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Annealing-ambient dependence of $LaAlO_3/SiO_2/Si$ gate stack structures studied by synchrotron radiation photoemission spectroscopy

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Introduction

Recently high dielectric constant (high-*k*) materials such as Al_2O_3, ZrO_2, HfO_2, rare-earth oxides, *etc.* have been intensively studied as alternatives to SiO_2 which has long been used as gate dielectrics in ultra-large scale integration (ULSI) metal-oxide-semiconductor field-effect transistors (MOSFETs) [1]. Among them, $LaAlO_3$ is regarded as a promising candidate for high-*k* gate dielectrics in MOSFETs [2].

Although thermal stability of $LaAlO_3$ under various conditions has been reported [3], the detailed behavior of $LaAlO_3$ thin films on Si during annealing has not been investigated so far. Thus, we have studied the annealing-ambient dependence of $LaAlO_3$/Si in terms of photoemission spectroscopy.

Experimental

$LaAlO_3$ thin films were prepared by laser molecular beam epitaxy method on clean *n*-type Si (100) substrates at the growth temperature of 300 °C using a Nd:YAG laser. Ambient oxygen pressure during deposition was 10^{-6} Torr. The nominal thickness of each sample was set at about 3 nm. Synchrotron radiation photoemission spectroscopy measurements were carried out at an undulator beamline BL-2C. Annealing of $LaAlO_3$ thin films was performed at 10^{-7} Torr (base pressure of the annealing chamber), N_2 10 Torr, and 100 Torr by the direct current flowing method through the samples for 3 min at 850 °C before the photoemission measurements.

Results and discussion

Figure 1(a) shows La 4*d* and Si 2*p* core level spectra for as-grown and 850 °C-annealed $LaAlO_3$ thin films at 10^{-7} Torr, 10 Torr, and 100 Torr N_2. La 4*d* and Si 2*p* oxide peak intensities dramatically decrease after the annealing under base pressure. This indicates that the annealing results in the thermal decomposition involving the reduction of $LaAlO_3$. On the other hand, the intensity ratio of La 4*d* to Si 2*p* substrate peak does not decrease after the N_2-ambient annealing, which indicates the suppression of reduction reaction. Furthermore, Si oxide peak intensity increases with introducing the N_2 ambient. This behavior can be explained by following two different scenarios;

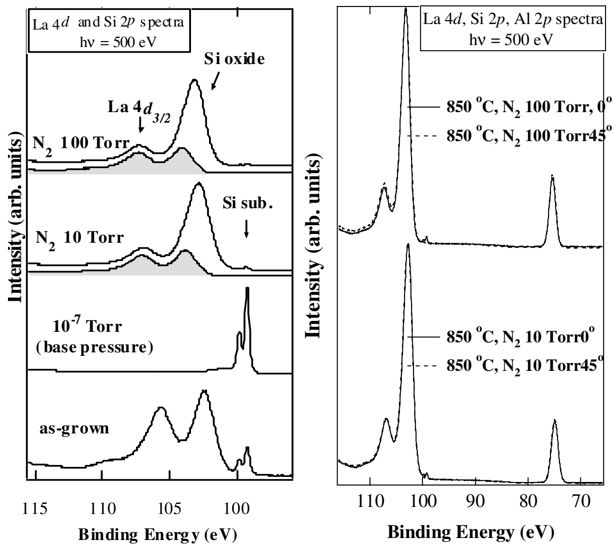

Fig. 1 (a) La 4*d* and Si 2*p* core level spectra for as-grown and 850 °C-annealed $LaAlO_3$ thin films at 10^{-7} Torr, 10 Torr, and 100 Torr N_2. (b) La 4*d* and Si 2*p* core level spectra with the take-off angle of 0° and 45° after annealing in N_2 ambient.

(1) Residual oxygen in ambient N_2 diffuses into the SiO_2/Si interface through $LaAlO_3$, which results in the oxidation of buried Si substrates.

(2) The diffusion of Si derived from substrates or the formation of SiO gas at the SiO_2/Si interface leads to the formation of $LaAlSiO_x$.

Figure 1(b) shows La 4*d* and Si 2*p* core level spectra with the take-off angle of 0° (bulk sensitive) and 45° (surface sensitive) after annealing in the N_2 ambient. No take-off angle dependence is observed, which indicates that the layered structure is not maintained. Since the former scenario should involve the $LaAlO_3/SiO_2$ layered structure, these results suggest the possibility of the later scenario.

References

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