Discovery of superconductivity in topological semimetal with ferroelectric structural phase transition

Department of Materials Engineering Science, Graduate School of Engineering Science

Associate Professor (Lecturer) Hidefumi Takahashi

Researchmap https://researchmap.jp/-taka?lang=en

Abstract

Superconductors play a crucial role in advanced industrial technologies, including medical devices like magnetic resonance imaging (MRI). Developing new superconductors is essential not only for these applications but also for fundamental scientific research. Recently, there has been a growing interest in discovering unconventional superconducting states that go beyond the standard BCS theory.

Our research group has identified superconductivity in a compound known as SrAuBi, which exhibits a polar-nonpolar phase transition. Traditionally, superconductivity was considered incompatible with polar structure transitions that break spatial inversion symmetry. However, cryogenic measurements and theoretical calculations suggest the presence of a novel superconductivity in SrAuBi, which cannot be explained by the standard theory, due to the existence of surface states derived from the polar structure and the topological band structure.

Background & Results

In conventional *s*-wave superconductivity described by BCS theory, phonon-mediated superconducting electron pairs (Cooper pairs) are formed, which have space-inversion symmetry. Therefore, polar structures without space inversion symmetry are generally incompatible with *s*-wave superconductivity. On the other hand, in systems without space inversion symmetry, the existence of unconventional superconducting electron pairs with a mixture of singlets and triplets has been proposed. Furthermore, recent studies have highlighted the potential for surface superconductivity in topological materials, attributed to their distinctive surface states. This possibility has spurred a vigorous pursuit of superconductivity within topological materials, making it an exciting area of ongoing research.

Our research group has successfully synthesized a single crystal of the semimetal SrAuBi, which is composed of strontium (Sr), gold (Au), and bismuth (Bi), and observed a polar-nonpolar structural phase transition at 214 K and a superconducting transition at 2.4 K. Therefore, SrAuBi is an unusual system that exhibits superconductivity despite its polar structure. In order to investigate the superconducting properties of this material, we measured the change in the superconducting transition temperature when an external magnetic field was applied in the in-plane and out-of-plane directions down to cryogenic temperatures near 0.2K. As a result, it was found that a superconducting critical field of 5 T, which exceeds the Pauli limit expected for conventional superconductors, is realized in the out-of-plane magnetic field. Furthermore, first-principles calculations have revealed that Rashba-type spin splitting is realized in the band structure near the Fermi level, reflecting the strong spin-orbit coupling and polar structure of Bi derived from the *p* orbitals. In addition, we found the existence of multiple Dirac points. Therefore, SrAuBi is expected to be a system that exhibits a new unconventional superconductivity, possibly reflecting the superconductivity in the topological surface state and the Rashba-type band structure.

Significance of the research and Future perspective

The present work reveals for the first time the superconducting properties of the topological semimetal SrAuBi, which undergoes a polar structural phase transition. The superconductivity in this system is attributed to the electronic states of bismuth and gold with strong spin-orbit coupling, and has potential as a superconducting spintronic material with a novel magnetic field response. Furthermore, topological superconductivity derived from the polar structure is expected to be realized and to have potential as a quantum computer device.

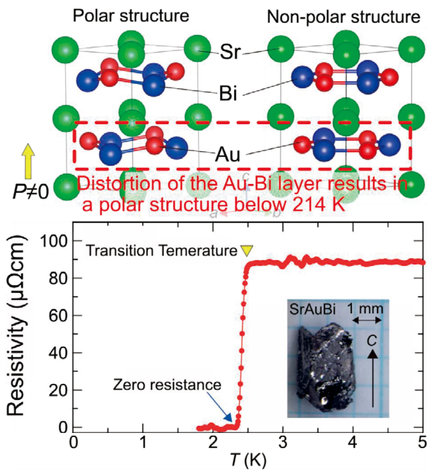

Fig. 1 Crystal structure of SrAuBi (top), superconducting transition temperature and picture of the single crystal (bottom).

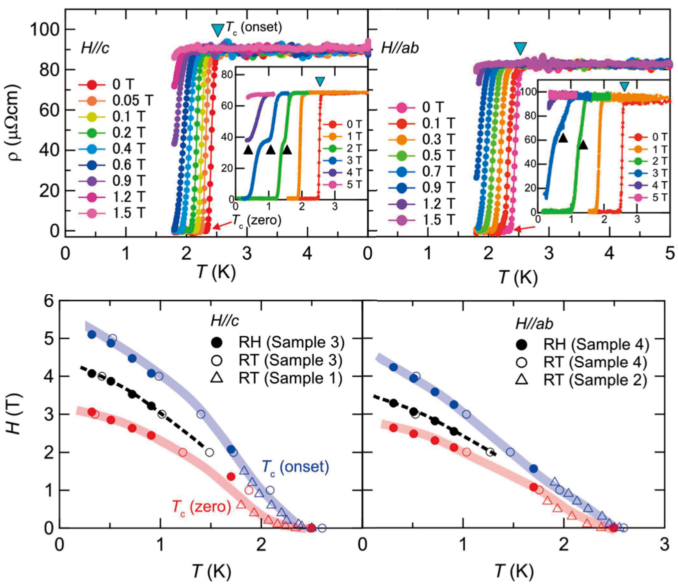

Fig. 2 Magnetic field dependence of the superconducting transition temperature.

Patent

Treatise Takahashi, Hidefumi; Sasaki, Tomohiro et al. Superconductivity in a ferroelectric-like topological semimetal SrAuBi. npj Quantum Materials. 2023, 8, 77. doi: 10.1038/s41535-023-00612-4

URL

Keyword topological semimetals, superconductivity, spintronics