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Pigment formulated 225 years ago could be key in emerging technologies

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Imagine turning on your computer and not having to wait for it to load the operating system, virus protection, firewalls and other programs. Imagine that random access memory is accessible immediately, like turning on room lights.

That could be the reality of future devices that allow electrons to be manipulated by their magnetic properties as well as by their electrical charge. The ability to manipulate electrons' magnetism, in addition to controlling their charge flow, has the potential to create broad new capabilities for computers and other devices and is the basis for an emerging technology called "spintronics." A major barrier to creating such devices is finding nonvolatile magnetic semiconductor materials, ones that don't demagnetize easily. So far the only materials found that meet the requirements operate only at a decidedly uncomfortable 200 degrees below zero Celsius, about minus 328 Fahrenheit.

But now researchers at the University of Washington have demonstrated a material – a mixture of zinc oxide and cobalt first formulated in 1780 as a pigment called cobalt green – that appears capable of operating in more suitable environments and would allow electrons to be manipulated both electrically and magnetically.

"The big challenge is to develop materials that can perform these kinds of functions not just at cryogenic temperatures but at practical temperatures," said Daniel Gamelin, a UW assistant professor of chemistry. "The breakthrough with the materials we tested is that they exhibit their magnetic properties at room temperature."

Silicon-based semiconductors that incorporate many tiny transistors are at the heart of computers and an array of other devices. But while silicon chips allow complex manipulation of electrons based on their charges, current chip technology is not useful for manipulating the electrons' magnetism, or spin.

It is believed the simplest way to manipulate an electron's magnetic state in a semiconductor device is by using a semiconductor material such as silicon or zinc oxide that incorporates magnetic elements. Previous research has suggested that some such magnetic semiconductors could operate at room temperature, but there has been strong debate about whether the results actually support that conclusion.

To test cobalt green, researchers at the Pacific Northwest National Laboratory in Richland, Wash., processed zinc oxide, a semiconductor with a simple chemical structure, so a small number of zinc ions were replaced with cobalt ions, which are magnetic. Then, in Gamelin's UW lab, the cobalt ions were aligned – making the material magnetic – by exposure to zinc metal vapor, which introduces extra electrons to the zinc oxide. The magnetic properties remained strong at room temperature even when the vapor exposure ended. When the cobalt-doped zinc oxide was heated in air, the researchers observed the extra electrons dissipate and the magnetic properties disappear, in a way that demonstrated the two are interdependent.

"This work shows there is a real effect here, and there is promise for these materials," Gamelin said. "The next step is to try to get these materials to interface with silicon semiconductors."

The bright bluish-green mixture of zinc oxide and cobalt, called cobalt green or Rinman's green, was first devised as an art pigment in the 19th century by Swedish chemist Sven Rinman. The low concentration of magnetic cobalt ions made it a good candidate for testing as a spintronics material, Gamelin said.

He is corresponding author of a paper describing the work, published in the July 21 **Physical Review Letters**. Co-authors are Kevin Kittilstved and Dana Schwartz, UW chemistry doctoral students, and Allan Tuan, Steve Heald and Scott Chambers of the Pacific Northwest lab. The work was funded by the National Science Foundation, the Research Corp., the Dreyfus Foundation, the Sloan Foundation and the U.S. Department of Energy.

Because development of these materials is in the early stages, it is not yet clear what their final properties will be, and their final properties will determine how they can be used, Gamelin said. But eventually such materials could have profound impact on computers and digital devices, from the way they are used to their power requirements.

"For instance, the general sense is that you will use a lot less power in these devices, so you will need a lot less cooling capacity," he said. "That would be a major advance."

Source: University of Washington