Devices with a spin

In pursuit of the spin transistor and alternative memory technologies.

In research, it can sometimes take a while for a theoretical prediction to be experimentally confirmed. The Higgs boson, for example, was first predicted in 1964 through the development of models that could explain why fundamental particles have mass^{1–3}. But it took until 2012 — and the work of thousands of scientists and engineers — before researchers at the Large Hadron Collider in Geneva were able to announce that they had observed a particle that was consistent with the Higgs boson⁴. Alternatively, in condensed-matter physics, but building on ideas from particle physics, experimental evidence for the existence of Majorana fermions grows⁵. These particles, which are their own antiparticle and could be of use in quantum computing, were first proposed around 80 years ago⁶.

In terms of electronic devices, the memristor — a resistor with memory — is another such example. It was originally postulated by Leon Chua of the University of California, Berkeley in 1971⁷. Thirty-seven years later a team from Hewlett Packard Labs, led by R. Stanley Williams, connected experimental observations to this theoretical prediction⁸. Another device example, this time with a relatively modest wait of 19 years, is the spin transistor. It was originally proposed⁹ by Supriyo Datta and Biswajit Das of Purdue University in 1990, and a version of the device was first experimentally demonstrated in 2009¹⁰.

The story of how the spin transistor was first proposed is one that Datta recounts in our [Reverse Engineering column](#) in this issue of *Nature Electronics*. The device is a field-effect transistor (FET) based on the spin of the electron rather than its charge. It emerged from the idea of exploiting the similarities between electron spin and photon polarization, and involves the injection and detection of polarized spins using magnetic source and drain electrodes.

The pursuit of the spin transistor is though only one facet of the diverse field of spintronics, which aims to exploit the spin of electrons for information processing. Another key area for the field is alternative memory technologies and, in particular, the development of magnetoresistive random-access memory (MRAM), a type of non-volatile memory that offers fast operation and high endurance. In MRAM, data is

Optical image of a three-terminal magnetic tunnel junction device used by Zhao and colleagues. Credit: Springer Nature Ltd.

stored in magnetic elements known as magnetic tunnel junctions. These junctions are composed of a magnetic free layer, a magnetic fixed layer, and a thin insulating layer sandwiched between the two magnetic layers. The resistance across them depends on the relative orientation of the two magnets and, therefore, information can be written by switching the magnetization of the magnetic free layer.

In the first generation of MRAM products, switching was achieved using a magnetic field. However, it can now be done electrically with the help of an effect known as spin-transfer torque (STT). Here, a spin-polarized current passing through the junction exerts a torque on the magnetization of the free layer, switching its magnetization. A number of companies are currently pursuing this technology and Everspin Technologies introduced a 256 Mbit STT-MRAM to the market in 2016¹¹.

At the same time, innovation at a more fundamental level continues and, in recent years, an alternative switching mechanism, which relies on an effect known as spin-orbit torque (SOT), has been proposed for such devices. Here, a current is passed laterally through a metallic layer that is below the free magnetic layer. Due to spin-orbit coupling, this generates a perpendicular spin current that can be used to switch the magnetization of the free layer. The approach could be used to improve the reliability and lower the switching times

of the devices. However, the switching requires the use of an external magnetic field. It also uses a three-terminal structure, in contrast to the two-terminal structure of STT-MRAM, which increases the size of the device and could limit the density of the memory devices.

In an [Article](#) in this issue of *Nature Electronics*, Weisheng Zhao and colleagues show that switching without an external magnetic field can be achieved through a combination of spin-orbit and spin-transfer torques. Increasing one type of current allows the other to be reduced, and so, by adjusting the relative currents, the behaviour of the device can be effectively tuned from STT-dominated to SOT-dominated. This is first demonstrated with three-terminal devices, but the researchers — who are based at Beihang University, Qualcomm Technologies, the University of Minnesota, and the University of Paris-Sud — also show that the interplay between SOT and STT can be used to achieve switching in two-terminal devices. This result follows a recent demonstration of similar effects in two-terminal MRAM devices from Shan Wang and colleagues at Stanford University and Tsinghua University¹².

As Pedram Khalili Amiri of Northwestern University notes in a [News & Views article](#) accompanying the work of Zhao and colleagues, “the most valuable application of SOT-MRAM is in fast memory”. And thus, he continues, “it will be important to examine the combined SOT-STT switching in the nanosecond regime”. This has not yet been done. But in this case, we should hopefully not have to wait too long to get some experimental answers. □

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