Electric field in-situ TEM of metal-insulator-metal devices

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Recent advances in microelectromechanical systems (MEMS) based chips for in-situ transmission electron microscopy are opening exciting new avenues in nanoscale research [1]. The capability to perform current-voltage measurements while simultaneously analyzing the corresponding structural, chemical or even electronic structure changes during device operation would be a major breakthrough in the field of nanoelectronics. We aim to directly link the atomic structure to the physical properties, under working or so called operando conditions, in electrically contacted electron transparent lamellae of defined metal-insulator-metal (MIM) structures. Here, we present our current advances in two MIM device systems that are relevant, for example, for random access memory devices (RRAM) or microwave applications.

In the first case, we have demonstrated for the first time how to electrically contact and operate a lamella cut from a resistive random access memory (RRAM) device based on a Pt/HfO_2/TiN MIM-structure [1]. The device was fabricated using a focused ion beam (FIB) instrument and an in-situ lift-out system. The electrical switching characteristics of the resulting electron-transparent lamella were comparable to a conventional reference device. The lamella structure was initially found to be in a low resistance state and could be reset progressively to higher resistance states by increasing the positive bias applied to the Pt anode (figure 1a-d).This could be followed up with unipolar set/reset operations where the current compliance during set was limited to 400 µA. FIB structures allowing to operate and at the same time characterize electronic devices will be an important tool to improve RRAM device performance based on a microstructural understanding of the switching mechanism [1, 2]. The second system consists of a Pt/$Ba_{0.4}Sr_{0.6}TiO_3$/$SrTiO_3$/$SrMoO_3$/$SrTiO_3$/$GdScO_3$ epitaxial oxide thin-film heterostructures. By using a FIB in-situ lift-out routine we fabricated an electron transparent lamella device and contacted it on a special biasing nano-chip (Figure 2a). Epitaxial growth of highly conducting $SrMoO_3$ as oxide bottom electrode [3], followed by epitaxial growth of (Ba,Sr)TiO_3 as dielectric material, and then deposition of Pt/Au as top electrode results in a tunable capacitor with superior microwave performance. We studied the variations in the local crystal structure of the (Ba, Sr)TiO_3 thin film layer in-situ under electric field by using High-Angle Annular Dark-Field (HAADF) imaging in the scanning transmission electron microscope (STEM).

References:

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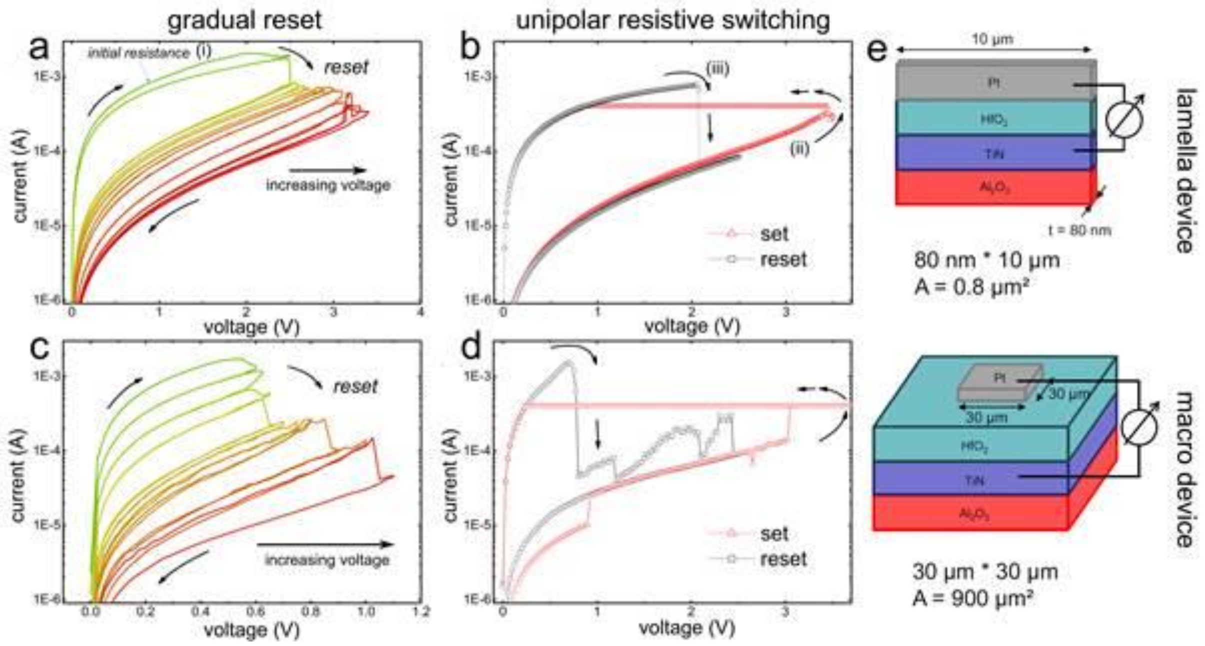

Figure 1: a. Initial gradual reset operation in a Pt/HfO_2/TiN lamella device, b. Unipolar switching of the lamella device, c. Gradual reset operation of the macro device, d. Unipolar switching of the macro device, e. Schematics showing the device geometries used for the switching experiments.

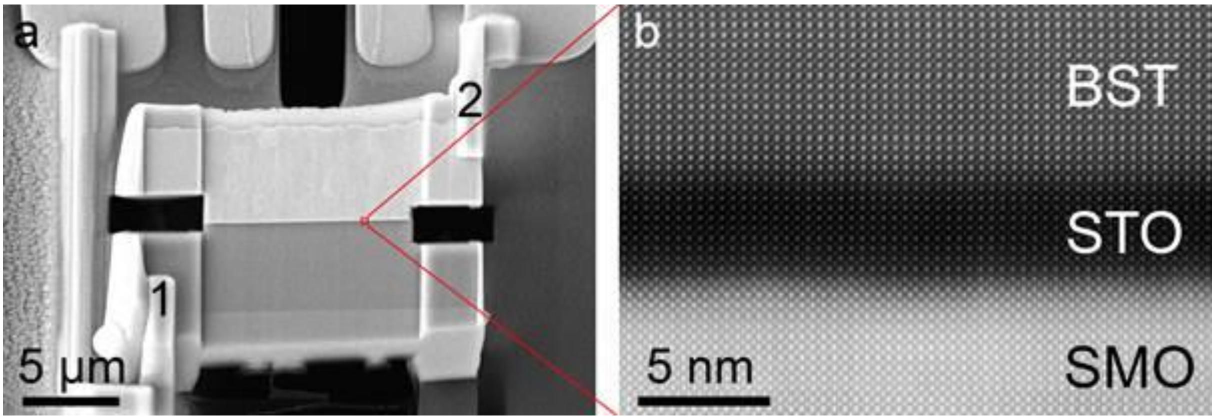

Figure 2: a. SEM image of the contacted lamella where the two used electrodes are denoted as 1 and 2, b. PCA filtered HAADF-STEM image of the SMO electrode, STO blocking layer and BST thin film.