Accelerating voltage and probe current dependence of electron beam drilling rates for silicon crystal

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Energy dispersive X-ray spectrometry (EDS) and Electron energy loss spectrometry (EELS) in scanning transmission electron microscopy (STEM) are very popular for analysis of semiconductor devices, since we require elemental and binding states of sample as well as sample shape and dimension. However, it requires more electron dose onto a sample than that of imaging due to small signal intensity. The sample lamella may receive the electron beam damage if energy and density of an electron probe is inadequate for the sample. The damage could be categorized into two types, one is structure deformation of sample and the other is beam drilling caused from etching and/or migration of sample atoms [1]. The latter is crucial for elemental analysis, since it significantly affect the results of compositional and quantitative chemical analyses. Several results on the beam drilling have been reported so far [2, 3]. In this paper, we report beam drilling of Si crystal, which depends on accelerating voltage and electron probe current, because it should be avoided for long time or high magnification analysis.

We used a field emission S/TEM (JEM-2800) equipped with two large-sized silicon drift detectors (dual SDD, 100 mm^2). A lamella of a silicon device (Si(110)) was prepared by Ar^+ ion milling (ION SLICER™). The thickness of the lamella was measured to be approximately 15 nm using the EELS ratio method. To estimate the electron beam drilling rate, we measured a decay of Si X-ray (KΦ#177;) count rate, performed in point analysis mode.

Figure 1 shows decay profiles of Si count rates for various accelerating voltages with a probe current of 3.72 nA. The decay rate becomes slower at the lower accelerating voltages. The measured X-ray count rate (R) is fitted with the relation: $R = R_0*\exp(-at)$, where R_0 is initial count rate, a is drilling coefficient, and t is elapsed time. The drilling coefficient is exponentially proportional to accelerating voltage, as plotted in Fig. 2. The drilling rate becomes almost zero at 60 kV.

Figure 3 shows the decay profiles for various probe currents at 200 kV. And Fig. 4 plots the probe current dependence of the drilling coefficient. The drilling coefficient is approximately proportional to probe current, though the electron densities under these probes are approximately constant to be 2.0 nA/nm^2. By reducing a probe current, the drilling rate reduces exponentially. Therefore, for analysis of fragile samples, it is more beneficial to use small probe current and long analysis time to obtain the same amount of signals.

In conclusion, we quantitatively evaluated how the elemental analysis is very effective for reduction of the electron beam damage when we perform the analysis at the low accelerating voltage with small probe current, as well as higher sensitivity due to larger ionization cross section of an element.

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Fig.1

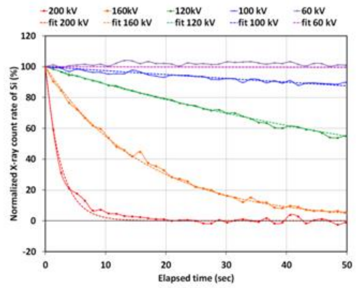

Fig.2

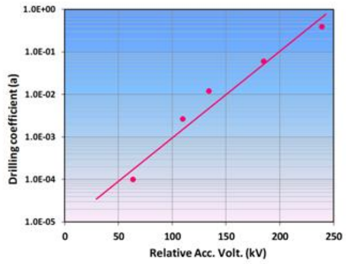

Fig.3

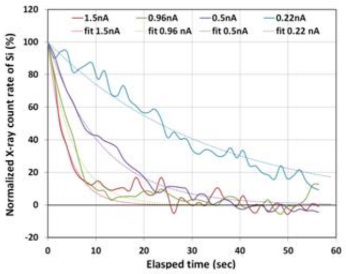

Fig.4