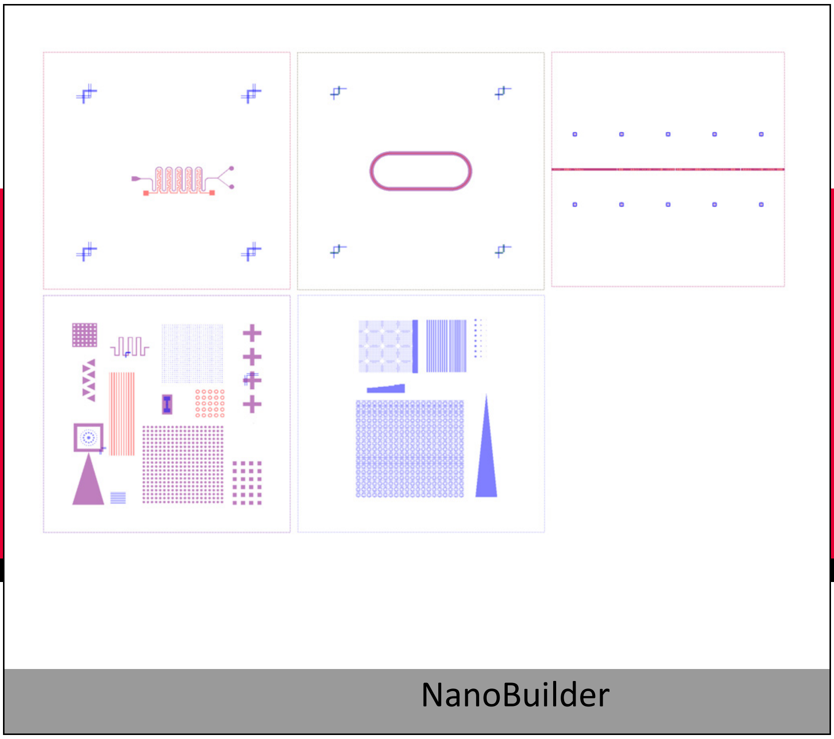
NanoBuilder User's Guide (Version 2.0 and higher)

PN 1048027-B



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Production Acknowledgments

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Document History

Revision A: version 2.0, May 2013; Initial release
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1 Overview

Introduction

NanoBuilder is a standalone application for rapid nano-prototyping using all FEI beam processes: ion milling, gas-assisted milling, electron beam- and ion beam-induced deposition (EBID, IBID) to create desired structures available in CAD files.

NanoBuilder allows the creation of structures that are not possible with other lithographic methods (e.g., a sloping surface to make a tilted nano-mirror). Users can modify their designs faster and more economically than the traditional lithography process, resulting in quicker iteration and a shorter time-to-market. Customers involved in micro-fluidics, nano-optics (optical resonators, nano-mirrors), and nano-imprinting will benefit from NanoBuilder.

NanoBuilder Product Line

In addition to NanoBuilder itself, the product line consists of NanoArchitect™ and NanoBuilder LTL™.

- NanoArchitect is for use on a PC without a microscope. It allows you to create, view, and edit NanoBuilder jobs.
- NanoBuilder LTL is the *limited trial license* 60-day version.

Additional Benefits

NanoBuilder automatically sets the parameters for the microscope using information available in the beam chemistry module. Its editor allows you to specify data such as beam and pattern settings and automates the execution.

NanoBuilder also:

- Makes it easy to pattern CAD (GDSII CAD file) designs with the SEM/FIB.
- Optimizes unique parameters for EBID and IBID operation.
- Adds SEM- and FIB-specific information such as beam energy, current, patterning parameters, GIS parameters.
- Automates the alignment of layers/patterns to fiducials on the sample, not only beam shift, but also rotation, magnification and shear errors.
- Automatically patterns the layers/patterns with the given settings at multiple locations on the sample.
- Allows designing structures without the need for an external GDS editor.
- Allows creating structures that span multiple write fields.
- Create structures that span multiple write fields.

Finding a GDSII Editor

For creating GDS files you may want to try one of the editors below; FEI does not endorse the use of any particular editor.

Table 1-1 GDSII Editors

Editor	Web Page
Layout Editor	*http://www.layouteditor.net/*
KLayout	*http://www.klayout.de*
CleWin	*http://www.wieweb.com*
L-Edit Pro	*http://www.tannereda.com/l-edit-pro*
Electric	*http://www.staticfreesoft.com*

More information about the GDSII format and the available commercial and open source products supporting it can be found at http://en.wikipedia.org/wiki/GDSII.

2 User Interface

Overview

Topics in this chapter include:

- *"Terminology" on page 5*
- *"UI Elements" on page 6*

Terminology

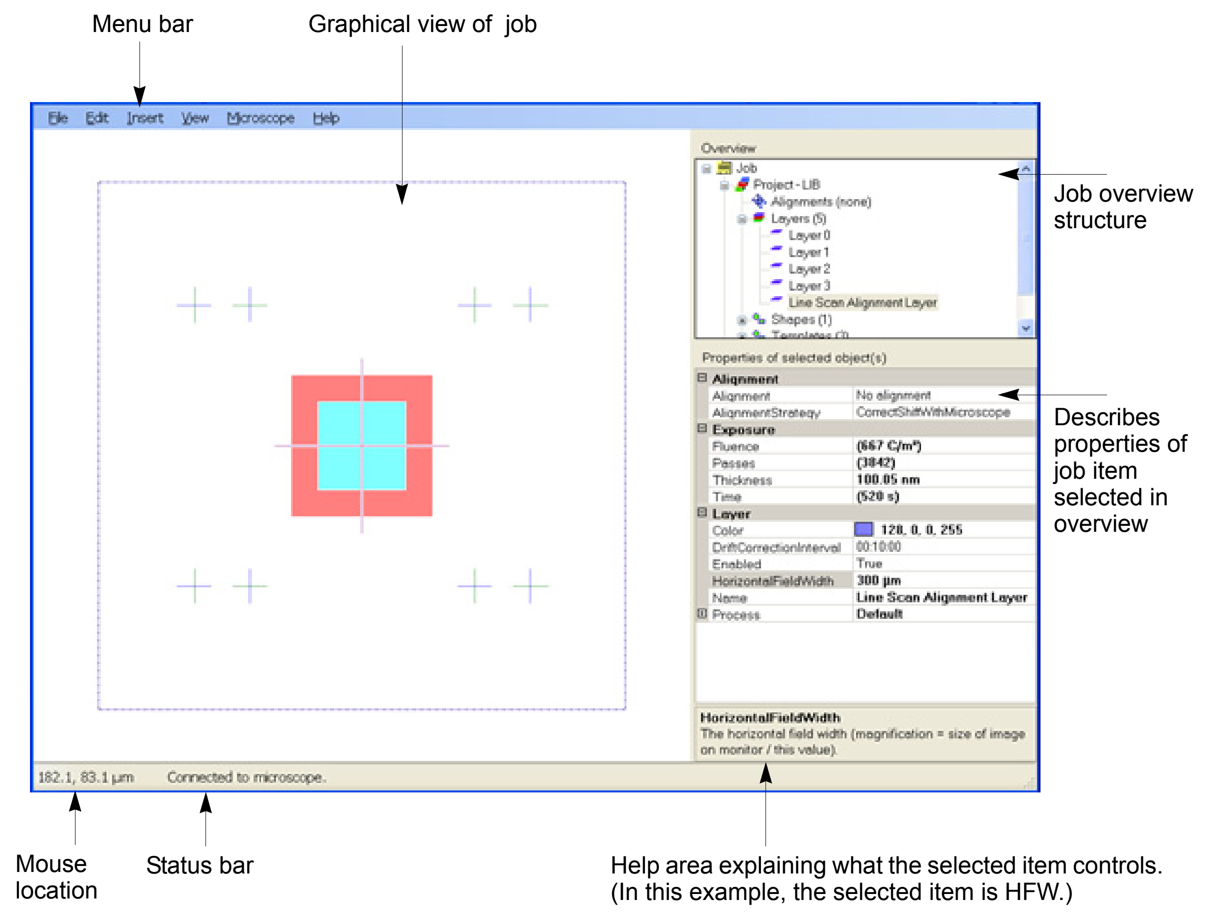
The following terms are used in NanoBuilder:

- **Alignment**: A corrective step to align the microscope scan field to the substrate.
- **GDSII**: A file format (Graphic Data System) that is the industry conventional standard for the transfer of IC layout data between design tools.
- **Job**: The entire set of instructions for creating or modifying devices on the DualBeam™ microscope. Jobs are organized in *projects* (what) and *site lists* (where).
- **Layer**: Defines a set of *patterns* and *shapes* the microscope settings (process) to use when patterning them. Optionally, it can have an alignment.
- **Pattern**: An extension of the *shape* object that describes an area to be exposed by the beam.
- **Process**: Contains all the settings that should be applied when patterning a layer: the beam (electron/ion), settings for the beam (energy, current, etc.), patterning parameters (dwell time, overlap, etc.), and the GIS (and its parameters).
- **Project**: The DualBeam instructions to be performed at a single site consisting of *alignments*, *layers, shapes,* and *templates*.
- **Reference**: A *shape* or *pattern* created by shifting or rotating another shape or pattern.
- **Shape**: A two-dimensional geometric object.
- **Composite Shape:** A shape that is composed of other shapes.
- **Site List**: A list of programmed locations, called sites, on the substrate.
- **Template**: A *shape* or *pattern* that is being referenced.

UI Elements

The main elements of the NanoBuilder user interface are shown in *Figure 2-1*.

Figure 2-1 NanoBuilder User Interface

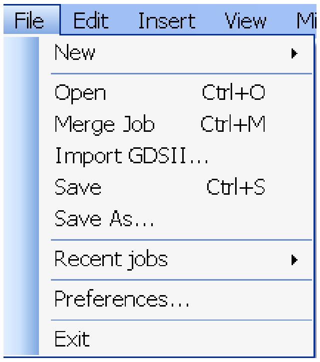


Alignment	
Alignment	No alignment
AlignmentStrategy	CorrectShiftWithMicroscope
Exposure	
Fluence	(667 C/m²)
Passes	(3842)
Thickness	100.05 nm
Time	(520 s)
Layer	
Color	128, 0, 0, 255
DriftCorrectionInterval	00:10:00
Enabled	True
HorizontalFieldWidth	300 µm
Name	Line Scan Alignment Layer
Process	Default

HorizontalFieldWidth
The horizontal field width (magnification = size of image on monitor / this value).

182.1, 83.1 µm Connected to microscope.

File Menu

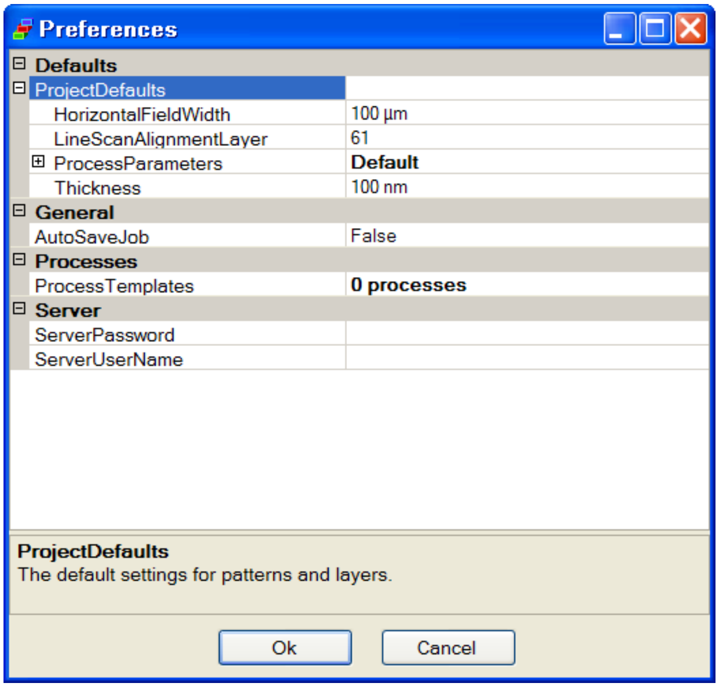


Use the File menu to open, import, and save NanoBuilder jobs.

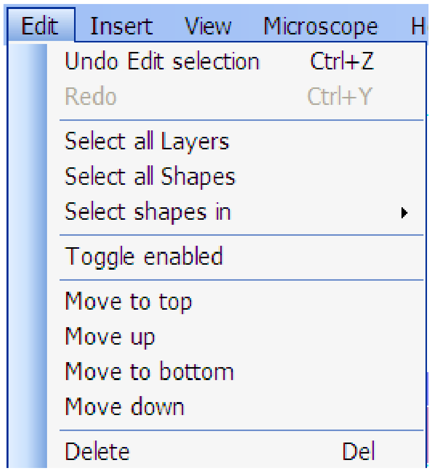
Table 2-1 File Menu Overview (1 of 2)

Menu Item	Description
New	Opens a new job or project.
Open (Ctrl+O)	Displays the Open dialog box to select a job.
Merge Job (Ctrl+M)	Displays the Open dialog box to select a job for merging with the loaded job.
Import GDSII...	Displays the Open dialog box for importing a GDSII file.
Save (Ctrl+S)	Saves the job. If the job is new and hasn't yet been named, it opens the Save As dialog box.
Save As...	Opens the Save As dialog box to save the job under a different file name and/or location.
Recent jobs	Displays a list of recent jobs opened during this session.

Table 2-1 File Menu Overview (2 of 2)

Menu Item	Description
Preferences...	Opens the Preferences dialog box.  **Defaults** ProjectDefaults HorizontalFieldWidth 100 µm LineScanAlignmentLayer 61 ProcessParameters **Default** Thickness 100 nm **General** AutoSaveJob False **Processes** ProcessTemplates **0 processes** **Server** ServerPassword ServerUserName **ProjectDefaults** The default settings for patterns and layers. Use this dialog box to set default parameters. ***Note:*** *Normally you can leave ServerPassword and ServerUserName and NanoBuilder will reuse the credentials you used when logging into the xT UI. To run NanoBuilder without xT UI, you must enter those credentials here.*
Exit	Closes the NanoBuilder application.

Edit Menu



Use the Edit menu to perform basic editing functions that help in working with NanoBuilder jobs.

Table 2-2 Edit Menu Overview (1 of 3)

Menu Item	Description
Undo Edit selection (Ctrl+Z)	Erases the last change done, as if not done.
Redo (Ctrl+Y)	Reverses the undo action.

Table 2-2 Edit Menu Overview (2 of 3)

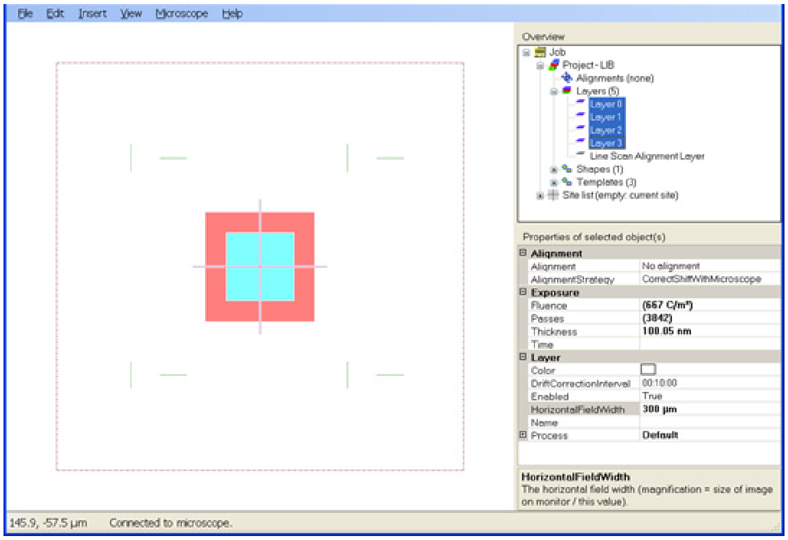
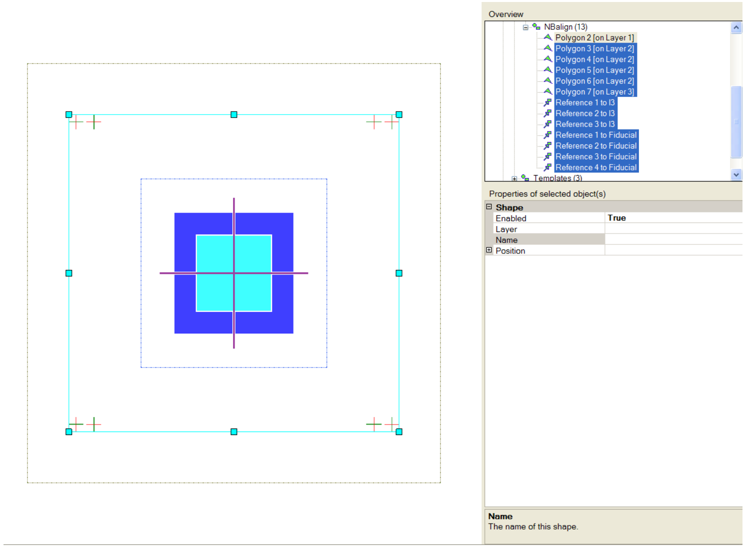
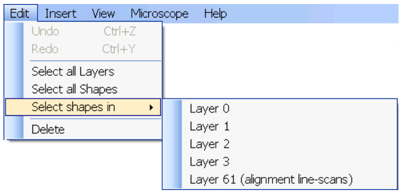
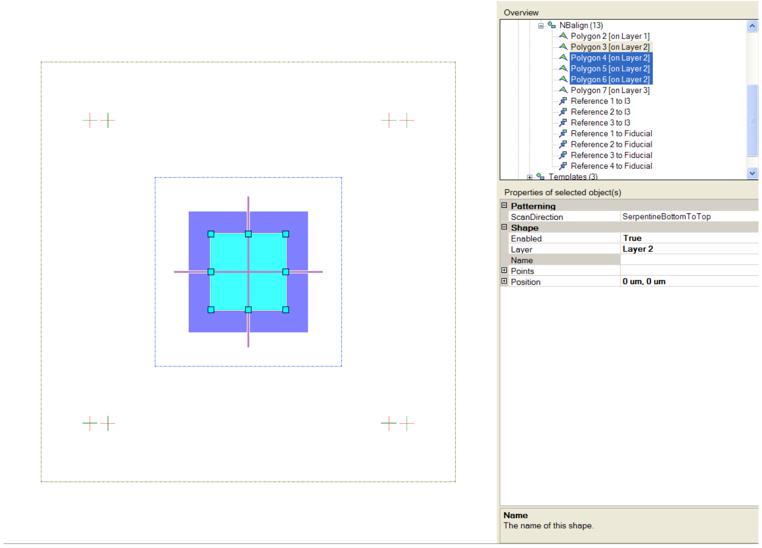
Menu Item	Description
Select all Layers	Selects all layers on the job, highlights the layers in the Overview, and provides layer details in the Properties portion of the UI. This allows you to make changes to all layers at the same time, rather than having to set them one at a time. This is particularly useful for parameters that you want to be common to all layers, e.g., HFW or beam current.  Alignment Alignment: No alignment AlignmentStrategy: CorrectShiftWithMicroscope Exposure Fluence: (667 C/m²) Passes: (3842) Thickness: 100.05 nm Time: Layer Color: ☐ DriftCorrectionInterval: 00:10:00 Enabled: True HorizontalFieldWidth: 300 µm Name: Process: Default **HorizontalFieldWidth** The horizontal field width (magnification = size of image on monitor / this value). 145.9, -57.5 µm Connected to microscope.
Select all Shapes	Selects all shapes on the job, highlights the shapes in the Overview, and provides shape details in the Properties portion of the UI. This allows you to make changes to all shapes at the same time, rather than having to set them one at a time.  Shape Enabled: True Layer: Name: Position: **Name** The name of this shape.

Table 2-2 Edit Menu Overview (3 of 3)

<table>
<tr><th>Menu Item</th><th>Description</th></tr>
<tr><td>Select shapes in</td><td>After choosing a layer from the sub-menu, this option selects all the shapes on that layer. Displays a list of the various layers containing shapes.



When you select the shapes in a layer, NanoBuilder displays those shapes, highlights them in the Overview, and provides shape details in the Properties portion of the UI. This allows you to make changes to all shapes at the same time, rather than having to set them one at a time.

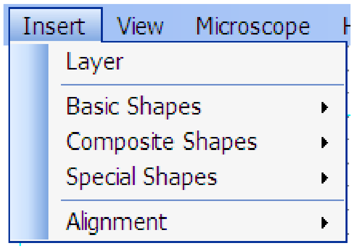


Overview
NBalign (13)
Polygon 2 [on Layer 1]
Polygon 3 [on Layer 2]
Polygon 4 [on Layer 2]
Polygon 5 [on Layer 2]
Polygon 6 [on Layer 2]
Polygon 7 [on Layer 3]
Reference 1 to I3
Reference 2 to I3
Reference 3 to I3
Reference 1 to Fiducial
Reference 2 to Fiducial
Reference 3 to Fiducial
Reference 4 to Fiducial
Templates (3)

Properties of selected object(s)
Patterning
ScanDirection: SerpentineBottomToTop
Shape
Enabled: **True**
Layer: **Layer 2**
Name:
Points
Position: **0 um, 0 um**

Name
The name of this shape.</td></tr>
<tr><td>Toggle enabled</td><td>This enables/disables the currently selected item in the tree view.</td></tr>
<tr><td>Delete</td><td>Deletes the selected layer, shape, or alignment, etc.</td></tr>
</table>

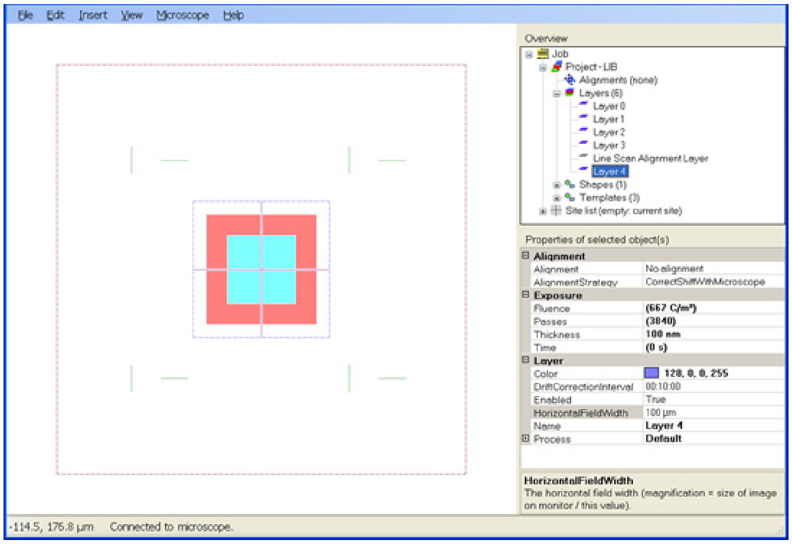
Insert Menu



Use the Insert menu to add a layer, pattern, reference, or alignment to the project.

Table 2-3 Insert Menu Overview (1 of 2)

<table>
<tr><th>Menu Item</th><th>Description</th></tr>
<tr><td>Layer</td><td>Adds another layer, which is also added to the Overview and detailed in the Properties portion of the UI.



<table>
<tr><th colspan="2">Alignment</th></tr>
<tr><td>Alignment</td><td>No alignment</td></tr>
<tr><td>AlignmentStrategy</td><td>CorrectShiftWithMicroscope</td></tr>
<tr><th colspan="2">Exposure</th></tr>
<tr><td>Fluence</td><td>(667 C/m²)</td></tr>
<tr><td>Passes</td><td>(3840)</td></tr>
<tr><td>Thickness</td><td>100 nm</td></tr>
<tr><td>Time</td><td>(0 s)</td></tr>
<tr><th colspan="2">Layer</th></tr>
<tr><td>Color</td><td>🟦 128, 0, 0, 255</td></tr>
<tr><td>DriftCorrectionInterval</td><td>00:10:00</td></tr>
<tr><td>Enabled</td><td>True</td></tr>
<tr><td>HorizontalFieldWidth</td><td>100 µm</td></tr>
<tr><td>Name</td><td>Layer 4</td></tr>
<tr><td>Process</td><td>Default</td></tr>
</table>

HorizontalFieldWidth
The horizontal field width (magnification = size of image on monitor / this value).

-114.5, 176.8 µm Connected to microscope.

<i>Note:</i> <i>The newly inserted layer will be inserted after the currently selected layer, or appended to the list of layers if none is selected. You can move its position using the methods described in “Change the Patterning Order” on page 22.</i></td></tr>
<tr><td>Basic shapes</td><td>Displays a submenu of basic shapes:

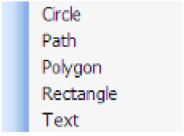
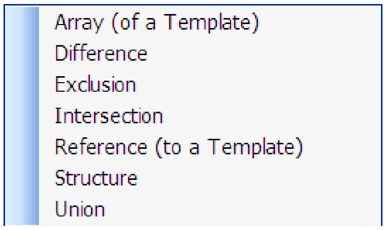
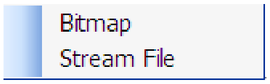
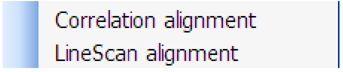
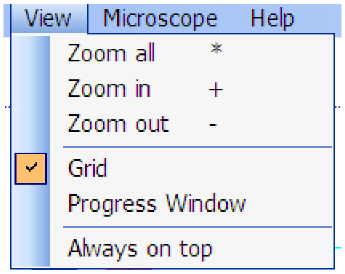

</td></tr>
</table>

Table 2-3 Insert Menu Overview (2 of 2)

Menu Item	Description
Composite shapes	Displays a submenu of composite shapes: 
Special shapes	Displays a submenu of special shapes: 
Alignment	Displays a submenu of alignment shapes:  • Correlation: Inserts a correlation alignment, which is also added to the Overview and detailed in the Properties portion of the UI (see *“Correlation Alignment” on page 51*). • Line Scan: Inserts a line scan alignment, which is also added to the Overview, along with settings and user controls in the lower portion of the UI (see *“Line Scan Alignment Properties” on page 47*).

View Menu

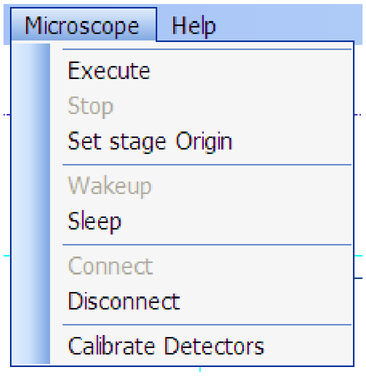


The View menu provides zooming and viewing options.

Table 2-4 View Menu Overview

Menu Item	Description
Zoom all (*)	Place your cursor over the area of interest and click *.
Zoom in (+)	Place your cursor over the area of interest and click **+**. To zoom to another area, you must first zoom out and then reposition your cursor.
Zoom out (-)	Place your cursor over the area of interest and click **-**.
Grid	Toggles grid in the viewer on or off. The grid scales automatically when zooming in or out; shapes will snap to the grid when moving or resizing.
Process Window	Shows or hide the progress popup window. Note that the progress window can also be shown by double clicking the status bar or progress bar.
Always on top	Keeps the NanoBuilder interface and dialog boxes on top of all other user interface components, other than Task Manager and a few other system component windows.

Microscope Menu



The Microscope menu serves as the communication link between NanoBuilder and the microscope system.

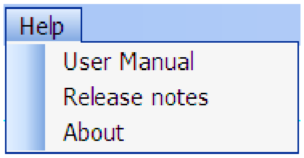
Table 2-5 Microscope Menu Overview (1 of 2)

Menu Item	Description
Execute	Starts the project and begins patterning.
Stop	Stops the project.
Set Stage Origin	Marks the current stage location as the origin for relative stage position in the site list.
Wakeup	Initializes the beam, high voltage, and ion source, including heating if necessary. ***Note:*** *When using only the SEM, use BeamOn in the xT UI to avoid unnecessarily switching on the FIB source and reducing its lifetime.*
Sleep	Stops the beam, high voltage, and ion source. ***Note:*** *When the FIB will be used again within the next hours, use BeamOn in the xT UI to avoid switching the FIB source off and on, which can reduce its lifetime.*
Connect	Automatically connects to the microscope system if xT is running. Make sure that the login settings are set correctly in the Preferences dialog box (*“Preferences...” on page 8*).
Disconnect	Keeps you in NanoBuilder, but disconnects from the microscope system.

Table 2-5 Microscope Menu Overview (2 of 2)

Menu Item	Description
Calibrate Detectors	Acquires a series of images with different detector gain and offset settings to measure the detector response for optimal performance of the Auto Gain Offset function. Calibrate Detectors should be run after the installation of NanoBuilder on the microscope, and thereafter at periodic intervals depending on the aging of the used detectors. Before selecting Calibrate Detectors, position the sample with a uniform surface, such as an unpatterned area on a piece of a silicone wafer, under the E-beam. The Calibrate Detectors functions will then go through a series of image acquisitions for each enabled detector and save the results of the calibration to disk for later use by the Auto Gain Offset function.

Help Menu



The Help menu shows the About box and this online user's guide.

3 Basic Operations

Overview

Topics in this chapter include:

- *"Getting Started" on page 17*
- *"Stitching Multiple Write Fields" on page 30*
- *"Job Editing" on page 39*

Getting Started

This section shows how to load a GDSII file into NanoBuilder, specify how it should be patterned, add an alignment, and execute the resulting job.

Setting up the Microscope

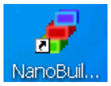
1. Load the sample to be patterned.
2. Set the sample to eucentric height.
3. Tilt to 52°.

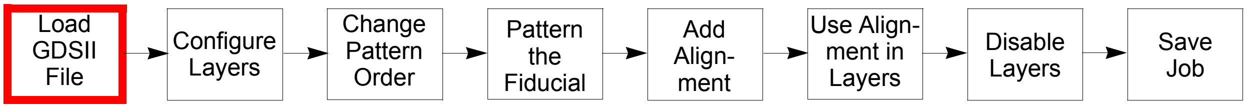
   NanoBuilder does not adjust focus and stigmation, so the beam currents being used (100 pA, 1 nA, and 3 nA) must be in focus and stigmated. Small amounts (< 2 µm) of beam shift between the currents are allowed.
4. Move the stage to the position on the substrate where you want to pattern.

Making a Job

A *job* in NanoBuilder terms is the complete set of data that describes what needs to be patterned—layers, shapes, sequences, beam settings, alignments, etc.

Go to **Start > Programs > FEI Company > Applications > NanoBuilder** to start the program. Alternatively, click the NanoBuilder desktop icon to launch the application.



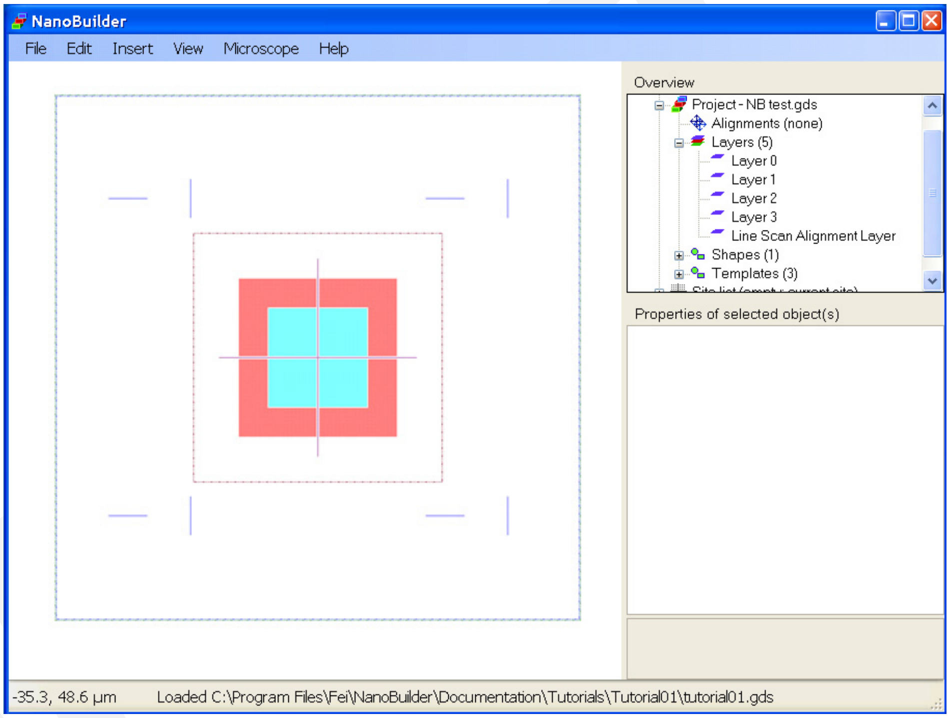


Load the GDSII File

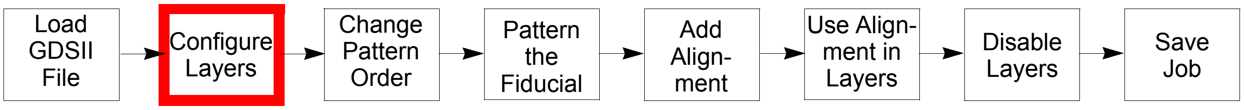
NOTE *Although you can create your design in NanoBuilder, this tutorial uses a GDSII file, as this is a common use case.*

Go to **File > Import GDSII**... and select *Tutorial01.gds* file
(a sample *.gds* file is located at:
c:\Program Files (x86)\Fei\NanoBuilder\ Documentation\Tutorials\Tutorial01).

NanoBuilder displays an interface similar to the one below.



-35.3, 48.6 µm Loaded C:\Program Files\Fei\NanoBuilder\Documentation\Tutorials\Tutorial01\tutorial01.gds



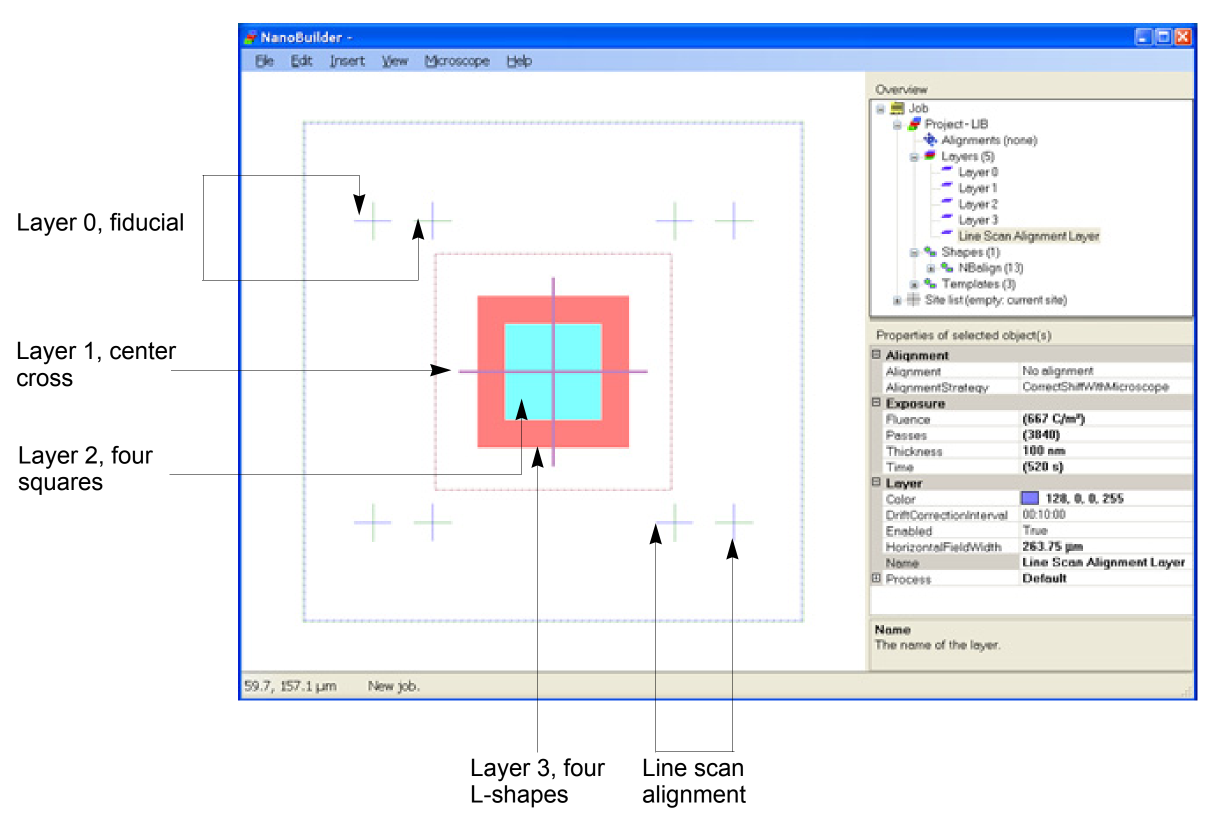
Configure the Layers for Patterning

As shown in *Figure 3-1*, the project contains five layers:

- Layer 0 is the fiducial.
- Layers 1, 2, and 3 contain the shapes to be patterned: the thin cross in the center, the four squares around it, and the four L-shape polygons around the four squares.
- The Line Scan Alignment Layer is used to align the layers.

Click on a layer to select it, then view and edit its properties.

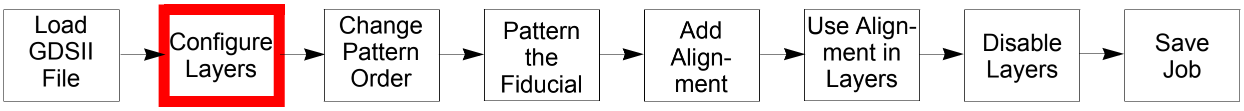
Figure 3-1 NanoBuilder Layers



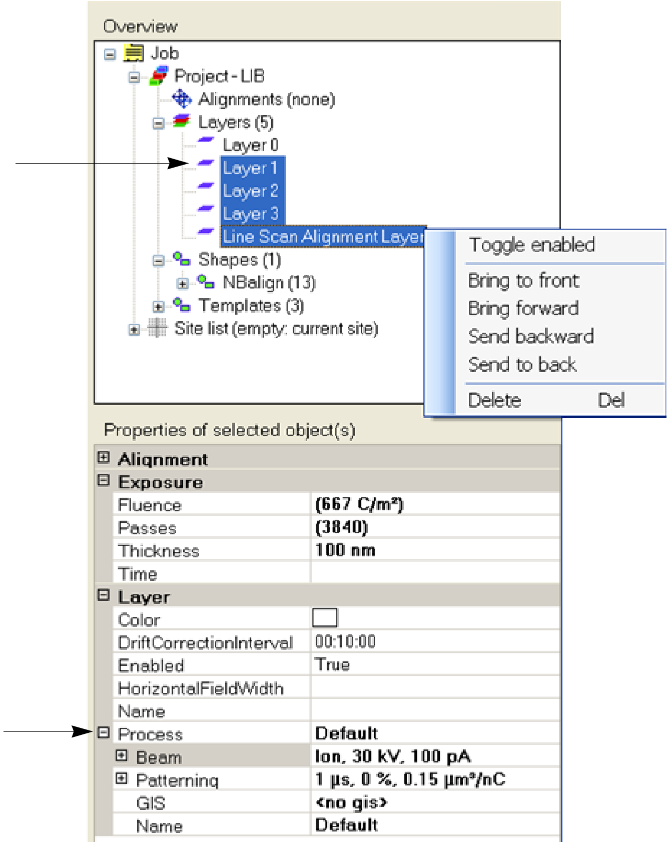
Alignment	
Alignment	No alignment
AlignmentStrategy	CorrectShiftWithMicroscope
Exposure	
Fluence	**(667 C/m^2)**
Passes	**(3840)**
Thickness	**100 nm**
Time	**(520 s)**
Layer	
Color	🟦 **128, 0, 0, 255**
DriftCorrectionInterval	00:10:00
Enabled	True
HorizontalFieldWidth	**263.75 µm**
Name	**Line Scan Alignment Layer**
Process	**Default**

Name
The name of the layer.

More than one layer can be selected; (hold **Shift** or **Control**) and change the properties for all at the same time.

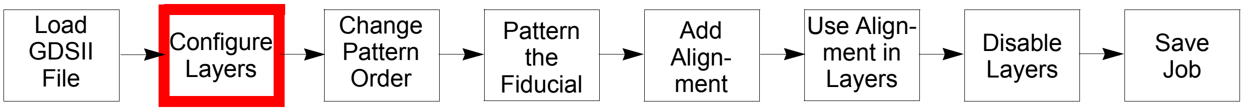


Select Layer 1 in the Overview. Click the **+** to the left of Process to expand this item, then expand the **Beam** item that appears in the same way.

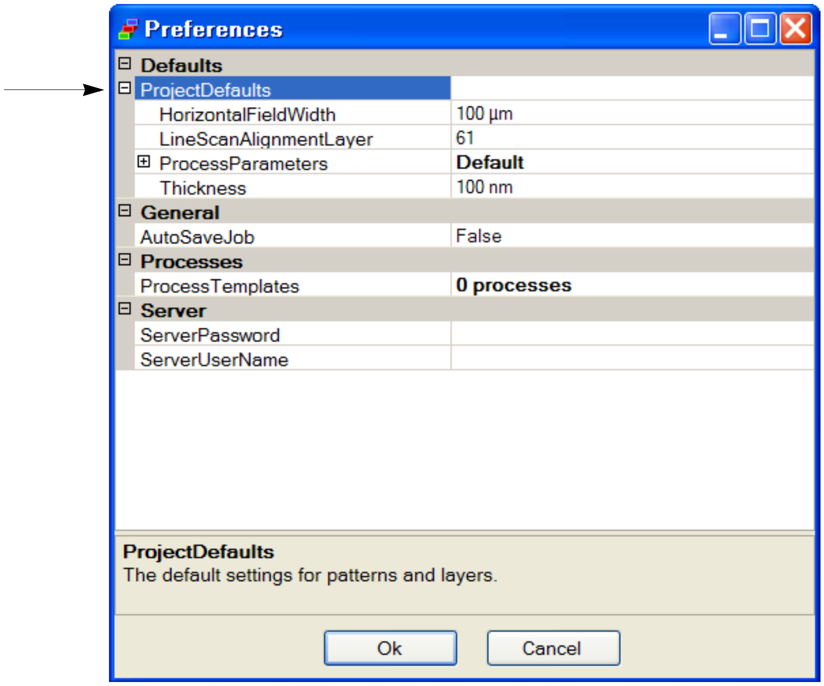


⊞ **Alignment**	
⊟ **Exposure**	
Fluence	**(667 C/m²)**
Passes	**(3840)**
Thickness	**100 nm**
Time	
⊟ **Layer**	
Color	☐
DriftCorrectionInterval	00:10:00
Enabled	True
HorizontalFieldWidth	
Name	
⊟ Process	**Default**
⊞ Beam	**Ion, 30 kV, 100 pA**
⊞ Patterning	**1 µs, 0 %, 0.15 µm³/nC**
GIS	**<no gis>**
Name	**Default**

Change the specifications for each layer in this manner, as needed. NanoBuilder will select the closest possible current on the microscope when executing the job.

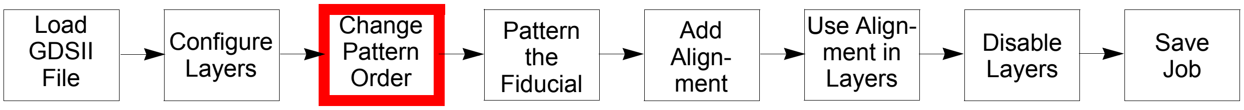


Change the default values for new (imported GDSII) jobs from **File > Preferences > Project Defaults**.



Defaults	
ProjectDefaults	
HorizontalFieldWidth	100 µm
LineScanAlignmentLayer	61
ProcessParameters	**Default**
Thickness	100 nm
General	
AutoSaveJob	False
Processes	
ProcessTemplates	**0 processes**
Server	
ServerPassword	
ServerUserName	

ProjectDefaults
The default settings for patterns and layers.

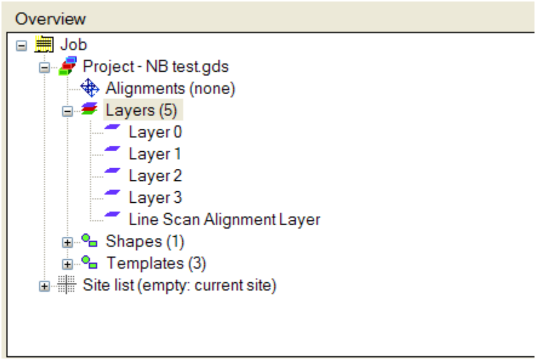


Change the Patterning Order

The layers will be patterned in the sequence in which they are shown, e.g., Layer 0 will be patterned first, then 1, 2, and 3. However, we want to change the order of Layers 1, 2, and 3 so they are patterned in decreasing beam current order. The layer order can be changed via drag and drop. To inverse the order of the layers:

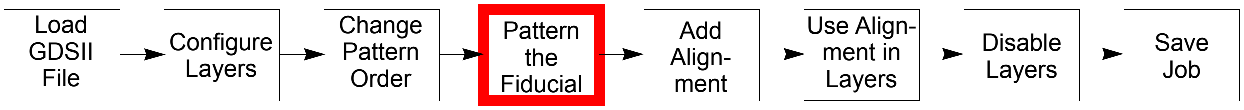
1. Select the bottom layer and drag it onto the first layer.
2. Select the new bottom layer and drag it onto the second layer.

Alternatively, use the right mouse button to click on a layer and use **Move Up/Down/To Top/To Bottom** to change the order layer.



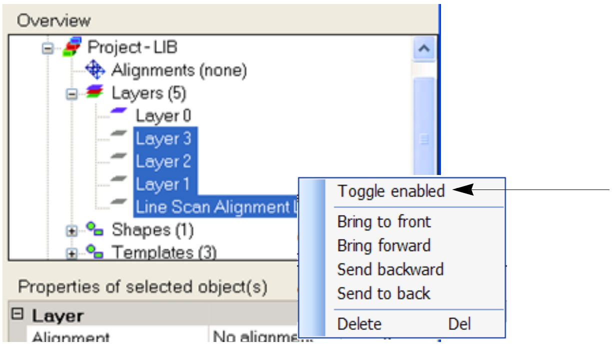
Overview

- Job
  - Project - NB test.gds
    - Alignments (none)
    - Layers (5)
      - Layer 0
      - Layer 1
      - Layer 2
      - Layer 3
      - Line Scan Alignment Layer
    - Shapes (1)
    - Templates (3)
  - Site list (empty: current site)



Pattern the Fiducial

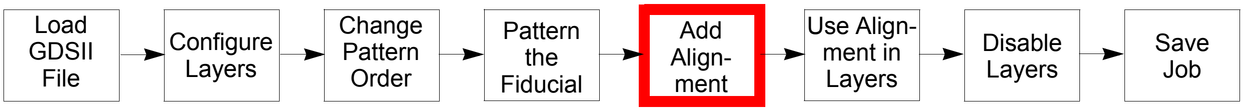
In this GDSII file, the fiducial is defined in Layer 0.



1. With the electron beam, navigate from xT to an unpatterned area of at least 300 µm.
2. Set the beam current to 1 nA from NanoBuilder.
3. Save the job. If AutoSave Job is enabled, this will happen automatically.
4. To execute only Layer 0, right-click it in the tree view and select “Execute at current location”.

NOTE	*Tutorials are located under Program Files. Do not save your data to this location, as it will be lost upon subsequent reinstallation.*

5. Verify that fiducial patterning was successful.



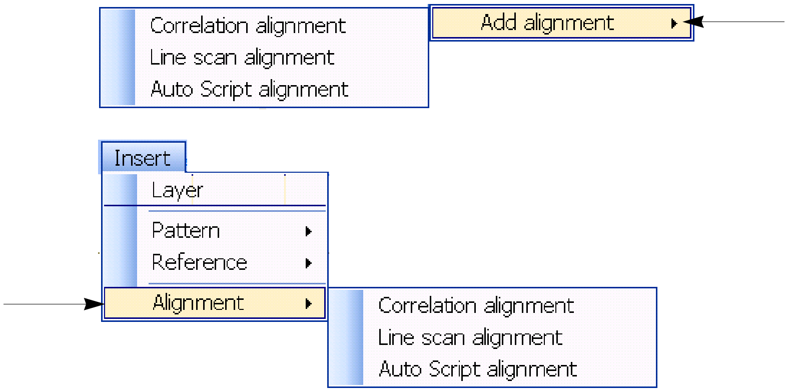
Add an Alignment

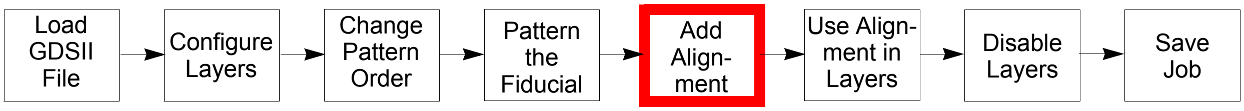
Using alignments achieves two things:

- **Align a layer to the sample:** Accurately position the patterns in a layer relative to these marks by finding marks on the sample. Even if the position relative to the sample is not critical, it is useful to align layers with respect to each other.
- **Drift correction:** Correct for drift while patterning by realigning at fixed intervals during patterning.

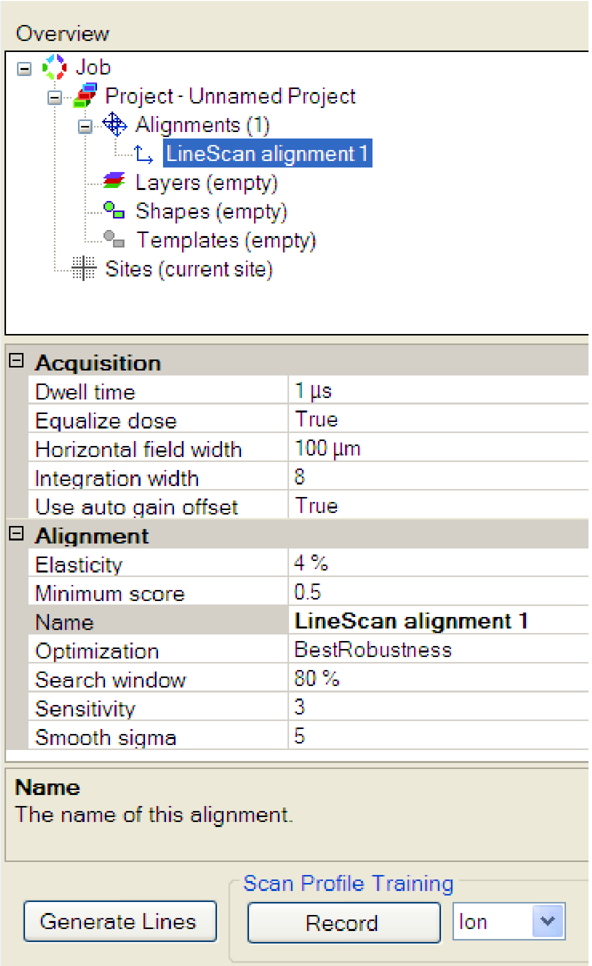
To add an alignment:

1. Select **Alignments** in the Overview.
2. Add an alignment either by right-clicking the alignment selection or by selecting to **Insert > Alignment**. In this example, choose **Line scan alignment** from the list.





The new line scan alignment will be selected automatically. The line scans that were generated can be seen by expanding the Line Scan Alignment in the tree view.



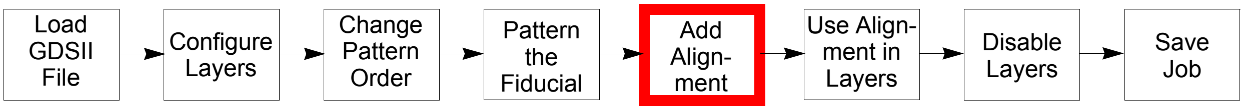
Overview

- Job
  - Project - Unnamed Project
    - Alignments (1)
      - LineScan alignment 1
    - Layers (empty)
    - Shapes (empty)
    - Templates (empty)
  - Sites (current site)

Acquisition	
Dwell time	1 µs
Equalize dose	True
Horizontal field width	100 µm
Integration width	8
Use auto gain offset	True
Alignment	
Elasticity	4 %
Minimum score	0.5
Name	**LineScan alignment 1**
Optimization	BestRobustness
Search window	80 %
Sensitivity	3
Smooth sigma	5

Name
The name of this alignment.

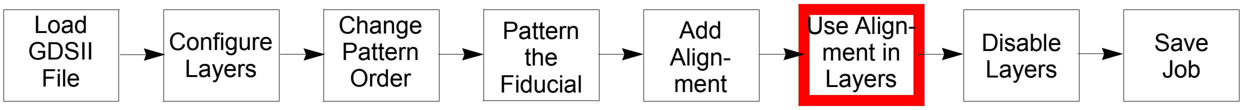
3. To re-generate the line scans (converting the shapes on the Line Scan Alignment layer to lines scans) click **Generate Lines**. This can be used to update the alignment after you have modified the design. Set HorizontalFieldWidth to 300 µm.



4. Set IntegrationWidth to 4.

NOTE

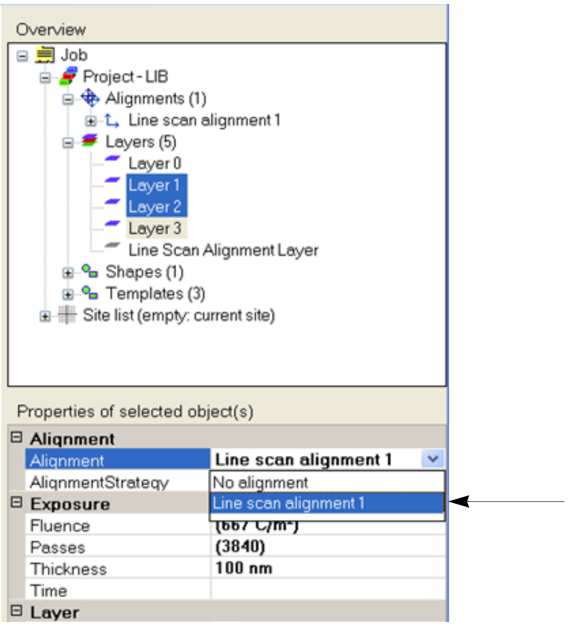
The line diagnostics are shown when you select a line.



Use the Alignment in Layers

After defining an alignment, the alignment must be assigned to each layer that should use it. This extra step allows having different alignments for different layers, having layers without alignment, and sharing a single alignment in multiple layers.

1. Select Layers 1–3 (**Shift** + click).
2. Click in the box to the right of Alignment in the Properties area (where it says **No alignment**).
3. Click on the dropdown arrow that appears and select **Line scan alignment 1**.



Overview

- Job
  - Project - LIB
    - Alignments (1)
      - Line scan alignment 1
    - Layers (5)
      - Layer 0
      - Layer 1
      - Layer 2
      - Layer 3
      - Line Scan Alignment Layer
    - Shapes (1)
    - Templates (3)
  - Site list (empty: current site)

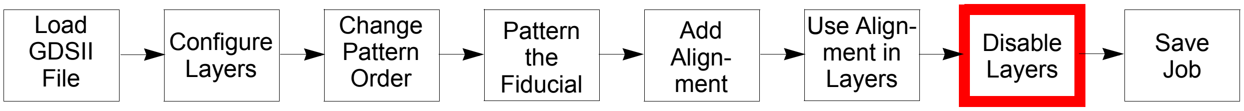
Properties of selected object(s)

Alignment	
Alignment	**Line scan alignment 1**
AlignmentStrategy	No alignment Line scan alignment 1
Exposure	
Fluence	**(667 C/m²)**
Passes	**(3840)**
Thickness	**100 nm**
Time	
Layer	

4. Enable layers 1, 2, and 3 by selecting them and right-clicking **Toggle enabled** from the popup menu, or right-clicking **True** in the Enabled property.
5. Set HFW to 300 µm for each layer.
6. Set the thickness to 10 nm.

> **NOTE** *The greater the current, the faster the mill.*

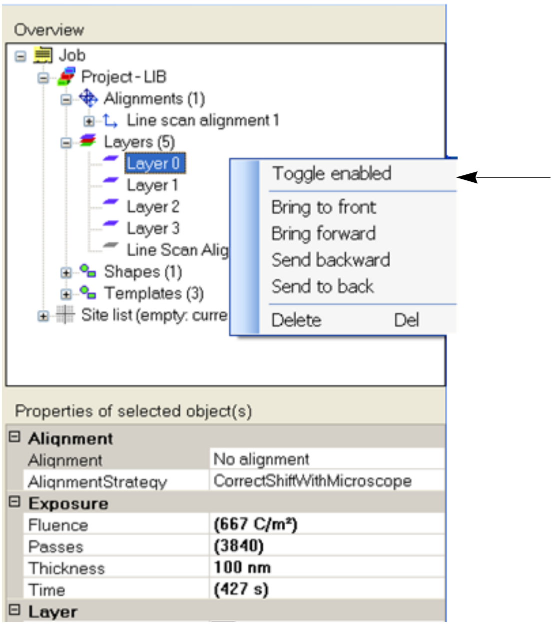
7. Click on each layer and set the beam current for each. Choose one of the available apertures. The range of typical beam current settings is 1 pA to 1 nA.



Disable Layers Not To Be Patterned

Layer 0 (fiducial) and the Line Scan Alignment layer help define the line scan alignment and should not be patterned, so they should be disabled.

Right-click on Layer 0 and choose **Toggle enabled** from the popup menu. Or, right-click **True** in the Enabled property.



Alignment

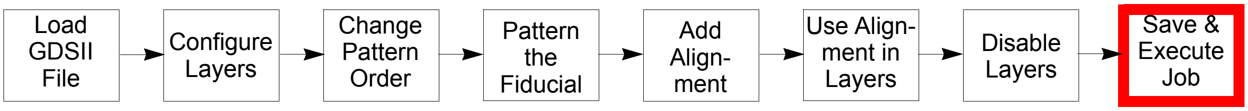
Alignment	No alignment
AlignmentStrategy	CorrectShiftWithMicroscope

Exposure

Fluence	**(667 C/m²)**
Passes	**(3840)**
Thickness	**100 nm**
Time	**(427 s)**

Layer

Disabled layers have a gray icon and are not drawn in the graphical view.



Save the Job

1. Use **File > Save** to save the job as an *.nbj*. file.

NOTE	*Tutorials are located under Program Files. Do not save your data to this location, as it will be lost upon subsequent reinstallation.*

Or use **File** > **Save** as to give it a new name.

GDSII is not savable, since that format cannot store the extra data that was added.

Execute the Job

NOTE	*At this point, the color of the line scan alignments changes from blue to green, following successful line scan alignment at that line. Red indicates failure.*

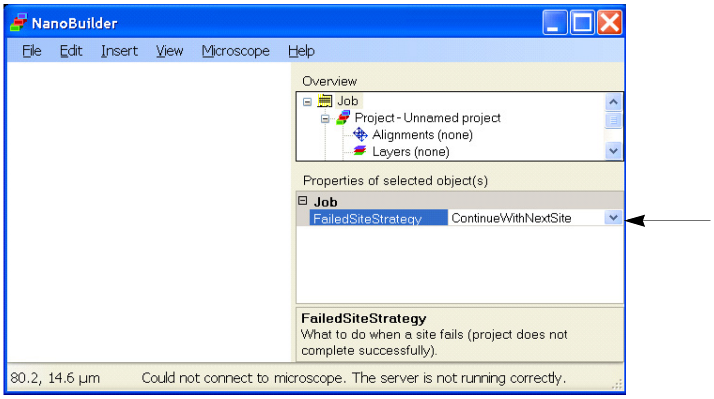
Select **Microscope > Execute** and begin patterning.

The job will now be executed. The progress is shown in the progress window and in the status bar. The progress window is minimized by clicking **Hide** and re-opened by double-clicking the status bar.

176.0, 231.7 µm   Executing "LIB" (23%, Executing "Layer 1")   Patterning

Failed Site Strategy

If an error occurs during job execution, a failed site strategy message displays in the Job window.



FailedSiteStrategy   ContinueWithNextSite

FailedSiteStrategy
What to do when a site fails (project does not complete successfully).

80.2, 14.6 µm   Could not connect to microscope. The server is not running correctly.

There are two strategies:

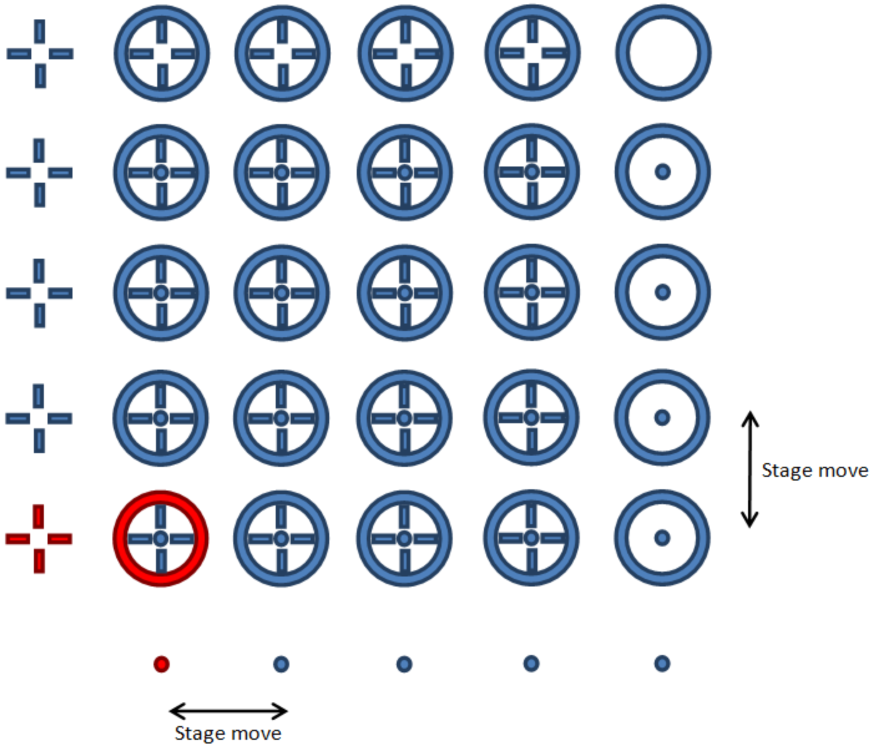
- **ContinueWithNextSite:** Stops execution at the current stage position and continues processing at the next site.
- **AbortJob**: Stops execution of the entire job.

Stitching Multiple Write Fields

This tutorial creates a repetitive design, using the stage to move from one write field to the next and correlation alignments to correct for the stage inaccuracy. For the sake of execution speed (so the demo can be executed in a few minutes) it only creates a small, shallow pattern at each write field.

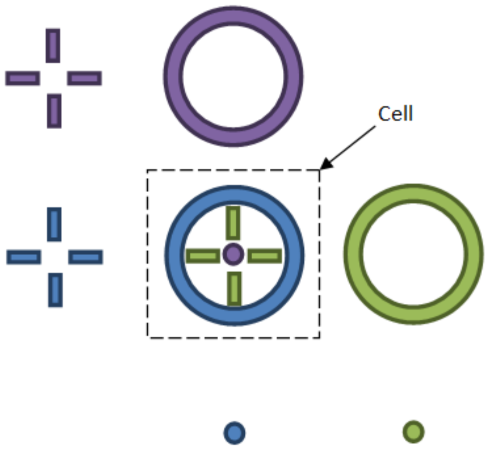
Final Result

The final result will be an array as shown in the figure below. Each cell consists of an outer circle (donut), a cross and a central dot. Between any two cells there is a stage move.



At each stage location the elements as shown in red (for the bottom-left stage location) will be milled: a large donut in the write field center, the 4 lines that make a cross in the column to the left, and a small dot in the row below. At the edges only some of these elements are visible, while the central area contains 4 x 4 complete cells. If the alignment after a stage move fails then the donut, cross and dot will be displaced relative to each other–allowing a quick visual check of the alignment quality.

To allow judging the alignment quality each cell consists of parts patterned at 3 different stage positions. In other words, if the alignments fail then the donut, cross and dot will not be aligned to each other.



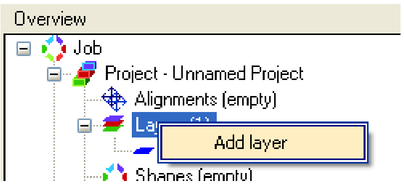
To create a single cell, the results from 3 different stage positions must be combined.

Creating the Job

This section describes how to create the entire job in NanoBuilder (without making use of a GDSII file).

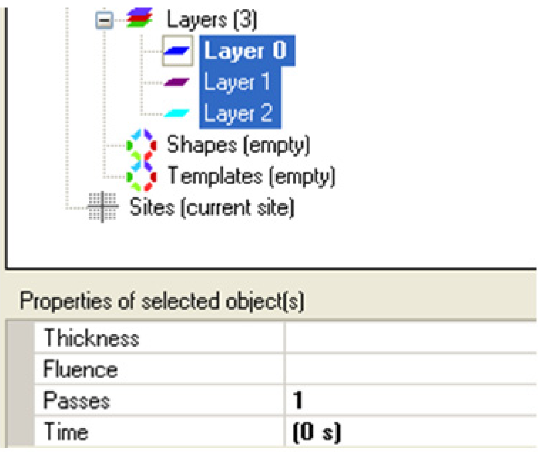
Creating the Layers and Shapes

1. Open NanoBuilder. This job starts with a single layer.
2. Right-click **Layers in Tree View** and select **Add Layers** to add a second layer. Repeat to add a third layer. The first two layers will only be used to run an alignment; they will not contain any shapes.



3. Select all three layers (so we only have to set the values below once):

- Set the horizontal field width to 50 µm.
- Expand the Process section.
  - Expand Beam and set the Ion Beam to 10 pA and 30 kV.
  - Expand Patterning and set 1 µs dwell and 0% overlap.
  - Ensure GIS is set to <no gis>.
  - Set up all three layers at the same time to ensure they have identical settings. The time shows as (0 s) because no shapes have been added yet.

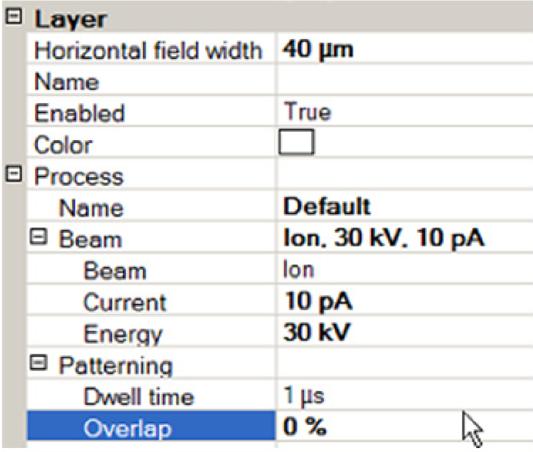


Layers (3)
- Layer 0
- Layer 1
- Layer 2

Shapes (empty)
Templates (empty)
Sites (current site)

Properties of selected object(s)

Thickness	
Fluence	
Passes	1
Time	(0 s)



⊟ Layer	
Horizontal field width	40 µm
Name	
Enabled	True
Color	☐
⊟ Process	
Name	Default
⊟ Beam	Ion, 30 kV, 10 pA
Beam	Ion
Current	10 pA
Energy	30 kV
⊟ Patterning	
Dwell time	1 µs
Overlap	0 %

4. Select only **Layer 2** (so newly added shapes will be on this layer).

5. Click in the graphical area and press the * key on the numeric key pad to center the zoom. This ensures that newly added shapes will not have an offset.

6. From the **Insert** menu, choose **Basic Shapes > Circle**.

- Set the OuterRadius to 3 µm.
- Set the InnerRadius to 2.8 µm.

7. From the **Insert** menu, choose **Basic Shapes > Circle**.

- Set the OuterRadius to 0.5 µm, 0.
- Set the Position to 0, -10 µm.

8. From the **Insert** menu, choose **Basic Shapes > Path**.

- Expand the Points section.
- Set the first point to 1 µm, 0.
- Set the second point to 2 µm, 0.
- Set the Line width to 200 nm.

9. Drag the Path from the Shapes into the Templates section. It becomes available for Reference shapes.

10. From the Insert menu choose **Composite Shapes > Reference (to a Template)**. In the dialog that appears:
    - Ensure the Template is set to Path 0.
    - Ensure the Rotation is set to 0°.
    - Click **OK.**
11. Repeat 3 more times, setting the Rotation to 90°, 180°, and 270°, respectively.
12. Select all 4 References and set the Position to be –10 µm, 0.
13. Select Layer 2 and set the Time to 10s.
14. Save.

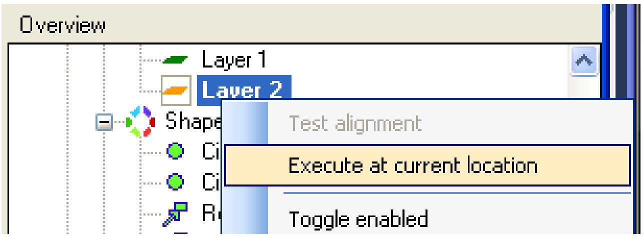
Creating the Alignments

You must first create an image that the correlation alignments can use as their reference image (the image to search for). You could directly acquire this image from within NanoBuilder, but in practice it is often more convenient to acquire it in the xT UI, save it to disk and load that image into NanoBuilder. It is easier then to reuse the image if you later need to add a similar alignment (as you cannot export the image).

Acquiring the Reference Image

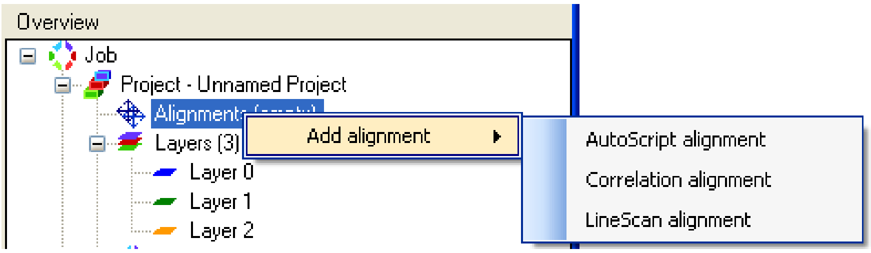
1. Load a sample that is easily marked by the FIB, like a piece of silicon wafer (for example the calibration wafer on the standard multi-stub sample).
2. Using the xT UI, set the stage to eucentric position and 52° tilt, optimize focus and stigmation for the FIB at 30 kV, 10 pA (take the nearest available current).
3. Select a FIB image resolution like 1024 x 884 or 1536 x 1024 and set the dwell time to 10 µs. The detector should ideally be in SE mode. Run Auto Contrast and Brightness.
4. Move to a fresh piece of sample, with as few existing features and particles as possible.
5. In NanoBuilder, right-click on **Layer 2**, select **Execute at current location** and wait until patterning has completed.

6. In the xT UI grab a FIB image, for example by un-pausing and immediately clicking **Pause** again (so the button becomes orange and acquisition stops at the end of the frame). Any shift between patterning and acquisition will result in an alignment error, so don't wait too long (drift) and certainly don't use beam shift or stage moves to position the image.
7. In the xT UI select **File > Save as**, select Tiff 8 bit gray scale Image Files and unselect both **Save Image with Databar** and **Save image with overlaid graphics**. Save the image in the folder where you saved the job. Right-click to execute it (without executing the other layers).



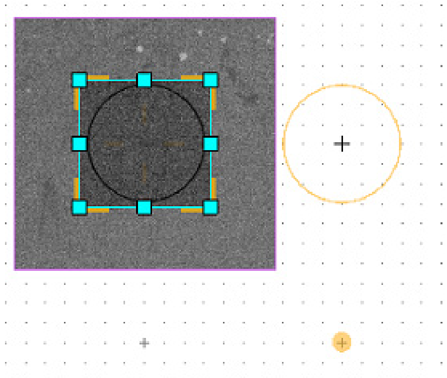
Aligning to the Previous Column

1. Right-click **Alignments** and choose **Add alignment > Correlation alignment**.

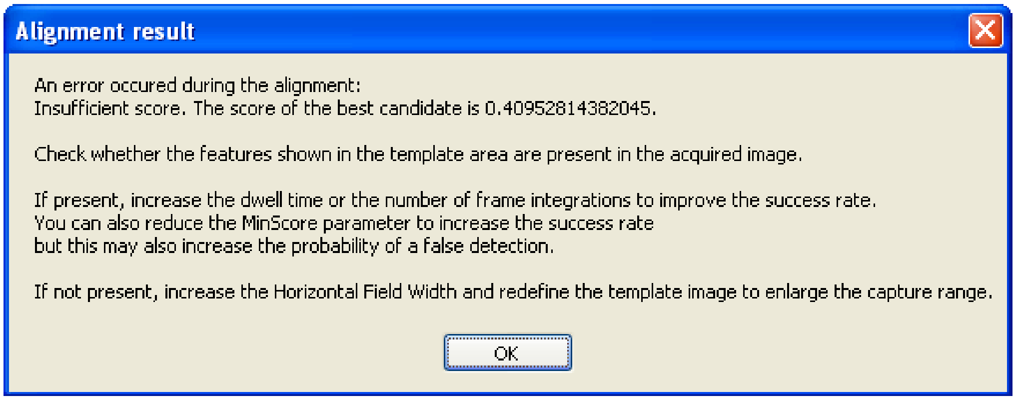


2. Click **Browse** in the dialog that appears, select the saved image, and click **OK**.
3. The new alignment is automatically selected:
   - Set the ReferenceImageOffset to –10 µm, 0 to make the alignment search at the previous site.
   - Set the name to “Align to previous column”.
4. Select **Layer 0.**
   - Set the alignment to be the newly created alignment.
   - Ensure the AlignmentStrategy is CorrectShiftWithMicroscope.

5. Click in the center of the alignment to select the Template area and resize it to only just contain the central circle (by zooming in you are able to decrease the grid pitch and make smaller steps when dragging). It is important to have as few other features visible as possible, because the alignment may otherwise try to align these to random features (dirt) on the specimen.



6. To test the alignment:
   - In the xT UI, make a relative stage move of 0.01 mm in x-direction (the circle needs to be about 10 microns left of the screen center).
   - In NanoBuilder, right-click **Layer 0** and select **Test alignment**.
   - If the alignment fails the most common problem is that the minimum score is set too high. The dialog that appears upon failure tells the actual score. Select the alignment and set the MinScore to a value somewhat lower (e.g., half of) the value in the dialog.



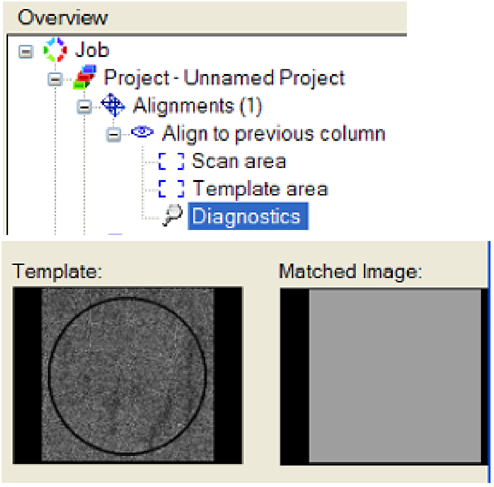
An error occured during the alignment:
Insufficient score. The score of the best candidate is 0.40952814382045.

Check whether the features shown in the template area are present in the acquired image.

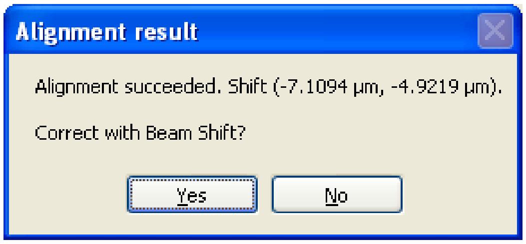
If present, increase the dwell time or the number of frame integrations to improve the success rate.
You can also reduce the MinScore parameter to increase the success rate
but this may also increase the probability of a false detection.

If not present, increase the Horizontal Field Width and redefine the template image to enlarge the capture range.

- If the alignment fails for a different reason you can often understand the cause by expanding the alignment in the tree view and selecting the Diagnostics item. If you do not see the template in the Matched Image then most likely the detector settings are wrong or the shift is larger than the scan area.



- Select the diagnostics node to see more information about failed correlation alignments. In this example, the quad 4 detector was set to External, resulting in a uniform gray image.
- If the alignment succeeds, you get the option to set the beam shift to correct for the error. It is a good idea to select Yes and re-run the alignment. The second time should also succeed, and the measured shifts should now be very close to zero.



Alignment succeeded. Shift (-7.1094 µm, -4.9219 µm).

Correct with Beam Shift?

Aligning to the Previous Row

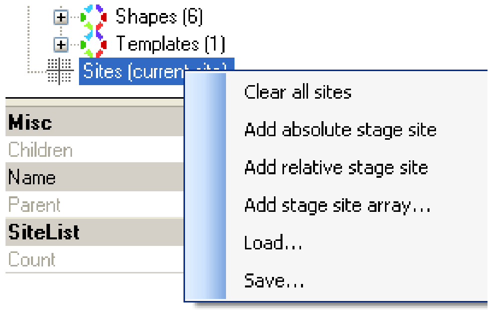
1. Add a second correlation alignment, setting it up identically to the first one, except that:
   - The ReferenceImageOffset is 0, –10 µm (this will cause it to get a red border because you are now trying to scan outside the field of view - we will fix this below).
   - Set the name to “Align to previous row”.
2. Select **Layer 1** and sets its Alignment to be this alignment.

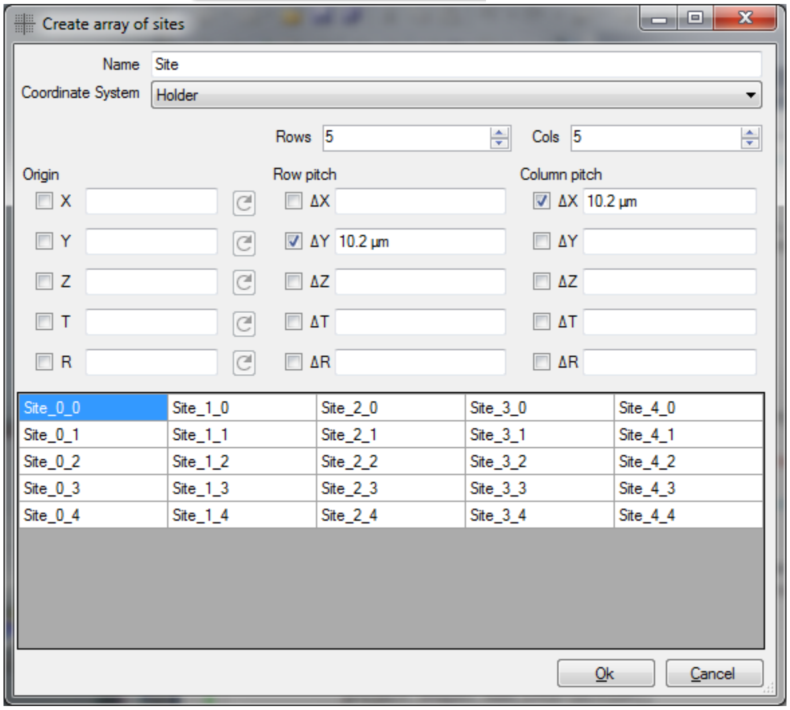
3. Set the template area to only just contain the circle; this also reduces the size of the scan area and it should be possible to make the red border disappear.
4. When testing the circle needs to be about 10 µm below the screen center, so make a relative stage move of –0.010, 0.010 mm (assuming you still are where the previous alignment was tested).

Adding the Stage Sites

1. Right-click **Sites** and choose **Add stage site array**. In the dialog that appears
   - Set the row and column pitch to be 10.2 µm. Theoretically these should be 10 µm, but we're going to introduce an intentional error so the alignments have something to correct. Note that the error is cumulative, so the last site will have 0.8 µm error.
   - Set the number of rows and columns to be 5 each (25 sites).
   - Leave the origin blank.
   - Press **OK**.
2. Select the first site, select **Execute specific layers** and select only **Layer 2**.
3. Select the next 4 sites (remainder of the first row), select **Execute specific layers** and select **Layer 0** and **Layer 2**.
4. Select the remaining sites, select **Execute specific layers** and select **Layer 1** and **Layer 2**.
5. Select the **Job** in the tree view and set the Failed site strategy to AbortJob. If one site fails there is no sense in continuing with the rest, as they all align to each other.

6. Save the job.





Name: Site
Coordinate System: Holder
Rows: 5
Cols: 5

Origin: ☐ X, ☐ Y, ☐ Z, ☐ T, ☐ R

Row pitch: ☐ ΔX, ☑ ΔY 10.2 µm, ☐ ΔZ, ☐ ΔT, ☐ ΔR

Column pitch: ☑ ΔX 10.2 µm, ☐ ΔY, ☐ ΔZ, ☐ ΔT, ☐ ΔR

Site_0_0	Site_1_0	Site_2_0	Site_3_0	Site_4_0
Site_0_1	Site_1_1	Site_2_1	Site_3_1	Site_4_1
Site_0_2	Site_1_2	Site_2_2	Site_3_2	Site_4_2
Site_0_3	Site_1_3	Site_2_3	Site_3_3	Site_4_3
Site_0_4	Site_1_4	Site_2_4	Site_3_4	Site_4_4

Executing the Job

1. Move to a fresh piece of the specimen.
2. Select **Microscope > Set stage Origin** from the Microscope menu to define the current position as the starting point.
3. Use **Execute** from the same menu to run the job.

Job Editing

NanoBuilder allows creating designs, by inserting shapes, and then resizing, moving, or deleting them. Note that it supports shapes not available in GDS, such as circles, Boolean shapes, bitmaps, and stream files.

NOTE	*NanoBuilder currently cannot save in the GDSII format, and the format of its native .nbj files may change in the future. Therefore, for long-term design use, it is better to make a GDSII file and convert that to NanoBuilder.*

Creating a Job

Start NanoBuilder.

Or, if NanoBuilder is already running, go to **File > New Job** to create a new job.

Creating a Layer

1. Go to **Insert > Layer** to add a layer.
2. Change the HorizontalFieldWidth and Thickness properties to the appropriate value for the size of the job.

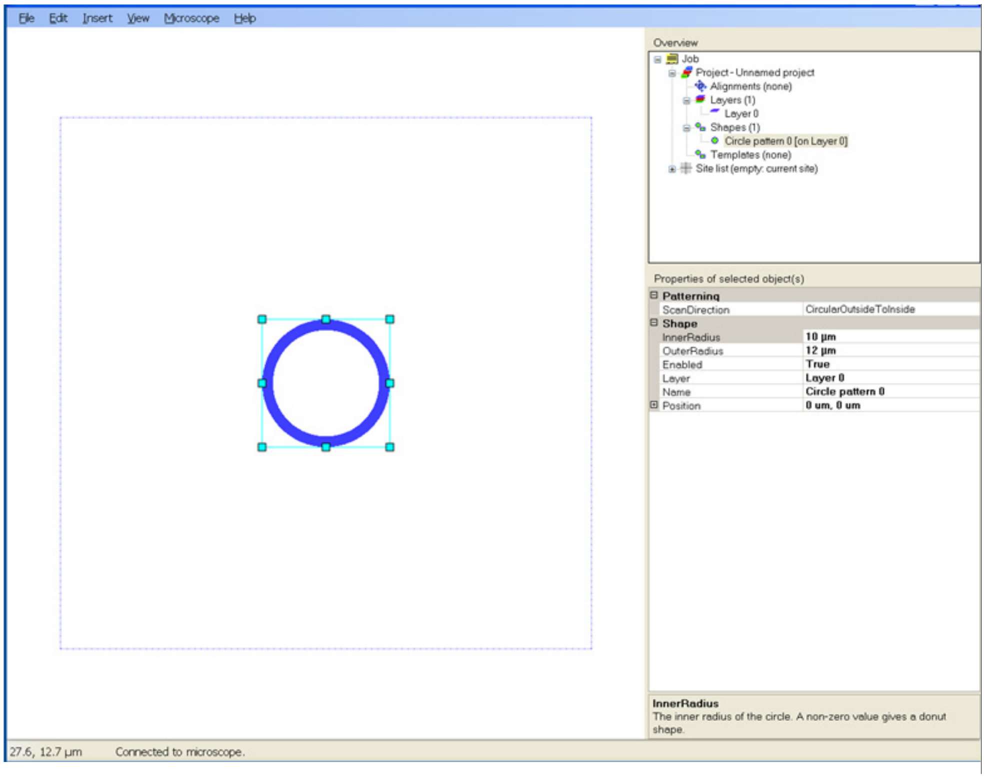
Creating a Circle

1. Go to **Insert > Basic Shapes > Circle**.

NOTE	*New shapes are placed in the screen center and are sized to about 10% of the screen width.*

2. Click on the circle that appears to select it. Resize the circle using the drag handles or enter the exact radius numerically.
3. Change the inner radius to 10 µm.

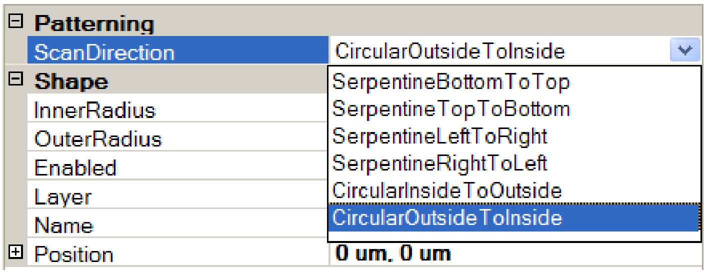
4. Change the outer radius to 12 µm.



Patterning	
ScanDirection	CircularOutsideToInside
Shape	
InnerRadius	**10 µm**
OuterRadius	**12 µm**
Enabled	**True**
Layer	**Layer 0**
Name	**Circle pattern 0**
Position	**0 um, 0 um**

InnerRadius
The inner radius of the circle. A non-zero value gives a donut shape.

5. Select the scan direction for patterning. See also *"Scan Direction" on page 45*.

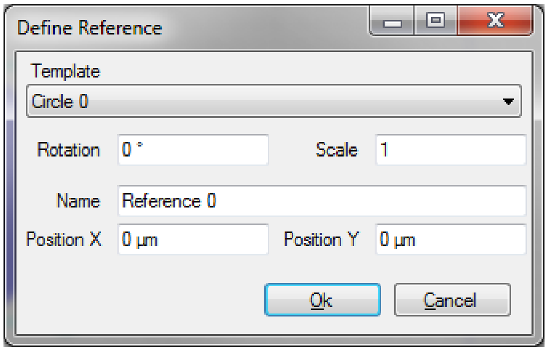


Patterning	
ScanDirection	CircularOutsideToInside
Shape	
InnerRadius	
OuterRadius	
Enabled	
Layer	
Name	
Position	**0 um, 0 um**

Creating a Reference

1. Create a circle.
2. Drag the circle from Shapes to Templates (in the tree view).

3. Go to **Insert > Composite Shapes > Shape Reference**. The Define Reference dialog displays.



Define Reference

Template: Circle 0

Rotation: 0 °

Scale: 1

Name: Reference 0

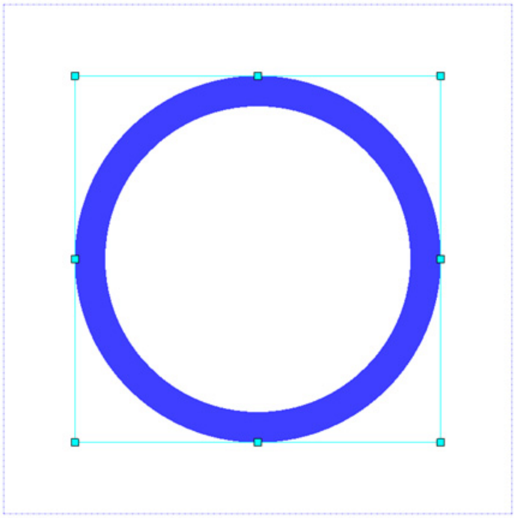
Position X: 0 µm

Position Y: 0 µm

This allows you to select a template shape (for reference), the rotation and scale, and the position (offset with respect to the template's position).

4. Under Template, select the circle pattern you just created.
5. Change the scale to 3.
6. Click **OK**.

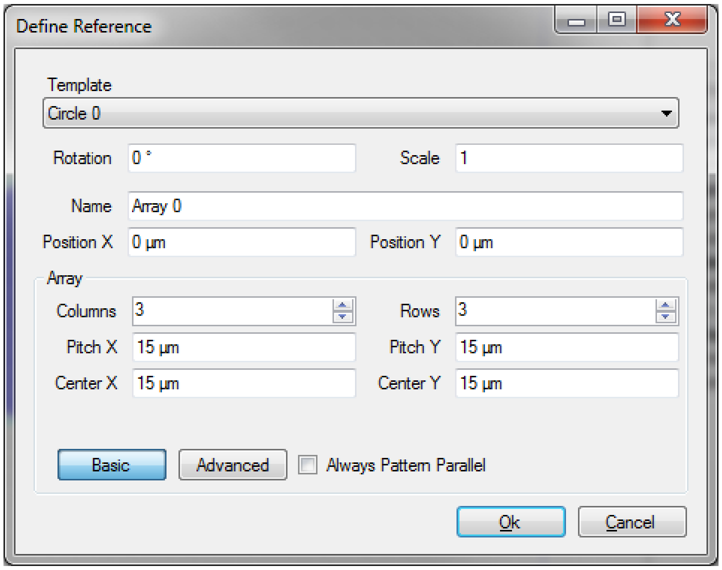
Your job now looks something like this:



Creating an Array

An array is similar to a reference, but it allows you to make multiple copies at once.

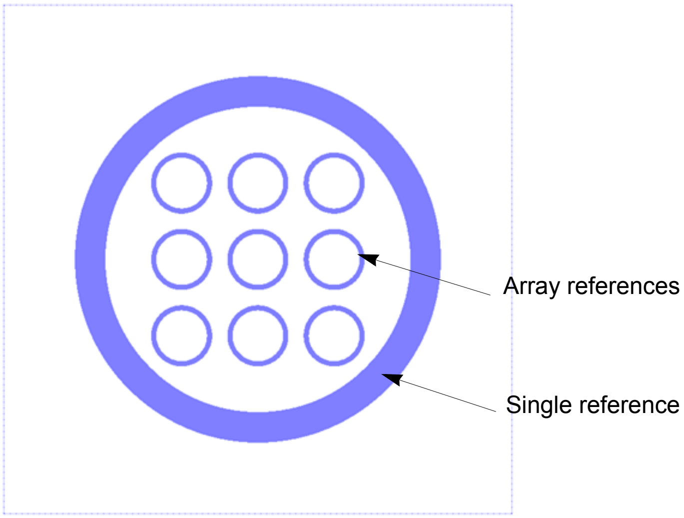
1. Assuming the circle has been moved to the Templates section as described above, go to **Insert > Reference > Array**. The Define Array dialog box displays. This allows you to quickly make multiple copies.



Template: Circle 0
Rotation: 0 °
Scale: 1
Name: Array 0
Position X: 0 µm
Position Y: 0 µm
Array
Columns: 3
Rows: 3
Pitch X: 15 µm
Pitch Y: 15 µm
Center X: 15 µm
Center Y: 15 µm
☐ Always Pattern Parallel

2. Select the circle pattern you created as the template.
3. Change the scale to 0.5 to reduce the size of the ring.
4. Change the number of columns to 3 and the number of rows to 3.
5. Change the width to 30 µm and the height to 3 µm.
6. Click **OK**.

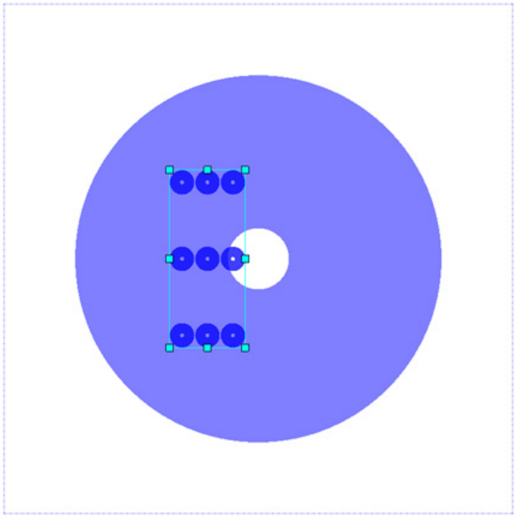
The result should be similar to that shown below.



Changing Array Properties

Change the array's properties, if necessary, after defining it:

1. Select Array 0 in the Shapes list in the Overview pane.
2. Change the Magnification to 0.2, and set the column pitch to 5 µm.

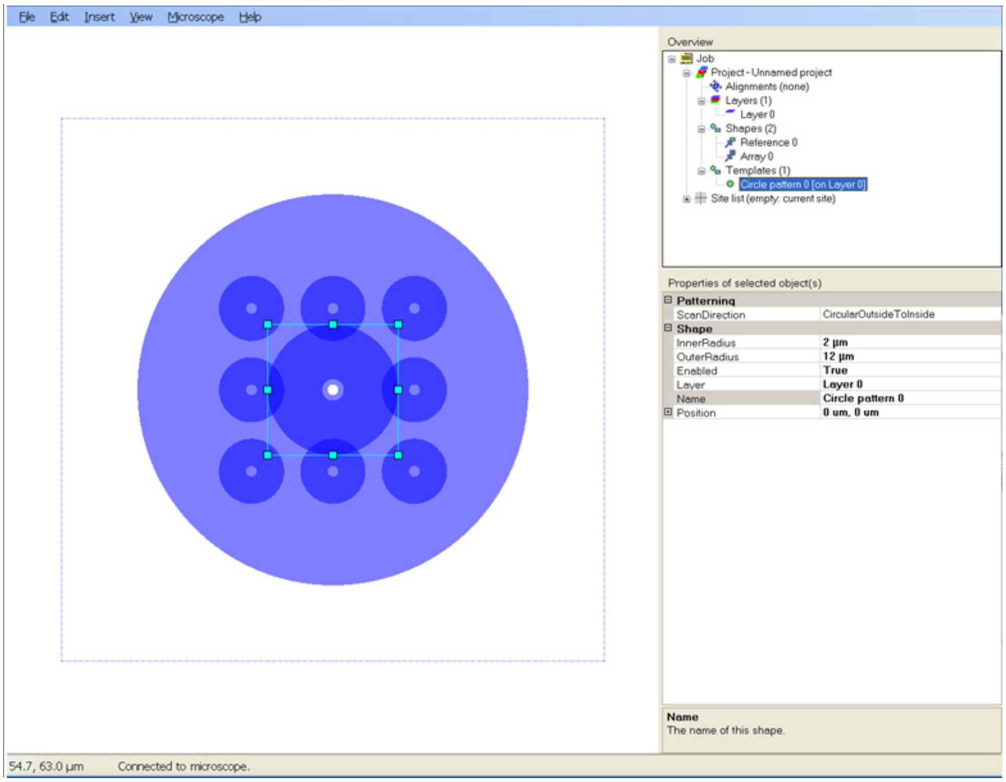


Reference Shape Influences Design

To see how changing the reference shape influences the design:

1. Select the circle template.
2. Set the inner radius to 2 µm.

As shown below, both references have changed. When you change a template, all references to that template will change. Also note that the original circle displays when it is selected in the Overview pane.



Patterning	
ScanDirection	CircularOutsideToInside
Shape	
InnerRadius	**2 µm**
OuterRadius	**12 µm**
Enabled	**True**
Layer	**Layer 0**
Name	**Circle pattern 0**
Position	**0 um, 0 um**

Name
The name of this shape.

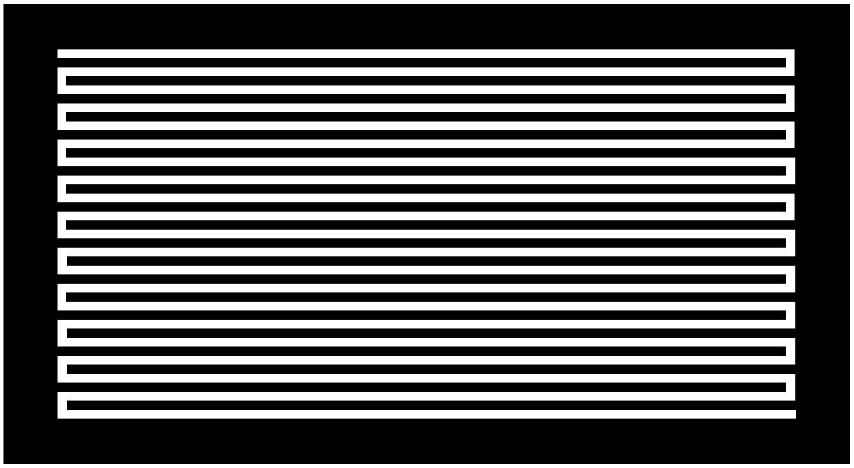
54.7, 63.0 µm Connected to microscope.

Scan Direction

NanoBuilder defines six different scan directions:

- Serpentine bottom to top
- Serpentine top to bottom
- Serpentine left to right
- Serpentine right to left
- Circular inside to outside
- Circular outside to inside

A schematic illustration of a serpentine scan for a rectangle is shown below.



4 Alignments

Overview

Topics in this chapter include:

- *"Line Scan Alignment" on page 46*
- *"Correlation Alignment" on page 51*

Line Scan Alignment

The line scan alignment works by scanning several line segments with the beam and measuring the detector signal along each line. Assuming the lines intersect with known features on the sample, transitions (jumps in the signal) will occur at these intersections. By comparing the actual transition locations with the expected locations, or the measured line profile with a reference profile, you can find the shift for each line. A fit to all the lines gives the shift, rotation, scale, and shear parameters that best match the measured shifts. These can then be used to correct these errors.

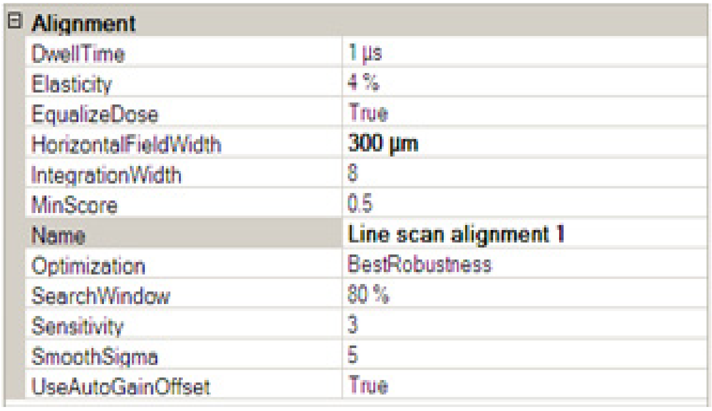
Creating a Line Scan Alignment

1. Create a GDSII file with shapes on the Line Scan Alignment Layer that indicate where the lines are to be scanned and shapes on any other layer that indicate the features that the lines will scan over (the fiducial marks).

NOTE	Make sure that LineScanAlignmentLayer is set to 61 in the Preferences dialog box.

2. Load this file into NanoBuilder.
3. Use **Insert > Alignment > Line Scan Alignment** (or right-click on **Alignments** in the Overview tree) to create a new line scan alignment.
4. The new alignment will automatically import the shapes on the Line Scan Alignment Layer as the lines to scan, checking for intersections with shapes on other layers.
5. Optionally, train the alignment if you need best layer-to-layer accuracy (at the cost of absolute accuracy to the fiducial marks).

Line Scan Alignment Properties



⊟ Alignment	
DwellTime	1 µs
Elasticity	4 %
EqualizeDose	True
HorizontalFieldWidth	**300 µm**
IntegrationWidth	8
MinScore	0.5
Name	**Line scan alignment 1**
Optimization	BestRobustness
SearchWindow	80 %
Sensitivity	3
SmoothSigma	5
UseAutoGainOffset	True

Table 4-1 Line Scan Alignment Properties (1 of 2)

Property	Description
DwellTime	This is the pixel dwell time for scanning the lines. A larger value will give better signal to noise, but also cause more damage per scan. It will also increase the total time to scan the alignment lines, but this is generally not a limiting factor.
Elasticity	If a line has more than a single transition, the real spacing between the transitions might be different from the expected spacing, causing the match to fail. This number influences how much the actual spacing may differ from the expected spacing by broadening each transition with a Gaussian. For example, for a line segment of 5 µm length, a value of 1% of the Gaussian has a sigma of 0.05 µm, meaning that each edge can be off by that amount relative to the other edges.
EqualizeDose	Keeps the dose constant at varying beam currents.
HorizontalFieldWidth	This is the horizontal field width (HFW ~ 1/magnification) at which to scan the lines. Use the same HFW in the alignment and in the layers that use the alignment to avoid small errors that might be caused by changing the HFW. This value must at least be so large that an image acquired at this HFW will contain all the lines that are to be scanned.
IntegrationWidth	By setting a number larger than 1, you can automatically scan multiple parallel lines. This will increase accuracy and reliability.
MinScore	Each line scan line receives a score from 0 to 1 indicating the confidence in the correctness of the measurement. The alignment accepts only lines with a score greater or equal to the value specified by the MinScore parameter. Use the MinScore parameter to control the probability of a false measurement.
Name	The name of the particular line scan alignment.

Table 4-1 Line Scan Alignment Properties (2 of 2)

Property	Description
Optimization	Determines the impact of redundant scan lines with a failed measurement on the alignment. There are two selections: • **HighestAccuracy** requires that all scan lines successfully measure the location of the underlying fiducials. Use this setting when the patterning process demands consistent alignment with the highest achievable accuracy. • **BestRobustness** tolerates measurement failures of redundant scan lines. The number of redundant scan lines is the total number of lines minus the number of parameters calculated by the alignment, which depends on the AlignmentStrategy field for the layer. The AlignmentStrategy field for the layer has two selections: — *CorrectShiftWithMicroscope* calculates two scalar parameters, namely shift in X and Y, — *CorrectWithShapes* computes scale in X, scale in Y, shear and rotation, in addition to shift in X and Y, resulting in a total of six scalar parameters. For example, a job uses the line scan alignment module located in the documentation folder to define an alignment. The alignment module defines four pairs, with each pair consisting of one horizontal and one vertical line. When using *CorrectShiftWithMicroscope*, the line scan alignment will tolerate the measurement failure of up to three horizontal and three vertical lines. On the other hand, the *CorrectWithShapes* selection will only tolerate the failure of one horizontal and one vertical line because of the higher number of alignment parameters calculated in this case.
SearchWindow	Reduces the search range to a fraction of the profile data acquired over the entire scan line. The search range is centered to form equal margins from either end of the scan line. Decrease this parameter to suppress the detection of scan artifact peaks near the extremes of the scan line.
Sensitivity	The Transition method matches inflection points in the scan profile to line transitions. The Sensitivity parameter filters the inflection points according to the strength of the slope at which they occur. A small value will suppress inflection points with soft slopes and, consequently, will lead to fewer detected inflection points to be matched to transitions.
SmoothSigma	Sets the width of the Gaussian used to smooth the detector signal. It is in units of points on the line that was scanned (similar to pixels).
UseAutoGainOffset	When set to True, the detector contrast and brightness will automatically be adjusted if the signal is too dark or bright. When set to False, you must manually adjust the detector signal while patterning with the real time monitor enabled.

Line Properties

The line scan alignment has a list of lines that are to be scanned when the layer is executed. At least two lines (nonparallel, ideally perpendicular) are required for measuring and performing a translation (shift) in X and Y. At least six lines (not all parallel) are needed to measure translation, rotation, scaling and shear.

Table 4-2 Line Properties

Property	Description
StartPoint	The starting point of the line. Expand to edit the x- and y value.
EndPoint	The end point of the line.
Length	Read only, the distance between the start and end points.
SearchMethod	• **Transition**: This method searches for inflection points in the profile and matches them to the line transitions. This is typically used when the intersection information comes from a GDSII CAD file and no knowledge is available on the actual detector signal profile. This works best if there are multiple transitions; the algorithm can then search for a sequence of jumps at the correct intervals. The more transitions, the less likely other features (like a piece of dirt) will match, decreasing the chance of a false match. • **ScanProfile**: Compare trained line profiles with the measured line profiles. This defines the scan field location where the training was done as the 'perfect' location, which the alignment will try to reproduce. If you want to position patterns with absolute accuracy relative to existing features, use Transition. For the best layer-to-layer alignment, use ScanProfile.
TrainedBeam	The beam that was used for training.
TrainedDetector	The detector that was used for training.
TrainedHFW	The horizontal field width at which training was done.

Use Single Lines with IntegrationWidth Parameter

Line scan lines can be widened to a larger scan area by using the IntegrationWidth parameter. All pixels perpendicular to the line direction are averaged to reduce noise and lessen the impact of fiducial line roughness. Values of 4–8 typically achieve good results for beam currents ranging from 50 pA–1 nA. In general, use larger values for smaller beam current.

Choose Search Method for Line Scan Alignment

The line scan alignment can search for the fiducial location in two different ways:

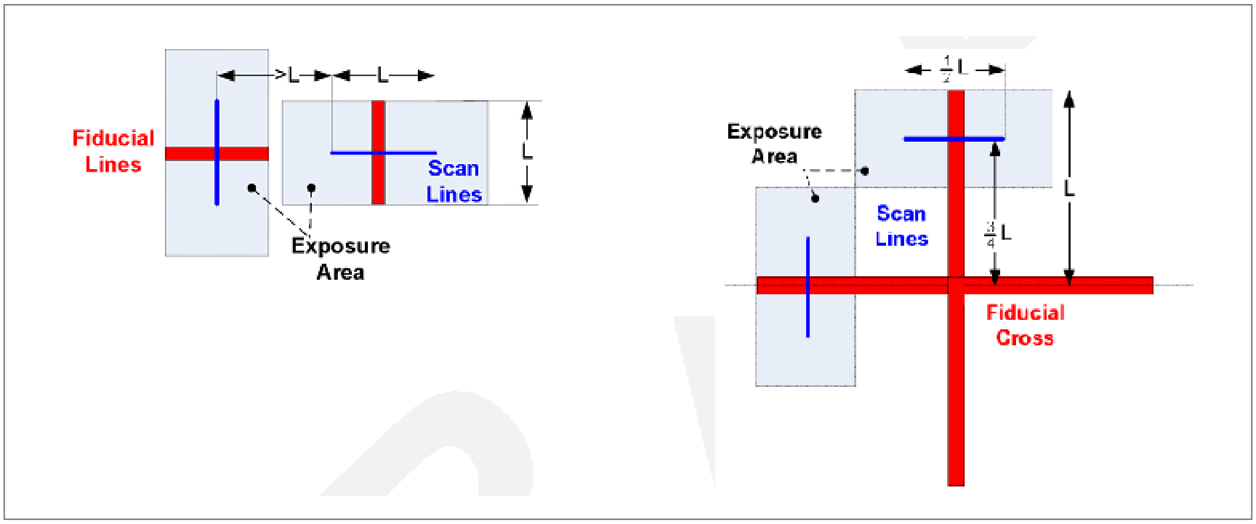
- The *Transitions* method matches inflection points in the line profile with material or topography transitions described by the fiducial layer in the GDSII file. Depending on the nature of the fiducial and the particular imaging conditions, the location of the detected inflection points may differ slightly from their respective calculated transitions. The Transitions method calculates the total shift from the average of the transition deviations to achieve “center of mass” alignment.
- The *ScanProfile* method, on the other hand, uses a sample scan profile recorded during the training step of the line scan alignment to find the fiducial.

Use the *Transitions* method when absolute pattern placement is critical and the edges of the fiducial display as bright narrow lines in the image. Typically, this is the case for features produced by a lithography process applied to a silicon substrate. The *ScanProfile* method is recommended when robust and precise alignment of the layers to each other is more important than absolute placement of the entire structure.

Line Scan Alignment Capture Range and Line Placement

The capture range of the line scan alignment is determined by the length of the fiducial line. Individual fiducial lines milled by NanoBuilder should be spaced from each other by at least their length to avoid the sample-staining or mill artifact of one scan line to alter the acquired profile of a neighboring scan line. This is illustrated by the figure below on the left. For fiducial crosses, place the scan line 3/4 from the center and set its length to 1/2 of the length of the cross arm. This will ensure a maximum capture range without scan line interference.

Figure 4-1 Line Scan Alignment Capture Range & Line Placement



Correlation Alignment

The correlation alignment is based on cross correlation techniques, using a predefined template image that is searched in an image that is acquired on the microscope during the alignment task.

Correlation alignment is most useful when:

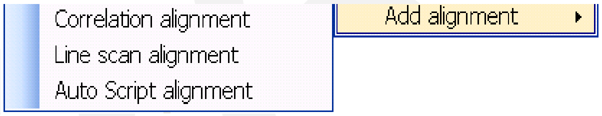
- Aligning to sites with prefabricated alignment fiducials. The following example demonstrates how multiple crosses on the mapping wafer test substrate can be modified consistently with one NanoBuilder job.
- You expect a relatively large shift. The line scan alignment typically has limited range, while the correlation alignment can handle much larger shifts.
- When the amount of noise in the acquired line scans is too significant for a stable line scan alignment. Cross correlation is generally less sensitive to noise.

Before beginning, prepare the microscope for patterning. Drive to a location on the mapping wafer sample, bring it to eucentric height, optimize the SEM and FIB images, and then align the ion beam with the E-beam using beam shift.

1. Start NanoBuilder and go to **File > Import GDSII... > Tutorial03** and select the file *Tutorial03.gds*

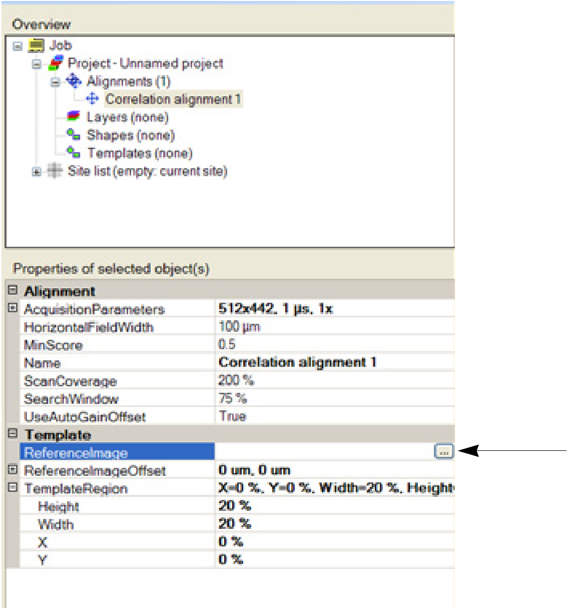
   C:\Program Files (x86)\FEI\NanoBuilder\Documentation\Tutorials\Tutorial03\tutorial03.gds.

2. Right-click on Alignments in the Overview window and select **Correlation alignment** from **Add alignment**.



3. In the Properties window, set HFW to 150 µm.

4. In the Template pane, click **Reference Image** to enable a **Browse** button at the right of that property.



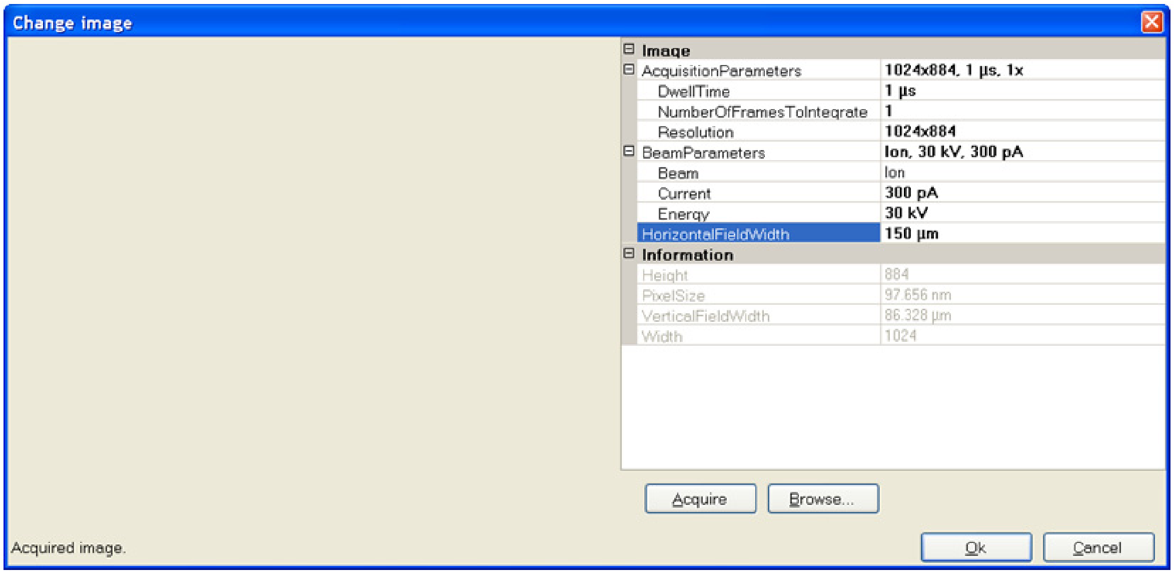
Overview

Job
  Project - Unnamed project
    Alignments (1)
      Correlation alignment 1
    Layers (none)
    Shapes (none)
    Templates (none)
  Site list (empty: current site)

Properties of selected object(s)

⊟ **Alignment**	
⊞ AcquisitionParameters	512x442, 1 µs, 1x
HorizontalFieldWidth	100 µm
MinScore	0.5
Name	Correlation alignment 1
ScanCoverage	200 %
SearchWindow	75 %
UseAutoGainOffset	True
⊟ **Template**	
ReferenceImage	...
⊞ ReferenceImageOffset	0 um, 0 um
⊟ TemplateRegion	X=0 %, Y=0 %, Width=20 %, Height
Height	20 %
Width	20 %
X	0 %
Y	0 %

5. Click the **Browse** button to display the Change Image dialog box.



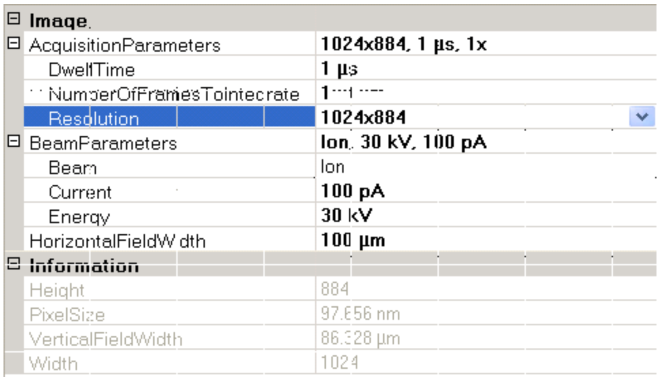
Change image

⊟ **Image**	
⊟ AcquisitionParameters	1024x884, 1 µs, 1x
DwellTime	1 µs
NumberOfFramesToIntegrate	1
Resolution	1024x884
⊟ BeamParameters	Ion, 30 kV, 300 pA
Beam	Ion
Current	300 pA
Energy	30 kV
HorizontalFieldWidth	150 µm
⊟ **Information**	
Height	884
PixelSize	97.656 nm
VerticalFieldWidth	86.328 µm
Width	1024

Acquired image.

6. Expand the Acquisition Parameters and Beam Parameters properties and set the following:

- Resolution: 1024x884
- Current: 100 pA
- HFW: 150 µm



⊟ **Image**	
⊟ AcquisitionParameters	**1024x884, 1 µs, 1x**
DwellTime	**1 µs**
NumberOfFramesToIntegrate	**1**
Resolution	**1024x884**
⊟ BeamParameters	**Ion, 30 kV, 100 pA**
Beam	Ion
Current	**100 pA**
Energy	**30 kV**
HorizontalFieldWidth	**100 µm**
⊟ **Information**	
Height	884
PixelSize	97.656 nm
VerticalFieldWidth	86.328 µm
Width	1024

NOTE

If the correlation alignment is not good, increase the dwell time for better signal-to-noise.

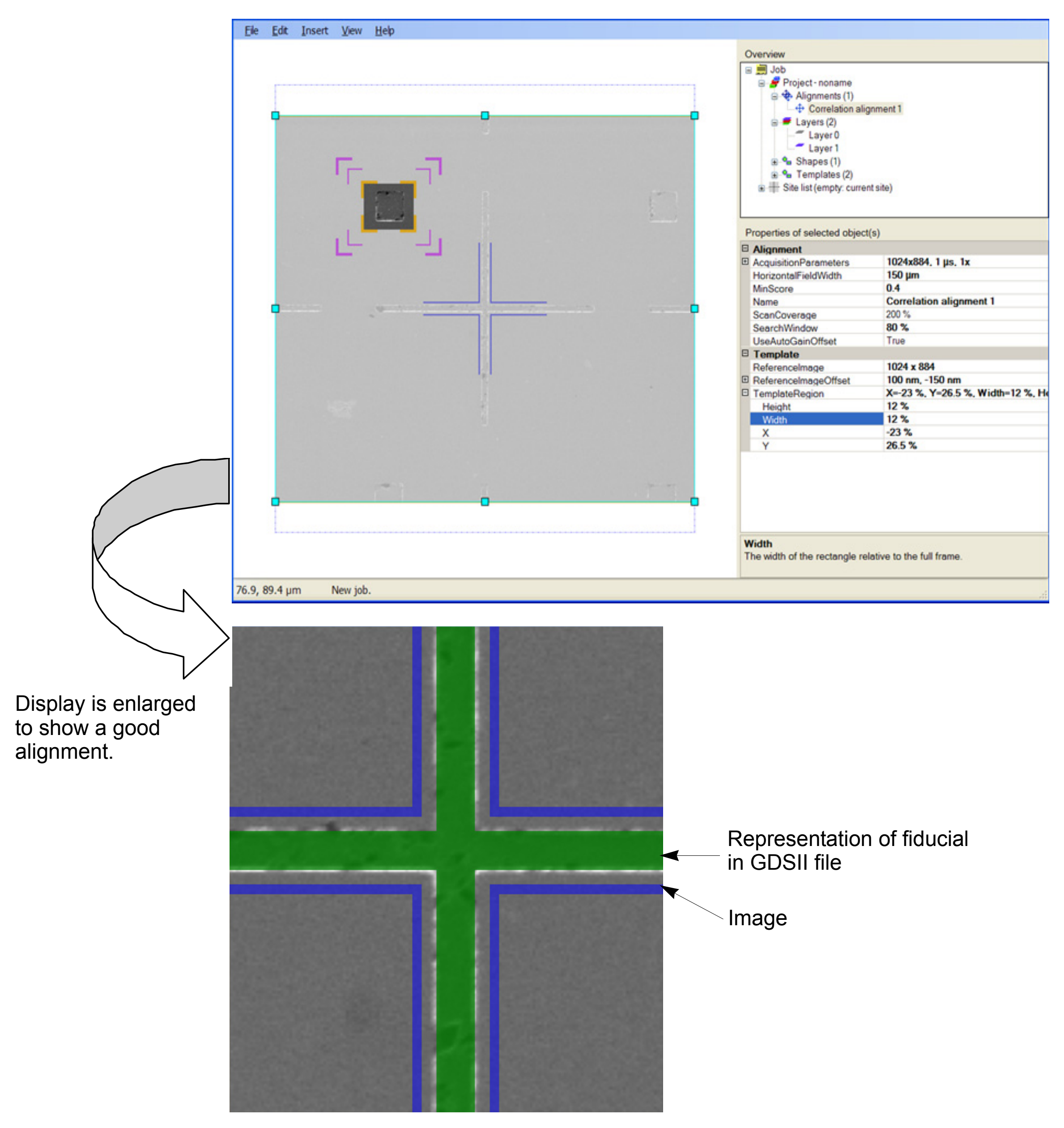
7. Click **Acquire**.

8. Click **OK** to close the dialog box.

9. In the Template pane, set the following parameters:

- X: –13%
- Y: 26%
- Width: 12%
- Height: 12%

Figure 4-2   Aligning Template to Fiducial



Overview

- Job
  - Project - noname
    - Alignments (1)
      - Correlation alignment 1
    - Layers (2)
      - Layer 0
      - Layer 1
    - Shapes (1)
    - Templates (2)
  - Site list (empty: current site)

Properties of selected object(s)

Alignment	
AcquisitionParameters	1024x884, 1 µs, 1x
HorizontalFieldWidth	150 µm
MinScore	0.4
Name	Correlation alignment 1
ScanCoverage	200 %
SearchWindow	80 %
UseAutoGainOffset	True
Template	
ReferenceImage	1024 x 884
ReferenceImageOffset	100 nm, -150 nm
TemplateRegion	X=-23 %, Y=26.5 %, Width=12 %, H
Height	12 %
Width	12 %
X	-23 %
Y	26.5 %

Width
The width of the rectangle relative to the full frame.

76.9, 89.4 µm   New job.

Display is enlarged to show a good alignment.

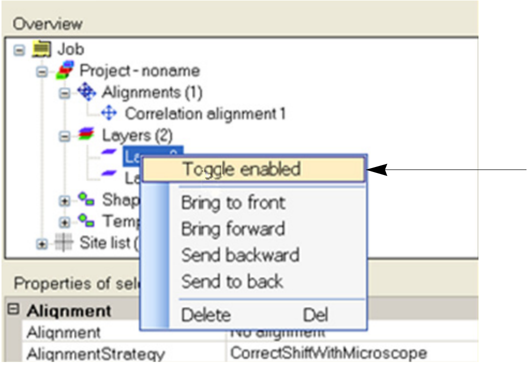
Representation of fiducial in GDSII file

Image

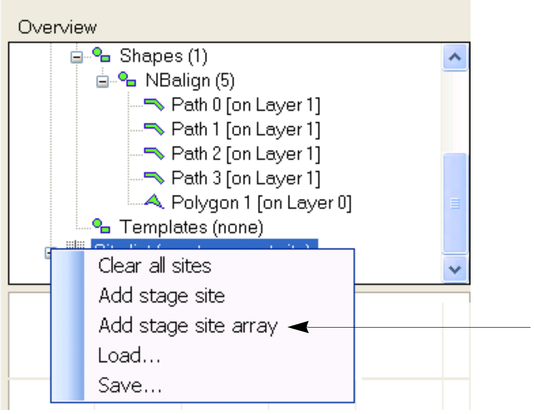
10. Set the *ReferenceImageOffset* to precisely align the template to the fiducial displayed in Layer 0. The display of the fiducial pattern in Layer 0 helps align the image template, as shown in *Figure 4-2*.

HINT	Once you have developed a robust alignment job, you can reuse it from different projects. To do so, save the alignment job for later use. Then when you need an alignment during the development of a new job, use the **Merge Job** selection on the File menu to include the previously saved alignment job. After you have merged the alignment job, move the fiducial layer and the burn-in layer, if present, to the start of the patterning list.

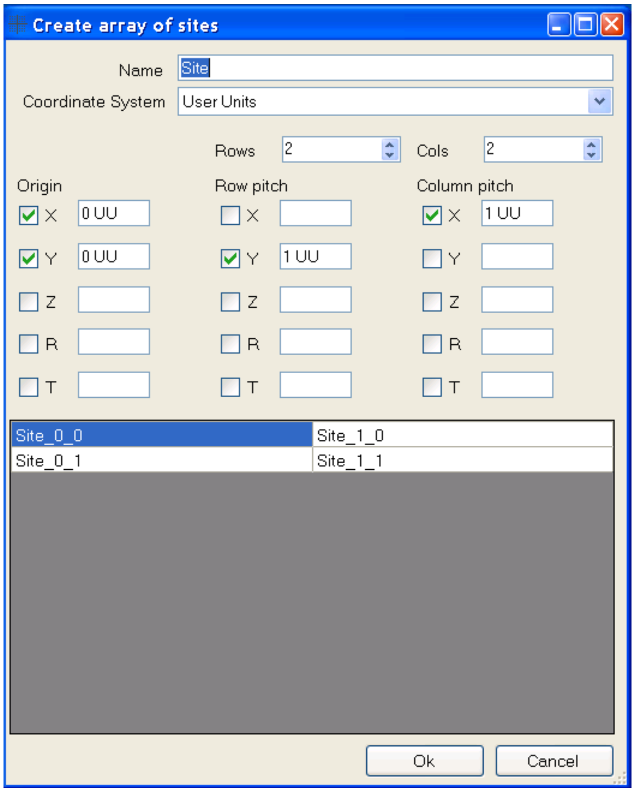
11. Right-click on **Layer 0** to disable it so that the fiducial will not be patterned.



12. Right-click on the **Site List** and select **Add stage site array**.



13. Click **OK** on the Create array of sites dialog box that displays.



Name: Site

Coordinate System: User Units

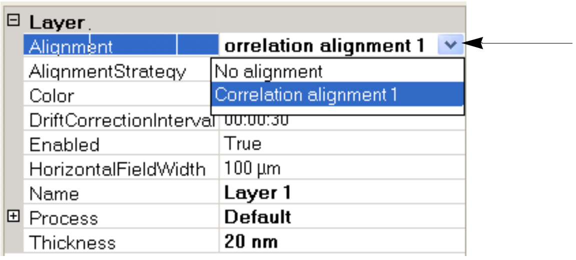
Rows: 2 Cols: 2

Origin	Row pitch	Column pitch
☑ X 0 UU	☐ X	☑ X 1 UU
☑ Y 0 UU	☑ Y 1 UU	☐ Y
☐ Z	☐ Z	☐ Z
☐ R	☐ R	☐ R
☐ T	☐ T	☐ T

Site_0_0	Site_1_0
Site_0_1	Site_1_1

14. Select **Layer 1** in the Overview window and make the following property changes:

- **HFW:** 100 µm (to pattern with the same HFW that is used for the alignment)
- **Thickness:** 20 nm (to shorten patterning time)
- **Alignment:** Correlation alignment 1



Layer	
Alignment	orrelation alignment 1
AlignmentStrategy	
Color	
DriftCorrectionInterval	00:00:30
Enabled	True
HorizontalFieldWidth	100 µm
Name	Layer 1
Process	Default
Thickness	20 nm

15. Go to **File > Save** and save the job.

16. Execute the NanoBuilder job to modify the fiducials at four sites.

5 Advanced Operations

Overview

Topics in this chapter include:

Patterning with a Certain Dose

Patterning with a certain dose is useful when exposing a resist layer.

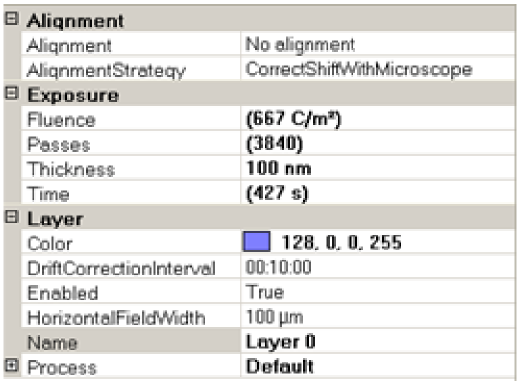
Dose and Fluence

The term *dose* is often loosely used, sometimes to express the total number of particles that hit the sample, sometimes to express the number of particles per area. The latter is called the *fluence*, while dose refers to the total number of particles. Assuming singly charged particles (electrons or Ga+ ions), the dose is more easily expressed in Coulomb (typically in the pC or nC range), while fluence is in units C/m^2, typically in the $nC/\mu m^2$ or $pC/\mu m^2$ range.

The relation between dose and fluence is that the dose is the fluence times the exposed surface area. For a specific layer in NanoBuilder, the dose is its fluence multiplied by the combined surface area from all the patterns on the layer.

Thickness, Fluence, Passes, and Time

Specify the exposure for a layer by setting either *Thickness, Fluence, Passes,* or *Time* in the Layer Properties section. NanoBuilder will automatically calculate the other quantities and display their values in parentheses to indicate that they were calculated rather than specified.



⊟ **Alignment**	
Alignment	No alignment
AlignmentStrategy	CorrectShiftWithMicroscope
⊟ **Exposure**	
Fluence	**(667 C/m²)**
Passes	**(3840)**
Thickness	**100 nm**
Time	**(427 s)**
⊟ **Layer**	
Color	🟦 **128, 0, 0, 255**
DriftCorrectionInterval	00:10:00
Enabled	True
HorizontalFieldWidth	100 µm
Name	**Layer 0**
⊞ Process	**Default**

For example, if you specify the *Thickness,* then the *Fluence, Passes,* and *Time* will be calculated as follows:

$$Fluence := \frac{Thickness}{VolumePerDose}$$

$$FluencePerPass := Current \cdot Pitch^2 \cdot DwellTime$$

$$Passes := INT\left[\frac{Fluence}{FluencePerPass}\right]$$

$$Time := Passes \cdot TimePerPass$$

NOTE

Calculated exposure values may be inaccurate as a consequence of the rounding to an integer in the calculation for the Passes property. Moreover, the Passes property cannot be smaller than 1. To reduce the dose with a Passes value of 1, you can select a smaller beam current or dwell time.

Selecting Apertures

When a current is selected that is available by more than one aperture, the one closest to the lowest index (lowest beam current) is used.

Parallel and Sequential Patterning

The concept of Parallel and Sequential patterning in NanoBuilder is the same as in xT, but there are some subtle differences. Conceptually the meaning is as follows:

- **Parallel:** All shapes in a layer receive a single pass of the beam, then they all receive the next pass, etc., until the required number of passes has been reached.
- **Sequential:** The first shape receives the number of passes specified for its layer, then the next shape, etc., until all shapes on the layer have been patterned.

Sequential Patterning Displays as Parallel in the xT UI

Even if you set a NanoBuilder Layer to pattern Sequentially, the Patterning page in the xT UI will still show Parallel. The reason is that NanoBuilder patterns the shapes one by one, starting/stopping patterning for each shape. This allows it to use the maximum number of points (currently 8 million) per shape, rather than all shapes having to fit in this limitation together.

Always Pattern Parallel

Arrays

By default the individual elements of an Array will be patterned one-by-one in Sequential mode. However, this can result in a very high number of start/stop patterning cycles, which is slower due to the cumulative overhead (especially for nested structures like Arrays of Arrays). If the total number of points for the Array is less than the maximum number of points it is more efficient to select the **Always Pattern Parallel** option of the array. This will pattern all the points for the array in one go, treating it as a monolithic shape.

Structures

Structures are collections of shapes, which can even be on different layers. When a layer is executed in Sequential mode all the shapes in the structure that are on the executing layer will be patterned one by one. As with the Arrays, the overhead of start/stopping patterning can be reduced by selecting the **Always Pattern Parallel** option for the Structure, in which case all the shapes in the structure which are on the executing Layer will be patterned in one go, treating the structure as a single shape.

Shapes in NanoBuilder

The shapes in NanoBuilder are grouped in a number of categories:

- **Basic shapes:** Simple geometric shapes
- **Composite shapes:** Shapes that are combinations of other shapes
- **Special shapes:** Shapes that deviate from the general concept of a shape

Shape Properties

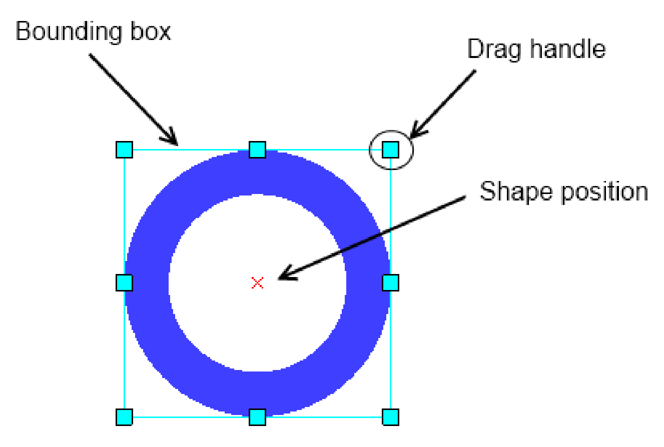
Each shape has a number of properties that are shown in the property box when the shape is selected. Some properties are applicable to all shapes (Name, Position, Layer), while others will vary from shape to shape. The available ScanDirections, (in the order which the pattern points are generated/rastered), will also depend on the specific shape.

Display and Selection

Shapes are visualized with the color of their layer and drawn in the same order as they are listed in the project. A slight transparency is applied to ensure overlapped shapes are still visible.

A shape is selected by clicking on the shape in the viewer or by clicking on its node in the overview tree. When a shape is selected, additional annotation is shown: its position (red cross), the bounding box, and drag handles.

Figure 5-1 Selecting a Shape



Shape Editing

When a shape is selected, its size and position is editable directly in the viewer. Adjust the size by using the drag handles that are attached to the bounding box of the shape. To move the shape, position the mouse cursor inside the bounding box and drag the shape (hold the mouse button down while moving).

For ultimate precision, use the property box (lower-right part of the screen) to edit the position and dimensions (and other properties of the shape) using numeric keyboard input.

Adjust the order in which the shapes are patterned (and displayed) by dragging their nodes in the overview tree. Alternatively, right-click on the shape in the overview tree and use the menu items **Move Up**, **Move Down**, **Move to Top**, and/or **Move to Bottom** to adjust the order.

Grid and Snap

A grid with drag handles that snap is available to facilitate shape editing in the viewer. The grid can be enabled via **View > Grid**.

The grid will scale dynamically with the zoom level with no need to specify the grid-spacing. If you need a higher grid density, just zoom in.

Basic Shapes

The basic shapes are the straight-forward geometrical shapes and can be considered as the NanoBuilder primitives.

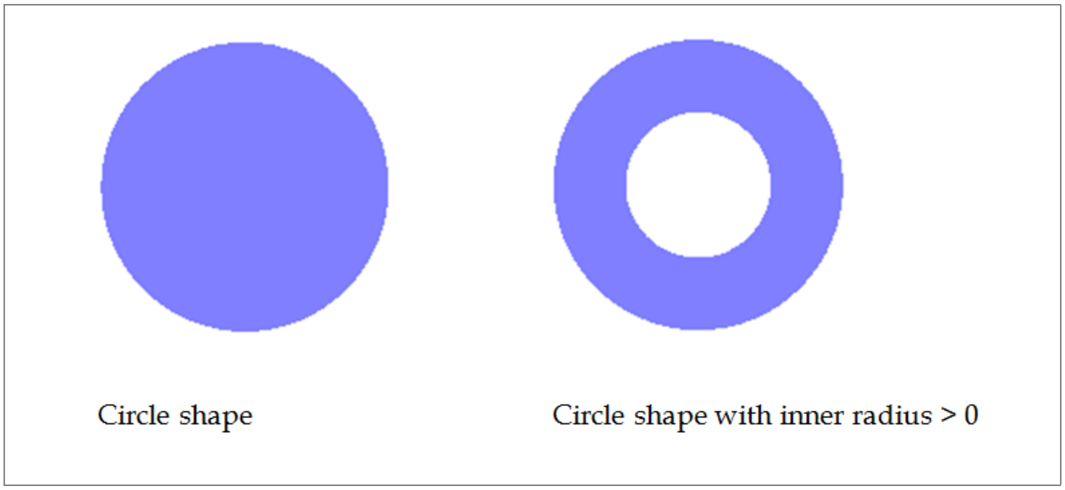
Circle

The circle represents a solid disk. If the inner radius has a value greater than 0, it becomes a donut (a circle with a line width that is equal to the outer radius minus the inner radius).

Shape-Specific Properties

- Outer radius
- Inner radius

Figure 5-2 Shape-Specific Properties



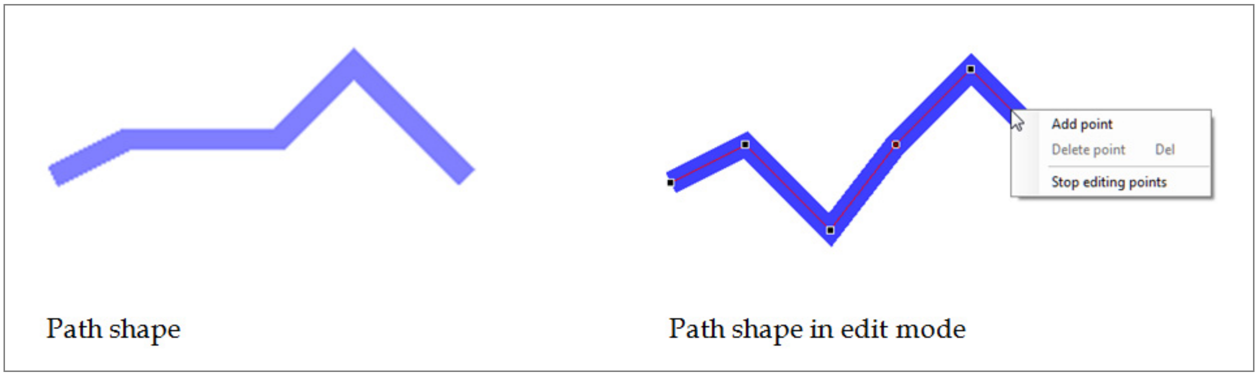
Circle shape

Circle shape with inner radius > 0

Path

A path is a single line or a number of connected lines, all with the same line width. To edit the points (or add/delete points), select the path shape, right-mouse click and select **Edit Points**. The shape will now be shown in **Edit Mode**, allowing you to drag the points. Add points by dragging the red line between two points; this will insert a new point between the two points. Alternatively, enter the exact point coordinates in the shapes property area.

Figure 5-3 Path



Path shape

Path shape in edit mode

Shape-Specific Properties

- **EndStyle:** Specifies how the two ends are drawn (rounded or straight)
- **Width:** The line width of the path
- **Points:** The end points of the line segments that define the path

TIP	When you want to close a path shape, define the first and last point to be at the same position, and choose them such so they are on a straight line (between the second point and second to last point).

Rectangle

The rectangle represents a solid rectangular area, specified by its width and height.

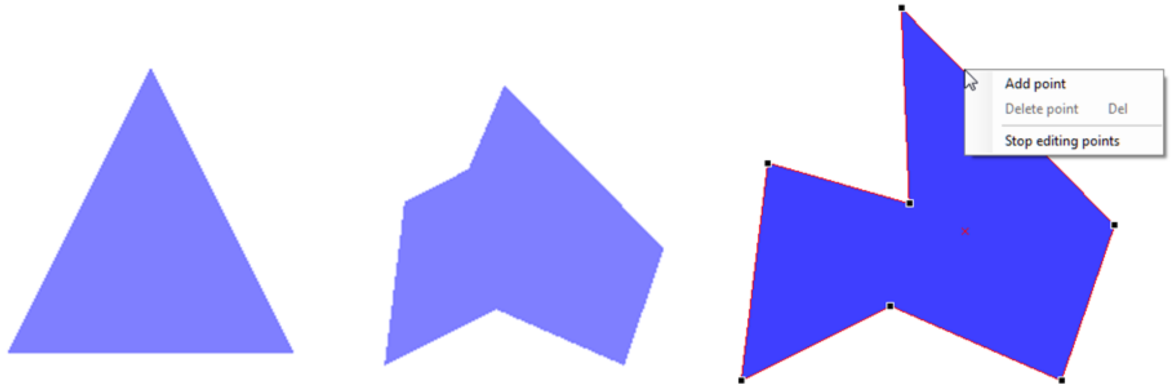
Shape-Specific Properties

- **Width:** Horizontal dimensions
- **Height:** Vertical dimensions

Polygon

A polygon is a solid multi-line shape, varying from three-point triangle to any number of points. To edit the points (or add/delete point), select the polygon, right-mouse click, and select **Edit Points**. The shape is now shown in **Edit Mode**, with points that drag. Points can be added by dragging the red line between two points. This will insert a new point between the two points. Alternatively, enter the exact point coordinates in the shapes property area.

Figure 5-4 Polygon



Triangle: a 3-point polygon

A polygon with 7 points

A polygon in edit mode

Shape-Specific Properties

The points are the end points of the line segments that circumference the polygon.

Text

With the text shape the design can be annotated with text labels; these labels are patterned and behave just like any other shape.

Some Text

Shape-Specific Properties

- **Alignment:** Specifies how the text is placed with respect to the position
- **Font:** Specifies font type, style, and size
- Text–the text to display and pattern

Composite Shapes

Composite shapes are shapes that are a combination of other shapes. The specific composite shape defines how the shapes are combined. **Boolean Shapes** and **Reference Shapes** can be identified within the composite shapes.

Reference shapes implement the concept of re-using copies of an existing shape (the template). Such references are based on a transformation or repetition of one of the shapes that has been placed in the Templates collection (see *"Reference" on page 68*).

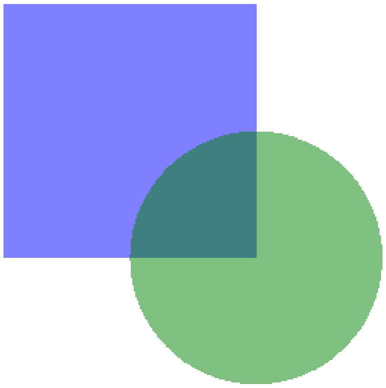
Boolean shapes use logical operations like AND, OR, XOR to combine the child shapes. The child shapes can be composed by dragging the shapes into the composite within the tree view. Though Boolean operations are typically applied to two operands, in NanoBuilder any number of child shapes is allowed.

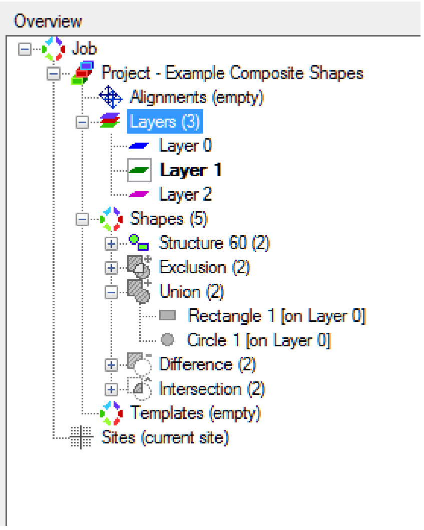
The individual shapes that make up the composite can be edited independently. With Boolean Shapes, all child shapes will inherit the layer of the composite.

Composites can be nested allowing you to create complex shapes.

Structure

A structure is a **collection of shapes**, typically used for grouping shapes in a functional block. The individual shapes can reside on different layers.



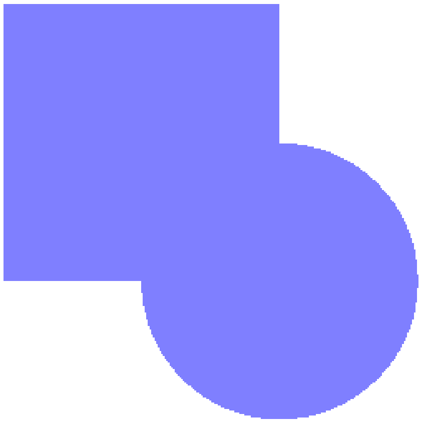


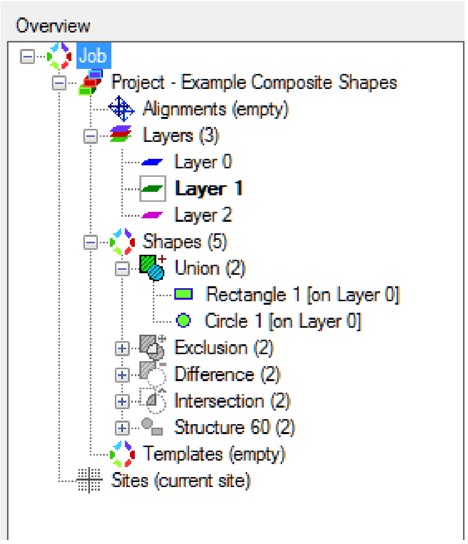
Shape-Specific Properties

If **Always pattern parallel** is selected, the shapes within the structure are patterned in a parallel fashion, even if the layer is set to serial patterning. This means the whole structure is treated as if it was a single shape. Patterning is still by layer, so only the shapes on the currently executing layer are combined. In previous versions, the structure was called "shape collection".

Union

The union shape is the equivalent of the Boolean OR operation, merging the constituents into one big shape. Unlike the Structure, overlapping parts are not patterned twice.



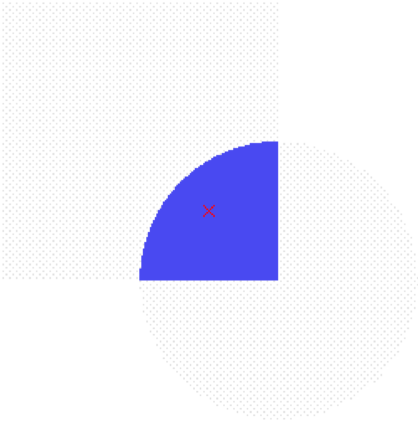


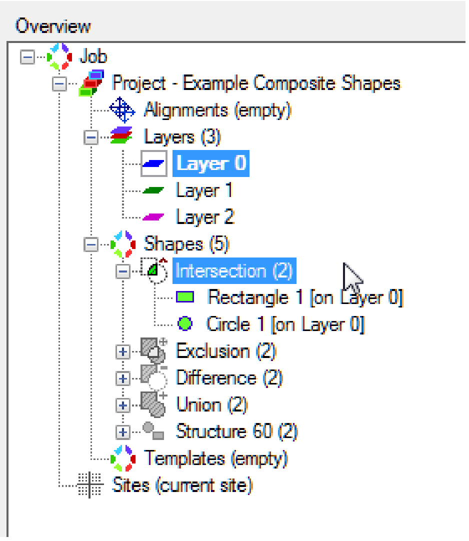
Overview

- Job
  - Project - Example Composite Shapes
    - Alignments (empty)
    - Layers (3)
      - Layer 0
      - **Layer 1**
      - Layer 2
    - Shapes (5)
      - Union (2)
        - Rectangle 1 [on Layer 0]
        - Circle 1 [on Layer 0]
      - Exclusion (2)
      - Difference (2)
      - Intersection (2)
      - Structure 60 (2)
    - Templates (empty)
  - Sites (current site)

Intersection

The intersection shape is the equivalent of the Boolean AND operation, only patterning the overlapping parts of the shapes.



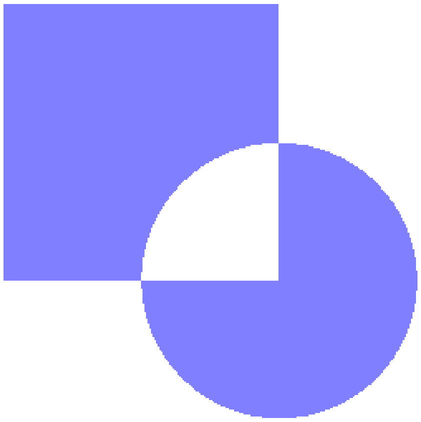


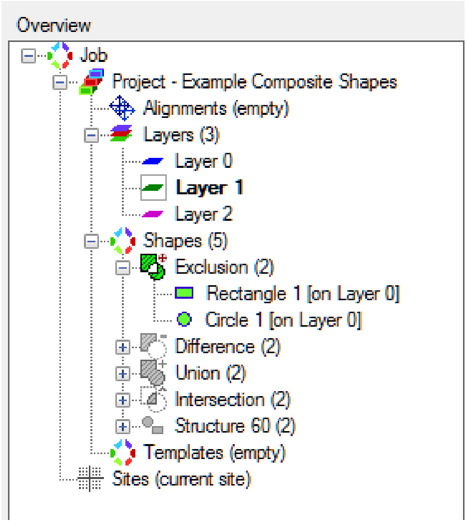
Overview

- Job
  - Project - Example Composite Shapes
    - Alignments (empty)
    - Layers (3)
      - **Layer 0**
      - Layer 1
      - Layer 2
    - Shapes (5)
      - Intersection (2)
        - Rectangle 1 [on Layer 0]
        - Circle 1 [on Layer 0]
      - Exclusion (2)
      - Difference (2)
      - Union (2)
      - Structure 60 (2)
    - Templates (empty)
  - Sites (current site)

Exclusion

The exclusion shape is the equivalent of the Boolean XOR operation, patterning everything except for the overlapping parts of the shapes. This is the inverse of the Intersection shape.





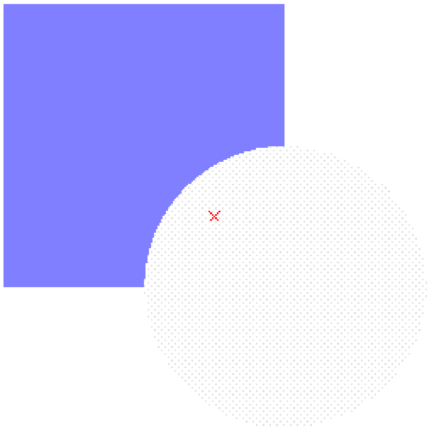
Overview

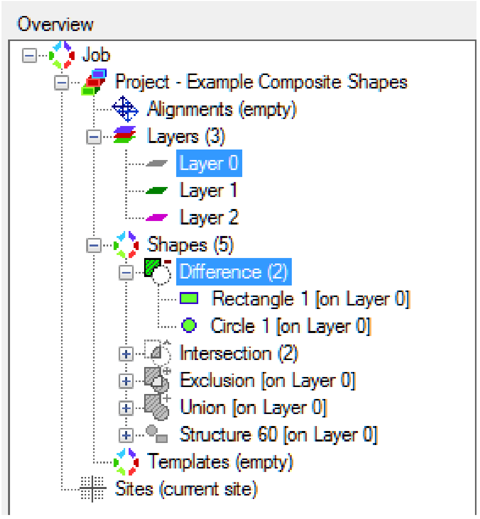
- Job
  - Project - Example Composite Shapes
    - Alignments (empty)
    - Layers (3)
      - Layer 0
      - **Layer 1**
      - Layer 2
    - Shapes (5)
      - Exclusion (2)
        - Rectangle 1 [on Layer 0]
        - Circle 1 [on Layer 0]
      - Difference (2)
      - Union (2)
      - Intersection (2)
      - Structure 60 (2)
    - Templates (empty)
  - Sites (current site)

Difference

The Difference shape is the equivalent of subtraction operation, removing the parts from the first shape that are overlapped by the other shapes.

The difference shape can be used to invert part of a design: use a rectangle as the first shape to define the 'exclusion zone' (which is milled away), in which the other shapes will not be patterned.





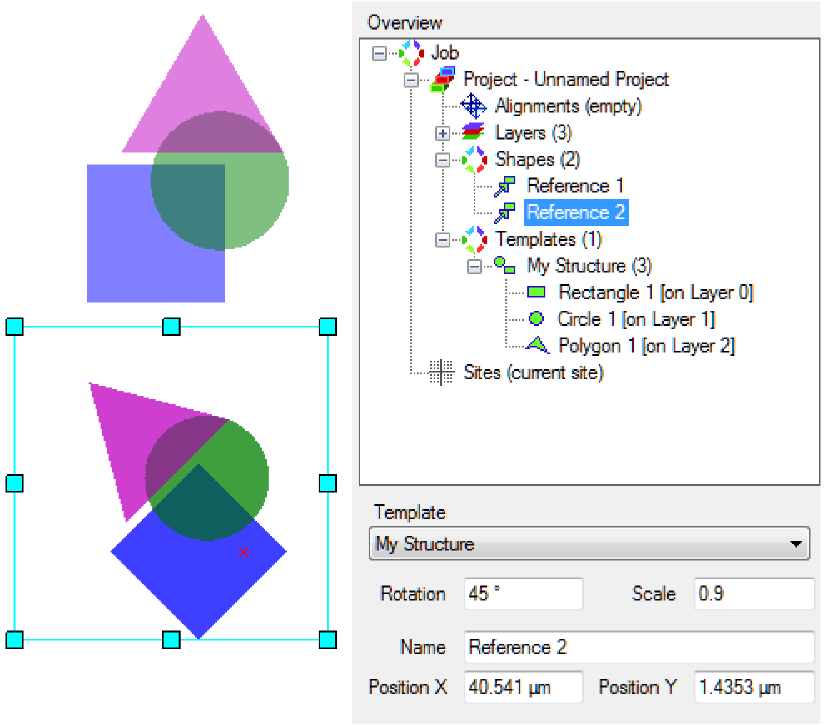
Overview

- Job
  - Project - Example Composite Shapes
    - Alignments (empty)
    - Layers (3)
      - Layer 0
      - Layer 1
      - Layer 2
    - Shapes (5)
      - Difference (2)
        - Rectangle 1 [on Layer 0]
        - Circle 1 [on Layer 0]
      - Intersection (2)
      - Exclusion [on Layer 0]
      - Union [on Layer 0]
      - Structure 60 [on Layer 0]
    - Templates (empty)
  - Sites (current site)

Reference

The Reference shape holds the concept of re-using an existing shape (the template) at different locations and optionally adjusting its size and/or rotation. In order to re-use another shape, that shape first has to be promoted to a template, which is accomplished by dragging the shape to the templates node in the tree view.

The image below shows two instances of a reference shape; with and without a rotational offset. In this example the referenced shape is a structure.



Template: My Structure

Rotation: 45 °
Scale: 0.9

Name: Reference 2

Position X: 40.541 µm
Position Y: 1.4353 µm

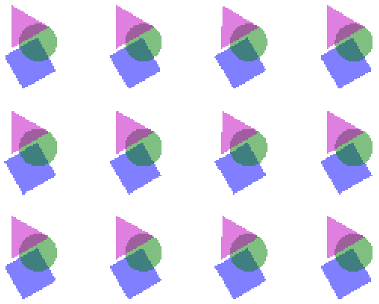
Shape-Specific Properties

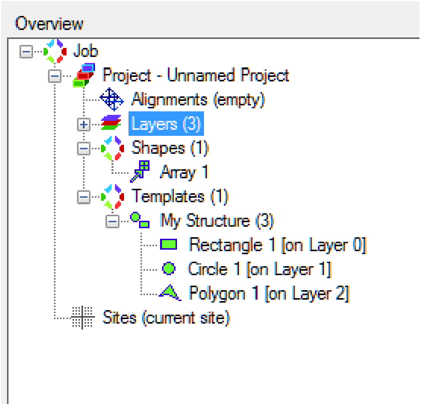
- **Template:** The shape that is used as the template for this shape
- **Rotation:** Angle to rotate the template with (default is 0)
- **Scale:** Scale factor to increase or decrease the size of the template (default is 1)

Array

The Array shape allows you to repeat in existing shape in a regular grid. Optionally the repeated shape–which has to be a template–can be rotated and rescaled when it is repeated in the grid.

The following image is a shape array using a 3 x 4 grid and a rotational offset. In this example the repeated shape is a structure.





Shape-Specific Properties

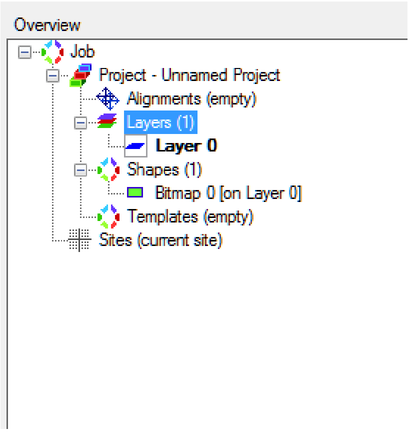
- **Template:** The shape that should be repeated in the array (the referenced template)
- **Rotation:** Angle to rotate the template with (default is 0)
- **Scale:** Scale factor to increase or decrease the size of the template (default is 1)
- **Columns, rows:** The number of columns and rows for repeating the template
- **Pitch X,Y:** The spacing between the repeated shapes
- **Center X,Y:** This is an alternative representation of the position of the array, using the center as the point of reference; this facilities aligning the center of the array to a specific position
- **Always pattern parallel:** If selected, the shapes within the array are patterned in a parallel fashion, even if the layer is set to serial patterning

Special Shapes

The special shapes are shapes that deviate from the general concept of shapes, for example in how they are rastered or how process parameters are applied.

Bitmap Shape

The bitmap shape is a pattern that uses an image from disk as the basis for patterning. The different gray scale values of the pixels are translated to specific dwell times at the corresponding pixel locations, such that after patterning an imprint of the image remains. The result of the Bitmap Shape is equivalent to patterning a bitmap in the xT UI.



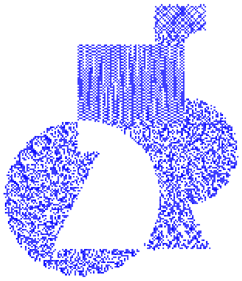
Overview
- Job
  - Project - Unnamed Project
    - Alignments (empty)
    - Layers (1)
      - **Layer 0**
    - Shapes (1)
      - Bitmap 0 [on Layer 0]
    - Templates (empty)
  - Sites (current site)

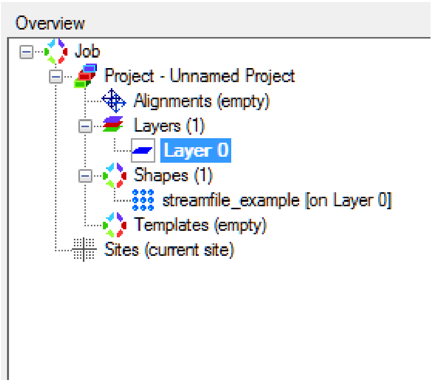
Shape-Specific Properties

- **Bitmap:** The image used for the shape; to change files, click the **[...]** button in the field. A bitmap shape is always patterned in a row-by-row serpentine, starting at top-left corner.
- **Physical height and width:** The actual dimensions of the image when it is patterned
- **Pixel:** The size of a pixel when patterned (pixel size = physical size/bitmap resolution). The maximum possible dwell time of a pixel–if it has value 255–is the dwell time as set for the layer.

StreamFile Shape

The StreamFile shape allows you to add an existing stream file (a native xT format for specifying pattern points) to be included in the design. The stream file has to be specified when the shape is added.





Overview

- Job
  - Project - Unnamed Project
    - Alignments (empty)
    - Layers (1)
      - Layer 0
    - Shapes (1)
      - streamfile_example [on Layer 0]
    - Templates (empty)
  - Sites (current site)

- The dwell times of the points in the stream file are not determined by its layer, but merely by the times specified for each point in the stream file.
- The number of passes is determined by the layer. When loading a stream file the number of passes for the layer is initially set to the value from the stream file, but you can edit this afterwards.
- Because the number of points in a stream file can be considerable, not all points are drawn for performance reasons. They may lead to interference patterns in the display. Zooming in to scale of a pattern point will show all points within the view port.

Sites

By default, NanoBuilder executes the Project at the current stage location. By adding one or more sites to the Job, it is possible to:

- Execute the same Project at multiple stage locations (simplest use case).
- Do perpendicular patterning with both the e-beam and i-beam, by tilting the stage per beam (see *"Tilt per Beam" on page 76*).
- Create a design that spans multiple write fields (see *"Stitching Multiple Write Fields" on page 30*).

Site List

The SiteList contains zero or more sites. If it is empty, the Project is executed at the current position, otherwise the sites are visited one by one (starting at the topmost one in the list). Drag the sites up or down to change the order.

Site

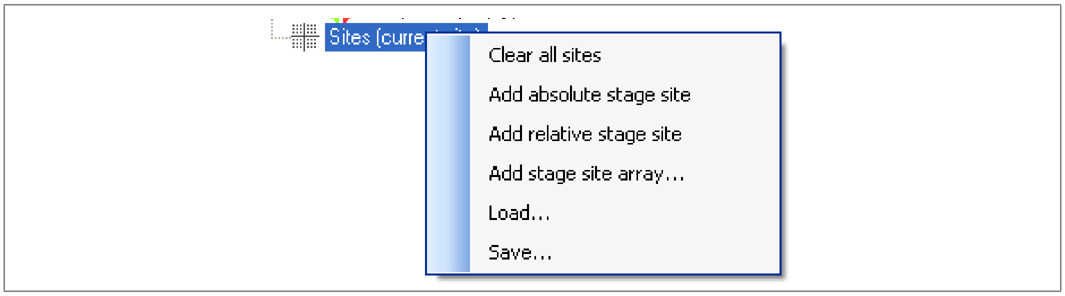
A site describes a stage location. There are two flavors:

- Absolute sites define an absolute position. For example, move the stage tilt-axis to 0°.
- Relative sites define a change in position. For example, move the stage x-axis by 100 µm.

For both, the user can define which axes need to move, e.g., move the x- and y-axis, but leave the z-, tilt- and rotation-axis where they are. It is also possible to define a site that changes no axes at all (leaves the stage where it is). You can mix relative and absolute sites.

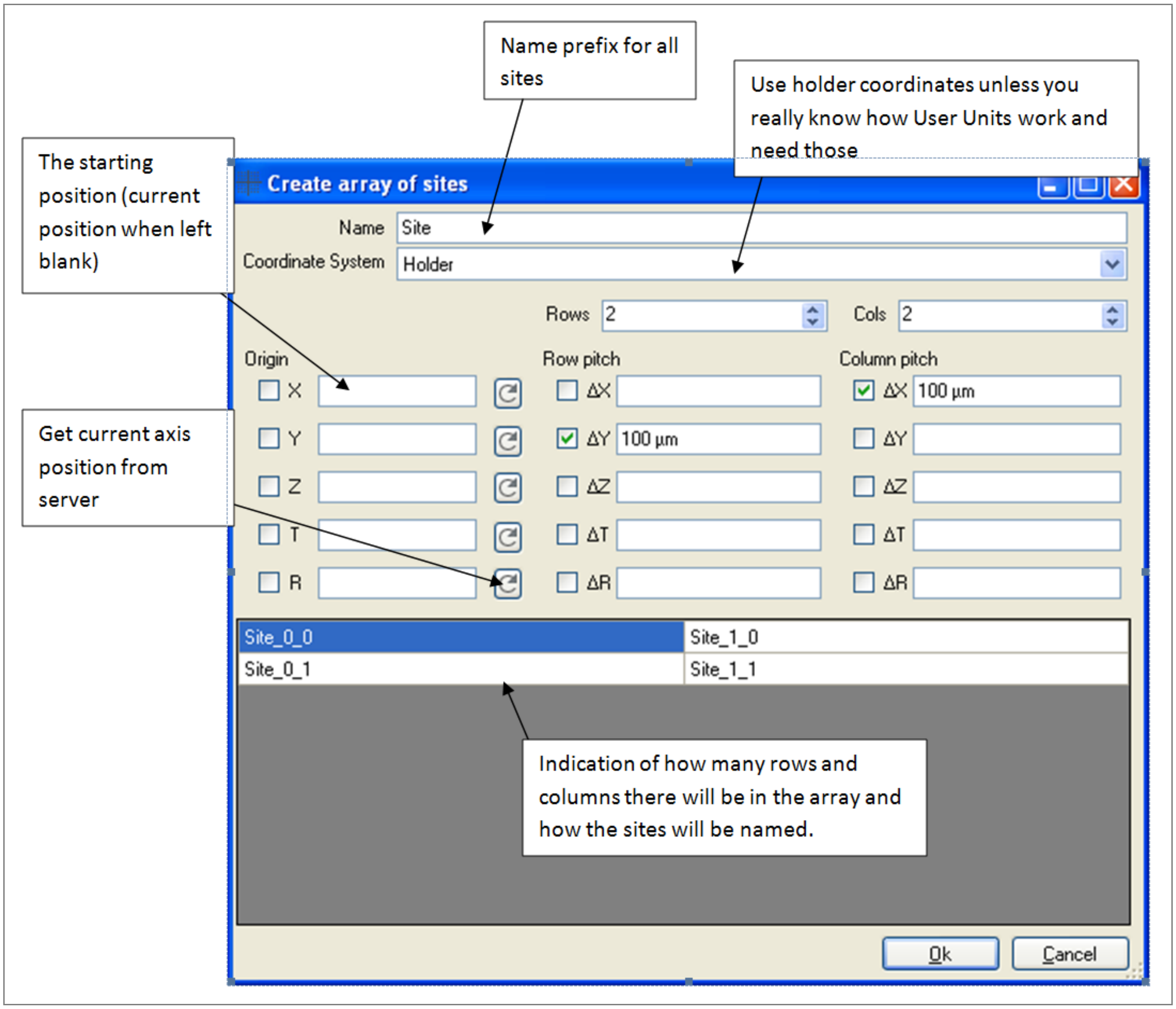
You add sites through the context menu of the SiteList (right-click the site list).

Figure 5-5 Site List



You can add multiple relative sites efficiently by choosing **Add stage site array…**; this will open a dialog where you can specify the number of rows and columns and the distance to move per row and column.

Figure 5-6 Create Array of Sites



Name prefix for all sites

Use holder coordinates unless you really know how User Units work and need those

The starting position (current position when left blank)

Get current axis position from server

Create array of sites

Name: Site

Coordinate System: Holder

Rows: 2

Cols: 2

Origin		Row pitch		Column pitch	
☐ X		☐ ΔX		☑ ΔX	100 µm
☐ Y		☑ ΔY	100 µm	☐ ΔY	
☐ Z		☐ ΔZ		☐ ΔZ	
☐ T		☐ ΔT		☐ ΔT	
☐ R		☐ ΔR		☐ ΔR	

Site_0_0	Site_1_0
Site_0_1	Site_1_1

Indication of how many rows and columns there will be in the array and how the sites will be named.

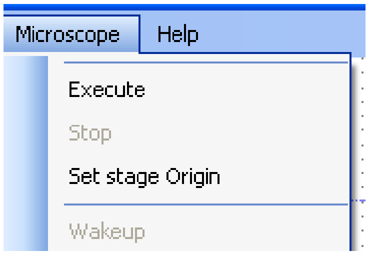
By default the x-axis is moved per column and y-axis per row. By setting this up differently you could, for example, also sweep the tilt axis.

The Origin column is empty by default; this will result in the first site being relative, with no change for any axis (leaves the stage where it is). If instead you specify an (absolute) stage position for one or more axes then the first site will be an absolute site. You can use the **Reload** button to copy the current stage location (when connected to the microscope) for the corresponding axis.

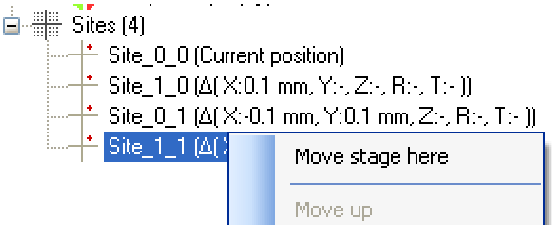
The dialog just creates a list of sites; it is not possible to re-run the dialog to change the sites. Instead you need to clear the existing sites and define a new list from scratch. You can manually change, delete or re-arrange the sites after creation.

Origin

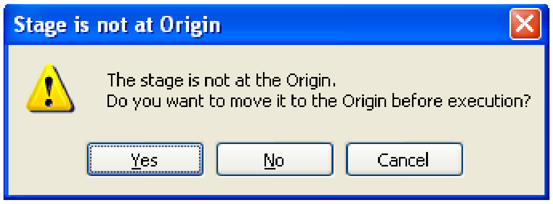
When using relative sites the concept of the stage Origin becomes important: this is the position relative to which the first move is made. You can specify the current stage position to be the origin by selecting **Microscope**, **Set stage Origin** in the menu. If you don't do this step, then the first move (e.g., by executing the Job) will automatically set the current position to be the stage Origin.



Having the Origin means you can right-click any site and select **Move stage here**. Conceptually all the (relative) moves are made one by one until the selected site is reached, starting from the Origin. This means you can move to the last site to check where that is on the sample, then move back to the first site before starting execution. And after the job has executed you can visit any site for inspection by right-clicking and selecting **Move stage here**.



You may get the warning dialog below when starting Job execution. This happens when the Origin has been defined and the current position is elsewhere. Selecting **Yes** will drive back to the previously defined Origin; **No** will use the current position as the Origin, and Cancel will stop execution.

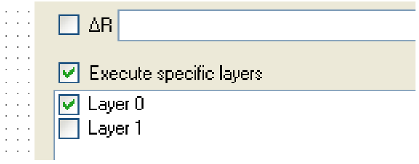


The stage is not at the Origin.
Do you want to move it to the Origin before execution?

When using absolute sites, the Origin is not used; when mixing absolute and relative sites, the Origin defines the starting point for any axes that have not been set yet by an absolute site.

Layers per Site

By default, the entire Project is executed at each site. By selecting one or more sites, then selecting **Execute specific layers** and selecting one or more layers to execute, you can define per site which layers need to be executed. In principle, each site could execute only its own layer or layers, but usually sites will share some layers.



☐ ΔR

☑ Execute specific layers

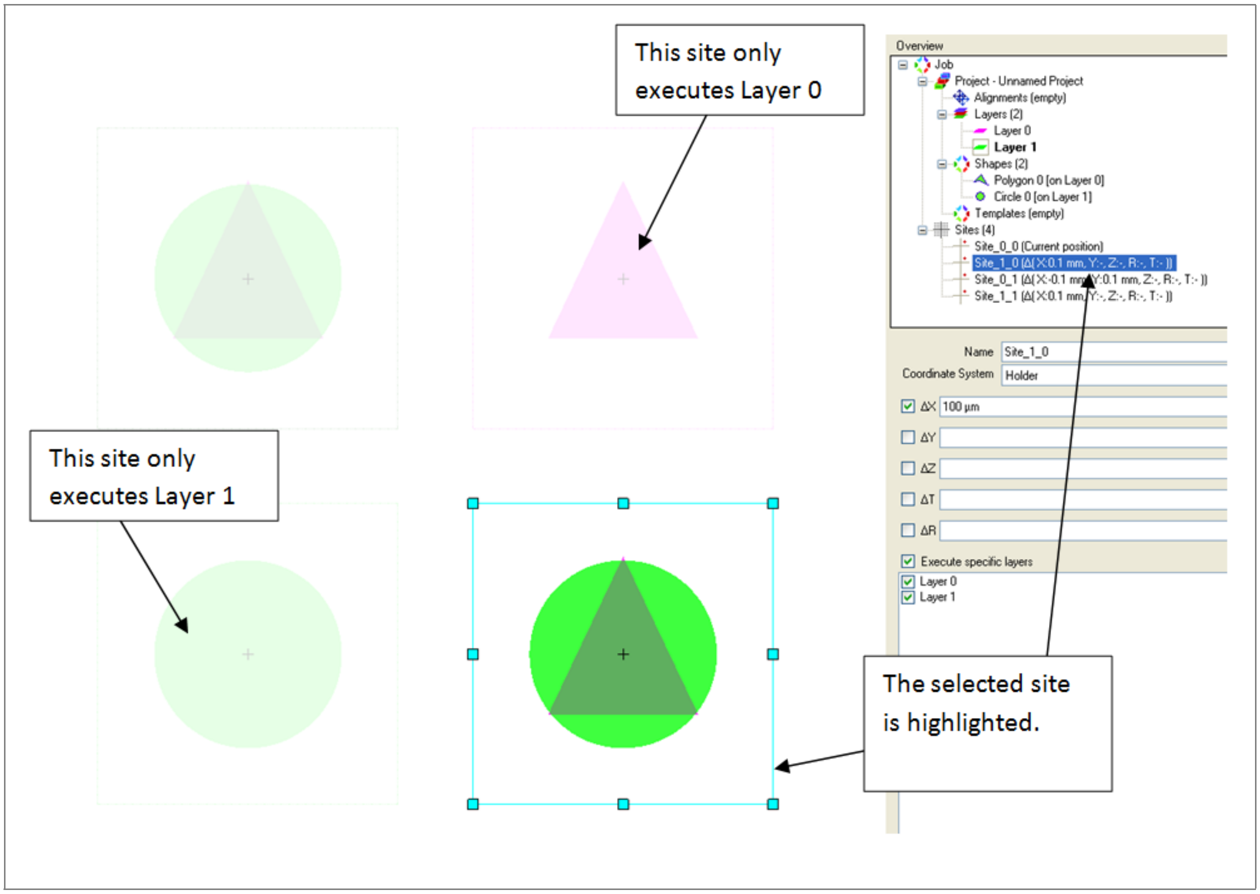
☑ Layer 0

☐ Layer 1

Visualization

By default, the zoom level only shows the first site. By zooming out, you can see where the other sites are relative to the first site. Only the layers selected for execution are visualized at each site; this should help to verify that the right layers have been selected.

Figure 5-7 Visualization



This site only executes Layer 0

This site only executes Layer 1

The selected site is highlighted.

Name Site_1_0
Coordinate System Holder
☑ ΔX 100 µm
☐ ΔY
☐ ΔZ
☐ ΔT
☐ ΔR
☑ Execute specific layers
☑ Layer 0
☑ Layer 1

Tilt per Beam

To let both beams be perpendicular to the specimen, the stage needs to tilt between 0° (SEM) and 52° (FIB). When patterning with both beams, you will need at least two layers; one for the SEM and one for the FIB. Perpendicular patterning can be achieved by also creating two absolute sites, one setting the stage tilt to 0° and the other to 52°, and letting these execute the SEM and FIB layer, respectively. You can even add an alignment to the second layer, letting it search for the structure created by the first layer, and in this way align the beams to each other.

Multiple Write Fields

A typical scenario is spanning a large design with multiple write fields, using stage moves between the write fields (stitching). Typically, such a design consists of a repeating structure; in this example, we assume that a single layer can create a cell of the design, and that stage moves are used to stitch as many of these cells together as needed to create the entire structure.

Stitching an array of cells typically shows three different situations:

1. At the first site, there is nothing to align to yet, so we just need to execute the design (to create the first cell).
2. At the second site, you need to align to the previous site to remove the stage inaccuracy. In a similar way the third site can align to the second one and by repeating this concept we can create the whole first row or first column. All these sites can reuse the same alignment.
3. When starting on the second row or column, you need to align in a different direction, i.e., to a site in the previous row or column. This requires a second alignment, that is set up differently from the first one.

One way to achieve this with a single Job is to define three layers (with identical Process parameters):

- **Layer 1:** Uses the alignment that aligns to the previous site in the same row, setting the beam shift to correct for the stage error. It has no shapes, but the beam shift will be inherited by the following layers so they will also be corrected.
- **Layer 2:** Uses the alignment that aligns to the site in the same column but the previous row, again setting the beam shift and not having any shapes.
- **Layer 3:** Contains the actual shapes to pattern (to create a single cell).

And to set the layers-per-site as follows:

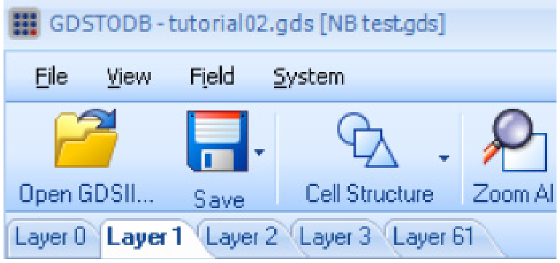
- The first site only executes Layer 3, as there is nothing to align to yet.
- The sites for the first row execute Layer 1 (to align to the previous site in this row, starting with the first site) and Layer 3 (to create the cell).
- The remaining sites execute Layer 2 (to align to the site in the same column but in the previous row) and Layer 3 (to create the cell).

Creating Stream Files

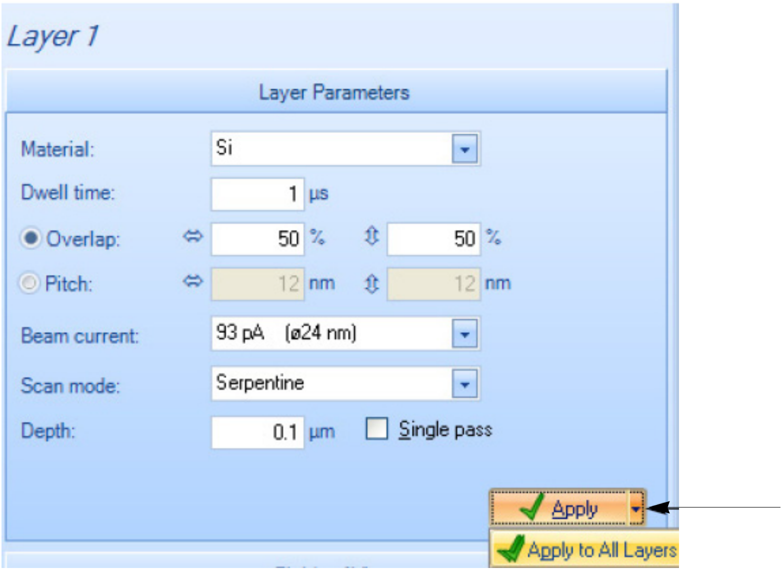
This section shows how to create stream files with GDStoDB and import them into NanoBuilder.

Creating Stream Files in GDStoDB

1. Start GDStoDB.
2. In the System menu, select the tool type you will use (e.g., *Helios NanoLab*™).
3. Go to **File > Open GDSII** and navigate to *tutorial02.gds* and click **Open**.
4. Select **Layer 1** by clicking on the corresponding tab.

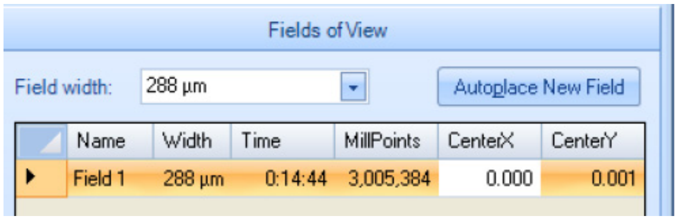


5. In the Layers Parameters dialog box that displays, make the following selections:
   - **Material:** Si
   - **Dwell time:** 1 µs
   - **Overlap:** 50%
   - **Beam current:** 93 pA
   - **Scan mode:** Serpentine
   - **Depth:** 0.1 µm



Material: Si
Dwell time: 1 µs
● Overlap: ⇔ 50 % ⇕ 50 %
○ Pitch: ⇔ 12 nm ⇕ 12 nm
Beam current: 93 pA (ø24 nm)
Scan mode: Serpentine
Depth: 0.1 µm ☐ Single pass

6. Click the down arrow next to the **Apply** button to display the **Apply To All Layers** button and click the button.
7. Select **Layer 2** and change the beam current to 920 pA (for this layer only).
8. Select **Layer 3** and change the beam current to 2.8 nA (for this layer only).
9. In the Fields of View dialog box, select 288 µm for Field width.



Field width: 288 µm

	Name	Width	Time	MillPoints	CenterX	CenterY
▶	Field 1	288 µm	0:14:44	3,005,384	0.000	0.001

10. Go to Add field and click in the center of the structure to create a field.
11. Select the CenterX box in the Field 1 row that was just added to the Fields of View box and change the value to 0. Do the same for CenterY.
12. Repeat Steps 11 and 12 for Layers 1 and 2.
13. Navigate to **File > Save > ASCII Stream File** and open the Browse for Folder dialog box.
14. Select the folder that contains the *tutorial02.gds* file (or create a new folder) and click **OK**. This will create two files in the selected folder.
15. Select **Layer 2** and repeat the above step, using the same folder.

16. Repeat for Layer 3.

The folder should now contain 6 files:

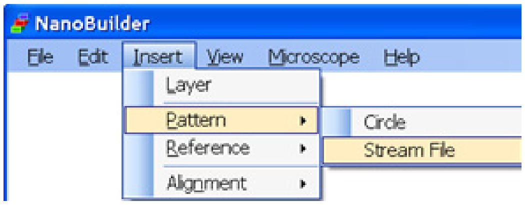
- Layer 1 - Field 1 [288µm 93pA].str
- Layer 1 - Field 1 [288µm 93pA].txt
- Layer 2 - Field 1 [288µm 920pA].str
- Layer 2 - Field 1 [288µm 920pA].txt
- Layer 3 - Field 1 [288µm 2.8nA].str
- Layer 3 - Field 1 [288µm 2.8nA].txt

Load GDStoDB Output into NanoBuilder

To add a stream file to a job, you must first have a layer to which to add it.

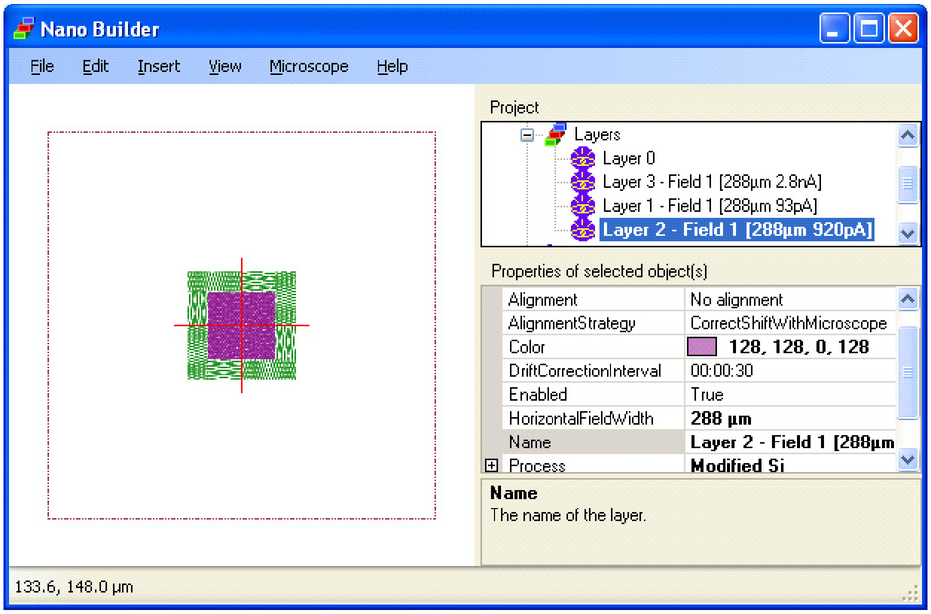
- If you load a GdsToDb.txt output file, NanoBuilder will create a layer based on the settings in the file and will load the stream file into that layer.
- If you load the .str file, it will end up in the active layer. You will need to set the layer parameters manually.

1. Start NanoBuilder.
2. Select Layer to create a new layer.
3. Select **Insert > Special Shapes > Stream File**.



4. In the Open dialog that appears, navigate to the folder that contains the result of *Step 16*, above. Select the three *.txt* files and click **Open**.

5. After loading the stream files, you should see three new layers.



- Layers
  - Layer 0
  - Layer 3 - Field 1 [288µm 2.8nA]
  - Layer 1 - Field 1 [288µm 93pA]
  - **Layer 2 - Field 1 [288µm 920pA]**

Properties of selected object(s)

Alignment	No alignment
AlignmentStrategy	CorrectShiftWithMicroscope
Color	🟪 **128, 128, 0, 128**
DriftCorrectionInterval	00:00:30
Enabled	True
HorizontalFieldWidth	**288 µm**
Name	**Layer 2 - Field 1 [288µm**
⊞ Process	**Modified Si**

Name
The name of the layer.

133.6, 148.0 µm

Executing the Job

Select **Microscope > Execute** and begin patterning.

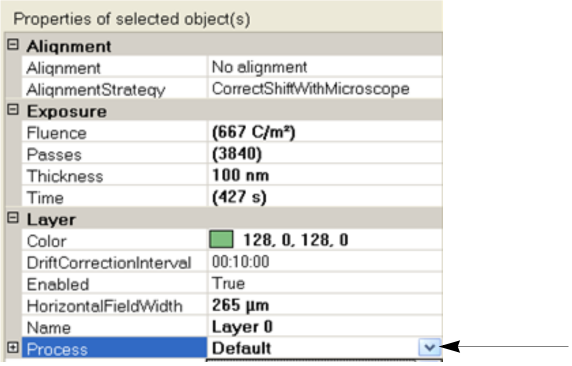
The job will now be executed. The status bar at the bottom of NanoBuilder displays the overall progress (0…100%), as well as a progress bar for the current activity.

14.6, -271.5 µm Finished executing project.

Setting Default Processes

A *process* in NanoBuilder contains all the settings that should be applied when patterning a layer, i.e., the beam and the beam settings, the patterning parameters, and the GIS and its parameters. This approach achieves two goals:

- Set all the parameters at once, without having to know any of the details, by selecting a predefined process from a list.

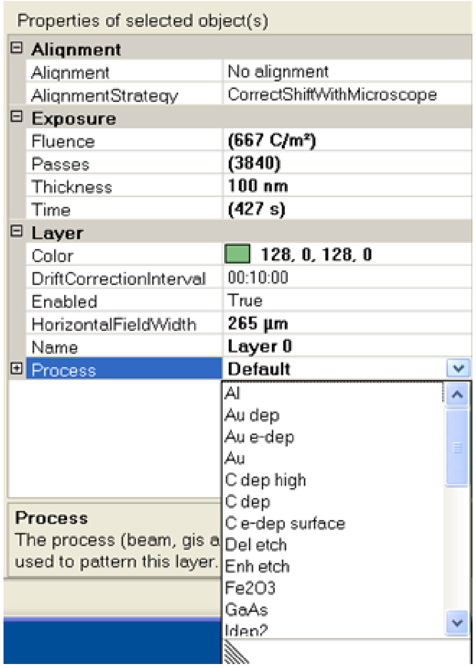


Properties of selected object(s)

⊟ **Alignment**	
Alignment	No alignment
AlignmentStrategy	CorrectShiftWithMicroscope
⊟ **Exposure**	
Fluence	**(667 C/m²)**
Passes	**(3840)**
Thickness	**100 nm**
Time	**(427 s)**
⊟ **Layer**	
Color	🟩 **128, 0, 128, 0**
DriftCorrectionInterval	00:10:00
Enabled	True
HorizontalFieldWidth	**265 µm**
Name	**Layer 0**
⊞ Process	**Default**

or

- Easily fine-tune any of the parameters by expanding the Process.



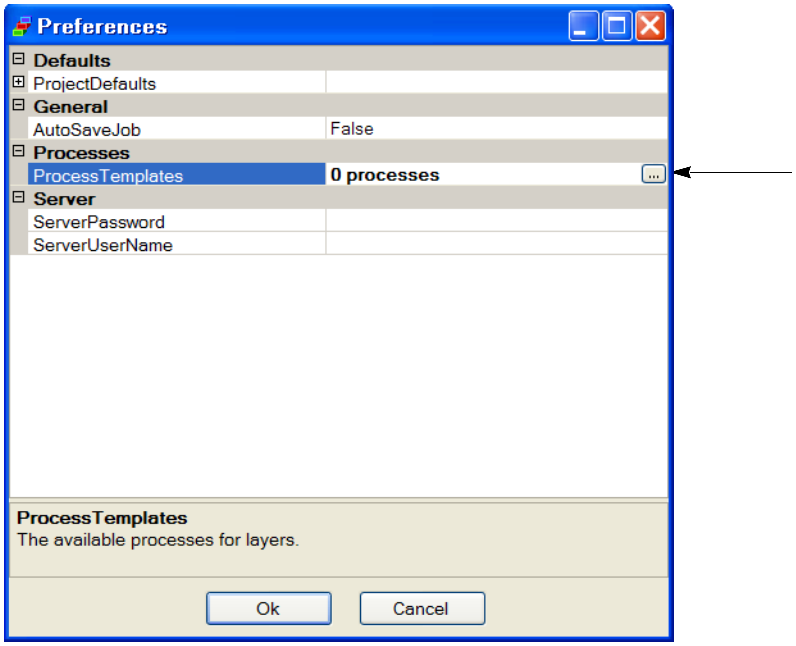
Properties of selected object(s)

⊟ **Alignment**	
Alignment	No alignment
AlignmentStrategy	CorrectShiftWithMicroscope
⊟ **Exposure**	
Fluence	**(667 C/m²)**
Passes	**(3840)**
Thickness	**100 nm**
Time	**(427 s)**
⊟ **Layer**	
Color	🟩 **128, 0, 128, 0**
DriftCorrectionInterval	00:10:00
Enabled	True
HorizontalFieldWidth	**265 µm**
Name	**Layer 0**
⊞ Process	**Default**

Process
The process (beam, gis a
used to pattern this layer.

Changing Available Processes

1. Open the Preferences dialog box by selecting **File > Preferences**.
2. Select the field to the right of ProcessTemplates (where it says “0 processes” in the example below) to display the Browse button.



ProjectDefaults

AutoSaveJob False

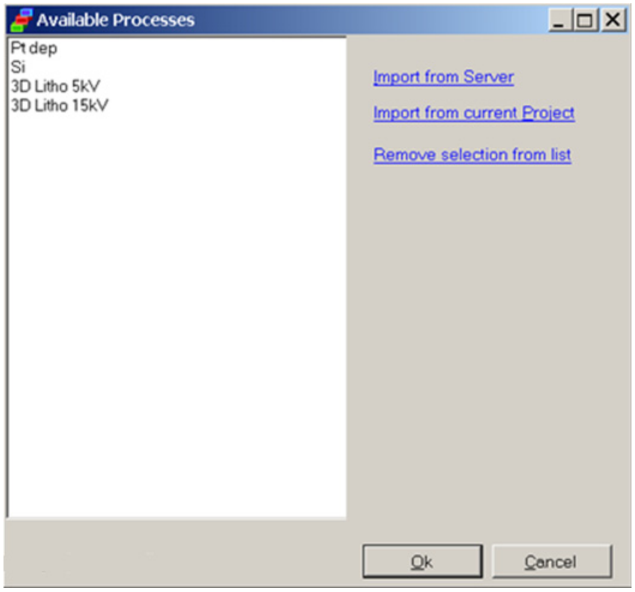
ProcessTemplates **0 processes**

ServerPassword

ServerUserName

ProcessTemplates
The available processes for layers.

3. Click the Browse button to display the Available Processes dialog box.



Pt dep
Si
3D Litho 5kV
3D Litho 15kV

Available processes are shown on the left.

- **Import from Server:** This link is enabled if NanoBuilder is connected to a microscope. Selecting it will import all the patterning applications from xT to equivalent processes (as far as possible, as the applications do not specify a beam or its settings).
- **Import from Current Project:** This link will import the processes from the layers in the currently open project in NanoBuilder (also see Editing a process below).
- **Remove Selection from List:** This link will remove the items you have selected in the list. This is useful when importing more items than you need; trimming the ones you won’t be using makes it easier to find the desired process in the list.

4. Click **OK** to store the new list, which you can use in any project. The list is stored per user (i.e. not as part of the current project), so if you log on as a different user, you will see a different list.

Editing a Process

It is easy to modify a layer's process. However, it is important to realize that these changes only influence that layer. In other words, if two layers are assigned the “Pt dep” process and you edit the process for one of these layers, the changes will not show up in the other layer. Similarly, the changes will not show up in a later layer that gets assigned the “Pt dep” process. The way to make the changes available to other layers is to change the name of the process (give it a unique name), then select the *Import from Current Project* link as described above.

NOTE	If you change a process called “ABC”, its name will change to “Modified ABC” to indicate it no longer corresponds to the original ABC. By typing in a new name, the “Modified” is removed, as it is now clearly a different process.

6 Troubleshooting

Overview

Topics in this chapter include:

- *"FEI Customer Service" on page 85*
- *"Known Issues" on page 85*

FEI Customer Service

For help, contact FEI Customer Service at 1-866-693-3426 (US) or email *cshelpdesk@fei.com*.

Known Issues

Table 6-1 lists the known issues along with workarounds for each.

Table 6-1 Known Issues (1 of 4)

Issue	Workaround
When a particular thickness is specified for a given layer in a NanoBuilder job, the actual thickness can vary from this value.	There are two main causes for this variation: • NanoBuilder does not read the actual current before calculating patterning times. Thus, if the aperture is delivering more current than its nominal value, the does applied to the sample also will be off by that factor. Apertures allow more current through as they age (wear out), and this will lead to deeper mills or thicker than expected depositions. • Beam chemistry depends on the precursor flux. If the needle alignment is off, or if the precursor has aged, the actual process speed will differ from the expected value. Perform a test exposure of critical layers, and if the actual mill depth or deposition height is different from what is expected, adjust the layer's thickness correspondingly. For example, if the requested thickness is 1 µm but the actual depth is 1.2 µm, change the layer thickness to 1/1.2 = 0.833 µm.
NanoBuilder does not support the xT wide screen display.	NanoBuilder sets the display area automatically to fit with the server XT display screen ratio. For example: when setting HFW in NanoBuilder to 150 µm, the height is automatically set to 100 µm for the patterning area.

Table 6-1 Known Issues (2 of 4)

Issue	Workaround
When the xT server is restarted while NanoBuilder is connected, NanoBuilder crashes after you select the Microscope menu.	Shut down NanoBuilder before you start xT.
The graphical display updates slowly when a job containing a large number of shapes is loaded.	Reduce the number of shapes in the design to only those that need to be patterned with NanoBuilder.
Using dwell times shorter than 25 ns will fail with a general error message.	Use larger dwell times.
E-Beam patterning fails with the message: “Cannot set the target value of *ElectronBeamSourceTilt...”*	At the start of job execution NanoBuilder prepares Quad 3 for patterning and Quad 4 for alignments. As part of this preparation, NanoBuilder grabs an image frame with the beam blanked so that sensitive areas on the sample are not unintentionally exposed to the E-Beam. The workaround for this issue turns off blanking and consequently exposes the entire write field to the E-Beam for a short period. **Instructions**: 1. Start Windows Explorer and set the folder path to *C:\Program Files\FEI\NanoBuilder*. 2. Create a backup copy of *NanoBuilder.exe.config*. 3. Open *NanoBuilder.exe.config* in Notepad. 4. Find line <add key="UseSourceTiltForBlankingEBeam" value="true"/>. 5. Set the value property to “false”. <add key=”UseSourceTiltForBlankingEBeam" value="false"/>. 6. Save the file. 7. If NanoBuilder does not start up after the modification to *NanoBuilder.exe.config file*, restore the original file and start over.
Line scan alignments:	
• Linescan alignment for layer fails with the error message: “Cannot access data pipeline for RTM.”	Save your NanoBuilder job and close the application. Restart the xT UI and the xT server, then start the NanoBuilder application again and load the job to continue.
• Line scan alignment limitation	A standard detector mode must be used during line scan alignment.
• Alignment fails because the real-time monitor cannot be accessed.	Restart the xT server.

Table 6-1 Known Issues (3 of 4)

Issue	Workaround
- Line scan alignment fails with insufficient signal error.	Use the build-in diagnostics of the line scan alignment (see *"Line Scan Alignment Properties" on page 47*), try to identify the root cause of the failure. If the transitions are not visible at all in the scan profiles, the scan field may be outside of the alignment's capture range. Either increase the length of the scan lines to increase the capture range, or realign the beam apertures. If the scan profiles contain noise that obscures the transitions, increase the dwell time and the *IntegrationWidth* parameter. If the transitions are too broad, calibrate focus and stigmation for the beam aperture that is being used.
Mode II Snapshot causes job to fail.	Do not perform this action.
SEM blur does not work. If you specify a value for the blur and the SEM as the beam, the blur (defocus) is not applied during patterning.	None.
Unreliable connection on the Quanta™ 3D FEG platform.	Set the ServerPassword in the Preferences dialog so that NanoBuilder can log on to the microscope server with an explicit password.
The immersion lens is not available after closing NanoBuilder.	Closing the NanoBuilder application may switch off the UHR lens. When this happens, restart xT to reactivate the UHR lens and make sure to leave the password field empty in the *Preferences* dialog.
Text:	
- Text shapes do not display after creation.	Change the zoom level of the shape display to force the newly created Text shape to be drawn.
- Text position does not refresh after changing coordinates.	Zoom in/out to refresh the changes.

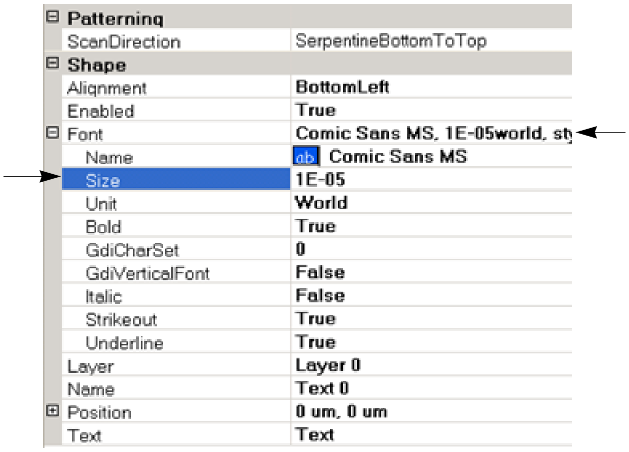
Table 6-1 Known Issues (4 of 4)

<table>
<tr><th>Issue</th><th>Workaround</th></tr>
<tr><td>

- The font size of a Text pattern cannot be set from the Font dialog.
- Text size does not change when using **Insert Pattern > Text > Change Font/Size**.

</td><td>

Expand the Font property and set the size of the font directly.



<table>
<tr><td>⊟ Patterning</td><td></td></tr>
<tr><td>ScanDirection</td><td>SerpentineBottomToTop</td></tr>
<tr><td>⊟ Shape</td><td></td></tr>
<tr><td>Alignment</td><td>BottomLeft</td></tr>
<tr><td>Enabled</td><td>True</td></tr>
<tr><td>⊟ Font</td><td>Comic Sans MS, 1E-05world, st</td></tr>
<tr><td>Name</td><td>ab Comic Sans MS</td></tr>
<tr><td>Size</td><td>1E-05</td></tr>
<tr><td>Unit</td><td>World</td></tr>
<tr><td>Bold</td><td>True</td></tr>
<tr><td>GdiCharSet</td><td>0</td></tr>
<tr><td>GdiVerticalFont</td><td>False</td></tr>
<tr><td>Italic</td><td>False</td></tr>
<tr><td>Strikeout</td><td>True</td></tr>
<tr><td>Underline</td><td>True</td></tr>
<tr><td>Layer</td><td>Layer 0</td></tr>
<tr><td>Name</td><td>Text 0</td></tr>
<tr><td>⊞ Position</td><td>0 um, 0 um</td></tr>
<tr><td>Text</td><td>Text</td></tr>
</table>

Do not use Font dialog box to set font size.

</td></tr>
<tr><td>

- The *Strikeout* and *Underline* properties in the Text Font dialog do not work.

</td><td>Do not use.</td></tr>
</table>