Researchers develop first high-temperature spin-field-effect transistor

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An international team of researchers featuring Texas A&M University physicist Jairo Sinova has announced a breakthrough that gives a new spin to semiconductor nanoelectronics and the world of information technology.

The team has developed an electrically controllable device whose functionality is based on an electron's spin. Their results, the culmination of a 20-year scientific quest involving many international researchers and groups, are published in the current issue of *Science*.

The team, which also includes researchers from the Hitachi Cambridge Laboratory and the Universities of Cambridge and Nottingham in the United Kingdom as well as the Academy of Sciences and Charles University in the Czech Republic, is the first to combine the spin-helix state and anomalous Hall effect to create a realistic spin-field-effect transistor (FET) operable at high temperatures, complete with an AND-gate logic device — the first such realization in the type of transistors originally proposed by Purdue University's Supriyo Datta and Biswajit Das in 1989.

"One of the major stumbling blocks was that to manipulate spin, one may also destroy it," Sinova explains. "It has only recently been realized that one could manipulate it without destroying it by choosing a particular set-up for the device and manipulating the material. One also has to detect it without destroying it, which we were able to do by exploiting our findings from our study of the spin Hall effect six years ago. It is the combination of these basic physics research projects that has given rise to the first spin-FET."

Sixty years after the transistor's discovery, its operation is still based on the same physical principles of electrical manipulation and detection of electronic charges in a semiconductor, says Hitachi's Dr. Jorg Wunderlich, senior researcher in the team. He says subsequent technology has focused on down-scaling the device size, succeeding to the point where we are approaching the ultimate limit, shifting the focus to establishing new physical principles of operation to overcome these limits — specifically, using its elementary magnetic movement, or so-called "spin," as the logic variable instead of the charge.

This new approach constitutes the field of "spintronics," which promises potential advances in low-power electronics, hybrid electronic-magnetic systems and completely new functionalities.

Wunderlich says the 20-year-old theory of electrical manipulation and detection of electron's spin in semiconductors — the cornerstone of which is the "holy grail" known as the spin transistor — has proven to be unexpectedly difficult to experimentally realize.

"We used recently discovered quantum-relativistic phenomena for both spin manipulation and detection to realize and confirm all the principal phenomena of the spin transistor concept," Wunderlich explains.

To observe the electrical manipulation and detection of spins, the team made a specially designed planar photo-diode (as opposed to the typically used circularly polarized light source) placed next to the transistor channel. By shining light on the diode, they injected photo-excited electrons, rather than the customary spin-polarized electrons, into the transistor channel. Voltages were applied to input-gate electrodes to control the procession of spins via quantum-relativistic effects. These effects — attributable to quantum relativity — are also responsible for the onset of transverse electrical voltages in the device, which represent the output signal, dependent on the local orientation of processing electron spins in the transistor channel.

The new device can have a broad range of applications in spintronics research as an efficient tool for manipulating and detecting spins in semiconductors without disturbing the spin-polarized current or using magnetic elements.

Wunderlich notes the observed output electrical signals remain large at high temperatures and are linearly dependent on the degree of circular polarization of the incident light. The device therefore represents a realization of an electrically controllable solid-state polarimeter which directly converts polarization of light into electric voltage signals. He says future applications may exploit the device to detect the content of chiral molecules in solutions, for example, to measure the blood-sugar levels of patients or the sugar content of wine.

This work forms part of wider spintronics activity within Hitachi worldwide, which expects to develop new functionalities for use in fields as diverse as energy transfer, high-speed secure communications and various forms of sensor.

While Wunderlich acknowledges it is yet to be determined whether or not spin-based devices will become a viable alternative to or complement of their standard electron-charge-based counterparts in current information-processing devices, he says his team's discovery has shifted the focus from the theoretical academic speculation to prototype microelectronic device development.

"For spintronics to revolutionize information technology, one needs a further step of creating a spin amplifier," Sinova says. "For now, the device aspect — the ability to inject, manipulate and create a logic step with spin alone — has been achieved, and I am happy that Texas A&M University is a part of that accomplishment."

Provided by Texas A&M University