The next wave

Spin waves look poised to make a splash in data processing.

Even before its discovery in 1897, control of the electron had already played a role in a technological revolution: electric power enabled the mass-production manufacturing methods of the second industrial revolution in the nineteenth century. Levels of its manipulation have now reached such highs that the technologies that pervade our daily lives would surely seem fanciful to the scientists who first probed this elementary particle. Now the world looks set to welcome a new way of exploiting the electron, in the form of magnonics.

The electron charge is firmly established as the information carrier of choice for modern technologies. But what of its second elementary property, spin? Despite being discovered just ten years after the electron charge was first measured, spin remains a relative passenger in information-processing technologies. But its presence could revolutionize these technologies, and in more ways than one.

The electron spin actually underpins magnetic-storage technologies, with magnetic 'bits' encoded in the direction of a material's magnetization, which reflects the behaviour of a collection of spins. What distinguishes spin from charge is that there are two possible values, say 0 and 1, for particles that have a spin of 1/2, such as the electron. An intrinsic property capable of existing in multiple states sounds like the ideal candidate for logic operations. Moreover, the manipulation of spins alleviates the losses associated with moving charges, such as Joule heating. So why aren't information-processing technologies utilizing this property? It's certainly not for want of trying.

Efforts to use spins for both data storage and information processing are a focus for many researchers in the spintronics community. The field of spintronics grew out of the discovery of spin-dependent electron transport during the 1980s[1] and is concerned with using magnetic and electric fields to manipulate spins. Although many logic devices based on spintronics are still in the development stages, some have already reached the market. But there are opportunities for technologies that go beyond electron-carried charge and spin currents.

It was proposed back in the 1930s[2], and experimentally observed in 1950s[3], that waves could be excited in magnetically ordered materials using the collective precessional motion of spins. As each individual spin precesses on its given position, spin-wave propagation occurs without electron charges being displaced. One can therefore envisage a device where an input voltage is converted into a spin wave, some wave-based computation is performed, and then the wave is converted back into a voltage. There are several advantages to such a device, including parallel data processing on different wave frequencies, low power consumption, and non-Boolean computing algorithms — enabled by the additional degree of freedom provided by the phase of the waves.

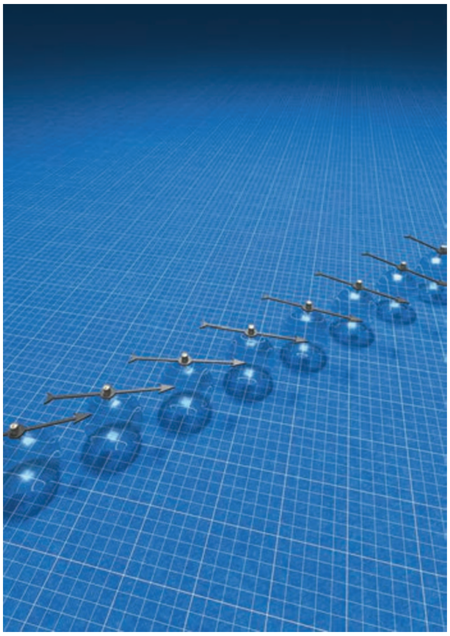

IMAGE COURTESY OF SANDER OTTE

The field of research that aims to exploit spin waves is known as magnonics, which refers to the quantized version of spin waves: magnons. In this issue of *Nature Physics*, we take a close look at the advances, prospects and challenges of developing information processing and wireless communication technologies based on spin waves.

Although spin waves were discovered decades before spin-dependent transport effects, magnonic devices are yet to reach the same heights as their spintronic counterparts. This progress has perhaps been hindered by the lack of appropriate materials, and the need for advanced nanoscience techniques to generate, manipulate and detect magnons on the nanometre scale. But recent demonstrations, such as the realization of a magnon transistor, highlight the progress being made.

To expand the set of materials capable of hosting magnons, artificial crystals are being used. In much the same way that photonic crystals exhibit tailored band structures for electromagnetic waves, certain magnonic crystals can modify the band structure for magnons. Modulation is achieved in such crystals by varying their magnetic properties On page 487 of this issue, Marc Vogel and colleagues show how reconfigurable magnonic crystals can be created in an insulating ferrimagnet using all-optical methods.

The potential for using such techniques in wireless communication technologies is examined by Dirk Grundler in a Commentary on page 438. Coupling electromagnetic waves to mechanical waves allowed for wireless communication technologies to be drastically miniaturized. Grundler discusses how magnonics could not only provide wireless technologies that are small, but also reprogrammable.

As one might expect, the magnonics and spintronics communities are closely intertwined. And as magnons can be converted into electron-carried spin and charge currents, circuits could be developed whose individual components utilize the strength of the different spintronic, charge or magnonic elements. Andrii Chumak and colleagues survey this topic in a Review Article on page 453. They discuss the generation and manipulation of magnons, the mechanisms and progress on converting between magnon currents and spin and charge currents, and recent experimental advances that are laying the foundations for magnon-based computing.

As this Focus helps to illustrate, spin can be used in technologies in more ways than one. And although magnonic devices have some catching up to do if they are to emulate their spintronic counterparts, they finally look set to be in the race. ❐

References

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2. Bloch, F. *Z. Physik* **61,** 206–219 (1930).
3. Brockhouse, B. N. *Phys. Rev.* **106,** 859 (1957).

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