Strong Anisotropic Spin-Orbit Interaction in Graphene Induced by Transition Metal Dichalcogenides

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Enhancing spin-orbit interaction (SOI) of graphene opens a new way to exploit this material as a spin-charge converter via the spin Hall effect, and also as a two dimensional topological insulator. In this study, we demonstrate strong SOI in graphene induced by transition metal dichalcogenides (TMDs). TMDs have strong intrinsic SOI due to heavy transition metal elements, and they have different band structures depending on the thickness.

We fabricated bilayer heterostructures with graphene and different TMDs (WSe_2, WS_2 and MoS_2) with different thickness (monolayer (for all TMDs) and bulk (for WSe_2 and WS_2)) to investigate the difference between them in the capacity for inducing strong SOI in graphene.

The amplitudes of the induced SOI in graphene are evaluated via magnetotransport measurements at low temperatures. For all samples, we observed weak antilocalization peaks, a signature of the strong SOI. Interestingly, the magnetoresistance curves exhibit drastically different shapes depending on the type of TMD in contact with graphene. For WSe_2 and WS_2, graphene/monolayer TMD samples show much stronger SOI than that of graphene/bulk samples. On the other hand, graphene/monolayer MoS_2 samples exhibit much smaller SOI than that of monolayer WSe_2 and WS_2. This difference in the amplitude of the induced SOI is consistent with the difference in the amplitude of intrinsic SOI of TMDs.

We also investigated the symmetry of the induced SOI. The mirror symmetric (Kane-Mele (KM)) SOI is essential to realize the quantum spin Hall (QSH) state. From the theoretical fits of the magneto-transport data, we found that symmetric SOI is much more dominant than the asymmetric one.

The symmetric SOI in this system is composed of the two contributions, the KM and valley-Zeeman SOI. In graphene, the two spin relaxation mechanisms, the Elliot-Yafet (EY) and D'yakonov-Perel mechanisms are possible. The former is attributed to the KM SOI, and the latter relevant to the valley-Zeeman (VZ) SOI. By analyzing the dominant spin relaxation mechanism we found that the EY contribution is dominant especially close to the Dirac point. This result indicates the existence of the intrinsic SOI, essential to realize the QSH state. [1, 2].

References

[1] T. Wakamura et al., Phys. Rev. Lett. 120, (2018) 106802.
[2] T. Wakamura et al., arxiv:1809.06230.

Figures

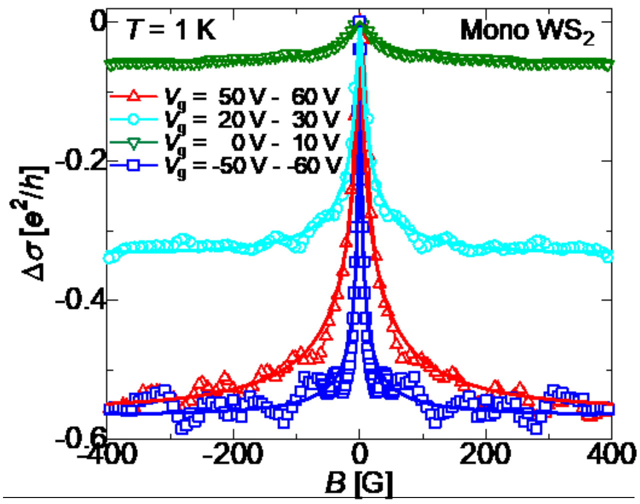

Figure 1: Magnetoconductivity correction $\Delta\sigma$ taken from a graphene/monolayer WS2 device. Weak antilocalization peaks are clearly seen.