Exchange Bias between van der Waals Materials: Tilted Magnetic States and Field-Free Spin-Orbit-Torque Switching

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Abstract:

Magnetic van der Waals heterostructures provide a unique platform to study magnetism and spintronics device concepts in the two-dimensional limit. Here, we report studies of exchange bias from the van der Waals antiferromagnet CrSBr acting on the van der Waals ferromagnet Fe_3GeTe_2 (FGT). The orientation of the exchange bias is along the in-plane easy axis of CrSBr, perpendicular to the out-of-plane anisotropy of the FGT, inducing a strongly tilted magnetic configuration in the FGT. Furthermore, the in-plane exchange bias provides sufficient symmetry breaking to allow deterministic spin-orbit torque switching of the FGT in CrSBr/FGT/Pt samples at zero applied magnetic field [1].

Summary of Research:

We study the interaction between ferromagnetic Fe_3GeTe_2 (FGT) [2] with perpendicular magnetic anisotropy (PMA) and antiferromagnetic CrSBr [3] with in-plane easy-axis anisotropy, and find that the interaction induces an in-plane exchange bias on the FGT. Since the exchange bias is an interface interaction and the anisotropy in FGT arises from a bulk mechanism, we conclude that the tilting is non-uniform through the thickness of FGT (illustrated schematically in Figure 1a).

We have also investigated whether the exchange interaction from the CrSBr can provide a sufficient symmetry-breaking field to allow for deterministic SOT switching in CrSBr/FGT/Pt heterostructures. In general, to achieve deterministic switching of a magnetic layer with PMA using SOT from a high-symmetry material like Pt requires an external symmetry-breaking field. We perform pulsed-current measurements with different fixed Bext, and after each pulse we measure the Hall voltage near zero current.

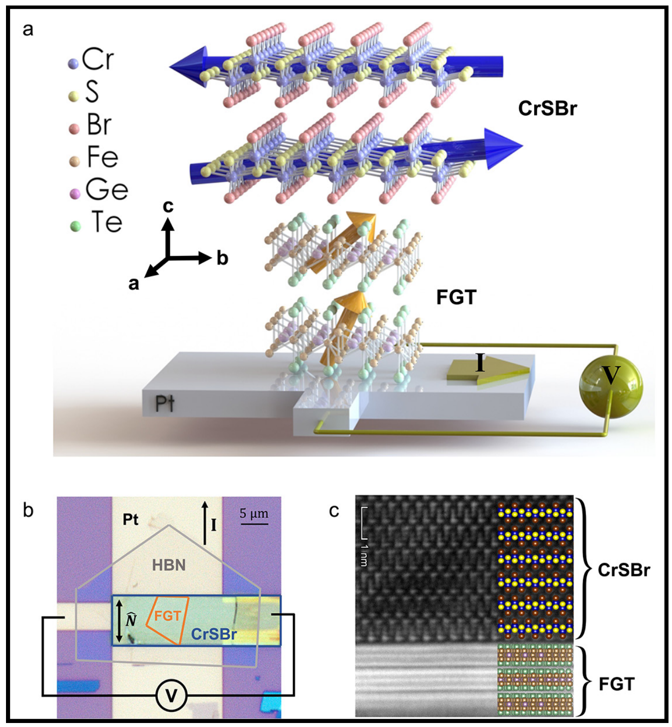

Figure 1: Device schematic and crystal structure (a) Schematic of a CrSBr/FGT het.erostructure dry transferred onto a Pt channel for spin-orbit torque pulse current switching measurements. (b) Top-view optical image of the CrSBr(30 nm)/FGT(9 nm)/Pt (10 nm) device with the b crystal axis of the CrSBr layer oriented parallel to the current (so that N^ ∥ I). (c) High angle annular dark field (HAADF) STEM cross-sectional image of the vdW interface of a different CrSBr/FGT heterostructure.

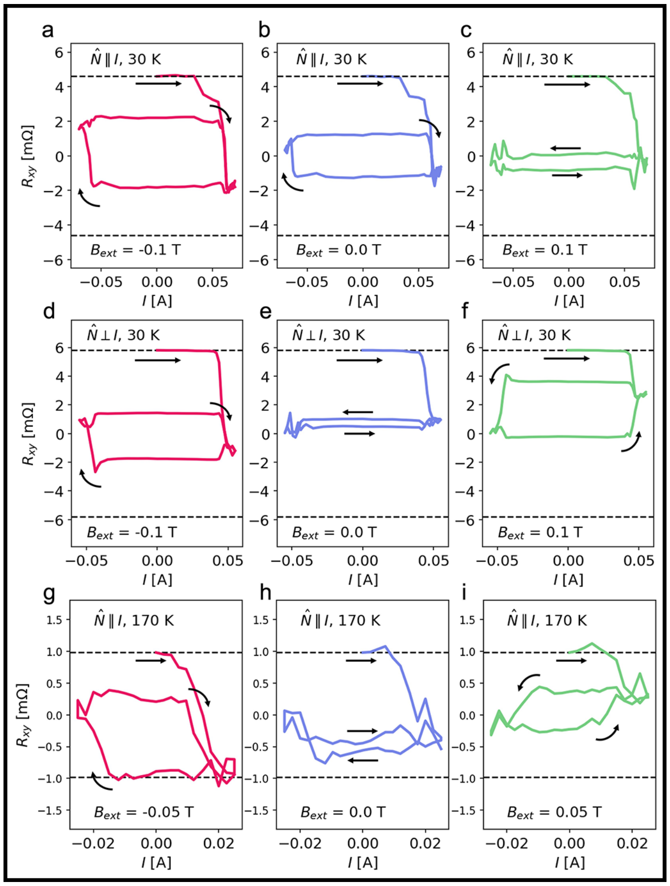

Figure 2: Pulsed-current-switching hysteresis loops of CrSBr/FGT/Pt samples. (a-c) Pulsed-current-switching hysteresis loops at 30 K for the sample with N^ ∥ I. The uniaxial exchange bias field enables deterministic spin-orbit-torque switching within the FGT layer at 0 T (panel (b)). (c) With a positive field of 0.1 T, the magnetization reversal hysteresis is quenched. (d-f) Pulsed-current switching hysteresis loops at 30 K for the sample with N^ ⊥ I. (g-i) Pulsed-current-switching hysteresis loops at 170 K, for the device with N^ ∥ I.

Figures 2a-c show the resulting switching loops for the device with $N^\wedge \parallel I$ at 30 K. We observe deterministic switching (Figure 2b) for B_{ext} = 0 T, with the same switching chirality as when B_{ext} = -0.1 T (Figure 2a). When B_{ext} = 0.1 T, we see a quenching of the hysteresis (Figure 2c). In comparison, in the device for which $N^\wedge \perp I$, there is negligible hysteresis at 0 T (Figure 2e) and the chirality of the magnetization reversal is opposite for ± 0.1 T (Figure 2d,f). When the temperature is raised above T_N to 170 K in the device with $N^\wedge \parallel I$, we see no switching at 0 T (Figure 2h) and opposite switching chiralities at ± 0.05 T (Figure 2g,i). These findings indicate that a net exchange bias is induced parallel to the Néel vector of CrSBr when the temperature is lowered below *T*N.

Conclusion and Future Steps:

In conclusion, we report measurements of an in-plane exchange bias from CrSBr acting perpendicular to the out-of-plane anisotropy of FGT, in a direction parallel to the in-plane anisotropy axis of CrSBr. This exchange field results in a strongly-tilted magnetic configuration within the FGT, and can serve as an in-plane symmetry-breaking field that enables field-free deterministic switching driven by SOT in CrSBr/FGT/Pt devices. Although the CrSBr in our samples is likely in a multidomain state, we can make a rough estimate of the exchange bias strength from the external magnetic field required to cancel the exchange field and eliminate the deterministic switching. We estimate values as large as 0.15 T at low temperature, decreasing gradually with increasing temperature up to the T_N of CrSBr. A CrSBr thickness greater than ≈ 10 nm is required to provide exchange bias for switching at 30 K. This work opens possibilities for exploiting unique characteristics of vdW magnets and heterostructures to enable new functionality in spintronics.

References:

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