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In-situ Observation of Cu Filaments Evolution in SiO_2 layer

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To fully understand the instability and variability issues requires a deep understanding of the physical process of the formation and rupture of the metallic conductive bridge filaments of the CBRAM. In order to understand the dynamics of resistive switching by the formation of the conducting filaments (CF) in CBRAM, we carried out in-situ TEM study with electrical biasing capability to observe the evolution of the conductive filaments. We perform real-time observations of the CF formation and dissolution processes in a typical CBRAM device using in-situ transmission electron microscopy (TEM). By changing the size of the active electrode tip in the memory cell, the metal ions injection can be modified, resulting in different size of the CF. By understanding the origin of the CF evolution in different dimensions, it will offer a chance to take advantage of the CF-size-variable switching nature and guide the design of future CBRAM devices.

In this work, we perform in-situ observations of the CF formation and dissolution processes in a typical CBRAM device of $Cu/SiO_2/W$ structure. By changing the size of the active electrode tip in the memory cell, the metal ions injection can be modified, resulting in different size of the CF. By understanding the origin of the CF evolution in different dimensions, it offers a chance to take advantage of the CF-size-variable switching nature and guide the design of future CBRAM devices. The in-situ TEM experiments were performed in an JEM-2100F microscope. The Cu tip was prepared through electrochemical corrosion in K(OH) solution.

We have directly observed the switching dynamics of $Cu/SiO_2/W$ cells with different active electrode sizes. The conducting filaments (CFs) grow from the active to inert electrode during the SET operations in different sizes. The dimension of the CF is determined by the size of the active electrode, because a wider active electrode can inject more cations into the electrolyte so that build a wider CF. A theoretical model is established to explain and simulate the electrode-size-dependent CF growth in SET operations.

Figure 1 illustrates the schematic of the *in-situ* TEM measurement set-up and the TEM in-situ observation results. The TEM specimen was fixed onto the Cu grid by silver paste inside the Nanofactory™ STM-holder. The W bottom electrode (BE) of the memory device was connected to a source meter through an electrical cable. A Cu tip was installed on a piezo-driven hat. The Cu wire was contacted to the surface of the SiO_2 film to form a $Cu/SiO_2/W$ CBRAM device. During the electrical measurements, an electrical bias was applied to the movable Cu tip respect to the fixed grid holder.

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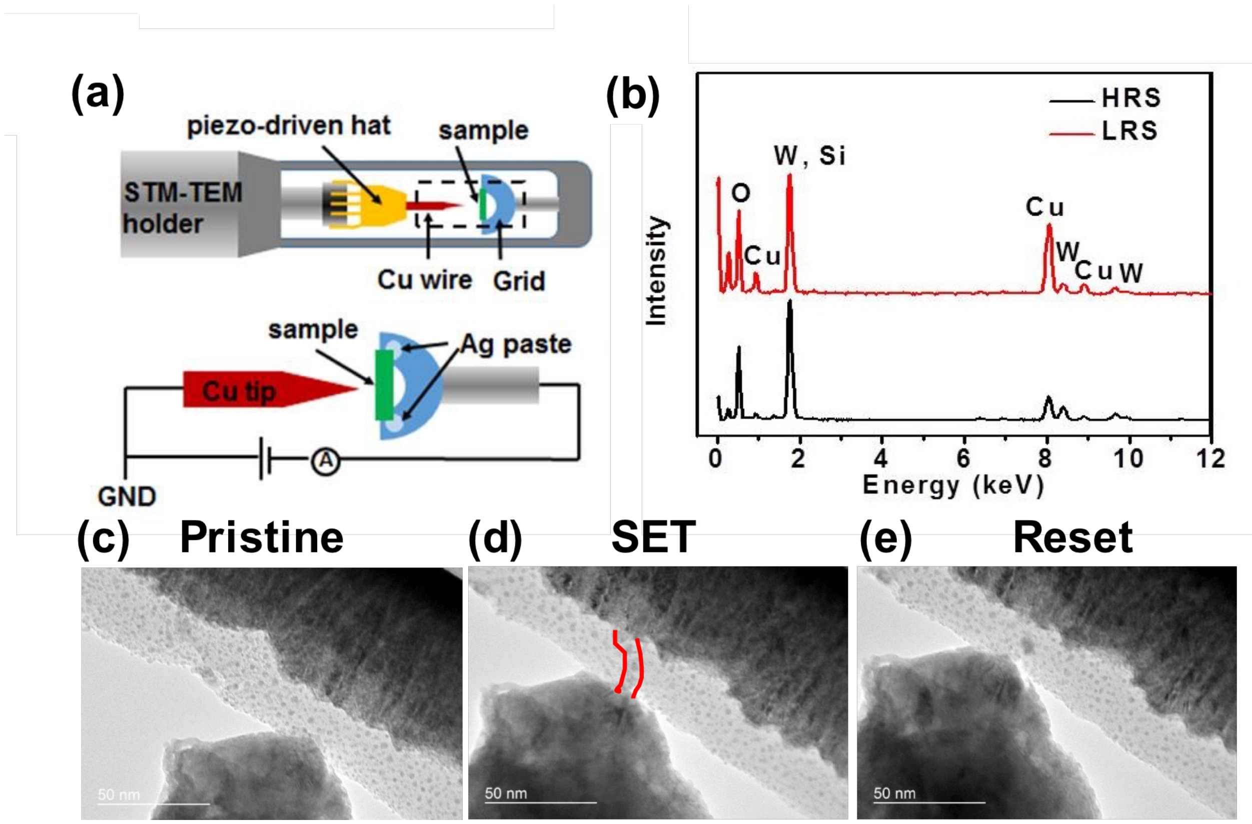

Figure 1. (a) The schematic of the *in-situ* TEM system set-up. (b) EDX analysis of the TEM specimen conducted at the LRS-, and HRS-states. The EDX spectra were sequentially obtained at the CF region, which proves the component of CF is Cu. In-situ TEM images of a CBRAM cell under (c) pristine, (d) SET and (e) RESET states.

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