Non-volatile electrochemical memory operating near the thermal voltage limit

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Non-volatile memories like flash, phase-change, and filament forming metal oxides are desirable as synapses for neuromorphic analog computation, which can consume much less power than a digital processor. One criterion for non-volatile memory is to minimize the switching voltage, both to reduce energy consumption and to prevent dielectric breakdowns. Due to the Boltzmann distribution of electrons, it is unclear if any memory can switch significantly below 1V; developing non-volatile memory operating near the thermal voltage limit is a grand challenge.

In this work, we use two silicon-free electrochemical devices to build non-volatile memory that operates below 300 mV (Fig. 1a). The first device is an ion insertion transistor which electrochemically shuttles lithium ions and electrons between the gate and the channel[1], analogous to a battery. Because the ions are mobile and move with the electrons, the process is charge neutral, and up to 10^{21} cm^{-3} of electrons and ions can be reversibly shuttled between the gate and channel without electrostatic charging. The second device is a diffusive memristor operating based on Ag^{+} migration and filament formation in the ON state, and diffusive filament dissolution to the OFF state[2]. The low activation energy for Ag^{+} motion enables the device to switch with low applied voltages. The combination of high charge density of the ion insertion transistor and low leakage current of the diffusive memristor enables these two electrochemical devices to retain memory. Because both devices operate at low voltage, we can linearly tune the electronic conductance using sub-300-mV voltage pulses (Fig. 1b). This device is also compatible with a V/2 crossbar select scheme without a select transistor, and demonstrates that non-volatile synaptic memory near the thermal voltage limit is attainable for low-power electronics.

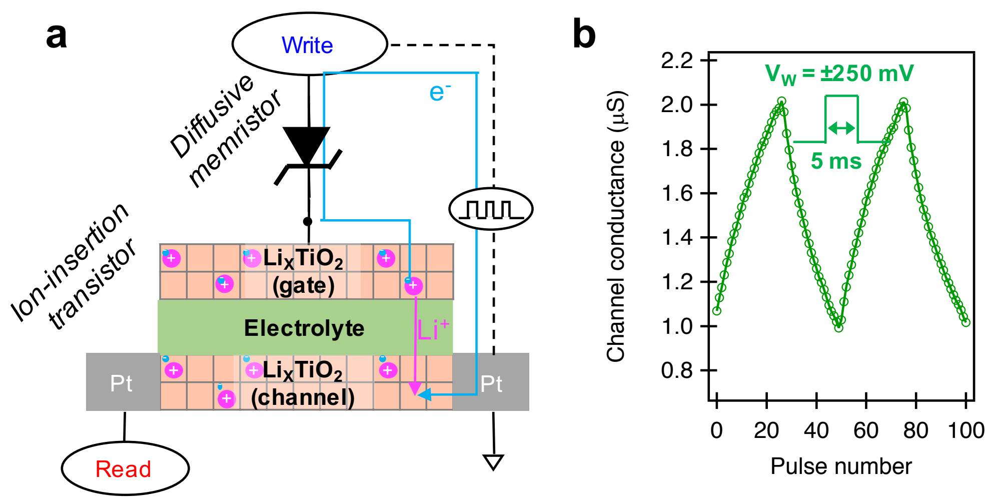

Fig. 1: Non-volatile synaptic memory. (a) Our synaptic memory contains an ion insertion transistor and a diffusive memristor access device. The ion insertion transistor shuttles lithium and electrons between the gate and the channel, while the diffusive memristor prevents charge leakage for retention. (b) Linear tuning of the channel conductance using voltage pulses near the thermal voltage limit.

[1] E. J. Fuller, et al. *Adv. Mater.*, 29, 1604310 (2017) [2]R. Midya, et al. *Adv Mater.*, 29, 1604457 (2017)

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