Anti-ferroelectric HfO_2 or ZrO_2: A Key Material for Novel Anti-ferroelectric Non-volatile Memories

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Ferroelectric properties of Si:HfO_2 were first reported in 2011 [1]. In the past years, the existence of a non-polar phase was experimentally verified [2,3] and together with theoretical work, stabilization mechanisms for this phase could be elucidated [4,5]. Moreover, the electric field cycling behavior of ferroelectric hafnia has emerged as one of the main topics of study [6,7]. This electric field cycling behavior [6] includes wake-up, fatigue, and imprint. All three phenomena are highly relevant for ferroelectric memories applications. Similar to PZT based devices [9], HfO_2 based anti-ferroelectric (AFE) dielectrics have a drastically improved field cycling behavior compared to their ferroelectric counterparts resulting in high endurance strength but at the same time volatile memory behavior. Based on Landau-Ginzburg-Devonshire theory, we proposed a simple way how non-volatility can be achieved in AFE ZrO2 based stacks [8]. By employing electrodes with different workfunction values, an internal bias field is introduced within the AFE stack. This bias field modulates the free energy landscape, thus creating two stable non-volatile states by centering one of the AFE polarizations vs. field branches (figure 1). Moreover, we report the fabrication of the world's first non-volatile AFE capacitor for AFE-RAM (random access memory) applications. Detailed characterization confirmed the high endurance and reliable operation of this non-volatile stack (figure 2).

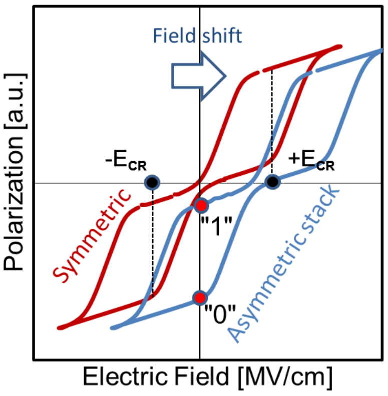

Fig. 1: Built-in bias induced centering of one of the loops of an AFE hysteresis enabling non-volatility of the AFE memory device.

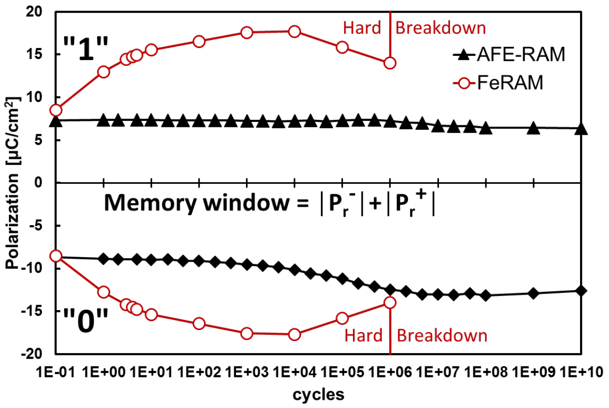

Fig. 2: Field cycling behavior of FE vs AFE capacitors for AFE-RAM applications

Remarkably, this film stack can be optimized using the knowledge of a current volatile DRAM capacitor. Here, an Al_2O_3 interlayer is introduced within the crystallized tetragonal ZrO_2 layer to improve the reliability of the capacitor device and to enable three dimensional high aspect ratio structures on highly scaled 20 nm technology nodes. Using a similar improvement, the reliability of the AFE RAM capacitor can be significantly improved without influencing the AFE properties of the ZrO_2 dielectric even in a 3D structure. Utilizing this feature we have demonstrated that the exceptional endurance of anti-ferroelectric ZrO_2 made a state-of-the-art DRAM stack non-volatile (figure 2). Detailed electrical characterization show high endurance as well as retention values that can be extrapolated to 10 years. By providing the speed of FE memories while enabling stable and low power operation, AFE-RAM could make highly scaled devices possible and significantly impact the non-volatile memory industry.

References

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