Diffusive Memristors with Uniform and Tunable Relaxation Times

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Diffusive memristors are volatile resistance switches that go to a low resistance state upon an electrical stimulus but automatically return to the original high resistance state when the stimulus is removed. The switching behavior is attributed to the formation and rupture of metallic filaments[1,2]. Because of their structural similarity with biological neurons, diffusive memristors are promising building blocks for energy-efficient neuromorphic computing hardware sysetms[3,4]. However, diffusive memristors relaxation time (from low to high resistance states) is non-uniform, limiting the wide adoption of such devices in large arrays.

In this work, we designed and fabricated diffusive memristors with uniform and tunable relaxation times. We used two silicon oxide layers, one doped with Ag and the other not, sandwiched between two Pt electrodes to make the device (Fig. 1). In fabrication, the 20 nm Pt electrode (with a 2.5 nm Ti adhesion layer) was first evaporated on a cleaned SiO_2/Si substrate. A 10 nm SiO_2 layer was then sputtered onto the electrodes, followed by a co-sputtering of a 4 nm Ag-doped SiO_2 (with an Ag concentration of 4.9 wt%). The 20 nm Pt top electrode was patterned and deposited by sputtering.

The device exhibited self-rectifying threshold switching behavior with voltage sweeping between −1 and 1 V (Fig. 2). It was turned on at around 0.4 V on the top electrode, with a threshold slope of <1mV dec^{-1}. A negative voltage on the top electrode did not turn the device on. The pulse response of the device is shown in Fig. 3. With a voltage pulse of 1.3V, the device was turned on after a short delay (40 μs), indicating the formation of an Ag filament. After the voltage pulse was removed, the current relaxed back to zero, suggesting the rupture of the filament. Among 500 switching cycles, 499 showed a relaxation time between 0 to 1ms (average μ 0.073ms) (Fig. 4). The standard deviation σ is 0.082ms, much improved from previous devices with only a single oxide layer[1]. Furthermore, the relaxation time can be tuned from 2.3ms to 1μs (3 orders of magnitude) by connecting a series resistor with the diffusive memristor (Fig. 5).

In summary, we demonstrated a new type of diffusive memristor with tunable and uniform relaxation time, which could pave the way for implementing spiking neural networks using diffusive memristors.

References

1. Wang *et al., Nat. Mat.* 16, 1 (2017). **2**. Woo *et al., Adv. Intell. Syst.* 3, 2100062 (2021). **3.** Midya *et al., Adv. Intell. Syst.* 1, 1900084 (2019). **4.** Yoon *et al., Nat. Comm.* 9, 417 (2021).

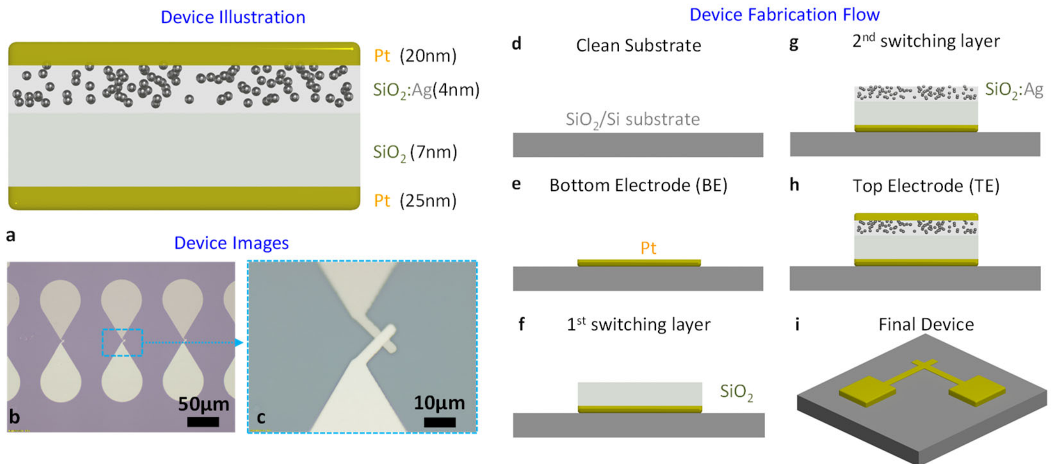

Figure 1. (a) Illustrations and (b) (c)microscope images of the diffusive memristor (crossbar area 5µm×5µm). Fabrication flow: (d) substrate clean, deposit of (e) bottom electrode, (f) 1st and (g) 2nd switching layer, (h) top electrode. (i) Final device

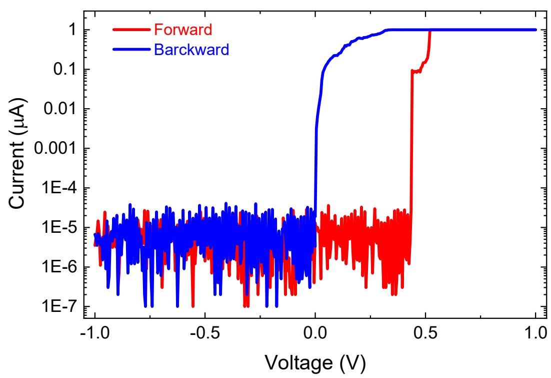

Figure 2. Switching curve of diffusive memristor under voltage sweeping.

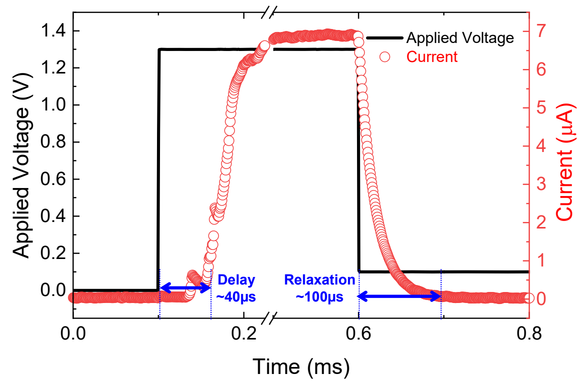

Figure 3. Switching of diffusive memristor under transient voltage pulse.

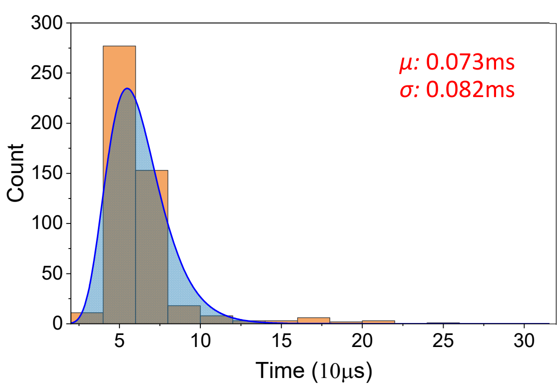

Figure 4. Histogram plot of the relaxation time within 500 cycles.

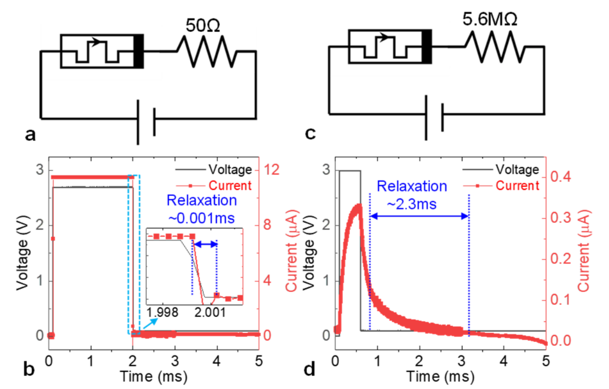

Figure 5. Schematic of measurement with (a) in-series resistor 50Ω and (c) 5.6MΩ. Relaxation curve obtained with (a) in-series resistor 50Ω and(c) 5.6MΩ