Position-Tuned Internal Å-Scale Al_2O_3 Barriers for Fatigue-Resistant HZO Capacitors

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Ferroelectric $HfZrO_2$ (HZO) capacitors suffer from endurance degradation, primarily due to polarization fatigue and increased leakage current density during cycling [1]. In this work, we demonstrate that inserting Å-scale Al_2O_3 layers within the HZO layer tuning their relative positions enables control over the trade-off between remnant polarization, leakage current, and fatigue performance.

All devices consist of TiN/HZO/TiN stacks with a total HZO thickness of 100 ALD cycles. In the three position-tuned configurations (**Dual-52c**, **Dual-72c**, and **Dual-92c**), two symmetric Å-scale Al_2O_3 layers (1 ALD cycle each) were inserted within the HZO layer at varying depths. The Al_2O_3-to-Al_2O_3 spacing was adjusted by varying the central HZO thickness to 52, 72, and 92 cycles, respectively, while the remaining HZO cycles were evenly distributed between the top and bottom segments (i.e., 24/14/4 cycles per side).

Switching speeds were first extracted using voltage pulses (3.5V, 10 ns to 10 µs), and the stress-pulse width was set per device at the point of 90% switching to ensure consistent endurance conditions. As the barrier spacing decreases, $2P_r$ gradually decreases, but leakage current improves (**Fig. 1**). The HZO-only device shows the highest $2P_r$ but suffers from fast leakage growth and early breakdown. Dual-72c, achieves one order of magnitude lower leakage, negligible $2P_r$ degradation up to 10^{10} cycles, and delayed dielectric breakdown (**Fig. 2(a)**). Furthermore, leakage current measured across cycling reveals that the rate of leakage increase slows systematically from HZO-only to Dual-72c, correlating with improved endurance and failure cycles (**Fig. 2(b)**). Our results highlight the importance of spatial control in barrier engineering for fatigue-resilient ferroelectric devices.

References

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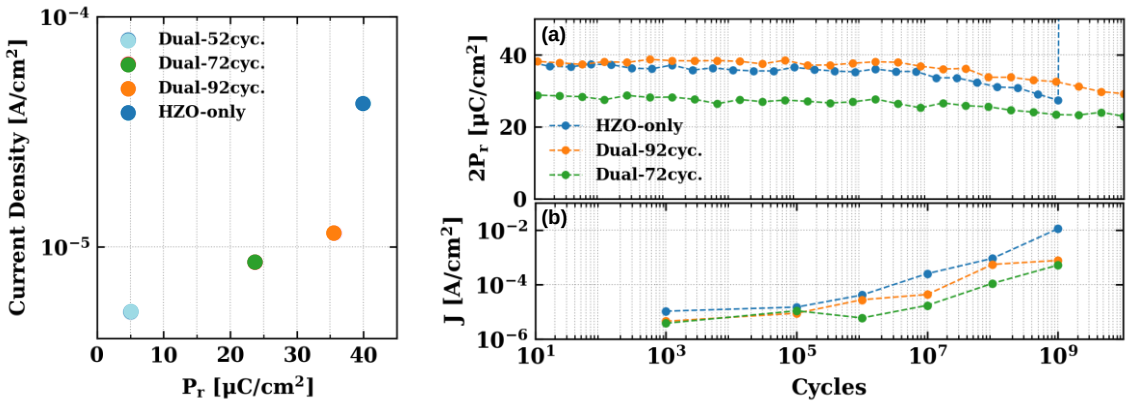

Fig1. Trade-off between remnant polarization ($2P_r$) and leakage current density at 1.5 V for position-tuned Al_2O_3-inserted devices and HZO-only device.

Fig2. (a) Endurance characteristics measured using device-specific pulse widths corresponding to 90% switching: **(a)** $2P_r$ vs. cycles and **(b)** leakage current (J) vs. cycles.