Magnetically Controllable Two-Dimensional Spin Transport in a Three-Dimensional Crystal

Intrinsic crystal anisotropy in a "fractional" perovskite, Eu_xTaO_3 (x = 1/3 ~ 1/2), is predicted theoretically to lead to stacked layers of quasi-2D electron gases (2DEG), despite being a three-dimensional bulk system. A non-montonic thermopower is proposed as a route to experimentally demonstrate the quasi-2D behavior.

The exploration of two-dimensional (2D) states has come to such prominence in condensed matter and materials research because their properties make them desirable, or even essential, for state of the art device applications. From ab-initio calculations, analytic toy models, and group theoretic arguments we were able to show Eu_xTaO_3, a fractional rare-earth transition metal perovskite with x = 1/3 ~ 1/2, naturally exhibits quasi-2DEGs stacked along its crystalline c-axis, as shown in Fig 1, despite it being a bulk 3D material[1].

An interplay between the underlying tetragonal crystal field (TCF) with the spin-orbit coupling (SOC) of the Ta sites and their exchange coupling with local Eu magnetic moments, leads to quasi-2D conduction bands of a single orbital character, spin-polarized along the magnetic axis. These bands have additional in-plane spin textures that have a topological monopole(anti-monopole) form, which arises from a coupling between two component Rashba fields[2], Fig1, and the strong SOC of the carriers.

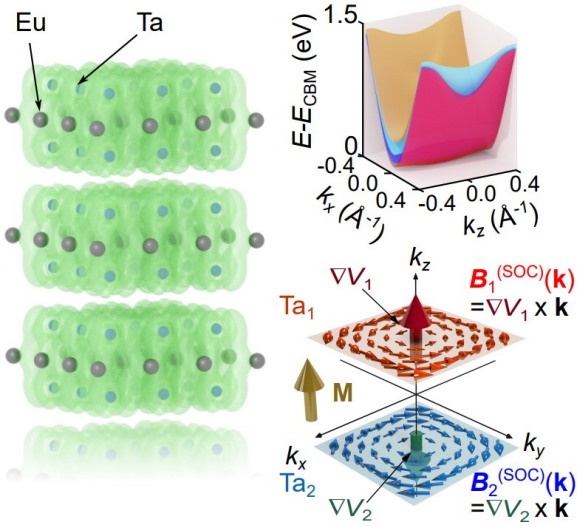

Figure 1 The charge density of quasi-2DEG phase, the quasi 2D conduction band dispersion, and component Rashba spin textures.

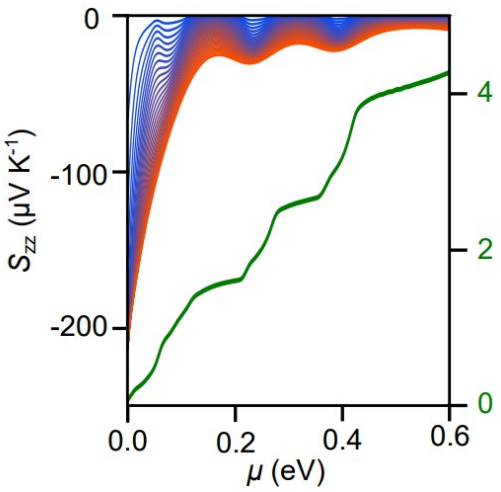

Figure 1 The Oscillating Seebeck coefficient, the arises from the quasi-2D DOS of the conduction bands as shown.

As the magnetic ordering of the charge carriers arises indirectly from an exchange interaction with Eu, these spin textures can be externally manipulated, for example, by the magnetic field orientation, without any change in their Fermiology. This makes EuxTaO3 a promising platform for a broad range of spintronic devices.

We went on to examine possible quantum states arising from this quasi-2D behaviour, and proposed methods to experimentally investigate them. In particular, an oscillatory Seebeck effect that deviates from typical metallic behaviour due to plateaus in the density of states (DOS)[3] as shown in Fig 2. We propose that this may be utilizable as a thermoelectric source with robust spin and orbital characters.

References

[1] Dowinton, Oliver et al. Advanced Functional Materials, 33:43 2023.

[2] Yua A Bychkov et al. JETP lett, 39(2):78, 1984.

[3] Ilaria Pallecchi et al. Nature Communications, 6, 03 2015.

Keywords: Spintronic, Thermoelectric, Magnetism

Oliver Dowinton, University of Manchester, School of Physics and Astronomy, Theoretical Physics group
E-mail: oliver.dowinton@postgrad.manchester.ac.uk