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B−3−5 Non-destructive Analysis of the Si-SiO_2 interface by Electron Energy Loss Spectroscopy Study

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The oxide in the MOS(metal-oxide-silicon) is formed by thermal oxidation of single crystal silicon. With regard to MOS device characteristics and its performance, the boundary layer between SiO_2 and Si is of critical importance.[1] The Si-SiO_2 system has been studied extensively by using such techniques as AES (Auger electron spectroscopy),[2] XPS(x-ray excited photoelectron spectroscopy)[3], ion backscattering[4] and transmission electron microscopy. Most AES studies were combined with sputtering technique, a destructive method, which distorts or broadens the real profile. Recently non-destructive investigations of the Si-SiO_2 interface have claimed that chemical transition region of the interface is considerably narrow and very thin transition layer of SiO_x exists.[3,4] However, there are some confusions about the details of the chemical and electronic structures.

In addition to the above techniques, electron energy loss spectroscopy(ELS) is also a powerful tool for study of electronic structures.[5] As electron escape depth increases with the kinetic energy above ~100eV, ELS study provides information on depth profile of film materials without destruction using a tunable electron beam. The present study composes of ELS measurements with incident energy of 200-2000eV, which corresponds sampling depth of some tens angstroms, in connection with XPS study. The measurements have been performed on oxide layer up to ~60Å thick grown on Si(100) substrate at 500-700°C in dry oxygen by using a PHI ESCA-Auger spectrometer with an integral coaxial electron gun and a double pass CMA(cylindrical mirror analyzer).

Figure 1 shows typical variations of the ELS spectrum with incident electron energy E_p at normal incidence. The oxide thickness of this sample was estimated to be about 34Å from the XPS measurements. In the low energy region of $E_p < 700$ eV, the ELS spectrum was similar to that of pure SiO_2 which is characterized mainly by a sharp slope at ~10eV and a maximum at ~23eV(plasmon loss). With increment of E_p the main features of the spectrum was dominated more by the characteristic plasmon loss peak of pure Si (at 17eV). Considering that electron escape depth in materials is reported to increase approximately in proportion to the root of the kinetic energy, the energy dependence of the ELS spectrum suggests the existence of a chemically sharp interface of the Si-SiO_2. When Si plasmon loss peak became considerable, a new feature was observed at $\sim$7.6eV as a shoulder. This shoulder is considered to contain a new information on $Si\text{-}SiO_2$ interface since it is not explained from both ELS spectra of SiO_2 and Si. In order to clarify the origin of the shoulder, ELS spectrum was measured in negative second derivative mode. The E_p dependence of the derivative spectrum, as is shown in Fig.2, is consistent with that of non-derivative spectrum. This feature at $\sim$7.6eV cannot be synthesized from both spectra of Si and SiO_2 in this case as well. On assumption that the ELS spectrum with E_p= 200eV, h(200eV), corresponds only to pure SiO_2 one and that the other spectra with higher E_p, $h(E_p)$, contain the same shape background, the deviations of $h(E_p)$ from h(200eV) are obtained and shown in Fig.3. Here, $h(E_p)$'s were normarized with the height of 10.7eV loss peak. For E_p= 700eV a maximum appeared at $\sim$7.6eV and for $E_p >$ 700eV, compared with 10.7eV peak, the peak grew up with the increment of E_p and saturated with $E_p \simeq$ 1800eV. The Si plasmon loss peak was observed for $E_p \gtrsim$ 800eV and became stronger with increasing E_p. From these situations the maximum at $\sim$7.6eV was considered to correspond to excitation derived from a $Si\text{-}SiO_2$ interface state since no loss peaks were observed near 7.6eV for Si or SiO_2. For SiO prepared by adsorption of oxygen onto Si crystal or derived from electron impacts of SiO_2, a peak was observed at 7.2eV in derivative spectra.[5] The peak at $\sim$7.6eV may be considered to correspond to SiO state of the $Si\text{-}SiO_2$ interface.

Dependence of ELS spectra on incident angle is also expected to be available as the case of E_p dependence. Details will be reported.

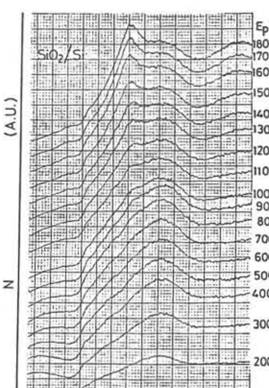

Fig.1

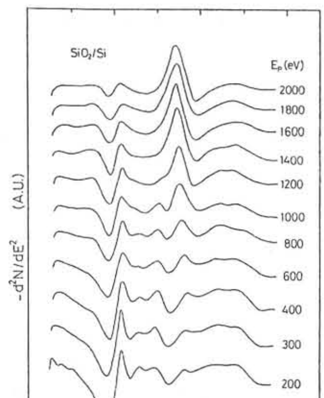

Fig.2

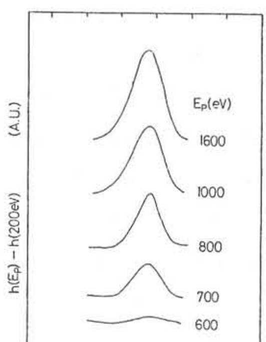

Fig.3

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