Dose Assignments for Exposures on Thin Membranes

One application of electron beam lithography is the fabrication of devices on membranes. Device features can be exposed both on and off the membrane. The electron scattering properties on and off the membrane are much too different to use either standard PEC or Topography-PEC methods in BEAMER. As a result, a manual dose modification is required to produce an optimized proximity effect correction. This application note describes the procedure.

INTRODUCTION

Certain electron beam lithography applications require- patterning resist on substrates that have "membranes" or "windows" suspended on a substrate. An example material stack might be a 50 – 200 nm silicon nitride membrane suspended on a crystalline silicon substrate that is 0.2 – 7 mm thick. These membranes are sometimes used to electrically and/or thermally isolated microelectronic and optical devices (Hall bars, Fresnel plates, etc.) However, other features such as electrical contacts and alignment marks are typically patterned off the membrane (with substrate). In electron beam lithography, electron

Figure 1. A not-to-scale schematic of a membrane. The silicon nitride layer is commonly 50 – 200 nm thick, and the silicon frame is commonly 0.2 – 7 mm.

scattering is heavily dependent on the substrate material stack. As a result, the thin membrane has a significantly reduced electron back-scattering profile compared to the surrounding region with substrate – in fact, long range scattering is nearly eliminated on the membrane. In simulation, TRACER will correctly produce two substantially different point spread functions (PSF) for each region. These differences have two important consequences. First, a one-PSF standard PEC cannot correctly assign doses to features in both regions. Second, a two-PSF Topography-PEC will fail, giving an error message. In this case, separate PEC are required for different regions. This note describes the procedure to do so in order to produce optimal PEC. The example flow, pattern and PSFs will be provided with this note.

PROCEDURE OVERVIEW

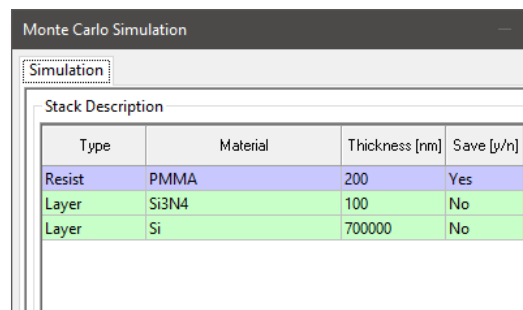This process has the following steps:

1. Generate representative PSFs in TRACER for both the on-membrane and off- membrane stack.
2. Prepare the pattern data in CAD so that "on-membrane" regions overlap with a separate layer.
3. Process the layout in BEAMER: separate on-membrane and off-membrane features, apply PEC to each, manually adjust the membrane region dose factor and then merge the patterns for export.

PROCEDURE DETAILS

1. GENERATE PSF FOR ON-MEMBRANE AND OFF-MEMBRANE RAGIONS

To correctly assign doses to features both on and off membrane, separate PSF for both areas must be generated in TRACER. Make sure that the simulation parameters for both simulations are identical except for the absence of the substrate in the on-membrane PSF, and that you are only "saving" the resist layers. An example material stack is shown in Figure 2.

Once the simulations are complete, "check" or select the same layer number (or z-height) in both simulations, as shown in Figure 3. The 2D-PSF from the middle of the resist stack usually works well. Save both 2D-PSFs to your archive for use in BEAMER. Right

Figure 2. A typical substrate or "frame" material stack in TRACER. The membrane stack would be identical except for an absent "Si" layer.

click the *off-membrane* PSF and select "Dose Factor." The window shown in Figure 4 appears. The window displays the relative dose factor of all "active" 2D-PSFs compared to the selected 2D-PSF. That is, the selected off-membrane 2D-PSF should have a nominal value of 1. Write down the dose factor value that is next to the corresponding membrane 2D-PSF. You will need it in future steps to correctly adjust the dose in BEAMER. In the example shown, it is 1.524292. The on-membrane dose factor should be substantially larger then the off-membrane dose factor due to the reduced electron backscattering in the

Figure 4. View of Dose Factor window which displays relative dose factors for each active 2D-PSF.
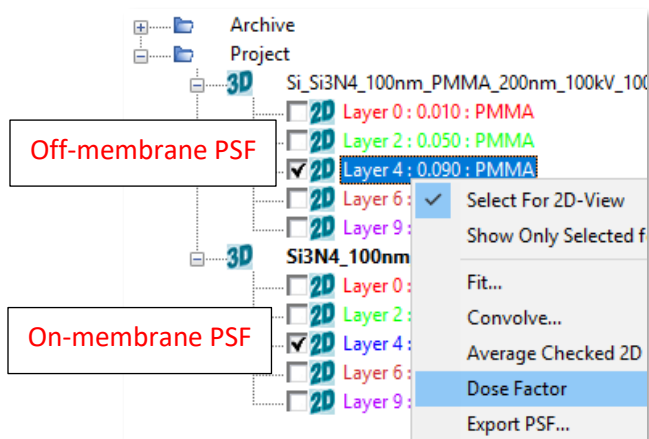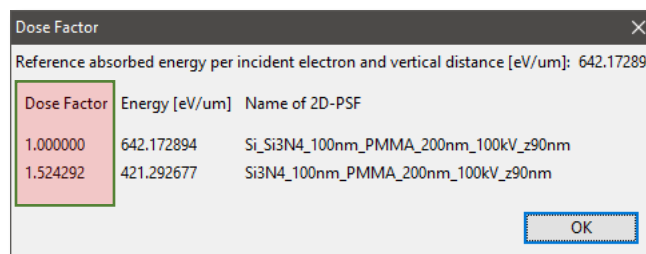
Figure 3. Simulation results for both regions with the same layer selected in both 3D-PSFs, as well as the "Dose Factor" option.

membrane.

2. PREPARE PATTERN

Before processing your pattern in BEAMER, make sure your layout pattern is set up correctly. You can use a CAD Layout program, the Edit module in BEAMER, or any other method you find most convenient.

Critically, *all features that will be exposed should be on one layer* (e.g. layer 1). Additionally, any features that are "on membrane" should overlap with a box placed on a *separate layer* (e.g. layer 2). Again, it is important that all features are placed on one layer, and all membrane region boxes are placed on a separate layer.

In the "Hall Bar" example shown in figure 5, the red features are on layer 1, and are the features to be exposed. In the center is the Hall Bar device on the membrane, with 100 nm features. The 50 µm blue box represents the membrane region (layer 2). It will be used to extract the on-membrane features and then be removed beforePEC. Once your pattern is prepared, proceed to BEAMER.
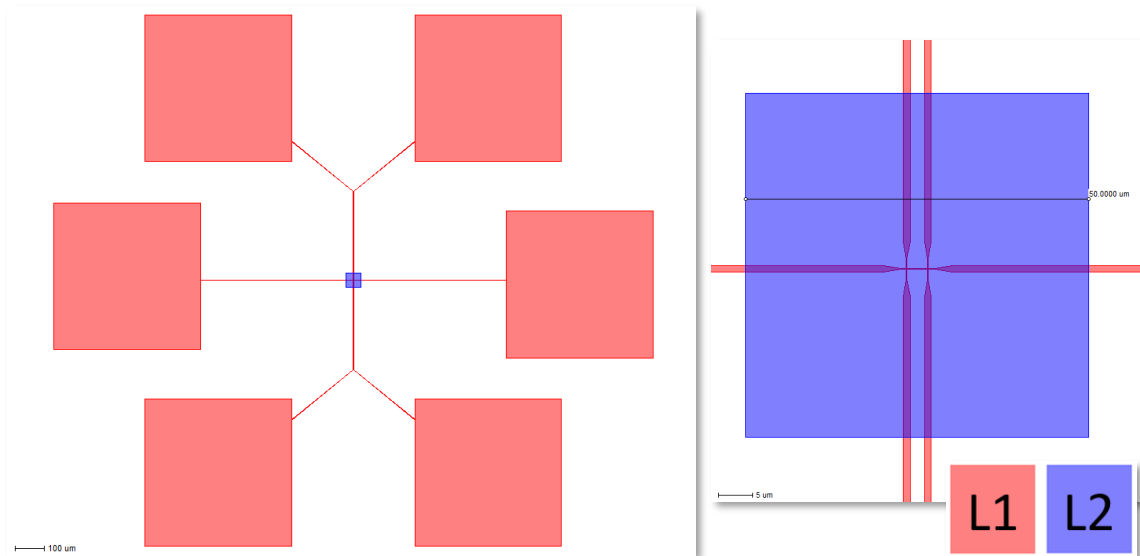

Figure 5. Left: a full view of a "Hall Bar" example pattern, with large contact pads on the outside leading to the nanoscale hall bar in the middle. Right: a higher magnification view of the membrane region.

3. PROCESS PATTERN IN BEAMER

Separate the on-membrane and off-membrane regions of your pattern and apply PEC to each separately. Then, adjust the dose factors assigned to the on-membrane region to compensate for the different energy spread profiles. Finally, re-merge and export the pattern as a single file for exposure. A commented sample version of this flow is shown in Figure 6, and will be provided with this application note. A summary is as follows:

1. IMPORT your pattern. Two extact modules are connected to import module. One extracts layer 1 (features), the other layer 2 (membrane regions).
2. Attach an AND to both extracts – the AND selects only the features that are on the membrane.
3. The minus module removes the "on-membrane" features so that On-membrane and off-membrane regions are separated.
4. Apply PEC to both "branches", with their respective PSFs.
5. Add an FDA to the on-membrane part, with Assignment Type of "multiply", and use the dose value found in Tracer (1.524292). This boosts the relative dose to account for the reduced back-scattering in the on-membrane region.
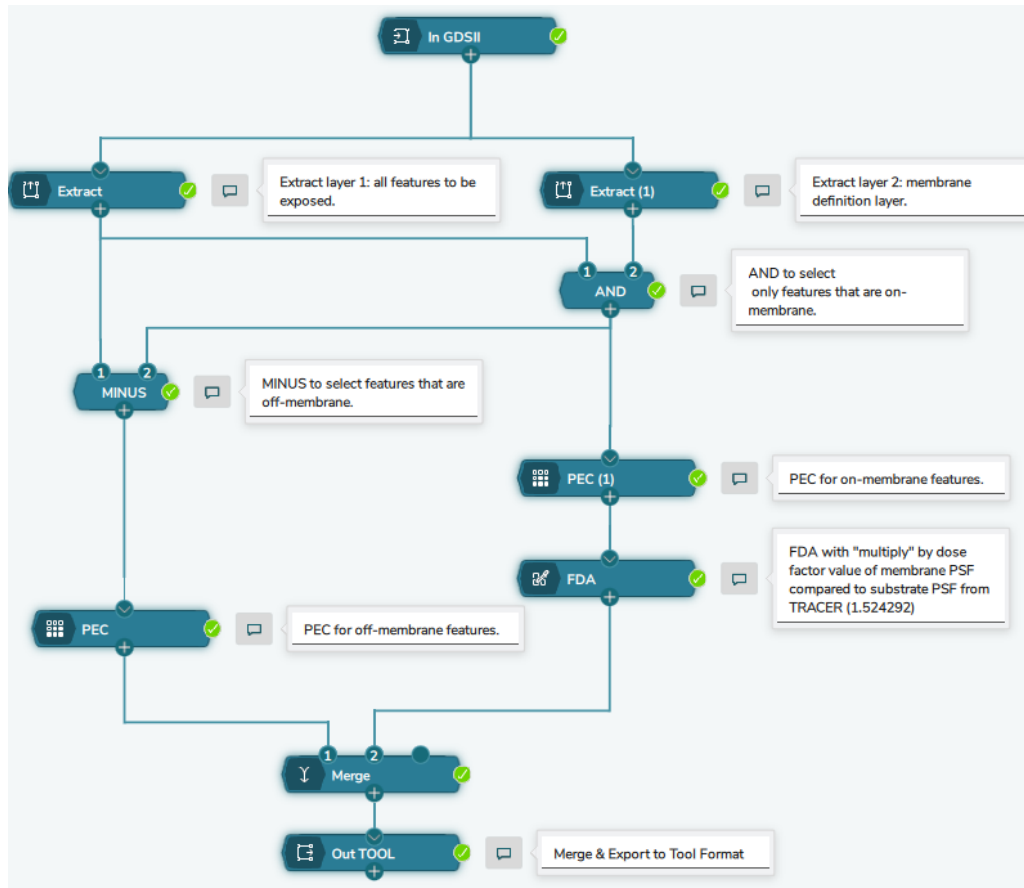
6. Merge and export your pattern.

Figure 6. Sample BEAMER flow for membrane dose assignment.

ADDITIONAL NOTES

- In general, when attempting to PEC a pattern with topography, using 3D-PEC in topography mode should be the first method attempted. The above method is only used when TOPO-PEC fails due to too large of a difference in the applied PSFs.
- A drawback of this method is that features that are near to or cross over the boundaries of the membrane region are not properly being proximity effect corrected. This is because each PEC does not "know" about nearby features on the off-membrane region. This can result in line widening at crossover points, where the true pattern density is actually higher than used for calculation. A consequence of this is that this method works best when pattern density in and around membrane ranges is low.