Filament-free Multilayer Bulk RRAM for Energy Efficient Compute in Memory

Duygu Kuzum*, Yucheng Zhou, Ashwani Kumar, Yue Zhou
Electrical and Computer Engineering Department, University of California San Diego, La Jolla, CA, United States

Filamentary resistive switching mechanisms in conventional RRAM technologies introduce variability, noise, and endurance limitations that hinder their deployment in neuromorphic and compute in memory systems. We present a filament-free bulk-switching RRAM (b-RRAM) technology that overcomes these challenges through systematic engineering of a trilayer metal-oxide stack [1,2]. By tuning the oxygen vacancy distribution across a TiO_x switching layer and integrating an AI-Ti-O tunnel barrier, we achieve stable filament-free resistive switching with strong nonlinearity, high retention and endurance without use of a compliance current.

Device-level characterization demonstrates multi-level resistance states up to 128 levels at MΩ-regime, enabled by the bulk switching mechanism. A compact physics-based model is developed, accurately capturing both DC and pulsed switching behaviors and enabling reliable circuit- and system-level simulations [3].

We integrate b-RRAM crossbars into a neuromorphic compute-in-memory platform to implement two edge-AI workloads: (1) a spiking neural network for real-time autonomous navigation, and (2) a dendritic computation-based few-shot learning algorithm leveraging behavioral time-scale plasticity. The platform supports on-chip, continual weight updates and rapid learning from few samples.

This work demonstrates the potential of filament-free b-RRAM for reliable, energy-efficient compute in memory and neuromorphic computing applications under tight area and power constraints, addressing key scalability barriers of filamentary RRAM.

References

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* Corresponding author: email: dkuzum@ucsd.edu

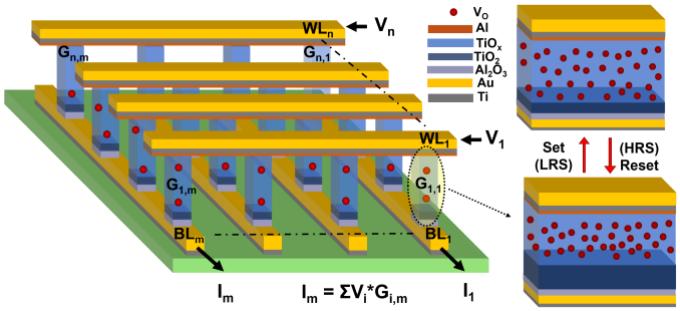

Fig. 1. Schematic of a trilayer b-RRAM crossbar array illustrating MVM operations. Schematics on the right explain Set & Reset switching in b-RRAM stack through modulation of oxygen vacancy (V_O) distribution.

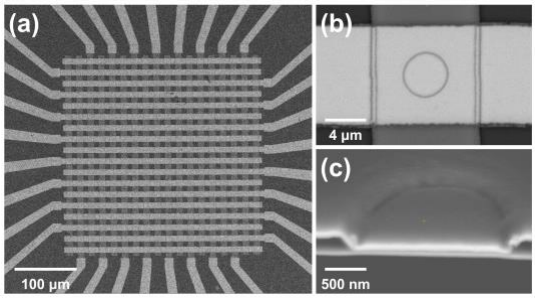

Fig. 2. SEM images of fabricated (a) 16×16 crossbar array (b) Single b-RRAM device, (c) Cross-section of half-cut b-RRAM device.