X-Ray Spectromicroscopy Investigation of Soft and Hard Breakdown in RRAM Devices

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Supplementary data

TXM-NEXAFS

The Ti 2p spectra consist of four main peaks (two doublets). The first doublet (2p3/2) (457-462 eV) originates from transitions to (2p3/2, 3d-t_2g) and (2p3/2, 3d-e_g) states while the second doublet (2p1/2) (462-468 eV) originates from transitions to the corresponding 2p1/2 states. The 2p3/2 – 2p1/2 splitting is due to spin-orbit coupling while the t_2g-e_g separation is the crystal-field splitting due to the surrounding O atoms. [1] In all spectra, the (2p3/2, e_g) peak is broader than the (2p3/2, t_2g) due to the large degree of hybridization of e_g orbitals with O ligand orbitals. [2]
The O 1s spectra can be divided in two regions. The doublet between 528 and 536 eV can be attributed to O 1s excitation to hybrid excited states in which the final level is a mixture of O 2p and Ti 3d orbitals. The spectral features at 531 and 533 eV are assigned to the t2g and eg orbitals, respectively. [3] This region is very sensitive to local symmetry and coordination. Peaks in the region between 536 eV and 555 eV correspond to O 1s excited states in which the final level is a hybridization of O 2p and Ti 4sp orbitals. This region is more sensitive to long-range order. [3]

References


**Figure S.I.1.** Optical images of Dev_SB viewed from the TE (a) before and (b) after switching
Figure S.I.2. SEM images of Dev_SB: (a) device viewed from the top electrode with location of lamella cut (red line) and detail of lamella extraction (inset); (b) lateral view of lamella with details of the damaged region cross-section; (c) electron transparent thin lamella mounted on W pillar
**Figure S.I.3.** Dev_HB: (a) 3D AFM image of selected defect area; (b) deflection error image with detailed zoom on a “linear” crater
Figure S.I.4. SEM images of Dev_HB. (a) device viewed from the top electrode with location of lamella cut (red line) and detail of lamella extraction (inset); (b) lateral view of lamella with details of the damaged region cross-section; (c) electron transparent thin lamella mounted on W pillar
Kelvin Probe Force Microscopy (KPFM)

Kelvin Probe Force Microscopy (KPFM) measurements were carried out using a Bruker Icon microscope with a NanoScope V Controller. We used highly doped silicon cantilever (Bruker Otespa R3). Nanoscope analysis v1.5 [1] was used to process the imaging data.

Figure S.I.5. Selected area of Dev_HB: (a) SEM image, (b) AFM topography, (c) KPFM potential map.