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Observation of Lateral Diffusion at Si-SiO$_2$ Interface by PEEM using Synchrotron Radiation

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Introduction

Silicon on insulator (SOI) has been widely studied, because it will potentially replace conventional silicon substrates in semiconductor technology due to excellent properties such as low capacitance. One of the methods to produce SOI is oxygen ion implantation in silicon followed by high temperature annealing. Therefore, longitudinal diffusion of oxygen upon heating has been extensively investigated. Taking into account the recent miniaturization of silicon devices, it is also of importance to examine lateral diffusion at nanometer-scale. In the previous study, we have developed a photoelectron emission microscopy (PEEM) system combined with synchrotron soft X-ray excitation in order to observe chemical state mapping of solid surfaces at nanometer scale [1]. In this study, the method is applied to the observation of the chemical states at the Si-SiO$_2$ interface upon annealing and mechanism of lateral diffusion is discussed.

Experimental

The experiments were performed at the BL-27A station. The PEEM system used was Elmitech Co. Model PEEMSPECTOR. The total photoelectrons emitted from the sample surface were accelerated and focused on the YAG screen using electrostatic lenses. The lateral spacial resolution of the system was about 41nm. The samples investigated were Si-SiO$_2$ micro-patterns prepared by O_2^+ ion implantation in Si(001) wafer using a mask of 12.5 μm periodicity. The sample surface was illuminated by soft X rays around the Si *K*-edge.

Results and discussion

Spectra (a), (b) and (c) of fig.1 shows X-ray absorption near edge structures (XANES's) for Si (Si^0), SiO (Si^{2+}) and SiO$_2$ (Si^{4+}) at the Si *K*-edge, respectively. Pictures (1)-(4) display PEEM images exited by 1846.6eV photons for Si-SiO$_2$ micro-pattern annealed at respective temperatures shown in the pictures. It was found that the temperature of the lateral diffusion is lower by 300ºC-400ºC than that reported for the longitudinal diffusion at the Si-SiO$_2$ interface [2]. As the photon energy (1846.6 eV) corresponds to the peak energy in XANES spectrum of SiO$_2$, bright areas in the images (1)-(4) are assigned to be SiO$_2$ (Si^{4+}). Lateral diffusion of SiO$_2$ is clearly seen upon annealing. For the image (4), the brightnesses of two domains shown by arrows are plotted as a function of the photon energy. The results are shown in (d) and (e). It is seen that no intermediate valence states such as SiO (Si^{2+}) are observed at the Si-SiO$_2$ interface during the diffusion. As the result, we found that the diffusion of oxygen induced the sudden changes of the Si valence state from Si^0 to Si^{4+} without taking any intermediate valence states. For longitudinal diffusion, it was reported that the existence of SiO states at the Si-SiO$_2$ interfaces promotes the diffusion [2]. The observed differences between lateral and longitudinal diffusion are interpreted by the sublimated property of silicon monoxide (SiO), i.e., SiO molecules, if they are produced, easily sublimated from the surface.

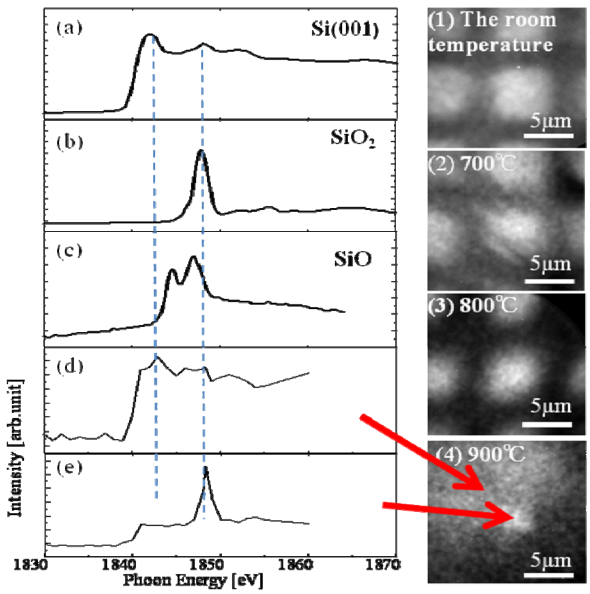

Fig.1 XANES spectra of (a) Si, (b)SiO$_2$, and (c) SiO. Pictures (1)-(4) show the PEEM images heated at respective temperature shown in the images. The photon energy dependences of the brightnesses of the areas shown by arrows in the the picture (4) are plotted in (d) and (e).

References

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[2] S. Fukatsu, K M.Itoh, M. Uematsu, H. Kageshima, Y. Takahashi, K. Shiraishi, Jpn. J. Appl. Phys., 93, 7837 (2004) .

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