Spintronics with low-dimensional materials

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Two-dimensional materials are an exciting new material family in which the proximity effect is especially important and opens ways to transfer useful spintronic properties from one 2D material into another. For instance, transition metal dichalcogenides (TMD) can be used to enhance the spin-orbit coupling of graphene. We have optimized bilayer graphene/WSe_2 van der Waals heterostructures to achieve magnetic-field-free spin precession. Remarkably, the sign of the precessing spin polarization can be tuned electrically by backgate voltage and drift current, being the first realization of a spin field-effect transistor at room temperature in a diffusive system [1].

The spin-orbit proximity in graphene/TMD van der Waals heterostructures also leads to spin-to-charge conversion (SCC) of out-of-plane spins due to spin Hall effect (SHE), first observed by our group using MoS_2 as the TMD [2]. The combination of long-distance spin transport and SHE in the same material gives rise to an unprecedented figure of merit (product of spin Hall angle and spin diffusion length) of 40 nm in graphene proximitized with WSe_2, which is also gate tunable [3].

The low symmetry present in many of these low-dimensional materials allows the creation of spin polarizations in unconventional directions and enables new fundamental effects and configurations for devices. For instance, we observe SCC of spins oriented in all three directions (x, y, and z) in graphene/$NbSe_2$ heterostructure, due to spin-orbit proximity and broken symmetry at the twisted graphene/$NbSe_2$ interface [4].

In this regard, chiral materials are the ultimate expression of broken symmetry, lacking inversion and mirror symmetry. We have recently demonstrated a gate-tunable chirality-dependent charge-to-spin conversion in Te, a 1D van der Waals material [5], detected by recording a large unidirectional magnetoresistance (up to 7%). The orientation of the electrically generated spin polarization is determined by the nanowire handedness, while its magnitude can be manipulated by an electrostatic gate. These results pave the way for the development of magnet-free chirality-based spintronic devices.

References:

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