

Imaging of orbital angular momentum textures in Weyl semimetal using soft x-ray ARPES

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Weyl semimetal, which is a type of topological semimetal, is a material whose electronic band structure features point-like crossings between the conduction and valence spin-split bands. In the vicinity of the crossing point, called Weyl point, electrons behave as massless Weyl fermions, and each Weyl point possesses a definite chirality. Weyl points necessarily appear in pairs with opposite chirality and act as monopoles and antimonopoles of Berry curvature in momentum space.

In Weyl semimetals, Berry curvature is strongly enhanced near the Weyl points, which serves as the origin of various transport and optical phenomena, such as the anomalous Hall effect, negative magnetoresistance arising from the chiral anomaly, and nonlinear optical responses. Therefore, elucidating the distribution of underlying Berry curvature both experimentally and theoretically is of great importance. As a probe of Berry curvatures and its geometries, orbital angular momentum (OAM) texture in momentum space has attracted attention. The OAM texture refers to the momentum-space distribution of the orbital angular momentum of electron wavefunctions, which is closely related to the spin texture and Berry curvature in the presence of spin-orbit coupling. Circular dichroism angle-resolved photoemission spectroscopy (CD-ARPES) enables access to momentum-dependent OAM texture information through the difference in ARPES intensity between left- and right-circularly polarized light.

In this study, we employed bulk-sensitive soft X-ray CD-ARPES (SX-CD-ARPES) to investigate the prototypical Weyl semimetal TaAs at BL25SU of SPring-8 - [1]. Since Weyl points are formed by crossings of bulk valence and conduction bands, using bulk-sensitive soft X-ray is key for their direct observations. In TaAs, two Weyl points, namely W1 and W2 points exist at k_z values corresponding to photon energies $\hbar\omega$ of 590 eV and 618 eV, respectively. By tuning soft X-ray photons from synchrotron, a clear $\hbar\omega$ dependence was observed in [Fig. 1(a)], reflecting signatures of the three-dimensional bulk dispersions. From this k_z band mapping, we disentangled the W1 Weyl points from the three-dimensional band dispersions, and focused on this point with $\hbar\omega$ of 590 eV.

Figure 1(b) represents the Fermi surface mapping on the k_x - k_y at $k_z = 12.9 \text{ \AA}^{-1}$ [line in Fig. 1(a)], taken with circularly polarized x-ray photons. The red and blue dots indicate the positions of the Weyl points, located at $(k_x, k_y) = (0.47, \pm 0.06)$ and $(-0.47, \pm 0.06)$ [2], respectively. In this data, the presence of the significant circular dichroism is already seen as an asymmetric intensity along k_y axis.

The SX-CD-ARPES imaging E - k_x cuts at $k_y = 0.06 \text{ \AA}^{-1}$ are shown in Figs 1(c) and (d). The dots in each panel indicate the locations of the Weyl points. Clearly, the sign of the CD signal reverses across the Weyl

point. The CD signal primarily reflects the x-component of OAM according to our experimental geometry. Let us note that the overall CD sign observed in Fig. 1(c) and (d) is reversed.

These results experimentally demonstrate that a pair of Weyl points with opposite topological charges exists, respectively.

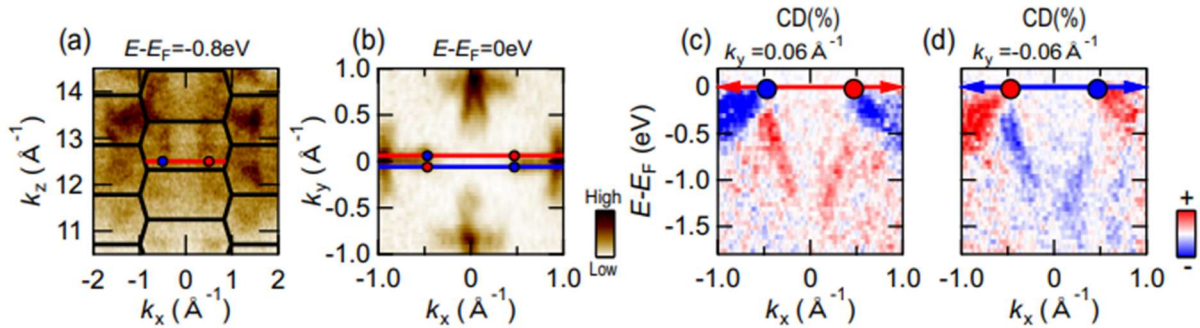


FIGURE 1. (a) k_z mapping of TaAs at $E - E_F = -0.8$ eV. The black line represents the Brillouin zone along the k_z direction. The red and blue dots in the figure indicate the positions of the Weyl points. The red line represents the k_z position ($k_z = 12.9$) that is accessible with the photon energy of 590 eV used in this experiment. (b) Equal-energy surface map acquired using left circularly polarized light at a photon energy of $h\nu = 590$ eV. The red and blue dots in the figure indicate the positions of the Weyl points, which are located at $(k_x, k_y) = (0.47, \pm 0.06)$ and $(-0.47, \pm 0.06)$. The red and blue lines represent cuts along $k_y = \pm 0.06$, respectively, and intersect the Weyl points. The Weyl points located in the positive and negative k_y regions form a pair. (c)(d) Cut along the red line in (b) at $k_y = 0.06 \text{ \AA}^{-1}$ (c) and $k_y = -0.06 \text{ \AA}^{-1}$ (d). The CD signal reflects the x-component of the orbital angular momentum (OAM), where the red regions indicate positive OAM and the blue regions indicate negative OAM. The blue and red dots in the figure represent the positions of the Weyl points: in panel (c), they are located at $(k_x, k_y) = (\pm 0.47, 0.06)$, while in panel (d), they are located at $(k_x, k_y) = (\pm 0.47, -0.06)$. These correspond to the source and sink monopoles, respectively.

REFERENCES

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