Antisymmetric planar Hall effect in rutile oxide films induced by the Lorentz force

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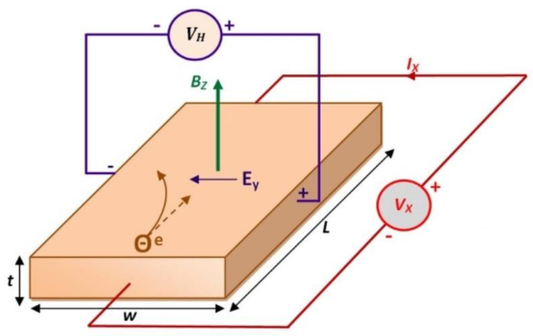
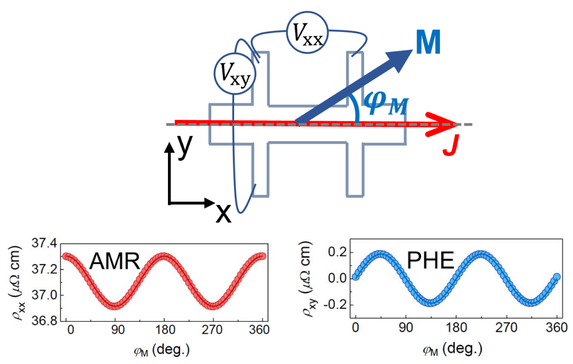
Introduction

➢ Ordinary Hall effect



$V_H \propto B_z$, antisymmetric.

➢ Planar Hall effect

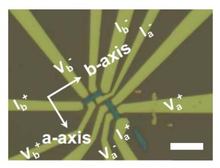


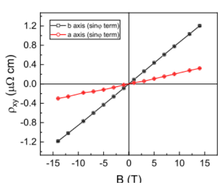
$\rho_{xy}(\varphi_M) \propto \sin 2\varphi_M$, symmetric

Whether there is antisymmetric planar Hall effect?
(In-plane Hall effect)

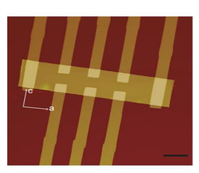
Existing experimental observations:

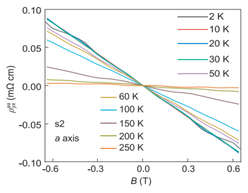
I. WTe_2



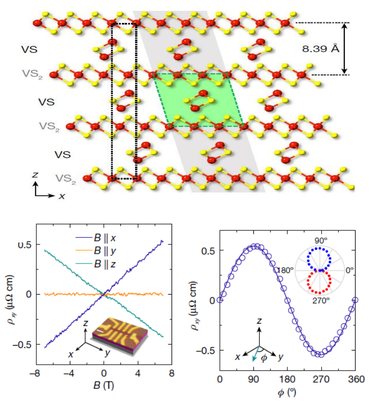


II. $ZrTe_5$





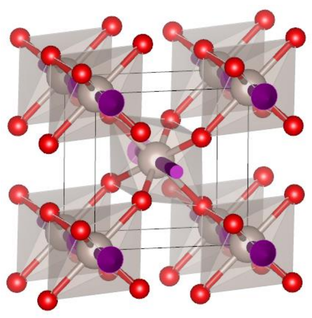
III. VS_2–VS superlattice



Liang, T. et al. Nat. Phys. 14, 451-455 (2018), Ge, J. et al. Natl. Sci. Rev. 7, 1879-1885 (2020), Zhou, J. et al. Nature 609, 46-51 (2022).

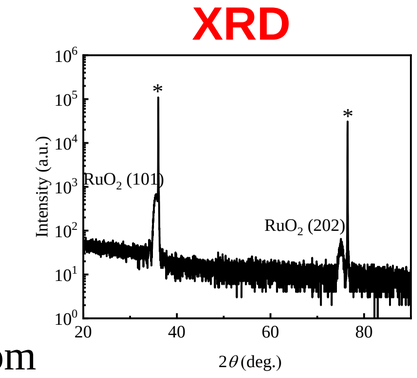
All above observations were attributed to the **Berry curvature**, whether the ***Lorenz force*** plays a role in the IPHE?

Sample preparation

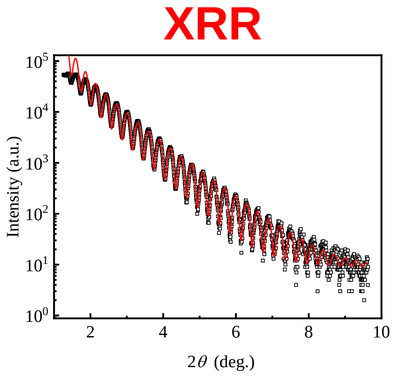


Ru (Ir) O atom

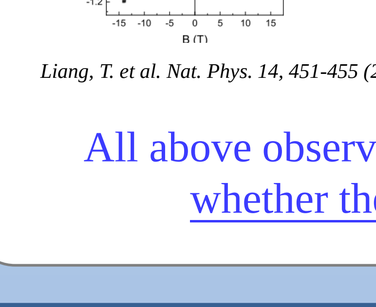
XRD



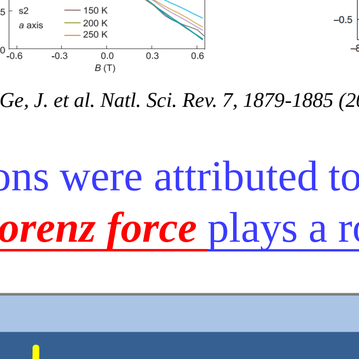
XRR



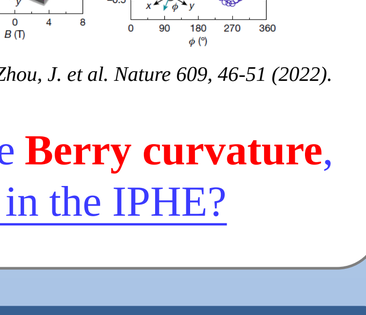
RHEED



STEM



AFM

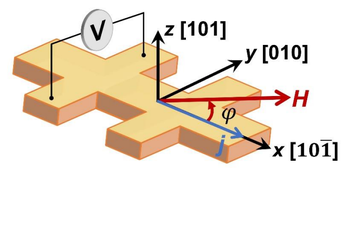


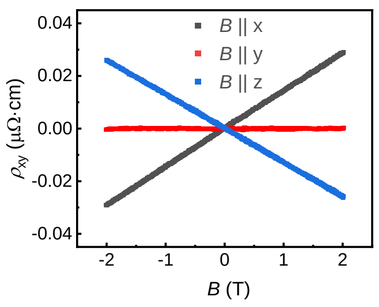
	TiO_2	RuO_2	IrO_2
a=b (Å)	4.59	4.492	4.545
c (Å)	2.96	3.106	3.19

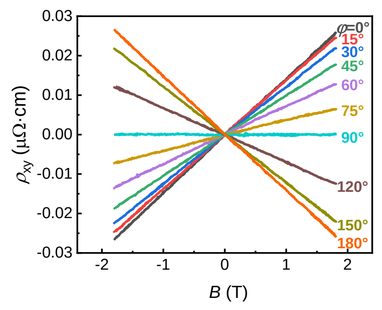
➢ Magnetron sputtering with O_2

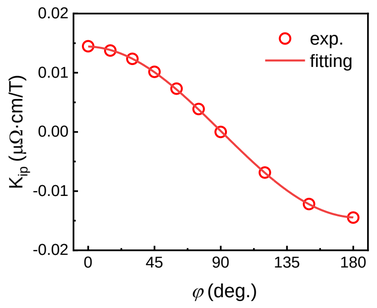
➢ High quality epitaxial growth

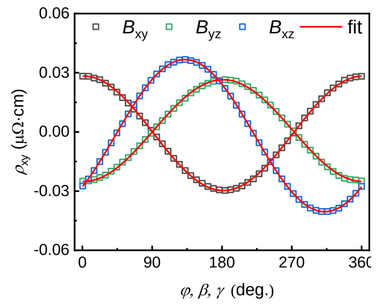
Observation of APHE in RuO_2(101)

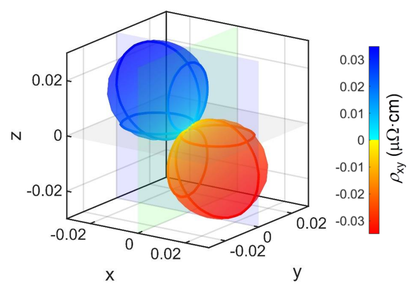










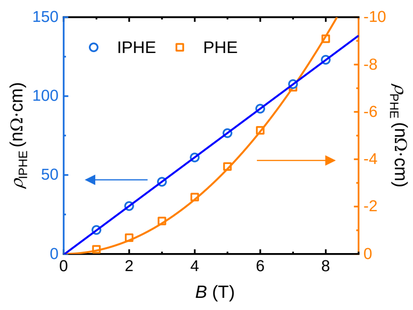


➢ Linearly dependent on in-plane magnetic field along $[10\bar{1}]$.

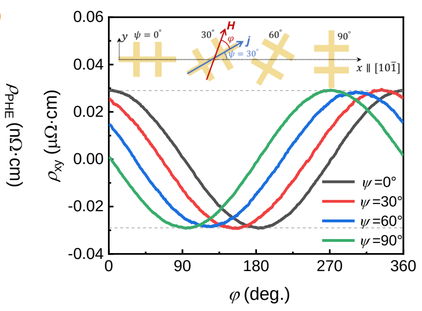
➢ The IPHE is comparable to the OHE in magnitude.

General Properties of APHE

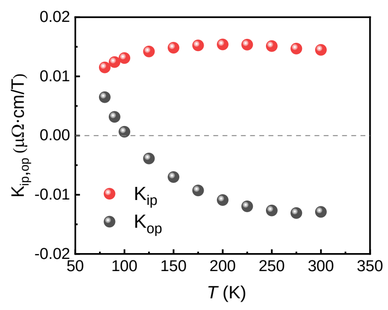
IPHE is not PHE.



Independent on current



Relation to temperature

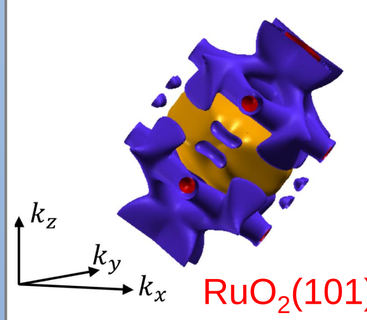


➢ Independent on orientation of current; ➡ $\rho_{xy} = -\rho_{yx}$

➢ Nearly independent on temperature. ➡ ρ_{xy} is independent of τ.

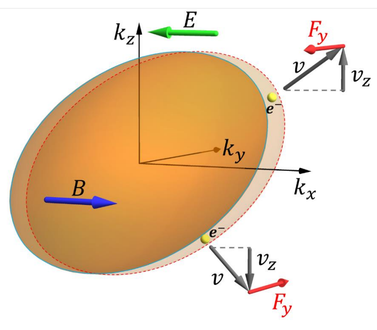
Lorentz force mechanism of the APHE

First principle calculation

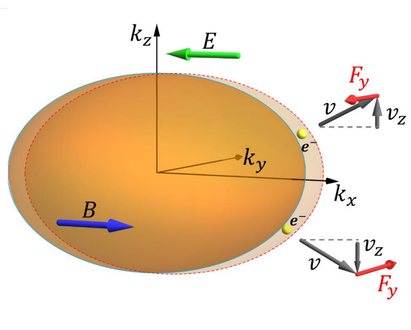


RuO_2(101)

(101) plane



(001) plane



S_z and S_x broken

S_γ $(\gamma = x, y, z)$ represents an arbitrary symmetry in the set of $\{M_\gamma, C_{2\gamma}, TM_\gamma, TC_{2\gamma}\}$

Net component of out-of-plane group velocity v_z

v_z cancelled owing to the out-of-plane or in-plane symmetry

Summary and Outlook

In-plane Hall effect observed in Rutile oxide films

➢ Independent on the direction and magnitude of current and temperature.

➢ Independent on magnetic order or spin canting.

➢ **Lorentz force** provides the dominant mechanism to induce the IPHE.

The physical picture of the IPHE can be readily generalized to the ***in-plane anomalous Hall effect*** in ferromagnetic materials with in-plane magnetization.