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The determination of the thickness of the silicon oxide film using EAL

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Introduction

In the determination of the thicknesses of the thin films by x-ray photoelectron spectroscopy (XPS), the attenuation length (AL) of photoelectrons is an important parameter. Formerly, the inelastic mean free path (IMFP) has been substituted for AL for this purpose. However, in the lower energy region, the IMFP cannot be used as the substitution of the AL because the elastic scattering is not negligible. Recently, the effective attenuation length (EAL) was proposed and defined for the substitution of the AL.

In this study, we measured the EALs of photoelectrons of various energies in silicon oxide using a thin film with a certified thickness. We determined the thickness of another thin film of silicon oxide from its XPS spectra and the measured EALs.

Experimental

Two thin films of silicon dioxide (SiO_2) were used for the measurements. One of the thin films was a certified reference material for the thickness of the thin film (NMIJ CRM 5204-a) (SiO_2 CRM) supplied from NMIJ. The thickness of the thin film has been certified as 3.49 ± 0.19 nm using XRR. The other thin film (SiO_2 2T) was also a silicon oxide film on the Si substrate, whose thickness was also estimated as 2.2 nm using the x-ray reflectivity (XRR).

SR-XPS measurements were performed at a soft x-ray beamline 13C of PF using an ultrahigh vacuum system which was originally designed and developed for the surface analysis of the solid. Photoelectron spectra were measured using a hemispherical analyzer (PHI Model 1600C) with an omni-focus lens attached to the analysis chamber. The incident angle of the x-ray was 55° from the normal of the sample surface and the axis of the analyzer was normal to the sample surface.

Results and Discussion

Figure 1 shows EALs of SiO_2 determined from the XPS spectra of CRM at each energy. IMFPs calculated by TPP-2M equations are also plotted as a solid line. The EAL becomes larger with increasing kinetic energy of the electron similar to the IMFP, and the EAL and IMFP in the energy range between 200 eV and 600 eV are similar. However, EALs are lower than IMFPs below 200 eV and higher above 600eV.

Using the EALs obtained from the SiO_2 CRM, the thickness of SiO_2 2T was determined from the spectra of SiO_2 2T. Figure 2 shows the thicknesses which were calculated from the EALs and the XPS spectra as a function of the kinetic energy. The thicknesses of SiO_2 2T determined from the EALs were distributed between about 1.7 nm and 1.9 nm. The arithmetic average and the standard deviation of the obtained thickness are 1.83 and 0.063, respectively. The offset of the measured thickness may be explained by the layer with lower density inserted in the SiO_2 thin film. This maybe a suboxide layer generated near to the Si–Si oxide interface, where the density of the oxide is probably reduced due to the lattice mismatch. There must be a suboxidelayer between the substrate and the oxide even if the thin film is fabricated very well.

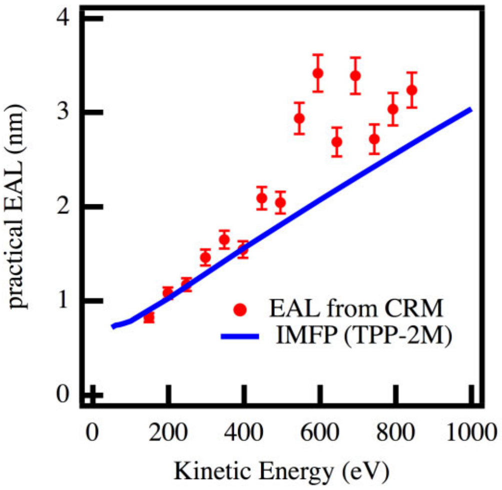

Fig.1 EALs determined from XPS of CRM

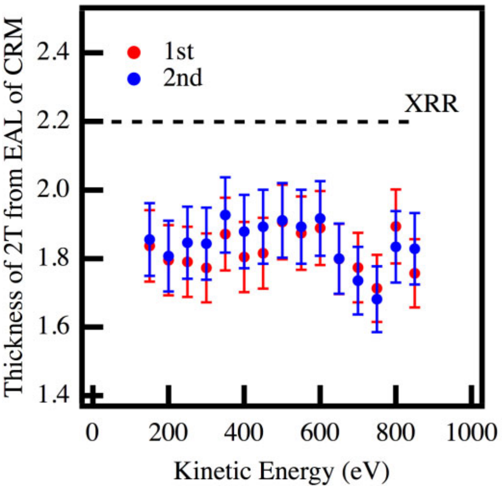

Fig.2 Thickness of 2T film determined from EALs

References

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