Due to the practical application of hardware aberration correctors, the instrumental resolution of transmission electron microscopes has been remarkably improved. In order to achieve the highest resolution in aberration-corrected (AC) high-resolution transmission electron microscopy (HRTEM) images, high electron doses are required. In the case of high accelerating voltages, materials can be damaged predominantly via the knock-on damage mechanism, where atoms are displaced by direct impacts of the energetic incident electrons. However, when reducing the accelerating voltage, ionization can become the dominating damage mechanism, as the inelastic scattering cross section increases [1]. Effective ways of reducing ionization damage may be cooling of the specimen [2], or conductive coating [3]. However, such approaches are not always feasible. In both, high and low accelerating voltages, images need to be acquired with limited electron doses.

In this work we have performed dose-dependent AC-HRTEM image calculations (Fig. 1), and the dose related noise is treated as stochastic fluctuations around the ideal electron counts on each image pixel, instead of the additive noise. We have studied the dependence of the signal-to-noise ratio (SNR), atom contrast and resolution on electron dose and sampling. Graphene is used as the example material due to the simplicity of its structure, as it is the thinnest and lowest Z-number crystalline material, which allows most straightforward interpretation of the results. We have introduced a dose-dependent contrast definition, which can be used to evaluate the visibility of objects under different dose conditions. Based on our calculations, we have determined optimum samplings for high and for low electron dose imaging conditions.

Our calculation shows: SNR, atom contrast and resolution, all improve with increasing electron dose, converging towards their values obtained at infinite dose. As the sampling increases, the SNR increases and the resolution decreases; the atom contrast improves as long as the damping of MTF is negligible. We have determined optimum sampling under high-dose and low-dose conditions. Under high-dose conditions, the optimum sampling depends mainly on the required specimen resolution; under low-dose conditions, the best sampling is determined by our criteria that the required specimen resolution should be achieved with the minimal electron dose.


Acknowledgement: This work was supported by the DFG (German Research Foundation) and the Ministry of Science, Research and the Arts (MWK) of Baden-Württemberg in the frame of the (Sub-Angstrom Low-Voltage Electron microscopy) (SALVE) project.
Fig. 1: Calculated HRTEM images of graphene for different doses and samplings with a usable aperture of 50 mrad under 80 kV. The last row shows the CTF (purple) for different samplings. The PCTF function (blue), focus spread envelope (red) and image spread envelope (yellow) are the same for each column. Reproduced from the reference [4].