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Estimation of Energy Acceptance of SE Detectors in Scanning Electron Microscopy

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In modern scanning electron microscopy (SEM), spectroscopic signal detection has been attracting increasing attention, because it has potential to emphasize the image contrast of our interest by selecting signal electron energy [1]. According this point, we have studied secondary electron (SE) image formation in aspect of SE energy [2,3]. Since SE detector set in actual SEM collects a part of electrons emitted from specimen with energy E and emission angle θ, we have to understand possible combinations of E and θ to be detected, i.e. detector acceptance $G(E, \theta)$. In most cases, however, $G(E, \theta)$ is not known clearly except few results obtained by simulation [4]. Thus, if we develop a simple and easy method to estimate $G(E, \theta)$, it is very useful to analyze SE image contrast. As a first step to do this, we have evaluated the energy acceptance of an annular in-lens SE detector set in so-called "Gemini column." We fabricated a specimen consists of several metal layers, and studied their SE image contrast comparing with standard SE spectrum to deduce energy acceptance of the SE detector.

A model specimen was fabricated by depositing layers of Cr, Fe, Cu, Ag, Au (200 nm thick each) and Pt (300 nm thick) onto *p*-Si substrate. After the cross section polishing with Ar^+ ion beam, the specimen was put in SEM chamber as immediately as possible. We used an UHV-SEM equipped with field emission electron gun (Omicron Nanotechnologies, Germany), for SE observation. The SE detector to be evaluated was an annular in-lens SE detector located inside of the electron gun column [5,6]. The vacuum of SEM chamber was kept lower than 10^{-7} Pa, which enables us to observe specimens without contamination.

The experimental results are shown in Fig. 1. A series of SE images of the model specimen is shown in Fig. 1(a), which is taken at primary electron energy E_p from 200 eV to 5 keV at constant beam current. Working distance, brightness and contrast were fixed. Figure 1(b) shows the plots of SE image intensity I_{SE} extracted from Fig. 1(a). Intensity order is shown in Fig. 1(c). The crossovers of plots of I_{SE} were observed between Cu and Cr at 420 eV, and Cu and Fe at 630 eV.

Considering SE energy distribution $N(E, E_p)$ and the detector acceptance, I_{SE} is generally written as [4]

$$I_{SE}(E_p) = \iint_G N(E, E_p) \cos\theta \, dE d\theta. \quad (1)$$

In this study, we adopt standard SE spectra $N_{ref}(E, E_p)$ given by Goto *et al* [7,8] to substitute $N(E, E_p)$. By introducing an approximation that G has weak θ dependence, SE intensity with standard spectra I_{ref} can be calculated as,

$$I_{ref}(E_p) = \int_{E_L}^{E_U} N_{ref}(E, E_p) \, dE \int_0^{\pi/2} \cos\theta \, d\theta, \quad (2)$$

where E_L and E_U is lower and upper limit of integration as shown in Fig 2(a). Thus, by finding E_L and E_U, with which I_{ref} reproduces intensity relationship in the plots of I_{SE}, we can estimate the energy acceptance of SE detector.

We found that with E_L= 14 eV and E_U= 30 eV, I_{ref} reproduces not only the order of the intensities of I_{SE},

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but also the energies of crossover between Cu and Cr, and Cu and Fe [Fig. 2(b)]. When E_L comes down to 6.5 eV, these features in the plots of I_{ref} in Fig. 2(c) are quite different from those of I_{SE}. This result suggests that the detector is not sensitive to SEs with energy less than 14 eV. Even though the approximation is still rough, we have estimated the energy range of the detector acceptance with this method [9].

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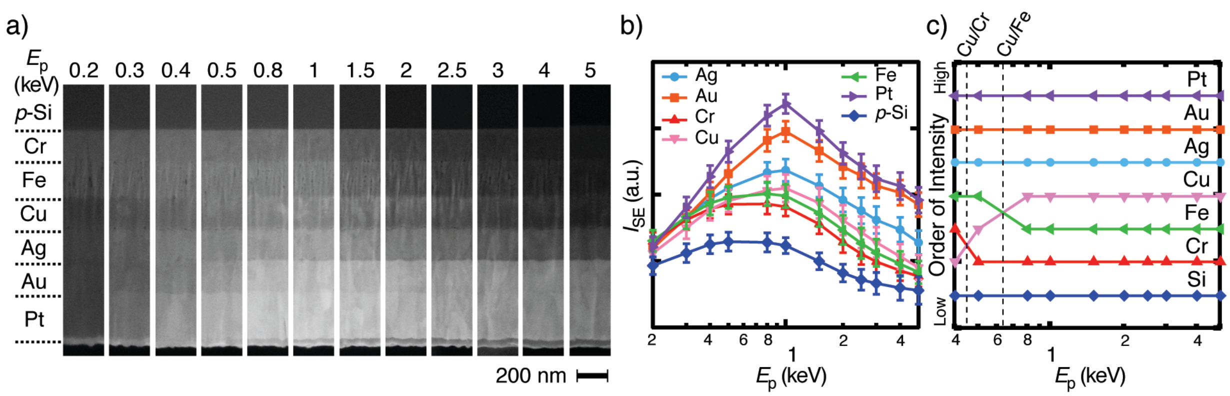

Figure 1. (a) A series of SE images taken with varying primary electron energy. Beam current, brightness and contrast setting were common for all images. (b) The plots of SE intensity of the metals obtained from the images in (a). (c) The order of SE intensity for the metals.

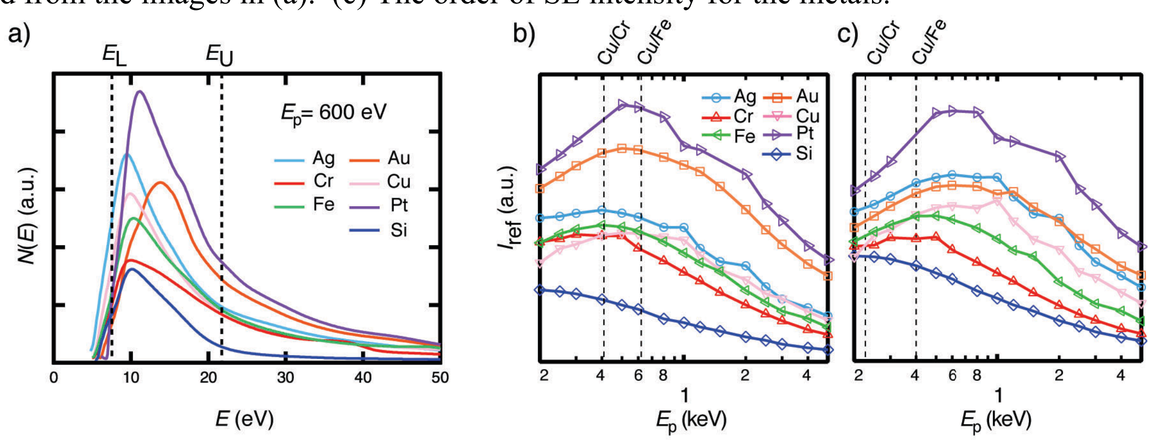

Figure 2. (a) The energy distributions of SE [8]. The plots of I_{ref} for the metals with (b) E_L= 14 eV, E_U= 30 eV, and (c) E_L= 6.5 eV, E_U= 30 eV.

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