Planar Hall Effect in Quasi-Two-Dimensional Materials

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The planar Hall effect (PHE) is the generation of longitudinal and transverse voltages [see Figure 1(a)] in the plane of the applied electric (E) and magnetic fields (B). PHE has extensive applications in magnetic sensors and memory devices. In 3D materials, PHE generally originates from the coupling of the Berry curvature ($\boldsymbol{\Omega}$, BC) and orbital magnetic moment ($\boldsymbol{m}$, OMM) to the band velocity and in-plane magnetic field, which generates a longitudinal and transverse planar response [1]. The planar Hall effect in 3D systems is an effective probe for their Berry curvature, topology, and electronic properties.

However, the Berry curvature-induced conventional planar Hall effect is forbidden in 2D systems as the out-of-plane Berry curvature cannot couple to the band velocity of the electrons moving in the 2D plane. In our paper [2], we demonstrate a unique 2D planar Hall effect (2DPHE) originating from the hidden planar components of the Berry curvature and orbital magnetic moment in quasi-2D materials. We identify all planar band geometric contributions to 2DPHE and classify their crystalline symmetry restrictions. Using gated bilayer graphene as an example [see Figure 1 (b-d)], we show that in addition to capturing the hidden band geometric effects, 2DPHE is also sensitive to the Lifshitz transitions. Our discovery of 2DPHE brings the vast class of layered 2D materials under the purview of planar Hall effect probes, which were limited to 3D materials, and motivates further study on planar band geometric quantity-induced other transport phenomena for innovative applications.

References

[1] S. Nandy, G. Sharma, A. Taraphder, and S. Tewari, Phys. Rev. Lett. **119**, 176804 (2017).
[2] K. Ghorai, S. Das, H. Varshney, and A. Agarwal, Phys. Rev. Lett. **134**, 026301 (2025).

Figures

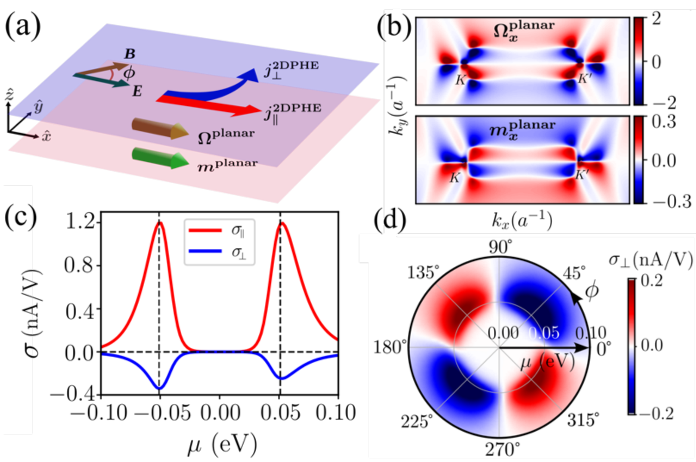

Figure 1: (a) Schematics of the planar Hall effect geometry. A transverse current is produced in the presence of in-plane electric and magnetic fields. (b) The planar Berry curvature (orbital magnetic moment) for the 1st conduction band for bilayer graphene around Dirac points. (c) The longitudinal and transverse Hall components of 2DPHE conductivity as a function of chemical potential. (d) The angular variation of transverse planar Hall conductivity as the angle between E and B varies within the plane.