mechanisms of retrograde migration exist in the large intestine, whose architecture is very similar to that of the small intestine: the stem cells also reside in crypts and are identified by the surface marker Lgr5, and the number of Lgr5-positive cells is remarkably similar. Yet the authors almost never observed stem-cell rearrangements and retrograde migration in the crypts of the large intestine (Fig. 1b).

This finding has two major implications. First, in the large intestine, Lgr5-expressing cells that are farthest from the base of the crypt cannot act effectively as stem cells, because they cannot relocate towards the crypt base and so are lost from the niche relatively quickly. Therefore, the number of bona fide functional stem cells is lower in the large intestine than in the small. Second, crypts in the large intestine become dominated by the activity of a smaller number of spatially restricted stem cells, and so progress to monoclonality (that is, to being entirely derived from one stem cell) more rapidly than do crypts in the small intestine. This renders the tissue more vulnerable to random harmful mutations or other tissue damage. Reinforcing the physiological significance of these differences, the authors found that, when stem cells are removed, the cell pool regenerates more quickly in the small intestine than in the large.

This work raises fascinating questions about the developmental roots and physiological consequences of differences in stem-cell dynamics along the intestinal tract. In particular, in humans, cancers of the small intestine are much rarer than those of the large intestine. Could this be explained, at least in part, by the absence of retrograde migration in the large intestine's crypts? The existence of such migration in the small intestine could mean that potential tumour-initiating stem cells there would have more wild-type stem cells to compete against than exist in the large intestine before they could initiate an overgrowth. Azkanaz and colleagues also found that retrograde migration depends on secreted Wnt proteins, probably supplied by niche cells known as Paneth cells that are present only in the small intestine. Administration of Wnt proteins would not be a tenable prophylactic treatment for people at high risk of intestinal cancers. But studies that seek to better define the molecular and biophysical factors that endow small intestine stem cells with this migratory capacity might open up viable therapeutic avenues.

Also of interest will be to understand how other microenvironmental differences between the small and large intestines – apart from the presence of Paneth cells – affect stem-cell regulation. Differences in tissue biomechanics and the composition of the extracellular matrix between the two regions might be crucial, especially with respect to the migratory capacity of stem cells. The distinct composition of gut microorganisms, inflammatory signals and immune-cell populations associated with each anatomical region are also likely to have a substantial influence on the repertoire of stem-cell behaviours.

Perhaps the most burning question of all is this: do the active rearrangements of stem cells serve as a general controller of long-term self-renewal in other tissues and organisms? This question will be one to mobilize the entire stem-cell field.

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Condensed-matter physics

Strain solves switch hitch for magnetic material

Kab-Jin Kim & Kyung-Jin Lee

Applying strain to a material that has a type of magnetism called antiferromagnetism allows its magnetization to be fully switched with an electric current – making it appealing for use in next-generation magnetic memory devices. **See p.474**

Conventional computers store much of their information using electric charge, but these memories are volatile, and miniaturizing components – to build laptops with high memory capacity, for example – increases their power consumption. Information can be more stably encoded magnetically, using the spin (intrinsic angular momentum) of electrons, in a form of electronics known as spintronics[1]. However, commercial spintronic devices are slower than conventional computers and are sensitive to stray magnetic fields. Attempts to overcome these problems using a type of magnetism called antiferromagnetism have yet to optimize switching between binary states in these devices. On page 474, Higo *et al.*[2] show that tensile strain can be used to achieve full electrical switching in an antiferromagnetic material.

> **"Switching with an electric current allows the components of the device to be densely packed into a tiny chip."**

Spintronic devices are typically built from ferromagnetic materials, in which all of the spins point in the same direction. This results in a large net magnetic moment, making these materials sensitive to external magnetic fields that can interfere with device performance. Attention has therefore turned to antiferromagnetic materials, in which neighbouring spins point in opposite directions[3,4]. Antiferromagnetic memories are insensitive to stray fields and can operate hundreds of times faster than ferromagnetic memories[1,5], but most antiferromagnetic materials have multiple directions along which they can magnetize, instead of the two that would correspond to binary states 0 and 1.

Full switching refers to the magnetization of a material being rotated through 180°, so as to switch between these states. Such switching is crucial for rapid operating speeds, because it maximizes the signal that the device reads to determine the state of the material, and this, in turn, reduces the time required to do so. Moreover, switching with an electric current allows the components of the device to be densely packed into a tiny chip. Electrical switching has been achieved in several antiferromagnetic materials[6–11], but full switching has not yet been demonstrated, owing to the multiple directions along which these materials can magnetize.

Higo *et al.* achieved full electrical switching of the antiferromagnetic manganese–tin compound Mn_3Sn, a material in which two single layers of manganese atoms lie in a pattern of

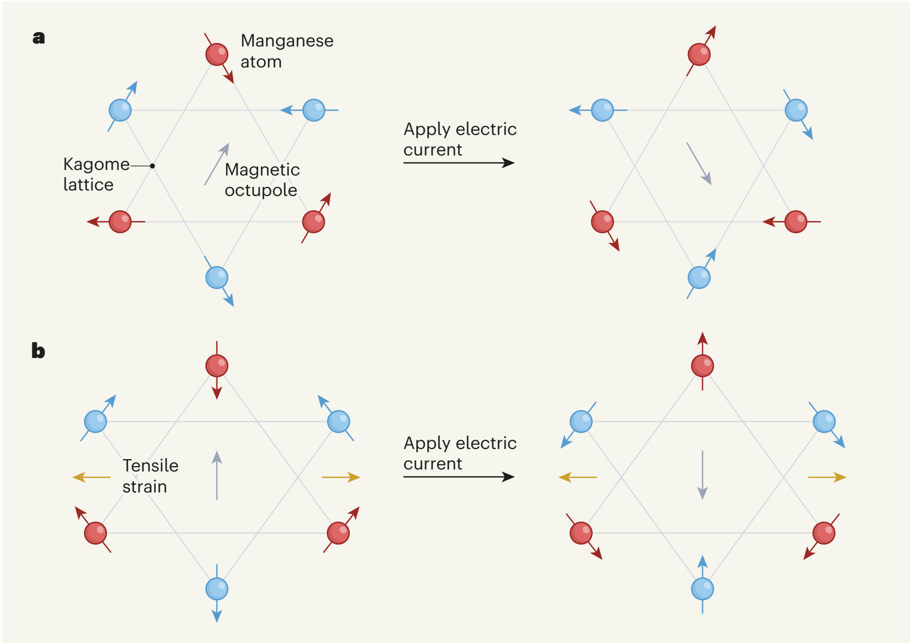

Figure 1 | Strain enables full electrical switching in an antiferromagnetic material. a, In the manganese–tin compound Mn_3Sn, two single layers of manganese atoms lie in a pattern of overlapping triangles, known as a kagome lattice; tin atoms are not shown. Red and blue arrows represent the magnetic moments in different layers, and clusters of six atoms form collective magnetic moments known as octupoles. The direction of these octupoles can be switched using an electric current (not shown), but because the kagome lattice has six directions along which the atomic magnetic moments can point, the octupoles can switch between six directions. **b**, Higo *et al.*[2] applied strain to Mn_3Sn by introducing a slight mismatch between the material's crystal lattice and that of the substrate on which the sample was grown. This strain induced two preferred directions along which the octupoles aligned, enabling an electric current to fully switch the octupoles between two binary states – for example, up and down octupole states – which opens up applications for the material in magnetic memory devices.

overlapping triangles, known as a kagome lattice. In the plane of these layers, clusters of six spins form collective magnetic moments known as octupoles, and authors in the same research group as Higo and colleagues had previously shown that these octupoles can be switched using an electric current[10]. But because the kagome crystal lattice has six directions along which the atomic moments can point, the octupoles could be only partially switched (Fig. 1a). Now, Higo *et al.* have shown that they can achieve full switching by applying tensile strain to the material.

When Mn_3Sn is under strain, the directions along which it can magnetize change substantially. The authors grew Mn_3Sn films using a technique called molecular-beam epitaxy, and applied strain by introducing a slight mismatch between the material's crystal lattice and that of the substrate on which it was grown. This strain induced two preferred directions for the octupoles (Fig. 1b), enabling full electrical switching of the magnetic octupole with the help of an external magnetic field applied in the plane of the film.

As well as allowing full switching, this simple strategy using strain makes the switching dynamics distinct from those in ferromagnets. The strain creates a strongly preferred direction of magnetization in the kagome plane, which makes the magnetic moments stay in this plane during switching. As a result, switching happens swiftly without the system passing through intermediate states, and the final state is reached as soon as the electric current is switched off. This differs from what happens in ferromagnets that use the same switching technique (involving a phenomenon known as spin–orbit torque), which tend to relax slowly towards their final state. Furthermore, the current density required for switching in the authors' material is comparable to or even smaller than that for a ferromagnet, suggesting that it can be operated at low power.

Although Higo and colleagues' demonstration of full switching in an antiferromagnetic material is undoubtedly a milestone, there is more work to do before antiferromagnetic spintronic devices can be fully realized. Such switching will have to be implemented without an external magnetic field, because accommodating a field source would complicate the miniaturization that is essential for commercialization of magnetic memory devices. Hints on how to achieve this might come from field-free switching schemes that have previously been investigated for ferromagnets[12].

Another required improvement involves the realization of a large magnetoresistance – the tendency of a material to change the magnitude of its electrical resistance depending on the magnetization direction. Increasing the magnetoresistance can boost the speed at which antiferromagnetic switching is detected in a material, and this can be achieved through various techniques[13,14]. It would also be worth checking whether the switching speed in this material can indeed reach the subnanosecond scale, which is one advantage of antiferromagnets over ferromagnets. Finally, molecular-beam epitaxy is not compatible with mass production, so demonstrating a film-deposition method that does not rely on this technique would be a step towards commercialization of antiferromagnetic spintronic devices using this material.

The resolution of all of these challenges might well spawn a revision to a remark in French physicist Louis Néel's 1970 Nobel lecture, in which he implied that antiferromagnetic materials are extremely interesting but ultimately useless (see go.nature.com/38xapnd). Higo and collagues' demonstration shows that this description might soon be updated to interesting and useful.

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