16A/2008U-004

# Nano-scale characterization of poly-Si gate on high-*k* gate stack structures by scanning photoemission microscopy

Satoshi TOYODA[1-3*], Koji Horiba[1-3], Yuki Nakamura[1], Hiroshi KUMIGASHIRA[1,3,4], Masaharu OSHIMA[1-3], Kenta Amemiya[3,5]
[1]Department of Applied Chemistry, The University of Tokyo, Tokyo 113-8656, Japan
[2]JST-CREST, Tokyo 113-8656, Japan
[3]The University of Tokyo, Synchrotron Radiation Research Organization, Tokyo 113-8656, Japan
[4]JST-PRESTO, Tokyo 113-8656, Japan
[5]KEK-PF, Tsukuba, Ibaraki 305-0801, Japan

## Introduction

Scaling and integration of complementary metal-oxide-semiconductor devices have made great development in the pursuit of higher performance and lower power consumption. Elemental devices of field effect transistors have been going through a transition from planar to three-dimensional structures for overcoming the physical limitation of thickness for the gate insulator. However, due to the rapid downsizing of devices in the in-plane direction, device analysis for failure caused by concentration of leakage current, and the control of dopant diffusion in thermally treated semiconductors have become more and more difficult. In order to establish guidelines for device fabrication processes, nano-scale characterization of three dimensional device structures becomes an important issue. Photoemission spectroscopy is one of the most powerful techniques to analyze electronic structures such as chemical states of thin films, energy-band discontinuity among heterointerfaces, space charge layers at semiconductor surfaces, and so on. However, the spot size of the light source is too large to characterize conventional nano-scale devices. Therefore, we have developed a measurement system for scanning photoemission microscopy (SPEM) using nano-beam focused by a Fresnel zone plate, and also have demonstrated nano-scale characterization of poly-Si gate pattern on high-*k* gate stack structures.

## Experimental

$HfO_2$ gate dielectric films and poly-Si gate electrodes were deposited on *p*-type Si substrates with shallow trench isolation (STI) of $SiO_2$ using atomic layer deposition. After the deposition, line and space patterns of the poly-Si gate were formed by photolithography and $Ar^+$ dry etching processes. The line width of the poly-Si gate pattern was selected to be 400 nm. Experiments were performed at BL-16A of the Photon Factory in High Energy Accelerator Research Organization (KEK). Synchrotron radiation (SR) light source is focused by a Fresnel zone plate. An order-sorting aperture is set up between the zone plate and the sample for eliminating zero and diffraction orders higher than one. The sample is mounted on a piezoelectric stage for adjusting scanning positions. For collecting photoelectrons emitted from the sample, we use a hemispherical electron analyzer equipped with a wide-angle lens for angular-resolved measurements (VGScienta R3000).

## Results and Discussion

In the poly-Si gate patterned samples, chemical images are obtained by tuning to binding energies for (a) Hf 4*f* and (b) Si 2*p* core-level photoemission spectra as presented in the Fig. 1. Hammerhead structures are clearly observed at edges of the poly-Si gate. In addition, the contrast for the Hf 4*f* image is accurately reversed from that of the Si 2*p* image, proving our success in element-selective imaging around the same sample position. Regions located inside and outside the dashed lines correspond to the $HfO_2$ film deposited on the Si substrates and STI layers, respectively. Although the chemical imaging of Hf and Si atoms both show homogeneous images over the STI region, a difference in contrast is observed between the edges and inward sides of the poly-Si gate over Si substrate regions. Site-specific chemical-state analyses for Si, Hf, and O atoms suggest significant differences in etching velocities between $HfO_2$/Si and $HfO_2$/STI structures when exposing the poly-Si gate pattern to dry etching processes [1]. The SPEM system has a high potential to characterize chemical states of nano-scale structures, which can give feedback to device fabrication processes.

## References

[1] S. Toyoda *et al.*, e-J. Surf. Nanotech. **9**, 224 (2011).
*toyoda@sr.t.u-tokyo.ac.jp

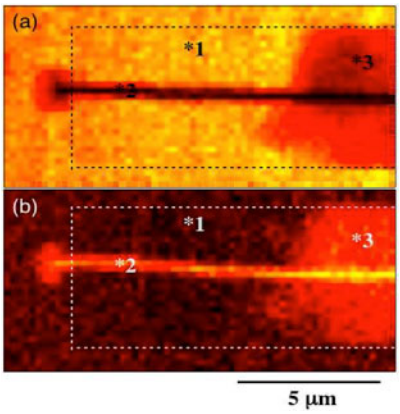


**Fig. 1.** Chemical images obtained by tuning binding energies for (a) Hf 4*f* and (b) Si 2*p* core-level photoemission spectra in poly-Si gate patterned samples.