Electron beam lithography simulation calculation EDA software V1.0 user guide

Catalogue

1 Summary

1.1 Application background

Electron beam lithography (EBL) is an important technology for micro and nano fabrication of high-resolution nano lithography layout, which has a wide application prospect. However, the proximity effect in EBL will reduce the pattern quality. Direct exposure without Proximity effect correction (PEC) will have a devastating impact on the resolution. It can be observed from the following figure: the uncorrected layout energy in Figure 1.1.1 is dense in the center of the layout and sparse around the layout, which will over expose the exposed graphics in the center of the graphics, slightly expose the edges of the layout, and blur the edges of the exposed layout. The corrected layout in Figure 1.1.2 has uniform energy distribution around, and most areas have reached uniform exposure, making the exposed layout more uniform and flat.

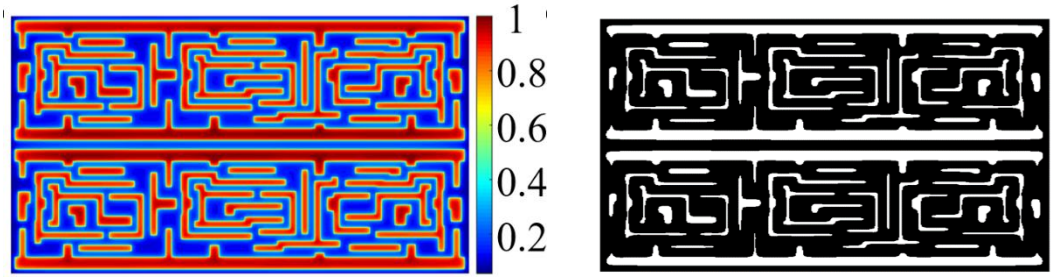


Figure 1.1.1 uncorrected layout dose distribution (left) and energy distribution after layout exposure (right)

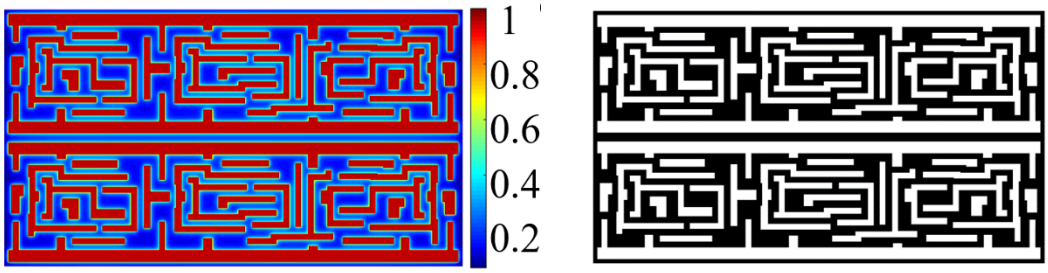


Figure 1.1.2 dose distribution of corrected layout (left) and energy distribution after layout exposure (right)

Since the 1970s, the international lithography organization has begun to develop the proximity effect of EBL. In order to get rid of the blockade of PEC products in EBL, EDA software for EBL simulation calculation is independently developed（HNUEBL

V1.0）。

1.2 System block diagram

The software function is divided into five modules (as shown in Figure 1.2.1):

- Monte Carlo simulation module
- Proximity effect correction module
- Edge placement error module
- Energy deposition module
- GDSII Visualization module

The whole process simulates the energy deposition from various resists to the substrate, and fits the multi Gaussian function (it is proved by T. H. P. Chan that the energy deposition function conforms to the multi Gaussian function distribution), then corrects the proximity effect of the dose factor of the input layout, outputs the corrected layout (the data format of layout input and output is .GDS file format), and views the layout.

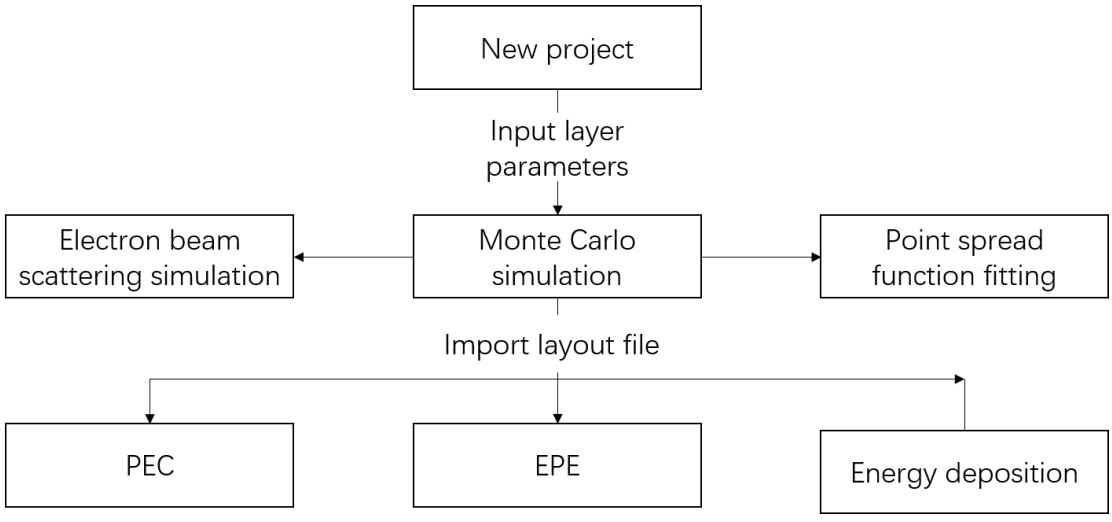


Figure 1.2.1 block diagram of the software system

1.3 Operating environment

- Operating system: Windows 7 and above
- Hardware environment: CPU 1.7GHz, 4 cores, memory 2GB, video memory 200M,

hard disk 500M

2 Software operation instructions

2.1 Monte Carlo simulation

(1) Monte Carlo method is a calculation method for mathematical simulation by describing random process. It is also called statistical experiment method or computer random simulation method. The scattering process of electrons in resist and substrate is simulated by Monte Carlo method to establish the energy deposition model. Monte Carlo method plays a leading role in the study of proximity effect generation mechanism, PEC and the selection of exposure physical parameters in the process of electron beam exposure.

(2) Before the calculation, a project needs to be established. Open the software, you can click "New Project" under "File" on the top toolbar to create a new project (as shown in Figure 2.1.1), and fill in the project name and project saving location (as shown in Figure 2.1.2) (Note: the path can only contain English letters and symbols, not Chinese)

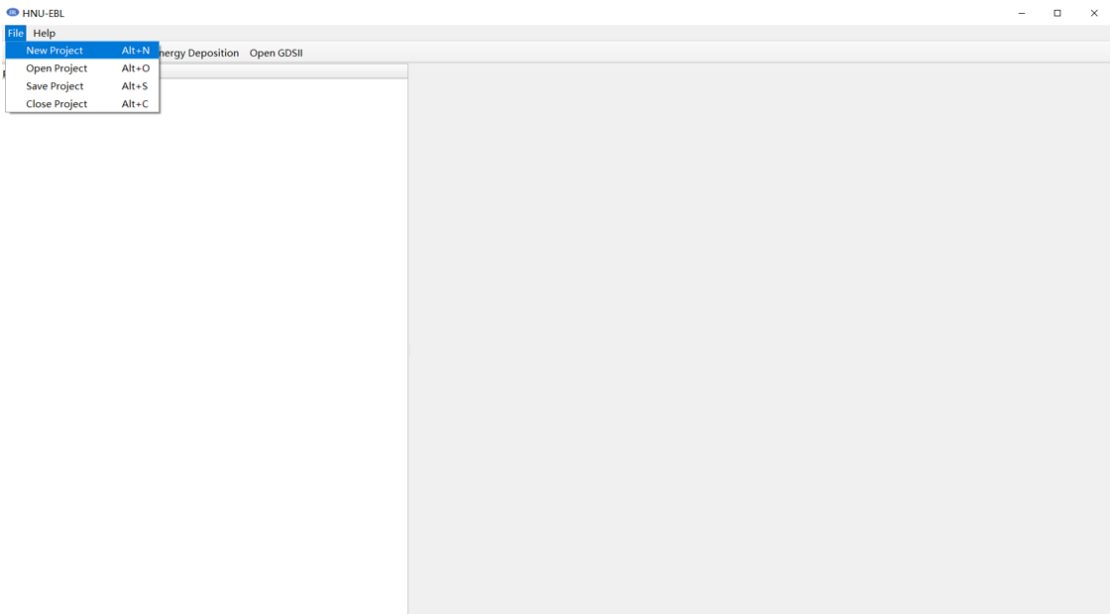


Figure 2.1.1 the main interface of software

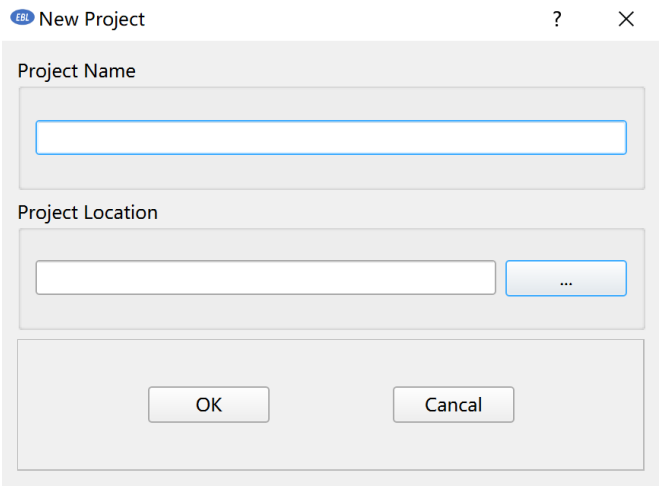


Figure 2.1.2 new project interface

(3) Then you can enter the layer name in "Material" (as shown in Figure 2.1.3), "such as PMMA, Si" (select from the drop-down menu). If this option is not available in the drop-down menu, you need to click "Edit Material" and enter the layer thickness in "Thickness".

(4) You can click "Insert Row" to add a layer at the selected position, and click "Delete Row" to delete the selected layer. The layer sequence diagram is shown in Figure 2.1.3, from top to bottom, Layer 1, Layer 2, ..., Layer N, substrate. (Note: the total number of layers shall not be less than two, and the substrate layer cannot be deleted.)

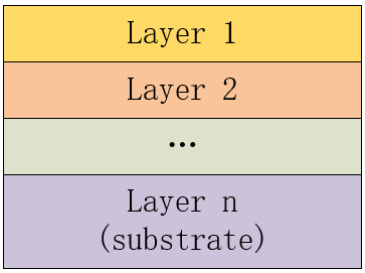


Figure 2. 1.3 schematic diagram of adding sequence of layers

(5) After adding all layers, you can input the simulated parameters related to EBL, such as "Beam Energy, Beam Diameter, Number of Electrons", and complete the parameter input setting. If the input parameters are incomplete, the software will prompt the user to improve the parameter input. All example parameter inputs are shown in Figure 2.1.4.

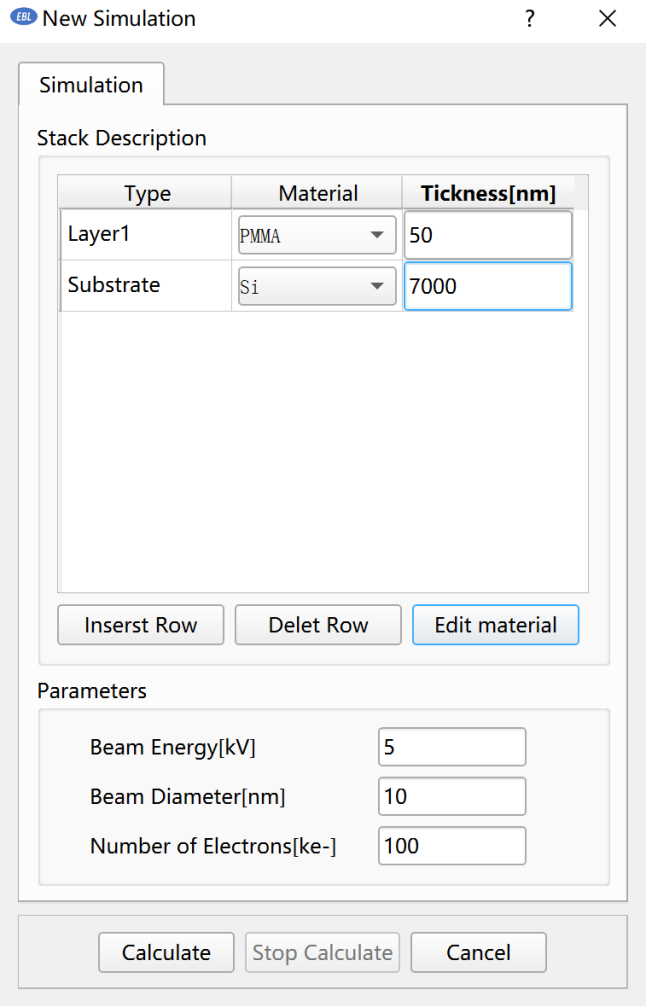


Figure 2.1.4 parameter input interface

(6) You can click "Calculate" to conduct Monte Carlo simulation calculation. After the calculation, the cost time is displayed, and you can click "OK" to complete (as shown in Figure 2.1.5). After Monte Carlo simulation calculation is completed, you can click "Save Project" in "File" at the top of the main interface of the software to save the calculation results (as shown in Figure 2.1.6). (Note: Please click the "Save Project" button to save the project in time)

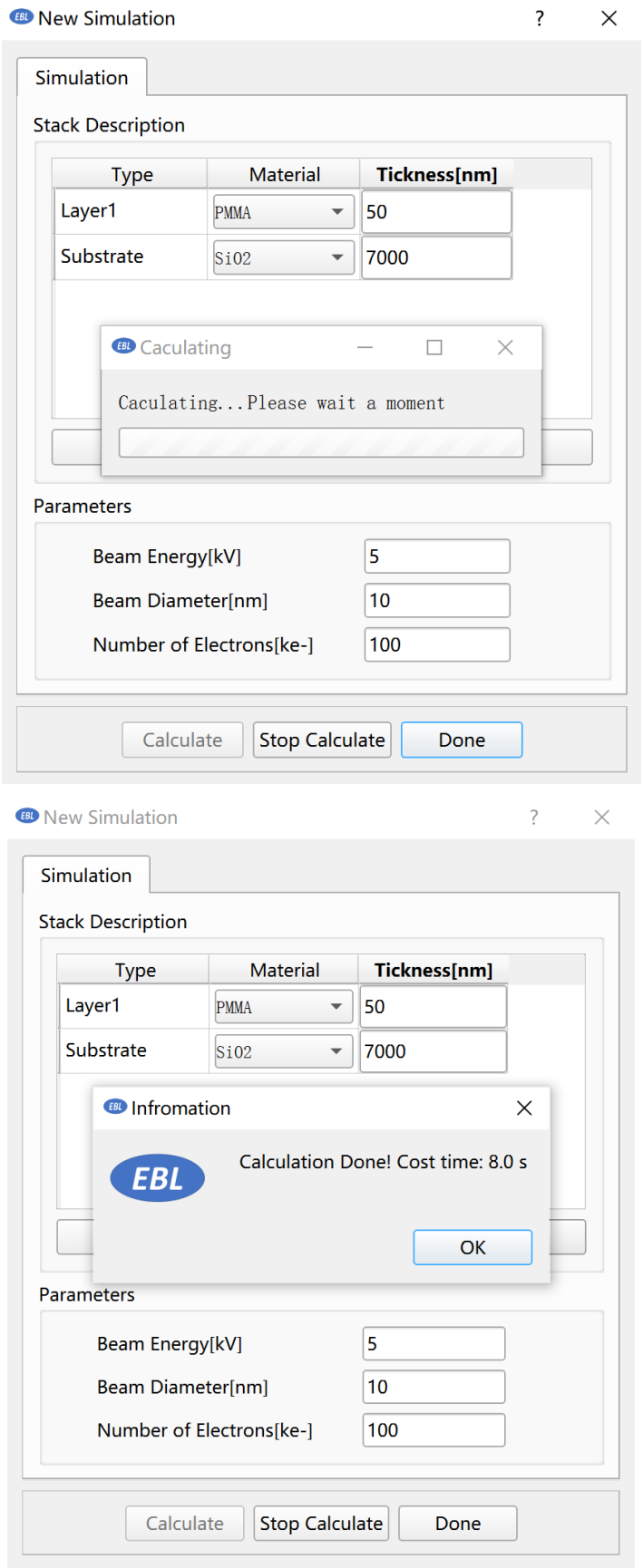


Figure 2.1.5 Monte Carlo calculation interface

(7) After Monte Carlo calculation, you can get the scatter calculated by Monte

Carlo method for function fitting, and click "PSF" to display the fitting results of the scatter function (as shown in Figure 2.1.6). Double Gaussian distribution (formula 1), three Gaussian distribution (formula 2) and three Gaussian plus exponential distribution (formula 3) are set. According to different simulation results, the optimal fitting function is selected. For example, simulate the fitting results of 100000 electrons at 5kV and 50nm PMMA on substrate Si (as shown in Fig. 2.1.6) can be seen from the correlation of fitting that the three Gaussian plus exponential function is more consistent with the point spread function under this condition.

$$f=\frac{1}{\pi(1+\eta)}\left(\frac{1}{\alpha^2}e^{-\frac{x^2}{\alpha^2}}+\frac{\eta}{\beta^2}e^{-\frac{x^2}{\beta^2}}\right) \quad (1)$$

$$f=\frac{1}{\pi(1+\eta+\nu)}\left(\frac{1}{\alpha^2}e^{-\frac{x^2}{\alpha^2}}+\frac{\eta}{\beta^2}e^{-\frac{x^2}{\beta^2}}+\frac{\nu}{\gamma^2}e^{-\frac{x^2}{\gamma^2}}\right) \quad (2)$$

$$f=\frac{1}{\pi(1+\eta+\nu+\nu_2)}\left(\frac{1}{\alpha^2}e^{-\frac{x^2}{\alpha^2}}+\frac{\eta}{\beta^2}e^{-\frac{x^2}{\beta^2}}+\frac{\nu}{\gamma^2}e^{-\frac{x^2}{\gamma^2}}+\frac{\nu_2}{2{\gamma_2}^2}e^{-\frac{x}{\gamma_2}}\right) \quad (3)$$

(8) If you need to view the coefficient of the corresponding Monte Carlo simulation results, right click the corresponding Monte Carlo simulation results on the left side of the main interface of software and click "Detail" (as shown in Fig. 2.1.7 and Fig. 2.1.8).

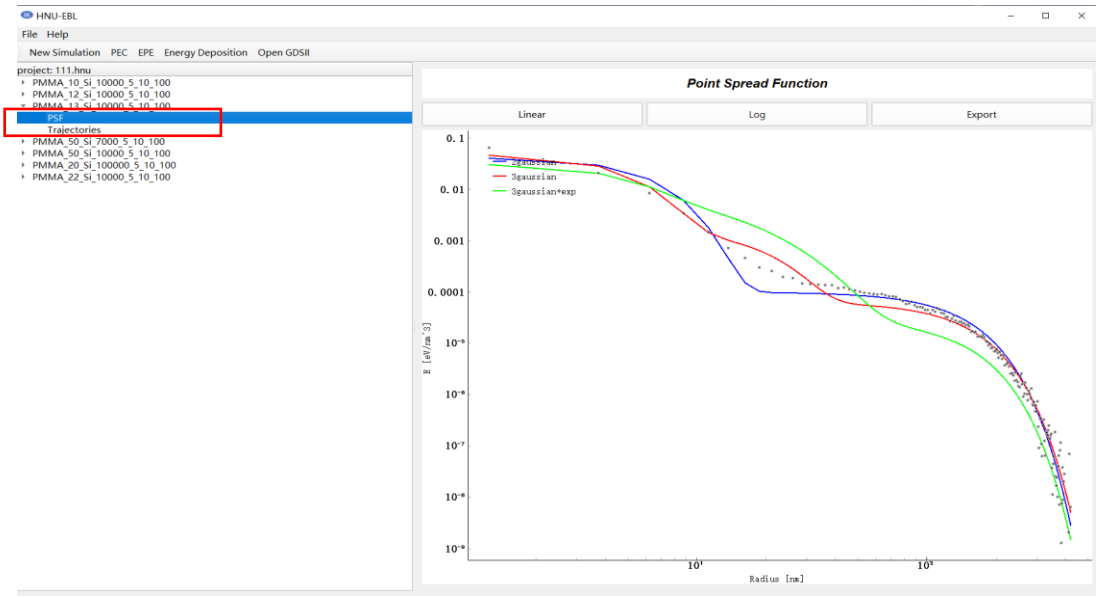


Figure 2.1.6 point spread function fitting interface

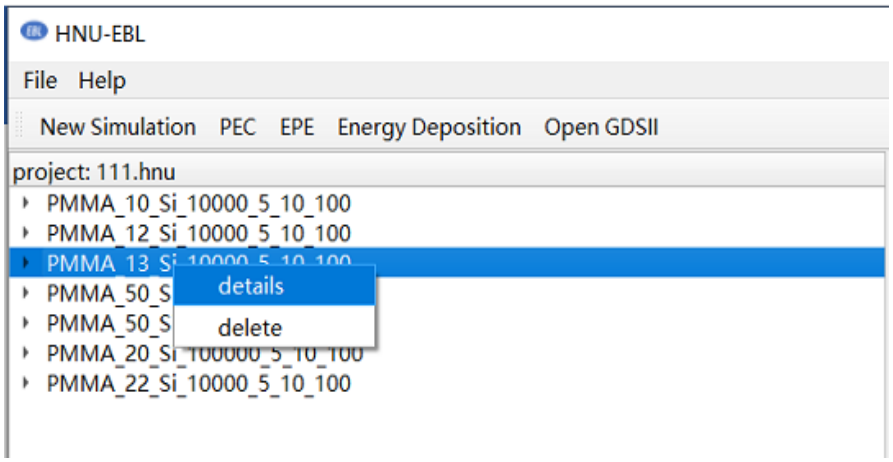


Figure 2.1.7 viewing the fitting coefficient interface of Monte Carlo simulation results

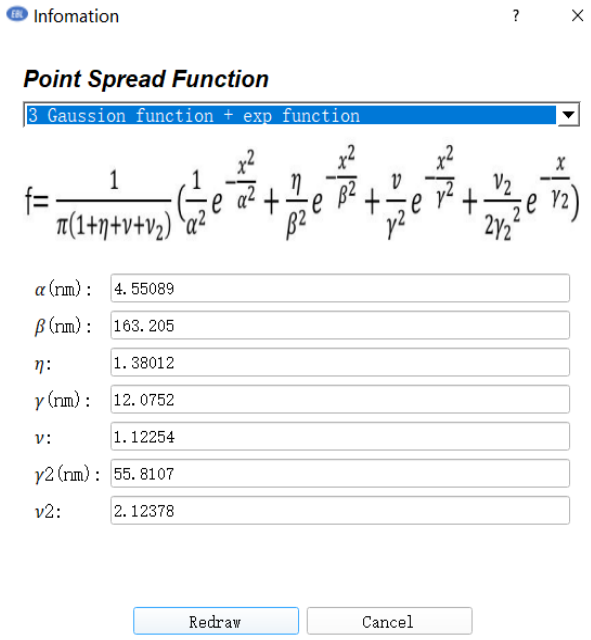


Figure 2.1.8 fitting coefficient interface

(9) Monte Carlo method simulates the scattering process of electrons in resist and substrate, and you can calculate the scattering path of electron beam. After the Monte Carlo calculation is completed, you can click the triangular symbol on the left of the corresponding Monte Carlo calculation results in the left result column, and click "Trajectories" to display the electron beam scattering simulation results (as shown in Figure 2.1.9). For convenience of observation, the red mark line is the material name and layer thickness of other layers except the base in the corresponding Monte Carlo simulation.

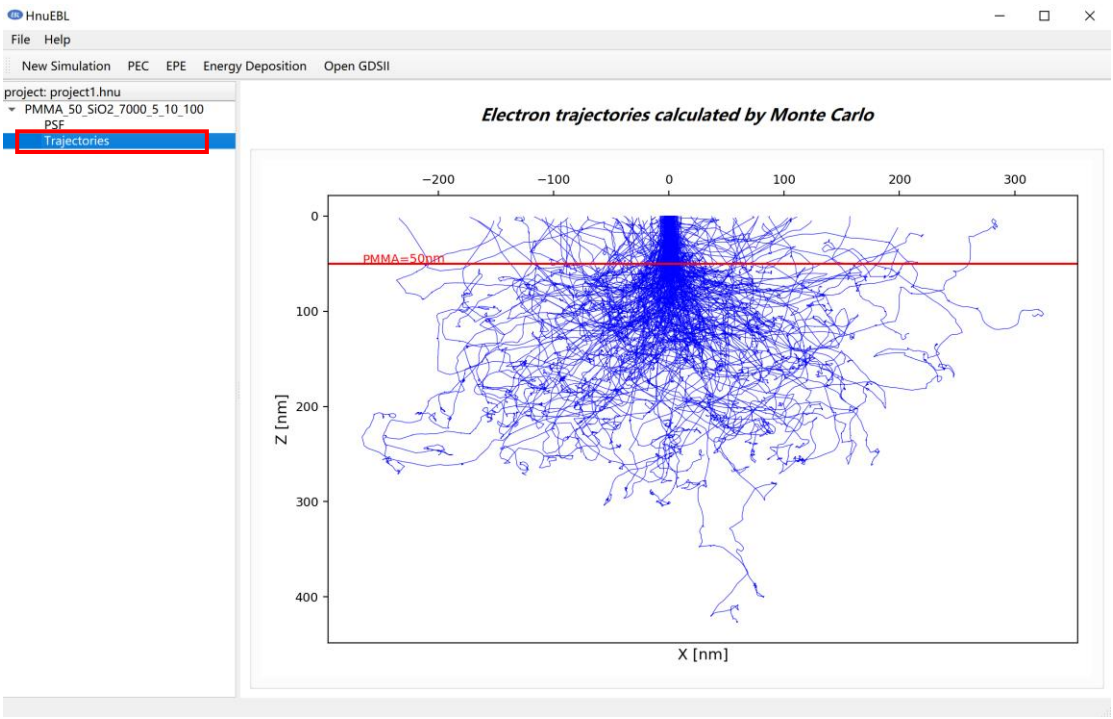


Figure 2.1.9 electron beam scattering fitting interface

2.2 Proximity effect correction

(1) The fundamental reason of proximity effect is that electrons are scattered in resist and substrate, which changes the original motion direction of electrons. PEC is a method to achieve the optimal exposure dose by inverse iteration of the fitted point dispersion function. Figure 2.2.1 and Figure 2.2.2 are dose comparison before and after exposure area correction. It can be seen that PEC modifies some doses of the layout. Figure 2.2.1 and Figure 2.2.2 show the comparison of energy deposition before and after PEC. It can be seen that the energy deposition of layout after PEC is more uniform, and the edge of such layout is clearer after development.

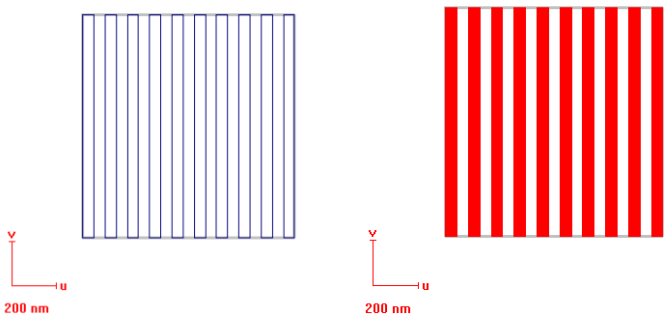


Figure 2.2.1 dose before correction of exposed area

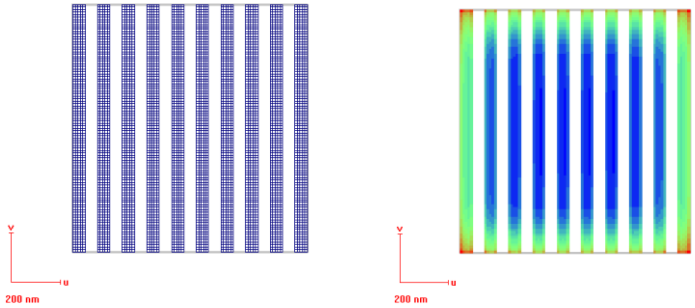


Figure 2.2.2 dose after correction of exposed area

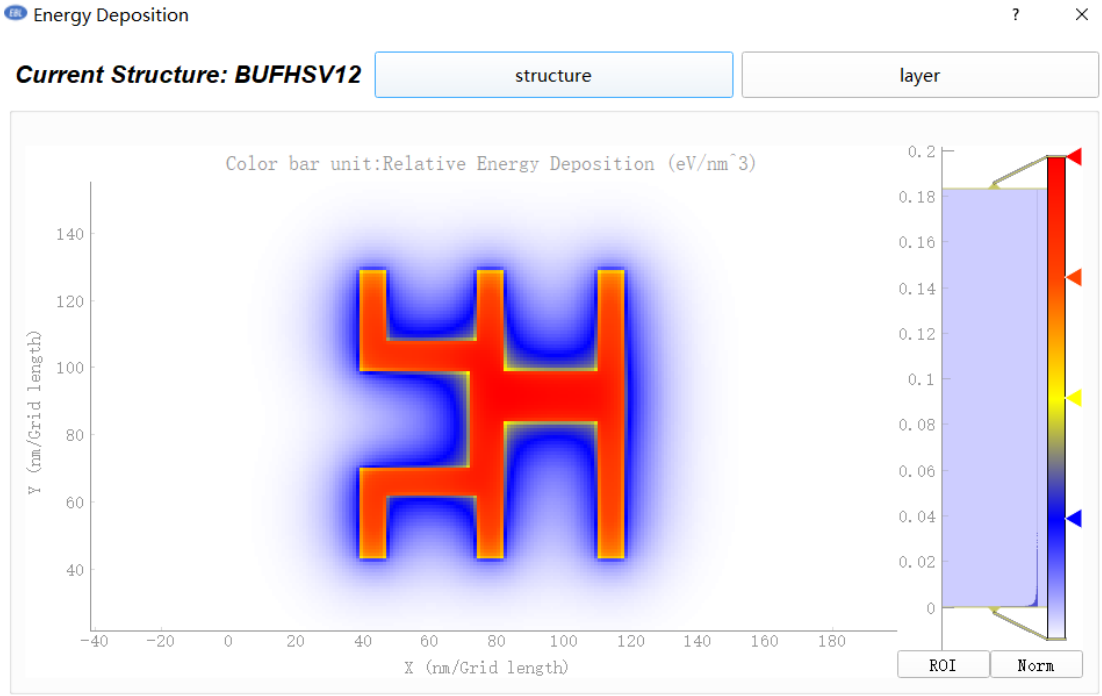


Figure 2.2.3 energy deposition before PEC

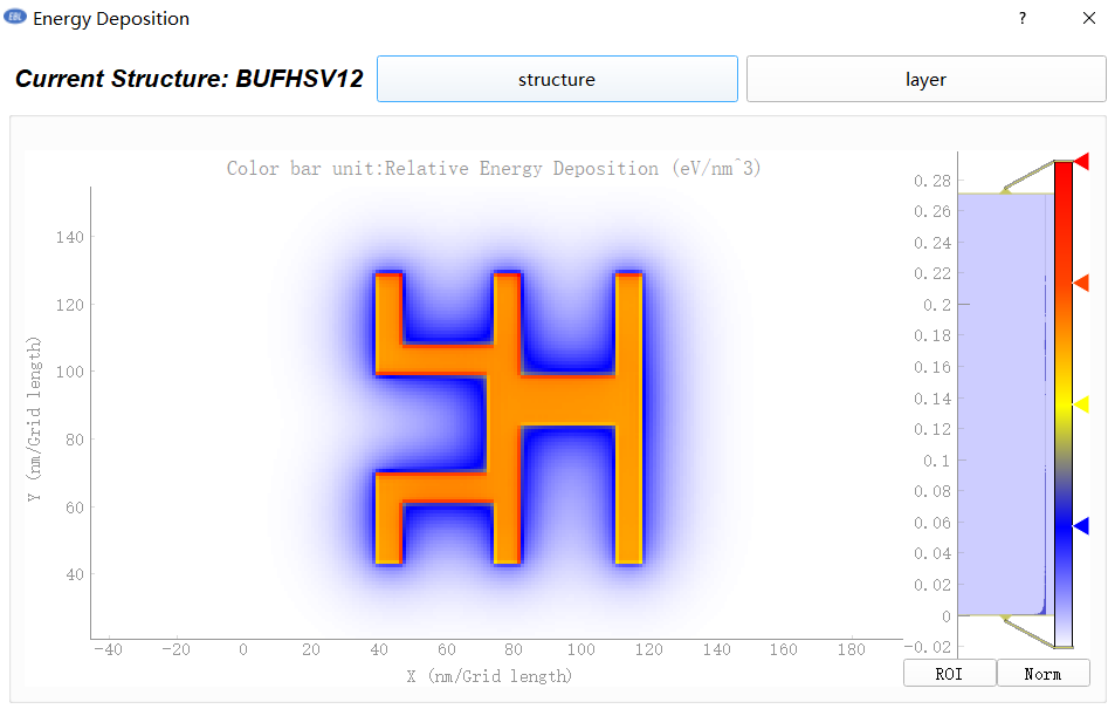


Figure 2.2.4 energy deposition after PEC

(2) PEC calculation can only be carried out after Monte Carlo calculation is completed. You can click "PEC" on the toolbar at the top of the main interface of software to start setting PEC related parameters (as shown in Figure 2.2.5).

(3) Set "PSF results" and select a group of Monte Carlo calculation results for PEC.

(4) Set "PSF parameters" and select the fitting formula. In the following figure, you can select one of the three Gaussian formulas to correct the proximity effect.

(5) You can set the minimum size (nm) of the exposure unit corrected by "Matrix Set", and 5nm is selected in the following figure. (Note: if the layout is large, the minimum size of the exposure unit should not be too small. If the size is too small and the computer memory is insufficient, a prompt will be given)

(6) You can use "GDSII file" to open the .GDS format layout to be corrected. The sample file is "simple-muti-struc.gds" (Note: the path can only contain English letters and symbols, not Chinese.)

(7) You can set the output file path after PEC calculation in "Result Folder" (Note: the path can only contain English letters and symbols, not Chinese.)

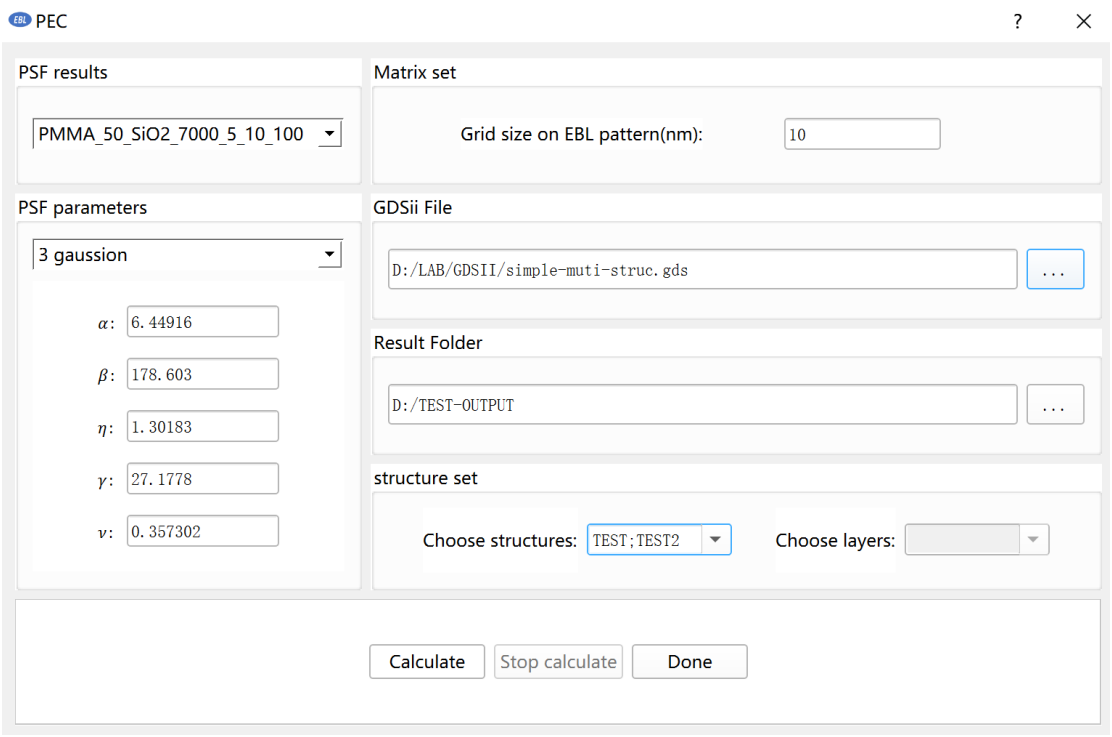


Figure 2.2.5 setting PEC interface

(8) A GDSII file can contain multiple structures, and a structure can contain multiple layers. If you only want to perform PEC calculation for partial layout in the file, you can click "Structure Set" at the bottom of the page to further set the layout to be corrected, "Structure" at least select one, "Layer" at least select one (as shown in Figure 2.13 (top)), if "Structure" has selected multiple, you can't select "Layer" (as shown in Figure 2.13 (bottom)).

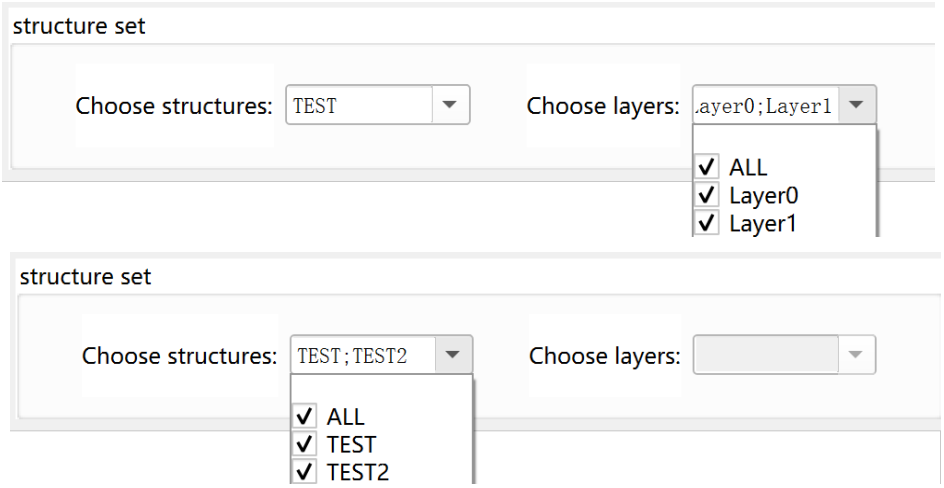


Figure 2.2.6 setting the layout to be corrected

（9）You can click "Calculation" (as shown in Figure 2.2.7) to perform PEC calculation, and the cost time will be displayed after the calculation is completed (as

shown in Figure 2.2.8). After calculation, click "Done" to close the current window and save the output file to the specified folder. The output file can be viewed using the GDSII visualization module.

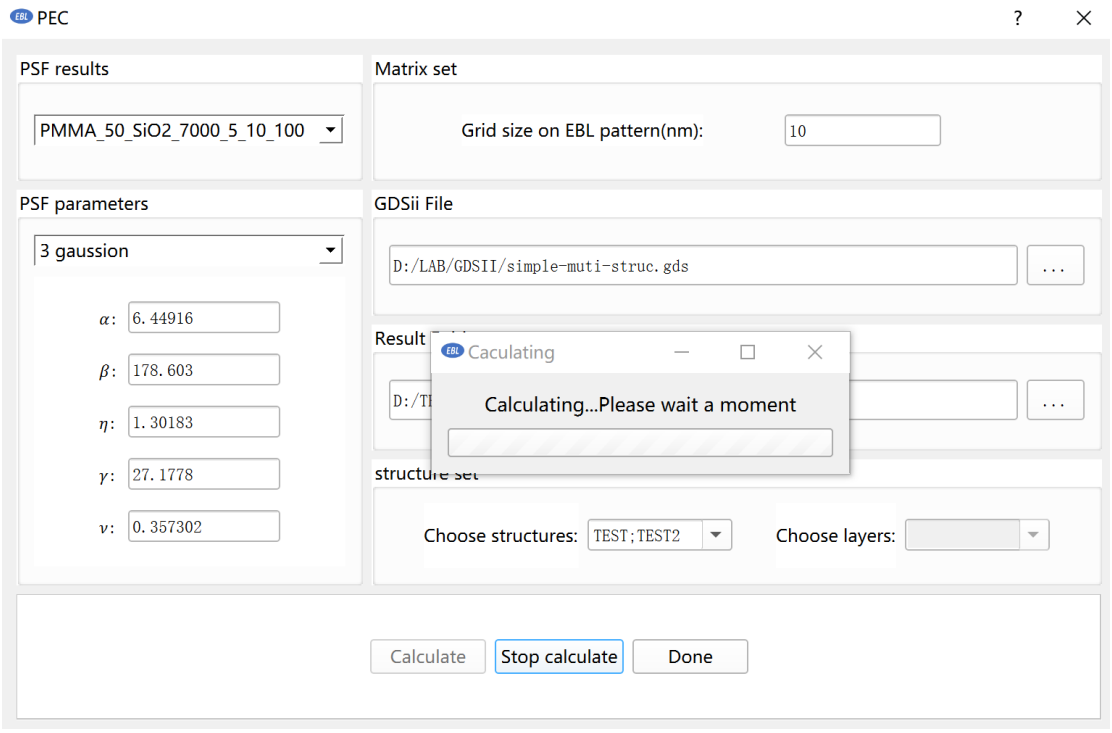


Figure 2.2.7 PEC calculation interface

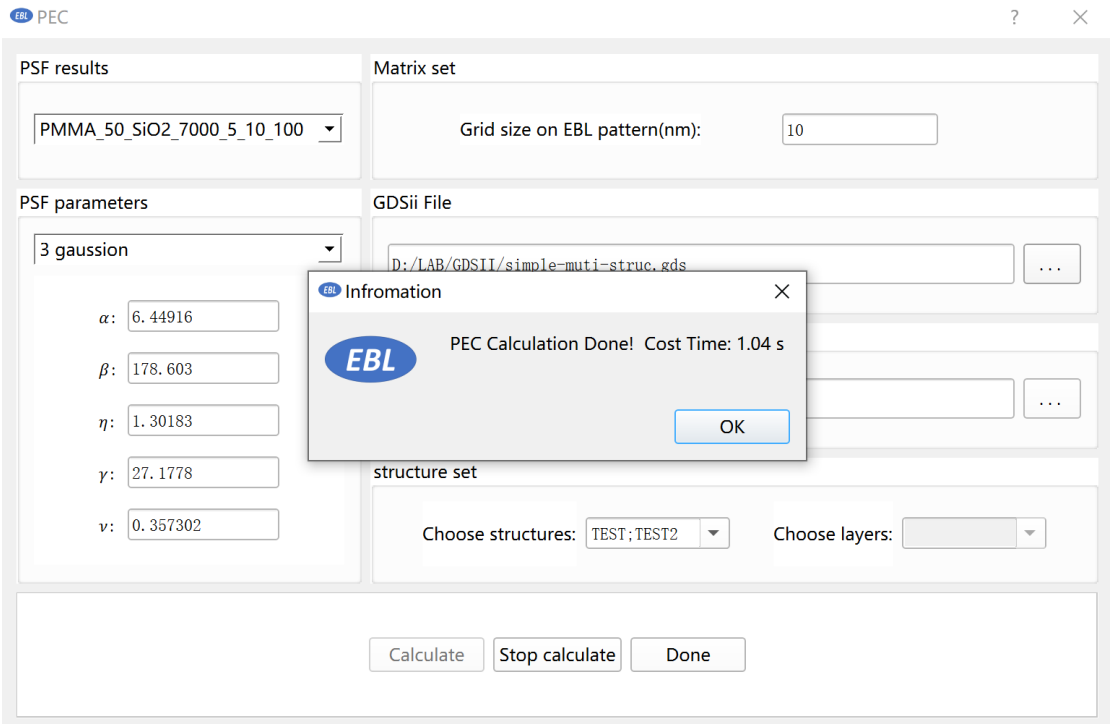


Figure 2.2.8 completion interface of PEC calculation

2.3 Edge placement error

(1) Edge placement error (EPE) is the difference between the edge of the resist pattern after exposure and the design pattern after exposure after simulation calculation. EPE is an index to measure the quality of optical proximity correction. Small EPE means that the exposed figure is close to the design figure. The "EPE" calculation can only be carried out after the Monte Carlo calculation is completed. Click "EPE" on the toolbar at the top of the main interface of software to start setting related to calculating EPE (as shown in Figure 2.3.1).

(2) Set "PSF results" and select a group of Monte Carlo calculation results for edge position error calculation.

(3) Set "PSF parameters" and select the fitting formula, and select the three Gauss formula in the figure below to calculate the edge position error.

(4) The "Matrix Set" setting calculates the minimum size of the divided exposure unit (nm), and 5nm is selected in the following figure. (Note: if the layout is large, the minimum size of the exposure unit should not be too small. If the size is too small and the computer memory is insufficient, a prompt will be given)

(5) "GDSII File" opens the calculated layout .GDS format. The sample file is " simple-muti-struc.gds " (Note: The path can only contain English letters and symbols, not Chinese.)

(6) You can click "Calculation" (as shown in Figure 2.3.2) to calculate the EPE. If the input parameters are incomplete, the calculation cannot be started. There is a prompt box after calculation (as shown in Figure 2.3.3). After calculation, you can click "Done" to close the current window.

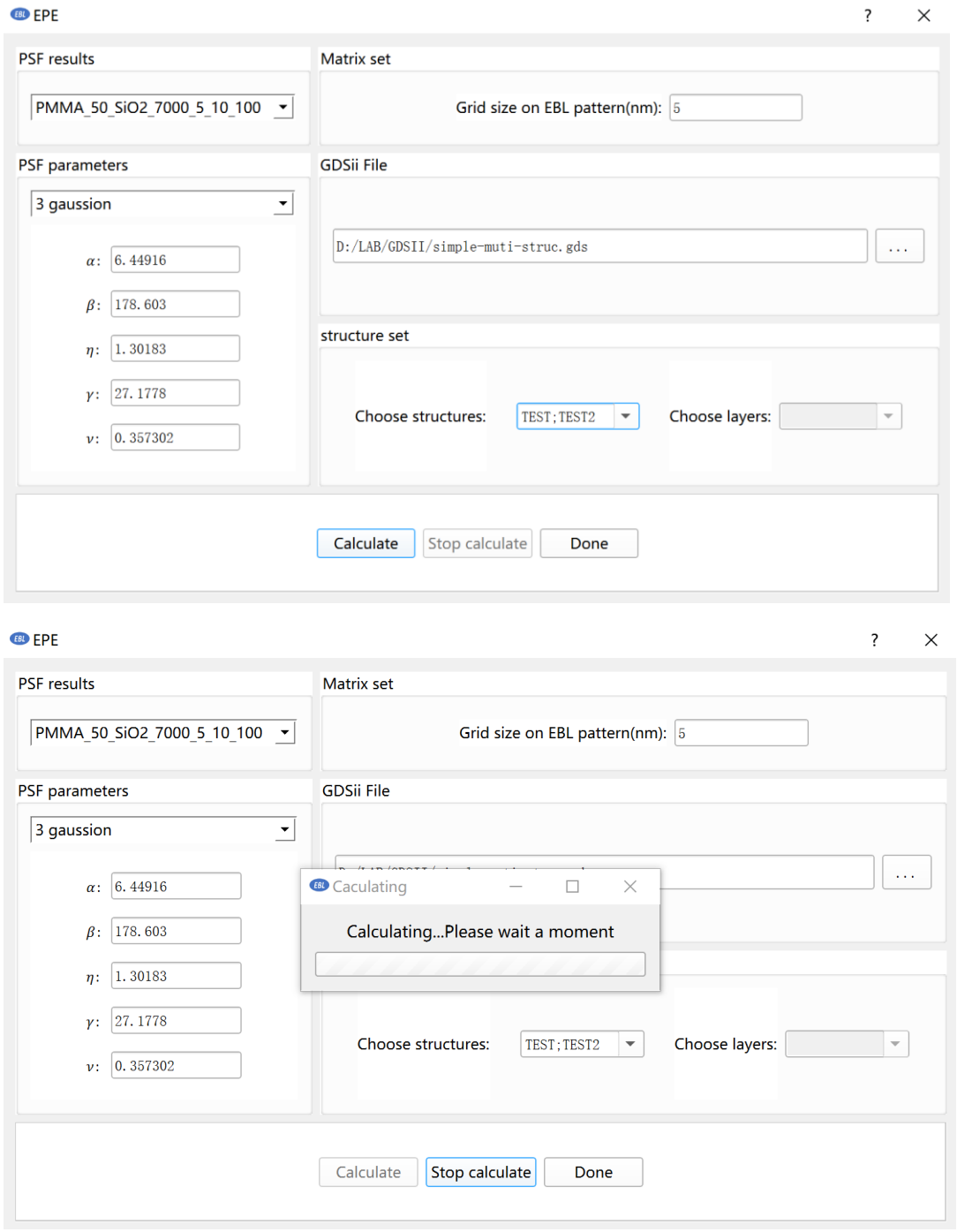


Figure 2.3.1 interface for calculating EPE

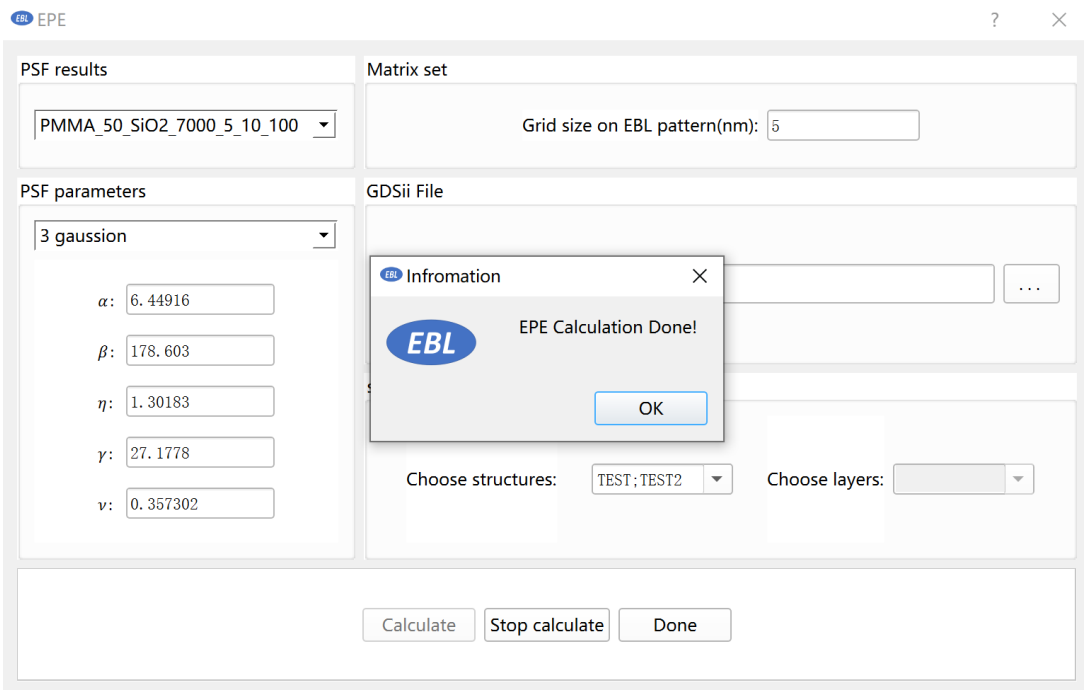


Figure 2.3.2 calculation of EPE completion interface

(7) After the EPE calculation is completed, you can click "OK" in the dialog box in Figure 2.3.2 to automatically pop up the dialog box displaying the layout EPE calculation results (as shown in Figure 2.3.3) (Note: the layout containing only text pixels cannot calculate the EPE)

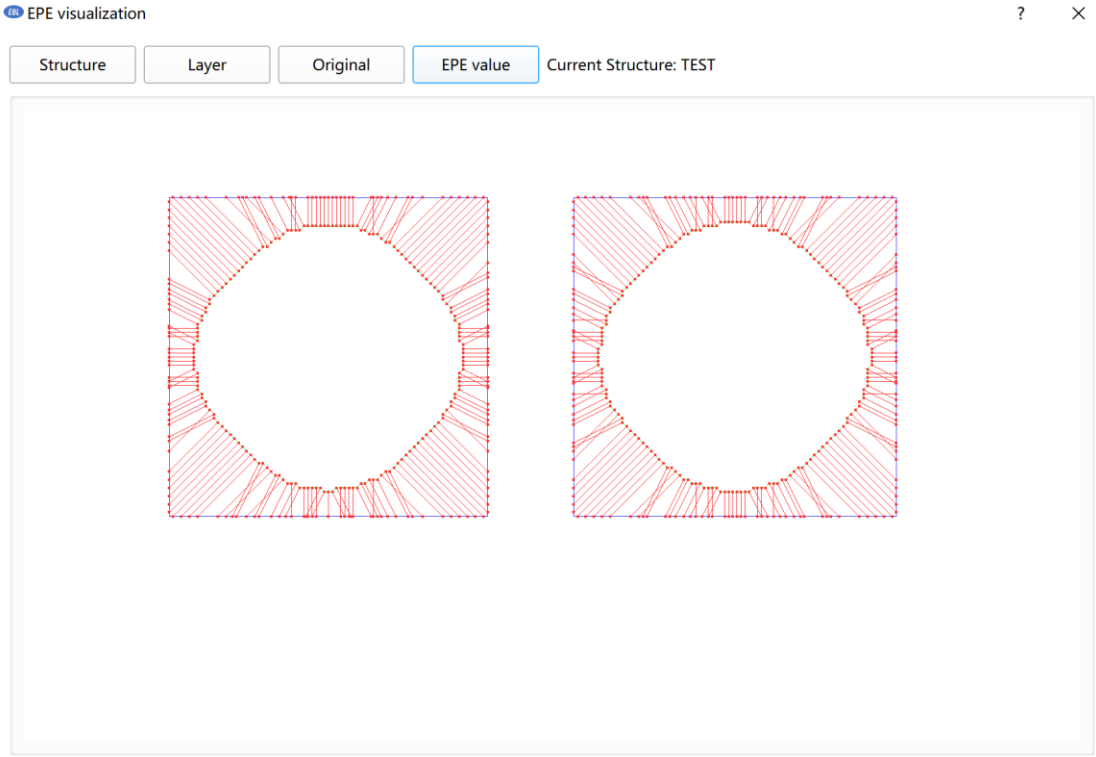


Figure 2.3.3 EPE interface

(8) You can click "Structure" at the top of the interface to select the EPE of any structure, and the first structure is displayed by default. Multiple structures cannot be selected for display. Click "Layer" above to select the EPE of any layer. All layers are displayed by default. Multiple layers can be selected for display. Click "EPE value" above to display the value of EPE. The smaller the value, it means that the exposed figure is close to the design figure.

(9) In the image display area, you can slide the mouse wheel to enlarge and reduce the image; Press and hold the left mouse button to drag the image; Right click to select some images for local magnification; Click "Original" to return the image to its original position.

2.4 energy deposition

(1) Monte Carlo method uses different random numbers to simulate the fluctuation phenomenon of random process. Using this method, a scattering event similar to the electron behavior can be generated. It can accurately simulate the energy deposition distribution of electrons in solids. The scattering paths of simulated electrons in different resists and other substances are calculated by Monte Carlo method, and the energy deposition at each position is calculated. Through numerical integration, a discrete energy deposition distribution whose independent variable is the distance r from the exposure center is obtained (as shown in Fig. 2.4.1). The energy deposition calculation can be carried out only after the Monte Carlo calculation is completed. Click "Energy deposition" on the toolbar at the top of the main interface of software to start the settings related to calculating energy deposition (as shown in Figure 2.4.2)

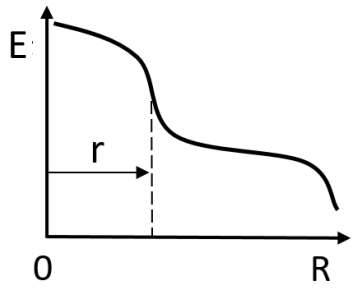


Figure 2.4.1 schematic diagram of energy deposition calculation

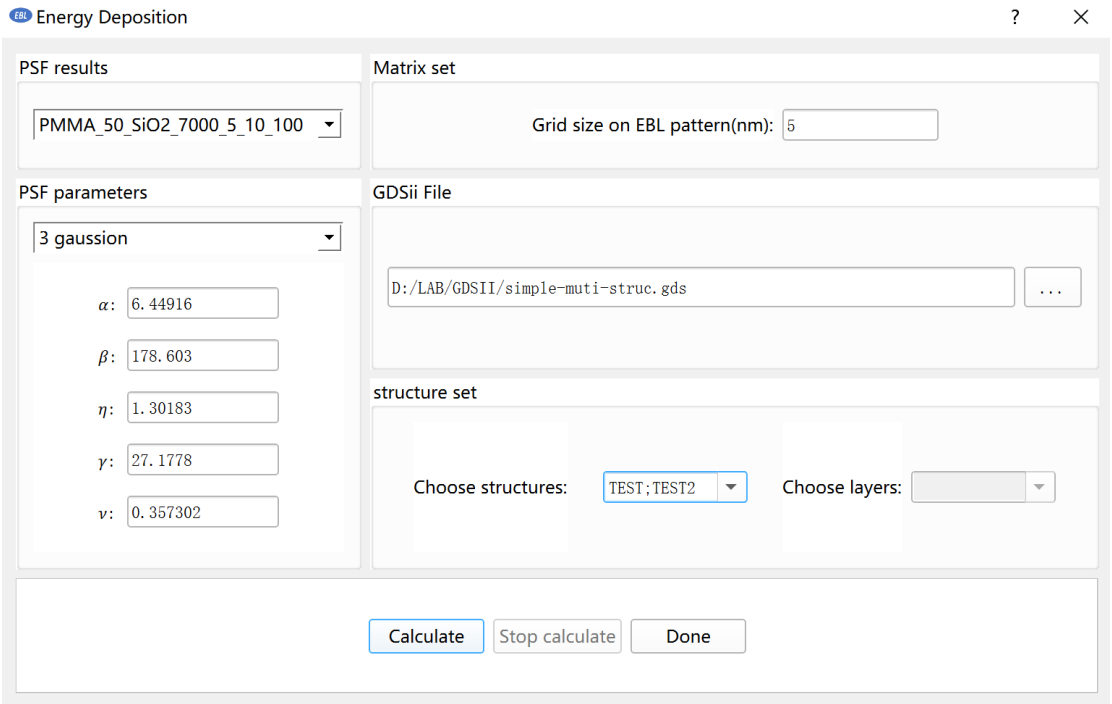
(2) Set "PSF results" and select a group of Monte Carlo calculation results for energy deposition calculation.

(3) Set "PSF parameters" and select the fitting formula, and select one of the three Gauss formulas in the following figure for energy deposition calculation

(4) You can calculate the minimum size (nm) of the divided exposure unit in the "matrix set" setting, and select 5nm in the figure below. (Note: if the layout is large, the minimum size of the exposure unit should not be too small. If the size is too small and the computer memory is insufficient, a prompt will be given)

(5) "GDSII File" opens the calculated .GDS format layout. The sample file is "simple-muti-struc.gds" (Note: the path can only contain English letters and symbols, not Chinese.)

(6) You can click "Calculation" (as shown in Figure 2.4.2) to calculate the energy deposition. If the input parameters are incomplete, the calculation cannot be started. There is a prompt box after calculation (as shown in Figure 2.4.3). After calculation, click "Done" to close the current window.



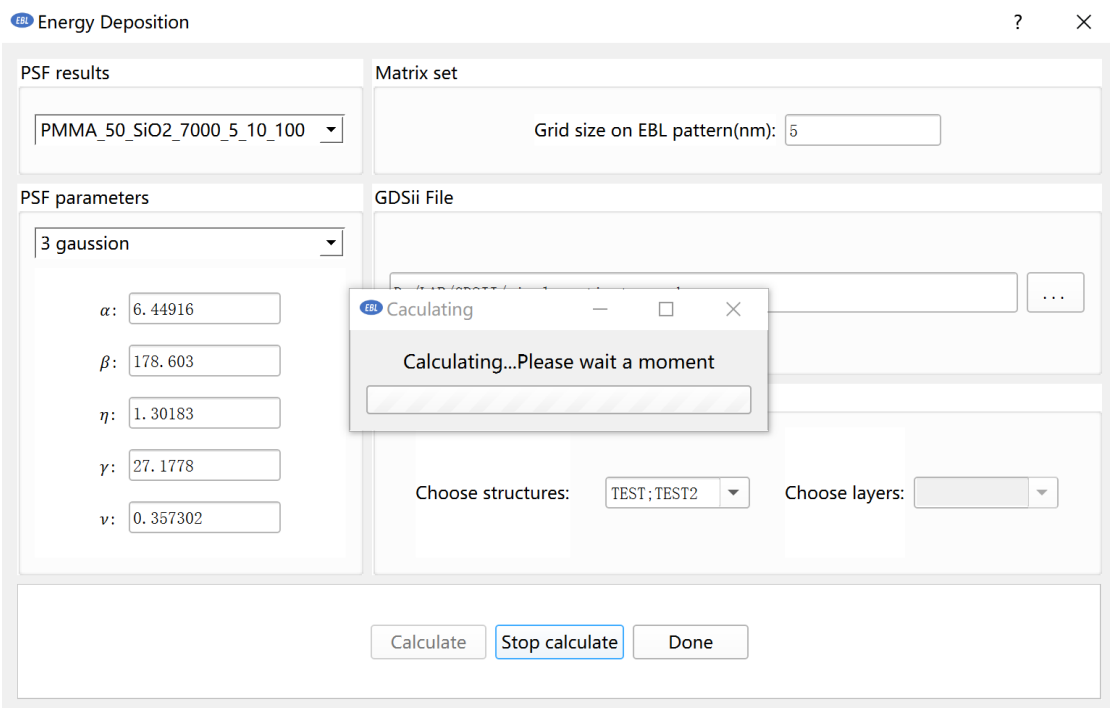


Figure 2.4.2 calculation of energy deposition interface

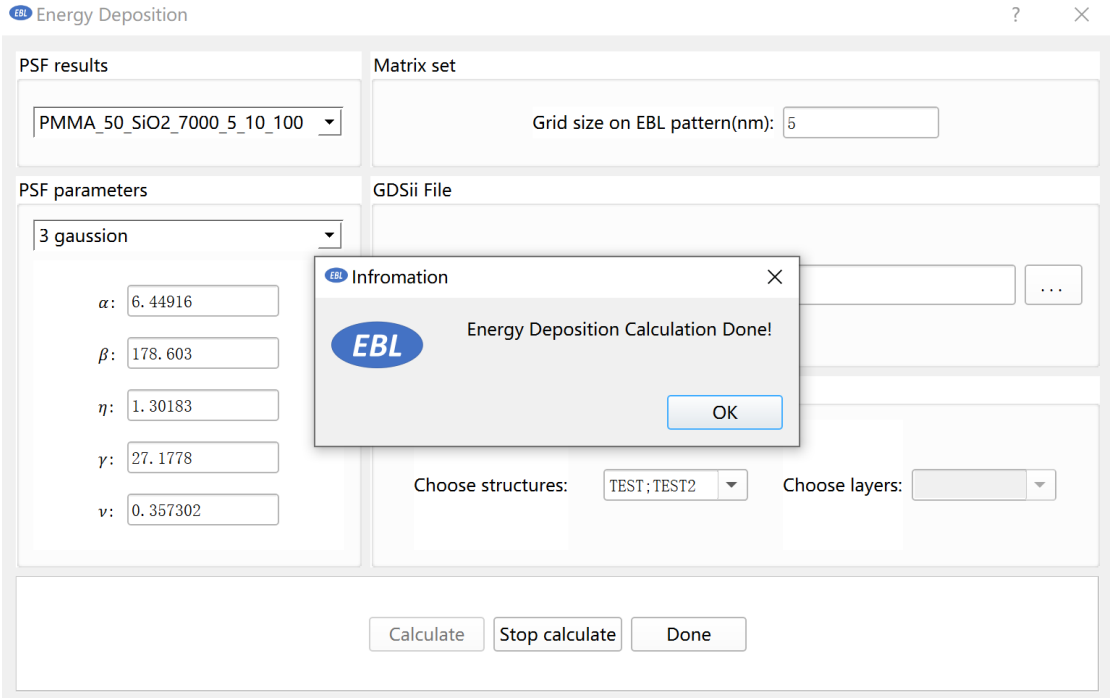


Figure 2.4.3 calculation of energy deposition completion interface

(7) After the energy deposition calculation is completed. You can click "OK" in the dialog box in Figure 2.4.3 to display the layout energy deposition calculation results (as shown in Figure 2.4.4) (Note: the energy deposition calculation cannot be performed for the layout containing only text elements; the calculation results cannot be displayed when the dose corresponding to the graphics is all 0).

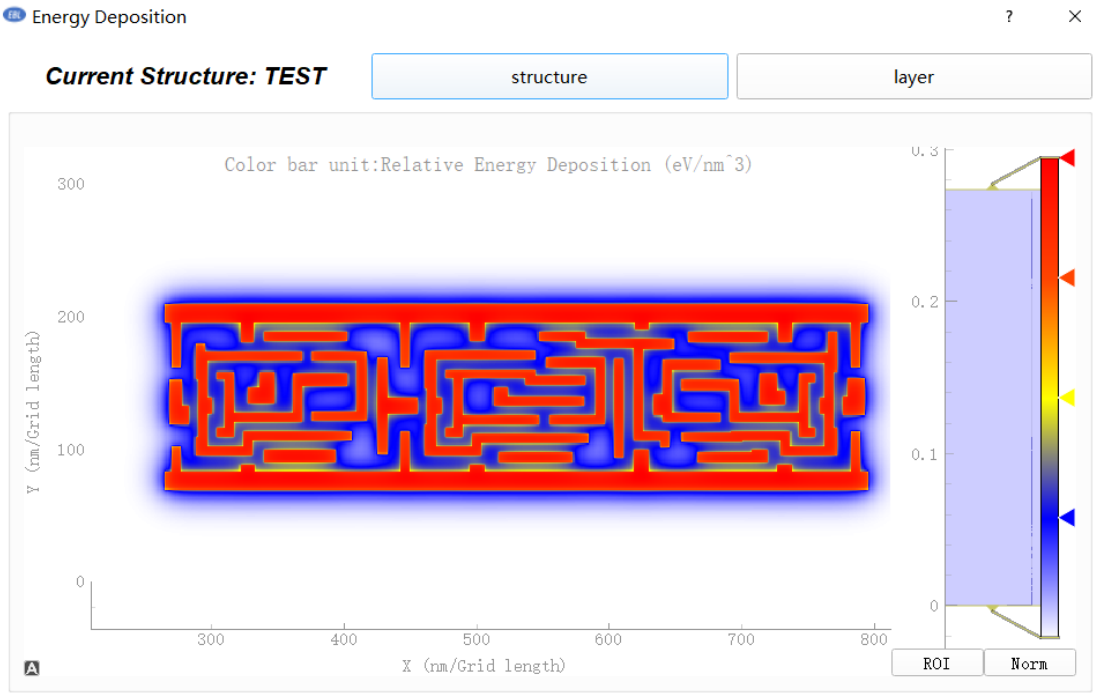


Figure 2.4.4 interface of energy deposition calculation results

(8) You can click "Structure" on the upper right to select and display the energy deposition of any structure, and the first structure is displayed by default. Multiple structures cannot be selected. You can click "Layer" in the upper right to select the energy deposition of any layer. The first layer is displayed by default. It can only be displayed in a single layer.

2.5 GDSII visualization module

(1) You can click "Open GDSII" in the toolbar at the top of the main interface of software to open the interface, and click "Open" to open a GDSII file. The example file is " grating.GDS" (as shown in Figure 2.5.1), and the results are shown as follows (Figure 2.5.2). If the GDSII file is large and the loading time is long, there will be a prompt at the bottom right of the software interface (as shown in Figure 2.5.3)

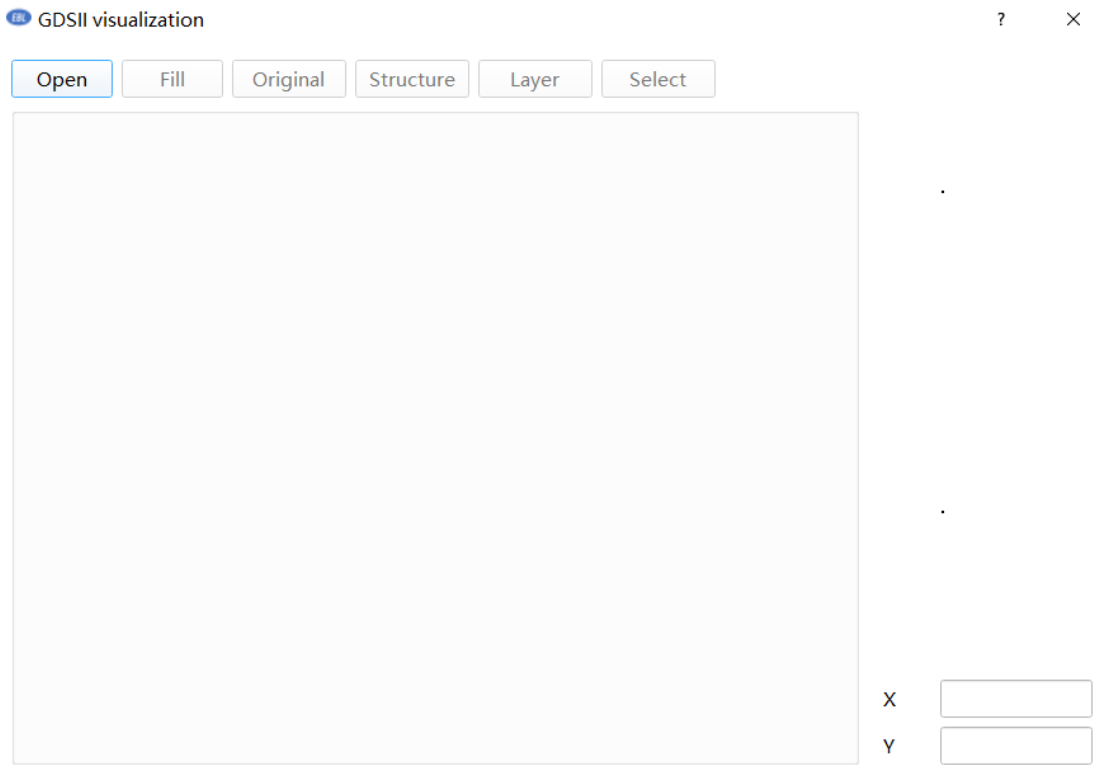


Figure 2.5.1 the main interface of software

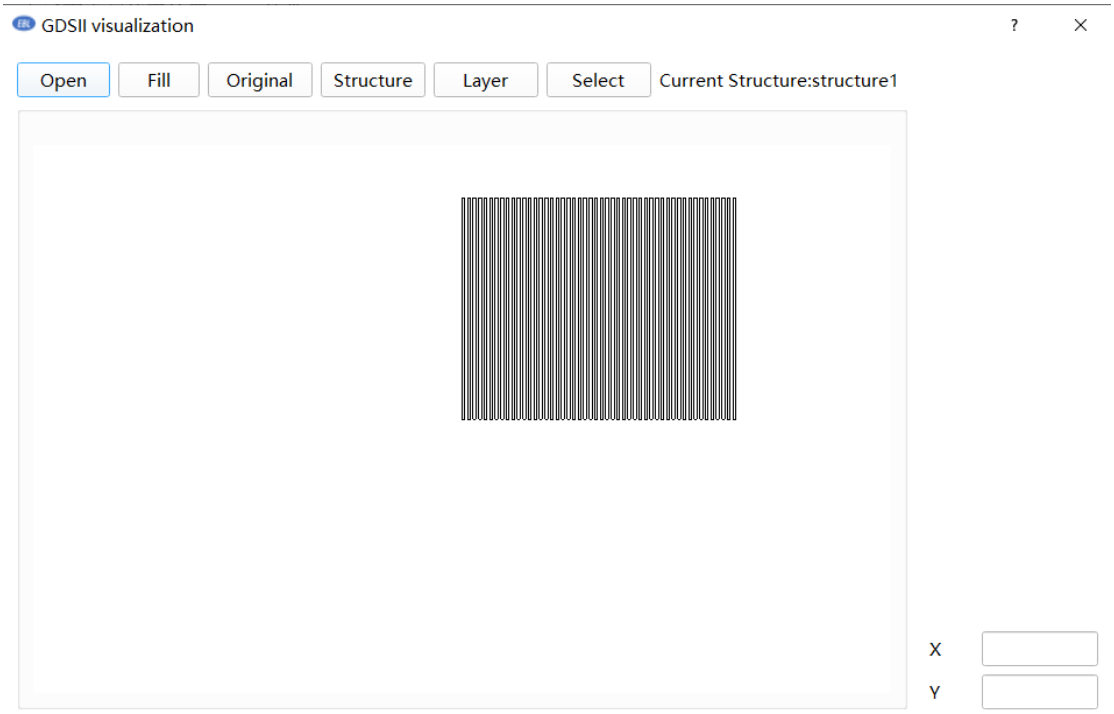


Figure 2.5.2 opening the file interface

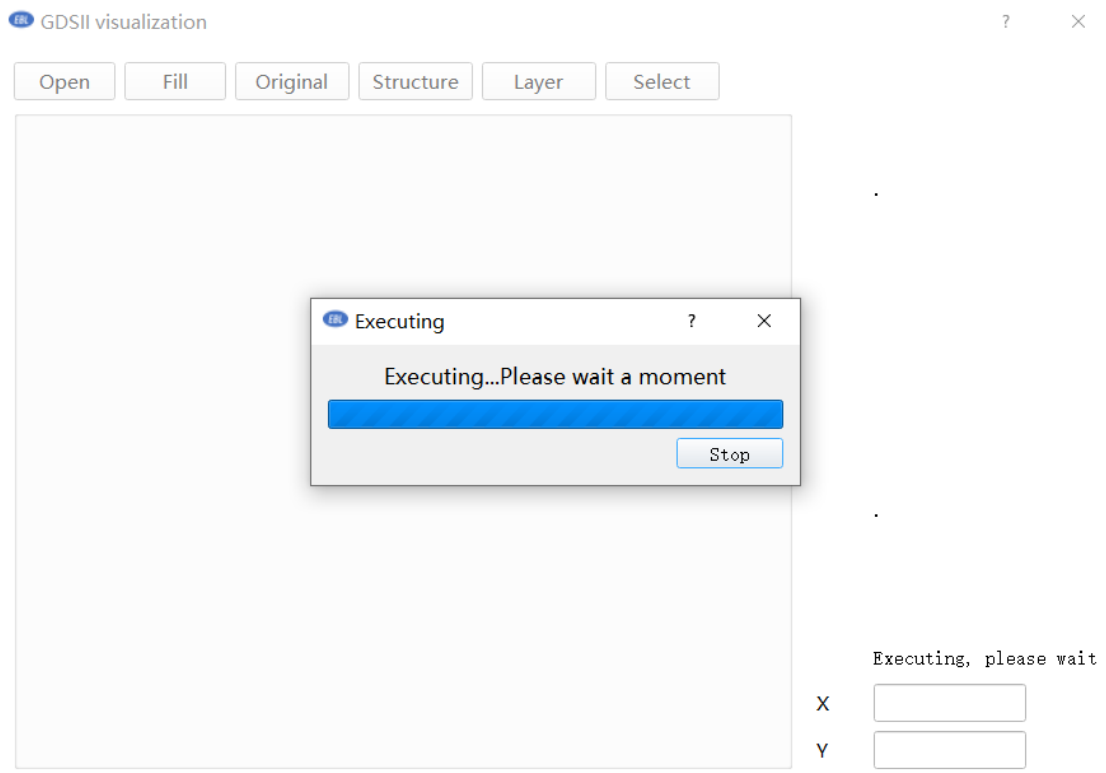


Figure 2.5.3 large file loading interface

(2) You can click "Structure" at the top of the interface, tick in front of the structure you want to view, and click "OK" to view it. (Note: only one structure can be selected) click "Layer" at the top of the interface, check the layer structure you want to view, and click "OK" to view it. (Note: multiple layers can be selected for display)

(3) You can click "Fill" at the top of the interface (as shown in Figure 2.5.4) to view the layout after the filling dose is displayed. The maximum and minimum value of the color bar on the right represents the maximum and minimum value of the dose of the current layout. If the layout has only one dose value, the right color bar has only one value and the color is red. (Note: fill only once)

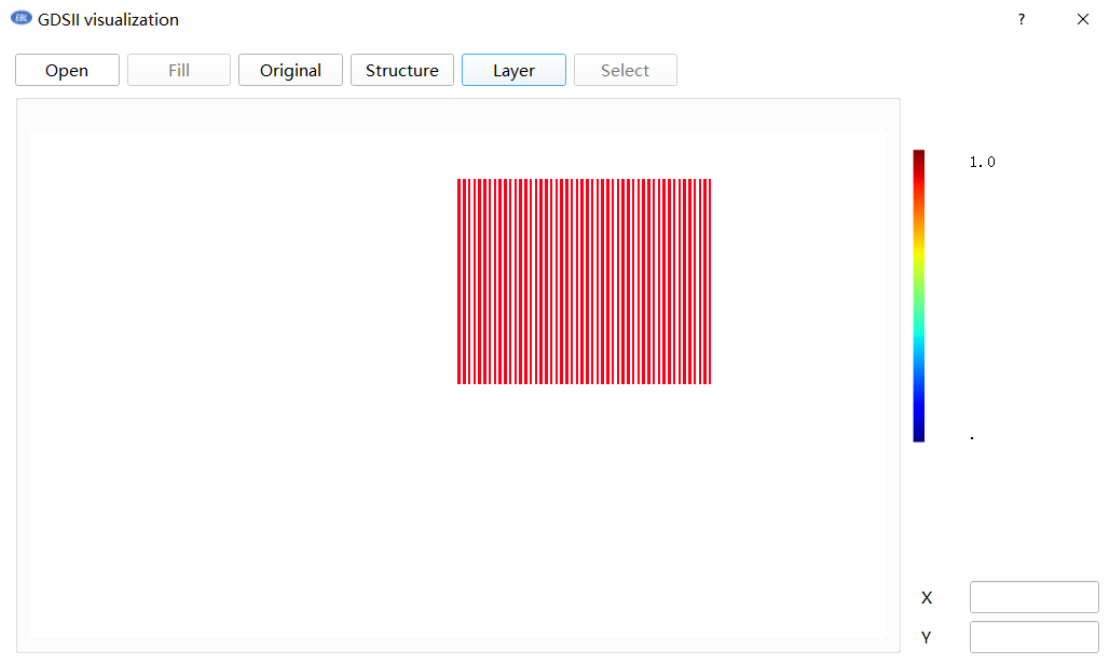


Figure 2.5.4 dose display interface

（4）You can click and drag with the left mouse button to move the layout position, and click "Original" to move the layout to the initial position. That is, (0, 0) coordinates move to the center of the screen

（5）You can slide the mouse pulley upward to enlarge the layout; Slide the mouse wheel down to reduce the layout. Right click to select the local layout to enlarge the selected part. The selected part of the layout can be enlarged multiple times by one local enlargement operation (as shown in Figure 2.5.5).

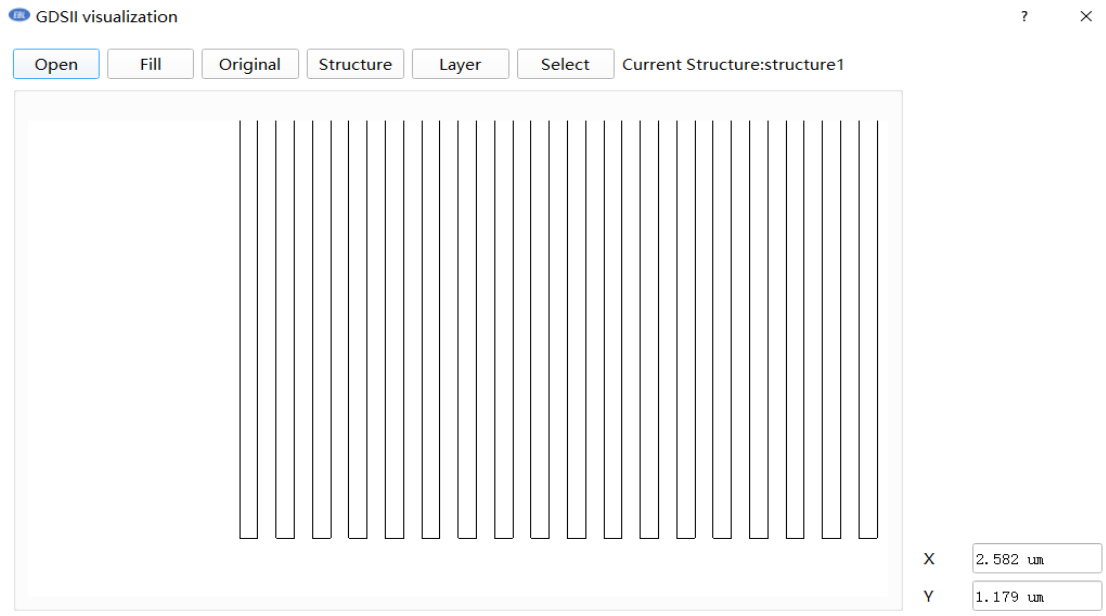


Figure 2.5.5 partially enlarged interface

（6）You can click any point in the layout, and the corresponding layout coordinates can be displayed in the bottom right corner of the main interface of software. (as shown in the lower right of Figure 2.5.6), the main interface of software can display the structure name currently displayed in the layout (as shown in the upper part of Figure 2.5.6)

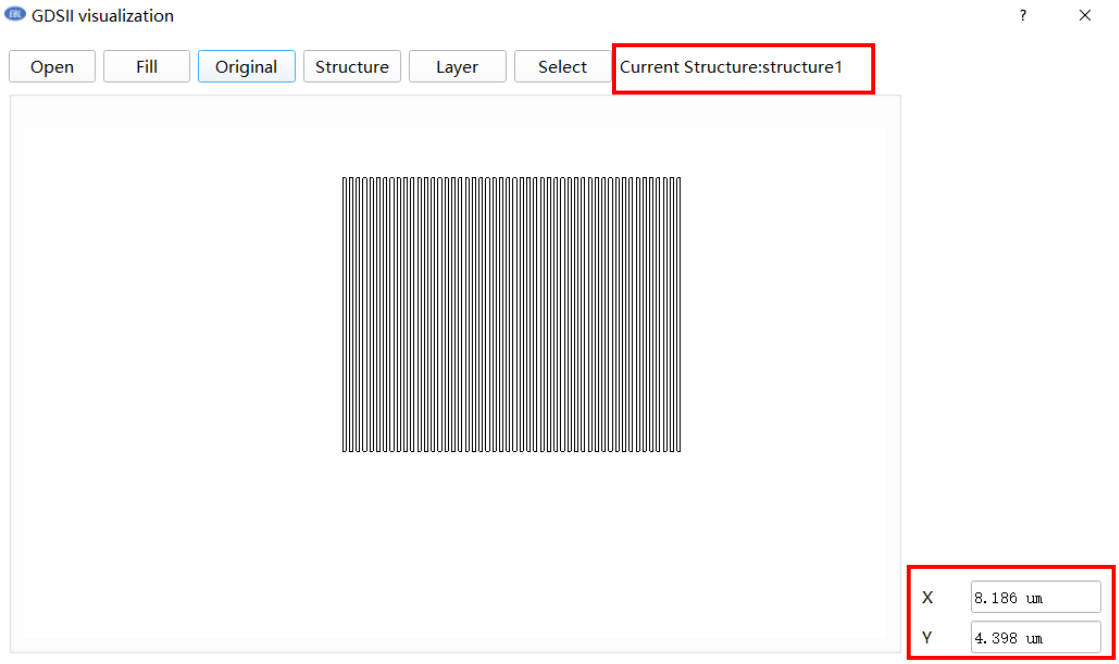


Figure 2.5.6 display layout coordinate interface

（7）You can double click a point inside the drawing in the layout to display the detailed information of the drawing, which cannot be changed. Figure 2.5.7 shows the information display interface of different pixels.

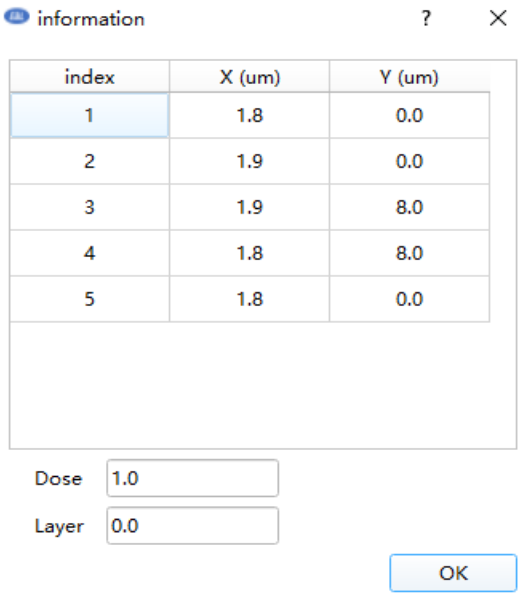


Figure 2.5.7 boundary element details

(8) Box selection function: you can press and hold the planning area with the left mouse button, release to form a box selection area, and a dialog box will pop up. Select whether to select the area, and select "Yes" to generate the corresponding GDSII file. As shown in Figure 2.5.8. At the same time, PEC, EPE, energy deposition and other functions appear (the operation is the same as above), as shown in Figures 2.5.9 and 2.5.10

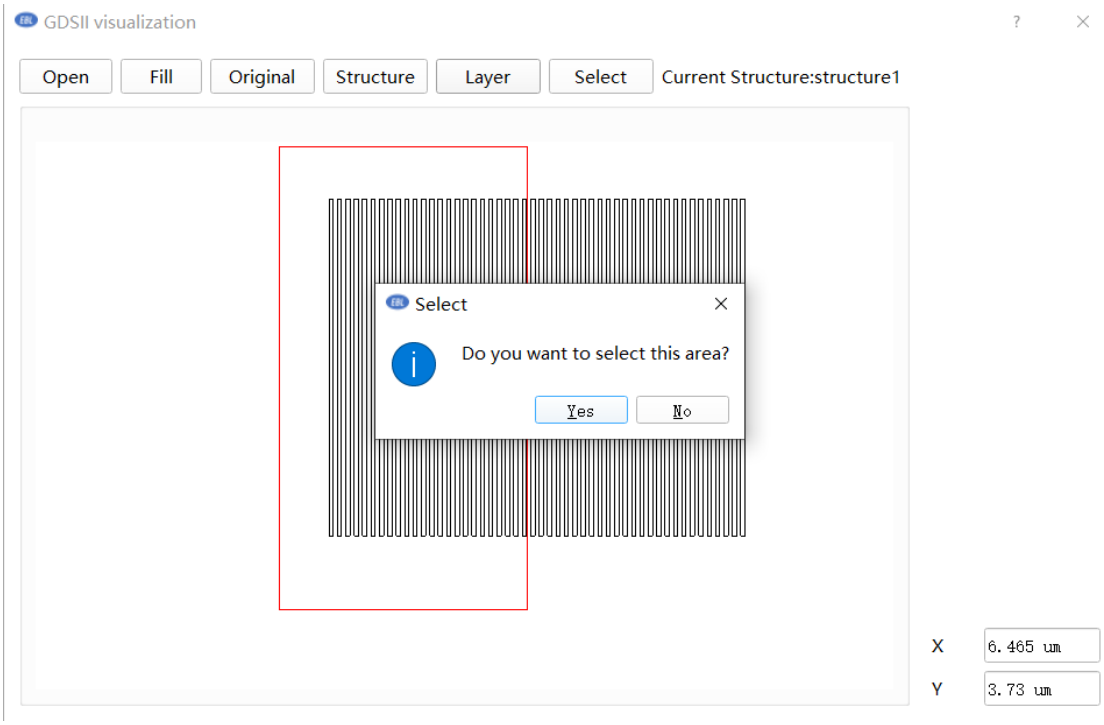


Figure 2.5.8 frame selection area

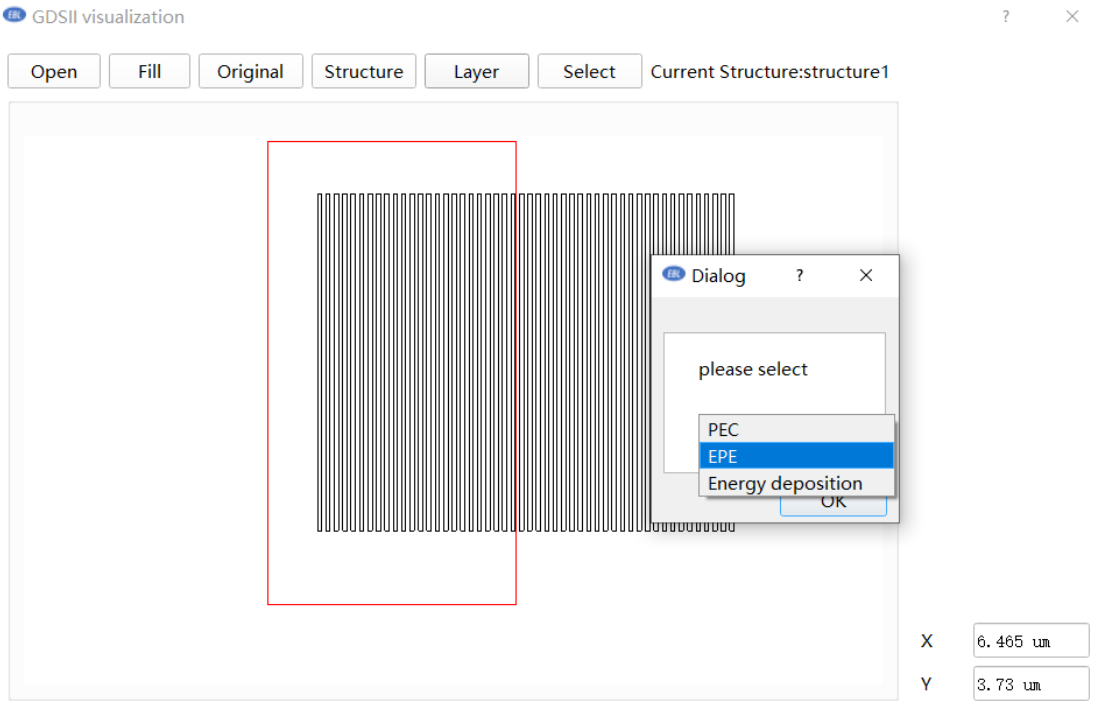


Figure 2.5.9 selection function

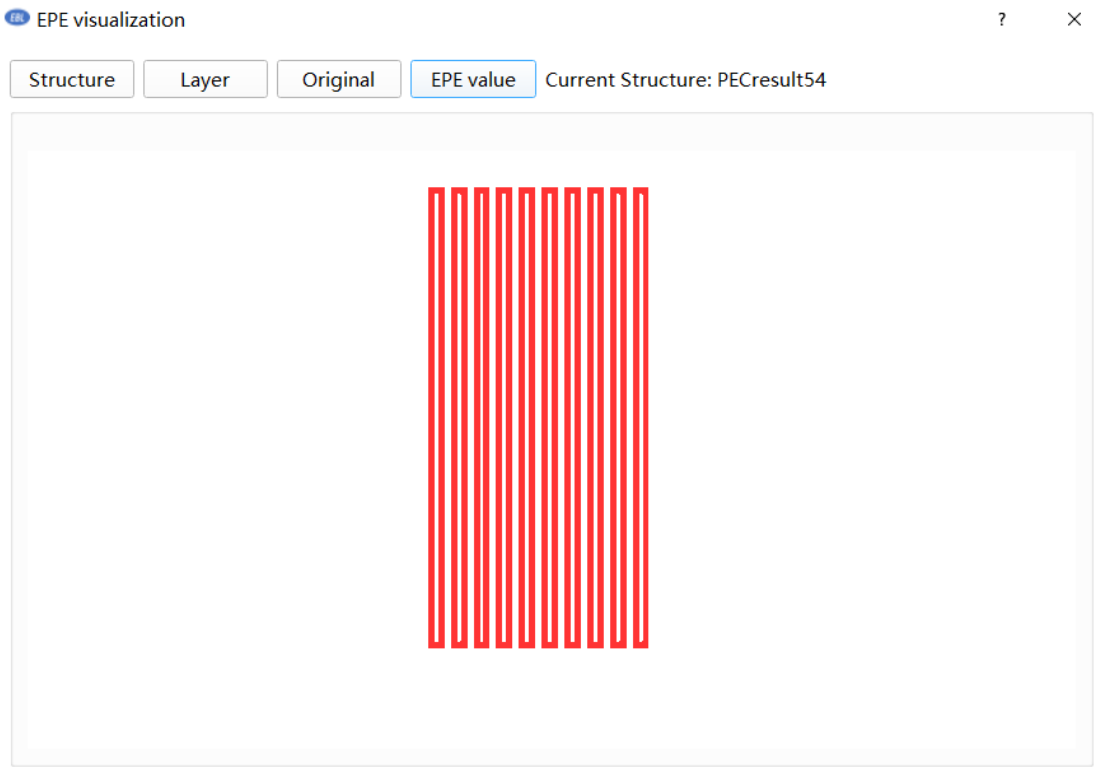


Figure 2.5.10 function of realizing selection