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2D SPINTRONICS

A barrier to spin filters

Electron tunnelling through a two-dimensional magnetic insulator is assisted by magnon inelastic processes that provide spin-filtering.

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Spintronics has recently emerged as one of the most vibrant topics in two-dimensional materials research. Graphene has, for example, been shown to offer promising spin manipulation capabilities by interfacing it with other 2D materials, and such structures could be used to build future magnetic random access memory (MRAM) or spin logic devices[1,2]. A spintronic architecture of particular relevance in this context is a double spin-filter tunnel junction, which consists of two magnetic insulating layers sandwiched between two nonmagnetic electrodes. Using bulk materials, it has been previously demonstrated that these junctions can be used as a memory bit[3], where information is encoded in their magnetoresistance. The recent discovery of heterostructures containing 2D magnetic materials[4,5] offers opportunities to engineer these spintronic architectures at the two-dimensional limit. Writing in *Nature Electronics*, Kostya Novoselov at the University of Manchester and colleagues now show that thin ferromagnetic insulating layers of chromium tribromide ($CrBr_3$) can form a tunnel barrier between two monolayer graphene electrodes[6]. They suggest that, at a low enough temperature, the tunnel barrier may act as a perfect spin filter and show strong evidence of magnetic proximity effects on the graphene electrodes, highlighting the potential of these 2D ferromagnetic barriers in graphene spintronics.

The researchers – who are based at institutes in the UK, Ecuador, Russia, Germany, and the Netherlands – fabricated a van der Waals heterostructure device composed of h-BN/graphene/$CrBr_3$/graphene/h-BN (Fig. 1a). The h-BN (hexagonal boron nitride) is used to encapsulate the stack and protect the $CrBr_3$ from degradation, and the device was assembled on an oxidised silicon wafer using a dry transfer method in an inert atmosphere. By applying a bias voltage across the tunnel barrier, the tunnelling current and its variation with temperature and external magnetic field were investigated. This showed that it was possible to tune the magnetic properties of the $CrBr_3$, as well as the electronic structure of the top and bottom graphene injector and collector electrodes. Further control of the tunnel barrier characteristics was achieved by varying the number of $CrBr_3$ monolayers from two to six.

Using an appropriate combination of in-plane and perpendicular magnetic fields, Novoselov and colleagues show that the electronic transfer in $CrBr_3$ is mediated by the coupling of tunnelling electrons with internal magnetic degrees of freedom (magnons) emerging from the magnetic ordering of the $CrBr_3$. They argue that, at low temperatures, the transmitted electron spins through the $CrBr_3$ are forced to flip their direction, from down to up, upon inelastic tunnelling, which is assisted by single-magnon activation processes. Since tunnelling from an initial spin-up state is prohibited, they conclude that the barrier must act as an efficient spin filter. (At high temperatures, electron scattering on localized imperfections of **the spin texture** in $CrBr_3$ becomes dominant.) Their interpretation is supported by theoretical analysis of the transport and magnon properties of the $CrBr_3$, which provide, for example, the proper energy scales to explain the dispersive step-like features in the differential tunnelling conductance

(Fig. 1b) and the temperature dependence of the zero bias tunnelling conductance as a function of in-plane magnetic field (Fig. 1c). In an independent work[7], spin filtering has recently been reported in the related layered compound, chromium triiodide (CrI_3).

The most advanced generation of MRAM is based on spin torque physics and current-induced magnetization switching, which are crucially dependent on interface and spin filtering effects[1]. The materials **used by industry** is limited to ferromagnetic transition metals, their alloys, and the tunnel barrier MgO, and it is a challenge to achieve larger magnetoresistance values and reliable switching as the insulating barrier thickness scales down. Here is where the sharp interfaces that can be achieved with van der Waals heterostructures can play a key role**, enabling ultracompact spintronics based on device architectures developed for bulk materials[3]**. Magnetic insulators are also typically characterized by a lower magnetic damping than magnetic metals and thus promise much lower energy operation. Therefore, using spin-orbit torque to switch the magnetization of magnetic insulators is of significant current interest. In this context, the work of Novoselov and colleagues, and their demonstration that magnetic proximity can lead to anisotropic magnetoresistance in graphene, is important. The measured magnetoresistance hysteresis, which disappears above the Curie temperature of $CrBr_3$, indeed indicates the presence of both exchange field and spin-orbit coupling in the graphene electrodes.

Additional work is needed to fully demonstrate spin-filtering with $CrBr_3$, and to achieve this mechanism at room temperature. To date, the use of magnetic insulators for such purposes has required cryogenic setups, jeopardizing their practical use in memory technologies. Overcoming this limitation implies demonstrating tunnelling in 2D materials that remain magnetic at room temperature. This is not an easy task due to the difficulty of growing and handling 2D ferromagnets[8,9]. It will also be interesting to see if high-quality interfaces between graphene and the thin ferromagnets can be achieved using **scalable techniques**, which could allow device performance to be assessed in an industrial environment. Thus, there is still a long way to go before the standards required by industry are reached. But this is the critical bottleneck for all applications of 2D materials in electronics and photonics[10], and not just 2D spintronics. Nevertheless, the demonstration of magnon-assisted tunnelling in $CrBr_3$, and the proximity effect in graphene, is a significant step forward. It opens the intriguing possibility of using van der Waals heterostructures in spin-filtering devices and in future spin-switching based memory technologies.

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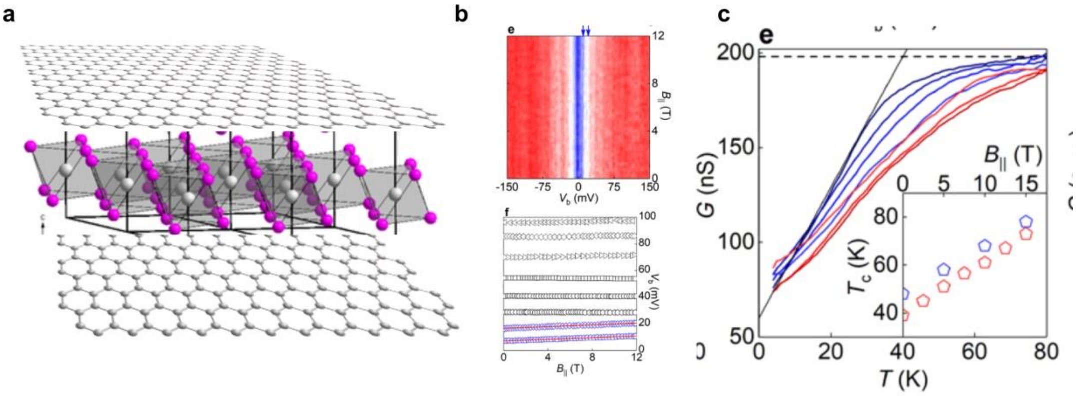

Fig. 1| **Electronic tunnelling through few-layer insulating $CrBr_3$. a.** The device is composed of a thin layer of chromium bromide ($CrBr_3$), sandwiched by single-layer graphene electrodes. This tri-layer van der Waals heterostructure is encapsulated by hexagonal boron nitride (not shown) and placed on a Si/SiO_2 substrate. For electrical characterization, Cr/Au edge contacts are added to the top and bottom graphene layers. **b.** The differential tunnelling conductance (G) shows step-like features as a function of bias (V_b) (top). Some of these features are dispersive as a function of in-plane magnetic field ($B_{//}$) (bottom) and are attributed to magnon-assisted tunnelling. **c**, The zero bias G shows a temperature dependence for different $B_{//}$ that is explained by a transition to a regime in which scattering by spin-texture imperfections within $CrBr_3$ dominates.