Research Group for Actinide Materials Science

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5*f* electrons in actinide compounds play essential roles in various phase transitions in actinide compounds. The electronic states can be modified by the chemical or physical environment around these electrons. It is therefore interesting to investigate new materials under various conditions such as pressure, magnetic field or low temperature to find new phenomena. The purification of a known compound also provides new insight particularly for phenomena occurring at low temperatures, where impurity disorder can deeply disturb and hence hide the intrinsic behavior. Here we report recent progresses in the studies of the formation of heavy fermion state, unconventional superconductivity in UPt_3 using a high-quality single crystal, and experimental development in high-pressure techniques.

Unconventional superconductivity of UPt_3

UPt_3 is a prototypical heavy fermion superconductor. Earlier studies revealed that an unconventional odd-parity Cooper pairing is realized. We have investigated the anisotropy of thermal conductivity in the superconducting state using a high quality single crystal. As a result, it is found that the superconducting state has a two-fold rotational symmetry in the basal plane which is lower than the six-fold symmetry of the crystal structure. The obtained superconducting symmetry successfully explains the characteristics of the superconducting phase diagram [1]. On the other hand, an anomalous enhancement of the electron effective mass has been detected in this compound depending on the magnetic field direction. This observation confirms the participation of heavy fermion in the unconventional superconductivity [2]. The work has been conducted in collaboration with Tokyo Institute of Technology and the University of Tokyo.

Fermi surfaces in the hidden-order state of URu_2Si_2

The electronic state of URu_2Si_2 was investigated using cyclotron resonance in collaboration with Kyoto University. Using this technique, Fermi surfaces with an extremely large effective mass were detected, where the conventional de Haas-van Alphen experiments were unable to detect these heavy masses. By measuring the angular dependence, the Fermi surfaces were shown to have two-fold symmetry, consistent with the recent observation in magnetic anisotropy [3].

Heavy fermion formation in a dilute magnetic alloy

It is well recognized that strongly correlated heavy fermion behavior in rare-earth and actinide compounds has its origin in the Kondo interaction between magnetic moments and conduction electrons. The experimental proof of the participation of magnetic electrons in the Fermi surface has not been reported. By detecting the Fermi surfaces in dilute alloys $Ce_xLa_{1-x}Ru_2Si_2$, the evolution of electronic state as a function of temperature was revealed. Here, the magnetic impurity state at temperatures higher than the characteristic temperature T_K is changed into a heavy conduction electron at low temperatures [4].

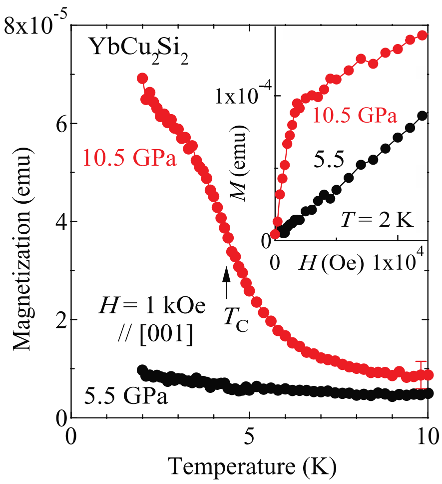

Fig.1 Magnetization measurement performed at high pressure. $YbCu_2Si_2$ is a paramagnet at ambient pressure. However, a clear ferromagnetic moment has been observed at 10.5 GPa.

Development of a high-pressure cell for magnetization measurement

5*f* electrons in actinides respond sensitively to pressure by changing their ground state. It is therefore interesting to study magnetic behavior of 5*f* electrons under pressure. We successfully developed a high pressure cell suitable for this purpose. By using ceramic anvils with extremely low background, high-sensitivity and high maximum pressure were both achieved. Using the present pressure cell in a commercial SQUID magnetometer, a pressure-induced ferromagnetism in an *f*-electron system was found [5]. Figure 1 demonstrates the observation of ferromagnetism at 10.5 GPa in a heavy fermion compound $YbCu_2Si_2$.

References

[1] Y. Machida *et al.*, Phys. Rev. Lett. **108**, 157002 (2012).
[2] S. Kittaka *et al.*, J. Phys. Soc. Jpn. **82**, 024707 (2013).
[3] S. Tonegawa *et al.*, Phys. Rev. Lett. **109**, 036401 (2012).
[4] Y. Matsumoto *et al.*, J. Phys. Soc. Jpn. **81**, 054703 (2012).
[5] N. Tateiwa *et al.*, Rev. Sci. Instrum. **83**, 053906 (2012).