Monte Carlo simulation models for SEM imaging: fast versus accurate

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In semiconductor industry, the continuously decreasing feature sizes and increasing device complexity poses new challenges for scanning electron microscopy (SEM) based inspection and metrology. It becomes essential to operate with optimized system parameters to handle the narrowed-down error margins in cases where resolution enhancement is required, 3D information needs to be extracted or buried structures and defects are present. These parameters can be predicted by using simulations. However, to achieve the predictive power needed, such SEM simulators preferably contain the most accurate scattering models, which unfortunately makes them notoriously slow. Another approach is to use simulators with well-chosen approximate models, which are fast and still produce reasonably accurate results.

Recently a full Monte Carlo simulator was developed at Delft University of Technology[1], based on first principles containing the most accurate models. The inelastic scattering is based on dielectric function theory. The elastic scattering is based on the relativistic Mott cross-sections. The scattering of low energy electrons with acoustic phonons is included and also boundary-crossing of electrons is treated quantum mechanically. Furthermore, the simulator runs on a GPU which decreases simulation times dramatically. However, the semi-empirical Monte Carlo simulator based on Bethe's continuous slowing down approximation (CSDA), as described by Arat[2] et al., is still faster, by almost an order of magnitude (see Figure 1). In Figure 2 we show, for two primary electron energies, SEM images of a long Si line was simulated with the two simulation programs. At first sight they look quite similar but when comparing them quantitatively they are not the same. It is the goal of this work to use the accurate 1st-principles code to study how sensitive the simulated results are to the various ingredients of the accurate model. The final goal is to identify the most important ingredients of the model such that a simplified, approximate model is obtained that can be used in a fast semi-empirical simulator. To that end, we 'switch off' parts of the model, e.g. phonon scattering, or surface plasmons, etc., and study the effect on the intensity profile of the simulated Si line. We discovered that the profiles are influenced most by the inclusion of quantum mechanical transmission of electron through interfaces, compared to classical interface transmission (see Figure 3). More details will be discussed at the conference.

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[1] T. Verduin; et. al. "GPU accelerated Monte-Carlo simulation of SEM images for metrology", Proc. SPIE 9778, (April 21, 2016); doi:10.1117/12.2219160.

[2] K. T. Arat; et. al. "Electric fields in Scanning Electron Microscopy simulations", Proc. SPIE 9778, (April 21, 2016); doi:10.1117/12.2219182.

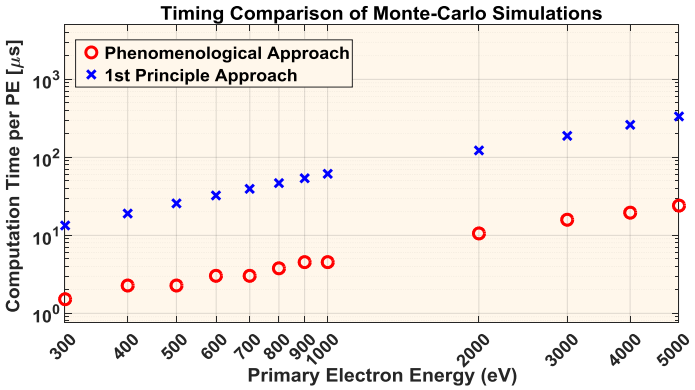

Figure 1- A computation time comparison shows that the semi-empirical approach running on Intel Xeon CPU E5-1620v3 is roughly 10 times faster than the first principle approach running on NVIDIA GTX 480.

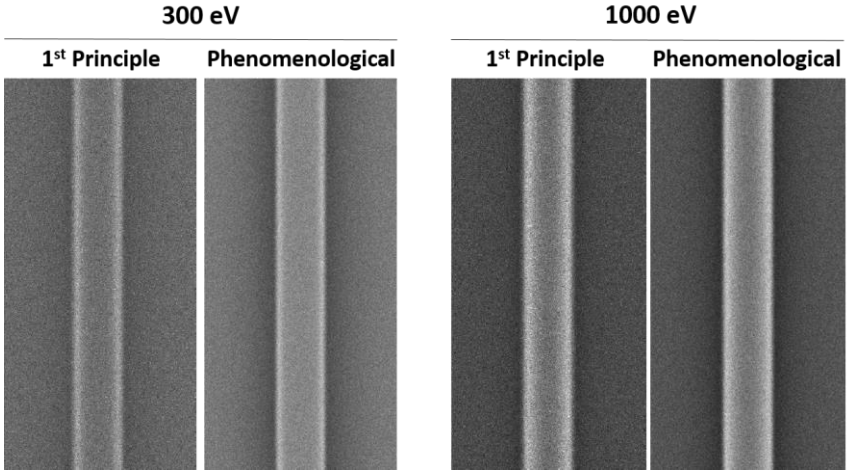

Figure 2 – Simulation, by two different approaches, of infinitely long Si lines (32 nm x 32 nm) on a Si wafer at 300 eV (left) and 1000 eV (right). The scan area is 64 nm x 256 nm and the pixel size is 0.5 nm x 0.5 nm. 100 electrons per pixel.

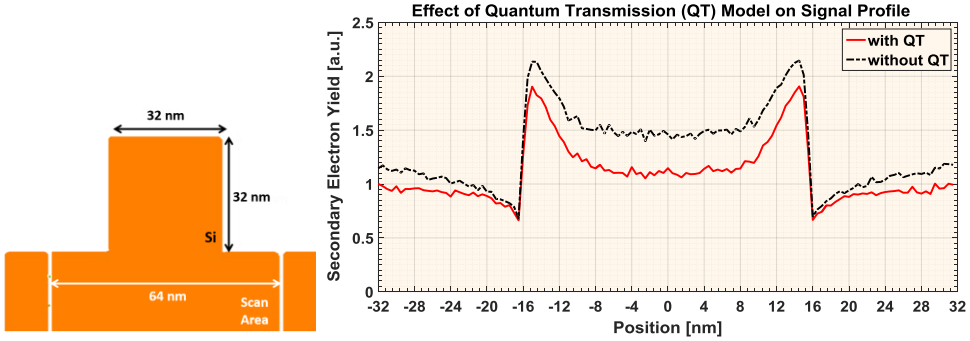

Figure 3 – Effect of including quantum mechanical transmission through a Si-vacuum interface. Left: the geometry, a 32 nm x 32 nm Si line on top of a Si wafer and 64 nm wide line-scan and 0.5 nm pixels; Right: result of a full 300 eV Monte Carlo simulation with (red solid line) and without (black dotted line) the quantum mechanical transmission (QT).