XPS study of nitrogen profiles at SiO_2/4H-SiC(0001) interfaces with NO annealing

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Interface nitridation through post oxidation annealing (POA) in NO ambient is being implemented to passivate the SiO_2/SiC interface and thus improves the channel mobility of SiC MOSFETs. Recently, Hatakeyama *et al*. reported that the field effect mobility of n-channel 4H-SiC(0001) MOSFETs increased by NO-POA as the annealing duration was increased from 10 to 60 min and then it slightly degraded for a longer annealing duration of 120 min [1]. In this study, to evaluate the physical features near the SiO_2/SiC interface for different NO-POA durations, we carefully investigated the nitrogen depth profiles in SiO_2/SiC structures through scanning x-ray photoelectron spectroscopy (XPS) analysis.

A 50-nm-thick SiO_2 was thermally grown on 4H-SiC(0001) substrate at 1200°C followed by Ar POA at the same temperature. NO POA was subsequently conducted at 1250°C for 10 min (hereafter called NO10), 60 min (NO60) and 120 min (NO120). Next, the SiO_2 layer was thinned down to ~3 nm by wet etching in a diluted HF solution. Finally, slope-shaped SiO_2/SiC samples were prepared by partially dipping into a 1% HF solution to evaluate the distribution of nitrogen just at the interface as well as in the bulk SiO_2 within few nanometers from the interface. The N 1*s* and Si 2*p* core-level spectra were acquired with a monochromatic Al Kα line (1486.6 eV) at a take-off angle of 90° for all the samples.

Figure 1 shows the N 1*s* and Si 2*p* core-level spectra taken from the NO60 sample. The binding energy (BE) was calibrated by SiC substrate peaks at the BE of 101.8 eV in Si 2*p* spectra. It was found that the N 1*s* peak intensity increases with decreasing SiO_x components (BE: ~104 eV) in Si 2*p* spectra. It should be noted that a distinct N 1*s* peak was observed even after dipping the sample into a 10% HF solution for 30 min for complete removal of SiO_x layer, suggesting that a significant amount of nitrogen remained at SiC surface. Figure 2 shows the N 1*s* peak intensity normalized by Si 2*p* peak intensity originating from SiC substrate plotted against the oxide thickness for the three samples. The oxide thickness was determined by peak deconvolution of Si 2*p* spectrum with SiO_x and SiC substrate components. The normalized N 1*s* peak intensity of NO10 was much lower than those of NO60 and NO120 and almost constant regardless of the SiO_2 thickness. This means that most of nitrogen atoms were localized at the SiC side of SiO_2/SiC interface for NO10. On the other hand, the N 1*s* peak intensities of NO60 and NO120 were almost identical when the oxide thickness is below 0.5 nm and clearly decreased after the removal of ~0.3-nm-thick oxide layers. Furthermore, the N 1*s* signal for NO120 increases with increasing SiO_2 thickness above 1 nm and its slope is larger than that of NO60. These results suggest that nitrogen atoms are incorporated at only a small part of the interface in NO10 and by increasing the annealing duration to 60 min, the interface was mostly occupied by nitrogen (NO60). Hence, when the annealing duration was further increased to 120 min (NO120), the excess nitrogen atoms diffused into the SiO_2 layer within a few nanometers from the interface since nitrogen atoms at the interface have already reached to a saturation point. Therefore, the slightly lower channel mobility of NO120-MOSFETs [1] can be explained by interface degradation owing to the diffusion of nitrogen atoms towards the SiO_2 side.

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Reference

[1] T. Hatakeyama *et al*., Appl. Phys. Exp. **10**, 046601 (2017).

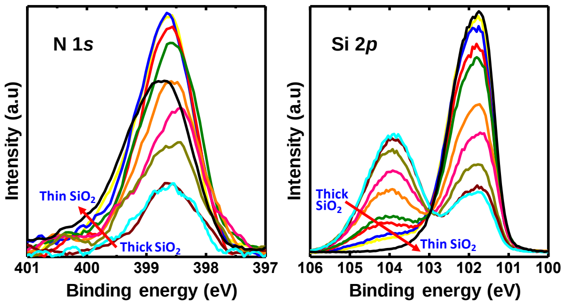

Fig. 1. N 1*s* and Si 2*p* core-level spectra taken from the SiO_2/SiC sample annealed in NO for 60 min (NO60).

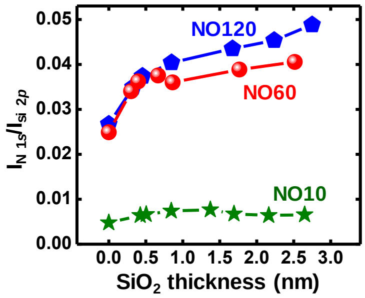

Fig. 2. N 1*s* peak intensity normalized by SiC substrate peak in Si 2*p* spectra as a function of SiO_2 thickness.