Acoustic properties of the Fulde–Ferrell–Larkin–Ovchinnikov state

Shusaku Imajo[1], **Toshihiro Nomura**[1], **Yoshimitsu Kohama**[1], **and Koichi Kindo**[1]

[1] *Institute for Solid State Physics, University of Tokyo, Kashiwa 277-8581, Japan*

Superconductivity is a macroscopic condensation state of electrons pairs. In the conventional superconducting state, the paired electrons have wavenumbers of the same magnitude with different signs like $\boldsymbol{k}$ and $-\boldsymbol{k}$, and thus, the center-of-mass momentum of the electron pair is zero. On the other hand, the Fulde–Ferrell–Larkin–Ovchinnikov (FFLO) state [1,2] has a finite center-of-mass momentum $\boldsymbol{q}$ because of the unbalanced pairing, $\boldsymbol{k}$ and $-\boldsymbol{k}+\boldsymbol{q}$. The finite $\boldsymbol{q}$ introduces the additional term $\cos(\boldsymbol{qr})$ to the superconducting order parameter. This periodic term induces the alternate appearance of the superconductivity and normal state. Therefore, one of the main features of the FFLO state is that the superconductivity oscillates macroscopically in real space. Since this periodic spatial modulation yields emergent anisotropy, the FFLO state is regarded as nematic superconductivity when the modulation breaks the rotational symmetry of the underlying lattice. However, it has been challenging to detect this feature due to experimental difficulties and severe conditions for the emergence of the FFLO state.

In order to investigate the emergent anisotropy unique to the FFLO state, in this study, we investigated one of the organic superconductors κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ employing multidirectional ultrasound measurements in pulsed magnetic fields [3]. When applying magnetic fields parallel to the *c*-axis in the conducting plane, the relative change in the sound velocity $\Delta v/v$ along the *b*-axis shows an anomaly at H_{FFLO}=21.3 T. According to numerous previous reports, this anomaly is attributable to the transition to the FFLO state. As the direction of sound-wave propagation reflects the anisotropy of elastic properties, the formation of the FFLO pattern should be detected by the sound-wave direction dependence. Figure 1 shows the comparison of the field dependence of $\Delta v/v$ when the polarization vectors of the applied sound waves are along the *b* and *c* axes. As mentioned above, the FFLO state occurs above 21.3 T, and the direction-dependent anomaly is significant only in the FFLO state. The anisotropic response of the acoustic property is attributed to the nematic-like behavior of the FFLO state.

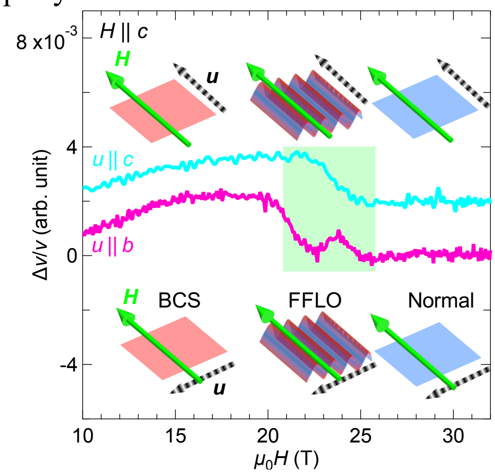

Fig. 1. Anisotropic acoustic response only in the Fulde–Ferrell–Larkin–Ovchinnikov state. The inset schematics show the electronic states (red: superconductivity, blue: normal state), directions of applied fields $\boldsymbol{H}$ (light green arrows), and sound polarization vectors $\boldsymbol{u}$ (striped arrows).

References

[1] P. Fulde and R. A. Ferrell, Phys. Rev. 35, A550 (1964).
[2] A. I. Larkin and Y. N. Ovchinnikov, Zh. Eksp. Teor. Fiz. 47, 1136 (1964).
[3] S. Imajo, T. Nomura, Y. Kohama, and K. Kindo, arXiv:2110.12774.