Quantitative Investigations of the Depth of Field in a Corrected High Resolution Transmission Electron Microscope

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Aberration correction in modern TEMs moves the interpretable resolution level to the ultimate information limit of the microscope in the sub-Ångström region. It was expected for HRTEM lattice imaging that the use of “Scherzer focus” settings will lead once again to directly interpretable images. Reduced aberrations directly result in larger opening apertures and thus in smaller depth of field. It is extremely difficult to determine experimentally the correct focus; even the smallest default focus step in a TEM may be too coarse. The acquisition of focus series followed by exit-wave restoration have been recommended for choosing the focus and, in this way, helping to find the perfect imaging condition by defocus post-propagation via the reconstruction software.

Here, we present investigations of the depth of field of aberration corrected TEM at different high tension settings (FEI Titan 300kV and 80kV) by analysing focus series of images of ultra small (~2nm) Si particles within a SiO_2 matrix (details about the preparation of the particles see [1]). Fig.1. depicts the drastic influence of different defocus values. A small focus change (Δf) of only 8nm leads to an almost completely disappearance of the contrast of the Si nanoparticle marked as NC#1 in Fig.1. However, the Si nanoparticles marked NC#2 is clearly in focus (Fig.1b). The experiments are accompanied by calculations using molecular dynamics for model preparation and multi-slice algorithm for image simulation. This systematic study includes the investigation of the influence of high tension, coherence (beam convergence), and signal-to-noise ratio (electron dose) on the contrast and the depth of focus. Fig.2 shows calculated HRTEM images (HT=300kV, C_S=-5µm). The model contains 2.5nm sized Si nanocrystals of different orientations in different depth positions within the matrix of amorphous SiO_2. Small focus changes of few nm already lead to an appearance or disappearance of the contrast of nanocrystals, respectively. The image calculations show that Scherzer focus conditions result only in a focussed image of the sample surface and are not useful if ultra small structures within amorphous volumes have to be imaged. We revealed by experiments and simulations that aberration correction allows z-resolution of less then 1nm. Increasing the semi-opening angle (reducing aberrations) while lowering HT (e.g. 20mrad at 300kV, 42mrad at 80kV for 1Å resolution) enhances the z-resolution even more and allows to obtain atomic 3D information about the sample. We will present first results on atomic depth sectioning as additional approach to TEM-tomography.

1. A. Romanyuk, Oelhafen, V. Melnik, Y. Olikh, J. Biskupk, U. Kaiser, M. Feneberg, K. Thonke, App. Phys. Lett. submitted
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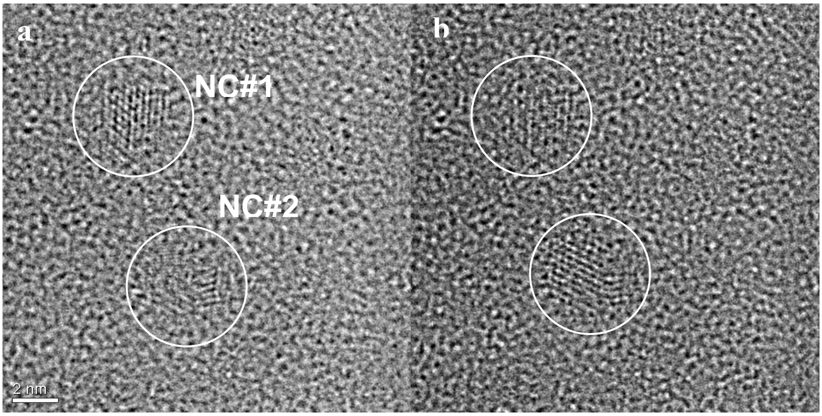

Figure 1. Exit-wave reconstruction of experimental HRTEM images (300kV) of Si nanocrystals in SiO_2. (a) and (b) differ by a focus change of 8.0 nm. (a) NC#1 is in focus, (b) NC#2 is in focus

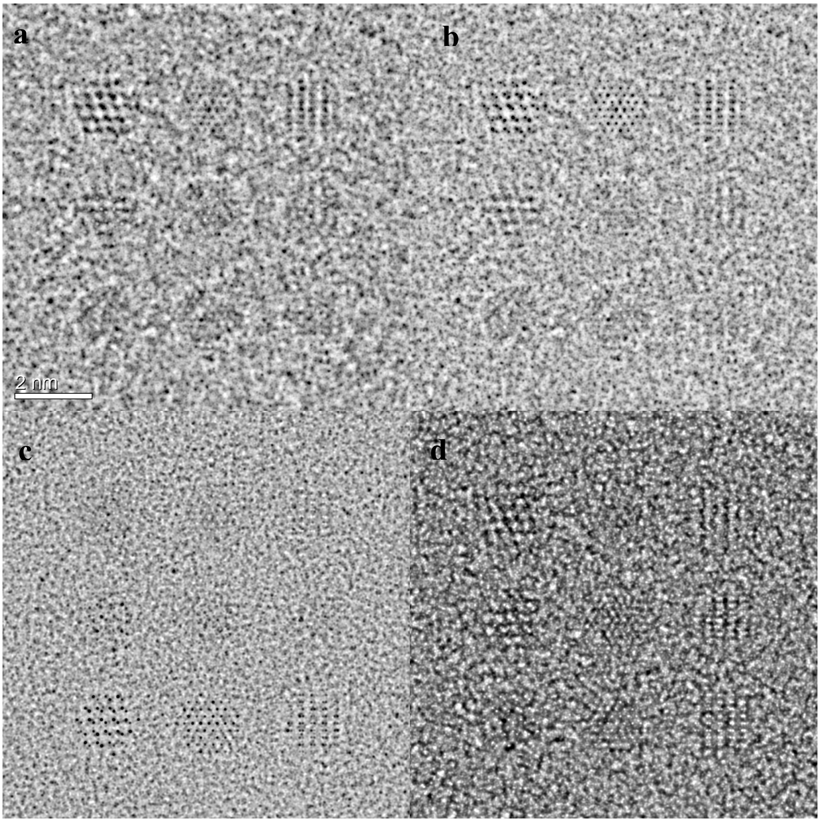

Figure 2. Calculated focus series (300kV, C_S=-5μm) of Si nanocrystals (2.5nm size, [110], [111], [112] orientations) at different sample depths (depths of 2.8nm, 5.6nm, 8.4nm) within SiO_2 (11nm thick). (a) defocus Δf =-15.0nm, (b) Δf =-13nm (c) Δf =-4.0nm, (d) Δf = +2.0nm.