3D in SEM, (S)TEM, Ion Imaging, incl. FIB-SEM and SBF-SEM

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SEM tomography of nanostructures by scanning-transmission imaging

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This paper highlights the implementation of electron tomography in the SEM and discusses the potential of this 3-D imaging technique. Electron tomography is one of the most promising and rapidly developing techniques for 3-D reconstruction at the nanoscale as it combines a reliable reconstruction algorithm with the signal corresponding to incoherently scattered electrons in the Scanning-Transmission (STEM) imaging mode 00. The STEM-in-SEM imaging has been successfully implemented in the SEM, where it takes advantage from some peculiar characteristics of the experimental set-up 0. The STEM approach attains nanometric resolution and is free from aberrations caused by post-specimen imaging lenses; in addition it is possible to collect transmitted electrons over a wide angular range 00. The optimization of detector design and performance, together with the formulation of a tailored detection strategy, make the contrast comply with local variations of composition or projected thickness. The bright-field component of the transmitted electrons can be effectively separated from the dark-field one, by varying the specimen-detector distance and the collection conditions of the detector [4]. The capability of the STEM-in-SEM imaging mode to preserve the monotonic variation of the signal with specimen thickness meets the basic projection requirement for reconstruction, and thus opens up the perspective for the 3-D analysis of volumes in approximately the 100 μm^3 range, such as nanowires, carbon based nanostructures or biological specimens. In addition, the large value for the maximum detection angle ensures a complete detection of the scattered electrons, even in case of relatively large specimen thickness. In the case of tomography, these features are essential to maintain the proper image contrast when the specimen is rotated through the tilt series. To demonstrate the technique, different systems were investigated: Fig. 1 shows the perspective view of the reconstructed volume of a ZnO crystalline nanostructure This comb-like structure exhibits a number of parallel nanowires with uniform section (average width 176 ± 15 nm) and tapered termination. The tilt series of STEM images was obtained by rotating the sample over a 110° range, with 1° step. ImageJ [0] with the TomoJ plug-in allowed obtaining the tomographic reconstruction 0. The main features of the samples are properly retrieved such as the disposition of the wires, their uniform section and the tapered termination. Similarly, carbon based tubes, filled with cobalt nanoclusters, were reconstructed and imaged in Fig. 2. The tomogram from the tilt series of STEM images, that feature compositional contrast, clearly shows the heavier cobalt clusters inside the tube. These results demonstrate the potential of the method and optimization of the experimental set-up is under development to consolidate this technique in the set of 3-D methods of electron microscopy.

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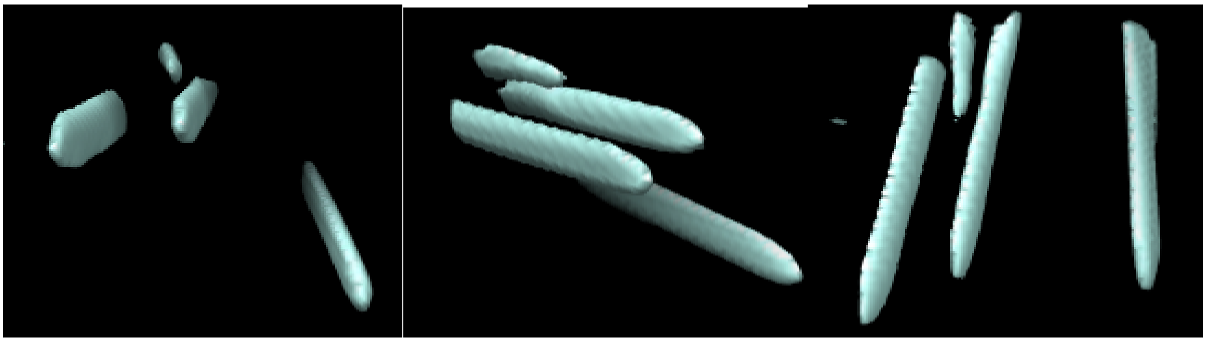

Figure 1. Volume renderings of ZnO nanowires. The disposition of the wires, their uniform section and the tapered termination are properly retrieved by the tomographic reconstruction based on a STEM-in-SEM tilt series of 110 images at 1° tilt. The reconstructed area of interest measures 4.5×4.5 μm, corresponding to a primary magnification of 50.000×.

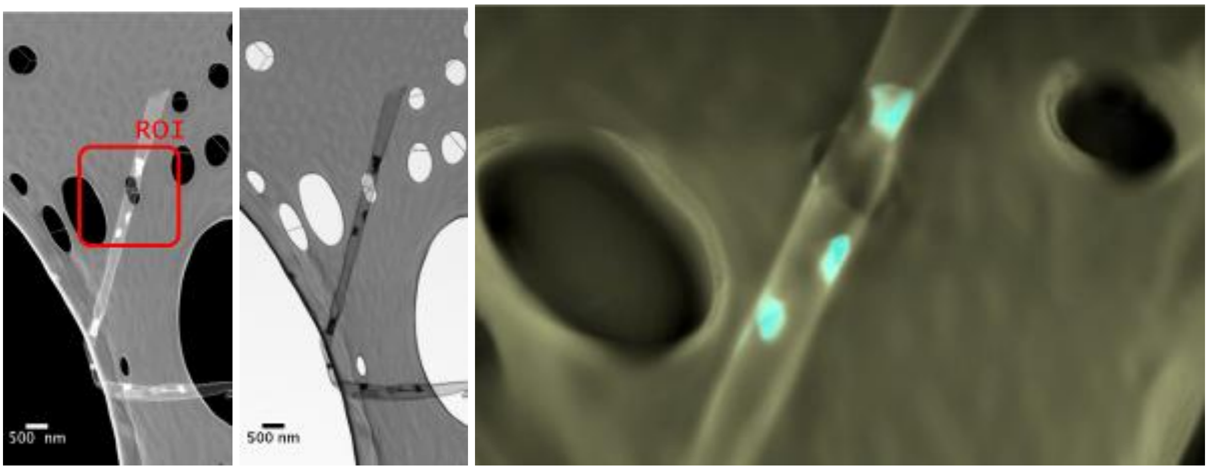

Figure 2. (Left and Center) STEM Bright- and Dark- field compositional images of carbon tubes filled with Co nanoclusters - Beam 30 keV – (Right) Tomogram from the Bright-Field tilt-series showing the cobalt clusters inside the carbon tubes.