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UCSB Scientists Learning to Use Electron's Natural Spin

Basic science is gearing up to stand the electronics industry on its head, at least figuratively. That is because scientists, such as condensed matter physicist David Awschalom of UC Santa Barbara, are learning new ways to harness electrons.

After a century of manipulating the direction in which the negatively charged subatomic particles flow, a phenomenon that results in the electrical current that powers most appliances and lights, physicists have discovered how to control the two directions in which electrons naturally spin.

"We call it the other face of the electron," said Awschalom, who has pioneered much of the still-meager experimental knowledge of the new research field called spintronics. (Spintronics is an acronym for SPIN TRansport electrONICS.)

Electrons, the particles that streak around the nucleus of atoms, generate a weak magnetic field when they spin, creating north and south poles not unlike that of a bar magnet. When the south pole is on top, electrons are said to be spinning in an "up" state; when the north pole is on top, electrons are said to be spinning "down."

Scientists do not yet know exactly why electrons spin, but they understand enough to change the direction of that spin on command.

Spintronics research is based on the fact that the electron's tiny magnetic field can be used to create new functions or behaviors at a quantum level.

"One of the most exciting possibilities," Awschalom said, "is to exploit these discoveries to construct a quantum mechanical computer, based on fabrication of 'qubits,' or quantum bits consisting of superpositions of up and down spin states." While current computers add or remove thousands of electrons to make an "0" or a "1" of a bit of information, a quantum computer would use a single spin, pointing up or down, of an electron to make a qubit.

Such a reduction in scale approaching the infinitesmal would place the technology in a realm known to physics as quantum mechanics. At the quantum level things like particles or light waves behave in ways very different to what scientists expect in a human-scale world. In the quantum world, as examples, an electron can exist in two places at the same time, what is called a "superposition" of states, or spin up and down at the same time. Exploiting the quizzical nature of quantum mechanics with computers, Aschalom noted, could mean communication with no possible eavesdropping, lightning-fast database searches, and code-cracking ability.

Awschalom, who directs UCSB's new Center for Spintronics and Quantum Computation, has secured nearly $ 7 million in grants to continue his interdisciplinary research group's voyage into uncharted scientific waters. This center is the first in the country to secure funding from DARPA, the U.S. Defense Advanced Research Projects Agency. In February, DARPA announced that it would grant $50 million over the next five years to further spintronics research nationally.

Drawing from materials, electrical and computer engineering, chemistry, physics, and other disciplines, the center's researchers have

produced some tantalizing findings. Awschalom's research group, for example, has developed new laser techniques that control electrons' spin so that they pass easily through certain semiconductor materials.

Changing the focus from an electron's charge to the magnetic fields generated by its spin has produced laboratory results that suggest that spin "currents" may allow greater speed with far less heat than that produced by present electrical technology. "The difference could be staggering, because the size of today's microelectronics is limited by how much heat is generated when current passes through miniature electrical wires," explained Awschalom.

In addition to speed, a spintronics-based computer, unlike today's electronic chips, might be better at remembering where it was when its power was cut. "You would

turn it on and the screen would look the same as when you turned it off," said Awschalom, emphasizing that this example is, at present, only a theoretical possibility.

Much of the work to be done leads to

understanding what environmental factors control the durability of an electron's spin. Results so far suggest that, contrary to initial theoretical predictions, the spin "is amazingly robust," he said, even when electrons move through different materials.

This potentially revolutionary technological change comes at a time when computer manufacturers are grappling with a disquieting trend: Costs and technological limitations are catching up with the ability to build a continually faster computer chip economically. Chip technology now operates on a scale that requires about 1,000 electrons to switch a circuit on or off; if past exponential gains in speed and memory continue, within a decade such switches will require only eight electrons. "Imagine the difficulty of trying to control eight electrons consistently," said Awschalom.

While he and his fellow researchers are aware of the difficulties that face them, that only seems to add to their excitement. "There are no road maps here," Awschalom said. "You are led by the science, and that is the way it should be."

About UC Santa Barbara

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