TEM Techniques for Charge, Strain and Polarization Mapping

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Modern device technology has been continuously developed to a level requiring the precise control of local lattice strain, polarization and free charge carriers within nanometer-scale materials and/or across interfaces. Ultimately, seeing the change of these properties in-situ during device operation paves the way for unambiguous understanding of the operation mechanisms and also for further optimization of device performance. Recent advances in TEM instrumentation enables direct observation of the switching processes of various non-volatile memory devices at working conditions in real-time. In this talk, I will present a few case studies in which advanced TEM techniques, such as electron holography and in-situ TEM, are used to address these challenging issues. In the first example, the amorphous-to-crystalline phase transition of Ge-Sb-Te (GST)-based vertical phase change random access memory (PCRAM) was observed by applying DC voltages in TEM, showing that the microstructure of GST, particularly the passive component surrounding the active switching volume, plays a critical role in determining the local temperature distribution and is therefore responsible for cell-to-cell inconsistent switching behaviors [1]. The in-situ TEM results also reveal that the failure of PCRAM occurs via two-step void formation due to the phase separation accelerated in the molten GST by the polarity-dependent atomic migration of constituent elements. In the second, the 180° polarization switching process of an epitaxial $PbZr_{0.2}Ti_{0.8}O_3$ (PZT) thin film capacitor has been observed [2]. The preferential, but asymmetric, nucleation and forward growth of switched *c*-domains were observed at the PZT/electrode interfaces, arising due to the built-in electric field induced at each interface. It was found that the preexisting *a*-domains split into fine *a*- and *c*-domains constituting a 90° stripe domain pattern during the 180° polarization switching process, revealing that these domains also actively participated in the out-of-plane polarization switching. Finally, as a model resistive random access memory (ReRAM), I will show in-situ TEM observation of the multi-level switching of a $TiN/Pr_{0.7}Ca_{0.3}MnO_3$ (PCMO)-based ReRAM which utilizes the resistance change as the two materials goes through reversible redox reactions at the interface. Based on the direct observations of the microstructural evolutionand correlated *I-V* characteristics, a resistive switching model for TiN/PCMO devices will be presented [3].

References

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