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Annealing effects of in-depth profiles in TiN/LaO/HfSiO/SiO_2/Si gate stack structure studied by angle-resolved photoemission spectroscopy from backside

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Introduction

Metal/high-dielectric metal oxide (high-*k*)/Si gate stack structures are widely studied for further scaling of complementary metal-oxide-semiconductor (CMOS) devices, in order to reduce the leakage current from channel to gate and avoid carrier depletion in the gate electrode. However, there remain critical issues to be solved in metal/high-*k* systems, for instance to control the threshold voltage (V_{th}) after high-temperature thermal annealing performed for dopant activation. In order to design device structures of optimum V_{th}, it is necessary to understand the chemical states and electronic structures at the high-*k*/SiO_2 interfacial layer after high-temperature annealing processes. In this study, we have investigated annealing effects on in-depth profiles and band discontinuity in the TiN/LaO/HfSiO/SiO_2/Si structure by angle-resolved photoemission spectroscopy with synchrotron radiation, from the backside of the sample to avoid oxidation of the TiN metallic surface.

Experimental

HfSiO films with thicknesses of 2.0 nm were deposited on 1.0 nm SiO_2 interfacial layers using atomic layer deposition (ALD). 0.7 nm LaO capping layers were deposited by ALD, and 5.0 nm TiN gate electrodes were deposited by magnetron sputtering. Rapid thermal annealing was performed at the temperature of 1030 °C in He ambient. Photoemission measurements were performed at BL-2C of the Photon Factory. Photoelectron emission angles (θ_e) were changed from the surface normal to 60° for enhancement of surface sensitivity. To analyze in-depth profiles from angle-resolved core-level photoemission spectra, the maximum entropy method was utilized [1].

Results and Discussion

Figure 1 shows in-depth profiles for as-grown (a) and annealed (b) sample, which is obtained from the angle-resolved core-level intensity as a function of θ_e. Insets of the figure indicate data points and simulated curves for dots and solid lines, respectively. Upon annealing, in-depth profiles are drastically changed; (i) La atoms diffuse into the high-*k* layer and reach the interfacial SiO_2 layer, (ii) the concentration of Si slightly increases at the interface between the high-*k* layer and the TiN electrode. Diffusion of La atoms is consistent with the previous report. In addition, Si atoms at the vicinity of the interfacial SiO_2 layer may be transported into the side of TiN electrodes resulting from diffusion of La atoms. In order to investigate the relationship between in-depth profile and band discontinuity, annealing effects on the chemical shift of the Si 2*p* core-level spectra are examined. We found that La atoms diffuse from the LaO cap layers to the high-*k*/SiO_2 interface and the band discontinuity is tuned for NMOS devices upon annealing [2]. Our photoemission results are qualitatively consistent with V_{th} shift based on interface dipole models at the high-*k*/SiO_2.

References

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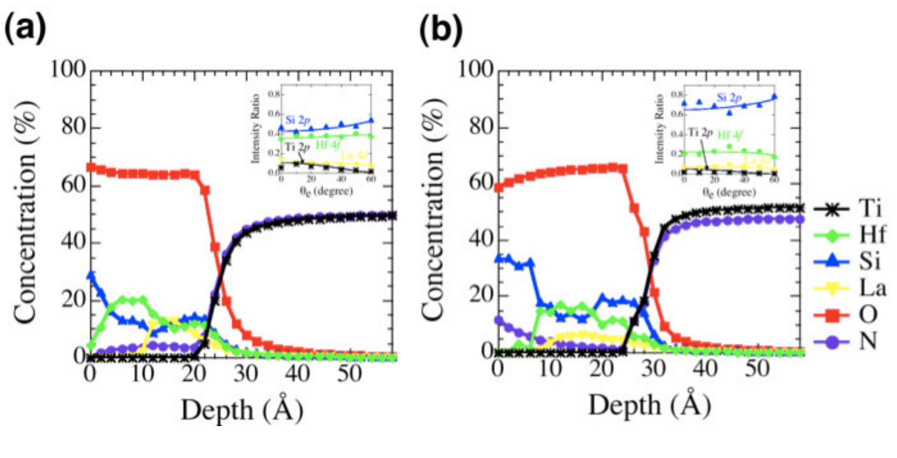

Fig. 1. In-depth profiles for as-grown (a) and annealed (b) sample, which is obtained from the angle-resolved core-level intensity as a function of θ_e. Insets show data points and simulated curves in dots and solid lines, respectively.