Terahertz spectroscopy for dynamics in Dirac and Weyl semimetals toward high-speed electronics and spintronics

ISSP, The Univ. Tokyo [1], °Ryusuke Matsunaga[1], Natsuki Kanda[1], and T. Matsuda[1]

E-mail: matsunaga@issp.u-tokyo.ac.jp

Recently nonlinear light-matter interaction in terahertz (THz) frequency has attracted considerable attention for fundamental interests in physics and photonics and also for finding novel functionalities of materials. We have found efficient THz harmonic generation in a superconductor [1] originating from the resonance with the collective excitation mode of the order parameter amplitude. If such an efficient THz harmonic generation is also realized at room temperature, it would be a key technology for frequency conversion and mixing in high-speed electronics as well as for sensitive detection of the cosmic microwave background. Here we demonstrate room-temperature efficient THz harmonic generation with $3f$=2.4 THz in a thin film of 3D Dirac semimetal Cd_3As_2 [2]. Our pump-probe spectroscopy for Cd_3As_2 driven by the THz field reveals that the nonlinearity originates from intraband acceleration of massless electrons across the Dirac node as theoretically anticipated. The unprecedentedly efficient harmonic generation in the 3-dimensional material would open a new avenue for developing a novel THz frequency convertor.

We also investigated the THz response of a Weyl antiferromagnet Mn_3Sn. Spin motion in antiferromagnets is as fast as in THz frequency far beyond that in the ferromagnets and therefore it has been expected as a candidate for high-speed data processing in spintronic devices. But the readout of antiferromagnetic spin order is difficult due to the small net magnetization. The noncollinear antiferromagnet Mn_3Sn shows a large anomalous Hall effect comparable to ferromagnets in spite of the vanishingly-small net magnetization [3], owing to broken time-reversal symmetry by the cluster octupole moment on Kagome bilayer. Therefore, the detection of the anomalous Hall current in Mn_3Sn at THz frequency is essential for high-speed readout of the spintronic device based on the antiferromagnet. Here we report observation of the THz anomalous Hall effect in a Mn_3Sn thin film by a broadband polarization-resolved THz spectroscopy up to 6 THz. We found that the non-dissipative large anomalous Hall current appears at around ~1 THz, while at higher frequency the dissipative part of the Hall current grows up possibly due to the interband transition across the Weyl node. Our observation of a large THz response in the antiferromagnets depending on the spin order paves the way for ultrafast readout of magnetism with THz current on device.

[1] R.M., N. Tsuji, H. Aoki, R. Shimano *et al.*, Science **345**, 1145 (2014).

[2] B. Cheng*, N. Kanda*, T. N. Ikeda, T. Matsuda, R.M. *et al.*, Phys. Rev. Lett. **124**, 117402 (2020).
(*: equal contribution)

[3] S. Nakatsuji, N. Kiyohara, and T. Higo, Nature **527**, 212 (2015).

[4] T. Matsuda, N. Kanda, R.M. *et al.*, Nature Commun. **11**, 909 (2020).