Research Group for Materials Physics for Heavy Element systems

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In heavy element systems, valence fluctuations, the Kondo effect, and the RKKY interaction compete with one another. Because of this, exotic behaviors such as quantum critical points, heavy fermions, non-Fermi liquids, anisotropic superconductivity and multipolar ordering appear when such competition is strong. Recently, it has become clear that these exotic behaviors for 5*f*-electron systems are different from those for 4*f*-electrons. This is because electrons with different spin and orbital character can coexist in 5*f* actinide systems, in contrast to the case of 4*f* electrons. By means of advanced experimental and theoretical approaches, our research group tries to clarify these exotic behaviors due to the "many-fold" character of both 4 *f* and 5*f* compounds, including transuranium.

In this mid-term project, we also try to reclaim new fields such as topological and spintronic aspects in these compounds.

Two Quantum critical points in Ce_3PtIn_{11} [1]

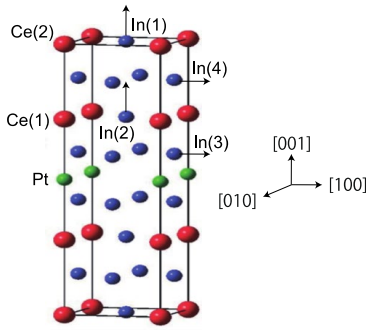

Fig. 1 Crystal structure of Ce_3PtIn_{11}. Ce(1) and Ce(2) are considered to be paramagnetic and antiferromagnetically ordered below $T_{N,}$ respectively. The arrows indicate the direction of quantization axis at each In site, i.e. V_{ZZ} determined by local symmetry and LDA calculations.

A heavy fermion compound Ce_3PtIn_{11} harbors two inequivalent Ce sites, which are considered to have different magnetic properties. This system exhibits magnetic transitions at T_{1n} = 2.2 K and T_N = 2 K, prior to entering a superconducting state below T_c = 0.32 K. Previous measurements imply that magnetism and superconductivity are spatially separated and only the Ce(2) sublattice orders magnetically, with a quantum critical point (QCP) at pressure p_c = 1.3 GPa, while the Ce(1) sublattice is paramagnetic. In this study, we have confirmed the difference of magnetic characters between the Ce(1) and Ce(2) sites by means of ^{115}In nuclear quadrupole resonance (NQR) measurements. The nuclear relaxation rate behavior of $1/T_1 \propto \sqrt{T}$ reveals the presence of critical spin fluctuations indicative of close proximity to another quantum critical point, presumably at a small negative pressure, which is associated solely with the Ce(1) sublattice. On the other hand, it is revealed that the internal field due to the magnetic ordering appears only at the Ce(2) site, confirming microscopically the previous study. In the present study, we have confirmed new QCP around p=0 associated with the Ce(1) site, in addition to previously confirmed second QCP around p=1.3GPa associated with the Ce(2) site.

Uranium compound with honeycomb layer [2]

A series of intermetallic compounds crystallizing in the hexagonal $Sc_{0.67}Fe_2Si_5$-type structure is known to form with rare earth, actinides and transition metal elements. Among them, uranium isostructural compounds were discussed in terms of atomic disorder in the uranium-containing layer suggested from the imperfect occupancy of the uranium and neighboring atom sites. It is the origin of the non-integer chemical composition.

We attempted to synthesize U-Pt-Al analogue and investigated structural and physical properties. The sample was synthesized by the arc-melting. A small single crystal piece was extracted from the ingot and examined by single-crystal X-ray diffraction. Sharp Bragg peaks were successfully indexed as the hexagonal structure, confirming the $Sc_{0.67}Fe_2Si_5$-type structure. In addition, weak streak reflections were systematically detected. They can be indexed as (h/3 k/3) in the basal plane and elongated along the c* direction. This result suggests a superstructure in the basal plane and stacking disorder along the c* direction. The simplest basal plane structure satisfying both the streak scattering and cite occupancies is the honeycomb arrangement having a larger lattice parameter $a' = \sqrt{3}a$ as shown in Fig. 2. Such honeycomb arrangements actually exist in a series of rare earth compounds $LnNi_3X_9$ (Ln: rare earth, X: Al, Ga). Based on this model, the resulting chemical composition is $U_2Pt_6Al_{15}$. Similar superstructure is suggested for rare-earth analogues.

Magnetization measurement on $U_2Pt_6Al_{15}$ revealed a well-defined magnetic transition at low temperature around 26 K despite the disordered structure. Since each honeycomb layer is separated more than 8 Å, disorder effect brought about by the modulated interlayer magnetic interaction may not be significant. The preparation of the single crystal and further measurement are in progress to clarify the ground state properties.

The present investigation addresses a new family of the layered structure uranium intermetallic compound with honeycomb arrangements of uranium atoms. In contrast to previous study, an ordered honeycomb layer is established and considered to be quite stable, enabling further material investigation by chemical substitution.

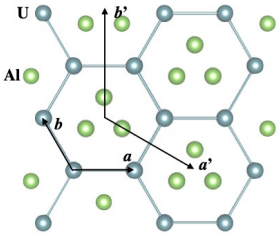

Fig. 2 Structure model for $U_2Pt_6Al_{15}$. Only the uranium-containing layer is shown.

References

[1] S. Kambe et al, Phys. Rev. B 101, 081103(R), (2020).
[2] Y. Haga et al., JPS Conf. Ser. 29, 013003 (2020).