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

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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 SrTiO$_3$ [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

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.