Argon-Ion Plasma Defect Engineering of GaN Memristors for Multilevel Conductance and Quantized Synapses in Leaky-Integrate & Fire Networks

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Artificial intelligence hardware is increasingly constrained by the energy cost of data movement: a single DRAM access can consume 200× the energy of an on-chip compute operation. Neuromorphic computing reduces this bottleneck by integrating memory and computation. However, a key challenge is low precision, as learning is often demonstrated using idealized synaptic weights rather than actual physical states of the devices. This study investigated whether defect-engineered gallium nitride memristors could support hardware-constrained neuromorphic learning by fabricating and characterizing GaN memristors, constraining a Spiking Neural Network to measured conductance states. Memristive behavior was induced in GaN by argon-ion plasma treatment, introducing lattice defects and tuning charge trapping behavior. Dynamic I-V sweeps and pulse programming were used to quantify resistive switching, analog programmability, and state stability. Pulse-train measurements were converted into discrete conductance states and implemented as differential conductance pairs (G+ - G-). Treated devices showed reproducible resistive switching, pulse-dependent conductance modulation, and 27-29 stable monotonic conductance levels; when integrated into a logic circuit, they also enabled adaptive learning. The device-constrained network achieved 86.8% test accuracy on the MNIST handwritten-digit task. Spike-driven inference reduced the estimated synaptic workload by ~6×, while weight storage decreased ~3.2× relative to float32 parameters. This study demonstrates that defect-engineered GaN memristors can support hardware-constrained neuromorphic learning using experimentally measured conductance states, advancing toward low-power edge AI, neuromorphic sensors, and embedded intelligent systems.

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