In-situ Transmission Electron Microscopy Investigation of Ferroelectric Domain Switching

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Ferroelectrics result from the displacement of ions that leads to spontaneous polarization with the internal electric field pointing towards a specific direction in materials. A region with the same polarization direction is called a ferroelectric domain. Understanding ferroelectric domain switching behaviour under external stimuli is extremely important for the applications of ferroelectrics in memories, actuators and nanoelectronic devices.

Reversible and precise ferroelectric domain manipulation with a high spatial resolution is critical for memory storage devices based on thin film ferroelectric materials. Here we demonstrate experimentally that a high-energy electron beam (e-beam) from the transmission electron microscope (TEM) can be used to precisely and reversibly control ferroelectric nano-domain morphology. Our results suggest that local accumulation of trapped electrons contribute to the local electric field that determines domain configurations. Although high-energy e-beam has been widely used for imaging and for local materials heating, its capability of generating a controllable local omni directional electric field has not been well explored. Compared with the existing domain manipulation techniques, TEM presents an ultrahigh spatial resolution and local nanoscale charges that generate an external electric field along all directions, which potentially allows nanoscale domain writing.

Nanoscale ferroelectric domain structures can also be manipulated by uniaxial electric field and mechanical loading. Our in-situ electron microscopy experiments and phase-field simulations revealed the domain switching processes of ferroelectric single crystals under different external loading conditions. Hierarchical ferroelastic domain transition was found when significant mechanical stress was applied. Phase-field simulations confirmed the experimental observations that the 90° ferroelastic transition takes place under electrical poling with mechanical loading, while 180° micro tetragonal domain reversal occurs under electrical loading without mechanical loading. The formation of 90° nano domains assists ferroelectric domain switching and reduces the threshold field for the domain switching by 40%, indicating the unique role of mechanical loading plays during the electrical poling. This study provides new insights into achieving a controllable ferroelastic transition to facilitate ferroelectric switching in bulk ferroelectric materials.