Photon Factory Activity Report 2019 #37 (2020)

BL-28A/2018S2-008

Bulk and surface electronic states of axion insulator candidate $EuIn_2As_2$

Takafumi Sato,[1,2,3]* Zhiwei Wang,[4] Daichi Takane,[1] Seigo Souma,[1,2,3] Chaoxi Cui,[4] Yongkai Li,[4] Kosuke Nakayama,[1,5] Tappei Kawakami,[1] Yuya Kubota,[1] Yugui Yao,[4] and Takashi Takahashi[1,2,3]
[1] Department of Physics, Tohoku University, Sendai 980-8578, Japan
[2] WPI-AIMR, Tohoku University, Sendai 980-8577, Japan
[3] Center for Spintronics Research Network, Tohoku University, Sendai 980-8577, Japan
[4] Beijing Institute of Technology, 100081 Beijing, China
[5] PRESTO-JST, Tokyo 102-0076, Japan

1 Introduction

Interplay between magnetism and topology is now becoming an exciting topic in condensed-matter physics. Amongst various magnetic topological materials, axion insulator is currently attracting a particular attention because of magnetoelectric effect associated with a hypothetic quasiparticle called axion. Despite the numerous theoretical predictions, a realization of axion insulator has still been one of the hottest experimental challenges. Recently, Zhang *et al* [1] predicted that $EuIn_2As_2$, which undergoes the antiferromagnetic (AFM) transition at $T_N = 16$ K, exhibits the coexistence of axion insulator and higher-order topological insulator in a single material. Whereas $EuIn_2As_2$ inherently has a bulk band inversion at a single point in the Brillouin zone (BZ), a transition to the AFM state opens an energy gap in gapless surface state leading to the axion-insulator phase. To reveal the electronic structure related to the exotic properties of $EuIn_2As_2$, we have performed a systematic ARPES study by using energy-tunable synchrotron light [2].

2 Experiment

High-quality single crystals of $EuIn_2As_2$ were synthesized by flux method. Angle-resolved photoemission spectroscopy (ARPES) measurements were performed with a DA30 electron analyzer at BL28A. We used circularly polarized light of 50-100 eV. The energy and angular resolutions were set to be 5-20 meV and 0.3°, respectively. Crystals were cleaved *in situ* in an ultrahigh vacuum better than 1×10^{-10} Torr along the (0001) crystal plane. As seen from the core-level photoemission spectrum in Fig. 1(b), clean nature of the cleaved sample surface can be confirmed.

3 Results and Discussion

Figure 1(a) shows ARPES intensity mapping as a function of in-plane wave vector (k_x and k_y) of $EuIn_2As_2$. One can immediately recognize a circular intensity spot centered at the Γ point. This intensity is attributed to the hole pocket, as seen from the energy dispersion in Fig. 1(c) along a ***k*** cut crossing the Γ point which signifies a highly dispersive holelike band crossing E_F. From the invariance to photon energy and the comparison with the band calculation, we attribute the holelike band to the surface band (S1). On the other hand, we found that the week intensity inside the S1 band is of bulk origin. Upon entering the AFM phase, the B1 band exhibits a marked reconstruction characterized by the emergence of a "M"-shaped band near E_F [schematically shown in Fig. 1(d)]. The qualitative agreement with the first-principles band-structure calculations suggests the occurrence of bulk-band inversion at the Γ point in the AFM phase. $EuIn_2As_2$ thus provides an excellent opportunity to study the exotic quantum phases associated with axion insulator and higher-order topology.

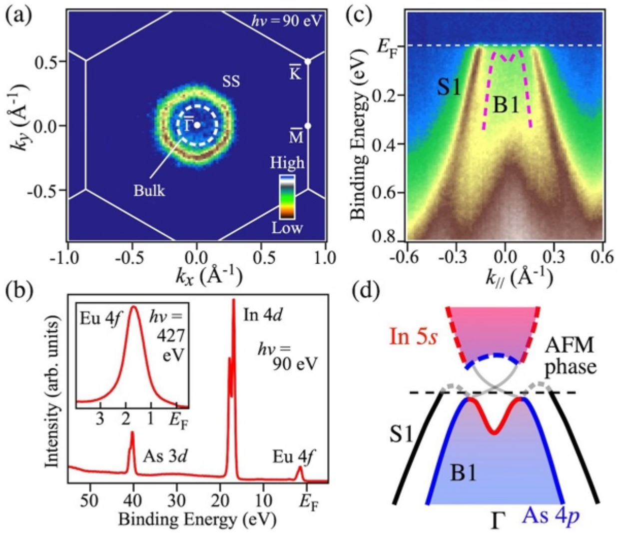

Fig. 1:(a) Fermi-surface mapping, (b) core-level spectrum, and (c) band dispersion around the Γ point of $EuIn_2As_2$. (d) Schematic band diagram in the AFM phase. "SS", "S1" denotes the surface band while "B1" to the bulk band.

Acknowledgement

We thank M. Kitamura, K. Horiba, and H. Kumigashira for their assistance in the ARPES measurements. We also thank T. Kim, C. Cacho (Diamond Light Source), and A. Arian, V. N. Strocov (Swiss Light Source) for their collaboration on this work.

References

[1] D. Zhang *et al*., Phys. Rev. Lett. **122**, 206401 (2019).
[2] T. Sato *et al*., *submitted*.

* t-sato@arpes.phys.tohoku.ac.jp