AMTC Letters
Vol. 1 (2008)

EELS Elemental Maps at an Atomic Column Resolution by a Spherical Aberration Corrected STEM

Eiji Okunishi, Hidetaka Sawada, Yukihito Kondo

JEOL. Ltd., Electron Optics Division, 1-2 Musashino 3-chome, Akishima, 196-8558, Tokyo, Japan

Z-contrast imaging by the High Angle Annular Dark Field (HAADF) technique is powerful to determine an atomic position or column at an atomic level resolution. The Z-contrast in HAADF imaging provides clear contrast that is roughly proportional to square of atomic number. However, it cannot directly specify atomic species. To determine an element, an Energy Dispersive X-ray Spectroscopy (EDS) and/or an Electron Energy Loss Spectroscopy (EELS) are commonly used with a scanning transmission electron microscope (STEM). Recently, the performance of STEM is greatly improved by the realization of a Cs corrector for the probe forming system. The Cs corrector mainly provides two advantages: a small probe size and high probe current. As to the former advantage, the smallest probe size was measured to be less than 0.1 nm at 200kV. This advantage serves high-resolution capability in imaging, has already been reported by the Pennycook's group [1, 2]. As to the latter advantage, the high probe current becomes roughly ten times higher than the one in an ordinary STEM with the same probe size. This enables us to analyze with higher sensitivity with an atomic level resolution. Point or line analyses with this high current probe have already been reported [3, 4, 5]. The present paper reports atomic resolution elemental maps by EELS with the Cs-corrected STEM.

The sample used in this experiment was a $SrTiO_3$ single crystal. The thin foil sample was prepared by ion milling. STEM observations and EELS analysis were carried out using JEM-2100F (JEOL) equipped with the STEM Cs corrector (CEOS GmbH) and parallel EELS (GATAN ENFINA). The probe size was 0.12 nm and the current was 280 pA on the specimen. EEL spectrums were corrected 40 x 31 pixels and the dwell time for a pixel to acquire a spectrum was 0.1 s. EELS maps were reconstructed by a spectrum imaging method.

Figure 1 (a) shows a high-resolution Z-contrast image of the SrTiO3 [100]. EELS elemental maps shown in Figs. 1 (b)-(d) were reconstructed. Each EELS map clearly shows atomic column positions of each element. To identify the positions of atomic columns in a crystal structure clearly, elemental maps in Figs. 1 (b)-(d) are summarized as the RGB-colored image shown in Fig. 1 (e). The atomic column positions agree well with the crystal structure model of $SrTiO_3$ shown in the inset of Fig. 1 (a). Figure 2 shows intensity profiles from the rectangle area in each EELS map. Spatial resolution for the elemental analysis was approximately estimated to be 0.17 nm from the full width of half maximum of the line profile, which reaches the atomic resolution. Thus, EELS spectrum-imaging method with Cs corrected STEM is concluded to be a very extremely powerful tool for the studies of materials.

References

[1] P.D. Nellist et al., *Science* **305**, 1741 (2004)
[2] E. Abe et al., *Nature* **421**, 347 (2003)
[3] A. R. Lupini and S. J. Pennycook, *Ultramicroscopy* **96**, 313 (2003)
[4] L. J. Allen et al., *Phys. Rev. Lett.* **91**, 105503 (2003)
[5] M. Varela et al., *Phys. Rev. Lett.* **92**, 095502 (2004)

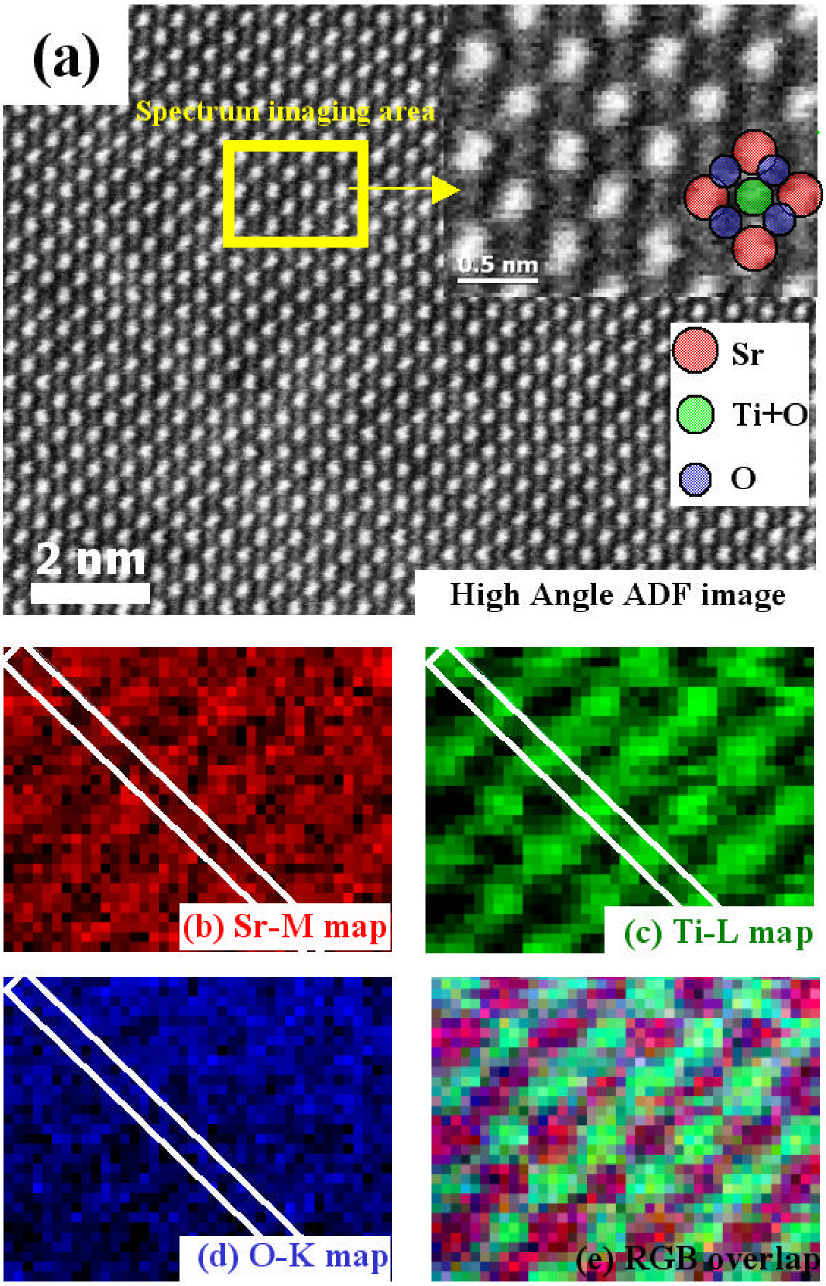

Fig 1. EELS elemental mapping with a spectrum imaging method.
(a) HAADF image of $SrTiO_3$ [100]. (b)~(e) EELS elemental maps.

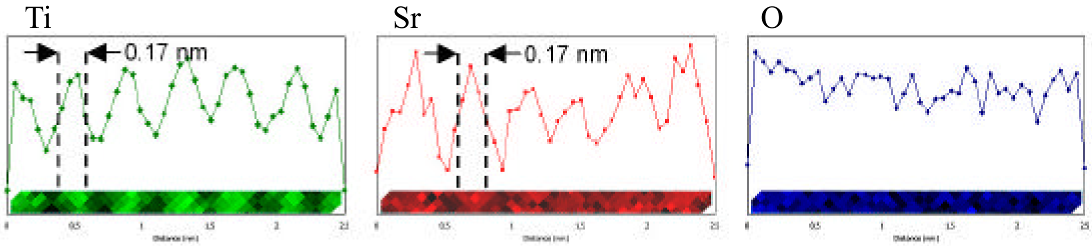

Fig 2. Intensity profiles from the white-squared areas shown in EELS maps.