Spin Transport in 2D Materials Heterostructures

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As the physical limits of CMOS loom closer, alternative state variable paradigms become increasingly important [1]. Devices utilizing the electron spin as a state variable are especially promising due to their intrinsic non-volatility, speed, and versatility. Fully incorporating spintronic devices into next-generation computing systems requires optimized architectures and materials capable of efficiently harnessing the electron spin. Due to their inherent thinness, 2D materials enable new spintronic control mechanisms through proximity effects and hybridization, allowing combinations of high spin-orbit coupled materials, such as topological materials with 2D materials, that reveal exciting new behaviors of potential use for computing. In this talk, we will discuss three such heterostructures. First, we will examine spin transport and spin dynamics in WS2/graphene/fluorographene non-local spin valves [2]. We demonstrate that the D'yakonov-Perel' mechanism is the dominant spin relaxation mechanism. Without WS2, linear scaling between the spin and momentum lifetimes points to spin-flip scattering during strong elastic scattering events strongly coupled to the electron spin. We attribute the spin relaxation type in part with the inclusion of WS2 as a substrate to proximity induced spin-orbit coupling due to the adjacent WS2 layer. Next, we replace the WS2 substrate with one of potentially higher spin-orbit coupling: the topological crystalline insulator PbSnTe. We demonstrate spin transport in the PbSnTe/graphene system and show that the hybridization between the materials causes a temperature and bias dependent spintronic phase transition. Finally, we explore spin transport in Cd3As2/fluorographene spin valves [3]. Cd3As2, a topological Dirac semiconductor, is sometimes thought of as three-dimensional graphene. Topological Dirac materials have high mobilities, 3D Dirac cones, and can exist in multiple quantum phases. We quantify the spintronic transport in the devices by measuring the spin Hall effect/inverse spin Hall effect, observing spin Hall angles up to θSH = 1.5 and spin diffusion lengths of 10-40 μm. We compare similarities of behaviors in all three systems.

[1] A.L. Friedman and A.T. Hanbicki. arXiv:2110.15822 (2021).
[2] A.L. Friedman, et al. Carbon 131, 18-25 (2018).
[3] G. M. Stephen et al. ACS Nano 15, 5459 (2021).