Computers that mimic the function of the brain

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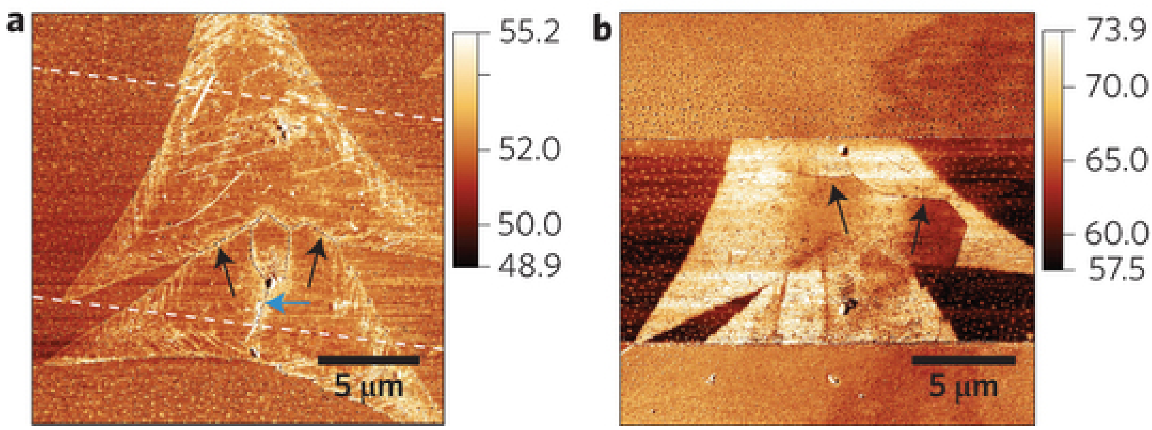

GB migration. Credit: *Nature Nanotechnology* (2015) doi:10.1038/nnano.2015.56

Researchers are always searching for improved technologies, but the most efficient computer possible already exists. It can learn and adapt without needing to be programmed or updated. It has nearly limitless memory, is difficult to crash, and works at extremely fast speeds. It's not a Mac or a PC; it's the human brain. And scientists around the world want to mimic its abilities.

Both academic and industrial laboratories are working to develop computers that operate more like the human brain. Instead of operating like a conventional, digital system, these new devices could potentially function more like a network of neurons.

"Computers are very impressive in many ways, but they're not equal to the mind," said Mark Hersam, the Bette and Neison Harris Chair in Teaching Excellence in Northwestern University's McCormick School of Engineering. "Neurons can achieve very complicated computation with very low power consumption compared to a digital computer."

A team of Northwestern researchers, including Hersam, has accomplished a new step forward in electronics that could bring brain-like computing closer to reality. The team's work advances memory resistors, or "memristors," which are resistors in a circuit that "remember" how much current has flowed through them.

The research is described in the April 6 issue of *Nature Nanotechnology*. Tobin Marks, the Vladimir N. Ipatieff Professor of Catalytic Chemistry, and Lincoln Lauhon, professor of materials science and engineering, are also authors on the paper. Vinod Sangwan, a postdoctoral fellow co-advised by Hersam, Marks, and Lauhon, served as first author. The remaining co-authors—Deep Jariwala, In Soo Kim, and Kan-Sheng Chen—are members of the Hersam, Marks, and/or Lauhon research groups.

"Memristors could be used as a memory element in an integrated circuit or computer," Hersam said. "Unlike other memories that exist today in modern electronics, memristors are stable and remember their state even if you lose power."

Current computers use random access memory (RAM), which moves very quickly as a user works but does not retain unsaved data if power is lost. Flash drives, on the other hand, store information when they are not powered but work much slower. Memristors could provide a memory that is the best of both worlds: fast and reliable. But there's a problem: memristors are two-terminal electronic devices, which can only control one voltage channel. Hersam wanted to transform it into a three-terminal device, allowing it to be used in more complex electronic circuits and systems.

Hersam and his team met this challenge by using single-layer molybdenum disulfide (MoS_2), an atomically thin, two-dimensional nanomaterial semiconductor. Much like the way fibers are arranged in wood, atoms are arranged in a certain direction—called "grains"—within a material. The sheet of MoS_2 that Hersam used has a well-defined grain boundary, which is the interface where two different grains come together.

"Because the atoms are not in the same orientation, there are unsatisfied chemical bonds at that interface," Hersam explained. "These grain boundaries influence the flow of current, so they can serve as a means of tuning resistance."

When a large electric field is applied, the grain boundary literally moves, causing a change in resistance. By using MoS_2 with this grain boundary defect instead of the typical metal-oxide-metal memristor structure, the team presented a novel three-terminal memristive device that is widely tunable with a gate electrode.

"With a memristor that can be tuned with a third electrode, we have the possibility to realize a function you could not previously achieve," Hersam said. "A three-terminal memristor has been proposed as a means of realizing brain-like computing. We are now actively exploring this possibility in the laboratory."

More information: Gate-tunable memristive phenomena mediated by grain boundaries in single-layer MoS_2, *Nature Nanotechnology* (2015) DOI: 10.1038/nnano.2015.56

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