Orientation-Tuned Hall Responses in Strongly Correlated Oxide Heterostructures

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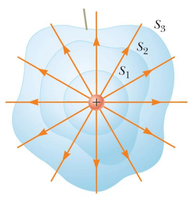
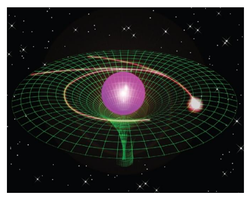
Geometry Matters in Quantum Materials

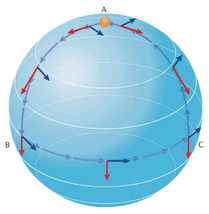
Gauss's Law: Electromagnetism



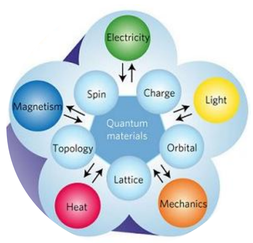
Spacetime Curvature: General Relativity

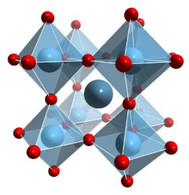


Berry Phase: Quantum Mechanics

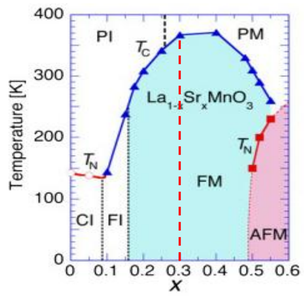


Geometry plays a central role in physics, from Gauss's law in classical EM, to Berry phase in QM



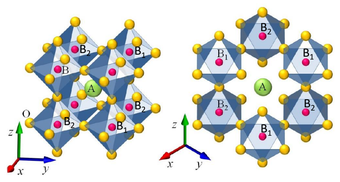


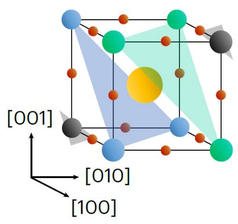
$La_{0.7}Sr_{0.3}MnO_3$

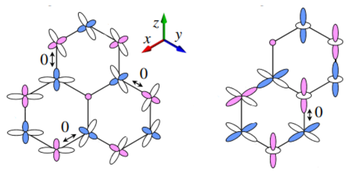


Strongly correlated oxides show complex phase diagrams due to the coupling between their internal degrees of freedom.

[001] **[111]**



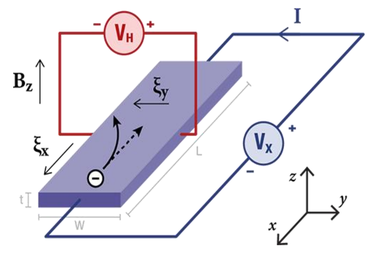


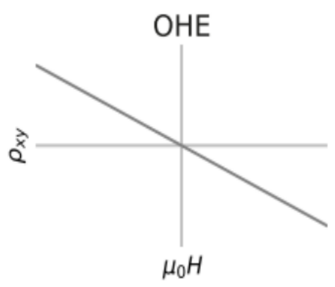


Changing from [001] to [111] orientation modifies the crystal field symmetry, the stacking sequence of planes, and the hybridization of Mn 3d orbitals

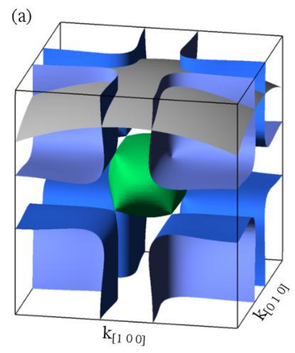
Geometric Origins of Hall Transport

OHE



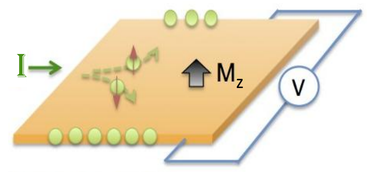


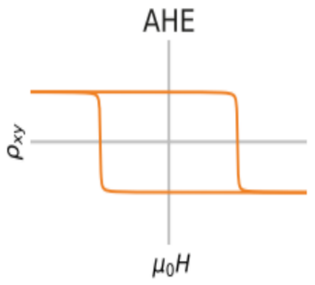
$$\rho_{xy}^{OHE} = R_0 \mu_0 H_z$$

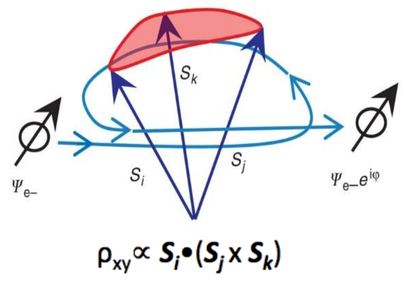


Linear dependence with magnetic field, the Hall effect indicates the dominant charge carrier type and depends on the Fermi surface geometry

AHE





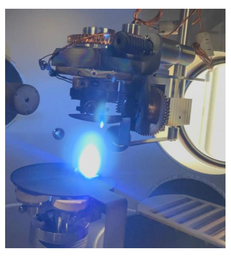


$$\rho_{xy} \propto S_i \bullet (S_j \times S_k)$$

Generally, appears in ferromagnets, depending on out-of-plane magnetization. In LSMO, it is governed by thermal spin fluctuations , which induce a B_{eff} through the Berry phase

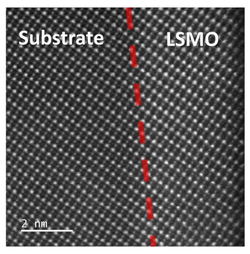
Epitaxial Growth & Characterization

Pulsed Laser Deposition



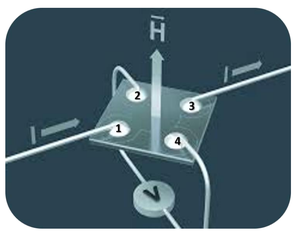
- Pure O_2 : 0.1 mbar
- Temperature: 700°C
- Fluence: 1 J/cm²

STEM-HAADF



Epitaxial growth by PLD yields high-quality films, as confirmed by HAADF-STEM structural analysis

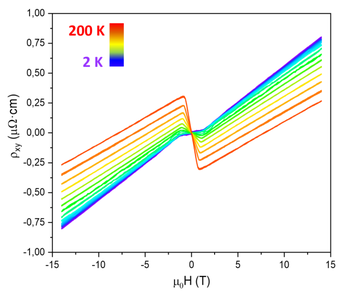
Transport measurents and data analysis



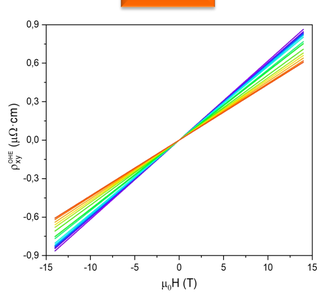
$$R_{xy} = \frac{V_{24}}{I_{13}}$$

$$\rho_{xy} = R_{xy} \cdot t_{LSMO}$$

Fitting at ↑H

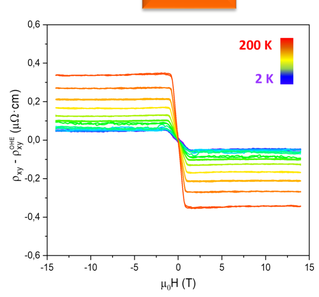


OHE

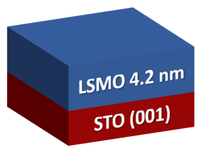


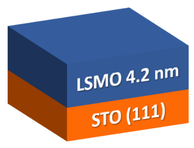
$$\rho_{xy}^{AHE} = \rho_{xy} - \rho_{xy}^{OHE}$$

AHE

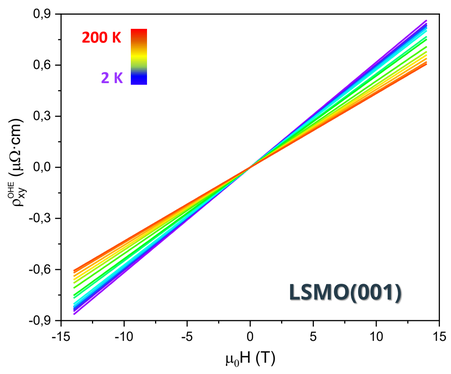


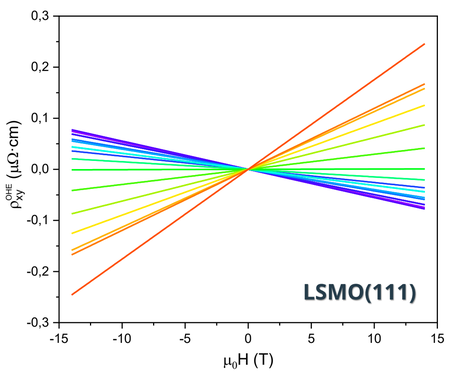
Orientation-Dependent Hall Transport





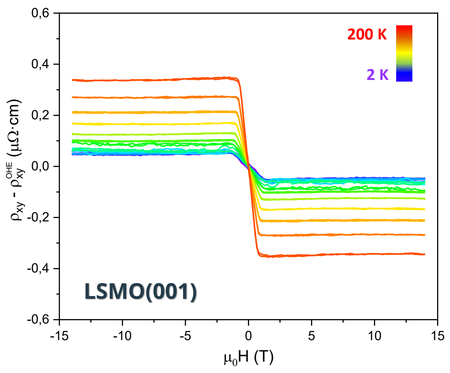
OHE

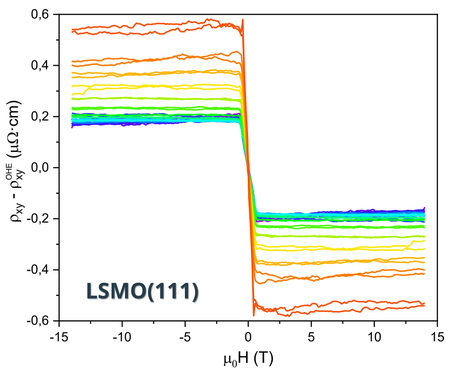




Positive and weakly temperature-dependent in (001), while (111) shows a temperature-dependent sign change, reflecting Fermi surface changes.

AHE





Stronger thermal spin fluctuations in (111) films compared to (001). Likely due to an increased energy difference between spin triad chiralities mediated by DMI.

Conclusions

- [111] orientation strongly modifies Hall responses compared to [001]
- OHE in [111] shows temperature-dependent sign change → Fermi surface changes
- Increased AHE in [111] → Enhanced chirality of thermal spin fluctuations
- Strongly correlated oxides grown on [111] orientation provide an ideal platform to explore geometry-dependent transport and emergent quantum phenomena

References:

[1] Kim, T., Puggioni, D., Yuan, Y. et al. Nature 533, 68–72 (2016)
[2] Chakhalian, Jak, Xiaoran Liu, and Gregory A. Fiete. Apl Materials 8.5 (2020).
[3] Hallsteinsen, Ingrid, et al. Apl Materials 3.6 (2015).
[4] Peng, W., Park, S.Y., Roh, C.J. et al. Nat. Phys. 20, 450–455 (2024)
[5] Lyanda-Geller, Y., et al. Physical Review B 63.18 184426 (2001).