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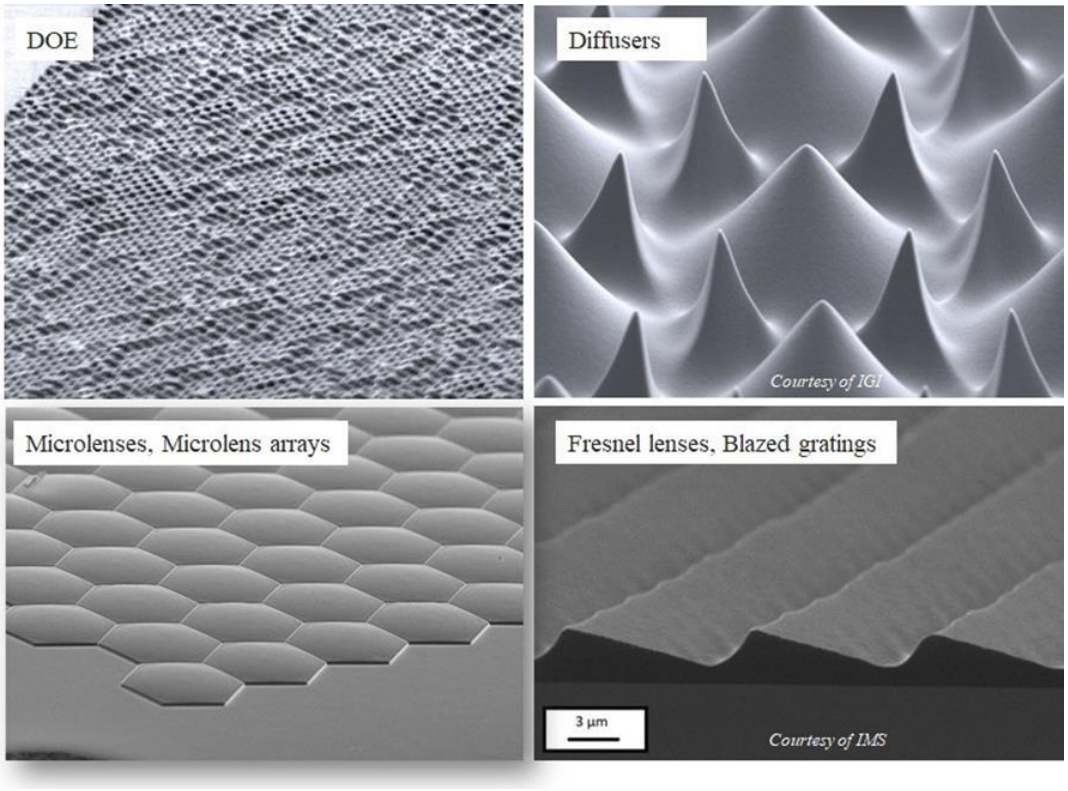
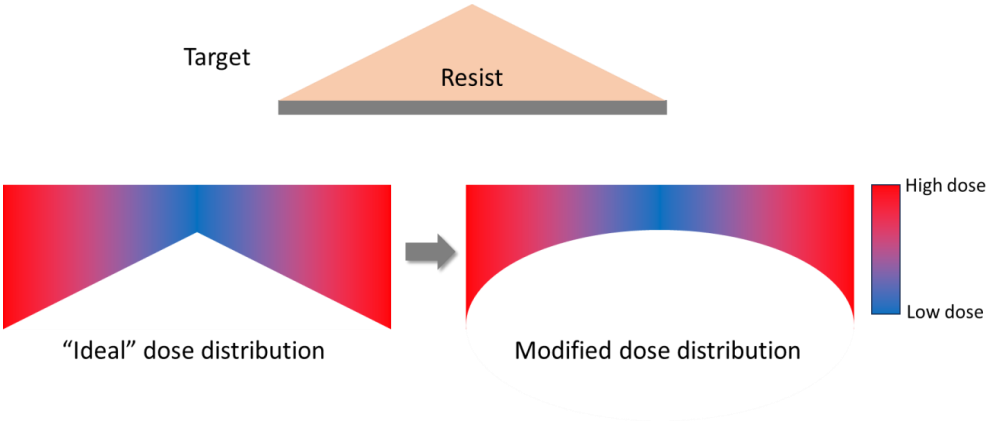
# 3D Laser Lithography in **BEAMER**

Many applications for 3D laser lithography exist. The images below illustrate a few of these applications. This Application Note describes in detail how to use **BEAMER** together with a Laser exposure tool to obtain 3D structures. Each module used for this Application will be explained with examples.

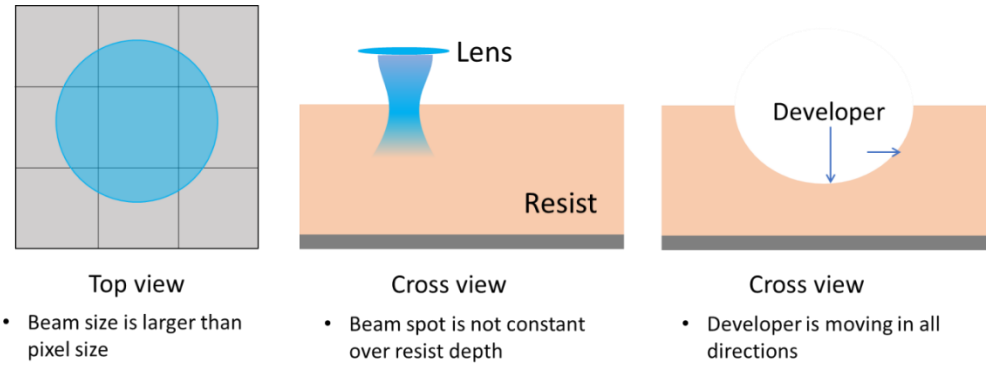


## Introduction

Light absorption in photoresist is a non-linear process. Therefore, it is necessary to modify energy distribution into grey levels. Pictured below on the left is the “ideal” situation while on the right side is the “modified” light distribution to achieve a particular target on the resist.



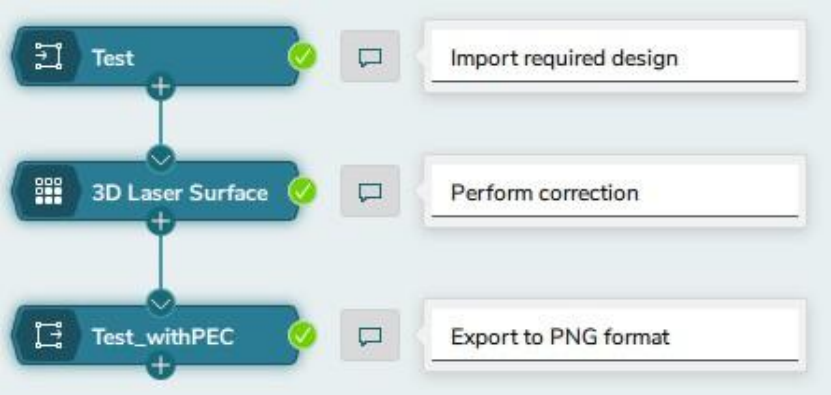

Output topography of the final photoresist structure strongly depends on target geometry and both tool and process parameters. The laser beam may not have a perfect structure and may not be constant along the z axis as shown below. In addition, the development process is not only in the desired z-direction, and a lateral development may occur. The effects have to be corrected prior to exposure to achieve the required results.




- Beam size is larger than pixel size
- Beam spot is not constant over resist depth
- Developer is moving in all directions

## Correction by **BEAMER**

A basic **BEAMER** flow for 3D laser lithography is shown. First an Import module is selected to load the required design data. The 3D PEC module performs the required corrections. Finally in the required format, the data are exported for the 3D exposure on a laser exposure tool.



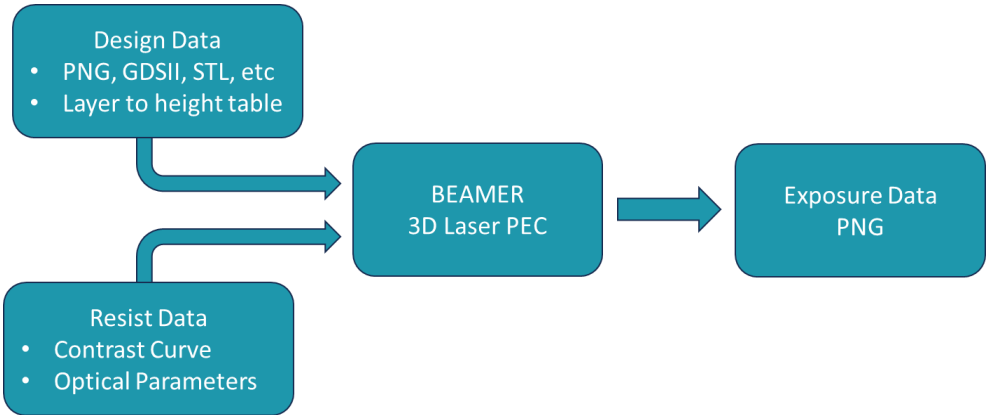

The following sections describe these steps in detail.

To obtain the required 3D structures, the following inputs are required:

- Layout (Design) data in a standard format
  - Corresponding layer-to-height table
- Resist data
  - Resist contrast curve
  - Optical data of the resist for the Proximity Effect Correction and exposure settings also from the Resist data sheet

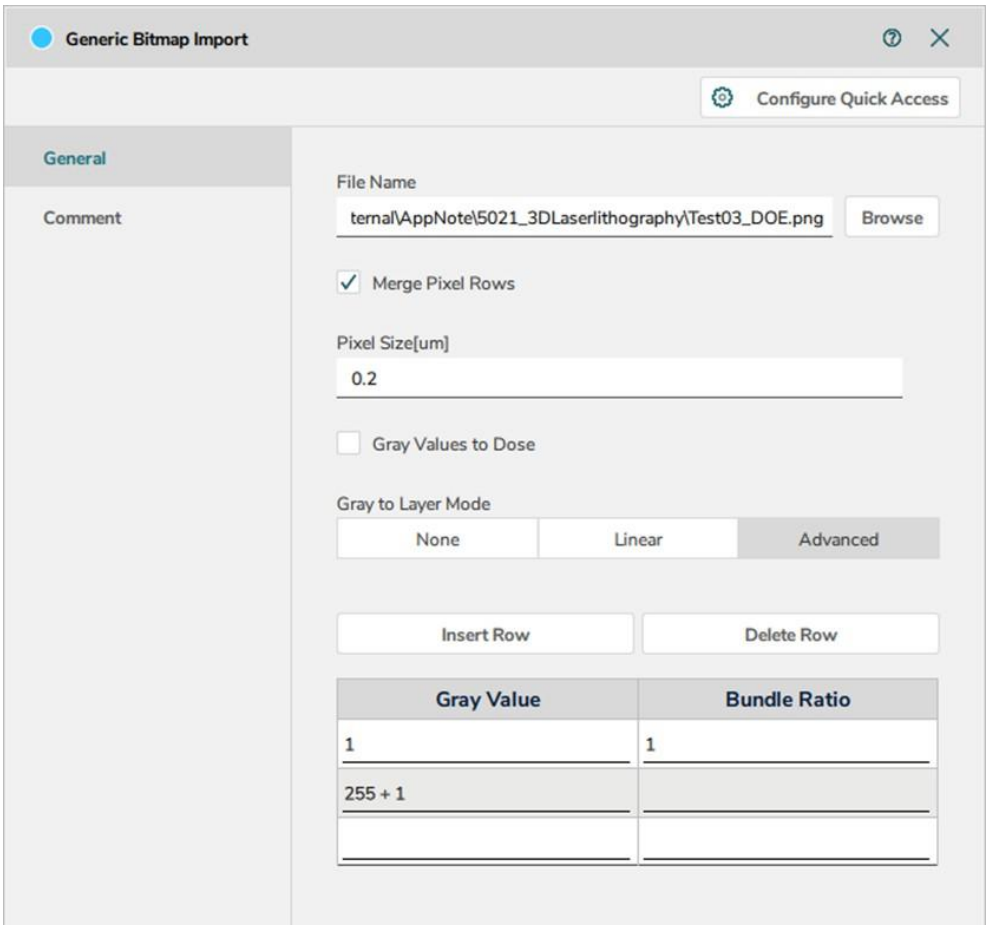
These issues will be discussed in detail in the following sections.

**BEAMER** offers a streamlined workflow to prepare exposure data for generating 3D resist profiles by combining the experimental contrast curve data with an arbitrary design of the user.



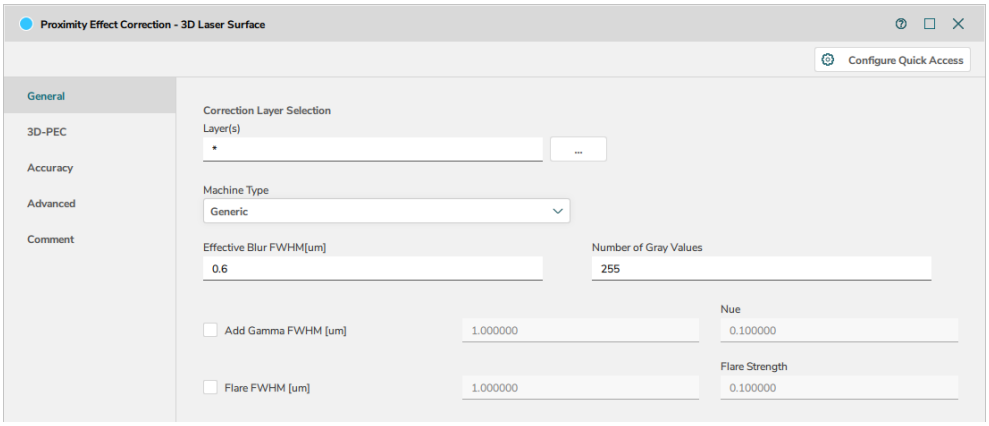

## Import Data

Design data can be in either of two formats: bitmap (PNG) or stereo (STL) format. Detailed information about import options is included in appendix.




## 3D Laser Surface PEC

3D Laser Surface PEC is required for Greyscale lithography using laser exposure. Application of 3D PEC to the exposure causes intensity modulation resulting in a varying resist thickness after exposure and development.




Specify **Layer(s)** for correction. The influence of other layers that are not defined in the list

will not be considered in the correction.

Choose the **Machine Type** to be either HIMT DWL tool or Generic tool. For Generic tool, user enters its value of **Effective Blur FWHM**.

**Add Gamma FWHM [um]** adds additional Gaussian components in the laser FWHM to compensate potential process effects.

**3D-PEC** tab assigns all the required information for proximity correction.

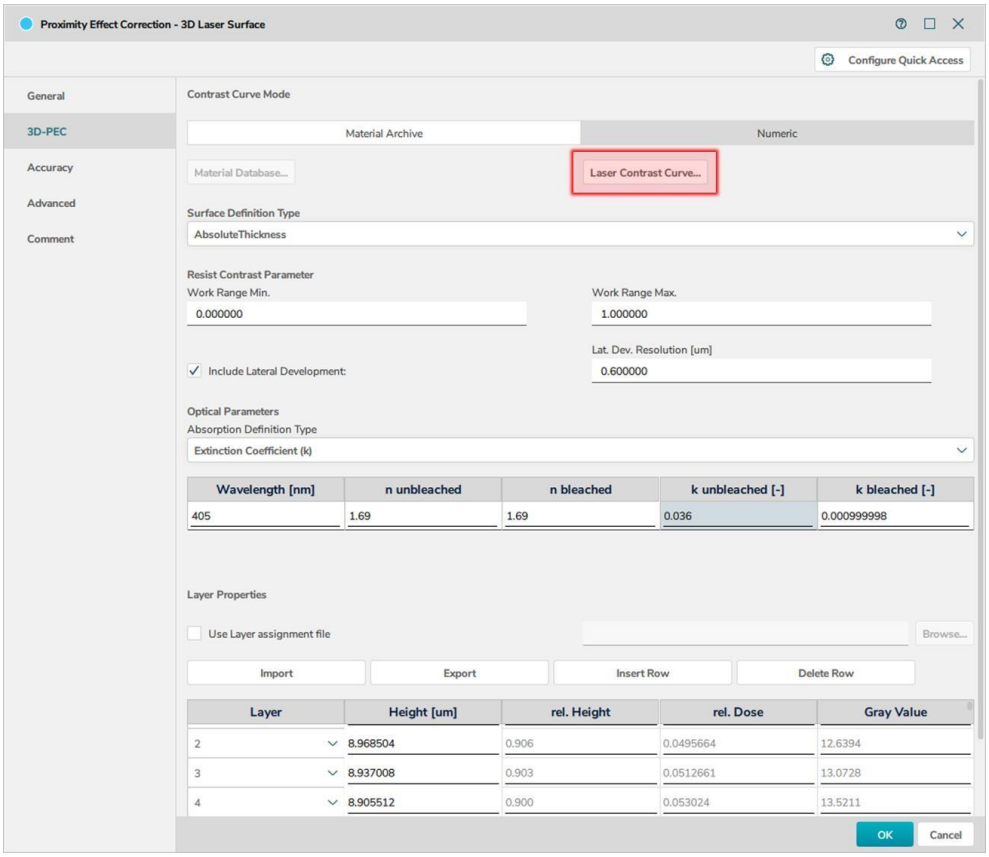
**Contrast Curve Mode** loads the resist either from Material Database via **Material Archive** or imports the **Laser Contrast Curve**, which is required for 3D PEC.

**Surface Definition Type** allows to set up the layer-to-height definition.

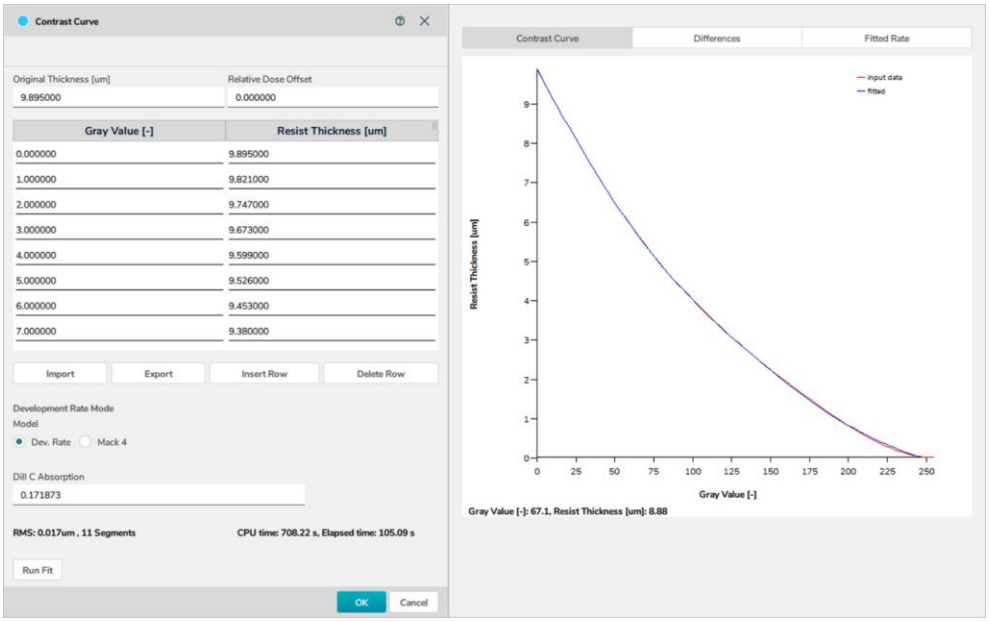
**Lat. Dev. Resolution [um]** affects the correction for the lateral development. As a rule of thumb, the value is set to be in the range of beam blur.

**Optical Parameters** define the refractive index (n unbleached and n bleached) and absorption parameters of the resist.

**Layer Properties** imports the layer-to-height table in design.

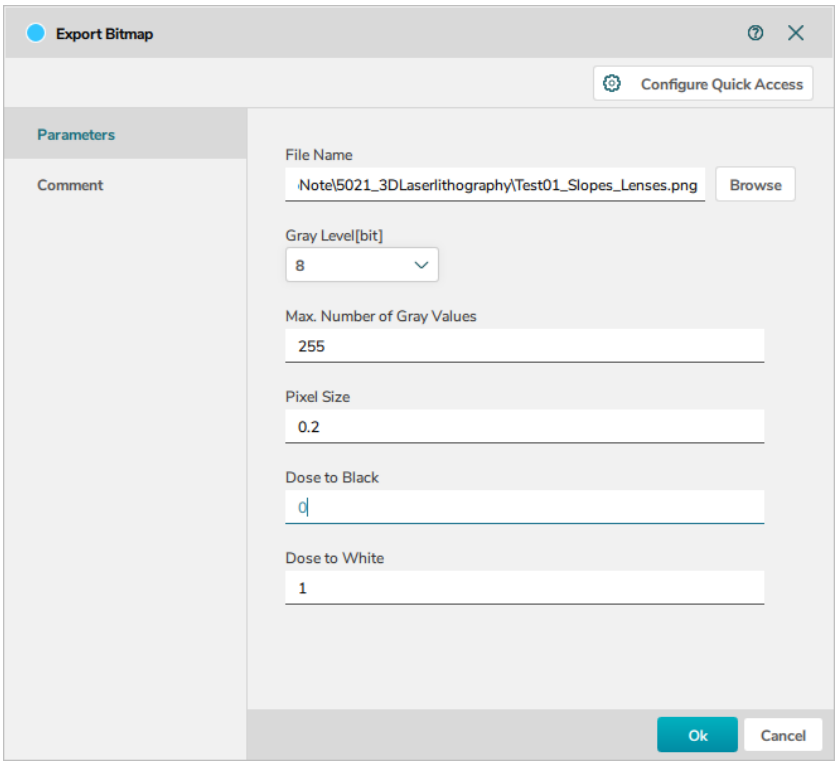


For 3D PEC, laser contrast curve is required to consider the nonlinearity of exposure and lateral development. How to determine a contrast curve on an exposure tool is discussed in appendix.




## Export the Data

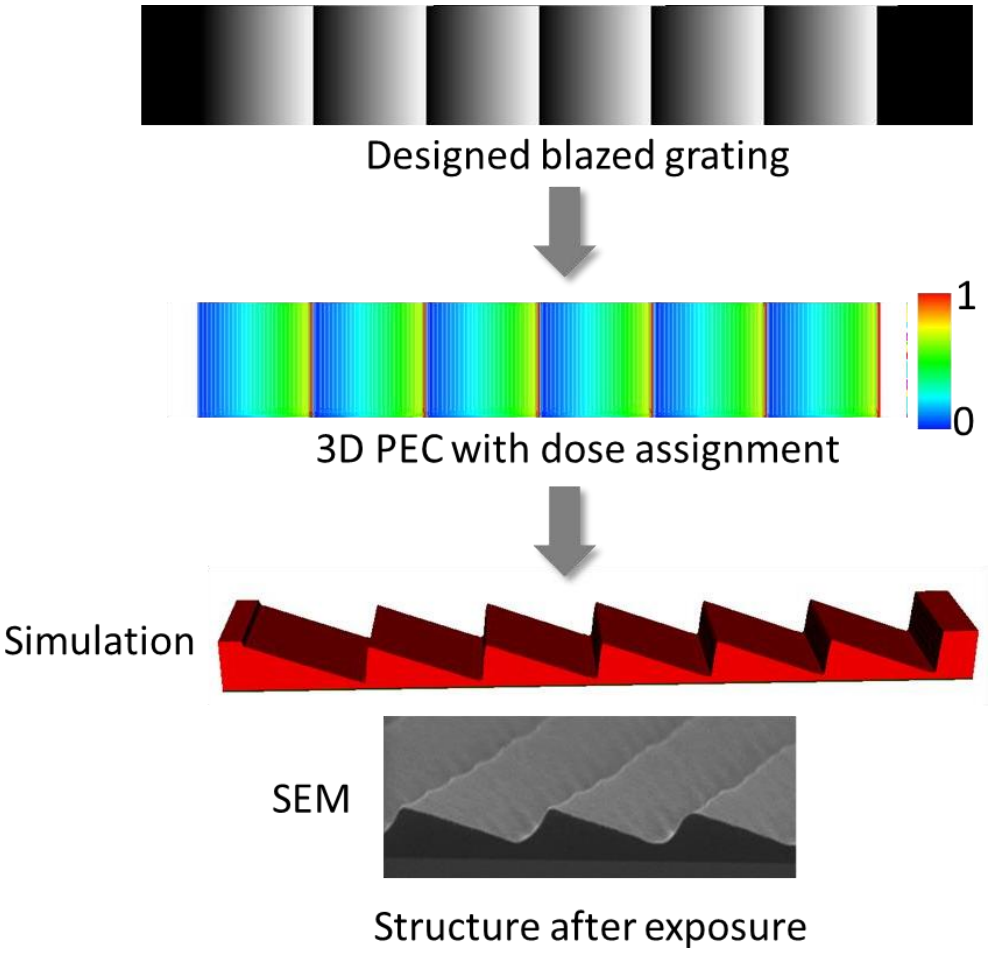
Having proximity correction of the data, an output file, which can be loaded into the Laser exposure tool, is created. A PNG file or machine formatter is exported with settings according to the machine type and process. For the PNG export, the dialog is shown below. The **Pixel Size** and **Max. Number of Grey Values** are set to the design and process. Dose to Black and Dose to White is set to be 0 and 1 because the dose range after 3D Laser PEC is between 0 and 1.


Export Bitmap
Configure Quick Access
Parameters
Comment
File Name
\Note\5021_3DLaserlithography\Test01_Slopes_Lenses.png
Browse
Gray Level[bit]
8
Max. Number of Gray Values
255
Pixel Size
0.2
Dose to Black
0
Dose to White
1
Ok
Cancel

## Summary

**BEAMER** 3D Laser surface PEC allows the fabrication of greyscale structure efficiently by taking into account the nonlinearity property of the process and lateral development of the resist. Without long trial-and-error experiments, it works well for complex shapes.

Below shows the realisation of a blazed grating. The blazed grating is designed using grey levels to represent the desired thickness. 3D PEC assigns the local dose assignment correspondingly. The simulation tool **LAB** verifies the resist profile.



# Appendix I: Import a Design

Design data can be in either in bitmap (PNG) or stereo (STL) formats, which are described in detail below.

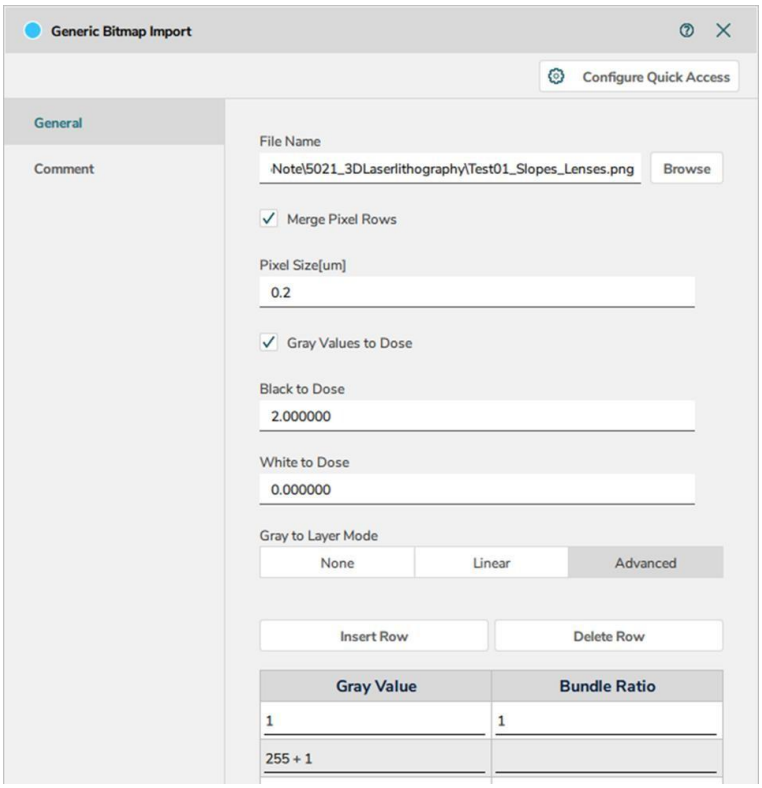
## Import Generic Bitmap

Generic Bitmap Format includes grey scale images which can vary in the number of shades of grey that are available in their color palette. This is dictated by the number of bits in the image. An 8- bit greyscale will have 256 ($2^8$) shades of grey. The color black has a value of 0, and the color white has a value of 255.

**Pixel Size [nm]** defines the size to convert an individual pixel.

**Grey Values to Dose** enables the conversion of grey values in the image to dose values upon import. When **Grey Values to Dose** is enabled the color black and white in the image can be assigned a specific relative dose value respectively via **Black to Dose** and **White to Dose**. All doses in between the black dose and white dose are interpolated. The number of doses generated depends on the number of bits of the image.

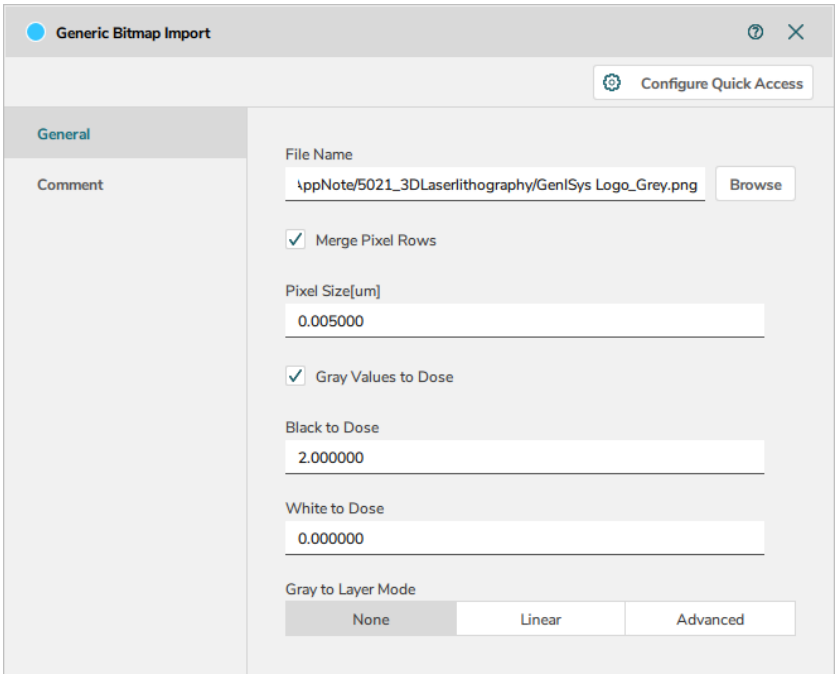
**Grey to Layer Mode** assigns grey values to specific layers upon import. In the table it can be specified how many Grey Values should be bundled into one Layer. The exclusion of certain Grey Values is possible, when the Bundle Ratio is undefined or specified with 0.

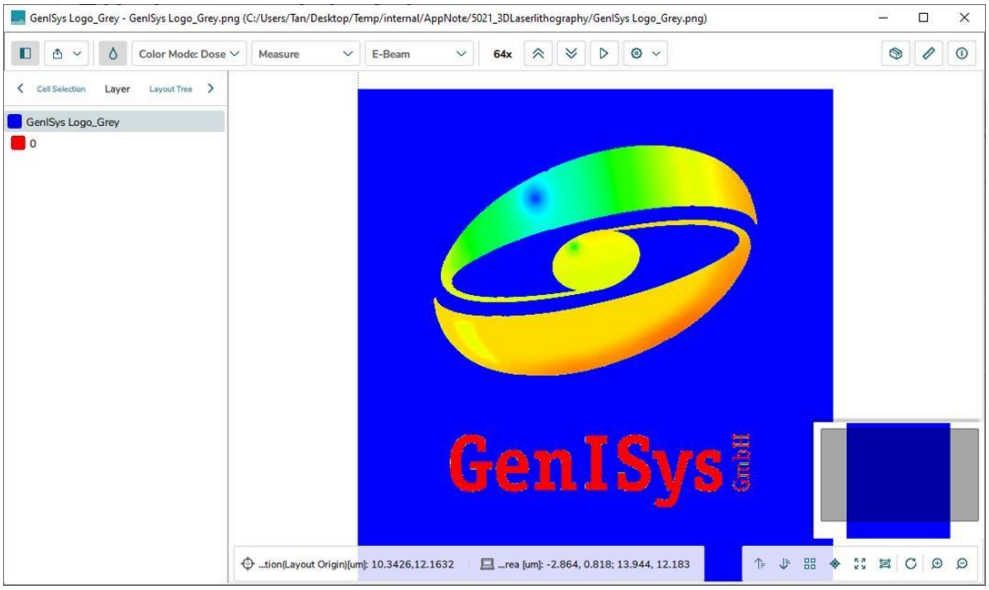


An example of importing a greyscale PNG is shown below. Here we are going to import a greyscaled version of the GenISys logo above. We will use various settings to demonstrate the various Import module settings.

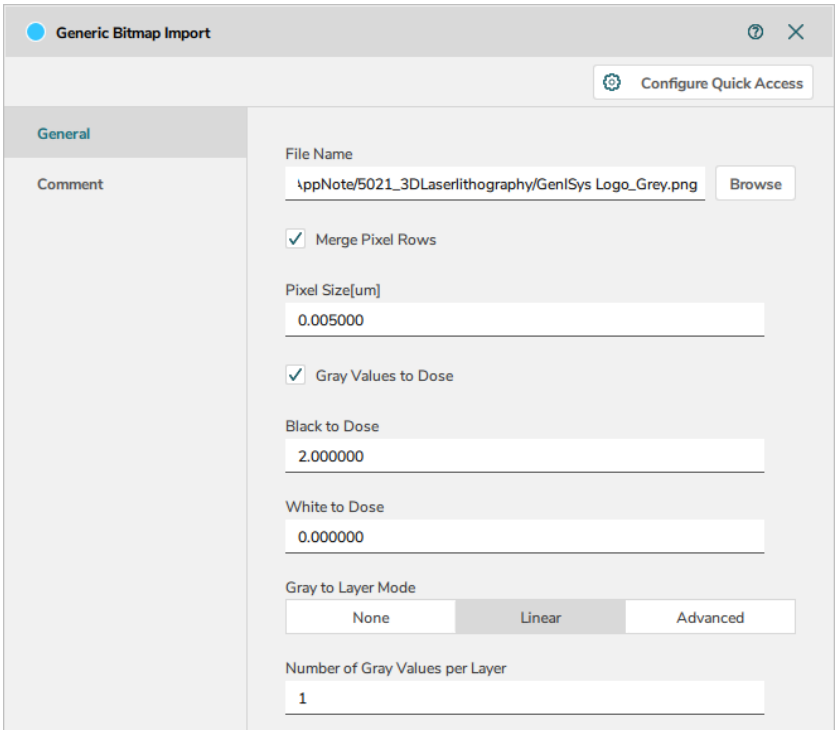
The image will be imported using a 5 nm pixel size.

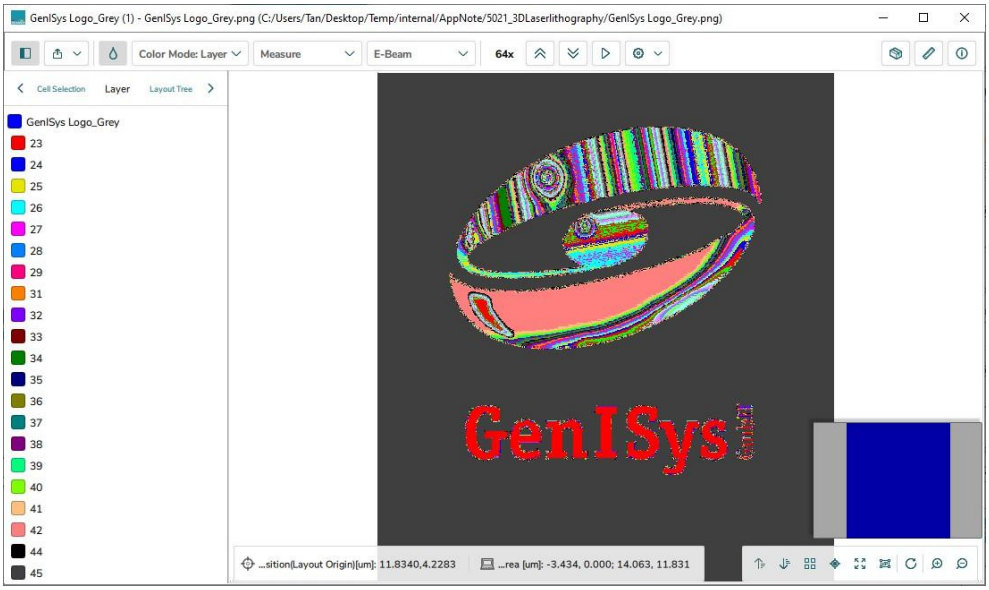
First, let's import the image using the default settings. This implies that completely black pixels will be imported with a relative dose of 2 and completely white pixels will receive a relative dose of 0, which means no dose. All doses in between are interpolated based on the number of shades of grey available for import. The **Grey to Layer Mode** is none. The result of the import is shown below. There is only Layer 0 after importing. Doses are assigned depending on the grey level. The lowest dose is in blue and the highest is in red.



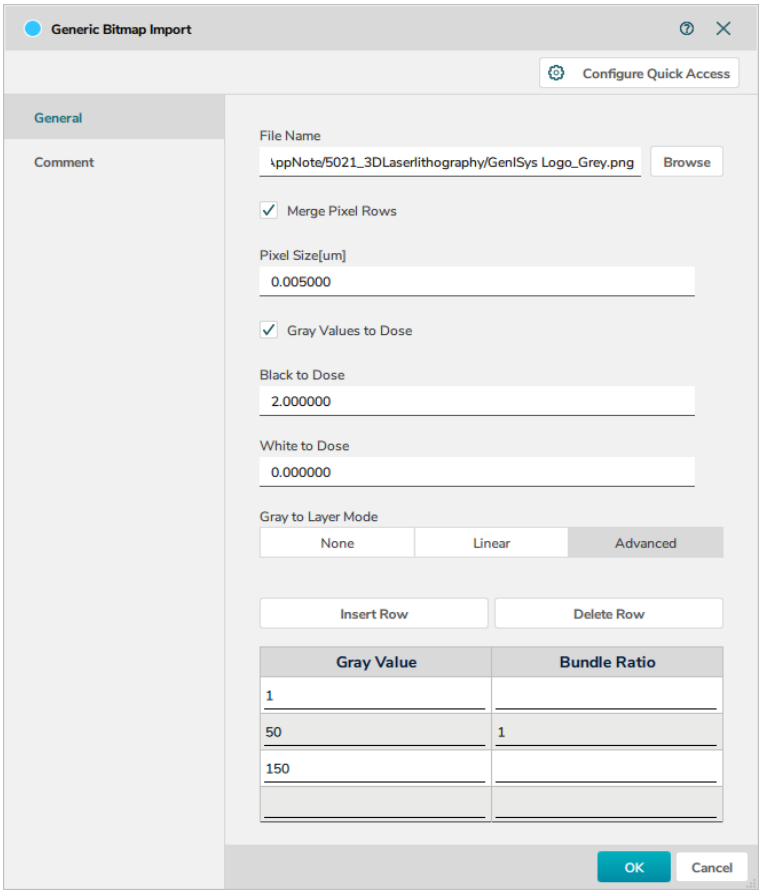



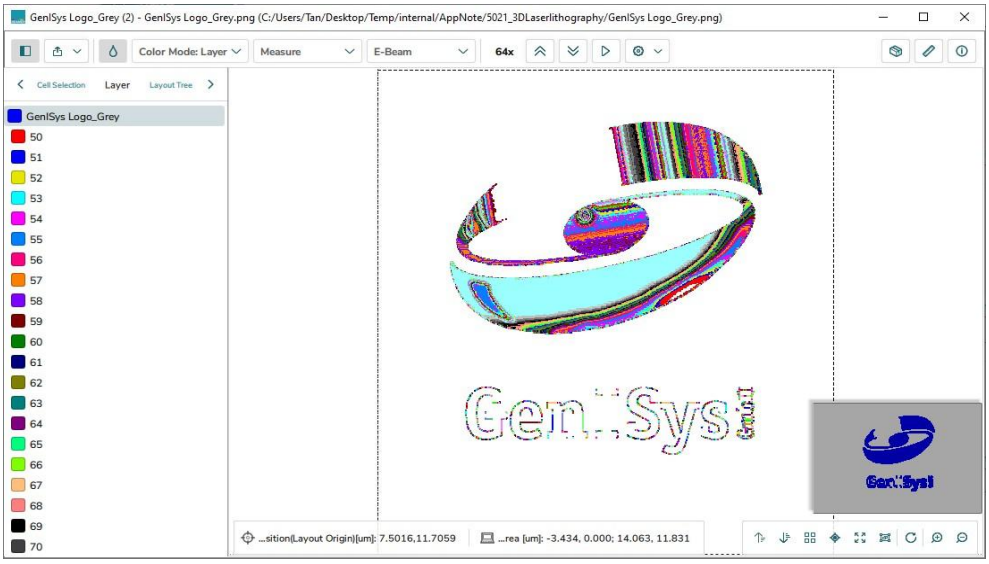

In the next example, the same color to dose assignments is maintained, however, the **Grey to Layer Mode** is Linear. The Import module will also import all grey values (between 1- 255) as layers upon import. Effectively, this image could be used for greyscale lithography where doses correspond to a particular resist height after development.



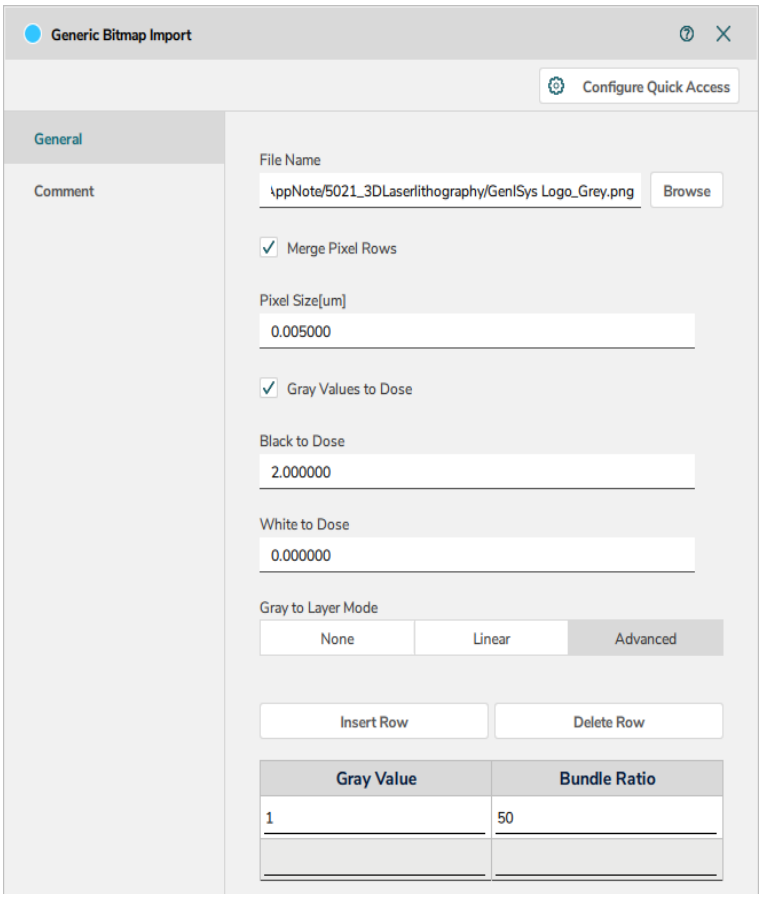



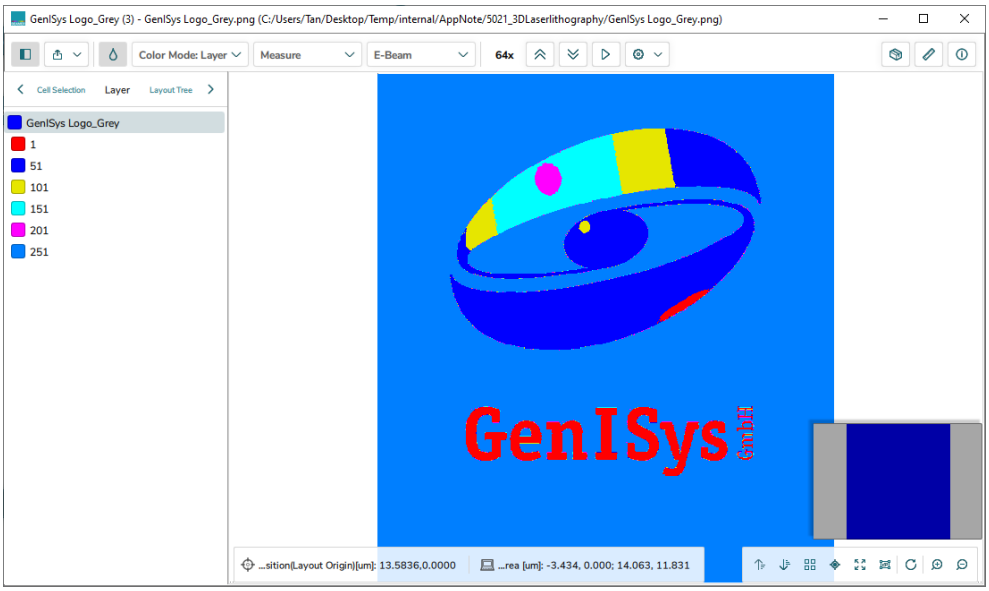

In the third example, the same color to dose assignments is maintained, however, the **Grey to Layer Mode** is set to be **Advanced**. The grey value range is limited to 50 to 149. This means that the module will only import greyscale values that fall in this range and assign them a layer. You'll notice that the white pixels are excluded. Again, the lowest dose is in blue and the highest is in red.



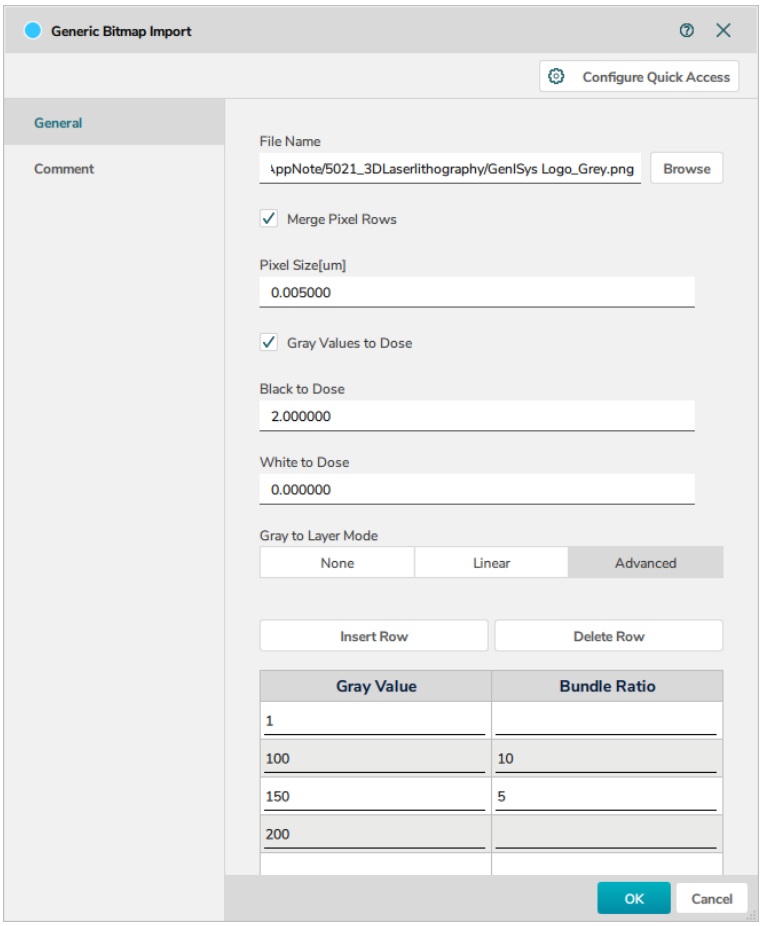



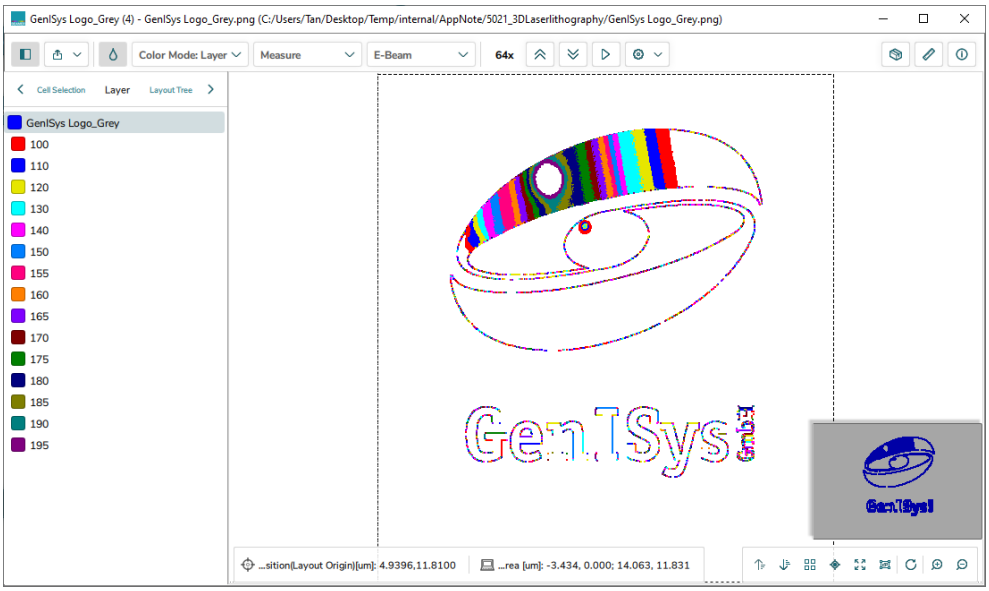

In the fourth example, the option Grey to Layer table has Grey Value 1 and Bundle Ratio 50. All grey values from 1 to 255 are bundled in groups of 50.



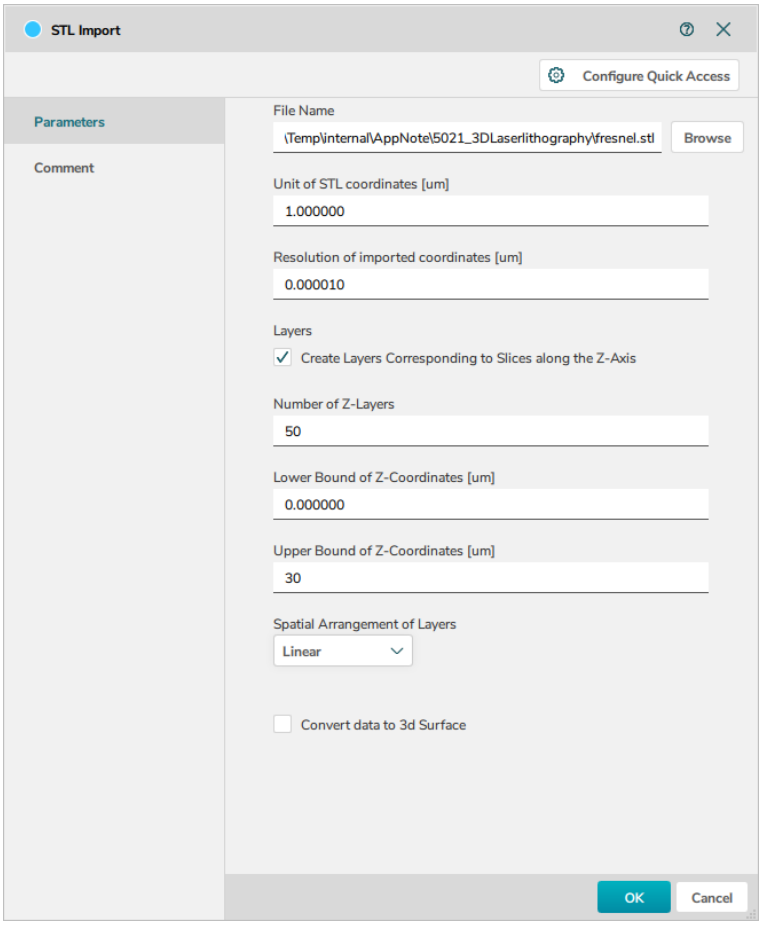

In the fifth example, the Advanced option Grey to Layer table is defined. All grey values from 1 to 100 are excluded as values from 200. Values from 100 to 150 are bundled in groups of 10 while from 150 to 200, groups of 5 were defined.


Generic Bitmap Import
Configure Quick Access
General
Comment
File Name
ppNote/5021_3DLaserlithography/GenISys Logo_Grey.png
Browse
Merge Pixel Rows
Pixel Size[um]
0.005000
Gray Values to Dose
Black to Dose
2.000000
White to Dose
0.000000
Gray to Layer Mode
None
Linear
Advanced
Insert Row
Delete Row
Gray Value
Bundle Ratio
1
100
10
150
5
200
OK
Cancel


GenISys Logo_Grey (4) - GenISys Logo_Grey.png (C:/Users/Tan/Desktop/Temp/internal/AppNote/5021_3DLaserlithography/GenISys Logo_Grey.png)
Color Mode: Layer
Measure
E-Beam
64x
Cell Selection
Layer
Layout Tree
GenISys Logo_Grey
100
110
120
130
140
150
155
160
165
170
175
180
185
190
195
GenISys

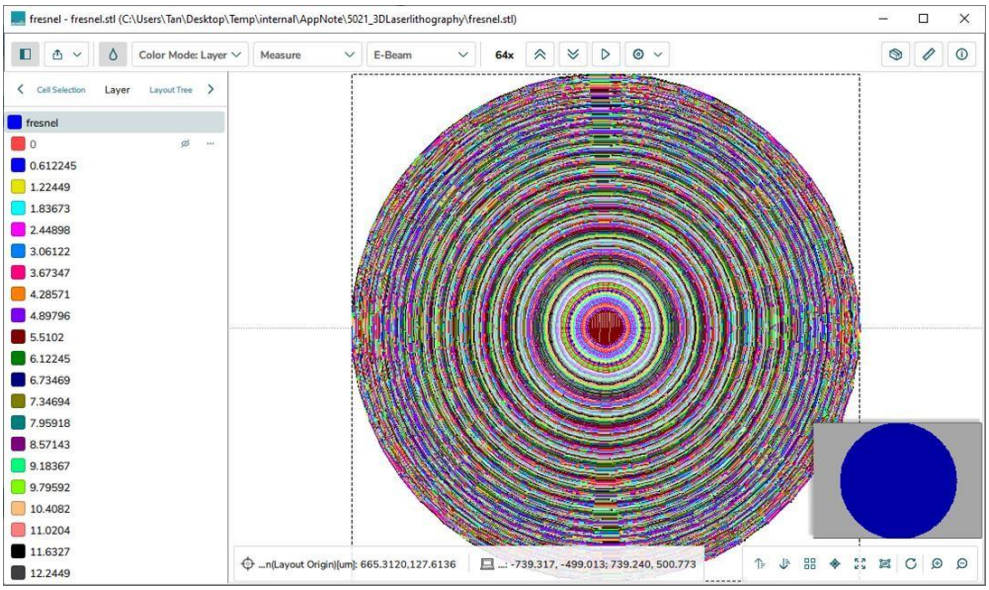
## Import STL format

STL (STereoLithography) is a file format native to the stereolithography CAD software created by 3D Systems. STL has several after-the-fact acronyms such as "Standard Triangle Language" and "Standard Tessellation Language". In **BEAMER** it is used to import 3D structures.

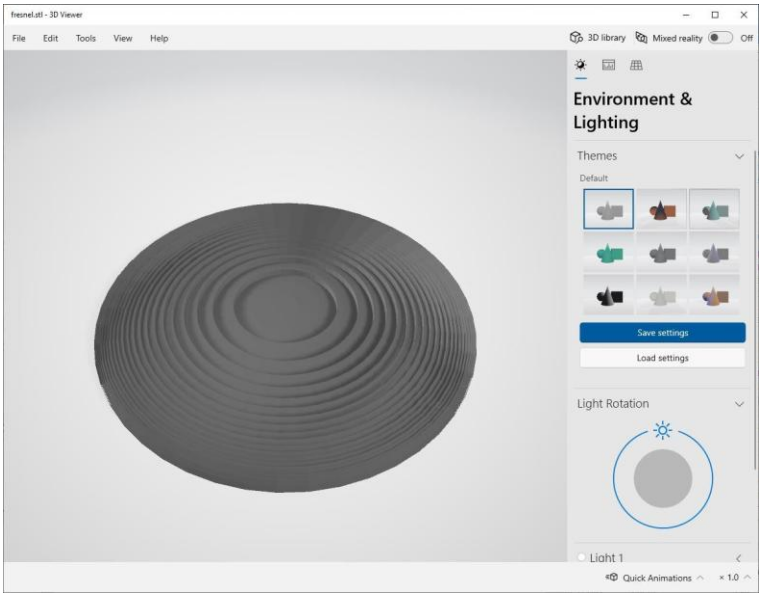



**Unit of STL Coordinates[um]** defines the database unit and **Resolution of imported coordinates** defines resolution of the STL file.

Check the box **Create Layers Corresponding to Slices along the Z-Axis**, the structure can be described as a number of layers via **Number of Z-Layers**. The **Lower Bound of Z-Coordinates [um]** and **Upper Bound of Z-Coordinates [um]** define the limits of the structure to be imported. When applied to curved structures the **Spatial Arrangement of Layers** can be chosen to be **QuadraticTopDown** or **QuadraticBottomUp**. This feature may be used for a better representation of curved structures such as lens type features.

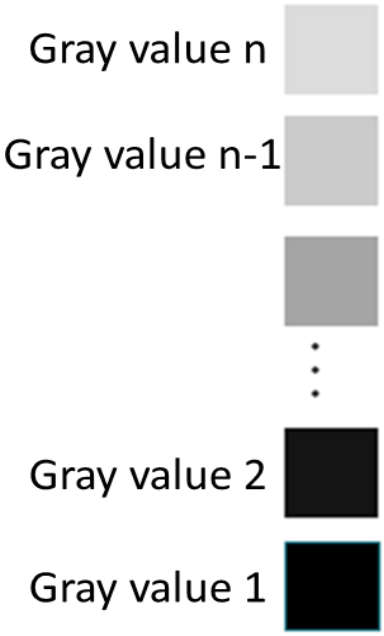



Windows 10 provides the ability to visualise 3D structures with 3D Viewer. Below is an image of the Fresnel structure used in the example above.



## Appendix II: Measuring a Contrast Curve

Contrast curves can be generated through exposure at different dose levels and measuring the remaining resist thickness.

The resist must be exposed with a dose matrix and on an area that is large enough to avoid stray light effects of the system. When the dose matrix is applied at sequential locations of one wafer, the separation of adjacent exposures must be big enough to avoid effects from adjacent areas. Make sure that the stack used for the determination of the contrast curve matches the stack of future experiments. The thickness and back reflection are unique for different stacks and can influence the accuracy of the correction. Measurement of remaining resist thickness in the center of each square was done using confocal microscope (Nanofocus). Alternative resist thickness measurement methods (like ellipsometry) may also be used.

A pattern for the contrast curve determination consisting of layers with square structures is shown below. Each square is assigned to a different layer and thus will be exposed with a different dose, represented by a grey value, ranging from 0 to the grey value which reaches the desired depth (i.e., at least as deep as the desired target structures). As a rule for sampling the contrast curve, around 30 points are recommended for 10 µm thickness change.