AMTC Letters
Vol. 1 (2008)

STEM ADF imaging with high-accuracy for structure analysis

Koji KIMOTO[1], Kazuo ISHIZUKA[1], Yoshio MATSUI[2]

[1]National Institute for Materials Science, 1-1 Namiki, Tsukukba, Ibaraki 305-0044, Japan
[2]HREM Research, Inc., Matsukazedai, Saitama 355-0055, Japan

Scanning transmission electron microscopy (STEM) and annular dark-field (ADF) imaging [1-3], become key techniques for high spatial resolution characterization. For practical application, not only a spatial resolution, but also other properties such as a signal to noise (SN) ratio are important. For example, a high SN ratio of ADF images is required to identify each atomic site of the crystalline specimen. In addition, the distortion in STEM images due to specimen drift should be minimized to analyze the local atomic structure. The advanced STEM imaging for materials science needs to be the high-accuracy or high-detectability imaging.

We have achieved inherent energy-resolution of a cold field-emission gun [4-6] or a monochromator [7] by using high-speed acquisition and drift correction techniques for EELS. Here, we have applied the same strategies to STEM imaging obtained by using a dedicated scanning transmission electron microscope (Hitachi High-Technologies co., HD-2300C) [8-10] equipped with DigiScan (Gatan Inc.), and STEM images are acquired using DigitalMicrograph scripts prepared by the authors.

We acquired a lot of ADF images with a short exposure time, and then we measured and corrected the relative shifts in the ADF images (Fig. 1). Figures 2a and 2b show an example of an ADF image (portion) and a summed ADF image after the drift-correction, respectively. Note that the distortion-free and noise-free results are obtained. It should be emphasized that Fourier filtering to improve the SN ratio of ADF images often introduces the filtered image the delocalization, which degrades one of the most important advantages in incoherent imaging. The appropriate deconvolution technique, such as maximum-entropy method, is effective to enhance the spatial resolution of ADF images [11].

Figure 3 shows other application of this technique to a perovskite oxide $La_{2-2x}Sr_{1+2x}Mn_2O_7$. We acquired bright-field (BF) and ADF images quasi-simultaneously, *i.e.*, alternate acquisitions of BF and ADF images were performed. Figures 3a and 3b show the raw data of STEM images, and the summed STEM images, respectively. After the drift-correction we can recognize the position of Mn. In addition to the improvement of the noise and the distortion of STEM images, this technique reduces the tip noise of field-emission electron source and other cyclic noise owing to the mains frequency *et al*. It is also important to mention that a lower dose-rate avoids the specimen heating and related specimen damages.

A spherical aberration corrector for probe forming lens allows us a high probe current and high spatial resolution, but some of STEM images observed using the aberration corrector still suffer the image distortion due to specimen drift. Therefore, this technique is still effective to achieve the inherent performance of the state-of-the-art equipments.

[1] A.V. Crewe, et al., *Science* **168** (1970) 1338.
[2] S. J. Pennycook and D. E. Jesson, Ultramicrosc. **37** (1991) 14.
[3] S. J. Pennycook & P.D. Nellist, in Impact of Electron and Scanning Probe Microscopy on Materials Science, pp. 161-207 (Kluwer Academic Publishers, London, 1999).
[4] K. Kimoto and Y. Matsui, *J. Microsc.* **208** (2002) 224.
[5] K. Kimoto, K. Ishizuka, T. Mizoguchi, I. Tanaka and Y. Matsui, *J. Electron Microsc.* **52** (2003) 299.
[6] K. Kimoto, K. Ishizuka, T. Asaka, T. Nagai, and Y. Matsui, *Micron* **36** (2005) 465.
[7] K. Kimoto, G. Kothleitner, W. Grogger, Y. Matsui and F. Hofer, *Micron* **36** (2005) 185.
[8] K. Kimoto, et al., *J. Electron Microsc.* **56** (2007) 17.

[9] K. Kimoto, et al., Nature **450** (2007) 702.
[10] K. Kimoto, et al., Micron **39** (2008) 257.
[11] K. Ishizuka and E. Abe, Proc. of EMC 2004.
[12] We thank Dr. Suenaga, Prof. Kurata, Prof. Terauchi for invaluable discussions. We also thank Drs. Rinaldi, Barfels, Kundmann, Menon, Wilbrink and Hunt of Gatan for their cooperation about DigiScan and DigitalMicrograph scripting, and Mr. Nakamura and Mr. Isakozawa for their cooperation to develop the STEM. This work is supported in part by the Nanotechnology Network Japan, JST-CREST, the NEDO/MIRAI project and the Grant-in-Aid for Scientific Research (C), 18560027.

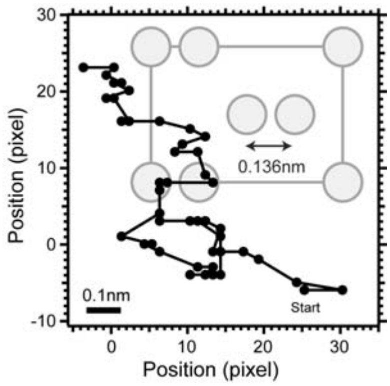

Fig. 1. An example of specimen drift during the acquisition of 50 ADF images.

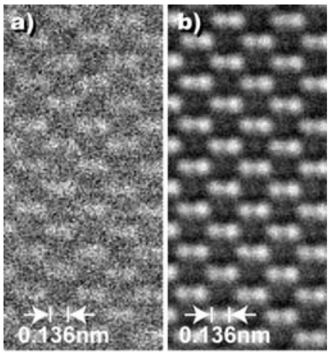

Fig. 2. ADF STEM images of Si (110) using conventional STEM (HD-2300C). (a) one ADF image with an short exposure time. (b) Summed ADF image after drift-correction.

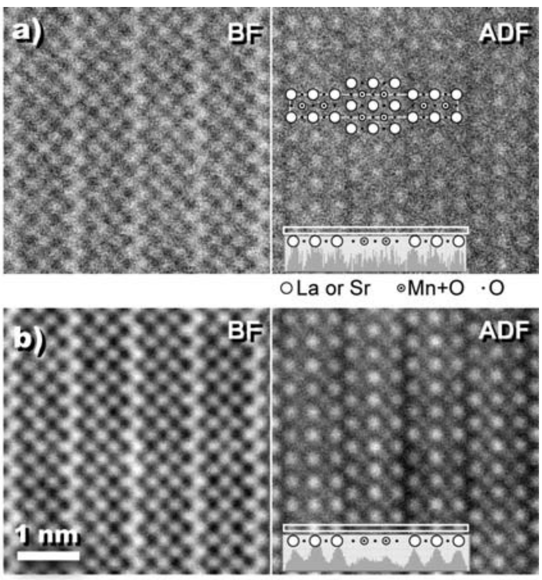

Fig. 3. BF and ADF STEM images of $La_{2-2x}Sr_{1+2x}Mn_2O_7$, (a) before and (b) after the drift-correction.