

# High-resolution photoemission study of CeRhX (X=Sn, In)

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## Abstract

The Ce 4f derived states in CeRhX (X=Sn and In) were directly examined by means of high-resolution 3d-4f resonance photoemission spectroscopy. Compared with the Kondo metal CePtSn, which has a low Kondo temperature, CeRhX has a strong Ce 4f<sup>1</sup> weight near the Fermi level ( $E_F$ ) and has a weak Ce4f<sup>0</sup> peak, indicating a strong valence fluctuation. The Ce 4f<sup>1</sup> spectral features indicate that the c-f hybridization strength in CeRhSn is weaker than that in CeRhIn.  
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Hexagonal (ZrNiAl-type) CeRhSn has attracted much interest because of its non-Fermi liquid (NFL) behavior at low temperatures.[1] The NFL behavior has been discussed from the viewpoint of the proximity to the quantum critical point (QCP), or the existence of the Griffith phase where the intersite Kondo effect and the Ruderman-Kittel-Kasuya-Yoshida (RKKY) interaction are competing due to lattice disorder.[1-3] Recently Kim et al. synthesized a CeRhSn single crystal, and revealed strong anisotropy in the resistivity ( $\rho$ ) and magnetic susceptibility ( $\chi$ ).[4] There has been no report, however, on the nature of the Ce 4f states in CeRhSn.

In the present paper, we clarify, by means of low-temperature high-resolution 3d-4f resonance photoemission spectroscopy (PES), the Ce 4f states of CeRhSn in comparison with CeRhIn, whose transport and magnetic properties are well explained by the Fermi liquid theory. The Ce 4f spectra obtained from CeRhX (X=Sn, In) are compared with that of the Kondo metal CePtSn with a low Kondo temperature

of  $T_K \sim 10$  K and a Néel temperature of  $T_N \sim 7.5$  K, where the Ce 4f electron is well localized.[5]

Single crystals of CeRhSn, CeRhIn and CePtSn were grown by the Czochralsky method [4,5]. The 3d-4f resonance PES experiments were conducted at beamline BL23SU at SPring-8 [6]. The sample temperature was kept at  $T=15$  K, and the overall energy resolution was set to  $\Delta E=100$  meV. Clean sample surfaces were obtained by fracturing the sample in the ultrahigh vacuum.

Figure 1 shows 3d-4f resonance PES spectra of CeRhSn. In the off-resonance spectrum at  $h\nu = 870$  eV, the peak at 2.3 eV is derived from the non-bonding Rh 4d state. In an on-resonance spectrum at  $h\nu = 881$  eV, the Ce 4f derived spectral feature is enhanced significantly. We have normalized the spectra and subtracted the off-resonance spectrum from the on-resonance spectrum, to obtain the Ce 4f partial spectrum. The Ce 4f spectrum consists of the 4f<sup>1</sup> final-state peak located near  $E_F$  with broad peaks at 1.5 eV and 3.3 eV.

Figure 2 shows the Ce 4f derived spectra obtained

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from CeRhX and CePtSn. Note that CeRhX spectra have weak  $4f^0$  final-state peak, such as that seen in CePtSn at 2 eV, indicating much higher  $T_K$ . [7,8] This result suggests the presence of strong valence fluctuations in these compounds, in agreement with transport and magnetic measurements [1,4].

Due to the spin-orbit interaction, the  $4f^1$  final-state peak in CePtSn is split into the  $4f^1_{7/2}$  peak at 220 meV and the  $4f^1_{5/2}$  peak (or a tail of the Kondo resonance) at  $E_F$ . In the framework of the single-impurity Anderson model, the Kondo resonance is scaled to  $T_K$ . [8] While the spin-orbit splitting is clearly observed in the low  $T_K$  CePtSn compound, the splitting is less clear in the CeRhX cases due to a significant contribution from the Kondo resonance. If one compares CeRhSn and CeRhIn, the shoulder at 250 meV in CeRhSn is more apparent, suggesting that the Ce 4f electrons in CeRhSn have more localized, or incoherent, nature compared with that in CeRhIn. On the basis of the present results, we can assume that the magnitude of  $J_{cf}D_F$ , which gives a measure of the c-f hybridization strength, becomes larger in going from CePtSn to CeRhSn to CeRhIn, where  $J_{cf}$  represents an exchange interaction between the spins of f and conduction electrons, and  $D_F$  the density of states of conduction electrons at  $E_F$ . On the basis of the anisotropic NFL behaviors in  $\rho$  and  $\chi$  of CeRhSn, the electronic properties of CeRhSn are the closest to the QCP among these compounds.

In summary, strong valence fluctuations in CeRhSn and CeRhIn have been clearly indicated by high-resolution 3d-4f resonance PES measurements. The Ce  $4f^1$  peak at  $E_F$  in CeRhSn indicates that the c-f hybridization strength is weaker than that in CeRhIn.

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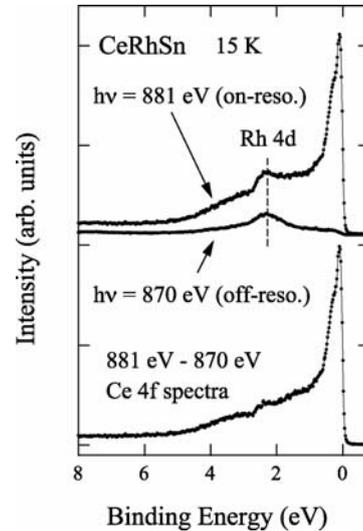


Fig. 1. High-resolution low-temperature 3d-4f resonance photoemission spectra of CeRhSn.

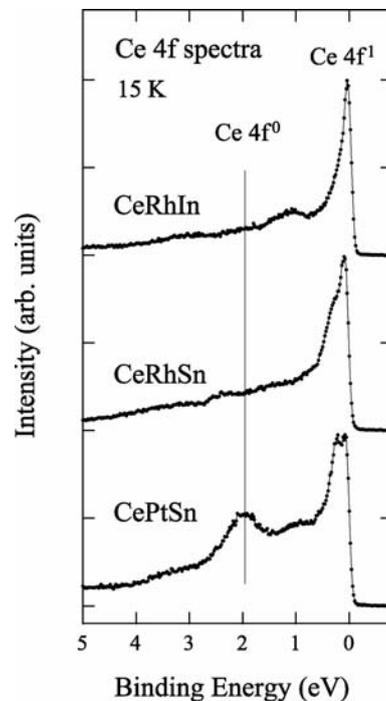


Fig. 2. Ce 4f spectra of CeRhIn, CeRhSn and CePtSn single crystals.