Peptoid-Guided Formation of Metallic Filaments in Memristive Devices

Xirong Liu, Xiaoqiu An, and Xiaogan Liang*

Mechanical Engineering Department, University of Michigan, Ann Arbor, MI 48109

Memristors are widely studied as key components for constructing next-generation hardware-based neuromorphic computing systems, owing to their capability of complementary memory and dynamic computation, bio-realistic emulation of synaptic plasticity, and energy-efficient operation beyond the von Neumann architecture restrictions.[1] However, the resistive switching operation of most state-of-the-art memristive devices relies on formation and rupture of conductive filaments through electromigration-style processes. Such nanoscale migration processes are highly stochastic and lead to significant cycle-to-cycle and device-to-device variability, limited reliability and constrained scalability, posing fundamental challenges for large-scale device implementation.[2]

Here, we present a nanofabrication strategy for utilizing peptoid nanostructures to regulate metallic filament formation in memristive devices. Peptoids are sequence-defined, biomimetic polymers with programmable side-chain chemistry that can self-assemble into well-defined nanostructures [3], which potentially provide preferential pathways for metallic ion migration. In this work, we demonstrated that in a memristor structure with peptoid nanostructures, metallic filaments preferentially nucleate along the peptoid features, enabling well-controlled nucleation locations of metallic filaments and potentially improving the consistency of device performance.

Figure 1a outlines the fabrication process for incorporating peptoid nanotubes into memristive device structures. **Figure 1b** shows the SEM of a representative as-fabricated peptoid-nanotube memristor with peptoid channel width of ~300 nm and channel length of ~1 μm. We performed multiple hysteretic I–V characterizations as well as post-switching SEM/EDS analyses to correlate bipolar resistive switching behaviors with peptoid-guided Ag filament formation. Specifically, after multiple electrical switching courses, our SEM and EDS results show that metallic filament formation selectively occurs along the peptoid nanotube pathway, indicating peptoid-guided metallization rather than random filament growth (**Figure 1b)**. **Figure 1d** displays the multiple hysteretic I–V characteristic curves measured from a representative peptoid-nanotube memristor, demonstrating highly repeatable resistive switching behaviors at low set/reset voltages even with a relatively long channel length (~1 μm). The corresponding threshold field magnitude for initiating filament formation is much lower than that for typical oxide Resistive Random Access Memory (RRAM) reports [4], implying a potential route toward more energy-efficient device operation.

Our work has preliminarily verified the validity for utilizing peptoid nanostructures as guided pathways for filament formation in memristive devices, offering a highly promising and practical route to suppress switching stochasticity

* Email: xiaoganl@umich.edu

and further advance potential reliable, scalable memristive hardware for neuromorphic computing and bio-integrated electronics. [5]

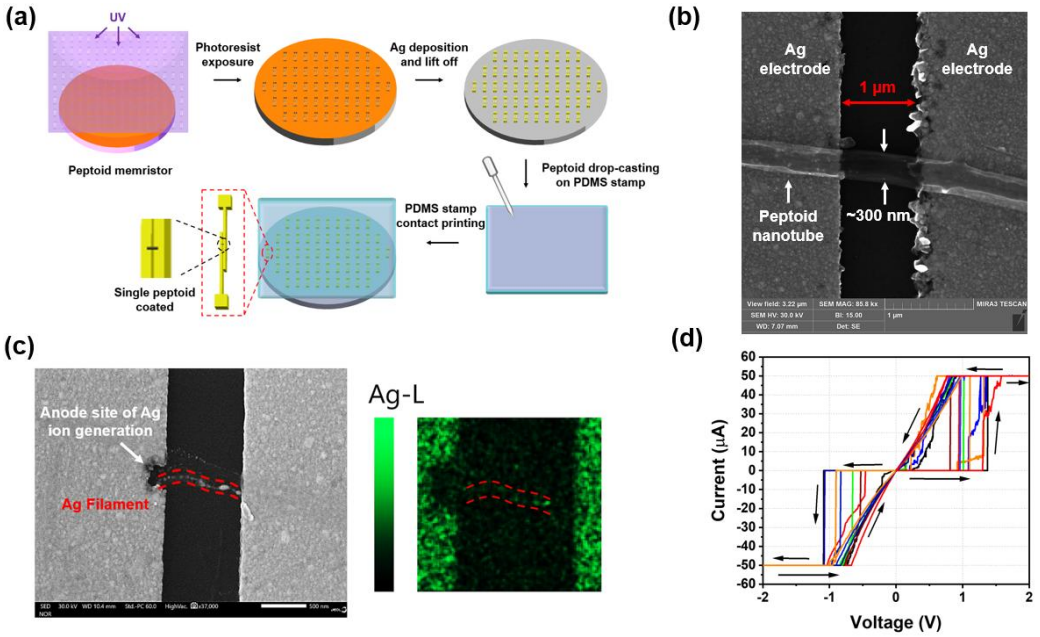

Figure. 1 (a) Schematic illustration of the fabrication process for making peptoid-nanotube-based memristors, involving photolithographic patterning of Ag electrodes, peptoid drop-casting on a PDMS stamp, and contact transfer printing to selectively bridge electrode gaps; (b) SEM image of a representative as-fabricated single peptoid-nanotube memristor (scale bar: 1 μm); (c) SEM and corresponding EDS Ag elemental mapping images of a peptoid-based memristor after a series of I–V sweeping cycles (scale bar: 500 nm), and (d) multiple hysteretic I–V curves of a representative peptoid-nanotube memristor.

REFERENCES

[1] C. D. Schuman, S. R. Kulkarni, M. Parsa, J. P. Mitchell, P. Date, and B. Kay, Nature Computational Science **2**, 10 (2022).
[2] Z. Lv, X. Xing, S. Huang, Y. Wang, Z. Chen, Y. Gong, Y. Zhou, and S.-T. Han, Matter **4**, 1702 (2021).
[3] Z. Lv *et al.*, Advanced Materials **36**, 2405145 (2024).
[4] F. Zahoor, T. Z. Azni Zulkifli, and F. A. Khanday, Nanoscale research letters **15**, 90 (2020).
[5] Z. Yi, Z. Lin, Y. Yao, Y. Zhai, Y. Wang, Q. Zhang, Y. Zhou, Z. Lv, and S. T. Han, Advanced Functional Materials, e17899 (2025).

* Email: xiaoganl@umich.edu