Computational Scanning Electron Microscopy

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For best results in nanometer-scale SEM imaging and measurements complete understanding and optimization of the signal and image formation are necessary. Finding the optimal the SEM parameters, i.e., electron beam landing energy, direction (incidence angle), scanning speed and pattern, signal detection, and the inherently weak signals arising from a few (dozens of) atoms that make up the 2D or 3D structures of interest, is experimentally at best laborious, and in many cases practically impossible due to the number of free parameters and missing pertinent data and information about SEM itself from instrument manufacturers. Computational scanning electron microscopy (CSEM), based on suitable models and simulations, is a powerful tool that can reveal the exact, atomic level details of signal generation, detection and image formation. It can generate images indistinguishable from actual SEM images and make atomic level accurate 3D SEM measurements possible.[1] CSEM is about to become indispensable for advanced SEM applications, including integrated circuit production and other fields of nanoscience and -technology.

Figure 1 shows the key parts of CSEM. For it to work efficiently, a priory knowledge of the electron beam and the SEM itself is useful, but CSEM simulations can use a suitable range of parameters to determine various optimal beam and SEM settings/parameters.

The physics model/computational engine can be about the generation of any SEM signal, secondary, backscattered, transmitted electrons, photons, x-ray, conductance, etc. Amorphous, crystalline, electrically conducting or insulating samples can be used if this part is set up for it. Currently, there is no comprehensive, all-encompassing solution yet, only partial solutions exist, e.g., for electron or x-ray generation, which are already extremely useful. Figure 2 shows Monte Carlo simulated CSEM images of a nanoparticle with varying landing energies and signals. For shape measurements, very low landing energy and the use of SE signal are the best choices, and for high-throughput particle size measurements simultaneous acquisition of SE, BSE and TE images with baseline thresholding gives the best results.

For nm-scale measurements CSEM offers the best solution for optimizing the measurements' speed and accuracy. New methods are being implemented to make CSEM orders of magnitudes faster than what was possible in the past. In this work, some use cases are presented and the outlook of CSEM development is discussed.

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[1] A. E. Vladar, et al., 10 nm 3D CD-SEM Metrology, https://doi.org/10.1117/12.2045977 (2014)

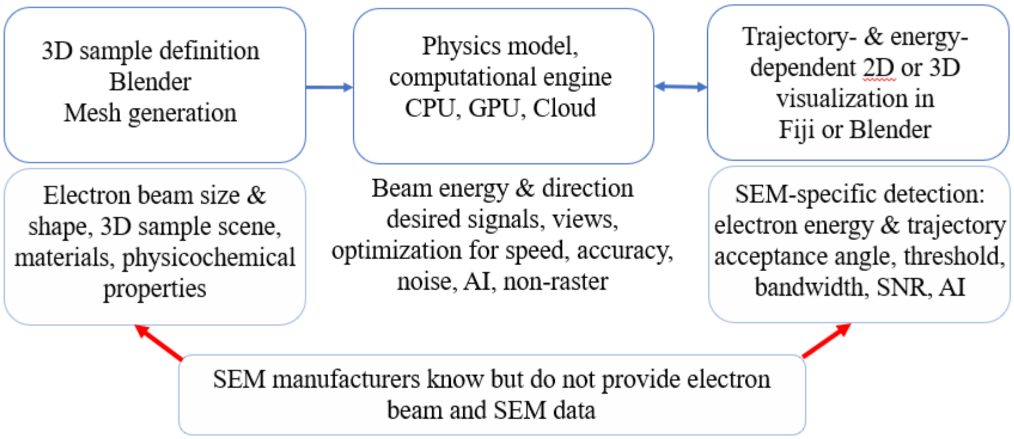

Figure 1: Block diagram of CSEM. The key pars are sample definition, the physics model/computational engine and selection of signals and visualization. Depending on the central part, the speed of generating images and their accuracy vary. Any of the SEM signals and the information they carry can be determined.

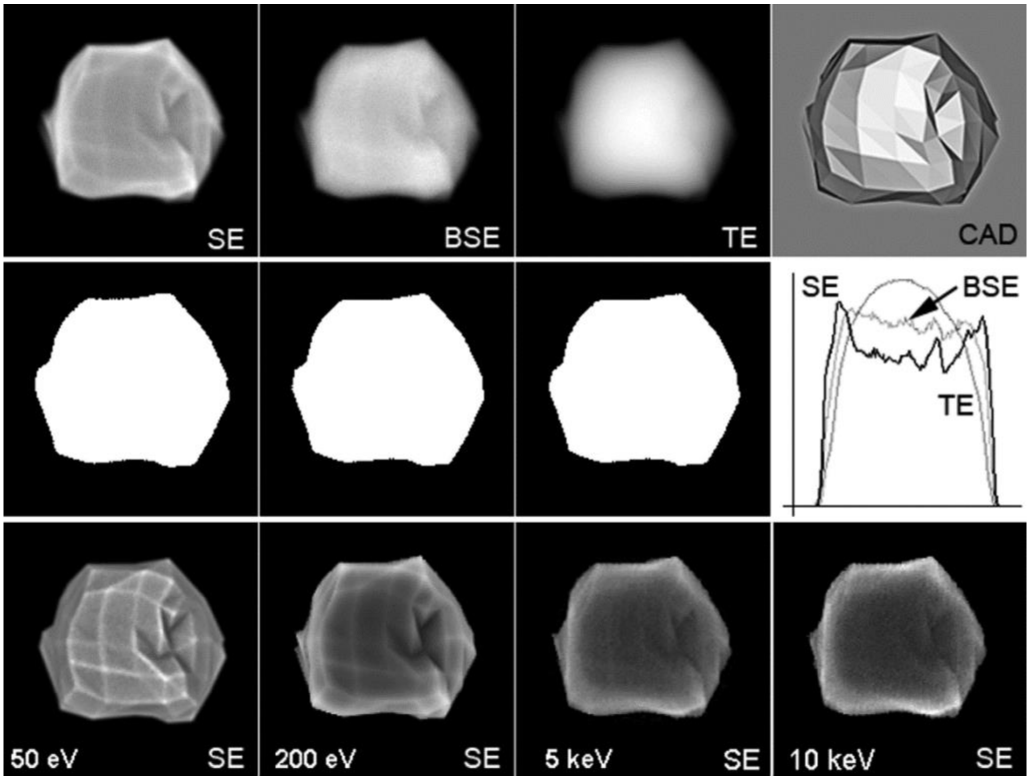

Figure 2: CSEM images of a 60 nm size gold nanoparticle. These images were generated by Monte Carlo simulation for various landing energies and secondary (SE), backscattered (BSE) and transmitted (TE) electron signals. The upper set is with 1 keV landing energy, the center set is these versions thresholded at their baselines, where the particle sizes are matching, and the lower set shows how the surface details differ with varying landing energy.