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Optimizing HfO_2-based RRAM through modeling of the operation processes

Gennadi Bersuker
SEMATECH
gennadi.bersuker@sematech.org

Non-volatile resistive random access memory (RRAM) devices are actively investigated for storage class and advanced embedded applications. The intended applications impose strict limits not only on device performance characteristics but also on the manufacturing cost. In this respect, the RRAM devices fabricated using fab-friendly TiN and HfO_2-based materials have recently moved to the forefront by demonstrating low switching times, high endurance, and low power consumption. However, not all of the reported impressive results, which clearly demonstrate the capability of this technology to meet the performance targets, were obtained on the same device stacks. This indicates that reaching the targets may require implementing trade-offs through both engineering of the RRAM stacks and optimizing operation conditions. This goal can be effectively assisted by employing physical models of the processes responsible for the switching operations.

In spite of significant efforts, no consensus has yet been reached on the RRAM mechanism although it is well-established that the resistive switching involves the formation/disruption of a conductive filament in hafnia. While RRAM devices fabricated using a variety of dielectric materials exhibit electrically similar characteristics, the underlying mechanisms can be material-specific. Thus, the critical step in developing of the physical model is to establish the relation between electrical properties of the HfO_2 film and its morphology and stoichiometry.

This presentation discusses how the nanoscale characteristics of the HfO_2 film, as determined by STM, C-AFM and XPS studies, affect formation of the conductive filament and the impact of the filament properties on resistive switching in the hafnia-based RRAM. Modeling the electron transport through the metal oxide film prior to a filament formation, as well as in high and low resistive states after the forming, allows the filament features responsible for the resistance changes to be extracted, which provides insight into the key processes governing the switching.

Based on the characterization results and ab initio modeling of the hafnia structure, the atomic-level description of the physical processes controlling the formation of the metal-rich filament and its re-oxidation during the reset operation has been developed. Within the proposed description, the key processes include the metal-oxygen bond breakage and subsequent oxygen ions diffusion and distribution in the surrounding oxide, the latter is shown to affect significantly the device switching characteristics. The model successfully reproduces experimental results on the effects of the forming temperature and voltage on filament stability, reset pulse amplitude on read current in the high resistive state, random telegraph noise, etc.