Sub-Ångstrøm Low-Voltage Electron Microscopy – future reality for deciphering the structure of beam-sensitive nanoobjects?

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Keywords: HRTEM, aberration correction, low voltage

In recent years, the scientific discoveries and technological developments of greatest economic impact have largely been those situated at the interface between the classical disciplines of physics, chemistry, biology and engineering. In this overlap region, nanoscale objects constitute the primary focus of numerous interdisciplinary research efforts. Of course, the various functions of nano-objects can be understood completely only by investigating them at the atomic level.

Nowadays new developments in aberration-corrected transmission electron microscopy (TEM) allow for direct imaging at the atomic scale (see the difference between Fig. 1a and b). When operating at a voltage of 300 kV, the resolution goes down to 80pm (for the case that the spherical aberration of the objective is corrected [1,2]) or even 50pm (design goal for the case that the spherical and chromatic aberration are corrected [3,4]). In the ideal case of an infinitely radiation-resistant specimen, the resolution of the image is solely determined by the instrumental resolution and therefore the increase of accelerating voltage will give highest resolution provided that one can tolerate the loss in contrast.

However, real samples are always damaged by the electron beam and thus by the tolerable duration for observing the sample (that is the tolerable electron dose *D* exposed on the sample). Maximum *D* depends on physical processes occurring due to interaction of electrons with the sample, where the contribution of the processes depends on the energy of the electron beam used for observation and on the materials characteristic (compare Fig. 1c and d). At lower accelerating voltage, atom displacement processes (knock-on damage) and surface etching are strongly reduced, however, other processes as heating (compare Fig. 1e and f) and ionisation are increased. The achievable specimen resolution becomes a function of the instrumental resolution limit d_i, the tolerable dose *D*, the contrast C and the signal to noise ratio S/N [4].

Highest phase contrast and maximum *S/N* at the Gaussian image plane can be achieved for weak phase objects by eliminating the axial aberrations (correcting for spherical and chromatic aberration) and shifting the phase of the non-scattered wave by $\pi/2$ (inserting a phase plate at the diffraction plane or at an image of this plane [5]) and by lowering the accelerating voltage of the electrons.

M. Luysberg, K. Tillmann, T. Weirich (Eds.): EMC 2008, Vol. 1: Instrumentation and Methods, pp. 35–36, DOI: 10.1007/978-3-540-85156-1_18,

These theoretical findings will be explained in detail by calculations and experiments. The experimental results will include phase contrast imaging of classical semiconductors, nanocarbons, polymers and organic crystals at 300kV and 80kV accelerating voltage using TITAN 80-300 instrument equipped with a corrector for the spherical aberration of the objective. We conclude that reducing the acceleration voltage much lower than 80kV may allow atomic resolution for a variety of beam sensitive materials in future if new components such as a dedicated C_C/C_S corrector and a phase plate can be implemented into a highly mechanical and electrical stable microscope platform.

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7. We acknowledge Dr. S. Roth, D. Obergfell, A. N. Khlobystov, M. Haluska, S. Yang for sample preparation.

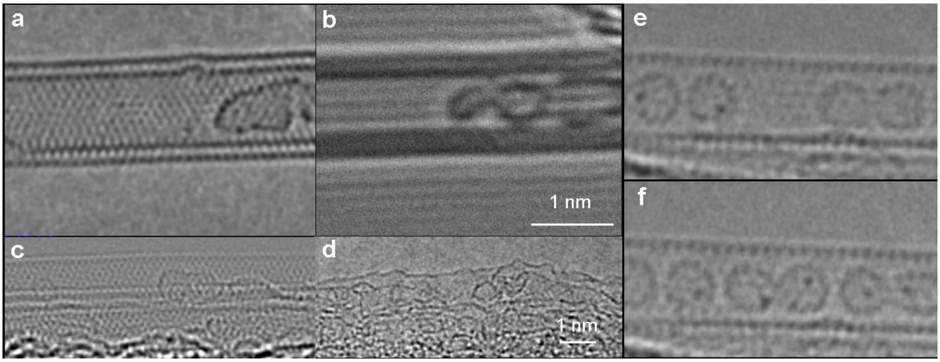

Figure 1. (a,b) show the effect of the C_S corrector on the example of a DWCNT at 80kV operating voltage (a) with C_S corrector (b) C_S corrector turned off, (c,d) show the effect of acceleration voltage on the example of a single wall CNT (c) at 80kV after 20min of observation (d) at 300kV totally damaged after 10sec. (e,f) show the effect of heating to molecules on the example of $(Dy@C_{82})@$ SWCNT, see the movement of the peapods and starting coalescence within 20 seconds of observation.