GET THOSE COMPUTERS SPINNING

Photo by Philippe Teuwen via wikimedia.

This week's issue of the magazine *Science* has no less than three papers on a single topic, namely new ways of computing using the quantum mechanical property of spin. Taken together, these provide a brief glimpse into the different ways researchers have progressed in incorporating spin into electronic devices.

The fundamental element of a computer chip is the transistor. The transistor is where the bits are switched from 0 to 1 and vice versa. Transistors are made from semiconductors such as silicon and operate by moving electrical charges between two contacts. But electrical charges are not the only possibility to operate a computer. Another one is to use spin.

What is spin and why do we care?

Spin is a quantity that is related to the rotation of fundamental particles around their own axis, similar to a spinning top. The concept of spin is deeply rooted in quantum mechanics, pioneered by people such as Wolgang Pauli and Niels Bohr. Of course, the analogy of such a fundamental property to a spinning top does not work fully. If you want to learn more about the intriguing world of spin, take a look at Dave Goldberg's blog post.

But how does spin have any relevance in computing? Well, if the particle with spin also has an electrical charge, as the electron does, this also creates a magnetic field, similar to that of a tiny compass. This magnetic field can be used to store information just like an electric charge. Whether the compass points upwards or downwards then corresponds to the 0 and 1 of a bit.

What are the benefits of using spin? Open a computer and just look at the efforts that are needed to cool the computer processor so that it doesn't overheat. In conventional electronics there is a lot of energy loss and heat generation. Spin can be switched with much less energy. Furthermore, spin is a property of all materials, not just semiconductors. And last but certainly not least, unlike the memory of a transistor, the information stored in spin is not necessarily lost if a computer is turned off. This could be useful for computers that don't need to be booted after being turned off.

Spins aligned

To use spin for computing, one first needs to have electrons whose spins all point in the same direction. There are a number of ways to achieve this. Magnetic fields are an obvious one, as they act on spins in the same way as the Earth's magnetic field on compass needles.

The approach that Marius Cost ache and Sergio Valenzuela from the Universit at Autònoma de Barcelona in Spain have now chosen has the added benefit that it also transports the spin across a device — without actually transporting any electrons.

In their work, the first spin-related paper in this week's *Science*, they fabricate a small superconducting 'island' that is connected from both sides with electrical wires. The island is so small that if an excess electron is brought on the island its electrical charge is sufficient to deter other electrons from travelling across the island. Also, the energy of that single electron is above the energy of the 'sea' of superconducting electrons.

The researchers now apply an external magnetic field in upward direction. This lowers the energy of electrons with spin aligned in the same direction and increases the energy barrier for those in downwards direction. This makes a perfect spin filter that is selective for electrons with the right spin orientations. But because of the superconducting properties of the island, no real electrons are passing through, only the spin orientation is transferred from one side to the other. The drawback is of course that this only works at the low temperatures at which superconductors operate.

Manipulating spin

The second paper in Science deals with another issue: how to manipulate the spin in a thin magnetic layer? Christian Pfleiderer from the Technical University of Munich and colleagues use a known approach to turn this spin around, which is an electrical current made of electrons that have spin in the direction the switching will take place. This ‘spin-torque effect’ is something like a brute-force approach as the sheer mass of electrons of spin in the other direction eventually changes the spin of the magnetic layer. It is as if you walk against a large crowd of people that eventually force you to walk in their direction. Because of the large electron current required, this torque effect has been only possible in nanostructures, where heating effects won’t be a problem. Pfleiderer and colleagues have now discovered that the spin-torque works very well in the magnet MnSi, where the spins form a complex assemblies, so-called skyrmions. These skyrmions reverse their direction much easier than conventional magnets, so that the electrical currents required are orders of magnitude smaller. The drawback here is that this still is a quite elaborate experimental far away from the device stage.

Storing spin

Magnets are of course ideal to store spin information for a long time. But there magnetism is set by the atoms and not by free electrons. To combine spin and electronics, however, it would be desirable to find ways to store spin with electrons. This is possible with the spins in the atomic nucleus, as these can be addressed by electrons and nuclear spins have comparatively long lifetimes. Christoph Boehme from the University of Utah and colleagues have now stored spin information in the atomic nucleus of phosphorus atoms embedded in a silicon chip. They demonstrate that the lifetimes of these spins are larger than 100 seconds. The benefit is that this is done completely electronically, and it is in silicon, which is the best material to combine spin electronics and regular electronics. On the other hand, this approach may not yet have reached the easy of implementation and reliability required for applications.

Of course, these three papers only provide a very specific view into some areas explored for spin electronics. And while the concept of electronics being to a large extend driven by spin instead of electrical charges is very appealing, it is still a long way for most of these approaches to become technologically viable. Nevertheless, the variety of ideas and approaches currently pursued is impressive and a good indicator of the ingenuity of researchers and the interesting physics coming out of this field as it moves closer towards applications.

Source: http://allthatmatters.heber.org/2010/12/17/get-those-computers-spinning/