Detector for the single-electron magnet discovered — pathway to the silicon-based quantum computer

Researchers from University of New South Wales (Australia), University of Melbourne (Australia), and Aalto University (Finland) have succeeded in demonstrating a high-fidelity detection scheme for the magnetic state of a single electron, that is, the spin. The research results have just been published in Nature.

The silicon industry is the basis of almost all commercial electronics today having given the rise of the modern information society and wealth ware. In microelectronics, for example in computer industry, less expensive, more powerful, and less power consuming microprocessors are sought constantly. Although the size of transistors has reduced dramatically during this development, it cannot shrink forever. However, a partial solution is potentially given by so-called quantum computer which is now being built with magnetic spin states.

In the recent work of the Australian–Finnish research team, Dr. Andrea Morello, Prof. Andrew Dzurak, and coworkers were able for the first time to measure and initialize the magnetic spin state of a single electron confined in a volume with a diameter of only a few nanometers by the strong attractive force of a single phosphorus donor atom. The phosphorus had been deliberately placed only a few tens of nanometers away from a charge detector. Depending on its spin state, the electron is made to move to the charge detector, thus resolving the direction of the electron spin. (See the figure and the Australian press release linked below for more information.) The ultimate goal of these studies is to build a working large-scale quantum computer, in which electron spins work as quantum bits, qubits. The success of this goal would give birth to a new era in information processing.
Figure caption: Scanning electron micrograph of metallic electrodes on silicon oxide. The electrodes are isolated from each other so that there is no electric current flowing through them. A schematic illustration has been added to the figure representing the electron layer induced below the silicon oxide (source and drain) together with so-called quantum dot (SET island) which works as a charge detector. Furthermore, the dashed blue line shows a region where phosphorus donors have been placed in the silicon with the magnetic moment of the outermost electron pointing either up or down. The energy of spin-up state is higher than the energy of spin-down state in magnetic field. By controlling the voltage on a nearby plunger gate, the system can be brought at will into a working point where spin-up electron has enough energy to tunnel into the charge detector but the spin-down state of the same electron remains bound to the phosphorus. The detector is very sensitive to changes in the charge state of the phosphorus yielding noticeable current ($I_{\text{SET}}$) after the spin-up electron moves. Thus the spin state of the electron can be measure by a single shot at any chosen time.

Although the spin arises from so-called quantum mechanics, it can be understood as a tiny bar magnet. In fact, the magnetism in the usual bar magnets is provided by extremely many single spins which align, thus enforcing each other.

“In hard disk drives, one uses presently at least millions of spins to store a single bit of information. Now we have found a way to handle a single spin in silicon,
which is the longed-for triumph in our research field”, says Dr. Mikko Möttönen, the Finnish collaborator in the work. “Recently, we measured the single-atom transistor and now the single electron spin in real time. I would not be surprised if we had a working qubit in near future”, he continues with great expectations.

Qubits replace bits in a quantum computer
The qubit is the abstract quantum counterpart of the classical bit 0 or 1 in the computers today. The spin of an electron is an ideal candidate for a qubit since it has exactly two independent states. The difference to a classical bit is that the qubit can be simultaneously in states 0 and 1 rendering it conceptually more general.

To achieve the envisioned quantum computing, one has to be able to initialize and measure the states of the qubits, rotate the single-qubit states arbitrarily, and to make a certain operation involving at least two neighboring qubits—all this with high fidelity of course. In the work reported now in Nature, the researchers were able to initialize the spin and measure it with 92% fidelity. Thus only single spin rotations and controllable spin–spin interactions are left for the future research. After achieving these goals, the demonstration of large-scale quantum computer would be at hand.

Original research article has been published in Nature on Sep. 26th, 2010:
http://dx.doi.org/10.1038/nature09392

See also the Australian press release on the same topic:
http://www.scienceinpublic.com/blog/other/qc_nature

See also the release of the single-atom transistor work from the same group:

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