Energy harvesting, Smart device, Material development

Exploration of thermoelectric and thermomagnetic materials hosting relativistic quasi-particles

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Abstract

The so-called Dirac materials, whose electronic state is described by the relativistic equations of motion, have attracted much attention owing to their ultrahigh mobility. Such prominent conduction properties are promising not only for electronics applications but also for thermoelectric power generation. However, so far, there have been few bulk Dirac materials that can be applied to thermoelectric power generation. Recently, our group has synthesized a layered bulk material consisting of alternating layers of Dirac fermion layer and insulating block layer. By partially substituting the elements in the block layer, we have succeeded in controlling a wide range of carrier concentration while keeping the high mobility of ~20,000 cm^2/Vs. As a result, we have shown that the thermoelectric performance can be optimized by the carrier concentration, demonstrating great potential as a thermoelectric material.

Background & Results

Recently, the so-called Dirac/Weyl semimetals, 3D bulk analog of graphene, are among the most active topics in materials science. In this class of materials, ultrahigh mobility due to the protection from backscattering is promising for potential applications. While the electronic application was an early target, the thermoelectric and transverse thermoelectric (Nernst) power generation has received current attention. To optimize the power factor, it is essential to finely tune the Fermi energy by chemical substitution.

Here we demonstrate chemically tunable Dirac fermions in layered material $EuMnBi_2$, which consists of the alternative stack of the 2D Dirac fermion layer and the insulating block layer (Figure 1). A major advantage of this material is that the spatially-separated block layer serves as a charge reservoir to the Dirac fermion layer. We have succeeded in controlling the Fermi energy across the charge-neutral Dirac point by partially substituting Eu^{2+} with Gd^{3+} in the block layer. Importantly, even in the doped samples, the high mobility is retained and hence clear quantum oscillations were observed, from which we have quantitatively estimated the carrier density. As a result, we have revealed the overall thermoelectric properties associated with the Dirac fermions as a function of carrier density (from *p*-type to *n*-type, see Figure 2). The experimental variation of thermopower is roughly reproduced by the first-principles calculation, achieving the optimized power factor of more than 100 μW/K^2cm. On the other hand, the Fermi energy dependence of Nernst signal shows an anomalous increase toward the Dirac point, which suggests the field-induced gap reduction of the Dirac band due the exchange interaction with the Eu moments.

Significance of the research and Future perspective

Our findings demonstrate the validity of the block layer concept for developing the thermoelectric Dirac/Weyl materials, providing a clear-cut guide for the future material design. This will inspire further exploration of the relevant topological materials as a new class of thermoelectrics.

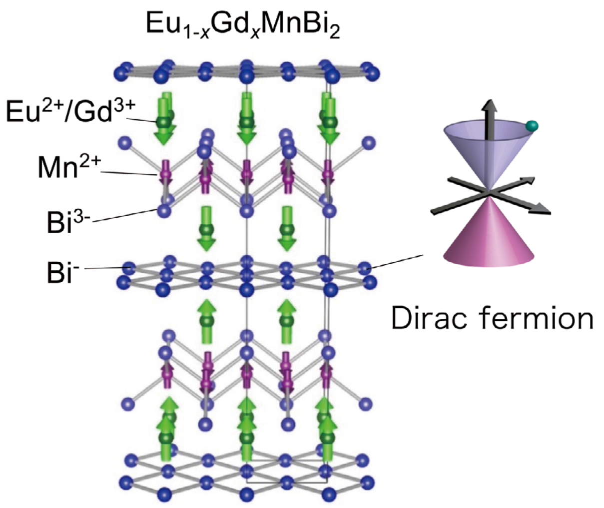

Figure 1

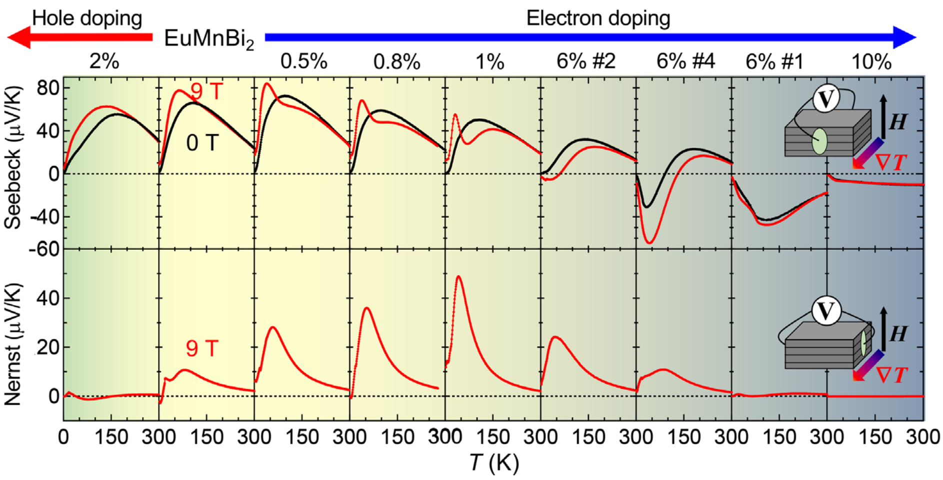

Figure 2

Patent

Treatise
Tsuruda, Keigo; Sakai, Hideaki et al. Enhancing thermopower and Nernst signal of high-mobility Dirac carriers by Fermi level tuning in the layered magnet $EuMnBi_2$. Adv. Funct. Mater. 2021, Volume 31, p. 2102275, doi: 10.1002/adfm.202102275
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