

Transition from Short-Term to Long-Term Memory in an Ag-Ag₂S Atomic Switch Network

○Samapika Mallik^{1,2}, Thien Tan Dang¹, Yusuke Nakaoka¹, Yuki Usami^{1,2}, Hirofumi Tanaka^{1,2}

¹ Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology (Kyutech), 2-4 Hibikino, Wakamatsu, Kitakyushu, 808-0196, Japan,

² Research Center for Neuromorphic AI Hardware, Kyutech, Kitakyushu, 808-0196, Japan
E-mail: mallik.samapika146@mail.kyutech.jp

[Introduction] In recent years, mimicking the functionality of biological synapses has become a pivotal goal in developing neuromorphic devices and artificial intelligence systems. Among various material systems, atomic switch networks (ASNs) based on Ag-Ag₂S have emerged as promising candidates for replicating synaptic behavior¹. Here, we investigated the short-term and long-term memory functions of an ASN using Ag-Ag₂S core-shell nanoparticles. Our findings reveal that the network exhibited a transition from volatile to non-volatile switching, corresponding to a transition from short-term to long-term memory (LTM) in biological synapses.

[Results and Discussion] The device structure features 16 electrodes with nanoparticles drop-casted into the central gap. Figure 1a shows the typical current-voltage (I-V) characteristics of the network at room temperature under voltage sweep (0 V to 3 V, 3 V to -1 V and -1 V to 0 V). During the forward sweep from 0 to 3 V with a voltage step of 20 mV, the device exhibited a SET process at 1.6 V, transitioning from the OFF to the ON state, indicative of metal filament formation within the network. Upon reversing the sweep from 3 V to -1 V, a RESET process occurred at 0.6 V, resulting in filament dissolution and volatile switching behavior.

This rapid return to the initial state upon voltage removal mirrors the characteristics of short-term memory (STM) in the human brain. Figure 1b illustrates the I-V characteristics over repeated sweeps from the 2nd to the 23rd cycle, revealing a transition from volatile to nonvolatile switching. With repeated voltage sweeps, the network gradually shifted from STM-like behavior to LTM-like behavior. Figure 1c shows the resistance versus cycle number, measured at 20 mV during the reverse sweep to 0 V. We found that the network showed an ON state (Figure 1d) of 2 kΩ at every repetition of five cycles. The first eight cycles represent a "learning phase," during which the network adapted to the voltage sweep, progressively stabilizing the ON state. Beyond this phase, the ON state consistently reappeared every five cycles, marking a "reinforcement phase" where repeated stimulation strengthened memory retention. These findings suggest that the Ag-Ag₂S nanoparticle network exhibits synaptic-like behavior, transitioning from transient to persistent memory states, akin to the biological processes underlying the formation of long-term memories.

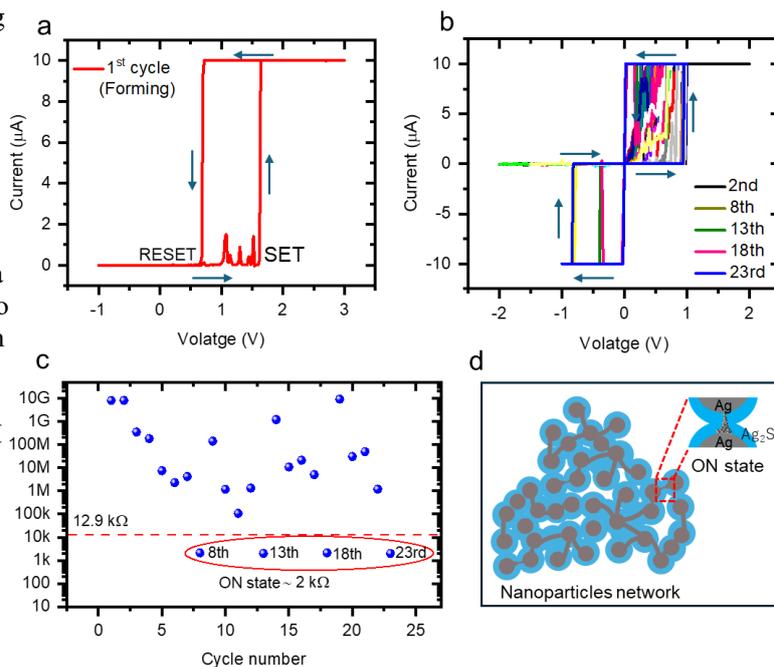


Figure 1: (a) I-V characteristics of the nanoparticle network for the first cycle, (b) 2nd to 23rd cycles, (c) Resistance vs. cycle number, and (d) Schematic of the nanoparticle network.

the network adapted to the voltage sweep, progressively stabilizing the ON state. Beyond this phase, the ON state consistently reappeared every five cycles, marking a "reinforcement phase" where repeated stimulation strengthened memory retention. These findings suggest that the Ag-Ag₂S nanoparticle network exhibits synaptic-like behavior, transitioning from transient to persistent memory states, akin to the biological processes underlying the formation of long-term memories.

Ref. [1] O. Srikimkaew, et al. *Adv. Electron. Mater.* 10, 2300709 (2024).