Chameleon-like material spiked with boron comes closer to mimicking brain cells

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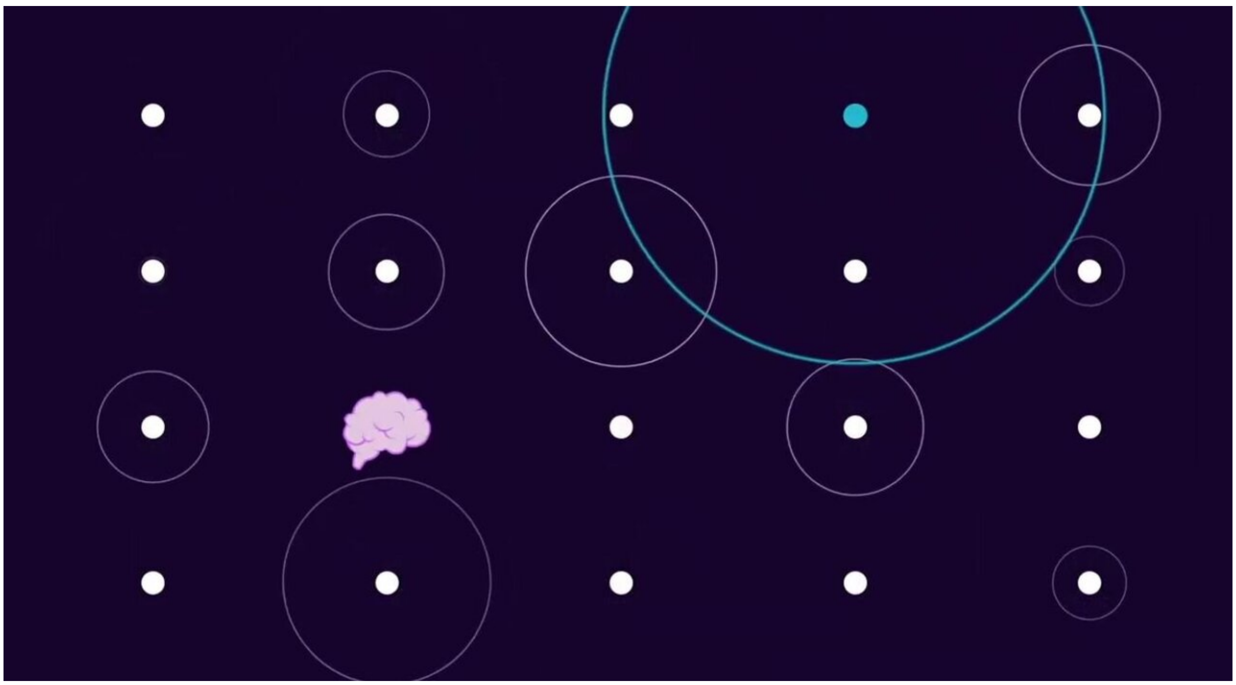

Each waking moment, our brain processes a massive amount of data to make sense of the outside world. Thus, by imitating the way the human brain solves everyday problems, neuromorphic systems have tremendous potential to revolutionize big data analysis and pattern recognition problems that are a struggle for current digital technologies. But for artificial systems to be more brain-like, they need to replicate how nerve cells communicate at their terminals, called the synapses.

In a study published in the September issue of *the Journal of the American Chemical Society*, researchers at Texas A&M University described a new material that captures the pattern of electrical activity at the synapse. Much like how a nerve cell produces a pulse of oscillating current depending on the history of electrical activity at its synapse, the researchers said their material oscillates from metal to insulator at a transition temperature decided by the device's thermal history.

Materials are generally classified into metals or insulators depending on whether they conduct heat and electricity. But some materials, like vanadium dioxide, lead a double life. At certain temperatures, vanadium dioxide acts like an insulator, resisting the flow of heat and electric currents. But when heated to 67 degrees Celsius, vanadium dioxide undergoes a chameleon-like change in its internal properties, converting to a metal.

These back-and-forth oscillations due to temperature make vanadium dioxide an ideal candidate for brain-inspired electronic systems since neurons also produce an oscillatory current, called an action potential.

But neurons also pool their inputs at their synapse. This integration increases the voltage of the neuron's membrane steadily, bringing it closer to a threshold value. When this threshold is crossed, neurons fire an action potential.

"A neuron can remember what voltage its membrane is sitting at and depending on where its membrane voltage is with respect to the threshold, the neuron will either fire or stay dormant," said Dr. Sarbajit Banerjee, professor in the Department of Material Sciences and Engineering and the Department of Chemistry, and one of the senior authors of the study. "We wanted to tweak the property of vanadium dioxide so that it retains some memory of how close it is to the transition temperature so that we can begin to mimic what is happening at the synapse of biological neurons."

The transition temperatures for a given material are generally fixed unless an impurity, called a dopant, is added. Although a dopant can move the transition temperature depending on its type and concentration within vanadium dioxide, Banerjee and his team's objective was to imbue a means of tuning the transition temperature up or down in a way reflecting not just the concentration of the dopant but also the time elapsed since it had been reset. This flexibility, they found, was only possible when they used the boron.

When the researchers added boron to vanadium dioxide, the material still transitioned from an insulator to a metal, but the transition temperature now depended on how long it remained in a new metastable state created by boron.

"Biological neurons have memory of their membrane voltage; similarly, boron-spiked vanadium dioxide has a memory of its thermal history, or formally speaking, how long it has been in a metastable state," said Dr. Diane Sellers, one of the primary authors of the study and a former research scientist in Banerjee's laboratory. "This memory determines the transition temperature at which the device is driven to oscillate from metal to an insulator."

While their system is an initial step in mimicking a biological synapse, experiments are currently underway to introduce more dynamism in the material's behavior by controlling the kinetics of the relaxation process of vanadium dioxide, said Dr. Patrick Shamberger, professor in the materials science department and a corresponding author on the study.

In the near future, Dr. Xiaofeng Qiang, professor in the materials science department and Banerjee's collaborator on this project, plans to expand on the current research by exploring the atomic and electronic structures of other more complex vanadium oxide compounds. In addition, the collaborative team will also investigate the possibility of creating other neuromorphic materials with alternative dopants.

"We'd like to investigate whether the phenomenon we have observed with vanadium dioxide applies to other host lattices and other guest atoms," said Dr. Raymundo Arróyave, professor in the materials science department and a corresponding author on the study. "This insight can provide us with several tools to further tune the properties of these types of neuromorphic materials for diverse applications."

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More information: Diane G. Sellers et al. Atomic Hourglass and Thermometer Based on Diffusion of a Mobile Dopant in VO2, *Journal of the American Chemical Society* (2020). DOI: 10.1021/jacs.0c07152

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