Assessing the Scalability of HfO_2 for Next-Generation Non-Volatile Memory Technologies

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The exponential growth in data generated by increasingly common intelligent systems in modern life ―encompassing the scope of the terms Internet of Things (IoT) and artificial intelligence (AI)― has necessitated continuous advancements in the technology that manages this data. As a result, innovations such as embedded memory in System-on-Chip (SoC) architectures or the idea of Logic-in-Memory (LiM) architectures has led to a reconsideration of the management of the computational demands on the processing unit. Despite these architectural shifts, memory remains a foundational component, with core requirements that remain unchanged: performance, reliability and cost-efficiency.

As the scaling of conventional memory technologies approaches physical and economic limits, considerations of area efficiency and alternative scalability have gained prominence. In this context, hafnium oxide (HfO_2) remains a versatile material, with potential applications across a range of "next-generation" non-volatile memory technologies, including Resistive RAM (RRAM) [1], Ferroelectric RAM (FeRAM) [2], Non-Volatile DRAM (NVDRAM) [3], and Ferroelectric FETs (FeFETs) [4].

Central to this appeal is the material's demonstrated capability to achieve high endurance and robust data retention [2], [3]. Still, it is relevant to assess the topic of scalability of HfO_2 to understand how most literature transfers to direct implementations. This work aims to examine scalability in a generalized geometric reduction manner, as well as regarding multiple-state operation, implying a quasi-scaling method by increasing memory density. First, a review on the impact of capacitor area and oxide thickness reduction is performed. Afterwards, an evaluation of the multiple-state operability of ferroelectric HfO_2 capacitors is approached by demonstrating the stability of intermediary states as depicted in Fig. 1. Finally, a discussion of potential applications is undertaken, where, by considering the scalability of HfO_2, it may be possible to achieve smaller footprints compared to the expectations of current prevalent technology, as compared in Fig. 2 for SRAM vs. FeRAM. In this context, the potential for enabling high-performance, dense, and energy-efficient non-volatile memory is highlighted here.

References

[1] K. Moon *et al.*, *Faraday Discuss.*, vol. 213, pp. 421–451, 2019, doi: 10.1039/C8FD00127H.

[2] J. Okuno *et al.*, *2021 IEEE IMW*: IEEE, May 2021, pp. 1–3. doi: 10.1109/IMW51353.2021.9439595.

[3] N. Ramaswamy *et al.*, *2023 IEEE IEDM*: IEEE, Dec. 2023, pp. 1–4. doi: 10.1109/IEDM45741.2023.10413848.

[4] S. Dunkel *et al.*, *2017 IEEE IEDM*: IEEE, Dec. 2017, p. 19.7.1-19.7.4. doi: 10.1109/IEDM.2017.8268425.

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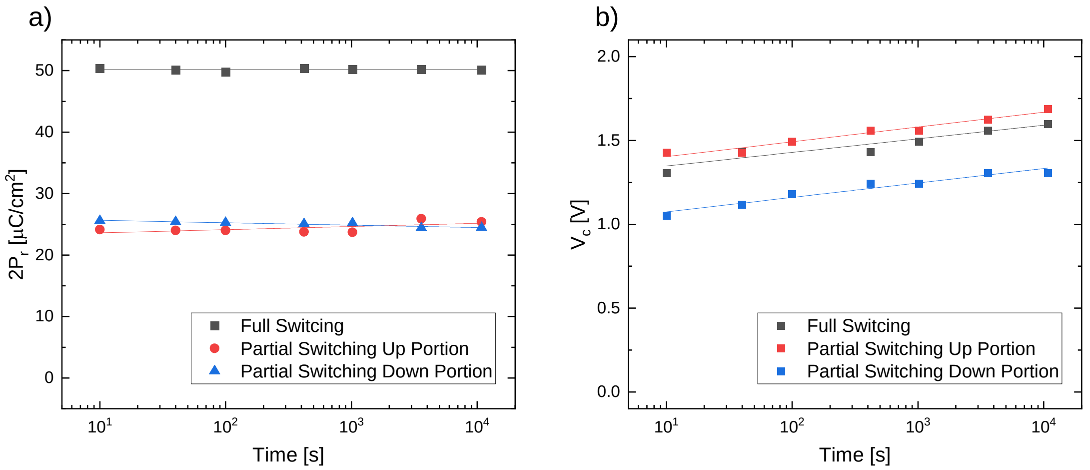

Fig. 1. Comparison of a) double remanent polarization ($2P_r$) and b) coercive voltage (V_c) vs. time after different storage times during a retention measurement of metal-ferroelectric-metal HfO_2-based capacitors. Three states are monitored: a fully switched film and the up and down portion of a partially switched film, roughly set at a 50% switching state of the maximum $2P_r$.

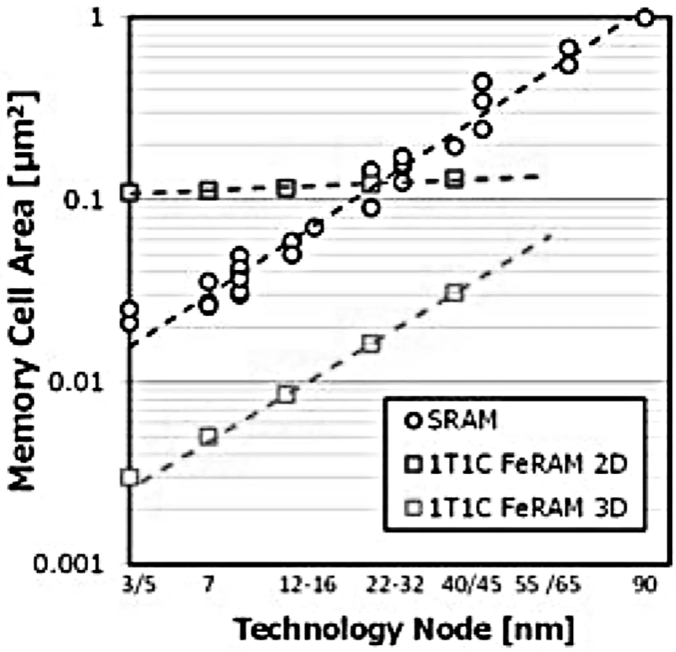

Fig. 2. Comparison of the memory cell area at different technology nodes for three different memory technology designs (J. Okuno, IEDM 2023).