Thickness-dependent quantum transport of Weyl fermions in ultra-high-quality $SrRuO_3$ thin films

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The recent observation of Weyl fermions in the itinerant 4*d* ferromagnetic perovskite $SrRuO_3$ points to this material being a good platform for exploring novel physics related to a pair of Weyl nodes.[1] For future investigations into $SrRuO_3$-based heterostructures aiming at applying magnetic Weyl semimetals to spintronic devices[2] and topoelectrical circuits,[3] it will be essential to realize Weyl transport near heterointerfaces. In epitaxial $SrRuO_3$ films, higher resistivity and lower Curie temperature are commonly found when the film thickness is decreased. Therefore, there should be a critical thickness for observing the transport signatures of Weyl fermions, depending on the quality of $SrRuO_3$ films.

In this presentation, we report the thickness-dependent magnetotransport properties of ultra-high-quality epitaxial $SrRuO_3$ films.[4] We grew $SrRuO_3$ films with various thicknesses t (= 1–60 nm) on (001) $SrTiO_3$ substrates by machine-learning assisted molecular beam epitaxy.[5]

We performed magnetotransport measurements on the $SrRuO_3$ films by using the standard four-point-probe method. Figures 1(a) and (b) show the Shubnikov-de Haas (SdH) oscillations for the $SrRuO_3$ film with $t = 10$ nm. Quantum oscillation peaks (black triangles) and dips (white triangles) are clearly seen in a *raw* σ_{xx} data. We confirmed a high quantum mobility of about 10,000 $cm^2V^{-1}s^{-1}$ and existence of a π Berry phase by detailed analyses of the SdH oscillation data using the Lifshitz-Kosevich (LK) theory. The signatures of Weyl fermion transport, i.e., unsaturated linear positive magnetoresistance accompanied by a SdH oscillation, were observed in the films with $t \geq 10$ nm: even a 10 nm-thick film showed the SdH oscillation. In addition, residual resistivity increased with decreasing film thickness, indicating disorder near the interface between the $SrRuO_3$ film and the $SrTiO_3$ substrate. These thickness-dependent magnetotransport measurements revealed that the threshold residual resistivity ratio to observe Weyl fermion transport is 21. The thickness-dependent disorder affects magnetic properties as well. The Curie temperature decreases and the coercive field increases with decreasing thickness. Our results provide guidelines for realizing quantum transport of Weyl fermions in $SrRuO_3$ near heterointerfaces.

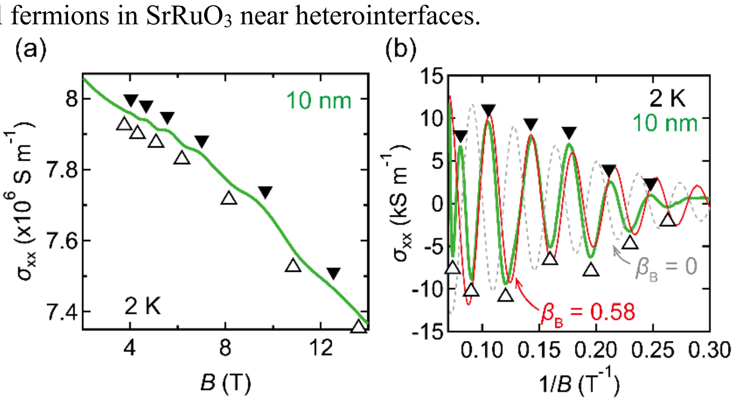

Figure 1 (a) SdH oscillation in raw σ_{xx} data at 2 K with magnetic field B (2 T < B < 14 T) applied in the out-of-plane [001] direction of the $SrTiO_3$ substrate for $SrRuO_3$ film with $t = 10$ nm. (b) Its background-subtracted SdH oscillation with B (3.5 T < B < 14 T). In (b), red and gray dashed curves are the LK formula fittings with the Berry phases $2\pi\beta_B$ of 1.16π and 0, respectively.

References [1] K. Takiguchi, Y. K. Wakabayashi, *et al.*, Nat. Commun. **11**, 4969 (2020). [2] Y. Araki *et al.*, Phys. Rev. Appl. **10**, 014007 (2018). [3] C. H. Lee *et al.*, Commun. Phys. **1**, 39 (2018). [4] S. Kaneta-Takada, Y. K. Wakabayashi, *et al.*, arXiv:2011.03670. [5] Y. K. Wakabayashi, *et al.*, APL Mater. **7**, 101114 (2019).