Spintronics Breakthrough: Negative Resistance of a Single Magnetic Domain Wall Measured

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Physicists for several years have been predicting a new age of semiconductor devices that operate by subtle changes in the orientation of electron spins. Known as "spintronics," the field relies on an intricate knowledge of the magnetic properties of materials and of how magnetic moments can be manipulated.Now, scientists at the California Institute of Technology have developed a novel method of measuring the resistance of "domain walls," which are the nanoscale boundaries separating areas of a magnetized material that possess different magnetic alignments, or a "twist" of magnetic spins.

Reporting in the September 2 issue of the journal Nature, Caltech physicists Hongxing Tang, Michael Roukes, and their colleagues show that their approach leads to an unparalleled precision in isolating, manipulating, and trapping domain walls one by one.

The authors have been able to trap individual domain walls between electrical probes for periods longer than a week. During that time, they are able to carry out extremely sensitive electrical measurements to identify the tiny amounts of resistance generated by this trapped single magnetic domain wall.

"We have demonstrated how a single magnetic domain wall can be monitored as it is made to traverse a patterned array of electrical probes in a microdevice made from single-crystal manganese-doped gallium arsenide," says Professor Roukes. Manganese- doped gallium arsenide belongs to a new class of ferromagnetic semiconductors that isexpected to have great potential for new spintronics devices.

This work also resolves an issue that has puzzled scientists for some time, according to Tang. Many physicists have thought that domain walls were a natural barrier to electron transport and that they cause positive resistance--in other words, the magnetic moments with different alignments created a natural opposition to the flow of charge from one side of the wall to the other. However, the new results show that the resistance is actually negative, which can be attributed to quantum effects in the locale of the domain wall itself. The very fact that the resistance is negative means that electrons can flow more easily under certain conditions, manifesting quantum mechanical origin in this novel phenomenon.

"We are certain that both this result and our new measurement methodology will be of interest to those working on future semiconductor devices based on spintronics," Tang says.

Understanding the dynamics of magnetic domain walls is crucial for magnetic storage devices such as magnetic hard drives, and for future magnetic memories. The methods have the potential to significantly alter the theoretical and experimental research for some time to come.

The work has been made possible through the Caltech team's earlier discovery of a phenomenon dubbed the "giant planar Hall effect." To reach the ultra-high resolution required to resolve the resistance of a domain wall, the authors advance a nanofabrication process for precise alignments of materials at the microscopic level and deploy an innovative way of manipulating domain walls.

"Using these advances, we have made careful measurements on many devices having domain walls of varying lengths and thicknesses," says Roukes. "All show negative resistance at the domain wall."

In addition to being a professor of physics, applied physics, and bioengineering at Caltech, Roukes is also founding director of Caltech's new Kavli Nanoscience Institute. Dr. Hongxing Tang is a senior research scientist at Caltech. Other authors of the paper are Sotiris Masmanidis, a Caltech graduate student in applied physics, and Roland Kawakami and Prof. David Awschalom, both of the UC Santa Barbara department of physics.

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