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Observation on chemical-state-selective images of Si-SiN$_x$ micro-patterns by photoelectron emission microscopy excited by soft X-rays

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Introduction

Nitrogen-ion implantation in silicon at high fluence is one of the promising methods for the fabrication of buried insulator layers termed as silicon-on-insulator (SIO). The precise analysis of valence states of silicon at the Si-SiN$_x$ interfaces is of great importance to explore new devices with more sophisticated properties. High resolution X-ray photoelectron spectroscopy (XPS) enabled us to observe precise valence state of Si-SiN$_x$ interfaces at surfaces. However, it has also become important to elucidate the lateral distribution of valence states at nanometer scale due the recent miniaturization of Si-based electronic devices. Here we present the results for the observations on valence states of Si-SiN$_x$ micro-patterns by means of photoelectron emission microscopy (PEEM) excited by soft X-rays around the Si *K*-edge.

Experimental

The experiments were performed at the BL-27A station. Micro-patterned Si/SiN$_x$ sample was prepared by 3 keV N_2^+-ion implantation in Si(001) using a grid of 12.5 μm periodicity as a mask. Sample surface was illuminated by synchrotron soft X-rays around the Si *K*-edge. The total photoelectrons emitted from the microscopic area were observed by PEEM (Elmitech. Co. PEEMSPECTOR). A mercury lamp (hν=4.9) was also used as an UV excitation source. The lateral spacial resolution of the PEEM was about 40 nm. For comparison, XPS and XAFS spectra for averaged areas were measured without the grid.

Results and discussion

Figure 1 shows the Si 1s XPS and Si *K*-edge XAFS spectra for the N_2^+ ion implanted Si(001). The XPS peaks, firstly broadened, gradually shifted to higher binding energy, and finally became sharp suggesting the formation of stoichiometric Si_3N_4. This means that the Si-N bonds gradually replace the Si-Si bonds. For XAFS spectra, the peaks C and D are originating from the resonance excitations from the Si 1s to the valence unoccupied σ^* orbitals in Si and Si_3N_4, respectively.

The PEEM images for the Si-SiN$_x$ micro-pattern are shown as photos (a)-(e) in fig.2. Although the image (e) by UV excitation is more clearly seen than those by X-ray excitation, the brightness of the image (e) originates from only differences in work functions between Si and SiN$_x$. In order to know the valence states of each domain in the image, we plotted the brightness of the spots in the PEEM images as a function of the photon energy. The typical examples are shown in plots (A) and (B). In comparison with the brightness curves and XAFS spectra (fig,1(c)), it is elaborated that the bright regions in the image (c) are composed of nearly stoichiometric Si_3N_4, while the dark areas correspond to Si. In a similar way, we could elucidate the valence states of all of the regions in the PEEM images.

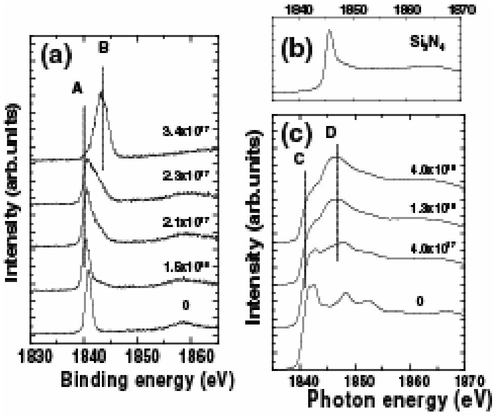
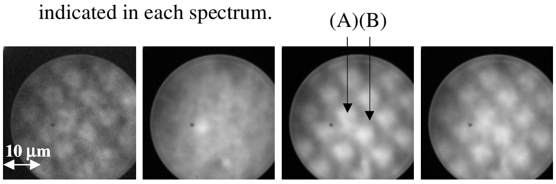
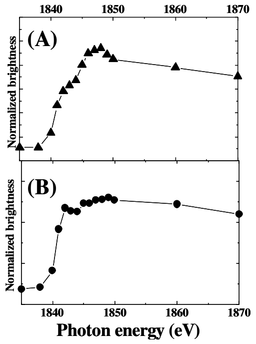
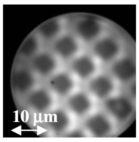


Fig.1 (a): Si 1s XPS spectra excited by 2200 eV photons for N_2^+-ion implanted Si(001). (b): XAFS spectrum for Si_3N_4. (c): XAFS spectra for N_2^+-ion implanted Si(001). Fluence of the ions (atoms/cm^2) is indicated in each spectrum.



(a)1835.0 eV **(b) 1840.0 eV** **(c) 1845.7 eV** **(d) 1870.0 eV**





(e) 4.9 eV

Fig.2 (a)-(e): PEEM images for Si-SiN$_x$ micro-pattern. Photon energy is indicated in each image. Plots (A) and (B) are photon-energy dependences of the brightness of the spots A and B, respectively, in image (c).

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