Direct observation of Landau level resonance and mass generation in Dirac semimetal Cd_3As_2 thin films

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Introduction

Three-dimensional topological Dirac semimetals have hitherto stimulated unprecedented research interests as a new class of quantum materials. Breaking certain types of symmetries has been proposed to enable the manipulation of Dirac fermions; and that was soon realized by external modulations such as magnetic fields. However, an intrinsic manipulation of Dirac states, which is more efficient and desirable, remains a significant challenge. Here, we report a systematic study of quasi-particle dynamics and band evolution in Cd3As2 thin films with controlled Chromium (Cr) doping by both magneto-infrared spectroscopy and electrical transport.

Experimental

Thin Film Growth. A series of Cd_3As_2 thin films were grown in a CREATEC MBE system. Magneto-optical measurements. The far-infrared transmittance was measured in a Faraday configuration (perpendicular field) with the superconducting magnet, SCM-3. The sample was exposed to the infrared light through light pipes. Infrared light was focused with a parabolic cone, detected by a bolometer and analyzed by a Fourier transform infrared spectrometer (FTIR). All the light tube, samples and bolometer were kept at liquid helium temperature in a cryostat. The light path was pumped under vacuum to avoid the absorption of water and other gases.

Results and Discussion

Without Cr doping, the inter-Landau-level resonance exhibits a sqrt(B)-dependence, a benchmark of ultra-relativistic Dirac fermions in Cd_3As_2. Reducing the magnetic field leads to a crossover from quantum to quasi-classical behavior that is characterized by a linear B dependence of the cyclotron resonance. Combined with transport measurements, an accurate extraction of quasi-particle mass has been achieved. Remarkably, by introducing Cr dopants into the Cd_3As_2 lattice, a novel phase transition is triggered along with mass generation in the absence of a long-range ferromagnetic order. Thus, the Cd_3As_2 system can be tuned from a massless to a massive Dirac state before turning into a trivial insulator. Further theoretical calculations unveil that the mass acquisition can be explained by explicit C4 rotation symmetry breaking which results in a gap generation. Our work establishes a feasible way to manipulate the 3D Dirac fermions through the controllable element doping.

Conclusions

In conclusion, we provide a direct spectroscopic determination of Dirac fermions in Cd3As2 thin films by magneto-optics, along with the observation of classical-quantum resonance crossover. Remarkably, the phase transition and Dirac mass acquisition can be achieved by the Cr doping. Our DFT calculations explain that the Cr substitution leads to the C4 rotation symmetry breaking which results in Dirac gap and band topology engineering. The controllable Dirac mass that we have achieved in the representative Dirac semimetal Cd3As2 opens up a feasible path towards the manipulation of exotic states stemming from the parent phase of Dirac semimetals.

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References

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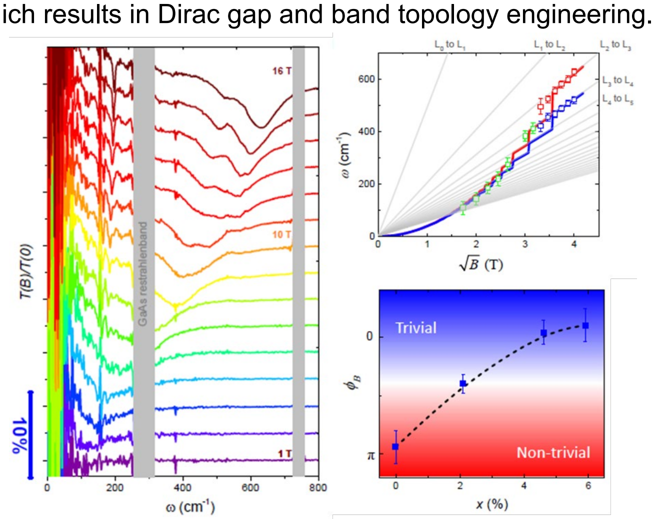

Fig.1 Dirac mass generation upon finite Fermi level and Cr doping. a, magneto-optical spectrum of undoped Cd_3As_2. b, quantum-to-classical transition at low field. c, Dirac mass acquisition upon Cr doping.