Optimization of Zirconium doped Hafnia-Based Ferroelectric Capacitive Memories via Thermal Annealing

Ziyi Wang, Tarun Maredla, Daniel Sabrsula[1], Ana Cohen[1], David Barth[1], and Lucas Barreto[1]

[1]*Singh Center for Nanotechnology, University of Pennsylvania, Philadelphia, PA 19104, USA*

Ferroelectric hafnia-based devices have emerged as a compelling candidate for next-generation non-volatile memory due to their CMOS compatibility, scalability to nanometer thicknesses, and robust polarization switching. In particular, zirconium-doped hafnium oxide (HZO) has attracted significant attention because appropriate Zr incorporation stabilizes the non-centrosymmetric orthorhombic phase responsible for ferroelectricity. A typical ferroelectric capacitive memory device consists of a metal–ferroelectric–metal (MFM) stack, where the ferroelectric layer stores information through its remanent polarization states. By applying an external electric field, the polarization can be switched between two stable states, enabling non-volatile data storage with fast switching speed and low power operation.

The ferroelectric properties of HZO are highly sensitive not only to Zr concentration but also to post-deposition thermal processing. Thermal annealing plays a critical role in crystallization dynamics, phase formation, grain structure evolution, and defect redistribution within the thin film. Improper annealing conditions may result in the dominance of the monoclinic or tetragonal phases, which suppress ferroelectric behavior, whereas optimized annealing promotes the formation of the orthorhombic phase and enhances polarization stability. Therefore, understanding and optimizing the annealing process is essential for achieving high-performance ferroelectric capacitive memories.

In this work, we systematically investigate the impact of thermal annealing on Zr-doped Hafnia MFM capacitors. Devices are fabricated with varying annealing temperatures and durations to study their influence on phase transformation and ferroelectric performance. We measure polarization–electric field (P–E) hysteresis loops, positive-up-negative-down (PUND), and endurance behavior to evaluate remanent polarization (P_r), coercive field (E_c), and fatigue properties under different annealing conditions. Structural characterization is correlated with electrical measurements to identify the optimal annealing window that maximizes ferroelectric phase stabilization while minimizing leakage and wake-up effects. The results are compared across multiple annealing profiles to determine how thermal treatment tunes the memory window and device reliability in HZO-based ferroelectric capacitors.