

# Nanometer Resolution XANES Imaging of Individual PC-RAM Devices

Jan H. Richter<sup>1,2</sup>, Milos Krbal<sup>1,2</sup>, Alexander V. Kolobov<sup>1,2,3</sup>, Paul Fons<sup>1,2,3</sup>, Xiamoin Wang<sup>1,2</sup>, Kirill V. Mitrofanov<sup>1</sup>, Robert E. Simpson<sup>1,2</sup>, Junji Tominaga<sup>1,2</sup>, Hitoshi Osawa<sup>3</sup> and Motohiro Suzuki<sup>3</sup>

<sup>1</sup>Nanoelectronics Research Institute, National Institute of Advanced Industrial Science and Technology, 1-1-1 Higashi, Tsukuba, 305-8562, Ibaraki, Japan

<sup>2</sup>Collaborative Research Team Green Nanoelectronics Center, National Institute of Advanced Industrial Science and Technology, 1-1-1 Higashi, Tsukuba, 305-8562, Ibaraki, Japan

<sup>3</sup>SPRING-8, Japan Synchrotron Radiation Institute (JASRI), Kouto 1-1-1, Sayo-cho, Sayo-gun, Hyogo 679-5148, Japan  
e-mail: Jan.Richter@AIST.GO.JP

## ABSTRACT

We present an x-ray absorption spectroscopy study focusing on the changes occurring in individual phase-change ( $\text{Ge}_2\text{Sb}_2\text{Te}_5$ ) memory cells. Synchrotron radiation based x-ray spectroscopy experiments at and around the Ge-K edge (11.105keV) using fluorescence response were carried out employing an x-ray nanobeam. Using Kirkpatrick-Baez x-ray mirror optics this nanobeam was focused into a spot of about 200nm in diameter as confirmed by a knife edge scan [1, 2]. This spot size made it possible to fully contain the x-ray beam within the spatial extent of the active area within a single device cell and enabled us to investigate individual devices without interference from non-switching material surrounding the area of interest. The cells were initially switched into a predetermined state (SET, RESET, as-deposited) at our home lab and then carried to SPRING-8 in order to be investigated. *In situ* switching of the devices and synchronization of the switching event with incident x-ray pulses has been achieved and will enable us to gain time resolved information of the switching dynamics. In this work however the focus is on static measurement of single devices. To this end XANES scan on and in the vicinity of the active area of the devices as well as 2D area

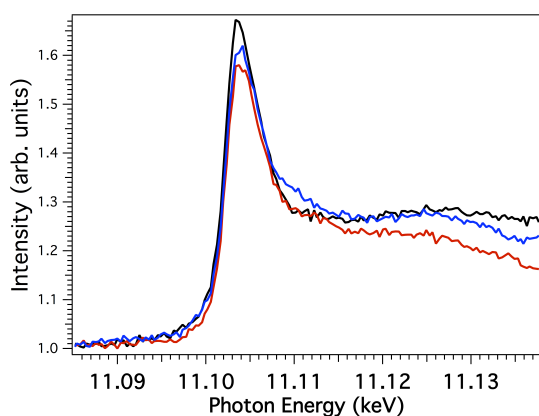


Figure 1: Ge K-edge spectra; red (a), blue (b) and black (c) traces represent spectra taken directly on, partly on and far away from the heater element respectively

maps of the Ge fluorescence response at a constant photon energy have been taken. Figure 1 shows Ge K-edge XANES spectra acquired from a cell containing an amorphous region (290nm x 290nm) embedded in a crystalline background. In order to gain a more complete understanding of the switched area, spatially overlapping XANES scans along a line crossing the switched area were performed. The three different spectra correspond to data collected directly on the heater element (red trace (a)), partly on the heater element (blue trace (b)) and significantly separated from the heater element (black trace (c)). We should thus expect to find evidence for the amorphous phase in trace (a), a superposition of crystalline and amorphous features in trace (b) and a spectra characteristic for crystalline  $\text{Ge}_2\text{Sb}_2\text{Te}_5$  in trace (c). In previous studies it has been found that the x-ray fluorescence response from Ge in  $\text{Ge}_2\text{Sb}_2\text{Te}_5$  exhibits an approximately 10% reduced intensity for the amorphous phase compared to the crystalline phase when excited with a photon energy corresponding to the Ge K-edge white line at about 11.105keV[3]. A slight change in the spectral shape of the Ge K-edge XANES spectra is also expected in the form of a more pronounced shoulder at photon energies just above the main absorption feature (approximately 11.108keV to 11.116keV). In figure 1 we can clearly observe these differences. The spectral shape for traces (a) and (b) contains amorphous contributions, while trace (c) is indicative of the crystalline structure. This is supported by the gradual decrease in intensity of the white line from the spectra recorded in the crystalline background over the one taken partially on the heater element to the one fully contained in the heater element. This indicates we have successfully managed to spatially trace the change of phase with trace (c) showing the crystalline background and trace (a) showing the amorphous region upon the heater element. Trace (b) originates from a superposition of the two different phases. In the following, 2D maps of the active region of the device and the surrounding area of a 290nm x 290nm amorphized cell are presented. To this end the position dependent germanium and tungsten fluorescence intensity response at a fixed photon energy of 11.105keV was recorded in an array of 30x30 data points. In figure 2 two 800nm x 800nm area maps for tungsten and germanium are

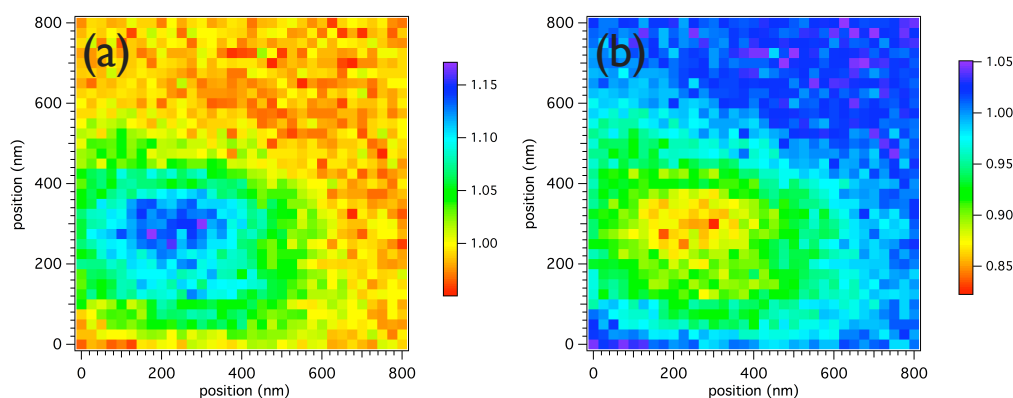


Figure 3: 2D map of an amorphous cell (290nm heater element): tungsten (a) and germanium (b) x-ray fluorescence intensity as a function of position recorded at a photon energy of 11.105 keV. In the bottom left corner of the map (a) the tungsten heater element is visible as an area of elevated intensity and (b) the amorphous area is visible as an area of decreased intensity.

displayed in figures 2 (a) and (b), respectively. In these maps red pixels correspond to low intensity and blue pixel to high. We observe a rather uniform background surrounding an anomaly in the bottom left region of area map. In figure 2(a), the tungsten signal response, a region of elevated intensity about 15% higher than the average background is clearly visible in the bottom left region of the scan indicating the presence of additional

tungsten. The dimension of this anomaly supports the conclusion that this elevated intensity is caused by the presence of the buried tungsten heater element. Figure 2 (b) shows a similar anomaly however with decreased intensity rather than an elevated one. As we recall from earlier we expect to find about 10% less fluorescence intensity response from germanium for the amorphous phase as compared to the crystalline phase when excited with a photon energy corresponding to the Ge K-edge absorption edge white line position. This is in good agreement with the observed decrease in intensity seen in this image. As the thickness of the  $\text{Ge}_2\text{Sb}_2\text{Te}_5$  phase change film and thus the amount of germanium per unit area is constant over the entire chip this change of intensity must result from a change of phase of the material.

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**Key words:** Phase change memory, XANES, nanobeam

#### Biography

2002-2006 Ph.D. at Uppsala University, Sweden with Hans Siegbahn

Thesis: “Electronic Properties of Metal Oxide Films Studied by Core Level Spectroscopy”

Surface science and synchrotron radiation based electron spectroscopy investigation of modification of metal oxide thin film systems.

2006-2008 Research Scientist at Ilika Technologies, Southampton, England

Contract based combinatorial, high throughput sample growth and analysis in the field of phase change memory materials. Construction of experimental equipment, such as static tester and lab maintenance.

2008-2010 Post Doc at Victoria University of Wellington, New Zealand

Growth and investigation of rare-earth nitrides with regard to magnetic properties as potential spintronics materials.

2010- Research Scientist at AIST, Tsukuba, Japan

Investigation of novel design phase change memory structures. Nanobeam investigation of single devices of phase change memory.