Low-Power Multiply-and-Accumulate Operations Using 2D Material-Based ECRAM Devices

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The rising complexity of modern computation demands increasingly efficient electronic devices. As integrated circuits (ICs) shrink, on-chip power density increases, leading to thermal constraints and performance degradation. Addressing this requires fundamentally more energy-efficient architectures. Neuromorphic computing offers a solution by integrating memory and processing, reducing energy-intensive data transfer inherent in von Neumann systems Non-volatile memory (NVM) devices such as Resistive RAM (ReRAM)[1], Phase-Change RAM (PCRAM)[2], Ferroelectric RAM (FeRAM)[3], and Electrochemical RAM (ECRAM)[4] enable in-memory computing through diverse physical mechanisms. High-performance neuromorphic systems require devices with large on/off ratios, multiple stable conductance states, linear and symmetric updates, and low energy consumption[5]. ECRAM stands out for meeting all these criteria[6,7,8]. In this work, we report on the fabrication and characterization of ECRAM devices based on two-dimensional (2D) materials, demonstrating up to 128 programming stable and distinct conductance states. We further design and evaluate crossbar array architecture incorporating these multi-state devices for energy-efficient multiply-and-accumulate (MAC) operations. Our results reveal high throughput, reduced energy consumption, and adaptable configurability, underscoring the potential of 2D ECRAM-based crossbars in accelerating linear algebra operations and enabling future hardware platforms for AI and scientific computing.

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