Ferroelectric Intelligence: Physics-Informed Modeling of FeFET for Edge Computing

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The rapid proliferation of edge intelligence demands computing hardware that simultaneously delivers ultra-low energy consumption, high reliability, and tight integration of memory and computation [1]. Hafnium-oxide–based ferroelectric field-effect transistors (FeFETs) have emerged as strong candidates for such platforms due to their CMOS compatibility, nonvolatile operation, and intrinsic capability for analog and multi-level conductance modulation [2]. However, the practical adoption of FeFET for edge and near-sensor computing is fundamentally limited by reliability challenges originating from ferroelectric material physics and gate-stack electrostatics, which directly impact circuit- and system-level robustness [3, 4].

This work presents a comprehensive physics-based numerical investigation of FeFET devices, with a specific focus on their suitability for reliable analog and in-memory computing at the edge. The modeling framework captures key ferroelectric phenomena, including polarization switching dynamics, depolarization fields, charge trapping and de-trapping, and wake-up effects, endurance fatigue, and nonlinear/asymmetric threshold-voltage modulation. By explicitly resolving multi-domain ferroelectric behavior and its interaction with transistor electrostatics, the study establishes quantitative links between material properties, gate-stack design, and analog conductance stability.

Through systematic numerical analysis, the impact of intrinsic variability, memory-window scaling, read/write disturbance, and long-term reliability degradation on edge-level operation is quantified. The results reveal critical tradeoffs between energy efficiency, analog linearity, and endurance, and identify operating regimes and material-stack configurations that inherently enhance robustness against non-idealities relevant to edge workloads.

By leveraging physics-informed modeling, this work provides a reliability-aware design pathway for optimizing FeFETs as dependable analog and multi-level computing primitives. The proposed framework bridges ferroelectric material physics and edge-system performance, enabling scalable, low-power FeFET-based architectures capable of supporting trustworthy edge intelligence beyond conventional von Neumann computing paradigms.

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