Landau Level Spectroscopy of Massive Dirac Fermions in ZrTe₅

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Introduction
A quantum spin Hall insulator (QSHI) hosts topologically protected states that enable dissipationless transport. Unfortunately, all the QSHIs discovered to date possess a small band gap, hindering its use in room-temperature applications. ZrTe₅, as a possible large-gap QSHI in its monolayer form, has recently attracted much attention. However, its electronic structure in the bulk is still under heated debate, with interpretations ranging from weak/strong topological insulator to Dirac semimetal. Using bulk-sensitive magneto-infrared (magneto-IR) spectroscopy technique, we investigated the mystifying band structure of ZrTe₅.

Experimental
Owing to its layered structure and the weak van der Waals force between layers, IR-transparent thin flakes of ZrTe₅ can be achieved by repeatedly exfoliating the material using an IR-transparent Scotch tape. In our experiment, we performed both broadband (unpolarized) spectroscopy measurements using Fourier transform IR spectrometer and circularly polarized measurements using a wavelength tunable Quantum Cascade Laser (QCL). The measurements were performed in SCM3 at 4.2K and in Faraday configuration with magnetic field up to \( B = 17.5 \) T.

Results and Discussion
Figure 1 shows the normalized transmission spectra of ZrTe₅ thin flakes taken at selected magnetic fields. Here, Landau level (LL) transitions are expected to manifest themselves as absorption dips and blue-shift with increasing magnetic field. Owing to the low carrier density of our samples (approaching the intrinsic limit), a series of inter-band LL transitions were observed. These transitions follow a peculiar \( \sqrt{B} \) and \( \sqrt{n} \) dependence, where \( n \) is the LL index, which can be described by a massive Dirac fermion model. Most saliently, a four-fold splitting of low-lying LL transitions was observed in high magnetic fields (marked by down triangles), which can be attributed to the combined effect of finite mass, large g-factor, and electron-hole asymmetry. The electron-hole asymmetry breaks the energy degeneracy of \( L_{-n} \rightarrow L_{n+1} \) and \( L_{-n-1} \rightarrow L_n \) transitions and therefore can be resolved in QCL-based circularly polarized measurements [1].

Conclusions
We enabled magneto-IR transmission measurements of layered topological material ZrTe₅. We found that ZrTe₅ thin flakes are Dirac semimetals with a small gap/mass that could not be resolved in previous angle-resolved photoemission spectroscopy and scanning tunneling spectroscopy measurements. In high magnetic fields, we observed a four-fold splitting of low-lying LL transitions, which signifies the importance of electron-hole asymmetry and Zeeman effect in this material.

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References