Atomic resolution STEM imaging in magnetic field free condition

Kohno, Y.[1], Morishita, S.[1] and Shibata, N.[2]

[1] JEOL Ltd., Japan, [2] Institute of Engineering Innovation, The University of Tokyo, Japan

It is difficult to realize high resolution imaging of scanning transmission electron microscopy (STEM) with preserving magnetic structures of a specimen using an ordinary magnetic objective lens because the specimen is placed in a strong magnetic field of about a few T. However, observation of atomic resolution in magnetic field free (MFF) condition is requested for the study of magnetic materials and devices. Thus, we have been developing a new MFF objective lens to image atomic structure and the magnetic field structure simultaneously. This objective lens has short focal length and small chromatic aberration coefficient, and the magnetic field strength around the specimen is less than 0.3mT [1]. Figure 1 shows a schematic of the objective lens, which is composed of two round lenses. The magnetic pole and coil are placed symmetrically with respect to the specimen plane, but the polarities of the coil excitation currents are anti-symmetric to cancel out z component of the magnetic field to be zero at the specimen position. The radial field component of a round lens is small around the optic axis. These symmetries realize the short focal length and small chromatic aberration in MFF condition.

The atomic resolution STEM imaging in MFF condition was realized by a microscope equipped with this symmetric objective lens, the cold field emission gun and delta type aberration corrector [2] that can compensate geometrical aberrations up to 5th order. Figure 2 shows experimental results taken at 180kV. The aberration corrected area indicated with the red circle was expanded to 26mrad in the Ronchigram shown in Fig. 2 (a). The 136pm dumbbell spacing of Si[110] was clearly resolved in real space in HAADF STEM image shown in Fig. 2 (b). And the spot corresponding 105pm is visible in the power spectrum shown in Fig. 2 (c). We expect to be able to image atomic-scale structure and magnetic field distribution simultaneously by this developed microscope equipped with segmented detector or pixelated detector system.

[1] Y. Kohno, et al, Micro. Microanal. 23(S1), 456(2017)
[2] H. Sawada, et al, J. Electron Microsc., 58, 341(2009)

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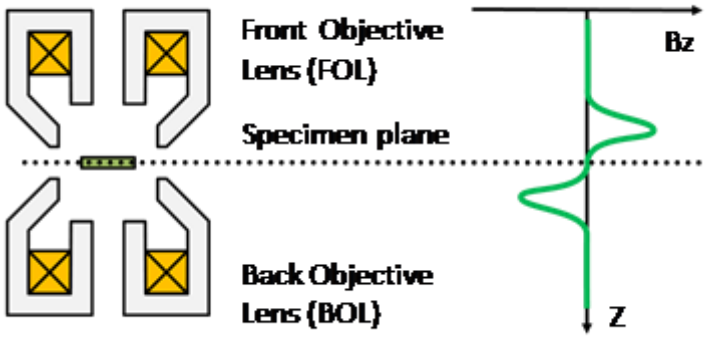

Figure 1. The schematic and Z-field distributions of the new objective lens

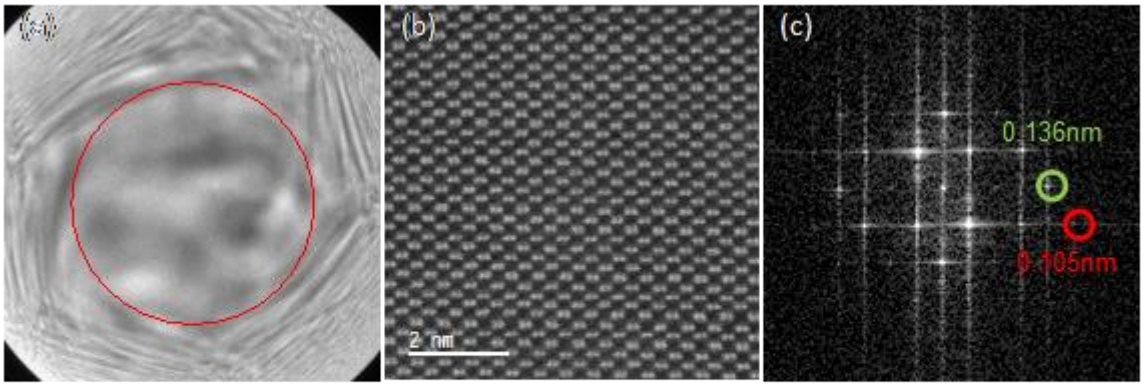

Figure 2. Results by magnetic field free aberration corrected STEM, obtained at 180 kV. (a) Rochigram using carbon film sample, (b) HAADF STEM image of Si[110], (c) Power spectrum of (b).