Depth sectioning by 4D-scanning confocal electron microscopy technique

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Recently, the acquisition of a 4D dataset composed of 2D convergent beam electron diffraction (CBED) patterns at every points of 2D raster in scanning transmission electron microscopy (STEM) with pixelated array detectors or high speed cameras has been practically used. By computationally analyzing the intensity distribution of the CBED patterns, followed by construction of scanning images, various kinds of STEM images such as bright field (BF), high angle annular dark field (HAADF) and differential phase contrast (DPC) images could be obtained simultaneously from one dataset [1]. This technique is called 4D-STEM.

In the present work, we apply this 4D-detaset acquisition technique in an optics of scanning confocal electron microscopy (SCEM), in where scattered electrons from the in-focus position of an incident probe is refocused on a center of the probe image, and those from out-of-focus positions are displaced from the center of that [2,3]. Since this displacement corresponds to the depth position of the origin of the scattered electrons, a series of depth-sections at different depth positions could be yielded from one dataset.

Figure 1 shows a schematic diagram of 4D-SCEM in an ADF mode [4-6]. An ADF aperture was fabricated with a focused ion beam machine and inserted into the objective aperture position of JEOL aberration corrected transmission electron microscope, JEM-ARM200F.
An incident beam was focused on a specimen with the convergence semi-angle of 14.8 mrad. The ADF aperture cut off a direct beam and only scattered beams were refocused on a Gatan ORIUS200D CCD camera with a magnification of 400,000. The inner and outer semi-angles of the ADF aperture were 26.0 and 34.8 mrad, respectively.

Figure 2 shows probe images on the CCD camera experimentally obtained and computationally calculated, respectively. ADF-SCEM images at different depths were produced by summing up signal intensity through concentric filters with different radius [7].

Figure 3a) is a conventional ADF-STEM image of polymerized carbon with cobalt nanoparticles on a carbon film. Figs. 3b)-3f) are the result of 4D-SCEM depth sectioning for the area in a red rectangle of Fig. 3a), produced using the beam intensity at 0-0.57nm, 0.57-1.33nm, 1.33-2.09nm, 2.09-2.85nm and 2.85-3.61nm, respectively, from the center of the beam image. Depth values denoted in the figures were calculated using an inner radius from the beam center. It should be noted that different cobalt particles appear at the different depth sections, while all cobalt particles show bright contract in ADF-STEM image. Hence, it was demonstrated that 4D-SCEM is capable of producing depth sections from one dataset.

References
[1] H. Yang et al., J. Phys.: Conf. Ser. 644, 012032 (2015).
[2] M. Takeguchi et al., J. Electron Microsc. 57 123 (2008).
[3] N. J. Zaluzec, Microscopy-Today 6, 8, (2003).
[4] A. Hashimoto et al., J. Appl. Phys. 106,086101 (2009).
[5] A. Hashimoto et al., Microsc. Microanal. 16, 233 (2010).
[6] X. Zhang et al., J. Electron Microsc. 61, 159-169 (2012).
[7] T. Hamaoka et al., submitted.

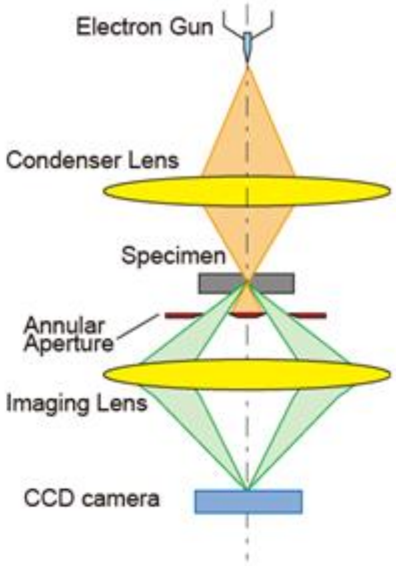

Fig.1 Schematic diagram for 4D-SCEM in an ADF mode.

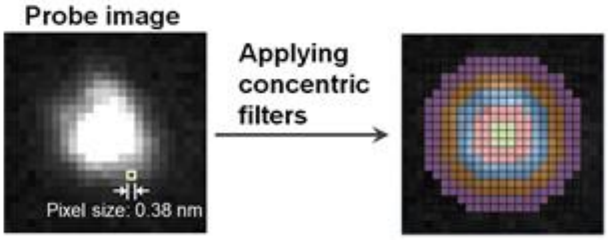

Fig.2 Experimental and simulated probe images in ADF-SCEM.

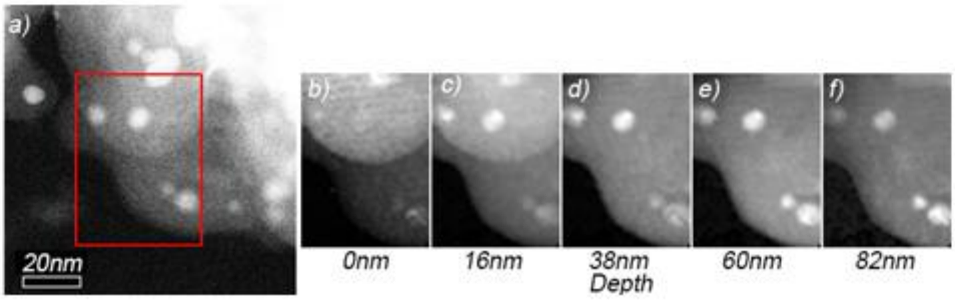

Fig.3 a) ADF-STEM image, and b)-f) a series of depth sections of polymerized carbon with cobalt nanoparticles on a carbon film produced by a 4D-SCEM. Depth values in the figures were calculated using an inner radius from the center of the beam.