Neuromorphic memory device simulates neurons and synapses

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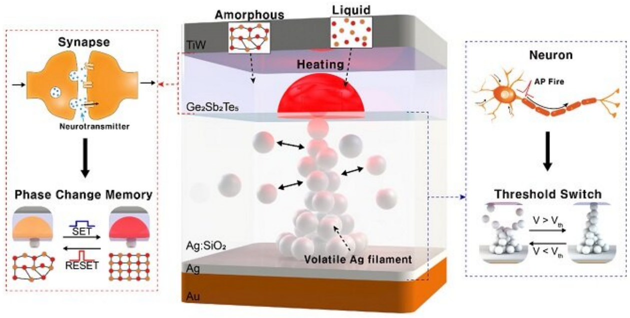


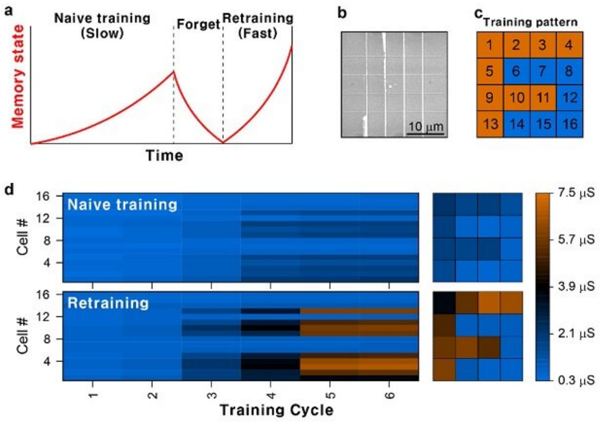
Neuromorphic memory device consisting of bottom volatile and top nonvolatile memory layers emulating neuronal and synaptic properties, respectively. Credit: The Korea Advanced Institute of Science and Technology (KAIST)

Researchers have reported a nano-sized neuromorphic memory device that emulates neurons and synapses simultaneously in a unit cell, another step toward completing the goal of neuromorphic computing designed to rigorously mimic the human brain with semiconductor devices.

Neuromorphic computing aims to realize artificial intelligence (AI) by mimicking the mechanisms of neurons and synapses that make up the human brain. Inspired by the cognitive functions of the human brain that current computers cannot provide, neuromorphic devices have been widely investigated. However, current Complementary Metal-Oxide Semiconductor (CMOS)-based neuromorphic circuits simply connect artificial neurons and synapses without synergistic interactions, and the concomitant implementation of neurons and synapses still remains a challenge. To address these issues, a research team led by Professor Keon Jae Lee from the Department of Materials Science and Engineering implemented the biological working mechanisms of humans by introducing the neuron-synapse interactions in a single memory cell, rather than the conventional approach of electrically connecting artificial neuronal and synaptic devices.

Similar to commercial graphics cards, the artificial synaptic devices previously studied often used to accelerate parallel computations, which shows clear differences from the operational mechanisms of the human brain. The research team implemented the synergistic interactions between neurons and synapses in the neuromorphic memory device, emulating the mechanisms of the biological neural network. In addition, the developed neuromorphic device can replace complex CMOS neuron circuits with a single device, providing high scalability and cost efficiency.

The human brain consists of a complex network of 100 billion neurons and 100 trillion synapses. The functions and structures of neurons and synapses can flexibly change according to the external stimuli, adapting to the surrounding environment. The research team developed a neuromorphic device in which short-term and long-term memories coexist using volatile and non-volatile memory devices that mimic the characteristics of neurons and synapses, respectively. A threshold switch device is used as volatile memory and phase-change memory is used as a non-volatile device. Two thin-film devices are integrated without intermediate electrodes, implementing the functional adaptability of neurons and synapses in the neuromorphic memory.



Retraining operation in the neuromorphic device array. a) Schematic graph showing the retraining effect. b) Scanning electron microscope image of the neuromorphic device array. c) Training pattern “F” for the retraining test. d) Evolution of the memory state of the neuromorphic device array for the naive training and retraining scheme. Credit: The Korea Advanced Institute of Science and Technology (KAIST)

Professor Keon Jae Lee explained, "Neurons and synapses interact with each other to establish cognitive functions such as memory and learning, so simulating both is an essential element for brain-inspired artificial intelligence. The developed neuromorphic memory device also mimics the retraining effect that allows quick learning of the forgotten information by implementing a positive feedback effect between neurons and synapses."

This result, titled "Simultaneous emulation of synaptic and intrinsic plasticity using a memristive synapse," was published in the May 19, 2022 issue of *Nature Communications*.

More information: Sang Hyun Sung et al, Simultaneous emulation of synaptic and intrinsic plasticity using a memristive synapse, *Nature Communications* (2022). DOI: 10.1038/s41467-022-30432-2

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