BEAMER 3D Correction for Dolan Technique

The Dolan technique is a method used for multilayer processes with overlapping structures, and thus, very practical for quantum devices manufacturing. This Application Note illustrates the optimization of this technique by the setup of a 3D Edge Correction in **BEAMER**.

INTRODUCTION

The Niemeyer-Dolan technique, also known as shadow evaporation, creates nanometre-scale overlapping structures in thin-film lithography. Using a suspended evaporation mask, precise angles allow shadow images to project onto the substrate, forming well-defined geometries.

For a stable production the control of opening and undercuts is essential and here **BEAMER** with the 3D Edge Correction comes into play to support the production process of this technique.

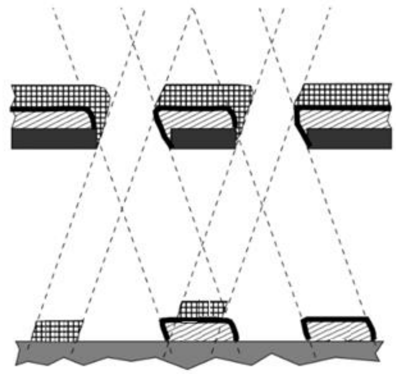

Figure 1. Dolan technique showing the resist mask and the layers deposited on it during the evaporations (https://en.wikipedia.org/wiki/Niemeyer%E2%80%93Dolan_technique)

DESIGN & DATA

For executing a correction, **BEAMER** needs a design of the structure itself together with the information about the resist behaviour. This can be provided by two methods, either as information about the ratios of sensitivity or by having the contrast curves that allows the computation of the sensitivities.

The design would be provided as a layout containing the desired opening at the top of the resist plus the desired undercut that should be corrected for. The contrast curve provides the resist thickness as function of the dose applied during the exposure.

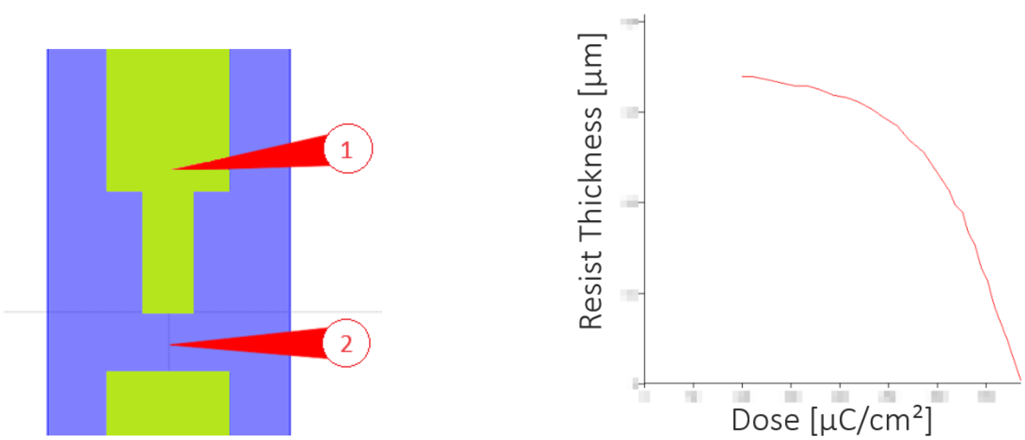

Figure 2. (Left) Layout with top opening in red and undercut outline in blue and (right) exemplary Contrast Curve.

3D EDGE PEC - THRESHOLD

The **BEAMER** 3D Edge PEC in Threshold mode just needs from the user the information about the relative sensitivities. **BEAMER** will use this ratio in the correction to make sure that both designs get the proper clearing energy at the edge of their patterns to achieve the desired openings.

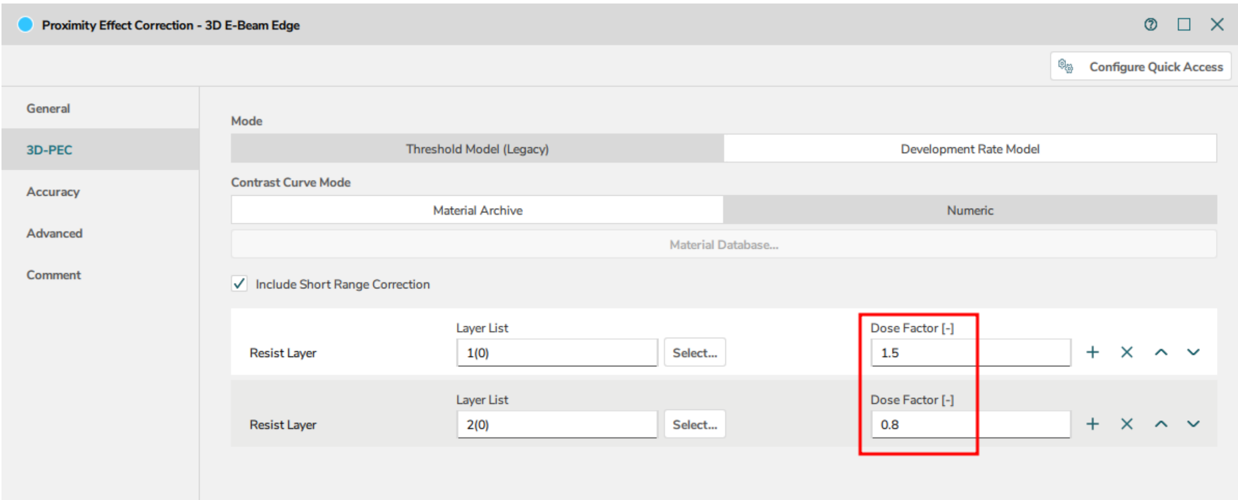

Figure 3. Threshold mode used in the 3D E-Beam Edge in BEAMER.

The figure above shows the 3D setup of the correction. The red rectangle highlights the spot where the dose ratios are given. The values are not so important for this correction as their ratio drive the correction. People have been using factors like 30% of the top resist is needed for the bottom resist giving a ratio of 1.0 and 0.3 or also 1000µC/cm² opposed to 300 µC/cm² would yield the same correction result. The layers 1(0) and 2(0) here would respond to the red and blue layer of the layout in Fig. 2.

3D EDGE PEC – DEVELOPMENT RATE MODEL

The development rate model takes the correction to a next level by not only computing from the contrast curve automatically the required doses but also considering how the resist is behaving during development. This leads to a more elaborated model with higher accuracy but also requires more input from the user.

In Fig. 4 the red boxes mark in order:

- Exposure dose of the process
- Contrast curve of the critical layer
- Contrast curve of additional layers

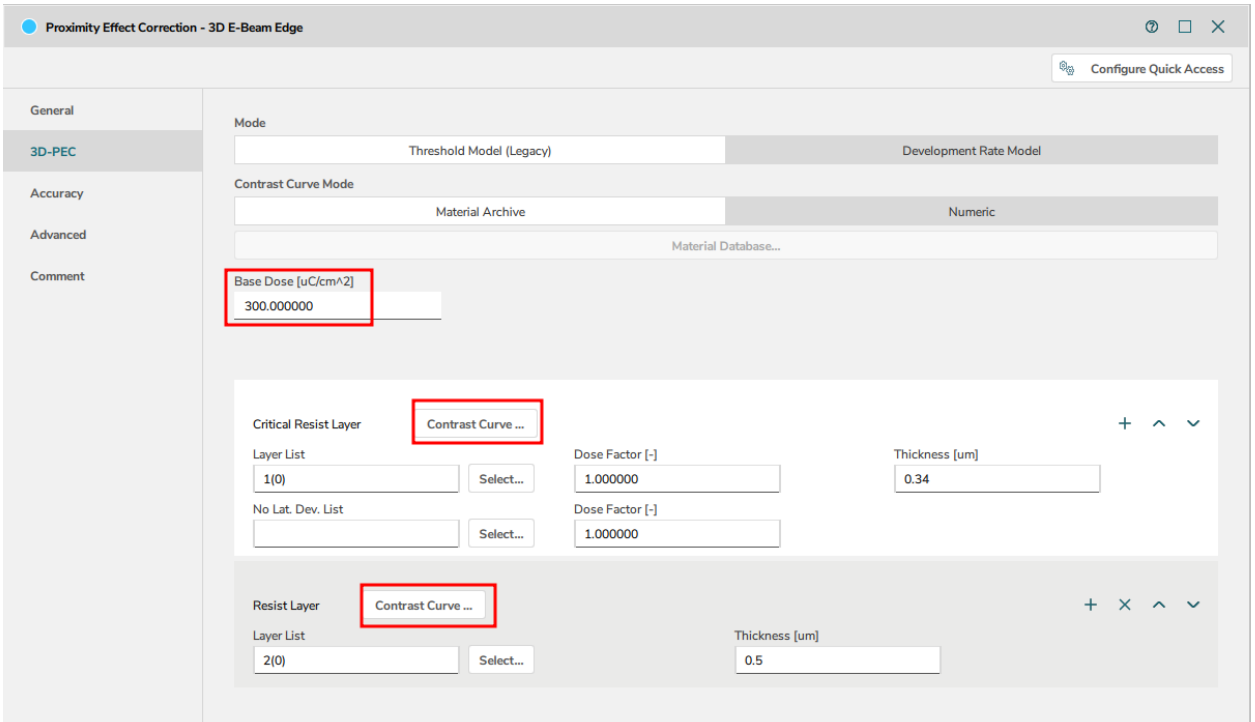

Figure 4. Contrast Curves required for the correction.

After setting the 3D-Edge PEC module, the corrected layout shows different dose classes depending on the features layer, geometry and surrounding density. The dose modulation intends to optimize the outcome and maximize the pattern fidelity. For our example, figure 5 shows the dose modulation for the layout shown in Fig. 2. The large areas, coloured blue, have a lower dose factor due to the back-scattering contribution and the undercut layer selection. On the other hand, the green and yellow areas have been assigned higher dose factors, given the sharper-angled edges and the critical layer assignment. This pattern is exported to the specific tool format for further processing.

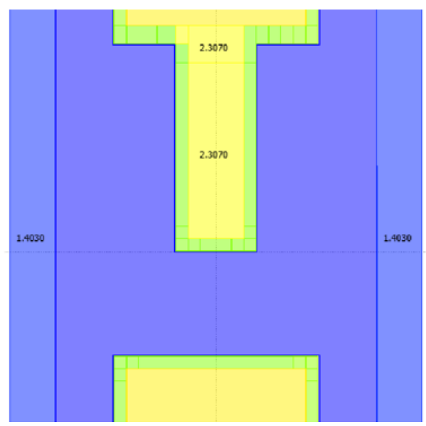

Figure 5. Layout proximity effect corrected using BEAMER.

SIMULATING THE CORRECTED PATTERN

Once the pattern is ready for exposure, **LAB** provides the 3D E-Beam module for exposure simulation allowing to visualize the lithography result and thus saving material and time resources. Using a flow as the one in Fig. 6, the exported file in **BEAMER** is imported in **LAB** where the simulations run using the experimental settings (substrate, layers and development conditions).

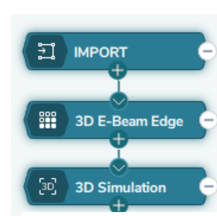

Figure 6. LAB flow for 3D simulation.

Using the flow from fig. 6, we obtain information of the absorbed energy in the different layers during the exposure. Figure 7 depicts the absorbed-energy cross section at z = 0.5 µm from the top of the resist. Moreover, fig. 8 shows a time sequence of the resist development starting with fig. a) after few seconds of development up to fig. c) after 60 seconds of development. Finally, fig. 8 d) shows 60 seconds of development using a different observer perspective.

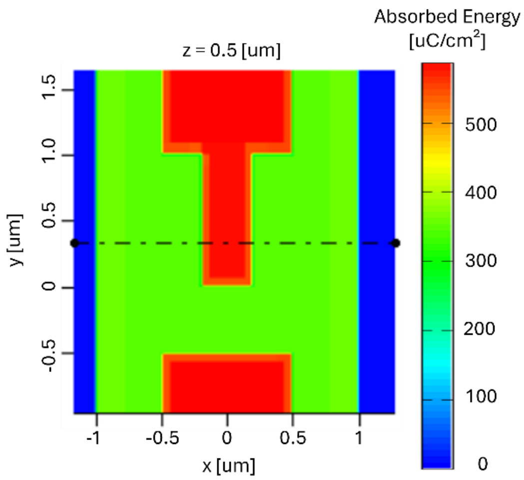

Figure 7. Absorbed energy cross section at z = 0.5 µm from the top of the resist.

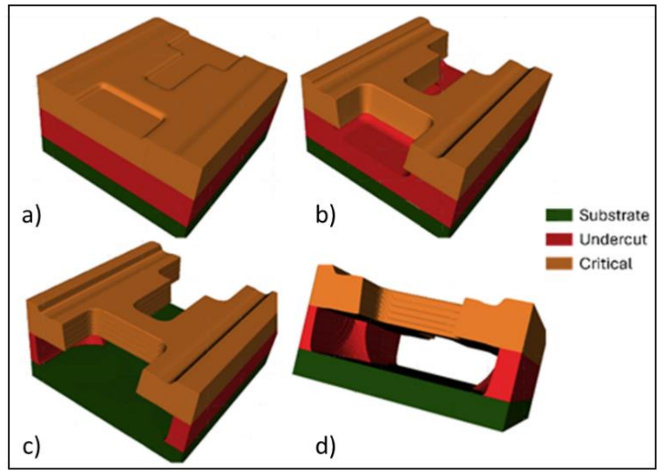

Figure 8. Time sequence of the resist development after e-beam exposure where a) after 5 second, b) 30 seconds and c) - d) 60 seconds changing observer perspective.

DOLAN BRIDGES EXAMPLES FROM THE NET

Some examples of the fabrication and usage of Dolan bridges are widely found in internet. For instance, a recommended lecture to the user is in the work from Alexander Bilmes 'In-situ bandaged Josephson junctions for superconducting quantum processors.' (*Alexander Bilmes* et al *2021* Supercond. Sci. Technol. *34 125011)*, it shows the shadow evaporation technique to fabricate sub-micrometer junctions to reduce dielectric loss of qubits.

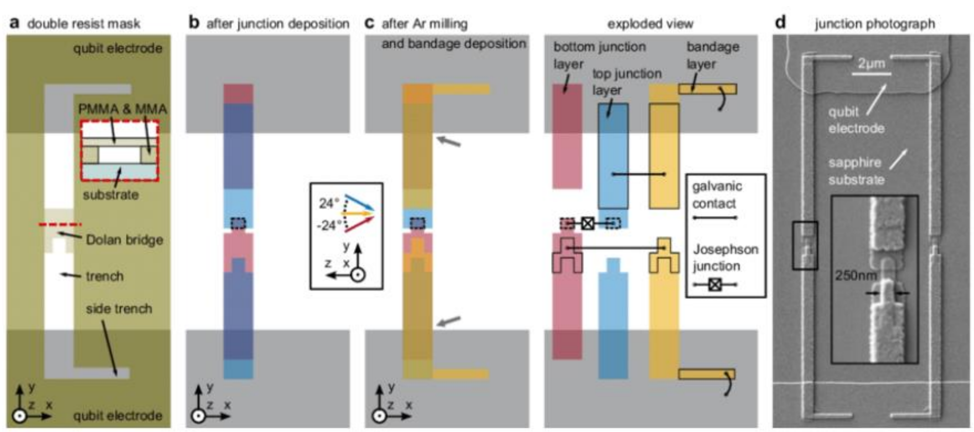

Figure 9. Sketch of a double resist mask and the Dolan bridge (Alexander Bilmes et al 2021 Supercond. Sci. Technol. 34 125011)