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Spin Moves With Unexpected Ease From One Semiconductor to Another

Successful Demonstration of Spin-Transfer Makes Way for Whole New Technology of Spintronics

Santa Barbara, Calif.-- Four researchers at the University of California at Santa Barbara (UCSB) and at Penn State University in University Park, Pa., report in the June 14 issue of Nature experiments that show high-efficiency spin transfer through interfaces between two different semiconductor materials. The paper "Persistent Sourcing of Coherent Spins for Multifunctional Spintronics" also announces the discovery of a new "persistent" mode of spin currents that makes semiconductor reservoirs act, in effect, as "spin batteries."

Physicist David Awschalom heads the research team that conducted the experiments reported in Nature. He is director of the UCSB Center for Spintronics and Quantum Computation, a key component of the new California NanoSystems Institute [CNSI] located jointly at UCSB and UCLA. The experiments are the result of long-standing collaboration between Awschalom and Nitin Samarth, a materials physicist at Penn State University.

This likely landmark paper is the subject of the lead "News and Views" article in the June 14 Nature. In his review of the paper, Caltech physicist Michael L. Roukes said of the demonstration of spin transfer across semiconductor interfaces, "This achievement is an important milestone in the race to build futuristic devices that exploit the true quantum nature of electrons."

Electrons have both charge and spin. Electronic devices such as transistors operate, as Roukes describes, "by internally shuttling small packets of electronic charge." All semiconductor technology is based on charge. But electrons also spin, or rotate. The results reported in Nature answer affirmatively the key question of whether a whole new spin-based technology is feasible.

Hold a pencil upright and rotate it in the same direction by turning it alternately between the thumb and index finger of one hand and the other. While rotating it, turn it upside down. Note that when inverted, the direction of rotation changes from, say, clockwise to counterclockwise.

That pencil is analogous to the axis of rotation of an electron. The two orientations of the axis of rotation--up or down--are the conventional or classical ways physicists describe spin. That description is sufficient for understanding the results in the Nature paper (though spin as a quantum mechanical property is understood not merely as up or down, but the superposition of all orientations of the axis of rotation).

Awschalom said, "The results of these experiments were as much a surprise to us as to anyone. Spin appears to be remarkably robust and moves relatively easily between semiconductors. Previously, theories of electron transport from one material to another suggested that the spin would lose its orientation or scatter from impurities or structural effects. These experiments point out that this is not the case."

In these measurements the spins of each electron all point in the same direction or are aligned. The question was whether a cloud or bundle of electrons all spinning the same way would retain that same spinning when the cloud is moved to an adjacent semiconducting material. The spins in fact stayed aligned. What astonished Awschalom, his graduate student Irina Malajovich (first author on the Nature paper), and her co-workers at Penn State is that the spins not only stayed aligned but did so as the temperature of the materials was raised, in some cases, to room temperature.

Certain semiconductors were found to work as spin reservoirs because spins survive there for long times. In analogy with conventional charge-based electronics, this work shows that electrons can be withdrawn from such reservoirs with their spin intact, using electric fields. Spin reservoirs are thereby "sourcing" a spin current.

A year ago Awschalom took his preliminary results to UCSB Engineering Professor Herb Kroemer, who won the 2000 Nobel Prize in Physics for envisioning the heterojunction, one example of which is a sandwich using n- and p-type semiconductors. The charge carriers in n-type semiconductors are electrons, and the charge is negative: in p-type semiconductors the charge carriers are holes, and the charge is positive. Kroemer saw that putting two materials, one n-type and the other p-type together, would create an internal electric field that would promote the flow of spins across the interface

Malajovich's initial experiments showed spin transfer between two n-type semiconductors. Kroemer suggested trying to move spin from a p- to an n-type semiconductor. "To my surprise," said Awschalom, "it worked very well. Instead of applying an external electric field to move the electrons from one material to another, we were able to use the internal field created by assembling two different kinds of semiconducting layers. It not only worked," said Awschalom, "but the effect was even stronger.

"The basis of the transistor is the p-n junction," said Awschalom. "The implication of these results is that there is no fundamental reason one can't move forward and fabricate spin transistors. I hope that some research team will demonstrate this in the near future. At present transistors are the building blocks of electronics. It's exciting to think about future technologies that exploit the electron spin and function in a completely different manner. For example, imagine devices that could combine photonics, electronics, and magnetics in a single structure."

There is yet another discovery reported. Said Awschalom, "Unexpectedly, if you keep pulling spin from one material to another, the spins in the adjacent layer acquire the original spin frequency and lifetime of the reservoir. Therefore the total transferred spin can have the properties of either the reservoir or the adjacent layer, and an external electric field 'gates' the transition between the two very different regimes. That is the 'persistent sourcing' of the paper's title. The fact that this behavior can be tuned with either electric or magnetic fields results in a new multi-functional type of 'spintronics.'"

In his "News and Views" article, Roukes notes that this "newly-identified, persistent mode of spin transfer (makes the reservoir act, in effect, as a spin 'battery.'"

Asked what that is good for, Awschalom said, "New discoveries enable new technologies. It's likely the most important applications are yet to be realized."

The Penn State University researchers, Samarth and his graduate student Joseph Berry, used Molecular Beam Epitaxy (MBE) to fabricate the compound semiconductor heterostructures for the physics experiments that were carried out at Santa Barbara. The choice of structurally compatible semiconductors with very different optical and electronic characteristics was particularly crucial to designing an experiment whose results would be unambiguous.

Samarth said, "One of the implications of this experiment is that one can construct basic building blocks for spin electronics using well-understood, conventional semiconductors. This collaboration also shows how integral material science is to fundamental research, and is a first-rate demonstration of how laboratories without walls can work. Getting these experiments to work needed close collaboration between the graduate students. Though not face to face, Irina and Joe worked smoothly together. And the results are delightful!"

DARPA (Defense Advanced Research Project Agency) funds the collaborative research between UCSB and Penn State through two programs, SPINS and QUIST. Awschalom went to Washington, D.C., to present his findings to the Defense Science Board on June 8.

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Images

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