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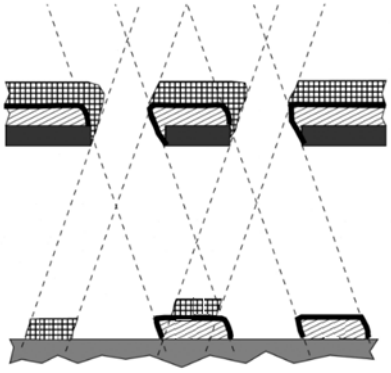
3D Correction for Dolan Technique

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 optimisation of this technique by the setup of a 3D Edge Correction in **BEAMER**.

Introduction

The Niemeyer-Dolan technique, also known as shadow evaporation, creates nanometer-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. The Dolan technique in the image below shows the resist mask and the layers deposited on it during the evaporation. (*https://en.wikipedia.org/wiki/Niemeyer%E2%80%93Dolan_technique*)

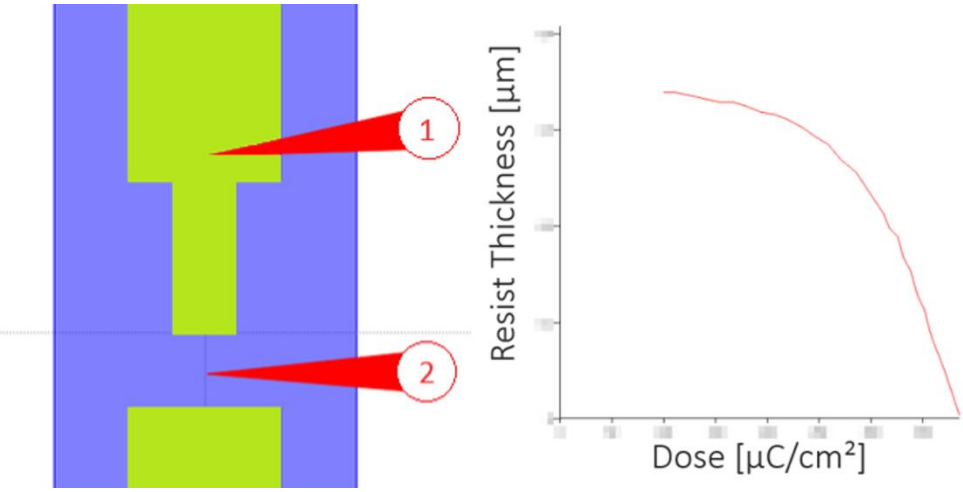


For stable production, the control of opening and undercuts is essential and here **BEAMER** with the 3D Edge Correction comes into play to support the production process of this technique.

Design & Data

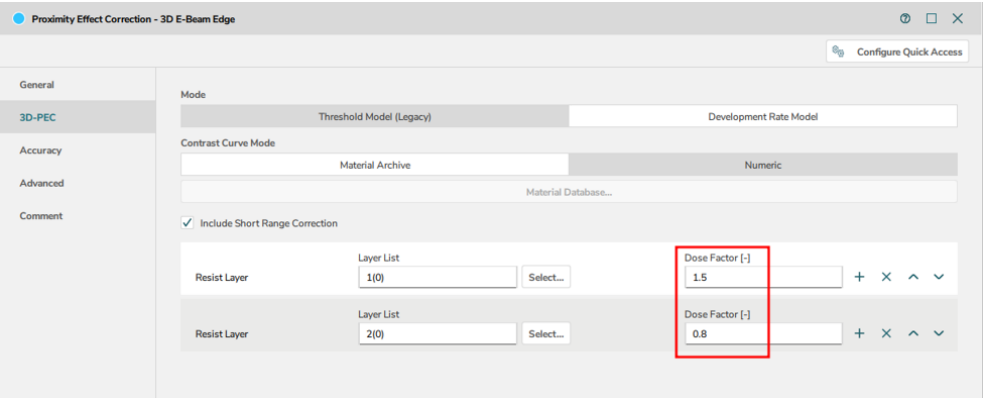
For executing a correction, **BEAMER** needs a design of the structure itself together with the information about the resist behavior. This can be provided by two methods, either as information about the ratios of sensitivity or by having the contrast curves that allow the computation of the sensitivity.

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. Below is an example layout with top opening in green and the undercut outline in blue. The exemplary contrast curve is shown on the right of the image.



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.



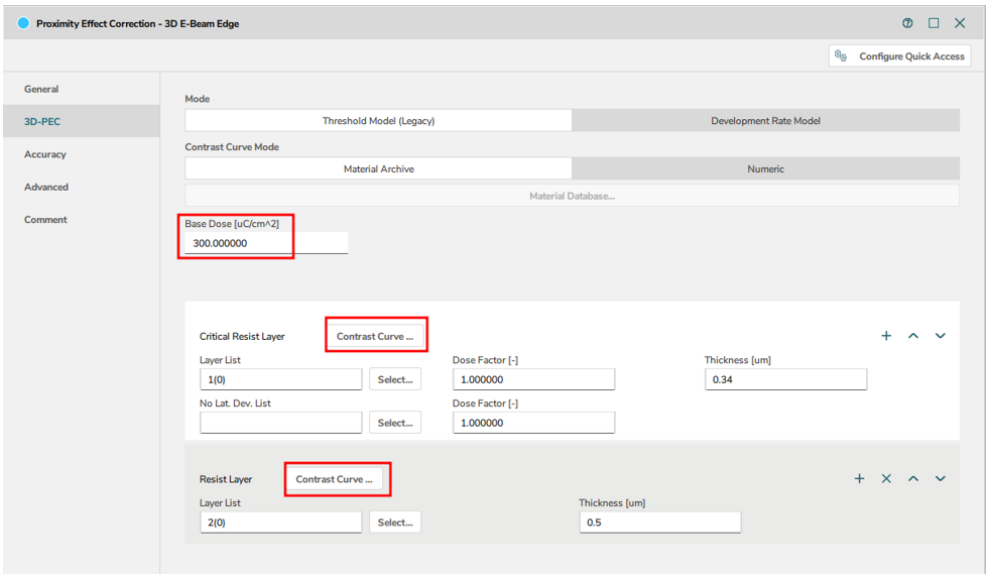
The figure above shows the 3D setup of the correction. The red rectangle highlights the spot where the dose ratios are given. The values are not so important for this correction as their ratio drive the correction. People have been using factors like 30% of the top resist is needed for the bottom resist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

3D Edge PEC – Development Rate Model

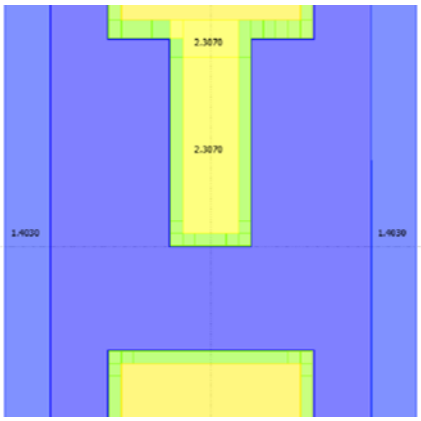
The development rate model takes the correction to a next level by not only computing from the contrast curve automatically the required doses but also considering how the resist is behaving during development. This leads to a more elaborated model with higher accuracy but also requires more input from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

In the following image red boxes mark in order:

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



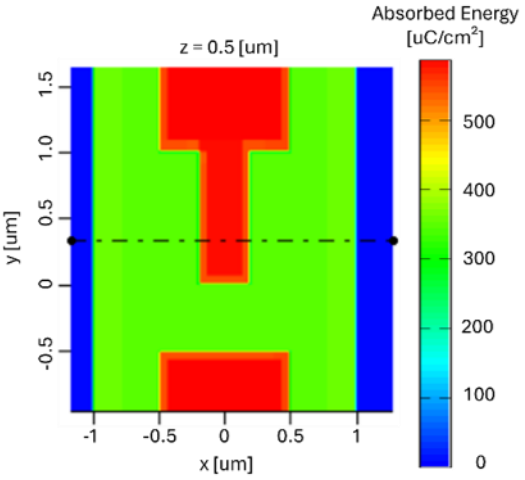
After setting the 3D-Edge PEC module, the corrected layout shows different dose classes depending on the features layer, geometry and surrounding density. The dose modulation intends to optimise the outcome and maximise the pattern fidelity. For our example layout, the dose modulation is shown below. 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.

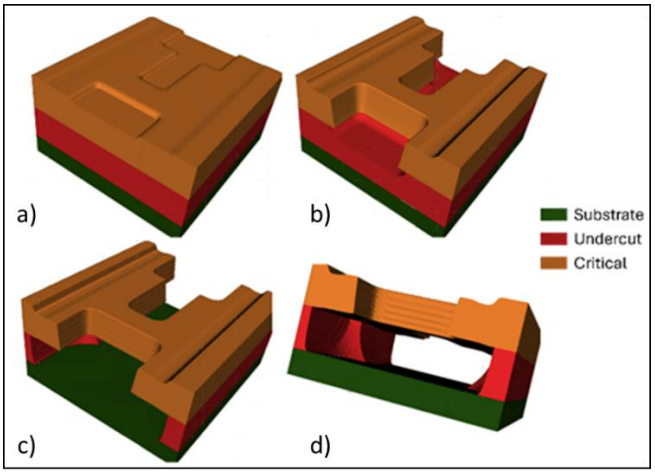


Simulating the Corrected Pattern

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

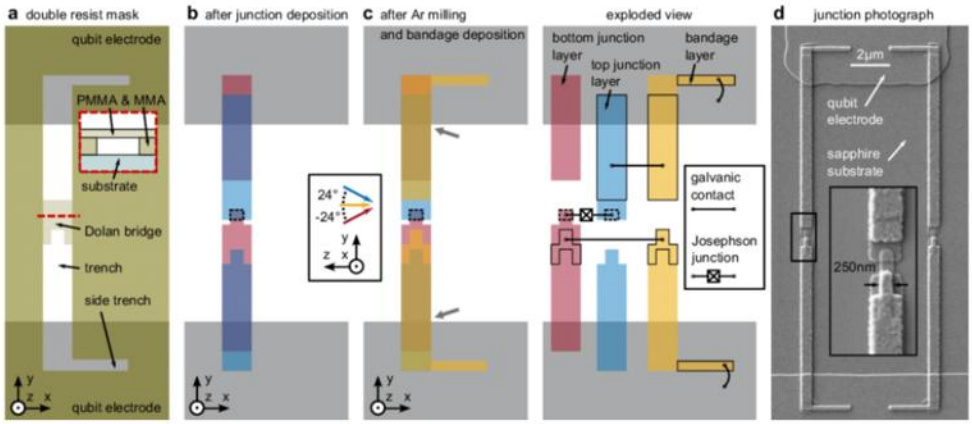
From 3D Simulation, we obtain information of the absorbed energy in the different layers during the exposure. The left picture depicts the absorbed-energy cross section at z = 0.5 µm from the top of the resist. Moreover, the right image shows a time sequence of the resist development starting with fig. a) after few seconds of development up to fig. c) after 60 seconds of development. Finally, d) shows 60 seconds of development using a different observer perspective.





Dolan Bridges Examples from the Net

Some examples of the fabrication and usage of Dolan bridges are widely found on the 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.



Summary

BEAMER's 3D Edge Correction provides an effective approach to optimising resist profiles for the Niemeyer–Dolan technique used in shadow evaporation processes. By accounting for the desired opening geometry, resist properties, and exposure conditions, appropriate dose corrections can be applied to improve pattern fidelity and achieve the required undercut profiles. Combined with **LAB** 3D lithography simulations, this approach supports the optimisation of exposure parameters and resist geometries, facilitating the fabrication of well-defined structures for quantum device applications.