Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

Nanoscopic structural rearrangements of the Cu-filament in conductive-bridge memories.

U. Celano,[a,b] G. Giammaria[a, †], L. Goux[b], A. Belmonte[a], M. Jurczak[a], and W. Vandervorst[a,b]

[a] IMEC, Kapeldreef 75, B-3001 Heverlee (Leuven), Belgium

[b] KU Leuven, Department of Physics and Astronomy (IKS), Celestijnenlaan200D, 3001 Leuven, Belgium.

[†] *currently with* University of Twente, 7500 AE Enschede, The Netherlands

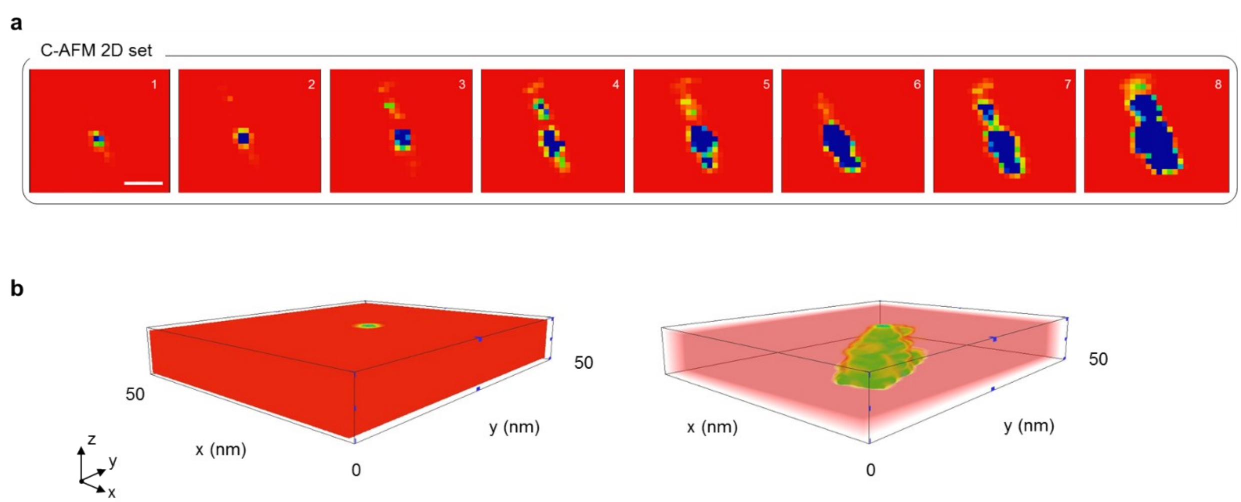

Figure S1. (a) Evolution from the top surface to the oxide/Cu interface of the C-AFM current maps used as 2D dataset for the 3D interpolation (scale bar 20 nm). (b) After interpolation the area of the filament is observed in 3D and the CF appears by subtracting the contribution of low current regions within the 3D tomogram.

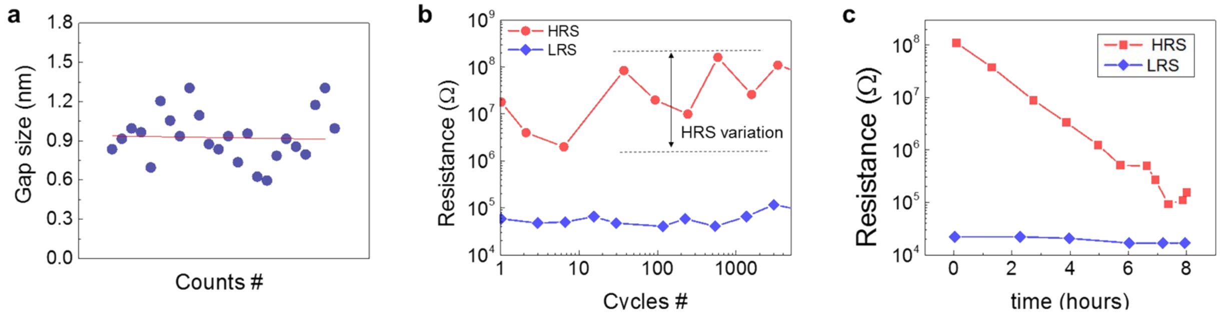

Figure S2. **(a)** By fitting some tens of tip-induced I-V characteristics we obtain the average value for the tunnel barrier gap size formed after filament rupture. Note the large dispersion that is due to the formation of slightly different tunnel gaps on every reset cycle. **(b)** The same effect is at the foundation of the large fluctuation observed in the HRS level in an endurance test for this type of CBRAM test vehicle. **(c)** As a consequence of the subnanometer tunnel gap formed, this type of CBRAM devices also present a poor HRS retention, during a temperature accelerated retention test (here reported at 150 ^{o}C), the LRS does not show instability while the HRS is rapidly degraded due to the thermally activated Cu migration that restores the filament in the tunnel gap.

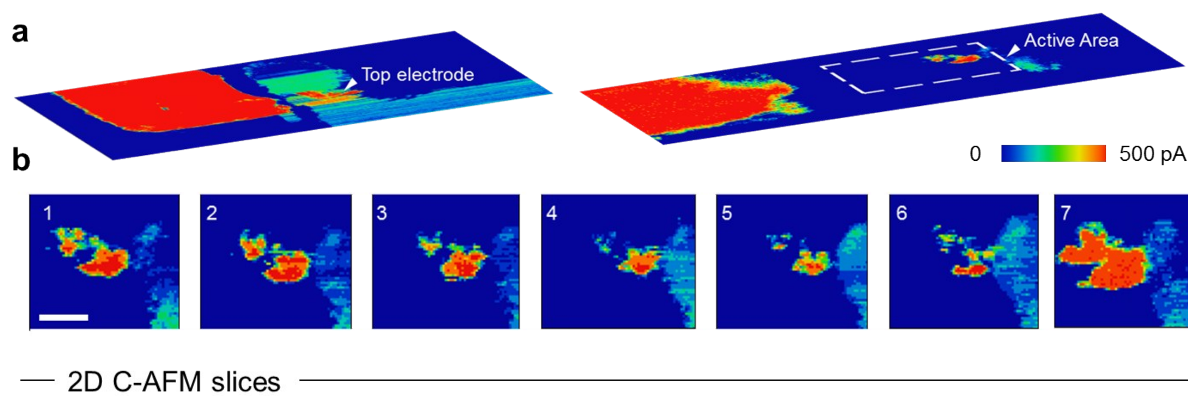

Figure S3. 2D current maps of the device under test (programmed at 100 microampere C.C.). The device is imaged with C-AFM while the top electrode is still present **(a)** (left inset). Once the top electrode is removed (right inset), the slicing of the oxide can start. **(b)** Complete evolution inside the switching layer of the conductive filament (scale bar 25 nm). Note the appearance of the two spots and the sudden change in shape of the left spots during the progressive removal of the oxide.