Interfacial Structure of Tunnel Oxynitride Films in Flash Memory

Flash memory is a kind of electrically erasable programmable read only memory (EEPROM). The name flash describes the technology's operation because it takes less than one second to erase a large number of cells at the same time. Flash memory has two major applications: one is nonvolatile memory integration in microprocessors to allow software updates, and the other is to create storing elements like *removable flash memory cards*. All of these applications require flash reliability in which a cell can be erased and programmed for a sufficient number of cycles without degradation of device functionality.

Electron trapping in charge-transfer dielectrics is known to be a limiting factor of the program/erase cycling endurance of nonvolatile floating-gate memory. In flash memory cells, which use channel hot-electron injection for programming and Fowler-Nordheim tunneling for erasing, electron trapping in the tunnel oxide reduces the electric field during erase operations, resulting in a gradual degradation of erase characteristics and the closure of the memory cell threshold window. The understanding of the charge trapping mechanism is therefore needed for the development of optimized program/erase schemes.

Oxynitrides (SiON) have drawn great attention as a candidate tunnel dielectric for nonvolatile memory due to the small charge-trapping amount [1]. The effect of nitrogen incorporation, however, was reported as exhibiting process-condition dependence rather than nitrogen-concentration dependence [2]. This implied the chemical state of nitrogen atoms playing a critical role in the dielectric characteristics. In this study, two kinds of 7-nm-thick SiON films with a significant difference in charge trapping behavior were prepared by thermally annealing oxide (SiO_2) film in either NO or N_2O ambient. The chemical depth profile of nitrogen atoms in the SiON films was studied by angle-resolved photoemission spectroscopy (AR-PES), which was carried out at beamline **BL15XU**. The excitation energy was chosen as 3 keV ± 0.3 eV on the basis of the balance of the detectable depth and photoelectric cross section.

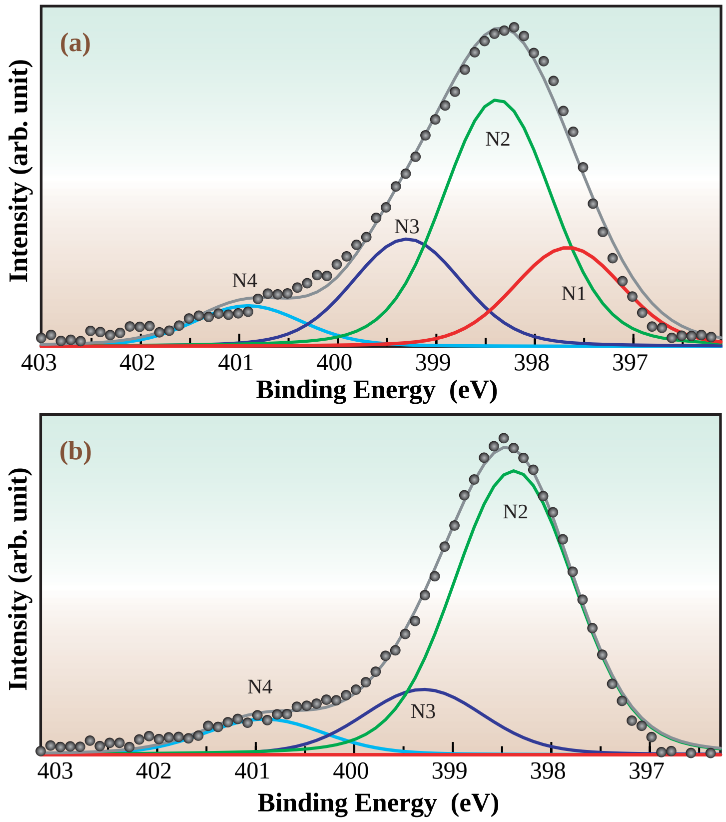

Fig. 1. N1*s* photoelectron spectra of SiON tunnel films prepared by annealing oxide in **(a)** NO and **(b)** N_2O ambient. The solid line shows the fitting results and the dots show the experimental results.

N1*s* spectra obtained from SiON films in normal emission (Fig. 1) were decomposed into four components, N1-N4. Both N1 and N2 were assigned to the [N-Si_3] group with either the mixture of nitrogen and Si atoms (N1) or all oxygen atoms (N2), respectively, bound as second-neighbor atoms. N3 and N4 were attributed to Si_2NO and $SiNO_2$, respectively [3,4]. The significant difference in the N1s spectra is that the N1 state is only detected from the NO-annealed film (Fig. 1(a)). To determine the depth distribution of N1-N4, the peak intensities normalized by the O1*s* peak were plotted as a function of the emission angle. The tendency of the angle dependence suggests that N1 and N2 exist closer to the SiO_2/Si interface, while N3 and N4 are distributed more homogeneously within the films. Moreover, an analysis result of the depth profile indicated that N1 is localized in the interface layer, while N2 is distributed further into the near-interface region (Fig. 2). Comparing the electrical properties suggests that the NO-annealed film contains a significantly higher number of electrically active electron traps existing mainly in the interface region than the N_2O-annealed film. We thus demonstrate that the source of interfacial electron trap generation might be related to interfacial nitrogen detected as the N1 component by AR-PES.

We have investigated the difference in interface structure of two SiON films by hard X-ray ARPES. We propose that SiON film with a nitrogen-free interface atomic layer is a promising tunnel film in flash memory for the improvement of program/erase cycling endurance.

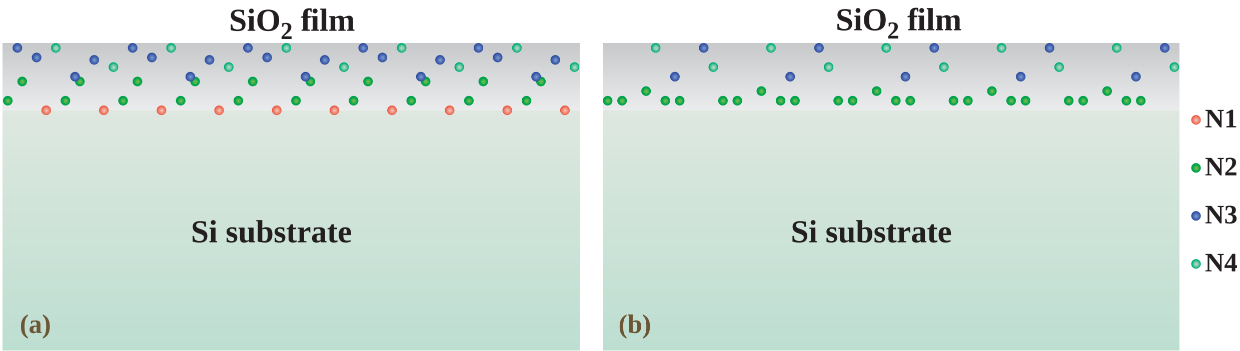

Fig. 2. Illustration of depth profile of nitrogen atoms decomposed as N1-N4 components in **(a)** NO-annealed and **(b)** N_2O-annealed SiON films.

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