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Novel Super-Fast Three-Dimensional SEM Image Simulation

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Three-dimensional (3D) photogrammetric surface reconstruction from scanning electron microscope (SEM) images recently gained importance, finding suitable applications in the science and industry. When this technique is to be used as a metrological tool, an assessment of its accuracy must be carried out. Solely using real SEM images is not satisfactory, since the amounts of the SEM-related disturbances in the images, e. g. edge-effect, noise, beam-profile-related blur, drift and vibrations, are unknown. On the other hand, amount of these effects in simulated images are not only known, but also deterministically tunable. Application of simulated images with consideration of the three-dimensional character of the sample is thus inevitable. The simulation can be carried out employing a Monte-Carlo-based technique, e. g. MCSEM [1] developed by the PTB. Another , significantly faster possibility a method based exclusively on calculation of the signal from the surface slope [2]. However, the latter technique does not cover edge- and proximity-effects. The technique presented in this work does, while satisfying all other necessary requirements for assessment of 3D-reconstruction and other methods.

Image simulation starts with a three-dimensional model of the sample. Such model can be created in any 3D computer graphics software. All samples processed in this work and displayed in the figures have been created in Blender. As the first step, sample objects are divided into tetrahedral sections. This tetrahedralization is carried out using the Tetgen library [3], which only accepts piecewise linear complexes (PLCs) as input. The sample must thus be modeled as a PLC, or a set of PLCs. When an SEM image is simulated, the signal (usually represented by a grey level) corresponding to each image pixel is calculated. The simulation starts with a simple beam model allowing for placing the beam source to an arbitrary point, which enables determination of the working distance and simulation of tilting of the sample. From this source point, the parametrized beam proceeds to the sample In order to find the point of interaction, which is the point where the beam intersects with the tetrahedralized sample first, all surface triangles must be tested. If multiple triangles are hit, which is mostly the case, the point of interaction lies on the triangle with the lowest distance from the source.

After calculation of the point of interaction, the algorithm deploys a signal source. In the current version, it is represented by a set of 870 points evenly distributed throughout a spherical volume. This sphere dips into the material of the sample leaving a minor part of it reaching somewhat above the point of interaction. (See Fig. 2a.) Currently, the size of the signal source as well as its dip depth are estimated. In the future versions, the distribution of points may be modified to better match real images. The points that are positioned out of the sample body contribute to the signal, while the ones inside do not. This simple principle already suffices to simulate edge effects and proximity effects. Rest of the disturbances usually present in SEM images (e. g. drift and vibration, noise, and beam-profile-related blur) are modeled using ARTIMAGEN, which is a two-dimensional artificial SEM image generator [4].

This Monte-Carlo-less 3D SEM Image Simulation technique has been used to evaluate a photogrammetric 3D surface reconstruction techniques. For this application, calibration of the grey-levels has not been necessary, because the photogrammetric techniques are based on cross-correlation. However, proper calibration using a Monte-Carlo technique combined with real SEM images is planned. Although the new technique is less accurate, it is many orders (over 100,000x, depending on the sample complexity) faster than Monte-Carlo-based techiques [5].

References:

[1] K-P Johnsen, CG Frase, H Bosse and D Gnieser, SEM image modeling using the new Monte Carlo model MCSEM, SPIE Proceedings 7638 (2010)
[2] A Seeger and H Haussecker, Shape-from-shading and simulation of SEM images using surface slope and curvature, Surf. Interface Anal. **37** (2005), p. 927.
[3] H Si and K Gärtner, Meshing Piecewise Linear Complexes by Constrained Delaunay Tetrahedralizations, Proceedings of the 14th International Meshing Roundtable (2005), p. 147.
[4] P Cizmar, AE Vladár and MT Postek, Scanning **30** (2008), p. 381.
[5] Acknowledgement: This work hs been supported by the "Metrology to Assess the Durability and Function of Engineered Surfaces" (MADES) joined European research project.

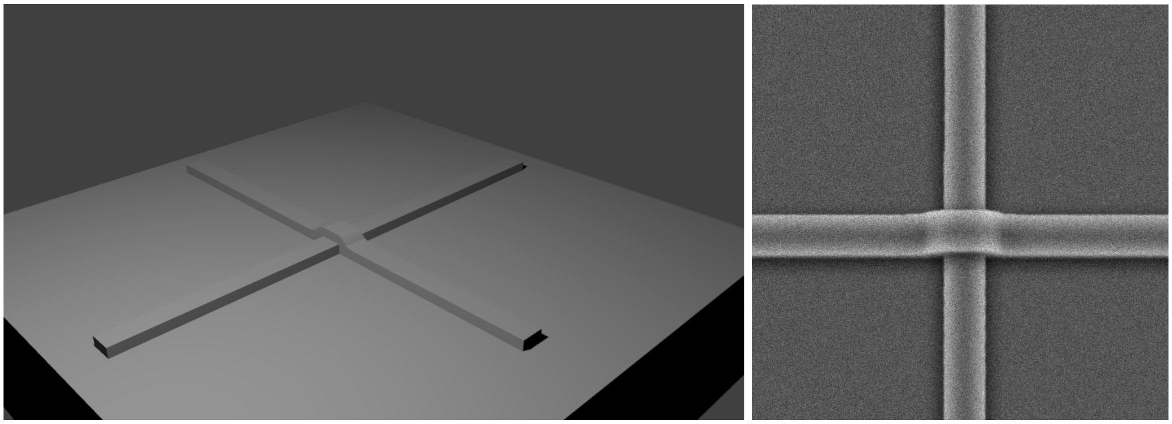
a. b.

Figure 1. a. Rendered model of two overlapping semiconductor-like band structures, b. Simulated SEM image of this structure.

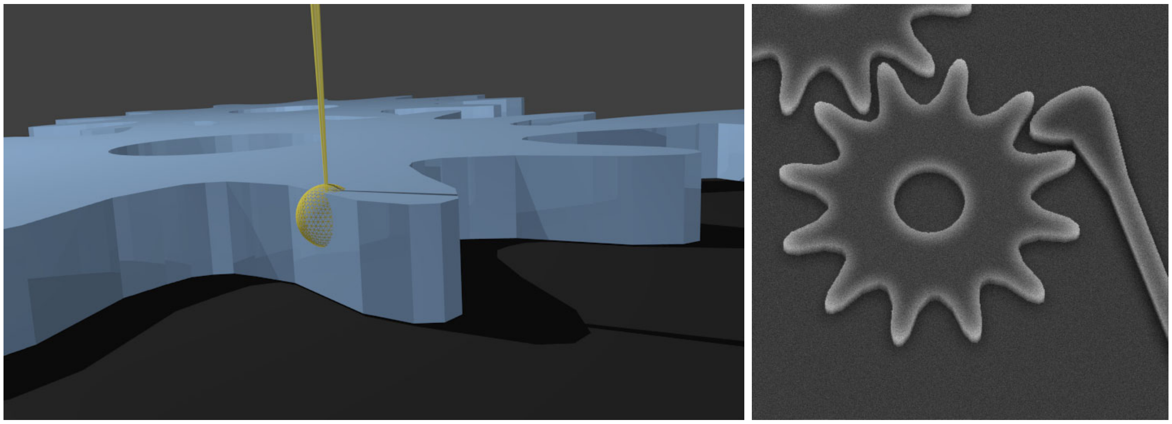
a. b.

Figure 2. a. Visualization of the SEM image simulation principle at a point near the edge, b. Simulated SEM image of a MEMS-like semiconductor structure exhibiting both edge and proximity effect.