Direct Observation of Reduced Path Formation in CuO-based Resistance-Switching Devices

The voltage-induced nonvolatile resistance switching (RS) phenomena observed in some oxide materials have recently attracted much attention as the basis for next-generation nonvolatile random access memory technology, called resistance random access memory (ReRAM). ReRAM has several advantages such as a simple structure consisting of metal/oxide/metal sandwich, a high-density integration, and a high operation speed [1]. However, the mechanism of RS has not been fully understood yet, and this has largely affected the future application potential of ReRAM. One of the most predominant models employed to explain the RS phenomena is the "conduction filament" model: conductive filamentary paths are generated by the application of voltage that induces the local reduction of oxides sandwiched between two electrodes. Therefore, a direct observation of the reduced path formation in ReRAM devices is the key to understanding the RS phenomena.

A photoemission electron microscope (PEEM) in combination with wavelength-tunable synchrotron radiation (SR) is a powerful tool for addressing this issue. The PEEM detects the lateral distribution of the photoelectron emission intensity as a function of the photon energy. Thus, the PEEM can be used to map the chemical states of constituent elements by X-ray absorption spectroscopy (XAS). In order to investigate the lateral chemical (oxidation/reduction) distributions in CuO-based ReRAM devices [2], we have performed the PEEM observation of planar-type Pt/CuO/Pt resistance-switching devices fabricated on SiO_2/Si substrates (Fig. 1). The XAS-PEEM measurements were performed using a high spatial resolution PEEM (ELMITEC LEEM III) installed at beamline **BL17SU** [3].

Figure 2(a) shows the reduced state map of Cu ions at the Pt/CuO/Pt device obtained from XAS-PEEM measurements. The bright regions in the map indicate the abundance of reduced components such as Cu_2O and/or Cu metal in the CuO matrix. It is clearly seen that the reduced regions vertically run from cathode to anode like a chain of islands, suggesting the formation of a reduction path due to the application of the voltage between the two electrodes. The reduction in chemical states in the filament path is also confirmed from the micro-XAS spectra, as shown in Fig. 2(b); a high degree of reduction from CuO to Cu_2O and/or Cu metal is clearly observed in the filament paths (Region I), while the original CuO components are dominant outside of the filament paths (Region II). Since the conductivity is strongly enhanced by the reduction of CuO [2], these results indicate that the reduction path formed in the CuO channel due to voltage application is responsible for the occurrence of the RS phenomena in Pt/CuO/Pt ReRAM devices. Furthermore, the present study demonstrates the usefulness of the microregion XAS measurements using PEEM for studying the chemical distribution in oxide devices and so on. We hope that this study promotes further XAS-PEEM works on the inhomogeneous chemical states in various types of ReRAM at SPring-8 in the near future.

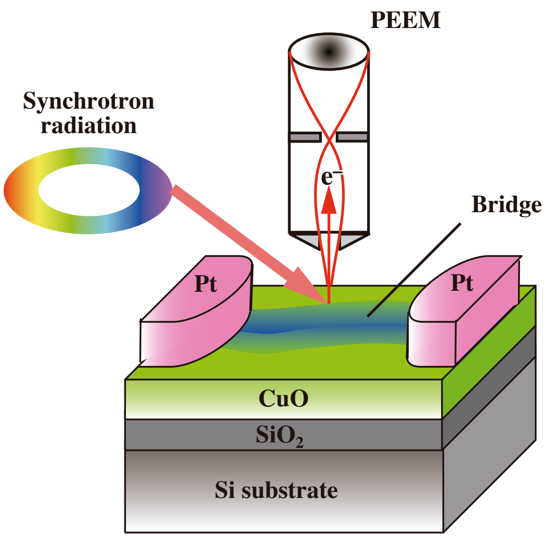

Fig. 1. Schematic illustration of PEEM measurements for Pt/CuO/Pt devices.

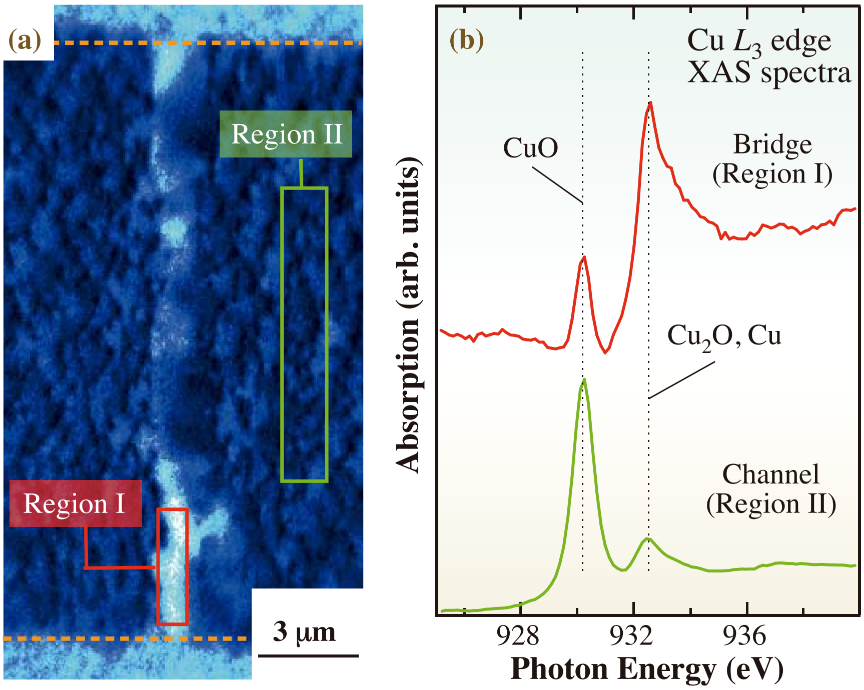

Fig. 2. **(a)** Chemical PEEM image of the planar-type Pt/CuO/Pt device after the application of voltage. The PEEM images were recorded at photon energies corresponding to the Cu L_3 absorption edge. **(b)** XAS spectra recorded in the filament path (Region I) and CuO channel (Region II) near the Cu L_3 absorption edge. These XAS spectra consist of two peaks, which are assigned to the CuO states at 930.3 eV and reduced states (Cu_2O and/or Cu metal) at 932.6 eV.

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