Revealing the Magnetic Order in a New Dirac Antiferromagnet EuMnBi₂ by Resonant X-Ray Magnetic Scattering

Dirac fermions in solids have recently attracted significant attention as a new electronic state that is described by the relativistic massless Dirac equation. In 2005, the experimental discovery of the half-integer quantum Hall effect (QHE) in graphene triggered worldwide researches on novel quantum magnetotransport of Dirac fermions. For potential application to spintronic devices, it is essential to know how the transport of Dirac fermions is controlled by magnetic order in a solid as well as by external fields, which has remained elusive so far. Although a variety of Dirac materials have been recently discovered, the quantum transport phenomena relevant to Dirac fermions were observable mostly in nonmagnetic systems.

To explore magnetic Dirac materials, in this study we focused on a layered bulk antiferromagnet EuMnBi₂. Recently, layered magnets AlMnBi₂ (A = Sr[1-3] and Eu[4, 5]) were found to host anisotropic 2D Dirac fermions, which is an ideal arena in which to examine the interplay between Dirac fermions and ordered magnetic moments. The crystal structure consists of the conducting layers of Bi square net hosting quasi two-dimensional (2D) Dirac fermions and the insulating magnetic layers consisting of the Mn-Bi and A layers (Fig. 1A). From detailed magnetic and transport measurements on EuMnBi₂, intriguingly we have discovered that the quantum transport properties of Dirac fermions are strongly coupled with the antiferromagnetic order of the Eu sublattice, as detailed below [6]. We report here the measurement of the (0 0 11) reflection was indeed observed in the EuMnBi₂ crystal and magnetic structures for EuMnBi₂. Figure 1A shows a schematic illustration of the crystal and magnetic structures for EuMnBi₂. The magnetic origin of the (0 0 11) reflection was indeed observed in the EuMnBi₂ crystal and magnetic structures for EuMnBi₂. The magnetic origin of the (0 0 11) reflection was indeed observed in the EuMnBi₂ crystal and magnetic structures for EuMnBi₂.

In the resonant X-ray scattering spectra near the Eu L₂ absorption edge, we found the (0 0 11) reflection at E = 6.975 keV, which is forbidden in the present space group (62m) of EuMnBi₂. Considering the evolution of the intensity below Tc = 1.9 K (Fig. 2B) and the sharp resonance at the Eu L₂ edge (Fig. 2D), we can assign to resonant magnetic scattering from the Eu sublattice. Furthermore, the magnetic origin of the (0 0 11) reflection was confirmed by polarization analyses as follows. The magnetic form factor (|f(mag)|²) of the Eu magnetic moment in the electric-dipole transition is described as

\[ f_{mag}(\mathbf{q}) \propto (e \cdot e') \cdot \mathbf{R}_{||}/|\mathbf{R}_{||}| \]

where e and e’ denote unit vectors of the incident and scattered polarization, respectively, and \( \mathbf{R}_{||} \) unit vector of the i/θ Eu magnetic moment. Based on this equation, the (0 0 11) reflection should appear only in the rotated α-β channel. As shown in Fig. 2E, the (0 0 11) reflection was indeed observed in the α-β configuration but not in the α-γ configuration.

Finally, we discuss the antiferromagnetic order pattern of the Eu sublattice at zero field. The observation of the (0 0 11) reflection indicates that the Eu magnetic moments order ferromagnetically within the ab plane and antiferromagnetically along the c axis, resulting in two kinds of AFM order as possible candidates (type 1 and 2 in Fig. 2F). To determine the order arrangement, we have measured the intensities (I(θ) of several 0 O) and (1 O) magnetic reflections and compared them with the calculated intensities (i(θ)) for type 1 and 2 (Fig. 2G). Measured intensities are in excellent agreement with the calculation results for type 1, indicating that the most probable Eu moment arrangement is type 1.

The obtained crystal and magnetic structure of EuMnBi₂ is regarded as a natural spin-valve structure embedded in a multilayer Dirac ferromagnet system, as shown in Fig. 1A. This implies that the magnetic order is suppressed by the staggered Eu moments along the c axis, whereas the ferromagnetic order within the plane may promote the in-plane transport, leading to extremely high carrier mobility of ~14,000 cm²/Vs at 2 K.

REFERENCES


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