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NIST invents fundamental component for 'spintronic' computing

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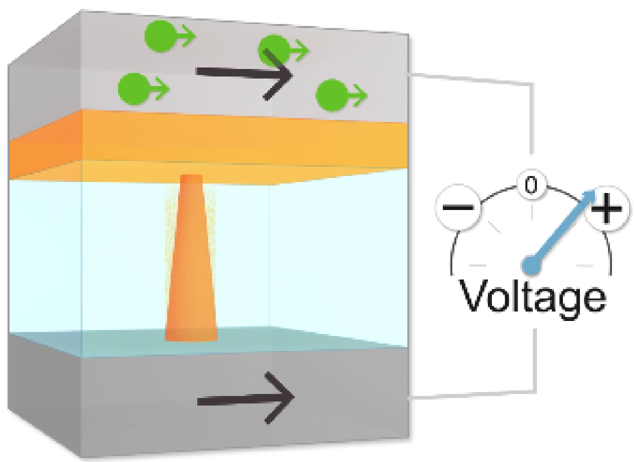

NIST has been granted a patent for technology that may hasten the advent of a long-awaited new generation of high-performance, low-energy computers.

Conventional microelectronic devices, for the most part, work by manipulating and storing electrical charges in semiconductor transistors and capacitors. Doing so requires a lot of energy and generates a lot of heat, especially as process engineers keep finding ways to pack more and smaller features into integrated circuits. Power consumption has become one of the principal obstacles to much higher performance.

One highly promising alternative approach, called "spintronics," utilizes the quantum spin of the electron to hold information in addition to the charge. The two different spin orientations (typically designated "up" and "down") are analogous to positive and negative electrical charges in conventional electronics. Because changing an electron's spin requires very little energy and can happen very fast, spintronics offers the possibility of significant energy reduction.

"Our invention," says co-inventor Curt Richter of NIST's Engineering Physics Division, "is designed to provide one key component in spintronic systems. It's a very simple, fundamental building block that can be used in a variety of different ways. It can serve as an on-off switch for spin currents, as an interconnect between different spintronic components, and as an interface between magnetic and electronic features to realize multifunctional devices."

Spin is what makes magnetic things magnetic: Every electron behaves somewhat like a bar magnet, with two opposite poles. Materials in which most of the electron spins are aligned in the same direction (polarized) produce a magnetic field with the same orientation. Electrons with the same spin alignment as the material pass easily through it; electrons with the opposite alignment are blocked.

This property has been exploited to make microscopic "spin valves"—typically a channel with a magnetic layer at each end. The relative polarity of the two magnets turns the valve on or off: If both magnets have the same alignment, the spin-polarized current passes through the channel. If the magnets have opposite alignments, current cannot flow.

The device is "switched" by reversing one magnet's polarity, which is done by applying a sufficient current of electrons with the opposite spin. However, flipping the magnet's polarity takes more energy than researchers would prefer.

"Typically with spin valves," Richter says. "You have to flow a significant amount of spin current to flip the component. Larger currents mean you're using more energy and generating more heat. Our invention dramatically reduces both."

At first, the researchers had no intention of making a device or obtaining a patent. They weren't even working directly on spin transport. They were studying the behavior of a different class of devices commonly referred to as "memristors" (memory resistors), a technology that is barely a decade old but is widely heralded as a potential high-speed, low-energy basic element for future computers.

Memristors are layered microstructure sandwiches with an electrode at the top and bottom, between which are a layer of metal (for example copper) which is a good electrical conductor and a layer of material (such as certain oxides) which is a poor conductor. This configuration is also the most common structure used in a new type of memory called resistive random-access memory (RRAM or ReRAM). When a voltage is applied to the electrodes in one direction, current can flow. Reversing the voltage shuts down the current.

Scientists believe that the reason for this phenomenon is that when a bias voltage is applied in one direction, it causes atoms of the metal conductor to diffuse into and interact with the oxide, forming tiny metal filaments that act as low-resistance channels penetrating through the insulating layer. If the voltage is applied in the opposite direction, the oxide layer is depleted of metal atoms, and resistance increases.

Either way, when the bias voltage is removed, the oxide's resistance state is frozen. Because that state was formed by a specific bias applied in a specific direction, the device "remembers" its last resistance. That characteristic makes memristors attractive for use in "non-volatile" computer memory in which the stored information does not disappear when the power is turned off.

"So when we got started, there were spin valves and there were memristors," Richter says. "But nobody had thought to put them together. Being measurement guys at NIST, we didn't originally think about putting them together to invent a new device. We put them together so that we could make measurements to better understand how memristors work.

"We wanted to investigate how this voltage switch turns on and off. We thought that if we added spin to the analysis, we could get more insights into how a normal memristor works. In the process of doing that, we made this device and said 'Hey, this thing by itself has very interesting technological ramifications.' It combines the non-volatile memory in memristors with the technology of a spin valve to create a device that allows you to turn on and off a spin channel."

"What makes it unique is that you can open or close a spin channel using an electric control," says co-inventor Hyuk-Jae Jang. "And so with a small amount of voltage, we can turn spin current on and off in sub-nanosecond time without having to flip the polarity of a spin valve's ferromagnetic electrode. This high speed and low power consumption operation is essential for building future spintronics-based logic technology to replace the current CMOS-based electronics technology used to fabricate nearly all integrated circuits today."

The NIST patent covers devices made with a variety of materials. The primary combination used in the inventors' experiments was, from the bottom up, a magnetic base layer made of cobalt that serves to spin-polarize the electrons, an insulating layer made of tantalum oxide, a layer of copper, and an alloy top electrode.

In the "on" configuration, the copper atoms are drawn into the oxide and their filaments extend all the way to the base cobalt layer. Reversing the voltage causes the copper to recede, and "there's an empty region in the oxide layer," Richter says. "As soon as that happens, the current stops. It could be only a few atoms' worth away, because of the exponential drop-off with distance. That makes it a very low-energy switch."

John Kramar, Acting Chief of NIST's Engineering Physics Division, calls the work "a very exciting invention that provides a great solution for the switching-energy problem for spin valves. It removes a significant technological barrier for spintronics to become a strong contender for beyond-CMOS microelectronics."

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