Evaluation of the spin-orbit interaction in atomically thin T_d-$MoTe_2$

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Spin-orbit interactions (SOIs) often play essential roles in spin-related phenomena, and they are key elements for designing novel spintronics devices based on the spin Hall effect or spin-orbit torques. While metals such as Pt or W have long been used as a source for strong SOIs, it is also tempting to exploit exotic quantum materials like two-dimensional (2D) materials and explore their spin-related transport. In contrast to intensive studies for decades on the SOIs in conventional metals and semiconductors, those on 2D materials are still in their infancy. Since many of the 2D materials such as transition metal dichalcogenides (TMDs) are expected to possess the strong SOI and its type and amplitude may vary depending on the thickness, evaluating the amplitudes of the SOI and spin relaxation lengths of 2D materials in the thin limit is highly called for.

T_d-$MoTe_2$ is a semimetallic TMD, and owing to heavy elements Mo and Te, strong SOIs are expected. Previous study on spin-charge conversion measurements in lateral devices with few-layer T_d-$MoTe_2$ reported a long spin relaxation length (L_{sf}=2.2 μm) coexisting with a large spin Hall angle (=0.32) at room temperature, representing its potential for 2D spintronics [1].

In this work, we perform weak antilocalization measurements of T_d-$MoTe_2$ at low temperatures, another method for estimating the spin relaxation length. We employ mechanically exfoliated few-layer samples with different thicknesses encapsulated by hexagonal boron-nitrides. Figure 1(a) displays magnetoconductivity $\Delta\sigma(B) = \sigma(B) - \sigma(0)$ obtained from a bilayer (2 L) sample measured at 4.3 K. Clear negative magnetoconductivity, a signature of weak antilocalization, is visible, indicating the strong SOI in T_d-$MoTe_2$. Contrary to the previous study of weak antilocalization in T_d-$MoTe_2$, where the SOI amplitude was not deduced [2], we successfully obtain the spin-orbit length (L_{so}) via theoretical fits based on the Hikami-Larkin-Nagaoka formula explicitly including the SOI [the solid line in Fig. 1(a)]. Similar fits for the samples with different thicknesses (ts) provide t dependence of L_{so}, as shown in Fig. 1(b). Interestingly, L_{so} monotonically *decreases* with decreasing thickness, showing a monotonic *increase* of the SOI. We also plot L_{sf} estimated from L_{so} for each thickness in Fig. 1(b). $L_{sf} \sim 9$ nm for the 2 L sample is in the same order of magnitude as that for Pt, one of the representative elements with strong SOI. In all thicknesses, however, L_{sf} is two orders of magnitude smaller than that reported in the previous study (L_{sf} = 2.2 um) [1]. This large discrepancy cannot be explained simply by the difference in the resistivity, which is just several factors. Our results indicate that more careful analysis using different experimental methods are required for evaluating the spin relaxation length and SOI in 2D materials.

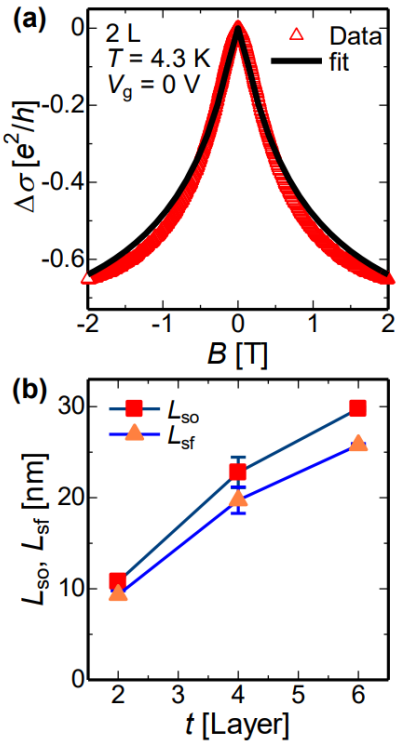

Fig. 1(a): Magnetoconductivity $\Delta\sigma(B)$ of the 2 L sample measured at 4.3 K. Fig. 1(b): Thickness (t) dependence of the spin-orbit length L_{so} and spin relaxation length L_{sf} obtained from the fits in (a).

[1] P. Song *et al*., Nat. Mater. **19**, 292 (2020).

[2] Q. Wang *et al*., Chin. Phys. Lett. **35**, 077303 (2018).