

Towards the Simulation of Scanning Electron Microscopy Images of Charging Samples

Hans Keur^{*a}, G.T.B. Coemans^a, G. Varnavides^a, T.F. Fliervoet^{a,b}, C.W. Hagen^a

^a*Delft University of Technology, Delft, The Netherlands*

^a*ASML Research, Eindhoven, The Netherlands*

To accurately interpret scanning electron microscopy (SEM) images, the underlying electron-matter interactions must be understood. To this end, several Monte Carlo simulators have been developed, including Nebula[1]. Currently, however, Nebula neglects electric fields generated by charge accumulation within the sample. Consequently, electron trajectories are not deflected by these fields, which can lead to inaccurate image simulations.

An example is shown in Fig. 1a, where the sample consists of 300-nm ruthenium plugs embedded in a 60-nm thick stack of silicon nitride and silicon dioxide. The two upper plugs are electrically grounded and appear brighter in the SEM image, whereas the two lower plugs are electrically floating and appear darker. In addition, a pronounced contrast variation is visible between the floating plugs. The simulated image obtained without electric-field effects (Fig. 1b) however, shows neither contrast differences between the plugs, nor dark tails between them. These observations motivate a quantitative investigation of the contribution of charge effects to SEM contrast formation.

To investigate this, a finite-element electrostatic solver has been integrated into Nebula. The solver computes the electrostatic potential and electric field by solving the Poisson equation for a given charge distribution and prescribed boundary conditions, such as a bias voltage. Particular attention has been paid to scalability on high-performance computing systems, enabling simulations of arbitrary sample geometries within practical runtimes of approximately one hour.

Initial results (Fig. 1c) show that strong, highly localized electric fields develop at the nanoscale near material interfaces and contacts, as evidenced by the dense clustering of equipotential lines. These fields significantly alter electron trajectories, and can cause electrons to terminate at locations far from those predicted by field-free simulations. This is an example of charge effects that are expected to have a substantial impact on the simulated SEM image contrast. Future developments are firstly, the inclusion of field-dependent trajectories. Later developments will incorporate additional charge-related processes, including charge trapping and detrapping, recombination, drift-diffusion, electron-beam-induced current (EBIC), and voltage breakdown, enabling increasingly realistic simulations of charging phenomena.

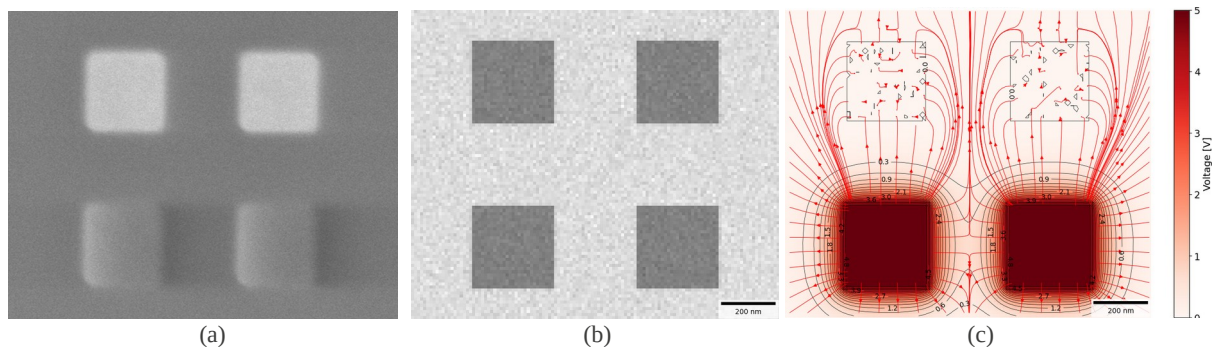


Figure 1. (a) An experimental secondary electron (SE) image of ruthenium plugs in silicon nitride and silicon dioxide. The upper two plugs are grounded, whereas the lower ones are not. (b) A simulated SE image of the same sample without E-fields. (c) The potentials and E-field lines surrounding the plugs at the sample surface, given that the two floating plugs have a potential of 5 V.

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References

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* Corresponding author: j.jkeur@tudelft.nl