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Pseudogap formation in Kondo insulators CeRhSb and CeRhAs studied by ultrahigh-resolution photoemission spectroscopy

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Abstract

We report an ultrahigh-resolution ($\Delta E \sim 8$ meV) temperature-dependent photoemission spectroscopy on the Kondo insulators CeRhAs and CeRhSb. We have observed a pseudogap at the Fermi level at low temperature for both compounds, which is gradually filled-in with increasing temperature. We found that the size of pseudogap is well scaled with the Kondo temperature (T_K) while the temperature evolution is dominated by another characteristic temperature much lower than T_K. © 2000 Published by Elsevier Science B.V. All rights reserved.

Keywords: CeRhSb; CeRhAs; Kondo insulator; Photoemission

Heavy fermion materials with the paramagnetic insulating ground state as named "Kondo insulators" have recently attracted much attention because of their anomalous physical properties [1,2]. It has been proposed that the observed anomalous properties may stem from a small (pseudo)gap at the Fermi level (E_F) formed through the strong hybridization between the half-filled conduction band and the narrow f band near E_F at low temperature [3,4]. While the existence of a small gap has been suggested by some experiments [1,2], there are little consensus on the size, shape, and temperature dependence although they should be directly related to the anomalous properties. In this paper, we report an ultrahigh-resolution ($\Delta E \sim 8$ meV) photoemission spectroscopy (UHR-PES) on the "Kondo insulators" CeRhSb and CeRhAs to observe directly the "Kondo gap" and its temperature evolution.

Polycrystalline CeRhSb and CeRhAs were prepared by argon arc melting. UHR-PES measurements were carried out using a Scienta analyzer with a Gammadata discharge lamp. Photoelectrons were excited with monochromatized He I_α resonance line (21.218 eV). A flesh and clean surface for PES measurement was obtained by in situ scraping by a diamond file under vacuum of 5×10^{-11} Torr.

Fig. 1 shows UHR-PES spectra near E_F of CeRhSb and CeRhAs at 13.5 K compared with that of gold. In contrast to gold, both CeRhSb and CeRhAs exhibit a small depletion of spectral weight at E_F and the depletion is larger in CeRhAs than in CeRhSb. This suggests a (pseudo)gap at E_F both in CeRhSb and CeRhAs and the size of (pseudo)gap is larger in CeRhAs. A similar depletion of the spectral weight at E_F has also been reported for other Kondo insulators $Ce_3Bi_4Pt_3$ [5] and YbB_{12} [6], but not for a typical heavy fermion material $CeSi_2$ [5]. This suggests that the depletion near E_F is a common characteristic feature in Kondo insulators. In order to clarify whether the observed gap is a simple semiconductor gap in a band insulator or a "Kondo gap" in a strongly correlated electron system, we have measured the temperature dependence of UHR-PES spectrum. Because, a "Kondo gap" should disappear at high temperature while a simple semiconductor gap does not. We show in Fig. 2 the temperature dependence of the density of states (DOS) near E_F obtained by dividing the UHR-PES spectra with the Fermi–Dirac function convoluted with an instrumental resolution at each temperature. The inset shows the result for gold obtained with the same procedure for comparison. In contrast to the

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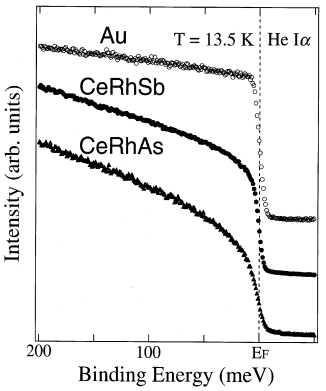

Fig. 1. Ultrahigh-resolution photoemission spectra near E_F of CeRhSb and CeRhAs measured with He I_α line at 13.5 K compared with that of gold.

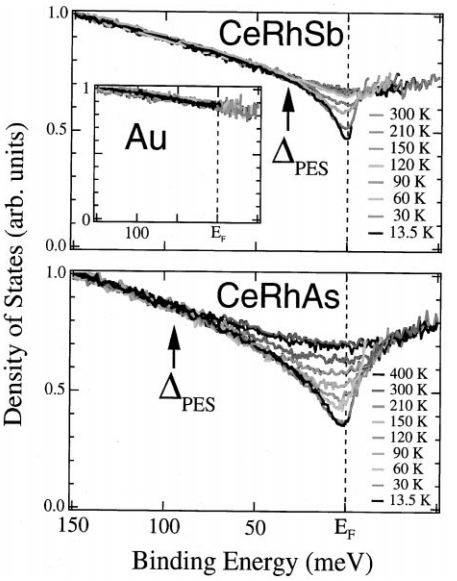

Fig. 2. Temperature dependence of spectral density of states (DOS) near E_F of CeRhSb and CeRhAs in comparison with that of gold (inset).

flat and temperature-independent DOS of gold, we find a clear temperature-induced evolution of a pseudogap at E_F for both CeRhSb and CeRhAs. As expected from Fig. 1, the gap size is larger in CeRhAs than in CeRhSb. It is also noted that the gap is not a full gap but a pseudogap with a finite DOS at E_F. We find that the temperature dependence of DOS is quite unusual: (1) The DOS at low temperature is strongly depleted up to a characteristic energy (Δ_{PES}). The value of Δ_{PES} is 30–35 meV for CeRhSb and 90–100 meV for CeRhAs. (2) On increasing temperature, the pseudogap is gradually filled-in with additional intensity, but no clear transfer of weight of DOS is seen in the present energy range. (3) The pseudogap collapses above a characteristic temperature (T_{coh}), 300 K for CeRhAs and 120 K for CeRhSb. These experimental results indicate that the pseudogap originates in the many-body effect correlated with the temperature-dependent magnetic interaction, since the observed behaviors as described above are not expected for a simple semiconductor gap in a band insulator. It is thus worthwhile to compare the obtained pseudogap size (Δ_{PES}) with the Kondo temperature (T_K). Using the result of susceptibility measurement, we have estimated $T_K = 360$ K for CeRhSb [2] and 1200 K for CeRhAs [7]. We find the ratio $\Delta_{PES}/k_B T_K$ being almost the same for both compounds (0.97–1.1 for CeRhSb and 0.87–0.97 for CeRhAs). These values are in good agreement with that of $Ce_3Bi_4Pt_3$ obtained by PES ($\Delta_{PES}/k_B T_K = 0.97$–1.2) [5]. This fact suggests that the Kondo temperature is an essential parameter to describe the pseudogap. On the other hand, the value obtained for YbB_{12} ($\Delta_{PES}/k_B T_K \sim 2.1$) [6] is larger than those for Ce compounds. This difference may be attributed to the fact that the main 4f state is situated above E_F in Ce compounds while it is below E_F in Yb compounds.

Finally, we discuss the temperature dependence of the pseudogap in comparison with the Kondo temperature. We find in Fig. 2 that the pseudogap formation starts around $T_{coh} = 90$–120 K (0.25–0.33T_K) in CeRhSb and 210–300 K (0.18–0.25T_K) in CeRhAs. This suggests that the temperature evolution of pseudogap is dominated by another characteristic temperature T_{coh} much smaller than T_K.

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References

[1] G. Aeppli, Z. Fisk, Comments Condens. Matter Phys. 16 (1992) 155.
[2] T. Takabatake et al., J. Magn. Magn. Mater. 171–181 (1998) 277.
[3] C. Gröber, R. Eder, Phys. Rev. B 57 (1998) R12659.
[4] M.J. Rozenberg, G. Kotliar, H. Kajueter, Phys. Rev. B 54 (1996) 8452.
[5] K. Breuer et al., Europhys. Lett. 41 (1998) 565.
[6] T. Susaki et al., Phys. Rev. Lett. 77 (1996) 4269.
[7] S. Yoshii et al., Physica B 223&224 (1996) 421.