SPIN ORBIT TORQUES

Go in the right direction

A connection between crystalline symmetry and the allowed symmetries of the current-induced torques generated via the spin-orbit interaction opens up their use to devices with perpendicular magnetic anisotropy.

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As spin-orbit coupling is the origin of some of the crucial anisotropies that are used to tune the properties of permanent magnets, it is a hidden backbone of many modern technologies — from the huge turbines that provide us with electricity to the tiny magnetic films that provide us with cheap, reliable ways to store data. The spintronics community are now trying to push this phenomenon to the center stage by using the magnetic torques that are generated via spin-orbit interactions, known as spin-orbit torques, as the key means of manipulating spins in memory devices — with electron spin acting as the main information storage. The problem, however, is that spin-orbit torques typically only act in certain directions, limiting the types of magnetic devices that they could be used in. Now, writing in *Nature Physics*, David MacNeill and colleagues show that the emergence of torques can be controlled by local symmetry breaking, in their case, by interfacing low-crystalline symmetry material with another layer [1].

Spin-orbit torques can be produced in a couple of ways, by spin-textures in momentum space [2] and by spin-Hall effects [3]. In the spin-Hall effect case, magnetic films are placed on top of a heavy metal, such as platinum, which has a strong spin-orbit interaction. When passing a current through such a layer, spin-orbit coupling causes spin-dependent scattering/deflection, leading to a flow of spin angular momentum (spin-current J_S) along the perpendicular direction to the electron flow J_C (Fig.1). This causes spins to accumulate at the boundaries of the sample, with a spin polarisation perpendicular to both J_C and J_S. These spins can be extracted by the adjacent magnetic layer, exerting a torque [4,5].

MacNeill *et al.* used a slightly different approach to generate a new type of spin-orbit torque, but to appreciate its significance, it is first useful to discuss the different classifications of magnetic torques. Classically, when a magnetic moment (**m**) is subjected to a magnetic field (**H**), it experiences a torque defined by $\mathbf{m}\times\mathbf{H}$. Thinking of a thin-film ferromagnet where both the moment and field lie within the film plane (in-plane), the direction of the torque direction will be out-of-plane. Current-induced magnetic torques that fall into this $\mathbf{m}\times\mathbf{h}_{\mathbf{eff}}$ symmetry are called 'field-like' torques.

There exists another type of current-induced torques of the form $\mathbf{m}\times(\mathbf{m}\times\mathbf{s})$, where **s** represents the spin polarisation direction of electrons. This mechanism, called the anti-damping (or spin-transfer) torque [6, 7], appears when polarised electrons scatter from magnetisation and an angular momentum transfer takes place between the electron spin and the magnetisation. Spin-orbit torques arising from the spin-Hall effect rely on this mechanism but the torque direction is always in-plane, as the direction of **s** is fixed in-plane (see Fig.1).

What makes the torque observed by MacNeill *et al.* so special is that it has the same anti-damping symmetry as a torque induced via the spin-Hall effect, but is polarised along the out-of-plane direction. This out-of-plane anti-damping torque has been much sought after as spin-orbit torques since high-density spin devices inevitably need perpendicular magnets for which this torque type can switch most efficiently.

So how did they achieve such a feat? Well, the trick was to replace the heavy metal layer with a material whose crystal structure is low in symmetry. Their material of choice was a transition metal dichalcogenide WTe_2. When interfaced with permalloy, this system has just one mirror symmetry, which is along one in-plane direction. Symmetry analysis [8, 9] can tell that a lower symmetry system can generate a wider variety of spin-orbit torques that are otherwise prohibited in higher symmetry systems — the out-of-plane anti-damping torques observed here are not allowed in NiFe/Pt bi-layers as two orthogonal in-plane mirror symmetries are present. **[OK?]**

To confirm the interfacial symmetry origin of their torque, they show that the torque only arises when the current is applied along the low-symmetry axis, disappearing when the current is along the high-symmetry axis. The torque also almost vanishes when measured in devices with two opposite crystallographic WTe_2 domains interfacing the permalloy layer. The spin-charge conversion efficiency, quantified as the effective spin-Hall angle, at the NiFe/WTe_2 interface is 0.013, which is the same order of magnitude as that produced by typical heavy metals such as platinum and tantalum — a promising start.

So what are the next steps? Clearly, the discovery of a new spin-orbit torque is a milestone but the microscopic origins of the new torque are still unknown. Phenomenologically, the out-of-plane spin polarisation in these experiments should have been generated, but it's not clear how? Local symmetry breaking at the interface seems to be key but realistic calculations of the electronic band structures at the interface would significantly help to elucidate the underlying physics. And as WTe_2 has attracted a great deal of attention as a potential topological material [10], it is possible that some spin textures in momentum space are involved. Let's hope that the interfacial symmetry breaking concept reported here is transferable to other groups of materials. **[OK?]**

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Figure 1 | Current-induced spin polarisation/separation processes for spin-orbit torques. **a,** the spin-Hall effect. An electric current $\mathbf{J_C}$ induces a spin current $\mathbf{J_S}$ along the perpendicular direction to $\mathbf{J_C}$. The spin axis of $\mathbf{J_S}$ is defined by $\mathbf{J_S} \times \mathbf{J_C}$. **b,** spin polarisation profile along the *z* direction with and without a current — the spin accumulation is represented by the chemical potential difference for up-spin and down-spin electrons $\mu_\uparrow - \mu_\downarrow$. **c,** The spin polarisation process within a material with inversion broken nature. Spin flipping (or rotation) processes by an electric current lead to uniform spin accumulation within the sample. **d,** spin polarisation profile along the *z* direction for this mechanism.