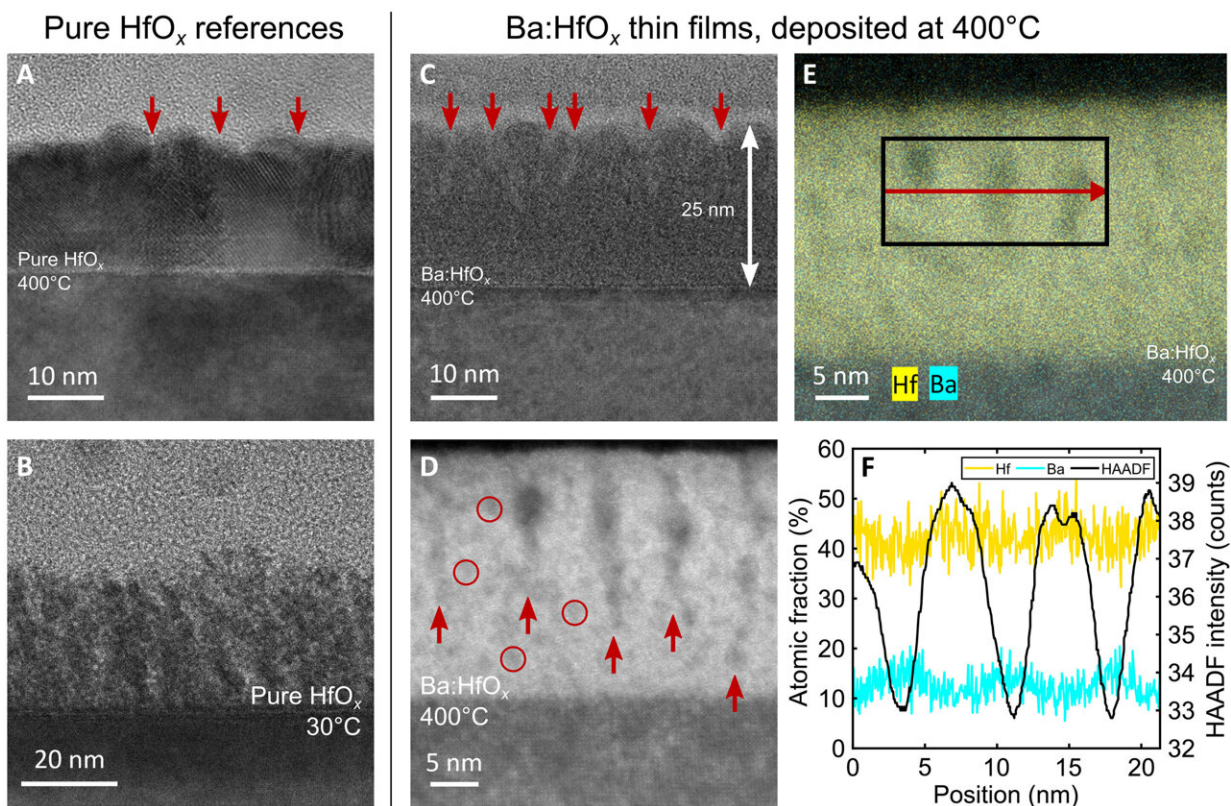


New type of computer memory could greatly reduce energy use and improve performance

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Cross-sectional TEM images and energy-dispersive x-ray measurements from high-angle annular dark-field scanning TEM for different thin films. (A) Pure HfO_x deposited at 400°C. Clear crystallites are visible in the film; red arrows indicate some of the grain boundaries. (B) Pure HfO_x deposited at 30°C. While these films are not polycrystalline like pure HfO_x deposited at 400°C, neither are they as uniform as the composite films presented in (C). (C) The thin films which resulted in stable electrical performance are amorphous or nanocrystalline. Some pillar-like structures can be discerned, indicated by red arrows. The

addition of Ba to the films clearly leads to material uniformity by suppressing crystallization. (D) High-angle annular dark-field scanning TEM (HAADF-STEM), zoomed in on some of the pillars. In addition, darker nanoparticles can be discerned throughout the films; four randomly chosen particles are marked by red circles. (E) HAADF-STEM image to indicate the area scanned for EDX and the elemental distribution of Hf and Ba. (F) Line scan EDX results acquired from the area indicated in (E). The dark areas in the HAADF-STEM image contain more Ba than the brighter ones. The ratio between Ba and Hf in the pillars is about 0.25 to 0.33, consistent with the Rutherford backscattering analysis discussed later. Credit: *Science Advances* (2023). DOI: 10.1126/sciadv.adg1946

Researchers have developed a new design for computer memory that could both greatly improve performance and reduce the energy demands of internet and communications technologies, which are predicted to consume nearly a third of global electricity within the next ten years.

The researchers, led by the University of Cambridge, developed a device that processes data in a similar way as the synapses in the human brain. The devices are based on hafnium oxide, a material already used in the semiconductor industry, and tiny self-assembled barriers, which can be raised or lowered to allow electrons to pass.

This method of changing the [electrical resistance](#) in computer memory devices, and allowing [information processing](#) and memory to exist in the same place, could lead to the development of computer memory devices with far greater density, higher performance and lower energy consumption. The results are reported in the journal *Science Advances*.

Our data-hungry world has led to a ballooning of energy demands, making it ever-more difficult to reduce carbon emissions. Within the next few years, [artificial intelligence](#), [internet usage](#), algorithms and

other data-driven technologies are expected to consume more than 30% of global electricity.

"To a large extent, this explosion in energy demands is due to shortcomings of current computer memory technologies," said first author Dr. Markus Hellenbrand, from Cambridge's Department of Materials Science and Metallurgy. "In conventional computing, there's memory on one side and processing on the other, and data is shuffled back between the two, which takes both energy and time."

One potential solution to the problem of inefficient computer memory is a new type of technology known as resistive switching memory. Conventional memory devices are capable of two states: one or zero. A functioning resistive switching memory device however, would be capable of a continuous range of states—[computer memory](#) devices based on this principle would be capable of far greater density and speed.

"A typical USB stick based on continuous range would be able to hold between 10 and 100 times more information, for example," said Hellenbrand.

Hellenbrand and his colleagues developed a prototype device based on hafnium oxide, an [insulating material](#) that is already used in the semiconductor industry. The issue with using this material for resistive switching memory applications is known as the uniformity problem. At the [atomic level](#), hafnium oxide has no structure, with the hafnium and oxygen atoms randomly mixed, making it challenging to use for memory applications.

However, the researchers found that by adding barium to thin films of hafnium oxide, some unusual structures started to form, perpendicular to the hafnium oxide plane, in the [composite material](#).

These vertical barium-rich 'bridges' are highly structured, and allow electrons to pass through, while the surrounding hafnium oxide remains unstructured. At the point where these bridges meet the device contacts, an energy barrier was created, which electrons can cross. The researchers were able to control the height of this barrier, which in turn changes the electrical resistance of the composite material.

"This allows multiple states to exist in the material, unlike conventional memory which has only two states," said Hellenbrand.

Unlike other [composite materials](#), which require expensive high-temperature manufacturing methods, these hafnium oxide composites self-assemble at low temperatures. The composite material showed high levels of performance and uniformity, making them highly promising for next-generation memory applications.

A patent on the technology has been filed by Cambridge Enterprise, the University's commercialization arm.

"What's really exciting about these materials is they can work like a synapse in the brain: they can store and process information in the same place, like our brains can, making them highly promising for the rapidly growing AI and machine learning fields," said Hellenbrand.

The researchers are now working with industry to carry out larger feasibility studies on the materials, in order to understand more clearly how the high-performance structures form. Since [hafnium oxide](#) is a material already used in the [semiconductor industry](#), the researchers say it would not be difficult to integrate into existing manufacturing processes.

More information: Markus Hellenbrand et al, Thin-film design of amorphous hafnium oxide nanocomposites enabling strong interfacial

resistive switching uniformity, *Science Advances* (2023). DOI: [10.1126/sciadv.adg1946](https://doi.org/10.1126/sciadv.adg1946)

Provided by University of Cambridge

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