Layout BEAMER

Application Note

JEOL v30
Formatter

Application Note - Formatter JEOL

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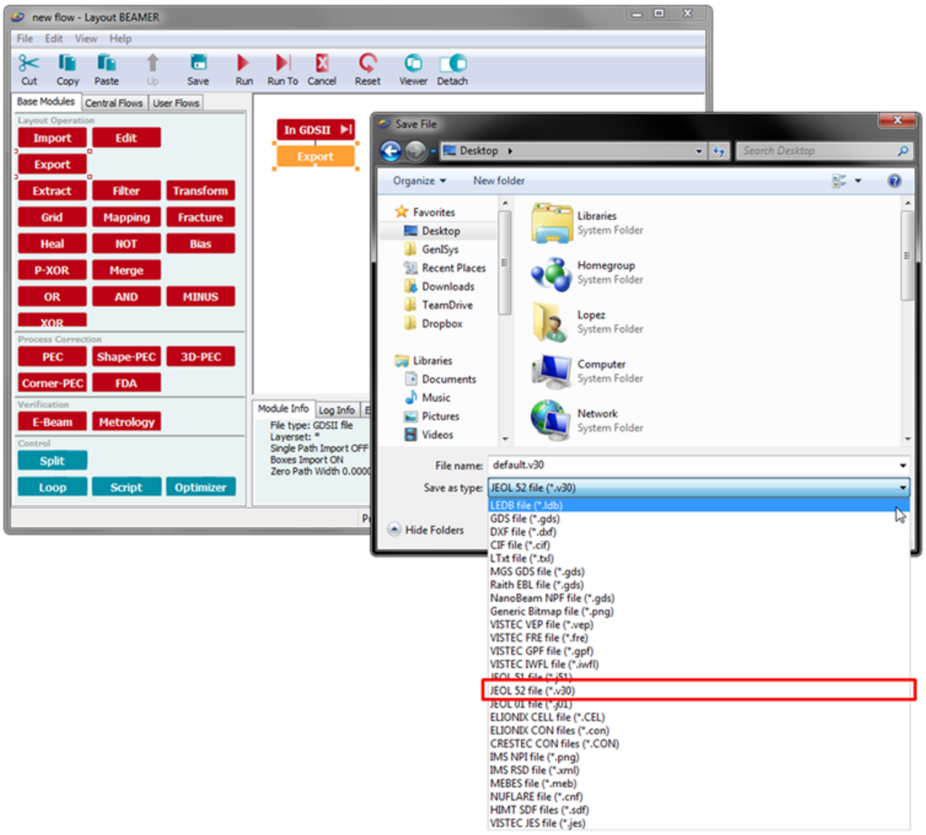
1 Introduction

This document is intended for JEOL users. It outlines and explains the functionalities of Layout BEAMER and its use with the JEOL formatter found in the Export module. Using the Export module to fracture a pattern to the machine format is the last step of a process flow. Only machine formats that have been licensed will be available in the pull down menu of the file dialog. Select the desired format, e.g. v30, enter the file name and click *Save*.

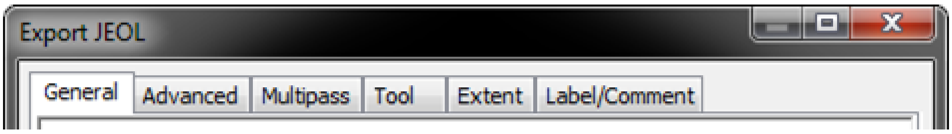


File type: GDSII file
Layerset: *
Single Path Import OFF
Boxes Import ON
Zero Path Width 0.0000

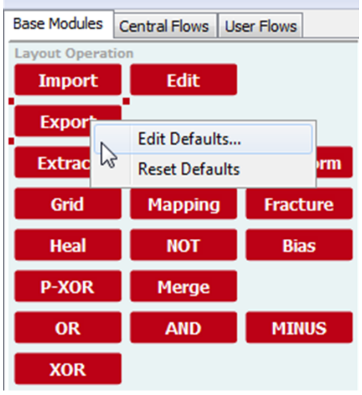
File name: default.v30
Save as type: JEOL 52 file (*.v30)

Upon clicking save, the Export dialog for the v30 format will appear.

This document is organized by chapters. Each chapter describes each tab of the Export dialog. In each chapter, each subsection describes the features available within each tab.



NOTE: It is possible to edit the defaults settings of the Export module by right-mouse-click on the Export module in the Base Module library and select "Edit Defaults..." and selecting the export format of choice (e.g. v30), assigning a default directory to which to output the file, default name and setting the parameter (like Pattern Unit, Shot Pitch, machine type, acceleration voltage, etc.) to your preferred settings. The Export module will use now the new default settings, when it is added to the flow.

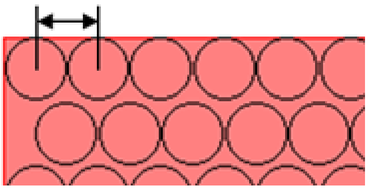


2 General Tab

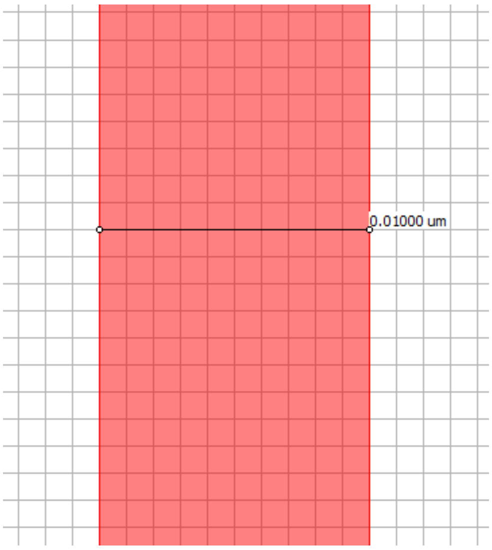
The General Tab allows the user to specify the tool type, Pattern Unit, Shot Pitch, fracture mode along with a few other available options. This chapter will describe these functions in greater detail.

2.1 The Design Grid, Exposure Grid and Shot Grid

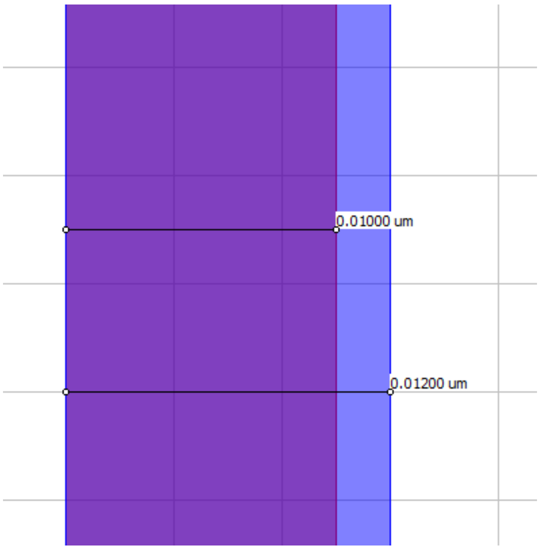
It is important to understand the relationship between the design grid, exposure grid (*Pattern Unit)* and shot grid (*Shot Pitch*). This section discusses the relationship between the three grids as they have a lithographic impact on printed features. The **design grid** is the snapping grid used to design a pattern in a CAD tool such as LayoutEditor, L-Edit, AutoCAD, Cadence, etc. The **Pattern Unit** is the positional accuracy of the shapes (fractured trapezoids) used by the tool for exposure. Finally, the **Shot Pitch** is defined as the center-to-center spacing of the shots (illustrated below) within an e-beam tool to expose the pattern.



The first relationship to understand is between the design grid and the Pattern Unit. To simplify the discussion, assume the Pattern Unit and Shot Pitch are equal. Ideally, a pattern should be designed with the Pattern Unit in mind to avoid the consequence of mismatching the two grids. To illustrate the aforementioned mismatch, let's hypothetically use the example of a 10nm wide line designed on a 1nm design grid (see image below on the left). To keep the example simple, the line-width is our only concern; the line length is not. Hypothetically, let's say that the tool is designed to use a 4nm Pattern Unit. If the 10nm wide line is exported to a 4nm Pattern Unit, the figure re-snaps to a 4nm grid, changing the width of the line from 10nm to 12nm (see image below on the right). Consequently, *grid snapping* is the result of the mismatch when converting a pattern from a fine grid to coarser grid; dimensional accuracy is lost in the conversion.



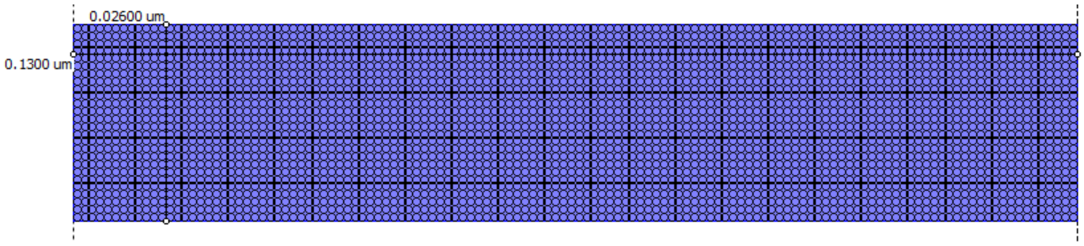
Illustrated above is a 10nm wide line on a 1nm design grid. The 1nm grid is in grey.



Exporting the 10nm wide line to a 4nm Pattern Unit snaps the shape to a 4nm grid (in grey), resizing the line width to 12nm.

To avoid snapping from a finer grid to a coarser grid, it is advised to know the available values of the Pattern Unit in advance and choose one of the available Pattern Unit values as the design grid. The finer the Pattern Unit chosen, the less chance to lose dimensional and positional accuracy. Ultimately, when exporting the design to the v30 format, re-snapping of the pattern can be avoided, since the dimensions of the pattern will be integer multiples of the Pattern Unit.

The third component in this discussion is the shot grid or Shot Pitch. Here, the Shot Pitch will be different from the Pattern Unit. Typically, the Shot Pitch is an integer multiple of the Pattern Unit and for some tools cannot be set equal to the Pattern Unit. Shot fill within a shape is an important component of exposure since the shot placements will directly affect the printed outcome of the pattern. If the design grid, Pattern Unit and Shot Pitch are equal and a fine Pattern Unit is used, dimensional and positional accuracy of the pattern will be maintained upon exporting to the v30 format. This kind of export will typically use a low current to enable a small beam size which increases the number of shots required to raster the shapes and ultimately extending the overall writing time.



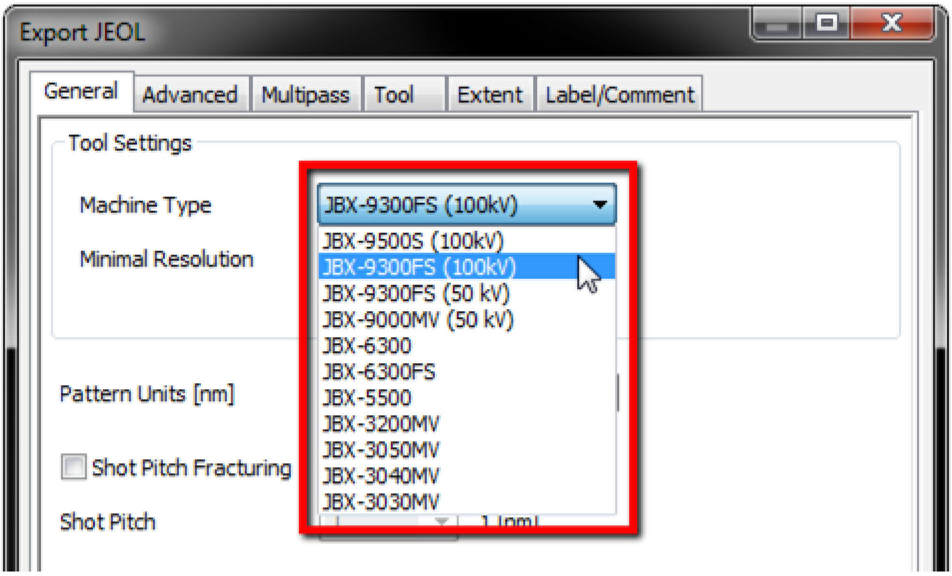
To reduce writing time, a larger beam current can be used to generate a larger beam size. By using a wider beam, fewer shots can be used to raster the shapes by increasing the Shot Pitch. If a pattern is designed such that the design grid and Pattern Unit are in good agreement, there may exist a possibility that the dimensions of the patterns are not an integer multiple of the Shot Pitch grid, especially if large Shot Pitch is chosen. The problem in converting from a fine grid to a coarser grid appears yet again. Using a fine Pattern Unit with a coarser Shot Pitch will lead to poor shot placement within the shapes, since dimensional and positional accuracy can be preserved with a finer Pattern Unit.

To summarize, the design grid, Pattern Unit and Shot Pitch are connected. For shorter exposure times, a larger Shot Pitch should be used (by adjusting the beam current, exposure dose and maximum frequency). Using small Pattern Unit will give a high accuracy for positioning and size of the shapes, but the accuracy will be lost by using a large Shot Pitch. Exposing with a large Shot Pitch using a large Pattern Unit may be preferred to avoid overdosing of trapezoids whose height or width < 1 Shot Pitch. Finally, it is always a good idea to know the Pattern Unit of your tool and using one of the available values as the design grid. Doing so will help avoid snapping and exposure issues down the road.

In case the Shot Pitch has to be larger than the Pattern Unit, Shot Pitch Fracturing might be used to mitigate some of the snapping issues. Refer to the section on Shot Pitch Fracturing for more information. Remember to always verify the fractured data for loss of shape accuracy especially if exporting to a Pattern Unit that is larger than the design grid.

2.2 Machine Type

After selecting the machine format and providing a file name for the exported file, the Export dialog box provides a number of options that will govern the fracturing. The first setting is to select the machine type:



Machine Type: JBX-9300FS (100kV)

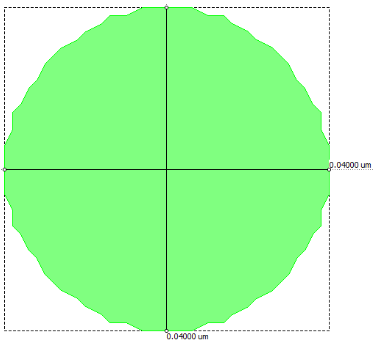
The subsequent description is based on the JEOL 9300FS at 100kV

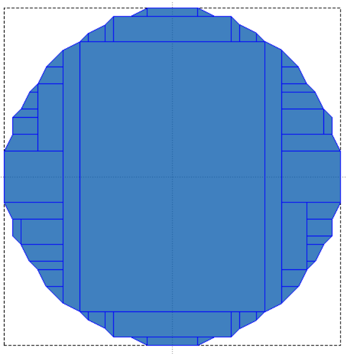
2.3 Pattern Units

The Pattern Unit defines the positional and dimensional accuracy of the shapes. When fracturing a pattern, the primitive shapes are used to make up the intended design for exposure.

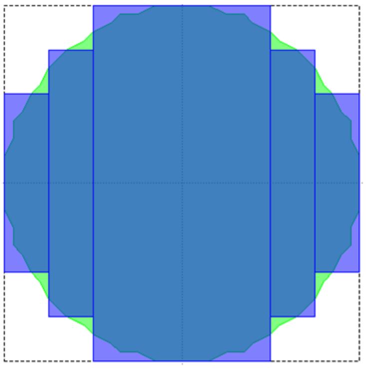
To maintain reasonable writing accuracy, the Pattern Unit should be selected equal to or finer than the design resolution. The accuracy of the conversion from polygons to trapezoids will be impacted if the Pattern Unit is set to a grid that is coarser than the design grid. As a result, *grid snapping* will occur.

The following examples highlight the effect of grid snapping. For the following examples, the original design (in green) is a 40nm diameter circle designed on a 1nm design grid is used.





The blue pattern (overlaid on the original design in green) is shown above to be dimensionally and positionally accurate after fracturing to the v30 format with a 1nm Pattern Unit using Conventional fracturing.



The blue pattern (overlaid on the original design in green) is shown above to be dimensionally and positionally inaccurate due to fracturing to the v30 format with a 5nm Pattern Unit. The 5nm Pattern Unit is a coarser resolution than the design resolution of 1nm using Conventional fracturing.

As shown in the examples above, positional accuracy is affected by the Pattern Unit chosen in the v30 format. The Pattern Unit will impact the dimensional accuracy and fracture by snapping the vertices to a coarser Pattern Unit.

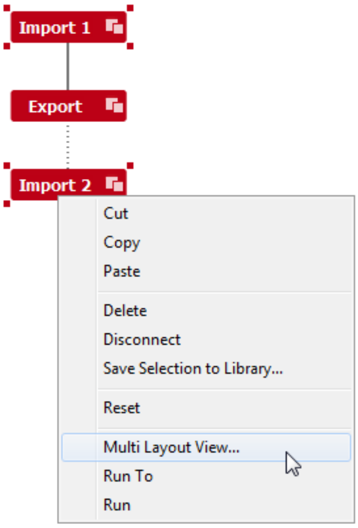
NOTE: Pattern Units depend on machine tool type and settings (e.g. the smallest resolution for a JEOL 6300FS depends on the acceleration voltage and the EOS mode). The smallest Pattern Unit for a 9300FS at 100keV is 1nm.

2.3.1 Patterns Units and Shot Pitch

The Pattern Unit and Shot Pitch are connected. For shorter exposure times, a larger Shot Pitch should be used (depending an beam current, exposure doses and maximum frequency). Using small Pattern Unit will give a high accuracy for positioning and size of the shapes, but the accuracy will be lost by using a large Shot Pitch (more on this topic in the Shot Pitch section). Exposing with a large Shot Pitch using a large Pattern Unit may be preferred to avoid overdosing of trapezoids whose height or width < 1 Shot Pitch. Always verify the fractured data for loss of shape accuracy when using a Pattern Unit larger than the design grid.

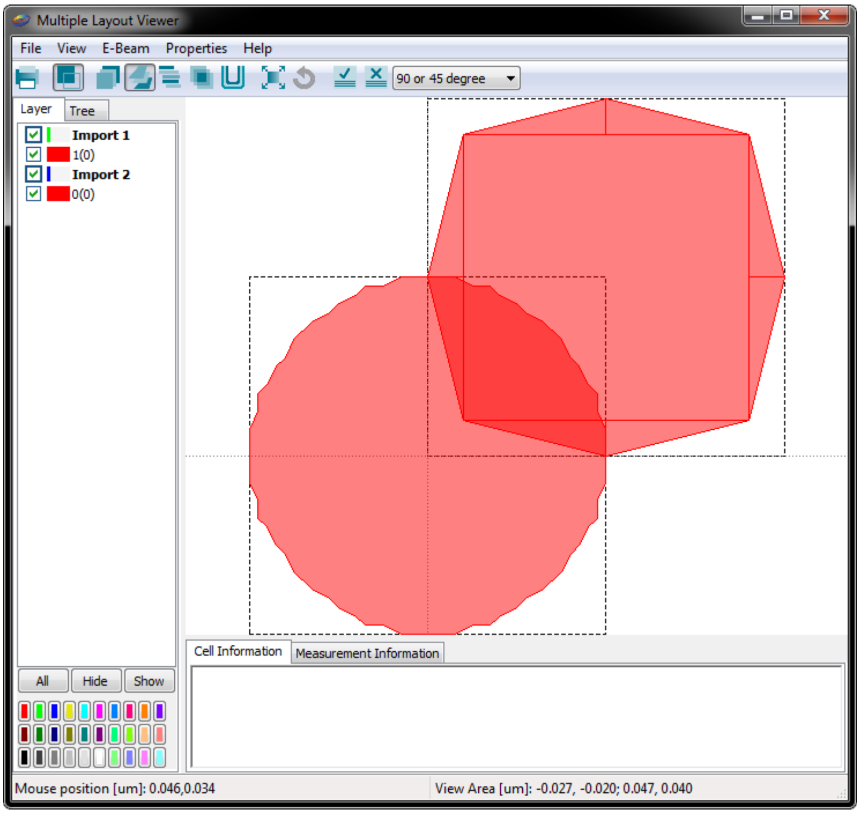
To visually inspect the initial import to the exported data, use the *Multi Layout View* option as described in the next section.

2.3.2 Verification Using Multi Layout View



The Multi Layout View is available when two or more modules are selected for viewing. This feature is not available for use with the Export module. To verify the fractured file results against the original layout, first, attach an Import module after the Export Module. Second, run the newly attached Import module. Next, using the mouse and keyboard, click on each Import module while holding down the Shift key and using the left mouse button to select the each module. Finally, right-click on one of the selected modules and select *Multi Layout View ...* to open the viewer. This feature can be used between 2 or more modules at once.

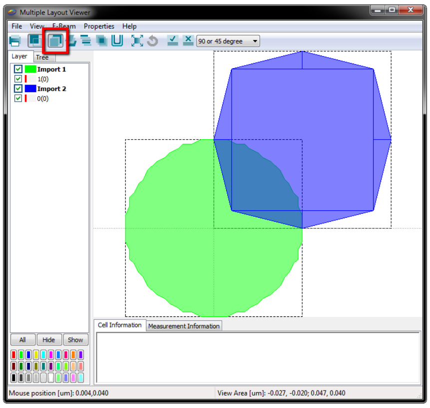
To compare patterns before and after fracturing, the patterns need to be aligned and uniquely colored in the Layout VIEWER.



Mouse position [um]: 0.046,0.034

View Area [um]: -0.027, -0.020; 0.047, 0.040

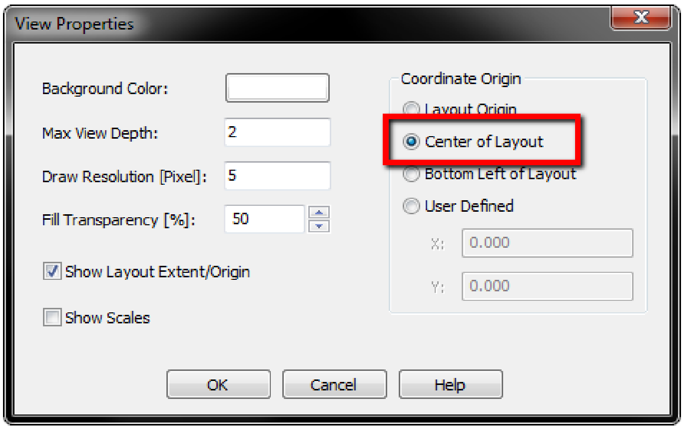
1. Click "Color by Layout" to assign each module view a color. The button is outlined in red below.



Mouse position [um]: 0.004,0.040

View Area [um]: -0.027, -0.020; 0.047, 0.040

2. To align the layouts, go to **View...** under **Properties**; this will call up the View Properties dialog. In the dialog, select "Center of Layout" and click OK.



Background Color:

Max View Depth: 2

Draw Resolution [Pixel]: 5

Fill Transparency [%]: 50

☑ Show Layout Extent/Origin

☐ Show Scales

Coordinate Origin

○ Layout Origin

● Center of Layout

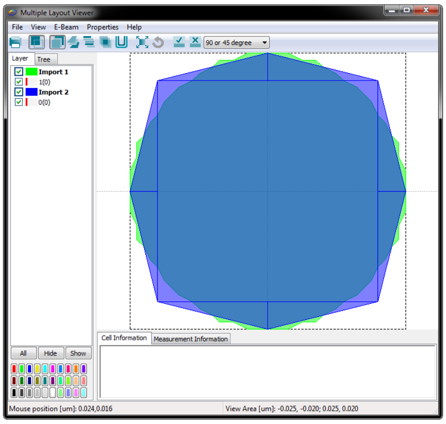
○ Bottom Left of Layout

○ User Defined

X: 0.000

Y: 0.000

3. With the patterns properly aligned, visual inspection for shape accuracy is achieved with the transparency enabled Layout VIEWER.

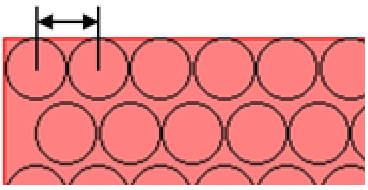


Mouse position [um]: 0.024,0.016

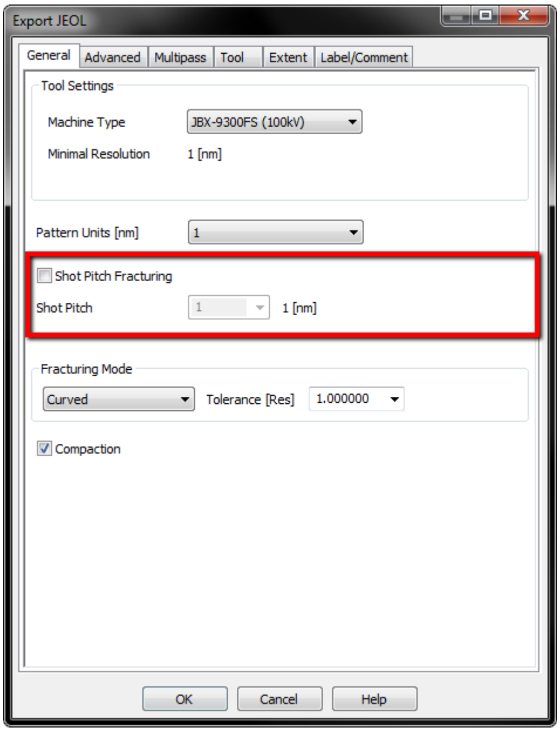
View Area [um]: -0.025, -0.020; 0.025, 0.020

2.4 Shot Pitch and Shot Pitch Fracturing

This section discusses *Shot Pitch* and Shot Pitch Fracturing. Shot Pitch is defined as the center-to-center spacing of the shots within an e-beam tool to expose the pattern and is illustrated in the following image.



It is important to understand the relationship between the design grid, Pattern Unit and Shot Pitch. Please read the section on The Design Grid, Exposure Grid and Shot Grid to understand the key grid relationships before proceeding with this section.



Tool Settings

Machine Type: JBX-9300FS (100kV)
Minimal Resolution: 1 [nm]

Pattern Units [nm]: 1

☐ Shot Pitch Fracturing
Shot Pitch: 1 1 [nm]

Fracturing Mode: Curved
Tolerance [Res]: 1.000000

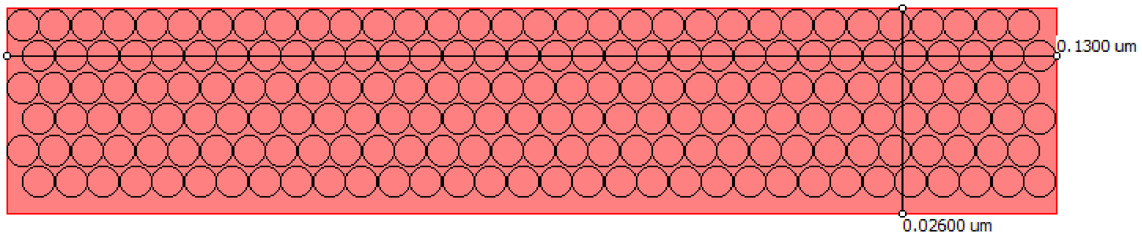
☑ Compaction

To illustrate the relationship between the design grid, Pattern Unit and Shot Pitch, 26nm width lines that are 130nm long designed on a 1nm grid will be used in the following examples. Shot Pitch Fracturing is disabled for the examples.

NOTE: The v30 file does not contain information on the shot pitch used during exposure. The shot pitch is defined in the JEOL SDF and can be set to any multiple of the minimum resolution in the jobdeck or schedule file at the time of exposure. The shot pitch parameter is specified in units of the smallest resolution supported by the chosen machine mode (e.g. 1nm for a JEOL 9300FS).

2.4.1 Example 1: Poor Shot Fill, Maintain Shape Accuracy

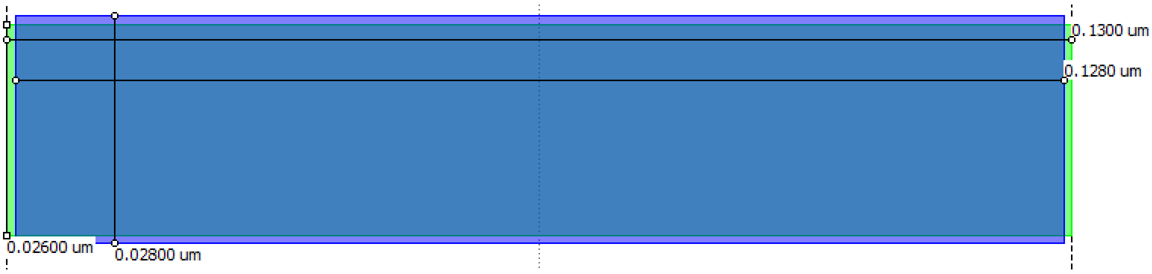
In this example, shape accuracy is maintained, but poor shot fill results from a mismatch between the design unit and Shot Pitch. If a pattern designed on a 1nm grid is exported to a JEOL format with a 1nm Pattern Unit and a 4nm Shot Pitch with Shot Pitch Fracturing disabled, there will be a poor shot fill for trapezoids whose dimensions are not a multiple of the Shot Pitch (4nm) as seen below.



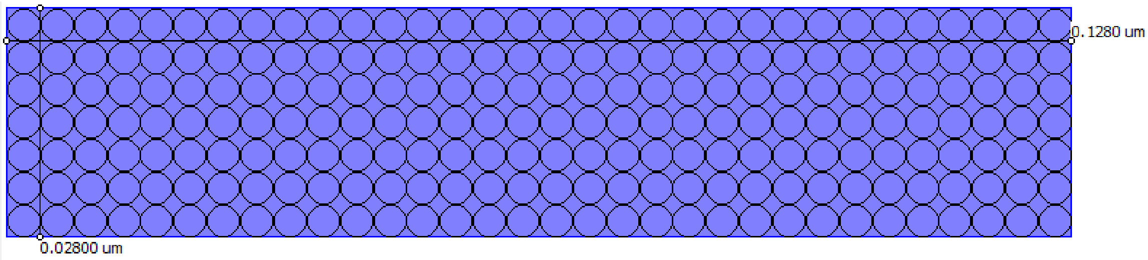
While dimensional accuracy from design to export is maintained with a Pattern Unit of 1nm, poor shot fill (gaps within the shape) is produced since the dimensions of the shape are not integer multiples of the Shot Pitch.

2.4.2 Example 2: Proper Shot Fill, Poor Shape Accuracy

In this example, shape accuracy is lost, but proper shot fill results the Pattern Unit is set to an integer multiple of the Shot Pitch. There is a mismatch between the design unit and the Pattern Unit. In this scenario, the same design will be exported using a 4nm Pattern Unit. In the jobdeck, the Shot Pitch will also be set to 4nm. Using the Multi Layout View, the original pattern is green and the exported pattern is in blue. The line width of 26nm is snapped to 28nm (multiple of 4nm), and the length of 130nm is snapped to 128nm, resulting in a loss of dimensional accuracy.



The exported pattern has proper shot fill, but as explained, there is a loss in dimensional accuracy when compared to the original design:



While dimensional accuracy is lost from the original design to the exported pattern, proper shot fill is achieved with no gaps in the shape from missing shots.

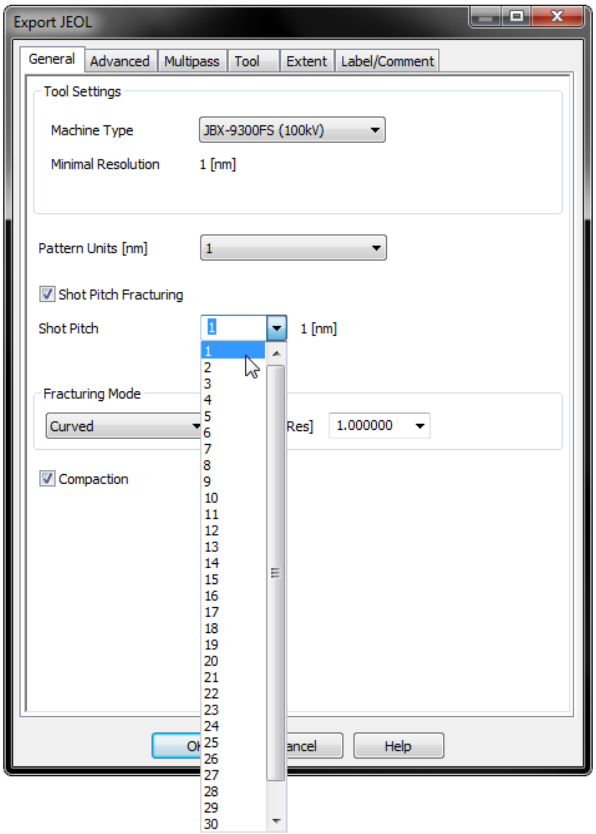
2.4.3 Shot Pitch Fracturing

In Layout BEAMER, Shot Pitch Fracturing is an OPTIONAL feature that aligns trapezoids to the Shot Pitch grid. As a result, this feature can make use of a fine writing grid in conjunction with a larger Shot Pitch while assuring the proper shot fill within the trapezoids.

The maximum frequency of the machine, base dose, exposure dose (minimum exposure dose in layout) and Shot Pitch interact with each other. To obtain a short write time, larger beam currents are used which leads to shorter exposure time per area for the same overall exposure dose. The time per shot (or the equivalent machine frequency) is a function of the Shot Pitch. A small Shot Pitch means short shot times (high frequencies), which may exceed the frequency range of the machine. Therefore it is desired to use a larger Shot Pitch. Without Shot Pitch Fracturing, a larger Shot Pitch would also require the use of a larger Pattern Unit.

If the Pattern Unit and the Shot Pitch are larger than the design grid, then there is potential loss of edge accuracy, since the layout will be snapped to the coarser Pattern Unit during fracturing as shown in the second example. Layout BEAMER allows the user to define the shot pitch larger than the Pattern Unit by checking the Shot Pitch Fracturing check box.

Once Shot Pitch Fracturing has been selected, be sure to select the Shot Pitch (that will be defined in the SDF) from the drop down menu.



Machine Type: JBX-9300FS (100kV)

Minimal Resolution: 1 [nm]

Pattern Units [nm]: 1

☑ Shot Pitch Fracturing

Shot Pitch: 1 — 1 [nm]

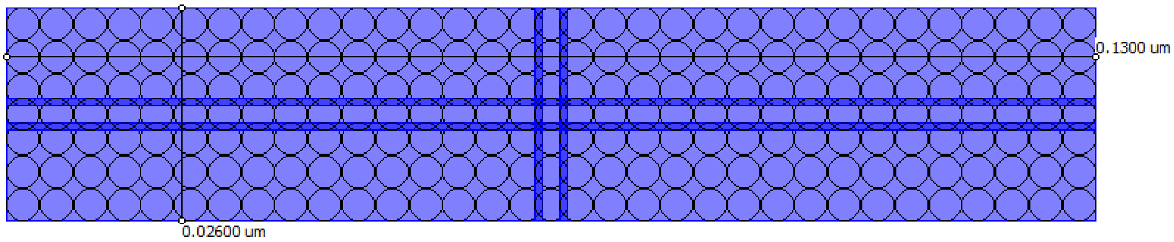
Fracturing Mode: Curved

Res]: 1.000000

☑ Compaction

When Shot Pitch Fracturing is disabled, the drop down is grayed allowing fracturing to occur according to the pattern units selected. The rectangles and trapezoids in the v30 file will be positioned on the grid determined by the Pattern Unit as shown in the first example in this section.

Shot Pitch Fracturing fracturing will generate trapezoids that are aligned with the Shot Pitch and position the rectangles at the layout edges accordingly. The design grid and Pattern Unit mismatch will be compensated in the center of the pattern. The same 26nm line fractured with pattern units of 1nm and a shot pitch of 4nm will maintain its original dimensions:

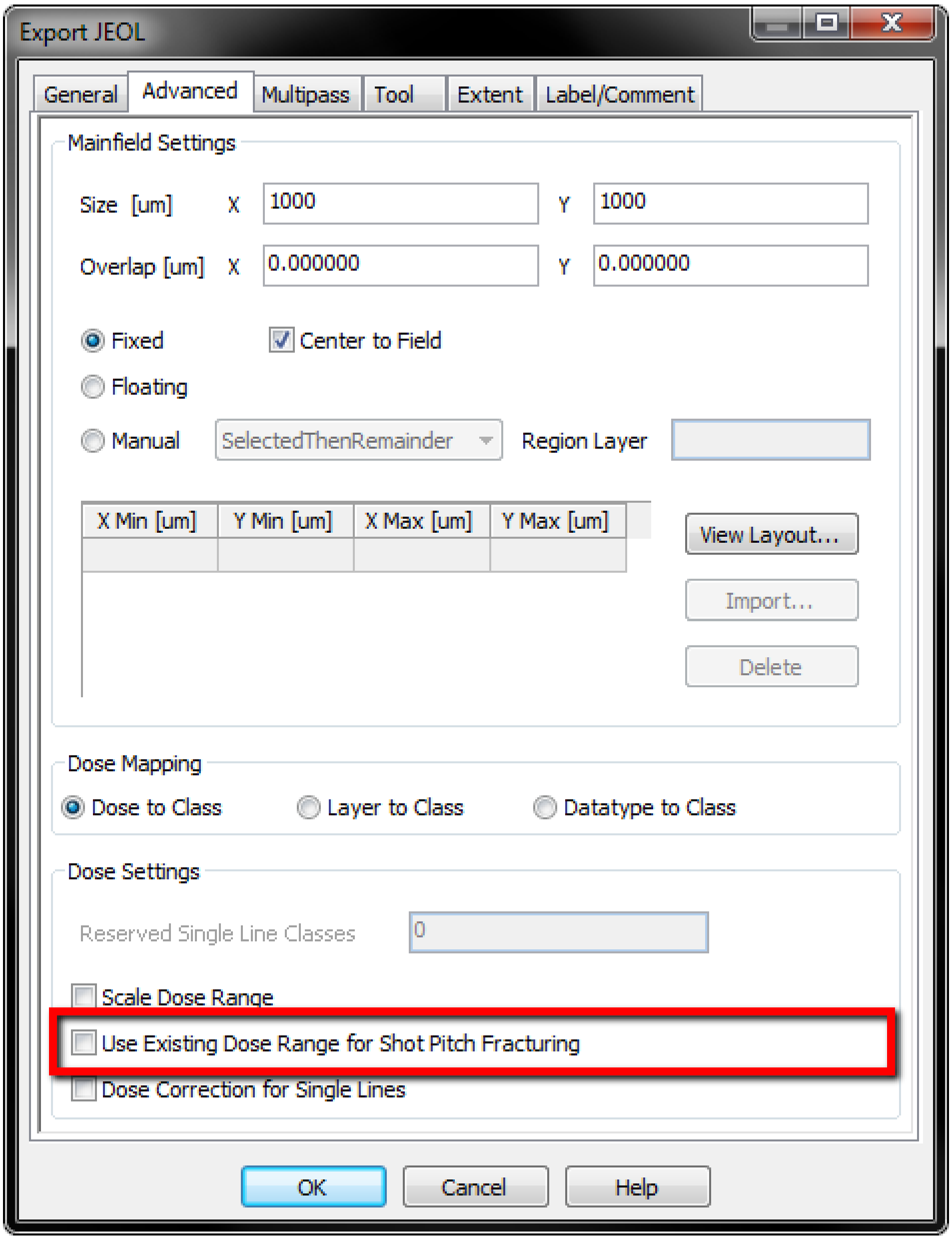


In general, with Shot Pitch Fracturing enabled (Shot Pitch > 1 Pattern Unit unit), a line with dimensions not aligned to the Shot Pitch will be divided into trapezoids (in this case rectangles) that are a multiple of the Shot Pitch. Any mismatch is compensated for by a small overlap in the center, assuring that the outer edges receive uniform shots.

Shot Pitch Fracturing will generate trapezoids of optimal dimensions that ensure the tool shots maintain the best shape control. Shapes which are not multiple of the Shot Pitch will be handled as follows:

- Mismatch < 25%: the mismatch is shifted to the center as described before, and a slight gap will be remaining
- Mismatch > 25%: the mismatch is shifted to the center as described before, and the mismatch in the center will be corrected by an extra trapezoid overlapping the border trapezoids.

Layout BEAMER will adjust the dose of the patch rectangles to compensate for the double exposure if the layout is proximity corrected or the parameter **Use Existing Dose Range for Shot Pitch Fracturing** in the **Advanced** tab is switched off.



Mainfield Settings

Size [um] X 1000 Y 1000

Overlap [um] X 0.000000 Y 0.000000

● Fixed ☑ Center to Field

○ Floating

○ Manual SelectedThenRemainder Region Layer

X Min [um]	Y Min [um]	X Max [um]	Y Max [um]

Dose Mapping

● Dose to Class ○ Layer to Class ○ Datatype to Class

Dose Settings

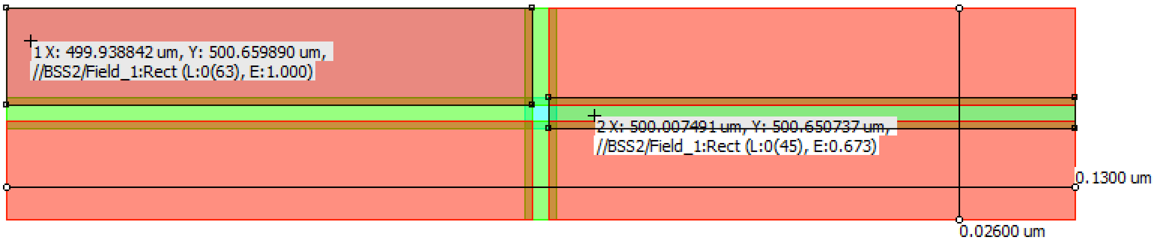
Reserved Single Line Classes 0

☐ Scale Dose Range

☐ Use Existing Dose Range for Shot Pitch Fracturing

☐ Dose Correction for Single Lines

With **Use Existing Dose Range for Shot Pitch Fracturing** disabled, the following export is generated. Dose modulation can be seen to compensate for overlapping shapes/shots.



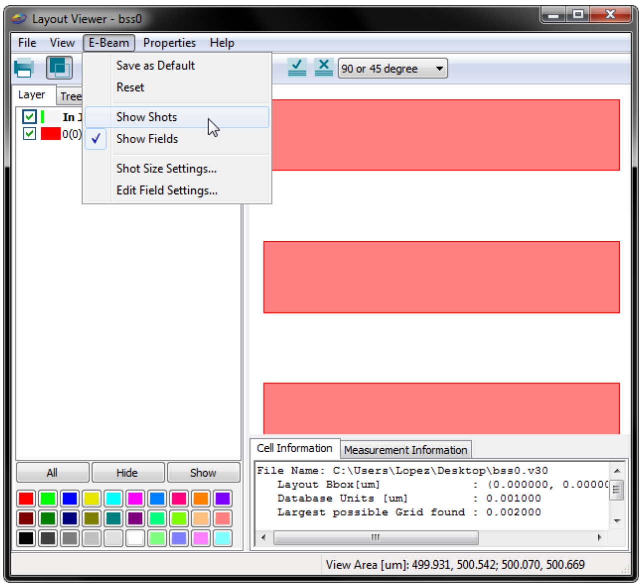
NOTE: In addition to the .v30 file, Layout BEAMER will generate a dose table file with the extension .JDI, if the doses of the patch rectangles are different from 1.0 (similar to Proximity Effect Corrected layouts). The JDI file is a simple text file containing the shot modulation table that needs to be integrated into the JDF file. (see detailed description below)

Fracturing using a shot pitch different than 1 for complex designs will result in a compromise of best shot positioning and shape accuracy.

To verify Shot Pitch Fracturing results, switch on then Shot Grid View and compare the original layout and the fractured result using Multi Layout View.

2.4.4 Shot View

Layout BEAMER allows for the inspection of shot fill of the fractured v30 trapezoids. To enable the shot view after importing or exporting a v30 file, click "Shot Shots" found under the "E-Beam" menu in the Layout VIEWER.

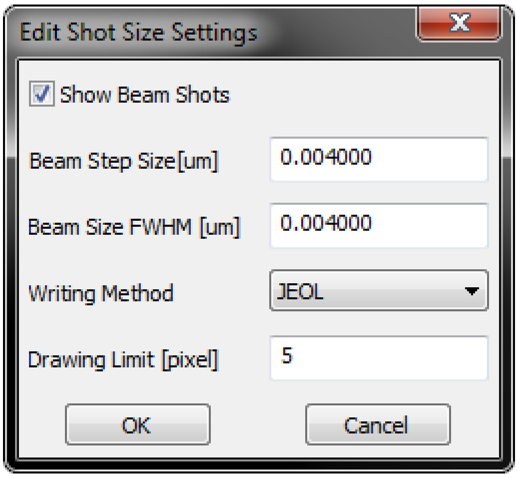


```
File Name: C:\Users\Lopez\Desktop\bss0.v30
   Layout Bbox[um]               : (0.000000, 0.00000
   Database Units [um]           : 0.001000
   Largest possible Grid found : 0.002000
```

View Area [um]: 499.931, 500.542; 500.070, 500.669

The "Edit Shot Size Settings" dialog control shot view by enabling shot view, adjusting the Shot Pitch (Beam Step Size) and adjusting the beam size. After activating the shot view, you need to zoom in until the shots are displayed.

NOTE: The JEOL shot placement algorithm can be used to view the shot view of your tool. Simply select the Writing Method to JEOL as shown.



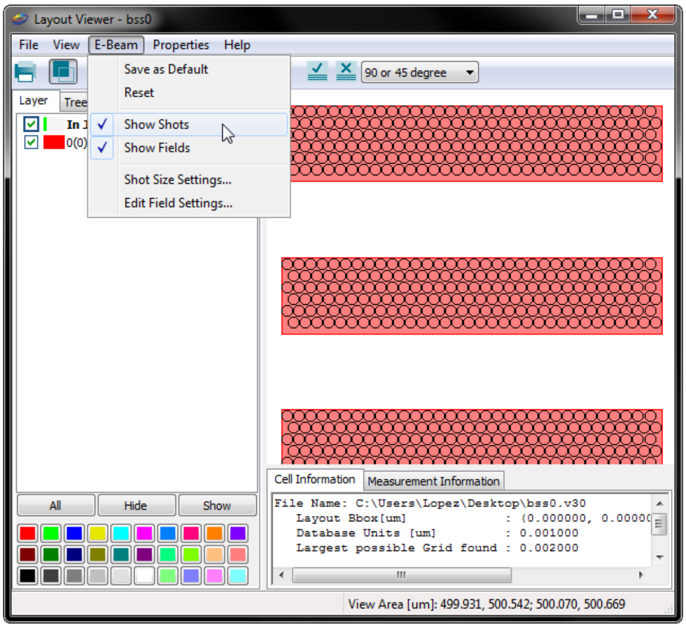
☑ Show Beam Shots

Beam Step Size[um]: 0.004000

Beam Size FWHM [um]: 0.004000

Writing Method: JEOL

Drawing Limit [pixel]: 5



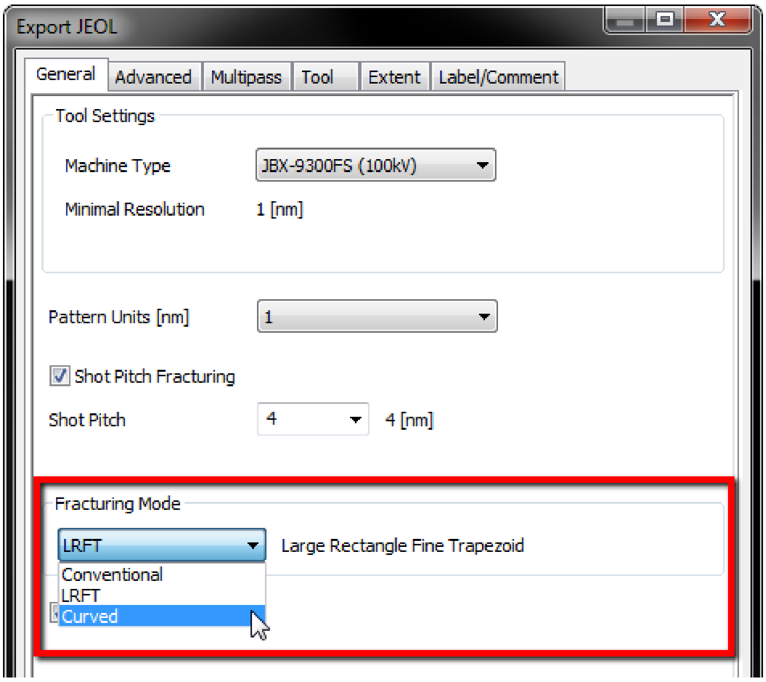
```
File Name: C:\Users\Lopez\Desktop\bss0.v30
   Layout Bbox[um]             : (0.000000, 0.00000
   Database Units [um]         : 0.001000
   Largest possible Grid found : 0.002000
```

View Area [um]: 499.931, 500.542; 500.070, 500.669

Using the shot view it is possible to inspect shot filling issues. After inspection, the layout and/or fracturing can be optimized. Additionally, Shot Pitch Fracturing can be enabled.

2.5 Fracturing Mode

In Layout BEAMER, 3 fracturing modes are available: **Conventional**, **LRFT** and **Curved**.



Tool Settings

Machine Type JBX-9300FS (100kV)

Minimal Resolution 1 [nm]

Pattern Units [nm] 1

☑ Shot Pitch Fracturing

Shot Pitch 4 4 [nm]

Fracturing Mode

LRFT Large Rectangle Fine Trapezoid

Conventional

This mode performs mainly horizontal fractures at polygon vertices that maintain the original design intent as good as possible. This leads to many slices of trapezoids representing the original layout.

LRFT - Large Rectangle Fine Trapezoid

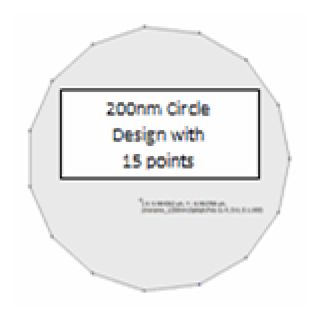
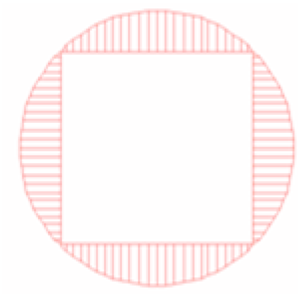
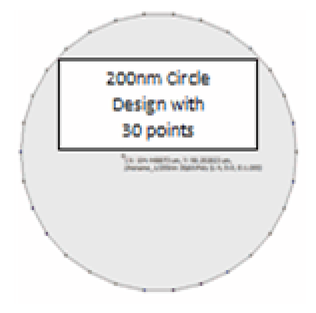
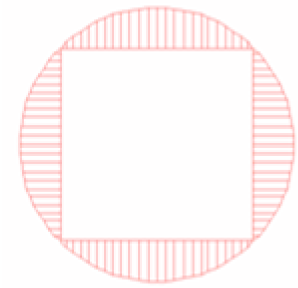
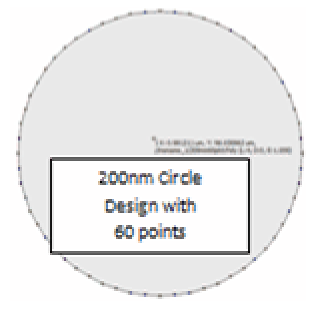
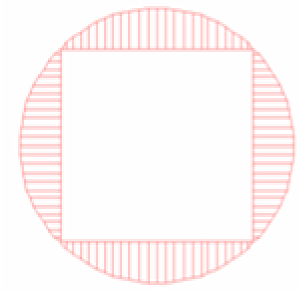
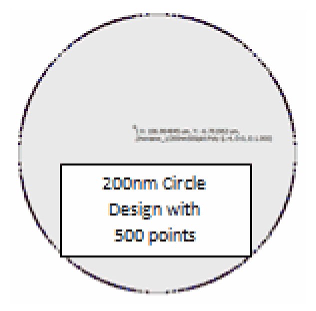
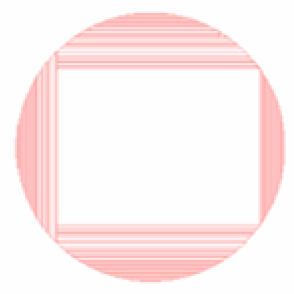
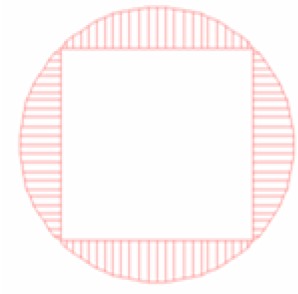
This mode fractures the polygons with as many large rectangles as possible and completes the filling with small trapezoids. The number of trapezoids is similar to the conventional mode, since LRFT maintains the original polygon vertices. Different to Conventional, it will avoid thin trapezoids, which are source to dose non-uniformity in the writing process.

Curved

In this mode, the user allows Layout BEAMER to shift the vertices along curves to get fractures consistent with the specified resolution and beam step size. In other words, this mode will try to detect curves in the given polygons and fracture these curves within a specified tolerance consistent with the specified resolution and beam step size. To increase the recognition of circles and rings, increase the tolerance parameter.

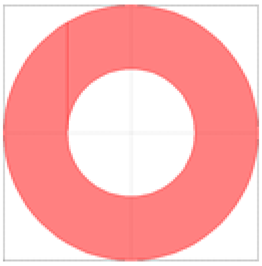
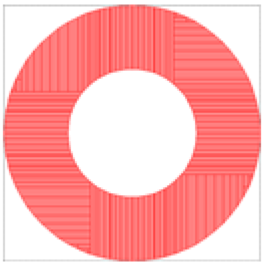
2.5.1 Example: Fracturing a Circle - Conventional vs. Curved

The table below compares Conventional and Curved fracturing for a circle at different design resolutions (resulting in a different number of vertices). The comparison highlights that Conventional fracturing depends on the design (number of vertices). The Curved mode detects the circle and fractures optimally, independent on the number of vertices.

Design	Conventional	Curved
		
		
		
		

2.5.2 Example: Fracturing a Ring - Conventional vs. Curved

The table below compares Conventional and Curved fracturing for a ring, resulting in a different fracturing. The comparison highlights that conventional fracturing depends on the design (number of vertices). The Curved mode detects the ring and fractures optimally, independent on the number of vertices.

Design	Conventional	Curved
		

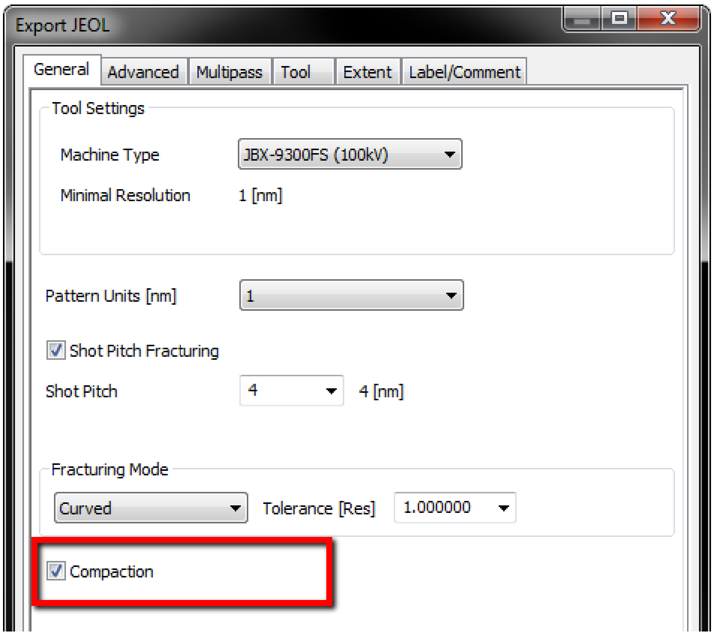
2.5.3 Notes on Fracturing

- All modes have their applications and it is necessary to check if one or the other fracture mode provides an advantage. LRFT is recommended for general curved layouts, whereas for fracturing circles and rings, consider using the Curved mode. In any case, it is recommended to inspect the fractured result, as the fracturing my influence the exposure result.
- For Conventional and LRFT fracturing, it may be advantageous to remove unnecessary vertices from curved polygons. The "Smoothing" function of the Grid module can be used prior to export. The smoothing should be set about equal to the writing grid resolution.

2.6 Compaction

JEOL offers strong capabilities for data compaction using arrays of geometries. Trapezoids, which are repeated within the main-field are detected and saved as "array" for minimizing the data volume. Layout BEAMER supports this functionality by default.

If data compaction is switched off, layout elements are fractured to trapezoids as they appear in the layout file. This mode can be used for controlling the writing order by controlling the order of layout elements in the layout file (e.g. in CIF or Ltxt). Please note that the order of the elements will be changed when applying layout operations and/or PEC.



Machine Type JBX-9300FS (100kV)

Minimal Resolution 1 [nm]

Pattern Units [nm] 1

☑ Shot Pitch Fracturing

Shot Pitch 4 4 [nm]

Fracturing Mode: Curved Tolerance [Res] 1.000000

☑ Compaction

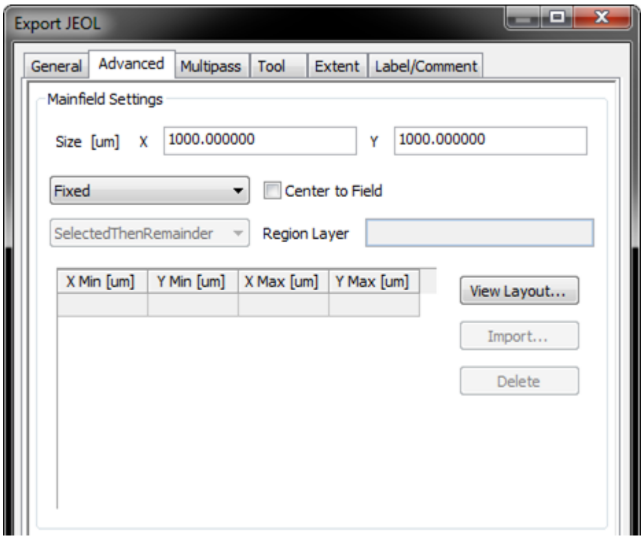
NOTE: Some issues with compaction in connection with 3D PEC application have been reported. It is recommended to switch of the compaction for 3D PEC application.

3 Advanced Tab

The Advanced tab allows the user to set specific mainfield and subfield parameters. The defaults are defined by machine type as selected in the General tab and the tool settings in the Tool tab. Layout BEAMER automatically sets the most optimal setting by default. The user is able to adjust the settings for special cases. In particular, mainfield positioning control and dose settings are detailed in this chapter.

3.1 Mainfield Settings

The JEOL tool exposes the layout mainfield by mainfield. The positioning of the beam within one main field is done by electromagnetic deflection, which is very fast and accurate. Movement from main field to main field requires a mechanical stage move, which is slower and less accurate. Therefore, the maximum main field size should be used when possible. Field placement and inspection are facilitated in Layout BEAMER. Fields can be positioned manually or automatically; overlap one another to maintain shape fidelity and to avoid field stitching; or can just be positioned in using a standard serpentine meander.



Size [um] X 1000.000000 Y 1000.000000

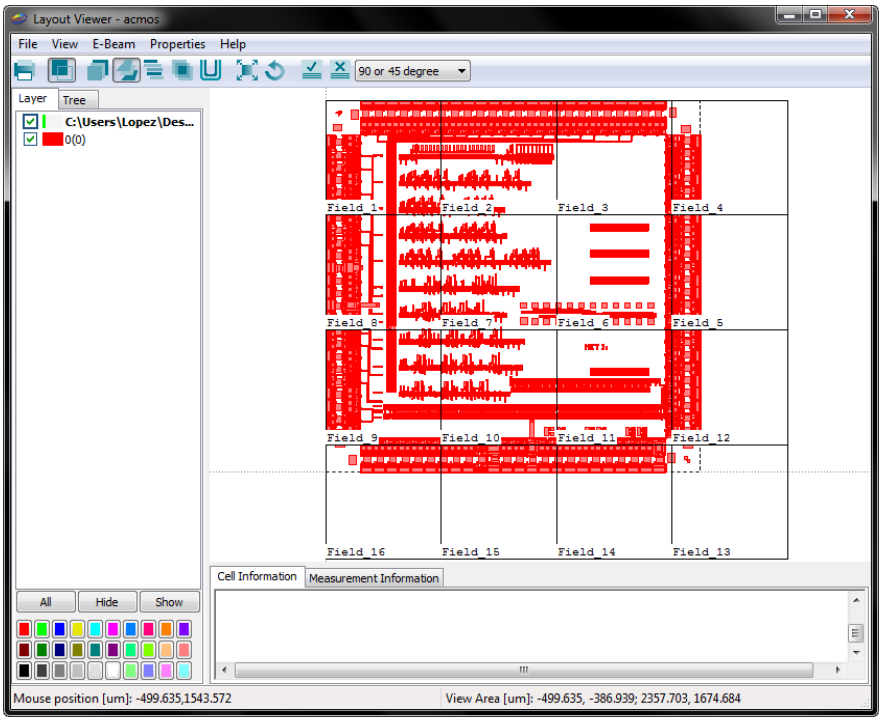
Fixed ☐ Center to Field

SelectedThenRemainder Region Layer

The maximum field size depends on the the tool configuration. Layouts exceeding the defined main field size are tiled into main fields. It is possible to adjust the mainfield size to values smaller than the maximum size. This may be desired for avoiding fractures of critical features at mainfield boundaries.

3.1.1 Viewing Field Positions By Color

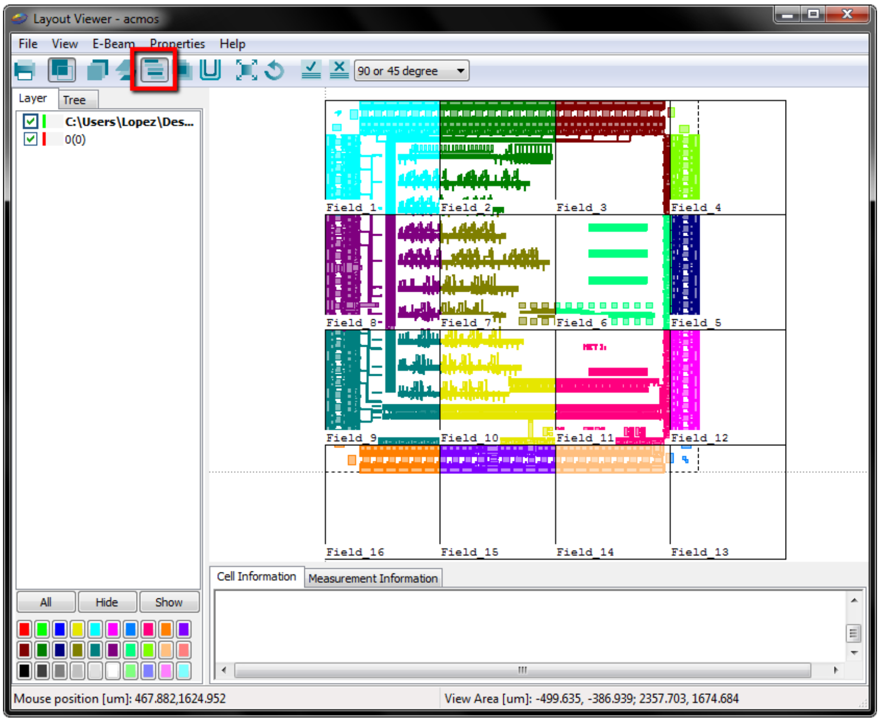
Layout BEAMER offers the possibility to view the main-field positions, numbers and borders by using the **View Layout** button:



Mouse position [um]: -499.635,1543.572

View Area [um]: -499.635, -386.939; 2357.703, 1674.684

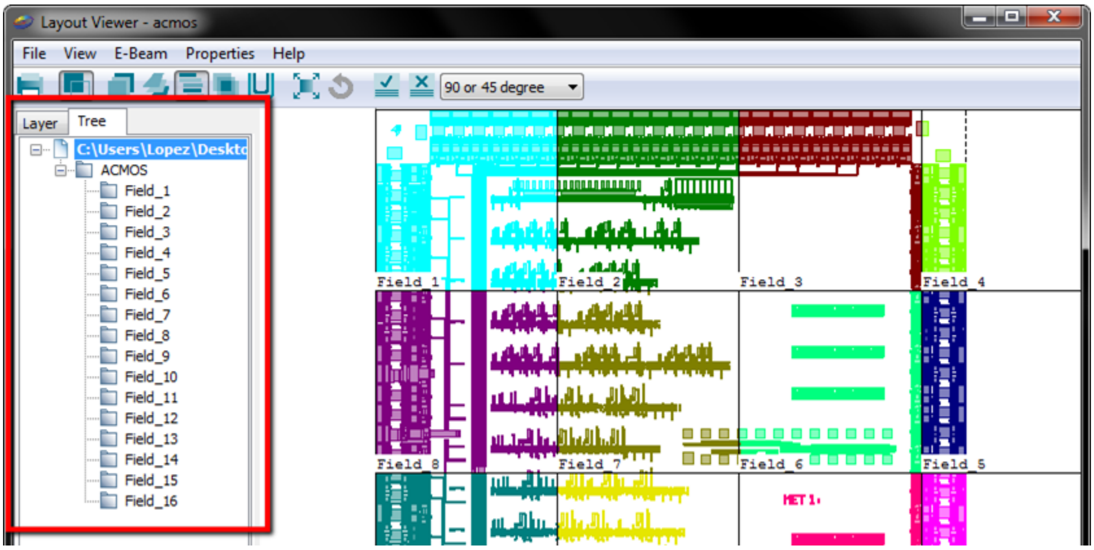
Unique coloring to each can be applied when clicking the **Color by Cell** button (outlined in red):

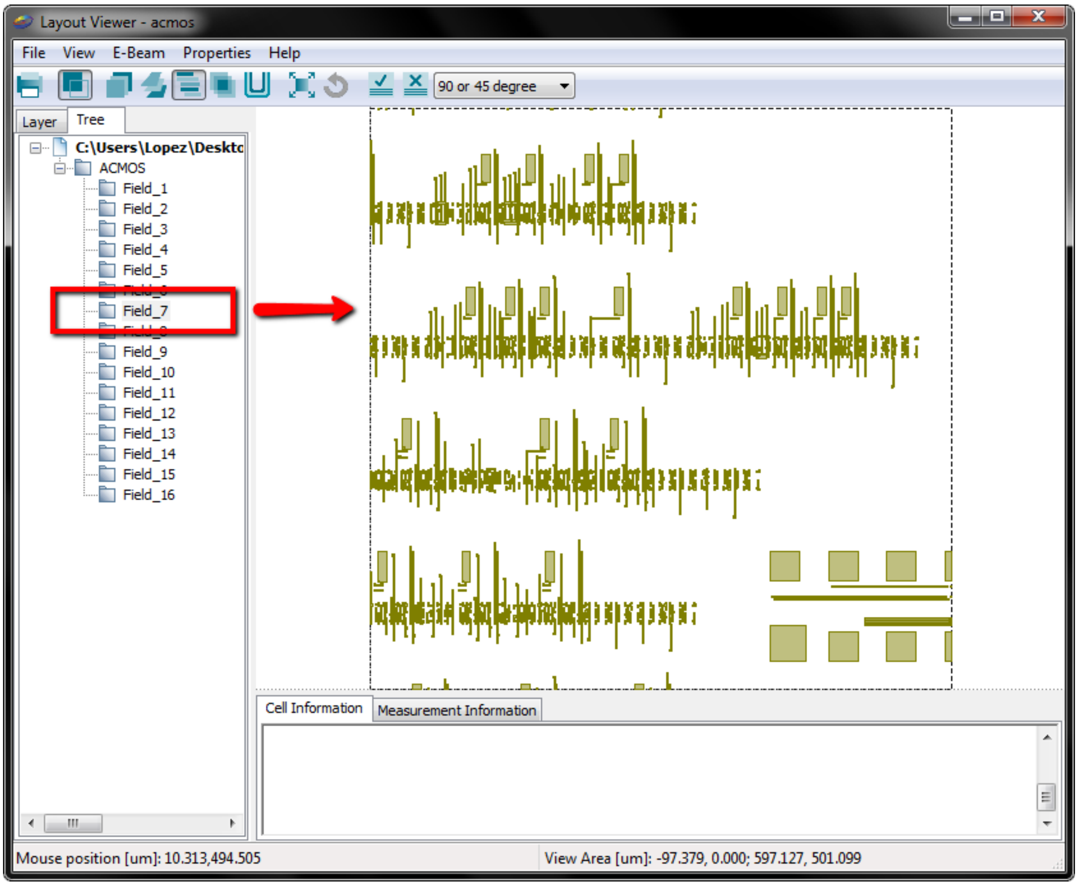


Mouse position [um]: 467.882,1624.952

View Area [um]: -499.635, -386.939; 2357.703, 1674.684

The Tree tab of the viewer allows to display the data within a specific field:



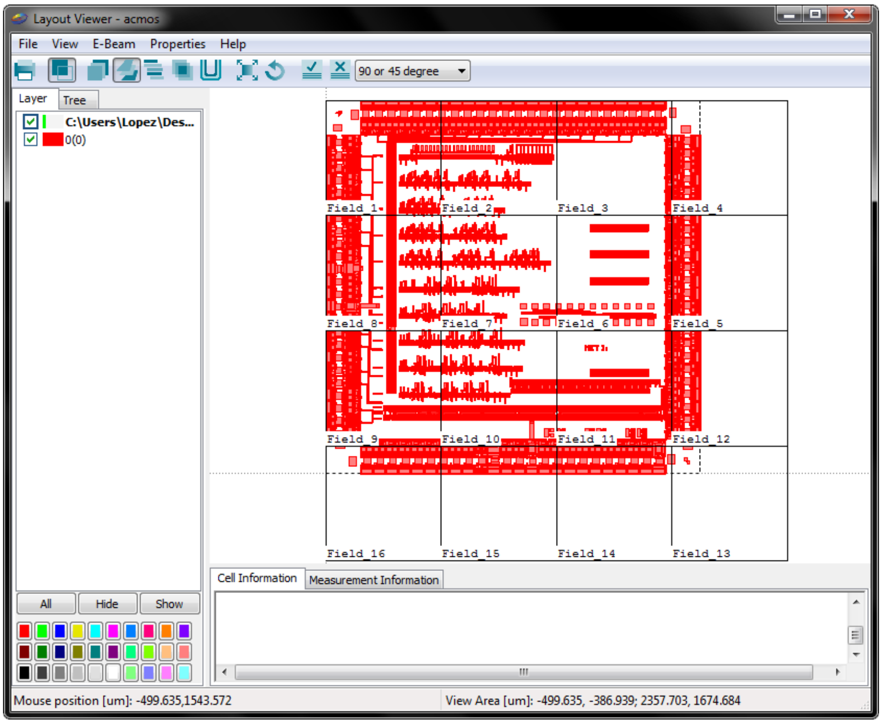


Mouse position [um]: 10.313,494.505

View Area [um]: -97.379, 0.000; 597.127, 501.099

3.1.2 Fixed Fields

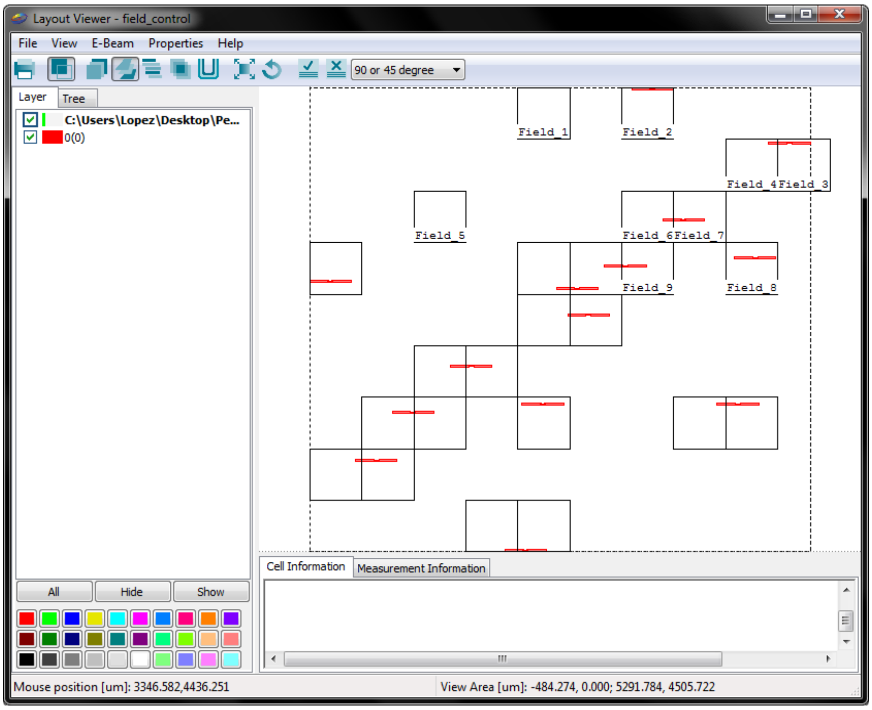
The default field positioning strategy is set to Fixed. In this mode, the layout is tiled into equal fields starting with the first field at the top left corner. The image below shows a Fixed field positioning for a chip layout.



Mouse position [um]: -499.635,1543.572

View Area [um]: -499.635, -386.939; 2357.703, 1674.684

The example below shows fixed tiling for a sparse layout:



Mouse position [um]: 3346.582,4436.251

View Area [um]: -484.274, 0.000; 5291.784, 4505.722

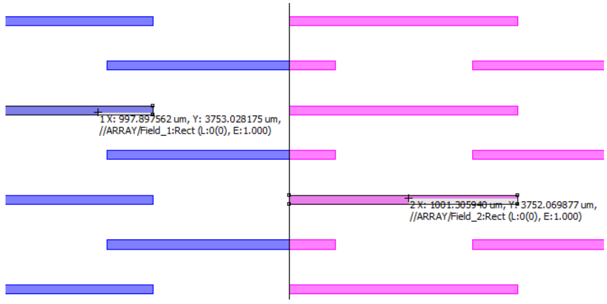
3.1.2.1 Center to Field

The origin for the first field on JEOL systems is always the upper left corner. Layouts smaller than maximum field size will be exposed in the upper right corner of the field. This is not optimal, as the best writing accuracy is in the center of the field. Checking this box will center the layout in the field, if the layout is smaller than one field.

3.1.2.2 Overlapping Fields

Field overlap reduces fractures at main field boundaries in the Fixed Fields mode. In case of no overlap, all features crossing the field borders will have to be cut at the field boundary. The overlap parameter defines a common region between the main fields where fractures (trapezoids split into two main fields) are avoided if the feature can be exposed completely in either one of the fields. The maximum overlap is half of the field size.

Consider the example where at the field boundary of Field 1 and Field 2, cutting of shapes occur for the following pattern. Assume the mainfield size is 1000um by 1000um square.



One can specify a field overlap in the X and Y direction as shown by going to the Multipass Tab:

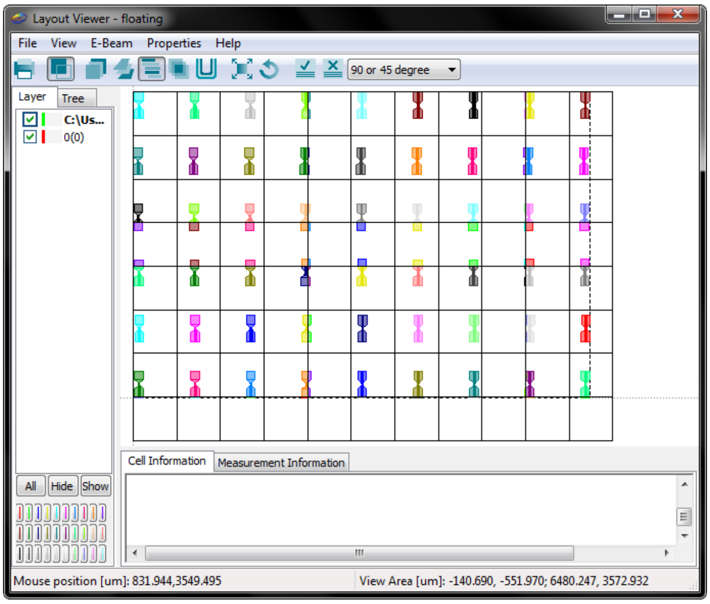

Overlap [um] X 5 Y 5

The overlap results in shapes being completely placed in one field, avoiding cutting at the field boundaries:

With field overlap enabled, a physical stage move from one field to the next is changed from 1000um to 995um, making field stitch prevention at the field boundaries possible.

3.1.3 Floating Fields

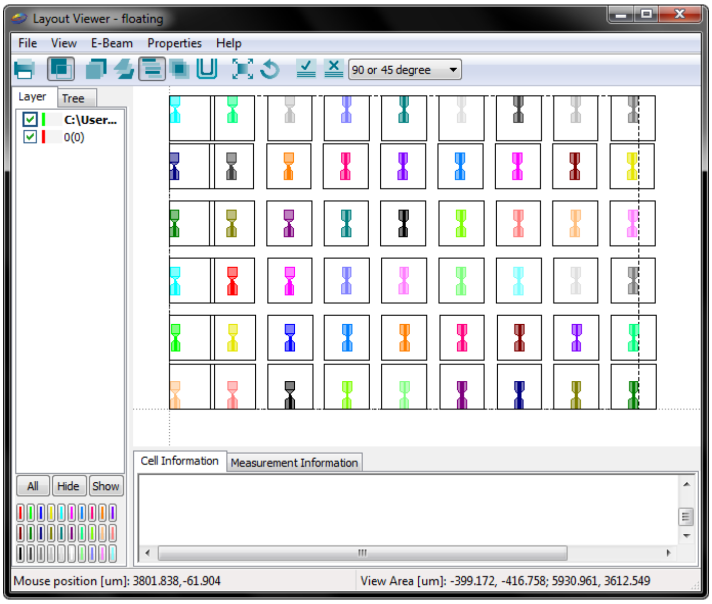
With fixed fields on sparse data, possible field stitching will occur:



Mouse position [um]: 831.944,3549.495

View Area [um]: -140.690, -551.970; 6480.247, 3572.932

The Floating field feature is an intelligent strategy that places the fields where the data exists. In addition, the fields are sorted to optimize stage travel (a.k.a. the *traveling salesman*). Mainfields start at the top left, centered to the data and then maps the order of fields while minimizing stage travel. This option should be used for sparse layouts. With Floating enabled, fields are placed such that field stitching is avoided. If possible, the fields are placed so the data is in the center of the field.



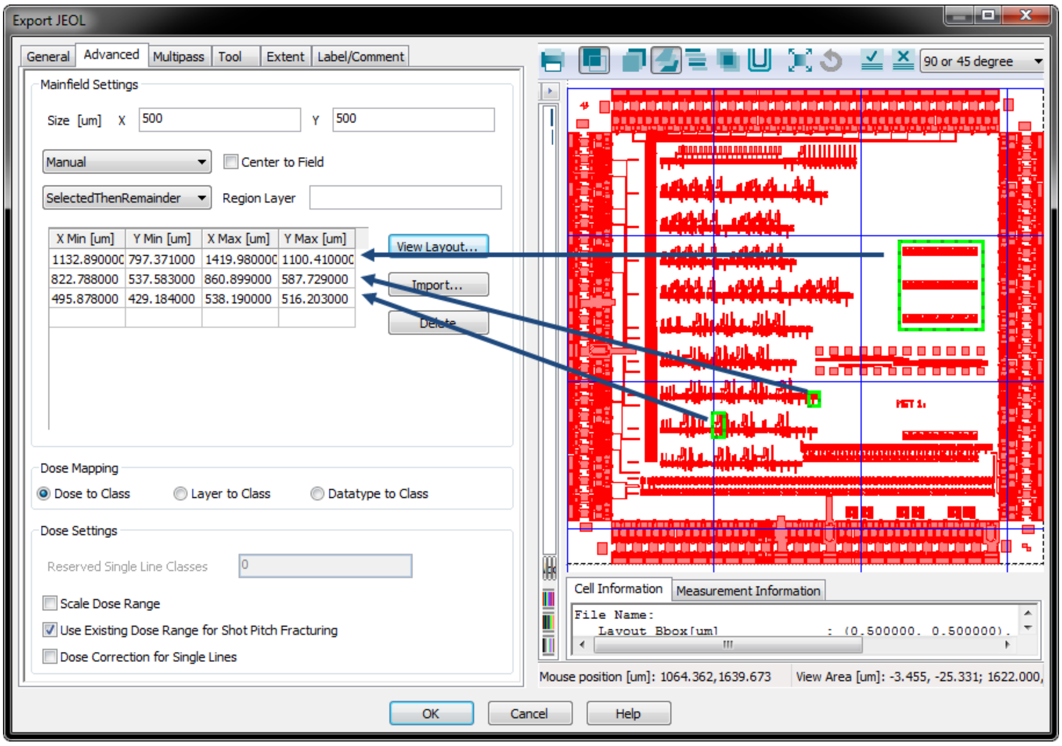
Mouse position [um]: 3801.838,-61.904

View Area [um]: -399.172, -416.758; 5930.961, 3612.549

NOTE: Currently, floating fields cannot be viewed in the JEOL Display program. However, floating fields can be viewed using the JEOL PCHK program.

3.1.4 Manual Fields

The most flexible field control method is the manual placement of fields. The user can specify which parts of the layout should be placed in separate fields. The region that defines the field content needs to be specified in a design rectangle either already in the layout in a particular design layer or manually inserted by using the "View Layout..." button:



Mainfield Settings

Size [um] X 500 Y 500

Manual ☐ Center to Field

SelectedThenRemainder Region Layer

X Min [um]	Y Min [um]	X Max [um]	Y Max [um]
1132.890000	797.371000	1419.980000	1100.410000
822.788000	537.583000	860.899000	587.729000
495.878000	429.184000	538.190000	516.203000

Dose Mapping

● Dose to Class ○ Layer to Class ○ Datatype to Class

Dose Settings

Reserved Single Line Classes 0

☐ Scale Dose Range

☑ Use Existing Dose Range for Shot Pitch Fracturing

☐ Dose Correction for Single Lines

```
File Name:
   Layout Bbox[um]                    : (0.500000, 0.500000),
```

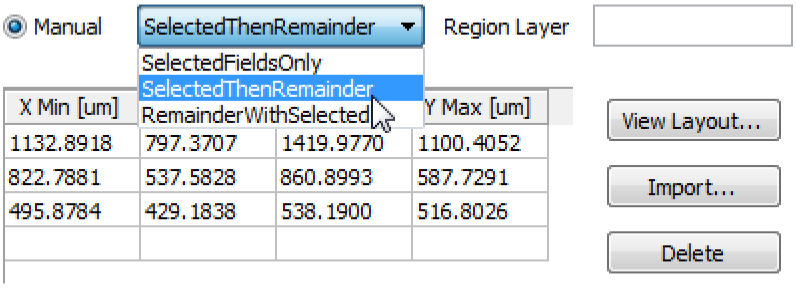
Mouse position [um]: 1064.362,1639.673

View Area [um]: -3.455, -25.331; 1622.000,

The fields definitions (green boxes) can be drawn into the layout by a keyboard/mouse command. To create a field definition, hold down the SHIFT key and click the left mouse button. Drag the mouse to size the field definition. Once the size is determined, fix the selection area by holding down the SHIFT key and clicking the left mouse button once. The coordinates of the field definition will automatically be placed in the table to the left. The user may also enter the coordinates directly to the table or edit the coordinates in the table. The selected field definitions in the image above will be used in the examples for each of the 3 available modes of Manual Field Control.

In the dropdown, there are 3 available modes of Manual Field Control:

- SelectedFieldsOnly
- SelectedThenRemainder
- RemainderWithSelected



● Manual SelectedThenRemainder Region Layer

SelectedFieldsOnly
SelectedThenRemainder
RemainderWithSelected

X Min [um]			Y Max [um]
1132.8918	797.3707	1419.9770	1100.4052
822.7881	537.5828	860.8993	587.7291
495.8784	429.1838	538.1900	516.8026

SelectedFieldsOnly

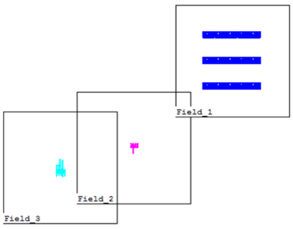
This option extracts only the regions that were selected for exposure in their respective floating fields. The writing order of the fields is determined by the order of which each field was defined.

SelectedThenRemainder

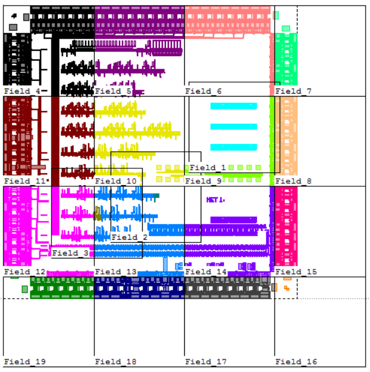
This option orders the defined floating fields to be written in order of their selection and then the remainder of the pattern using fixed fields. This is not an optimized writing strategy for stage movements.

RemainderWithSelected

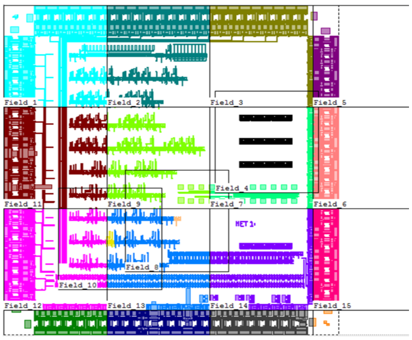
This option orders the defined fields to be written with remainder of the pattern. In this case, the fixed field sorting is used with the floating fields sorted into this traversal.



SelectedFieldsOnly



SelectedThenRemainder



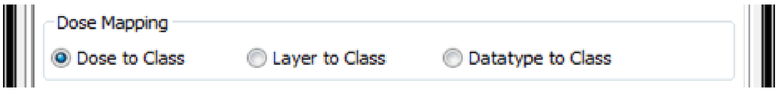
RemainderWithSelected

3.1.5 Notes on Field Positioning

Because of field stitching, fractures at field boundaries may create issues. Summarizing the above mentioned degrees of freedom, the following measures help to minimize fractures at field boundaries:

- Change the Main Field Size
- Use automatic floating fields for sparse data
- Shift the layout (change extents)
- Allow overlaps between fields
- Manually place fields around critical features

3.2 Dose Mapping


Dose Mapping

● Dose to Class ○ Layer to Class ○ Datatype to Class

Dose to Class

Maps the relative dose values of the layout (e.g. created by PEC, BSS corrected or dose assigned to layouts manually) to shot ranks defined in the modulation table (.jdi file) . This is the default setting used in connection with PEC.

Layer to Class

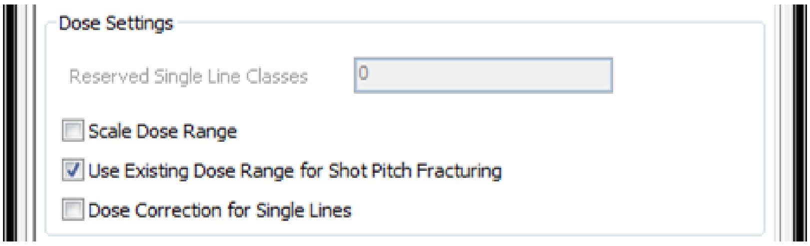
The layer numbers are used to assign the features to shot ranks, e.g. Layer 0 to shot-rank number 0, Layer 1 to shot rank number 1,... The dose values are defined then in the modulation table (.jdi file)

Datatype to Class

Same as to Layer to Class, but using data-types instead of layer

3.3 Dose Settings

This parameter is only important, if the layout has been proximity effect corrected.


Dose Settings

Reserved Single Line Classes: 0

☐ Scale Dose Range

☑ Use Existing Dose Range for Shot Pitch Fracturing

☐ Dose Correction for Single Lines

Scale Dose Range

The PEC algorithm of Layout BEAMER may generate relative doses smaller than 1. This option allows to scale the dose range such that the lowest dose is exactly 1. Use cases for this option include:

1. to avoid frequency limits on some tools
2. to create v30 files consistent to corrections from other PEC packages, and
3. to enable a simple way to make a judgment on base dose and shot pitch based on the dose range.

However, be aware that using this options means, that this will change the required base dose, or more important, the base dose will become dependent on the layout.

Use Existing Dose Range for Shot Pitch Fracturing

This parameter controls the dose of patch rectangles that are generated by shot pitch fracturing. If switched on, the dose can not be lower than the minimum dose of the layout, thereby avoiding frequency limits of the machine. If switched off, the dose computed for that patch will be used.

The default setting is to use the existing dose range, meaning,

1. PEC-corrected layouts will use the existing dose classes, and not generate additional (lower) dose classes for BSS patch rectangles, and
2. on non-PEC corrected layouts, all patches rectangles will get that default dose of 1, since the dose range of non-PEC corrected layouts is exactly 1 for all figures in the layout.

Reserved Single Line Classes

Only active for machines supporting single lines (e.g. 6300, 5500); controls the number of shot ranks used for single lines. If the number is 0, there will be no dose modulation of single lines. The full range of shot ranks can be used for the "area modulation". If the number is set to 16, the shot ranks 0-15 will be used for single lines.

Dose Correction for Single Lines

This option is only available for machine types which do not have single -line support (e.g. 9300FS). Layout BEAMER offers to use single lines at this machines by fracturing single lines to trapezoids with minimum widths such that the machine does expose this lines with single shots. This option allows to adjust the exposure dose for single lines depending on its angle

4 Multipass Tab

Writing errors are either systematic or statistical. Systematic errors include but are not limited to:

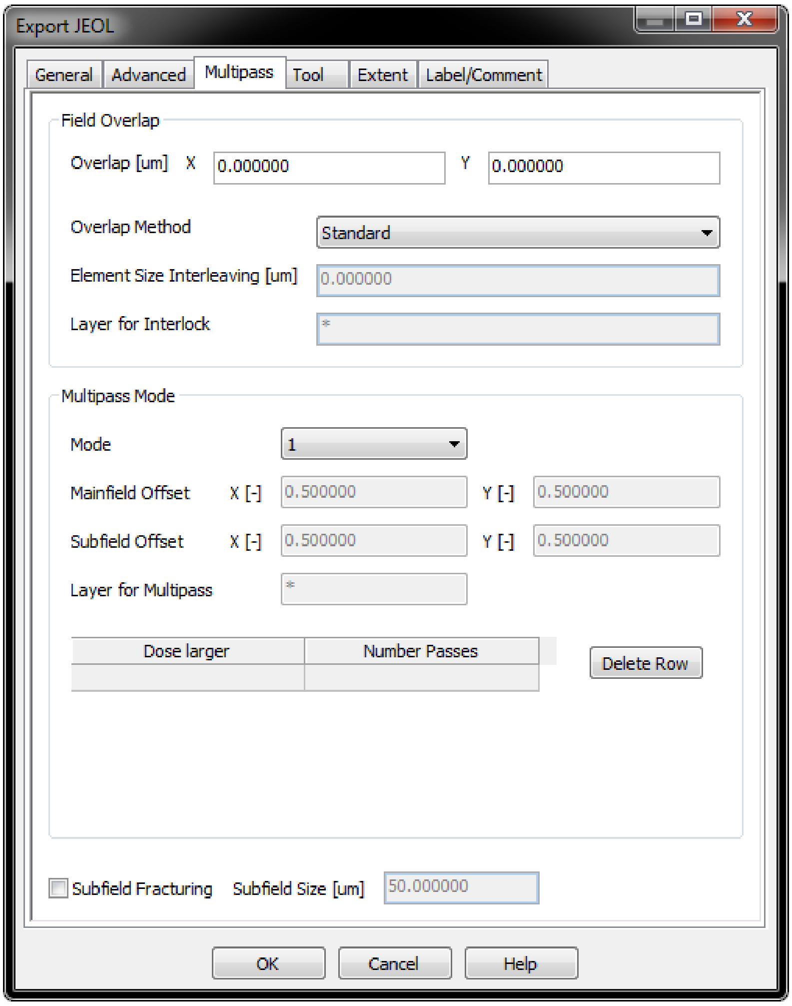
- Field Distortion and Field Aberration
- Scan Non-Linearities
- Shutter Effect
- X/Y asymmetries due to discrete spots in Y / dragging in X

Statistical Errors include but are not limited to:

- Beam Current Fluctuations
- Beam Jitter, Beam Drift
- Stage Position Errors, mechanical vibrations

Multipass reduces statistical errors by averaging. Systematic errors can be reduced by clever offset strategies. By default, the multipass feature uses a half-field size offset to mitigate systematic errors such as field stitching.

The Multipass tab allows the user to control multipass capabilities.



Field Overlap

Overlap [um] X 0.000000 Y 0.000000

Overlap Method: Standard

Element Size Interleaving [um]: 0.000000

Layer for Interlock: *

Multipass Mode

Mode: 1

Mainfield Offset X [-] 0.500000 Y [-] 0.500000

Subfield Offset X [-] 0.500000 Y [-] 0.500000

Layer for Multipass: *

Dose larger	Number Passes

☐ Subfield Fracturing Subfield Size [um] 50.000000

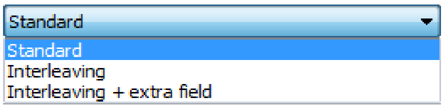
4.1 Field Overlap

Overlap

This specifies the overlap between fields for a fixed field traversal. More information can be found in the section on Overlapping Fields should the *Overlap Method* chosen is *Standard*.

Overlap Method

This specifies the type of overlap between fields for a fixed field traversal.

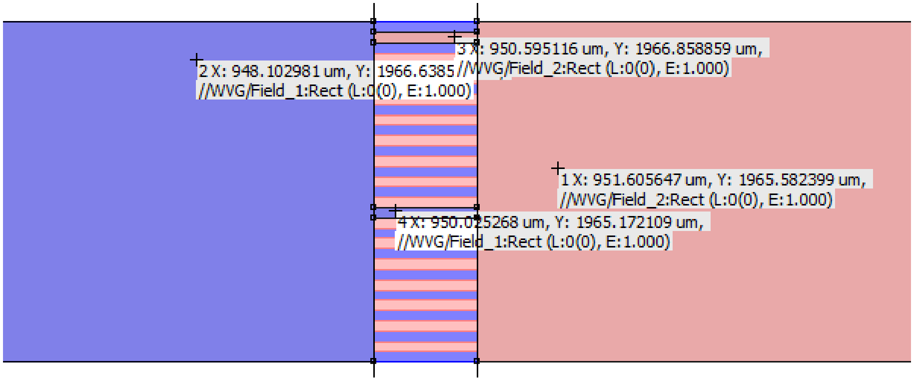


Standard

This default mode does not invoke a multipass writing strategy. Instead it overlaps fields enabling data to be completely written in one field or another. More information can be found in the section on Overlapping Fields for the *Standard* overlap method.

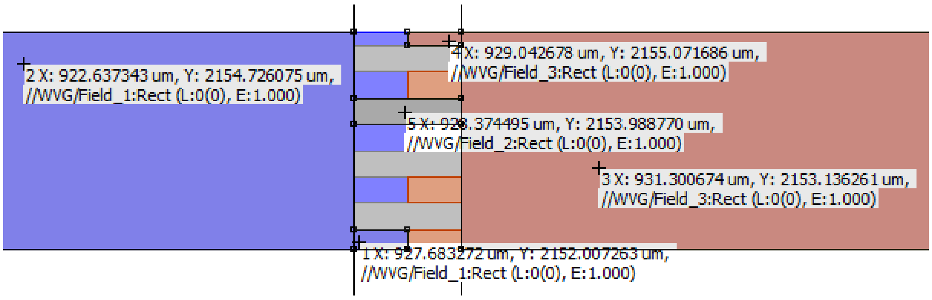
Interleaving

Interleaves elements that would normally be cut between two fields with an overlap:



Interleaving + extra field

Introduces an additional field to add additional interleaving elements which 50% of the area overlapping area. For every field overlap, there is a third floating field that writes the remaining 50% of the interleaving region.



Element Size Interleaving

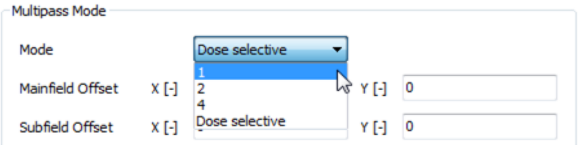
This specifies the height of the bars in the overlap.

Layer for Interlock

This is the layer for which to apply the *Interleaving Overlap* or *Interleaving*

Overlap + extra field. For example, say a pattern has layer 0, 1, and 2. The most critical structures are on layer 0. Therefore, the user can decide to exclusively overlap with the interleaving structures for only layer 0.

4.2 Multipass Mode



Multipass Mode

Mode: Dose selective

Mainfield Offset X [-] Y [-] 0

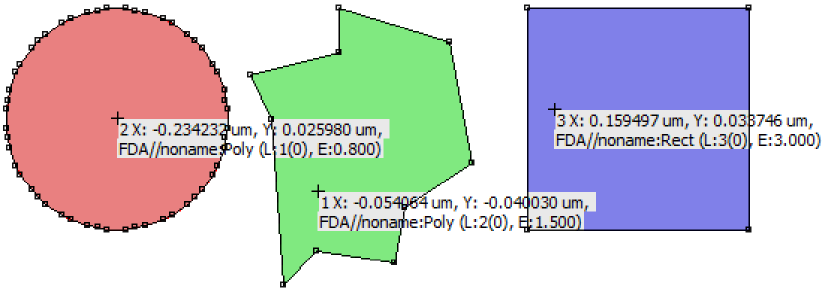
Subfield Offset X [-] Y [-] 0

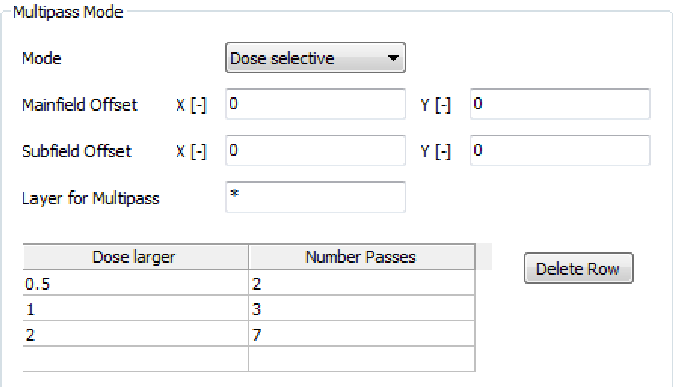
Mode

The number of passes can be 1 (default), 2 or 4. When using 2 passes, the base dose should be set to half of the base dose in the SDF file in a single pass. Likewise, when using 4 passes, the base dose should be set to a quarter of the base dose in a single pass.

Dose selective

When using the *Dose selective* mode, this will enable the table below the *Layer for Multipass* field. In the table, the user can specify that for any dose larger than a specific value, the number of passes will be performed on that shape whose dose assignment is larger than the indicated value. For the example below, any shapes with a dose between 0.5 and up to 1; between 1 and up to 2; and greater than 2 will receive 2, 3, and 7 passes, respectively.





Multipass Mode

Mode: Dose selective

Mainfield Offset X [-] 0 Y [-] 0

Subfield Offset X [-] 0 Y [-] 0

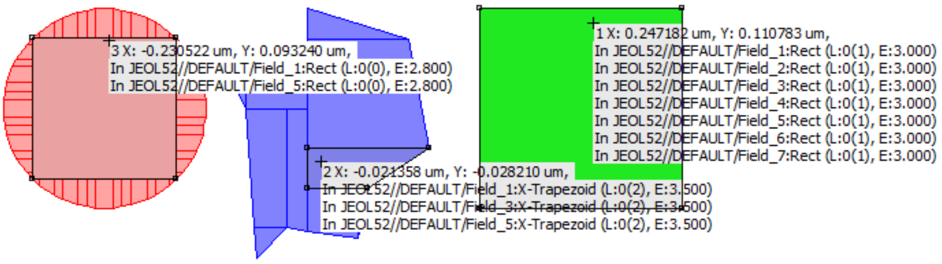
Layer for Multipass: *

Dose larger	Number Passes
0.5	2
1	3
2	7

When using the Dose selective mode, the dose with the highest number of passes ($dose_{passesmax}$) is used to normalize the final applied relative doses in the output of the machine format. Here, the highest number of passes ($passes_{max}$) of 7 for a relative dose assignment of 3 ($dose_{passesmax}$) will be maintained. The other doses: 0.8 and 1.5 both of which will receive 2 and 3 passes, respectively, will have their dose assignments adjusted using the following formula:

$$new\_dose = original\_dose * passes_{max} / dose_{passesmax}$$

As such, the new relative dose assignments are:
- 0.8 * 7 / 3 = 2.8
- 1.5 * 7 / 3 = 3.5



```
3 X: -0.230522 um, Y: 0.093240 um,
In JEOL52//DEFAULT/Field_1:Rect (L:0(0), E:2.800)
In JEOL52//DEFAULT/Field_5:Rect (L:0(0), E:2.800)
```

```
1 X: 0.247182 um, Y: 0.110783 um,
In JEOL52//DEFAULT/Field_1:Rect (L:0(1), E:3.000)
In JEOL52//DEFAULT/Field_2:Rect (L:0(1), E:3.000)
In JEOL52//DEFAULT/Field_3:Rect (L:0(1), E:3.000)
In JEOL52//DEFAULT/Field_4:Rect (L:0(1), E:3.000)
In JEOL52//DEFAULT/Field_5:Rect (L:0(1), E:3.000)
In JEOL52//DEFAULT/Field_6:Rect (L:0(1), E:3.000)
In JEOL52//DEFAULT/Field_7:Rect (L:0(1), E:3.000)
```

```
2 X: -0.021358 um, Y: -0.028210 um,
In JEOL52//DEFAULT/Field_1:X-Trapezoid (L:0(2), E:3.500)
In JEOL52//DEFAULT/Field_3:X-Trapezoid (L:0(2), E:3.500)
In JEOL52//DEFAULT/Field_5:X-Trapezoid (L:0(2), E:3.500)
```

This normalization method chosen here is used to maintain the reference for dose assignment in this differential multipass strategy.

Mainfield Offset

The default mainfield offset factor of 0.5 implies half of the actual mainfield size. Any value between 0 and 0.5 can be used to define the mainfield offset.

Subfield Fracturing

In addition to a mainfield offset, a subfield offset can optionally be enabled. Use this checkbox to enable or disable subfield fracturing.

Subfield Size

The subfield size of the tool should be specified in this field in microns.

Subfield Offset

The default subfield offset factor of 0.5 implies half of the actual subfield size. Any value between 0 and 0.5 can be used to define the subfield offset.

Layer for Multipass

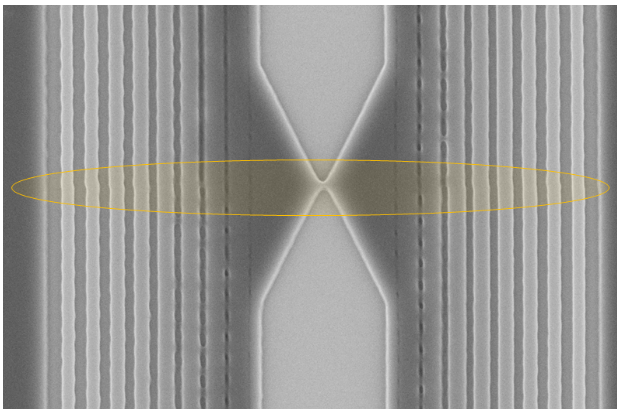
The layer a user can specify to impose a multipass exposure within a pattern when outputting to a machine format.

4.3 Proof of Concept

When enabling multipass and main/subfield offset strategies statistical and systematic error are respectively, averaged and reduced. By default, the multipass feature uses a half-field size offset to mitigate systematic errors such as field stitching. In the images below, ZEP was exposed on Si using three different techniques: single pass, 4X multipass only, and 4X multipass with a field offset. The qualitative results are provided.

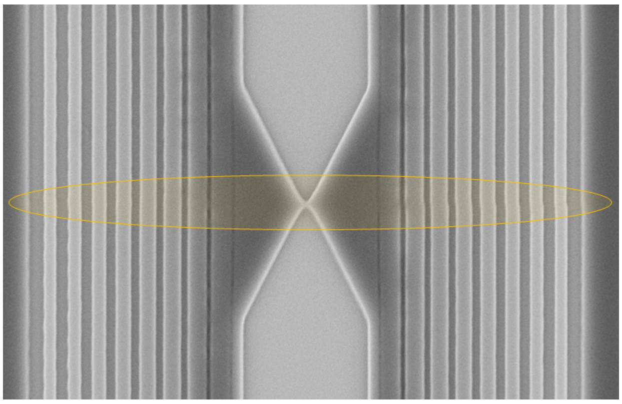
Single Pass

Writing the patterns as normal with a single pass reveals stitching errors and poor line-edge roughness.



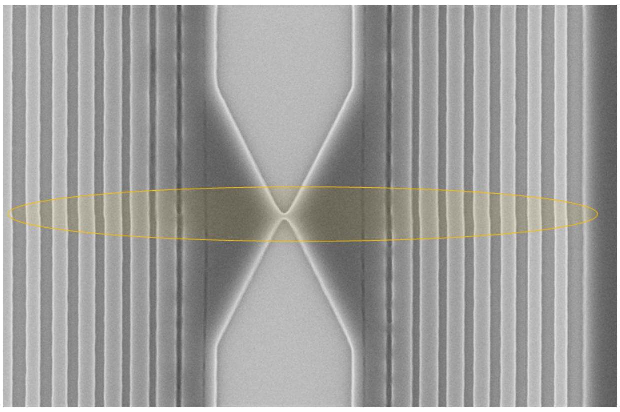
4X Pass Only

Writing the patterns as with a 4X pass reduces line-edge roughness, but the stitching is still apparent.



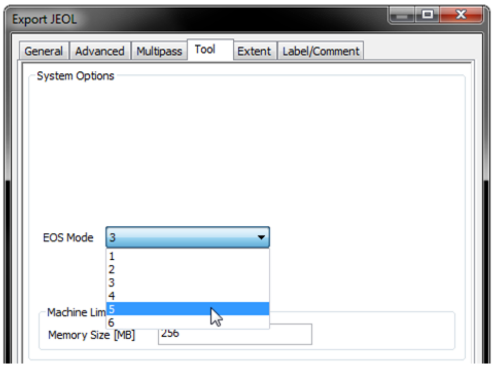
4X Pass with Field Offset

Writing the patterns as with a 4X pass with a field offset mitigates field stitching and line-edge roughness.



5 Tool Tab

This tab defines tool configurations the EOS mode settings of 5xxx and 6xxx series systems and onboard memory.



EOS Mode 3

Memory Size [MB] 256

EOS Mode

The EOS mode defines the available Pattern Units (General Tab) and the main field size for the machine. Please refer to the JEOL documentation for the specifications of the

EOS mode. Layout BEAMER will automatically set the available Pattern Units, Shot-Pitch and Main-Field Size according to the EOS mode selected. The JEOL JBX-9300FS does not have an EOS mode settings.

5500 Available EOS Modes	**Machine Settings**
1	25kV, 4th lens
2	50kV, 4th lens
3	25kV, 5th lens
4	50kV, 5th lens

6300FS Available EOS Modes	**Machine Settings**	
1	(a)	25kV, 4th lens, 500um
	(b)	25kV, 4th lens, 1000um
2	(a)	50kV, 4th lens, 500um
	(b)	50kV, 4th lens, 1000um
3	(a)	100kV, 4th lens, 500um
	(b)	100kV, 4th lens, 1000um
4	25kV, 5th lens	
5	50kV, 5th lens	
6	100kV, 5th lens	

Modes 1, 2 & 3 have two sub-modes that determine the maximum mainfield size. The current implementation sets the maximum value to 1000um in sub-mode (b) when selecting Modes 1, 2 or 3. Be sure to adjust the maximum mainfield size to the appropriate value in the Advanced Tab.

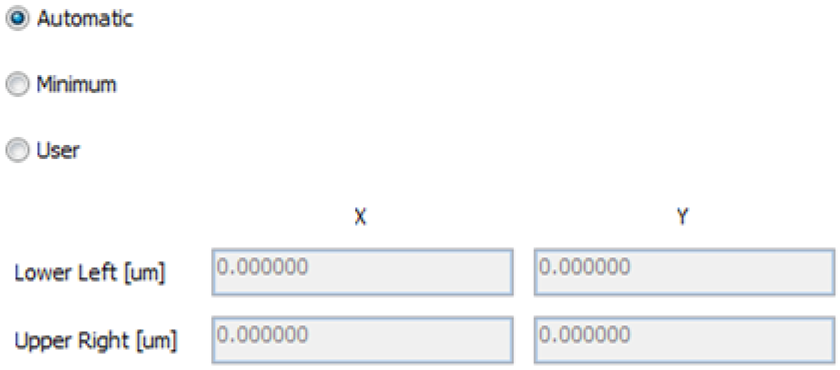
JBX-5DII, 6000FS and 5FE Available EOS Modes	**Machine Settings**
1	25kV, 4th lens, low current
2	25kV, 4th lens, high current
3	50kV, 4th lens, low current
4	50kV, 4th lens, high current
5	25kV, 5th lens, low current
6	25kV, 5th lens, high current
7	50kV, 5th lens, low current
8	50kV, 5th lens, high current

Memory Size

The tool does have a limit on the physical memory size per field for pattern data. The exposure will error if the data volume within one field exceeds this memory limit. Layout BEAMER allows the user to enter the memory limit of the tool, and will make sure that the data volume within one field will not exceed this limit.

6 Extent Tab

In the Extent tab the user can adjust the extents of the final layout using the following options.



● Automatic

○ Minimum

○ User

	X	Y
Lower Left [um]	0.000000	0.000000
Upper Right [um]	0.000000	0.000000

Automatic

Keeps the same extent as the original layout.

Minimum

Uses the minimum bounding box that encloses all polygons.

User

The user can specify the lower left and upper right coordinates of the extent

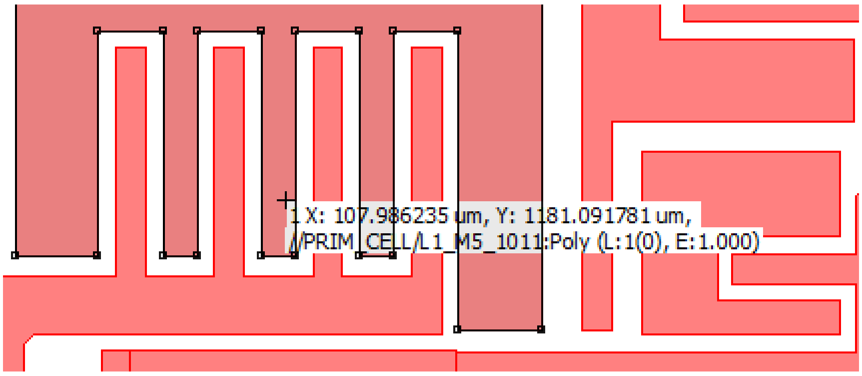
Note: It is only possible to adjust the extent to be larger than the layout extent. Making the extent smaller than the layout extent is not allowed.

7 Export of PEC Data

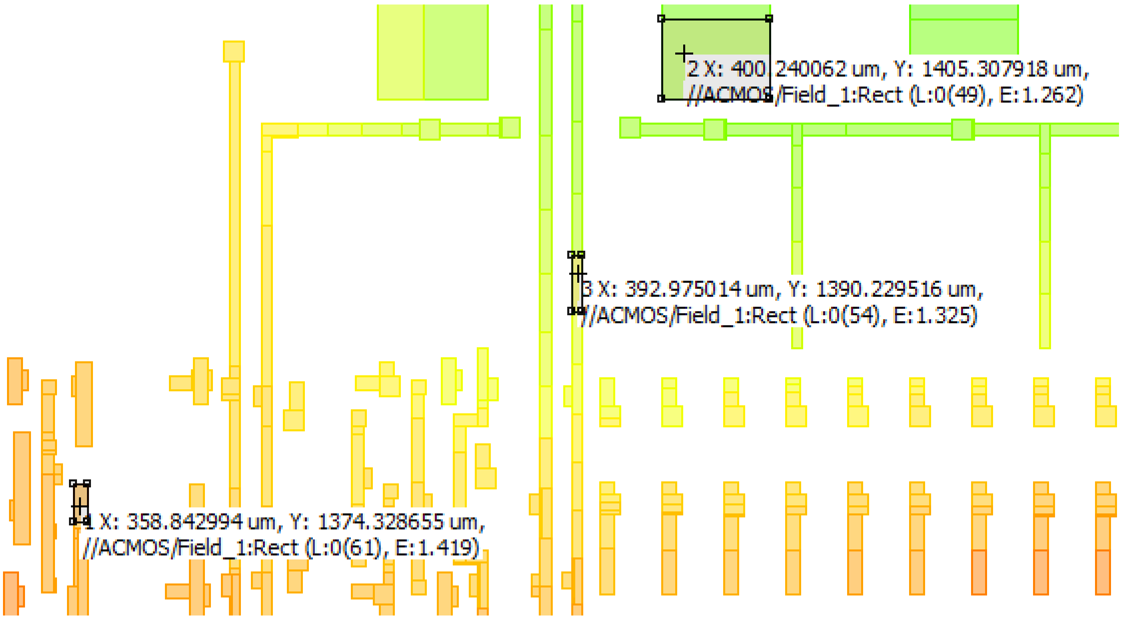
The export of a proximity effect corrected data is performed simply using the Export module. The exported file will include the dose information of the elements in a separate shot rank index file next to the v30 file containing the fractured data and a association to the index file.

Layout BEAMER uses a *non-linear edge equalization method* for corrections. This method provides the highest CD accuracy and CD linearity by adjusting the energy level at all feature edges to 50%. The base dose required on the tool is the dose-to-size for large elements. Please see other Layout BEAMER application notes for more detailed description of PEC and base dose calibration.

Figures with E:1.000 receive the base dose. The figures (trapezoids) with other dose factor receive the exposure dose = base dose * E

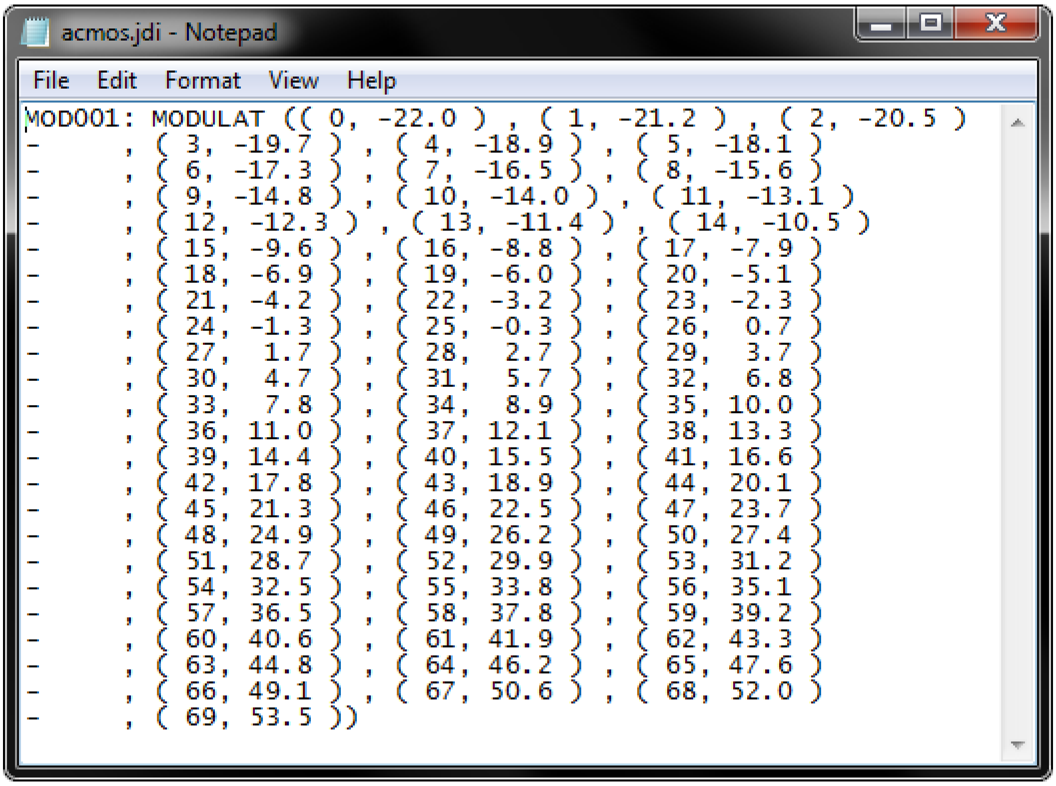


1 X: 107.986235 um, Y: 1181.091781 um,
/PRIM_CELL/L1_M5_1011:Poly (L:1(0), E:1.000)



Each datatype corresponds to a dose class (clock multiplier). Export generates a dose table with the extension .jdi, with the same name as the v30 file, in the same directory as the v30 file.

The JDI file is an ASCII text file and can be opened with a simple text editor. It contains the dose modulation table for the JEOL jobdeck file:



```
MOD001: MODULAT (( 0, -22.0 ) , ( 1, -21.2 ) , ( 2, -20.5 )
-     , ( 3, -19.7 ) , ( 4, -18.9 ) , ( 5, -18.1 )
-     , ( 6, -17.3 ) , ( 7, -16.5 ) , ( 8, -15.6 )
-     , ( 9, -14.8 ) , ( 10, -14.0 ) , ( 11, -13.1 )
-     , ( 12, -12.3 ) , ( 13, -11.4 ) , ( 14, -10.5 )
-     , ( 15, -9.6 ) , ( 16, -8.8 ) , ( 17, -7.9 )
-     , ( 18, -6.9 ) , ( 19, -6.0 ) , ( 20, -5.1 )
-     , ( 21, -4.2 ) , ( 22, -3.2 ) , ( 23, -2.3 )
-     , ( 24, -1.3 ) , ( 25, -0.3 ) , ( 26,  0.7 )
-     , ( 27,  1.7 ) , ( 28,  2.7 ) , ( 29,  3.7 )
-     , ( 30,  4.7 ) , ( 31,  5.7 ) , ( 32,  6.8 )
-     , ( 33,  7.8 ) , ( 34,  8.9 ) , ( 35, 10.0 )
-     , ( 36, 11.0 ) , ( 37, 12.1 ) , ( 38, 13.3 )
-     , ( 39, 14.4 ) , ( 40, 15.5 ) , ( 41, 16.6 )
-     , ( 42, 17.8 ) , ( 43, 18.9 ) , ( 44, 20.1 )
-     , ( 45, 21.3 ) , ( 46, 22.5 ) , ( 47, 23.7 )
-     , ( 48, 24.9 ) , ( 49, 26.2 ) , ( 50, 27.4 )
-     , ( 51, 28.7 ) , ( 52, 29.9 ) , ( 53, 31.2 )
-     , ( 54, 32.5 ) , ( 55, 33.8 ) , ( 56, 35.1 )
-     , ( 57, 36.5 ) , ( 58, 37.8 ) , ( 59, 39.2 )
-     , ( 60, 40.6 ) , ( 61, 41.9 ) , ( 62, 43.3 )
-     , ( 63, 44.8 ) , ( 64, 46.2 ) , ( 65, 47.6 )
-     , ( 66, 49.1 ) , ( 67, 50.6 ) , ( 68, 52.0 )
-     , ( 69, 53.5 ))
```

Copy and paste the modulation table to the JDF file, which needs to be prepared for the exposure, using a text editor.

NOTE:

- *For JDI files generated on Windows, tranferring them to a UNIX system requires special care because of the CR-LF vs. LF line end inconsistency between Windows and UNIX. Be sure to set the FTP transfer to ASCII mode when transferring the JDI file to avoid errors in compiling the magazine file.*
- *Layout BEAMER does not generate the jobdeck file (JDF) nor the schedule (SDF) file, required for exposure on the JEOL tool. Please follow the JEOL documentation and manual for proper settings of the JDF and SDF files.*

Please see also description of Dose Mapping and Dose Settings in this document.