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Nanotechnology and superconductivity pave the way for spintronics

Notre Dame, IN | 10 May 2005 -- An important breakthrough in the emerging scientific field of spintronics was reported recently by University of Notre Dame physicist Boldizsár Jankó and his research team from the Joint Institute for Theoretical Sciences of Notre Dame and Argonne National Laboratories.

Spintronics is developing as a result of the growing recognition that a replacement will have to be found for silicon, traditionally the key material in computer chips, if processing power is to continue to grow at rapid rates.

However, at some point, estimated by some experts to be as early as 2010, the fundamental physical laws that govern the behavior of transistors will preclude them from being shrunk any further and packed in greater numbers on computer chips. The continued shrinking of transistors will lead to various problems with electric leakage, power consumption and heat.

Many experts feel that spintronics, combined with nanotechnology, offers the best possible solution to this problem.

For the past two years, Jankó and a team of researchers have been using a National Science Foundation Nanoscale Interdisciplinary Research grant to develop and create manmade materials aimed at performing extremely fast functions in computers of future generations. These materials, known as diluted magnetic semiconductor-superconductor hybrids, possess magnetic, optical, and semiconductor properties that show great promise for new types of computers. Their research has been aimed at gaining a deeper understanding of these properties, so as to enable their control for the purpose of such applications as spintronics, which exploits magnetic properties to do computing. In spintronics technology, it is not the electron charge, but the electron spin that carries information, offering opportunities for a new generation of microelectronic devices.

Information storage, manipulation, and transport via electron spin offers several advantages, including higher data processing speed, low electric consumption, nonvolatility, and quantum computation. However, several important challenges, including efficient spin injection into devices, spin transport, and spin control and manipulation, must be first overcome.

Jankó and his team have developed a theory that they believe offers a solution to these challenges.

The effect resembles what happens when iron filings are sprinkled on a piece of paper, and then a bar magnet is held underneath, says Janko: the presence of the magnet (the flux tube) makes the iron filings (the spins) stand at attention. Furthermore, he says, just as the filings can be manipulated by moving the magnet underneath the paper, the spins in this system can be manipulated by moving the flux tubes.

For example, an electric current flowing through the superconductor will cause a given flux tube to move to one side (with the patch of spins underneath moving along with it), while a current flowing in the reverse direction will move it back to the other side. They are the spin/charge carriers of a diluted magnetic semiconductor (the iron filings), the quantum well in a diluted magnetic semiconductor (the sheet of paper) and the vortices of a superconductor (the bar magnets).

The superconducting vortex can be conceived of as a spinning tornado at nanoscale. The superfluid eddy current is trapping a dense bundle of magnetic field lines inside its core. This bundle can then be used like a small "spin tweezer" to achieve spin manipulation, much as the bar magnets are used as a magnetic tweezer to alter the structures of iron filing groups. If the spin manipulation can be achieved at a scale where quantum effects dominate, one of the most important conditions for quantum computation can be satisfied.

Jankó's research findings, performed in collaboration with Mona Berciu of the University of British Columbia and Notre Dame postdoctoral researcher Tatiana Rappoport, are published in the 5 May issue of the journal Nature. In addition, Jankó and another team of researchers have had a paper published in a companion journal, Nature Materials, describing their discovery of pressure-induced magnetism in diluted magnetic superconductors. This discovery paves the way, along the lines of the theory outlined in the Nature paper, for nano-engineering magnetic properties in magnetic semiconductors.

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