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Experimental Contrast of Atomically-resolved Cc/Cs-corrected 20-80kV *SALVE* Images of 2D-objects Matches Calculations

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Spherical aberration correction has become inevitable for atomic resolution imaging in transmission electron microscopy of conventional objects at medium accelerating voltages (100-300kV). However, there are classes of materials such as low-Z-number and/or low-dimensional materials that require lower accelerating voltages as their knock-on damage threshold is below 80kV. Unfortunately, the resolution of spherical aberration-corrected TEM at an accelerating voltage less than 80 kV with a conventional electron source is strongly limited by the chromatic aberration of the objective lens. There are two approaches to achieve atomic resolution at lower voltages: either develop a monochromated electron source with an particularly small energy width but reduced beam current [1, 2], or develop an aberration corrector that corrects for both, the spherical and the chromatic aberration of the objective lens [3, 4] which then can be used together with a standard field-emission gun. Here we report on a fruitful approach that combines the Cc/Cs-corrected 20-80kV SALVE technology with experiments on two-dimensional objects aimed to compare experimental and calculated image contrast.

Obviously, calculation routines for Cc/Cs-corrected HRTEM images cannot use standard routines which employ dampening due to the chromatic aberration. Instead, there is a need to account for a new source of contrast transfer dampening, so-called image spread due to thermal magnetic field noise (Johnson noise [5]). In our calculations we employ a new calculation algorithm involving the image spread envelope as well as the residual focus spread envelope [6, 7]. The calculations are performed in dependence of the dose [7]. Figure 1 and 2 show experimental HRTEM images of single-layer graphene resp. single-layer MoS_2 at 30kV. Corresponding to an information limit of 107 pm resp. 102 pm, a usable aperture of about 65mrad is achieved. The images were recorded with an electron dose of 5×10^6 e^-/nm^2 (graphene) and 3.1×10^5 e^-/nm^2 (MoS_2). In order to improve the signal-to-noise ratio of the experimental images, a self-averaging algorithm was applied where the hexagonal lattice is shifted in different directions to match the neighbour atoms. Thus an average of all the shifted images is obtained. This method is an indirect equivalent to increasing the electron dose. As can be seen from the comparison of the line profiles through the calculated and experimental images a good match has been obtained. This may allow in future suggesting the nature of single adatoms. [8]

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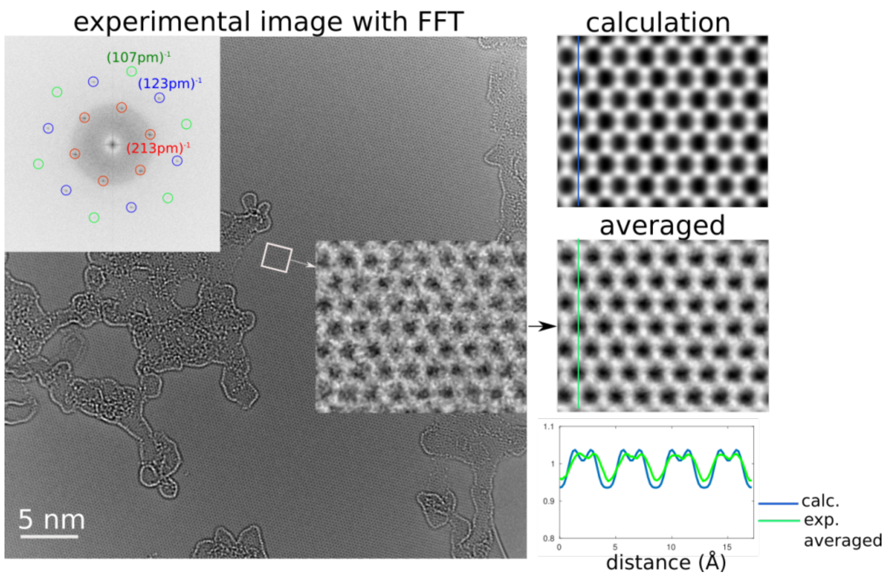

Figure 1. (Left): Experimental 30 kV C_C/C_S-corrected HRTEM raw image of graphene with inserts: top left: diffractogram of the whole area, middle right: a magnified image of the white rectangle showing bright atom contrast. (Right column): Comparison between calculated (top) and averaged experimental (middle) images. The corresponding lines are shown as profiles below.

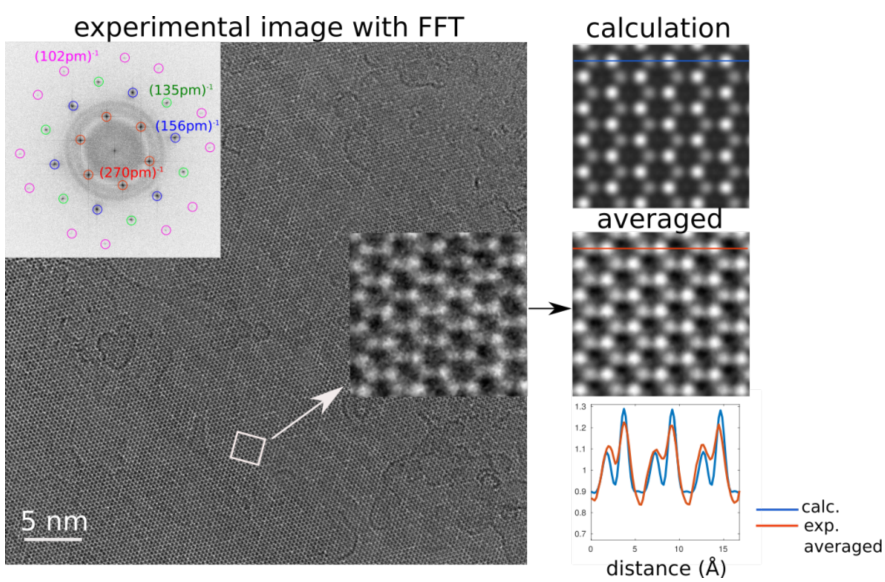

Figure 2. (Left): Experimental 30 kV C_C/C_S-corrected HRTEM raw image of MoS_2 with inserts: top left: diffractogram of the whole area, middle right: a magnified image of the white rectangle showing bright atom contrast. (Right column): Comparison between calculated (top) and averaged experimental (middle) images with the corresponding lines which are shown in the profiles below. Note that the difference in contrast between Mo and 2xS can be clearly seen.

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