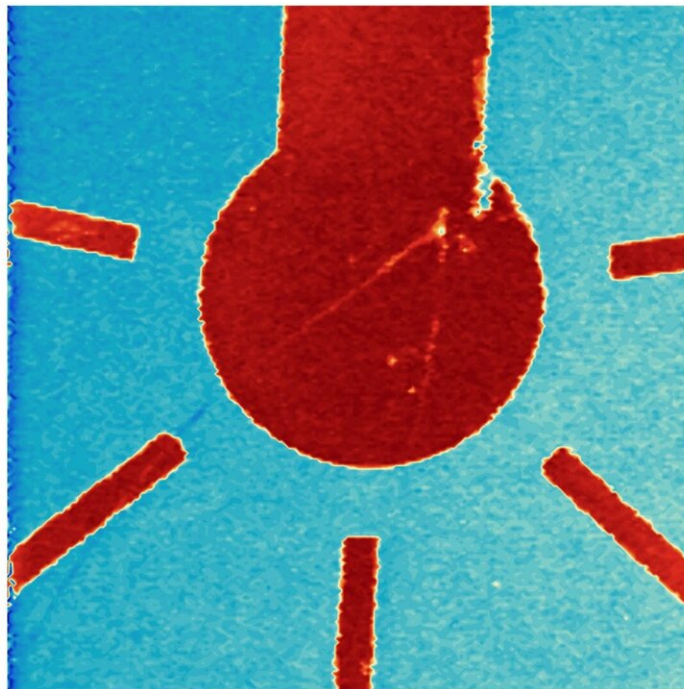# Elevating neuromorphic computing using laser-controlled filaments in vanadium dioxide

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Photoluminescence image showing NV centers near a network of five artificial synapses in a VO_2 film. A central electrode resembling a dendrite is connected to power sources, while five labeled electrodes A to E act like presynaptic terminals. Credit: Ce Feng, DOI: 10.1126/sciadv.adg9376

In a new _Science Advances_ study, scientists from the University of

Science and Technology of China have developed a dynamic network structure using laser-controlled conducting filaments for neuromorphic computing.

Neuromorphic computing is an emerging field of research that draws inspiration from the [human brain](link) to create efficient and intelligent computer systems. At its core, [neuromorphic computing](link) relies on [artificial neural networks](link), which are computational models inspired by the neurons and synapses in the brain. But when it comes to creating the hardware, it can be a bit challenging.

Mott materials have emerged as suitable candidates for neuromorphic computing due to their unique transition properties. Mott transition involves a rapid change in electrical conductivity, often accompanied by a transition between insulating and metallic states.

Co-lead author Prof. Chong-Wen Zou explained to Phys.org, "The pronounced electron-electron behavior in Mott materials leads to several orders of magnitude changes in conductivity over a very narrow temperature interval or even superconductivity."

In their study, the team chose vanadium dioxide (VO_2). Explaining their choice of material, co-lead author Fang-Wen Sun said, "VO_2 is a typical Mott material with the phase transition temperature near room temperature, thus possessing the feasibility for a variety of applications."

VO_2 as an electrical switch

VO_2, like all Mott materials, undergoes metal-insulator transition (MIT) at around 68° Celsius (154° Fahrenheit). This means that at this specific temperature, VO_2 changes from being an insulator to a conductor. The ability to switch between these states makes VO_2 suitable for various applications.

What makes VO_2 ideal for neuromorphic computing applications is its MIT behavior, which mimics the behavior of biological neurons. In simpler terms, VO_2 exhibits changes in [electrical conductivity](#), similar to how the strength between biological neurons in the human brain can change.

This similarity to the brain's plasticity means that VO_2 can adapt and change its conductivity, just like the brain adapts and rewires itself. Additionally, VO_2's exceptional ability to switch between conducting and non-conducting states makes it a valuable component for electrical circuits, acting like an efficient switch.

The flow of electricity and light through VO_2 materials can be controlled based on temperature, making them ideal for other applications. This is especially useful in applications like smart windows, allowing the control of light and heat passing through, enhancing energy efficiency.

Furthermore, VO_2 can be used to construct dynamic networks where signals can be processed and stored in a way that imitates the functionality of the human nervous system, especially in terms of adaptability and response to external stimuli.

Prof. Zou and Prof. Sun explained, "The controlled connections of conducting filaments in VO_2 devices are similar to those of the biological synapses. Therefore, we also explored the application of the network organized by the artificial synapses based on VO_2 devices in our research."

Focused lasers and quantum sensors

"In traditional artificial synaptic device research, properties of individual synapses are characterized, and these synapses are used as response functions to simulate neural networks. However, our dynamic network,

achieved through laser-controlled conductive filaments, exists in hardware, closely resembling the behavior of biological neurons, without relying on semiconductor circuits," explained the researchers.

The research team constructed a highly sophisticated experimental setup to study and manipulate conducting filaments within VO_2 materials. They began by growing VO_2 films with a precisely controlled thickness of 100 nanometers.

To gain insights into the behavior of the VO_2 material, the team utilized quantum sensors based on diamond nitrogen-vacancy (NV) centers known for their exceptional sensitivity to changes in electric conductivity due to atomic defects within the diamond crystal.

These sensors played a crucial role in detecting alterations in the electrical properties of VO_2. By manipulating the NV centers, the researchers were able to observe how conducting filaments formed and were controlled. The primary objective of their experiments was to have precise control over the location of the conducting filaments within the VO_2 devices, which acted as pathways for electrical signals.

To achieve this, the researchers used focused lasers, precisely directed within the VO_2 devices, to manipulate the conducting filaments' location. This level of control was crucial for regulating the flow of electrical signals, resembling the behavior of biological synapses.

Additionally, the team employed high-angle annular darkfield scanning transmission electron microscopy (STEM) to capture high-resolution images and analyze the structure of the VO_2 material, gaining valuable insights at the nanoscale.

The expertise of Prof. Sun's group with conducting filaments of nanowires using quantum sensors based on the diamond NV centers,

along with Prof. Zou's group, who have focused on the studies of VO_2 phase transition and device applications, helped the team successfully image conducting filaments with quantum sensors based on the diamond NV centers by detecting the current distribution.

Future work

The researchers found that the artificial synapses demonstrated long-term and short-term potentiation, with channels re-triggerable by current, lasting over two hours, and featuring transient resistance changes due to laser heating. In simple terms, the artificial synapses exhibited the ability to strengthen and adapt their connections over time, much like how our brain's neural networks learn and process information.

Speaking of the future applications of the work, "In the current demo, we've established a network with five artificial synapses using focused lasers to control conducting filaments," said Prof. Zou.

"Our future goal is to build more complex neural networks using multilayer electrodes and light fields for synaptic connectivity. Challenges remain in creating a feedback mechanism to regulate light intensity, but we're eager to explore practical applications of Mott materials," concluded Prof. Sun.

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