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In-situ Aberration-corrected HRTEM Studies of the Dynamics of Me@SWNT as a Function of Electron Dose and Low Electron Beam Energies between 20 and 80 keV

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Single-walled carbon nanotubes (SWNTs) recently attract great attention for their aptitude as nano-test tubes and have proven to be ideal containers for atomically resolved imaging of interactions and dynamics of sub-nanometer sized molecules. In our experiments SWNTs do not only offer a necessary confinement and protection against undesired beam damage effects as a result of ionization or chemical etching: SWNT for instance provide a unique environment for the investigation of carbon-based reactions on the atomic scale.[1] Furthermore SWNT represent a precious test-system for a detailed study of interaction mechanisms between the specimen and the energetic electron-beam by nature omnipresent in transmission electron microscopy (TEM) observations. In this work we study sub-nanometer sized d-element metal-nanoclusters (W, Re, Os, Ru, Fe) enclosed in SWNTs by means of low voltage aberration-corrected high-resolution transmission electron microscopy (AC-HRTEM).[2,3] This particular technique combines imaging tool and irradiation source in one integral experiment while further benefiting from the SWNTs low and regular contrast combined with minimized susceptibility to head-on collisions of the electrons with the carbon atoms nuclei (knock-on damage) while operating with electron energies less or equal 80 keV.[4] In our experiments we pursue the methodology of varying both, the metal type and the electron acceleration voltage (between 20 kV, 40 kV and 80 kV). Thus we are able to separate the influence of the electron beam from that of the specimen which is a necessary condition for the detailed and atomically resolved study of sample or irradiation induced structural SWNT-modifications. Finally it is our aim to explicitly describe the interaction mechanisms e.g. those of different "beam-damage" processes. While irradiating, in order to answer the demand of comparability, time series of interactions are recorded until reaching the same total electron dose of 1010 e-/nm2. Experiments are conducted using a Cs-corrected FEI Titan 80-300 operated at 80 kV and a monochromated/Cs-corrected SALVE (Sub-Ångstrøm Low-Voltage Electron Microscopy) Zeiss LIBRA prototype microscope operated at 20, 40 and 80 kV. [1] T. Zoberbier, T. W. Chamberlain, J. Biskupek, N. Kuganathan, S. Eyhusen, E. Bichoutskaia, U. Kaiser, A. N. Khlobystov, J. Am. Chem. Soc. (2012) [2] A. Chuvilin, A.N. Khlobystov, D. Obergfell, M. Haluska, S. Yang, S. Roth, U. Kaiser, Angew. Chem. Int. (2010) [3] U. Kaiser, J. Biskupek, J. C. Meyer, J. Leschner, L. Lechner, H. H. Rose, M. Stöger-Pollach, A. N. Khlobystov, P. Hartel, H. Müller, M. Haider, S. Eyhusen, G. Benner, UM (2011) [4] J. C. Meyer, F. Eder, S. Kurasch, J. Kotakoski, H. J. Park, S. Roth, A. Chuvilin, S. Eyhusen, G. Benner, A. V. Krasheninnikov, Ute Kaiser, Phys. Rev. Lett. (2012)