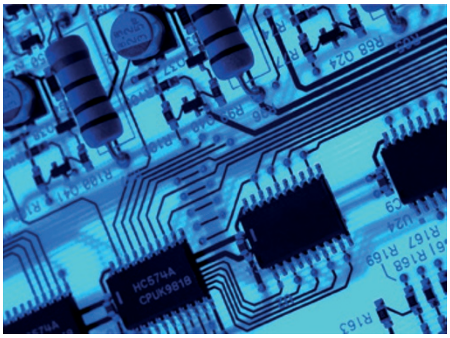
Memory with a spin

Spintronic devices that electrically store non-volatile information are promising candidates for high-performance, high-density memories.

Digital information can be stored in different types of device depending on the use and how frequently the data need to be accessed. For example, data that are to be stored for a long time, and infrequently accessed, are normally stored in hard disk drives. These are magnetic devices with high data density — nowadays on the order of terabytes — in which information is encoded in the direction of magnetization of small areas of a magnetic medium. Each of these magnetic 'bits' stores a logic '0' or '1', and is written or read by a recording head that flies over the disk at a distance of a few nanometres. The information stored in hard disk drives is non-volatile as it persists after power to the device has been cut off. The speed of access to the data is relatively slow (a few milliseconds) because the read/write procedures involve moving mechanical parts. On the other hand, data that are being used by a computer processor to perform an operation need to be accessed on a much faster timescale, and can be stored as volatile information. Memory devices dedicated to this purpose are usually random access memories (RAMs) — solid-state electronic devices in which information is electrically stored and can be accessed on the nanosecond timescale.

In the information storage industry there is now an effort to develop new concepts for memory devices that combine the best of both worlds — that is, cheap, non-volatile, high-density information storage, as in hard disk drives, and robust, fast access, as in RAM. Flash memory is an example, as it is a solid-state yet non-volatile memory, and is currently used in mobile applications. However, Flash is slow and has low endurance. As a result, several new solid-state technologies are currently being developed; one of these, spin-transfer-torque magnetic RAM (STT-MRAM), is about to hit the market — Everspin Technologies started distributing to selected customers a 64-Mbit demo-product at the end of 2012 (http://www.everspin.com/spinTorqueMRAM.php). In this issue of *Nature Nanotechnology*, in a focus on spin-transfer-torque memory, we look at the operation, prospects and challenges of commercializing this and other emerging non-volatile memories.

In STT-MRAM, the information is stored in the magnetic state of nanomagnets,



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but it is electrically written and read. This combination allows fast-access, non-volatile information storage. In the first of three Commentary articles, Andrew Kent and Daniel Worledge describe on page 187 the structure and operation of a STT-MRAM cell, and discuss its potential applications as a replacement for embedded Flash storage memory or embedded working memory. With access times on the order of 10 ns and high endurance, STT-MRAM has inherent advantages over other emerging technologies. However, challenges in materials engineering and device optimization remain, and will have to be addressed to improve device performance and widen the range of potential applications.

Beside STT-MRAMs, other non-volatile memories are emerging that do not store information in the magnetic state, but rather in the structural phase of the active materials. To define the competitive landscape of STT-MRAMs, the characteristics of these other technologies — phase change memory, resistive switching RAM and conductive bridge RAM — are discussed by H.-S. Philip Wong and Sayeef Salahuddin in a second Commentary article on page 191. These devices have the advantage of being made from materials that are commonly used in the electronics industry; phase change memory could also achieve multi-bit data storage. On the other hand, resistive switching RAM and conductive bridge RAM suffer from issues of reliability, and their physical principles of operation have not been firmly established, slowing down device development. These non-magnetic memory devices and STT-MRAMs both have potential advantages over existing devices such as Flash. In particular, they can potentially be integrated on the same chip as the processor; this could drive a change in the design of computing architectures, which could lead to improved performance and higher energy efficiency.

STT-MRAM cells are not the only memory devices that rely on spin-transfer torques for a writing mechanism. In another type of spin-based memory — racetrack memory — information is encoded in the magnetic state of domain walls in magnetic nanowires and spin-transfer torque is used to write data by displacing the domain walls along the wire. In the third Commentary on page 195, Stuart Parkin and See-Hun Yang discuss recent developments in device concepts for racetrack memory. This type of device is versatile, as speed can be traded off against data density by controlling the number of domain walls in each nanowire.

All the spin-transfer-torque memories discussed above rely on electrical currents to write bits of data. Although this is an advantage over the use of magnetic fields, the presence of currents implies energy dissipation by Joule heating. Instead, using voltages to control magnetic elements can significantly reduce energy dissipation, while retaining the benefits of all-electrical read/write operations. In a Review article on page 209, Fumihiro Matsukura, Yoshinori Tokura and Hideo Ohno examine recent progress in the electric-field control of magnetism in both ferromagnets and multiferroics. In ferromagnetic systems, electric fields can modify the magnetic anisotropy of the system, which in turn determines the properties of magnetization switching, such as the coercivity. In multiferroic materials, the electric and magnetic polarizations are coupled by the magnetoelectric effect, allowing for electric-field control of the magnetic order.

As our focus issue helps illustrate, there is an active interest from many of the industrial giants of the electronics industry in the development of memory technologies based on spin. But this is only the start of what spin-transfer-torque phenomena could offer — recent discoveries of these spin-dependent effects in non-magnetic materials could, for example, provide a further boost to progress in the field, and lead to a whole new set of device designs. ❐