Progress, prospects and challenges for *in situ* transmission electron microscopy of electrical and magnetic switching processes in functional materials and nanoscale devices

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The local electrical and magnetic properties of nanoscale materials and devices such as transistors, field emitters and memory cells can be affected by the presence of defects, dopants, interfaces and surfaces, as well as by local variations in morphology, chemical composition and crystallographic orientation. We are developing both diffraction contrast and phase contrast techniques in the transmission electron microscope, in combination with model-based and model-independent data analysis, for the study of electrical and magnetic switching processes in functional materials and nanoscale devices. I will illustrate how such measurements can be made in the presence of external stimuli such as applied voltage, temperature, reactive gas and light. I will highlight key experimental issues that need to be considered, including the influence of sample preparation, dynamical diffraction and electron-beam-induced charging. As a representative example, Fig. 1 illustrates the switching of an individual Ag-In-Sb-Te resistive-switching-based phase change memory device between a low resistance state and a high resistance state in the transmission electron microscope using short (<50 ns) current pulses. I will conclude with a perspective on future developments in instrumentation and techniques that may allow such measurements to be made with greater reliability, sensitivity, precision and accuracy.

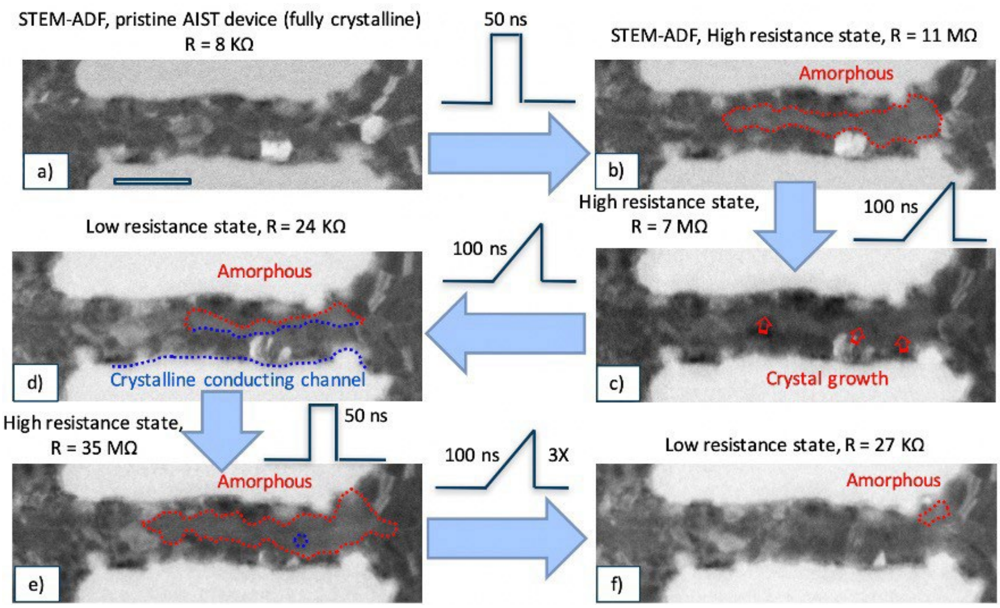

Figure 1. Annular dark-field scanning transmission electron microscopy images recorded during the switching of a Ag-In-Sb-Te phase change memory line cell. a) Pristine crystalline low resistance state (LRS) switched using a square pulse of duration 50 ns to b) a high resistance state (HRS). An amorphous region is outlined by a red dashed line. Images recorded after first and second "sweep" pulses (of duration 100 ns) are shown in c) and d) for the HRS and LRS, respectively. A crystalline conducting channel is marked with a blue dashed line. e, f) Subsequent switching from the HRS to the LRS. The scale bar is 80 nm.