Efficient dynamic computation through device physics via a compact model of volatile resistive random access memories

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Volatile Resistive Random Access Memories (vRRAM) are memristive devices in which high- and low-resistive states are achieved by the formation and rupture of a conductive filament between two electrodes [1]. Unlike their non-volatile counterparts, vRRAMs reset automatically to their OFF state due to high atomic diffusion. This auto-reset characteristic resembles biological synapses, making vRRAMs a promising candidate for neuromorphic applications. However, utilizing the volatility requires a dynamic model that captures the entire switching cycle.

To address this, we designed a compact model that incorporates electrochemical hopping [2], surface diffusion [3], and Joule heating [4] to describe the geometrical state of the conductive filament. Our model integrates the dynamics of the filament during both states, allowing us to study the device's behavior throughout the entire switching cycle. Importantly, thanks to its time-adaptive fourth-order integrator, our model is both fast and accurate, capable of replicating the broad set and reset times observed in volatile devices (see Fig. 1).

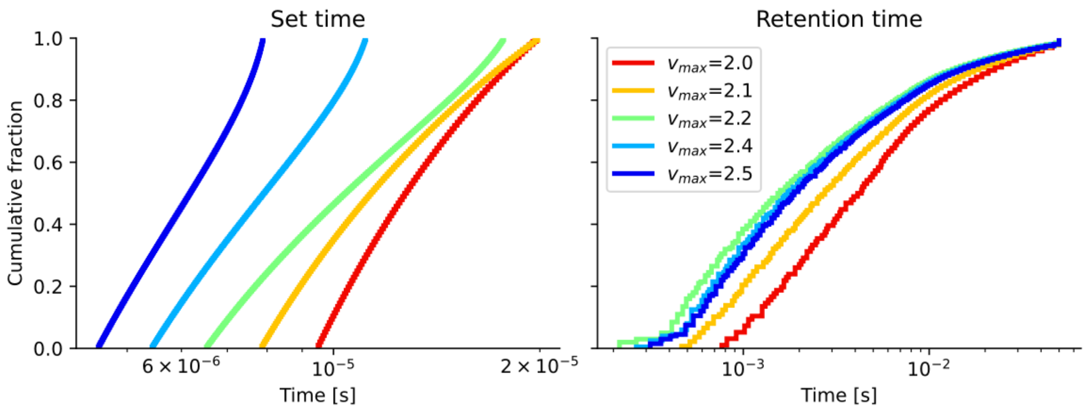

Figure 1: The set and retention times of various vRRAM devices with distinct geometry under a square pulse of strength v_{max} and a duration of 10 μs. Devices exhibit a wider range of set and retention times as reported in [1].

With this model at hand, we demonstrate how the dynamics of vRRAM can be exploited to perform non-trivial computations in time. Specifically, we show that by combining Joule heating and diffusion processes, it is possible to solve the temporal XOR problem. Unlike conventional systems that require multiple switches for this task, exploiting the physics of the device allows us to perform this task with a single device. Given that all forms of computation can be cast as a series of logical operations, our results highlight the high potential of vRRAMs for other forms of temporal computations.

In summary, this work demonstrates how the physics of an electronic device can be leveraged to perform non-trivial computations efficiently.

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