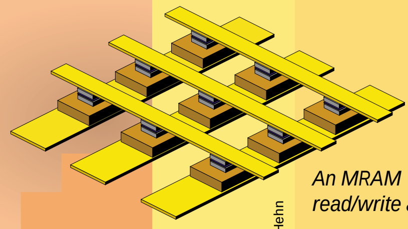
Institute of Physics

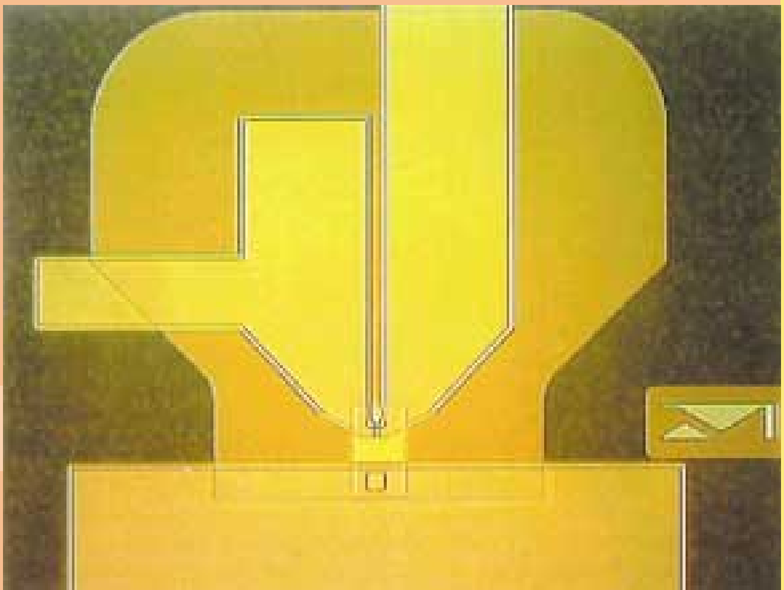


An MRAM read/write array

Michel Hehn

New devices exploiting the spin of the electron are poised to revolutionise the electronics industry

Spintronics



A GMR read head

Seagate

VISIONS 5
BRIEFING PAPERS FOR POLICY MAKERS

Electronics takes a spin into the

Conventional electronic devices rely on the transport of electrical charge carriers – electrons – in a semiconductor such as silicon. Now, however, physicists are trying to exploit the 'spin' of the electron rather than its charge to create a remarkable new generation of 'spintronic' devices which will be smaller, more versatile and more robust than those currently making up silicon chips and circuit elements. The potential market is worth hundreds of billions of dollars a year.

A magnetic field sensor made of GMR multilayers (iron-nickel with silver) for an angular encoder

CEA-LETI/Artechnique

Giant magnetoresistance

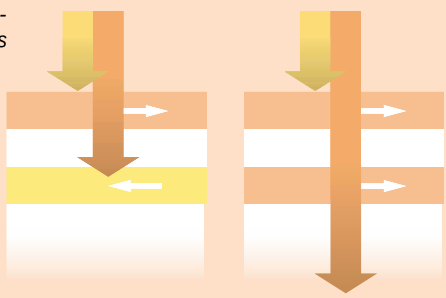
Electrons like all fundamental particles have a property called spin which can be orientated in one direction or the other – called 'spin-up' or 'spin-down' – like a top spinning anticlockwise or clockwise. When electron spins are aligned (*ie* all spin-up or all spin-down) they create a large-scale net magnetic moment as seen in magnetic materials like iron and cobalt. Magnetism is an intrinsic physical property associated with the spins of electrons in a material.

Magnetism is already exploited in recording devices such as computer hard disks. Data are recorded and stored as tiny areas of magnetised iron or chromium oxide. To access the information, a read head detects the minute changes in magnetic field as the disk spins underneath it. This induces corresponding changes in the head's electrical resistance – an effect called magnetoresistance.

Spintronics burst on the scene in 1988 when French and German physicists discovered a much more powerful effect called 'giant magnetoresistance' (GMR). It results from subtle electron-spin effects in ultra-thin 'multilayers' of magnetic materials, which cause huge changes in their electrical resistance when a magnetic field is applied. GMR is 200 times stronger than ordinary magnetoresistance. IBM soon realised that read heads incorporating GMR materials would be able to sense much smaller magnetic fields, allowing the storage capacity of a hard disk to increase from 1 to 20 gigabits. In 1997 IBM launched GMR read heads, into a market worth about a billion dollars a year.

The basic GMR device consists of a three-layer sandwich of a magnetic metal such as cobalt with a nonmagnetic metal filling such as silver (see diagram, left). A current passes through the layers consisting of spin-up and

The GMR effect
How giant magneto-resistance works



THANKS GO TO JOHN GREGG OF OXFORD UNIVERSITY AND JOHN BUNYAN OF DERA, MALVERN FOR

spin-down electrons. Those oriented in the same direction as the electron spins in a magnetic layer pass through quite easily while those oriented in the opposite direction are scattered. If the orientation of one of the magnetic layers can easily be changed by the presence of a magnetic field then the device will act as a filter, or 'spin valve', letting through more electrons when the spin orientations in the two layers are the same and fewer when orientations are oppositely aligned. The electrical resistance of the device can therefore be changed dramatically.

Memory chips

Physicists have been quick to see the further possibilities of spin valves. Not only are they highly sensitive magnetic sensors (see Box), they can also be made to act as switches by

future

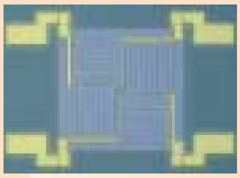
flipping the magnetisation in one of the layers. This allows information to be stored as 0s and 1s (magnetisations of the layers parallel or antiparallel) as in a conventional transistor memory device. An obvious application is a magnetic version of a random access memory (RAM) device of the kind used in your computer. The advantage of magnetic random access memory (MRAM) is that it is 'non-volatile' – information isn't lost when the system is switched off. MRAM devices would be smaller, faster, cheaper, use less power and would be much more robust in extreme conditions such as high temperature, or high-level radiation or interference. The US electronics company Honeywell has already shown that arrays of linked MRAMS could be made to work. The potential market for MRAMS is worth 100 billion dollars annually.

Over the past three years or so, researchers around the world have been working hard on a whole range of MRAM devices. A particularly promising device is the magnetic tunnel junction, which has two magnetic layers separated by an insulating metal-oxide layer. Electrons can 'tunnel' through from one layer to the other only when magnetisations of the layers point in the same direction, otherwise the resistance is high – in fact, 1000 times higher than in the standard spin valve.

Even more interesting are devices that combine the magnetic layers with semi-conductors like silicon. The advantage is that silicon is still the favourite material of the electronics industry and likely to remain so. Such hybrid devices could be made to behave more like conventional transistors. They could be used as non-volatile logic elements which could be reprogrammed using software during actual processing to create an entirely new type of very fast computing.

The field of spintronics is extremely young and it's difficult to predict how it will evolve. New physics is still being discovered and new materials being developed, such as magnetic semiconductors, and exotic oxides that manifest an even more extreme effect called colossal magnetoresistance.

What is certain is that the time-span from a breakthrough in fundamental physics to first commercial exploitation has been less than 10 years. The business opportunities for spintronics are still wide open. European research collaborations, some involving the UK, have a strong lead in developing the underlying physics and technology for this lucrative fledgling industry.



A general magnetic field sensor made of GMR multilayers (iron-nickel with silver)

SENSORS

GMR sensors are already being developed in UK universities. They have a wide range of applications and the market is worth 8 billion dollars a year. Applications include:

- Fast accurate position and motion sensing of mechanical components in precision engineering and in robotics
- All kinds of automotive sensors for fuel handling systems, electronic engine control, antiskid systems, speed control and navigation
- Missile guidance
- Position and motion sensing in computer video games
- Key-hole surgery and post-operative care

Spintronic sensor technology being tested on a Mercedes V8 engine at Oxford

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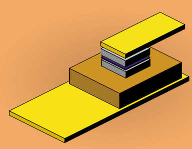

The single cell of an MRAM using a magnetic tunnel junction

Editor: Nina Hall. Design: Pete Hodkinson.