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Spherical Aberration Corrected TEM/STEM Analysis of La_2O_3 Thin Film Deposited on Si (001) Substrate

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Recently, thickness of the gate dielectrics in metal-oxide-semiconductor field effect transistors (MOSFETs) has reached atomic scale, which leads to excessive gate leakage currents [1]. This problem can be solved by changing the gate dielectrics from SiO_2 or Si-oxynitride to other materials with higher dielectric constants [2]. La_2O_3 is one of the promising candidates for future gate dielectrics because of high dielectric constant (20-30) and large conduction band offset (2.3 eV). In the present study, we have studied La_2O_3 thin films deposited on Si (001) substrate by using spherical aberration (C_s) –corrected electron microscopes.

After removing a surface oxide layer of a *n*-type Si (001) substrate, La_2O_3 was deposited on the substrate at room temperature by electron beam evaporation. Post deposition annealing (PDA) was performed for 5 min at 300 or 500 ℃ in N_2 atmosphere. As deposited, 300 and 500 ℃ PDA samples were thinned in the direction of Si <110> by 3 kV Ar-ion milling after mechanical polishing. Transmission electron microscope (TEM) / high-angle annular dark-field scanning transmission electron microscope (HAADF-STEM) observations and electron energy loss spectroscopy (EELS) measurements were performed by using two thermal-field emission TEMs (JEOL, JEM-2100F) equipped with a C_s-corrector for the illumination or the imaging system (CEOS GmbH).

Figures 1 (a) and (b) show C_s-corrected TEM and C_s-corrected HAADF-STEM images of the La_2O_3/Si interface after the 300 ℃ PDA, respectively. The bilayer structures of Si-oxide and La-silicate confirmed in the figures are formed in the as-deposited and the 500 ℃ PDA samples. The results of measuring surface/interface roughness indicate that they increase drastically after 500 ℃ PDA. It is considered that the degradation of the channel mobility in the 500 ℃ PDA sample [3] is due to the increase of the roughness. Figures 2 (a)-(c) show elemental profiles across the gate stack of each sample measured by EELS. As seen in the figures, the O composition ratio in the La-silicate layer increases by about 1.6 times after PDA, and the La composition ratio increases by about 1.2 times after 500 ℃ PDA, respectively. Based on all the experimental results, atomic diffusion and reaction models are discussed as follows. During PDA, a number of oxygen defects contained in the as-deposited sample are reduced by absorbing residual oxygen in the N_2 atmosphere. In addition, a part of La-O-Si bonds are replaced with La-O-La bonds during 500 ℃ PDA, which also leads to the degradation of the channel mobility due to remote phonon scatterings.

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We have clarified the reasons for the degradation of the channel mobility after 500 ℃ PDA in the present study. It is expected that the results provide important information for producing next-generation MOSFETs with higher performance.

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[4] The present work was partly supported by "Promotion of Leading Researches" in Special Coordination Funds for Promoting Science and Technology by Ministry of Education, Culture, Sports, Science and Technology, Japan, and JSPS KAKENHI (17201022).

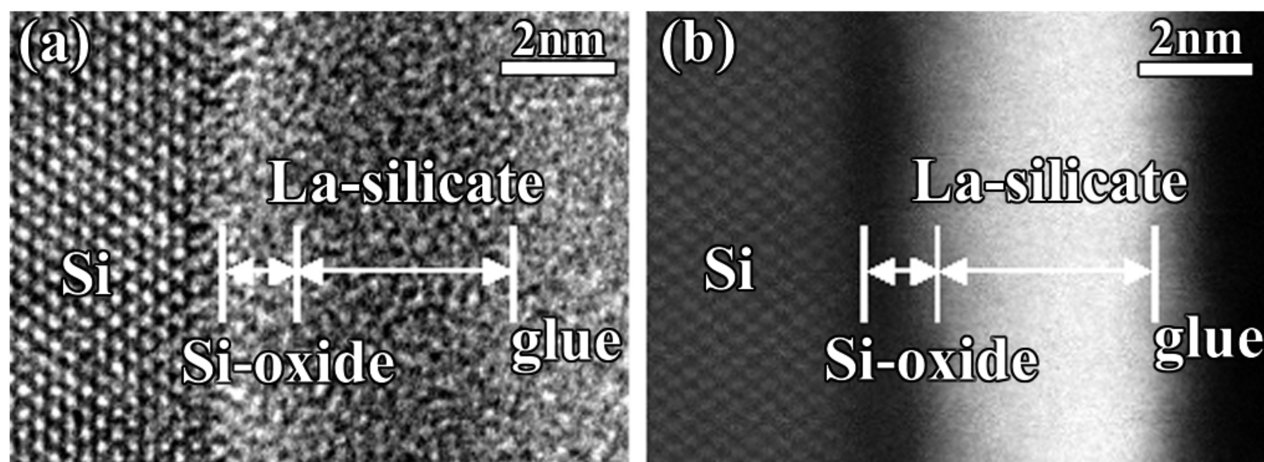

Figure 1. (a) C_s-corrected TEM image and (b) C_s-corrected HAADF-STEM image of a La_2O_3/Si interfaces after 300 ℃ PDA.

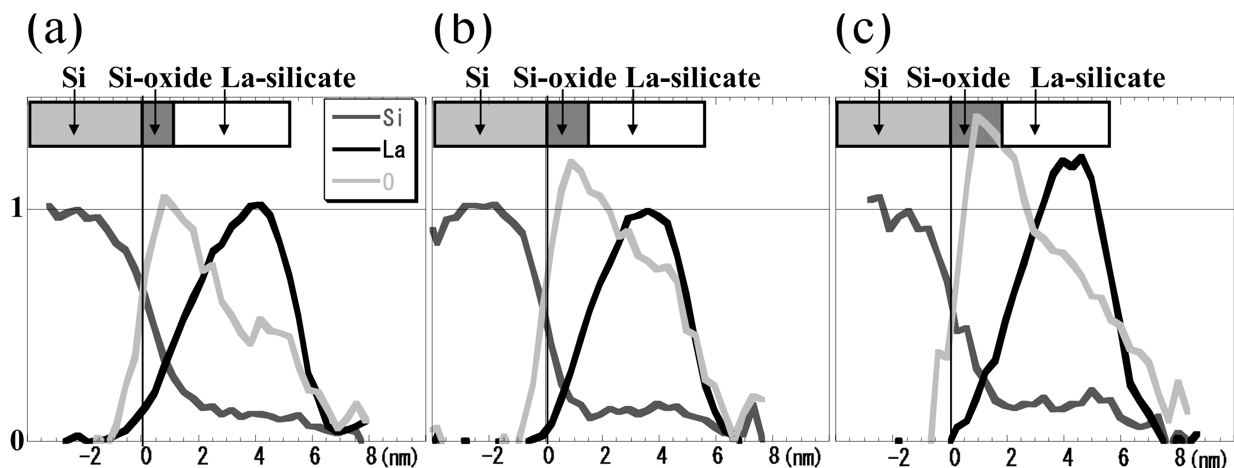

Figure 2. Elemental profiles across the gate stacks measured by EELS.
(a) As-deposited, (b) 300 ℃ PDA, and (c) 500 ℃ PDA samples.

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