SB2v8.00a/ w (Dec 5 2005).51C + model | PHYSB : 51140 | Prod.Type:FP pp.1–2(col.fig.:NIL) | ED:R.Jothil. PAGN:anu SCAN:Vgs

ARTICLE IN PRESS

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Physica B ▮ (▮▮▮▮) ▮▮▮–▮▮▮

PHYSICA B

www.elsevier.com/locate/physb

CeRhAs
Tunneling measurements of ~~cerhas~~ single crystal

Toshikazu Ekino[a,b,*], Hiroki Miyaoka[b], Tetsuya Sasakawa[b], Toshiro Takabatake[b], Alexander M. Gabovich[c]

[a]*Hiroshima University, Faculty of Integrated Arts and Sciences, Higashi-Hiroshima 739 8521, Japan*
[b]*Hiroshima University, Graduate School of Advanced Sciences of Matter, Higashi-Hiroshima 739 8530, Japan*
[c]*Institute of Physics, National Academy of Sciences, prospekt Nauki 46, 03028, Kiev, Ukraine*

Abstract

Kondo-semiconducting gap of CeRhAs single crystal has been measured by break-junction tunneling. The observed largest gap at 4.2 K is $2\Delta \sim 0.5$ eV, while smaller sizes below 0.3–0.4 eV are also reproducible. We present the temperature evolution of the gap and discuss the gap size in comparison with the other Kondo semiconductors.

Keywords: Tunneling; Break junction; Kondo semiconductor; Energy gap; Cerhas

Among the orthorhombic Kondo semiconductors, CeRhAs is a unique compound exhibiting super-lattice formations due to structural phase transitions [1]. Intensive studies have clarified that the gap formation is enhanced by the successive structural phase transitions involving electronic instabilities near the Fermi surface. These transitions occur at 370, 235, and 165 K below the susceptibility-maximum temperature $T_\chi = 510$ K, at which the Kondo coherence starts to develop [1]. Practically, this compound has been investigated as a potential complement of the conventional thermoelectric materials. Our previous study on polycrystalline sample of CeRhAs has shown the distinct gap structure with $2\Delta = 0.5 \pm 0.1$ eV [2], which is ~20 times larger than the activation energy from the transport measurements, but the same order of magnitude to that of the photoemission spectroscopy [3].

In this paper, we report on tunnel measurements of CeRhAs single crystal to have further insight into the gap structure. The tunnel measurements were done using in situ break junction, which has been indeed promising to clarify the gap feature of this class of compounds [4]. To design the junction interface parallel to the *a*-axis, the surface of thin platelet sample was scratched along this axis before mounting it to the sample holder.

*Corresponding author. Tel.: +81 82 424 6552; fax: +81 82 424 0757
E-mail address: ekino@hiroshima-u.ac.jp (T. Ekino).

0921-4526/$ - see front matter © 2006 Published by Elsevier B.V.
doi:10.1016/j.physb.2006.01.287

Fig. 1(a) shows the representative tunnel conductance dI/dV at 4 K obtained from the present measurements. Well-defined peaks are clearly visible for (a_1) and (a_2). They are naturally attributed to the gap-edge singularities in the electronic density of states. Such intensive gap-edge features are qualitatively different from the other orthorhombic Kondo semiconductors CeRhSb and CeNiSn, where the V-shape gap structures with broadened gap edges are always observed [4]. Since the break junction forms a semiconductor–insulator–semiconductor junction geometry, the peak-to-peak bias separation (V_{pp}) is attributed to $4\Delta/e$. The gap sizes thus obtained are $2\Delta = 0.5$ eV ($eV_{pp} = 1.0$ eV) (a_1) and 0.34 eV (0.68 eV) (a_2), which are representative among the observed distribution of 2Δ between ~0.15 to 0.6 eV.We show in Fig. 1 (a_3) the polycrystal data [2], where the specific two gap sizes observed in the single crystal are reproduced as the double-gap feature. For the single-crystal data, a small leakage of the zero-bias conductance (ZBC) is obtained, which is ~10–20% of the gap-edge peak in most cases. This is significantly smaller than the ZBC of 50% found in the polycrystal as shown in (a_3). Probably, contaminated junction interface formed at grain boundary of polycrystal causes such a large leakage, although the gap size is quite similar to that of the single crystal.

Fig. 1(b) shows the T evolution of the tunnel conductance showing a representative gap of $2\Delta = 0.3$ eV

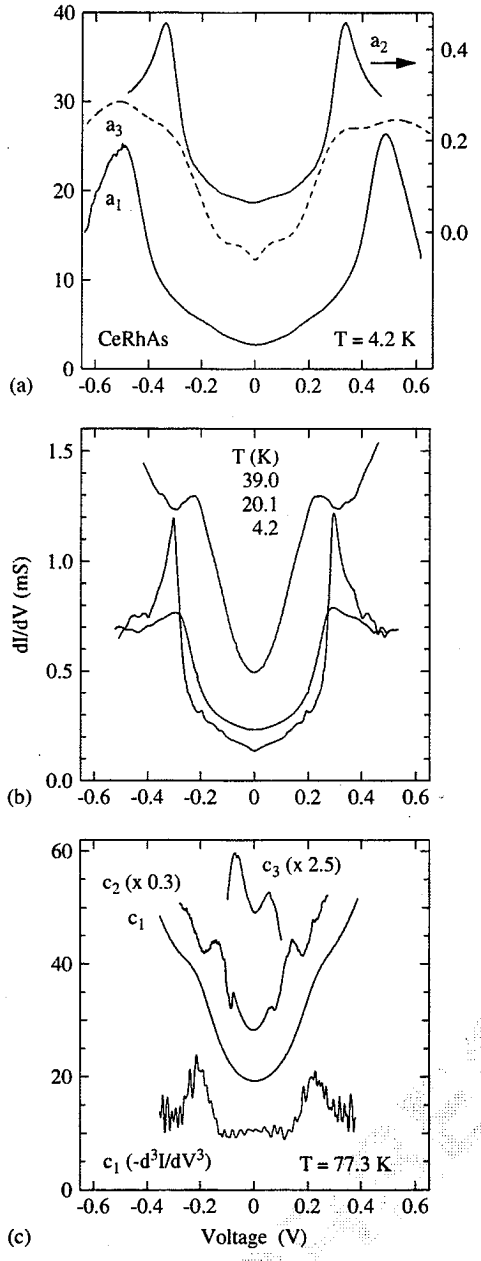

Fig. 1. Tunnel conductance of CeRhAs at (a) 4.2 K, (b) 4.2–39.0 K, and (c) 77.3 K.

($eV_{pp} = 0.6$ eV) at 4.2 K. With increasing T, the intensive gap-edge peaks found at 4.2 K decrease drastically. At higher $T > 20$ K, the junction changes slightly, resulting in the change of background conductance. Nevertheless, we can readily distinguish the gap-edge features up to 39 K, at which the gap value is reduced to $2\Delta \sim 0.22$ eV. The similar reduction rate $d\Delta/dT \simeq 10^{-3}$ (eV/K) is also obtained for the larger gap of 2Δ (4.2 K) = 0.5 eV.

In Fig. 1(c), we show the tunnel conductance at 77.3 K. The large conductance leakage and the broadened gap edge as compared with those at low T's are believed to be mainly due to thermal effect. Particularly, the gap (c_1) is largely broadened, but we can determine the gap edge explicitly by calculating d^3I/dV^3, as shown in the figure. The values of $eV_{pp} = 0.45$ eV (c_1), 0.30 eV(c_2), and 0.15 eV (c_3) are the representative ones among the distribution at 77.3 K. The smallest gap (c_3) can be due to the accidentally formed semiconductor–metal junction with $eV_{pp} = 2\Delta$, judging from the large conductance asymmetry and the half-value of eV_{pp} as compared with (c_2). Therefore, we obtain the gap values $2\Delta = 0.23$ eV (c1) and 0.15 eV (c_2 and c_3). These values are consistent with Fig. 1(a), the reduction rate $d\Delta/dT$ below 40 K in Fig. 1(b) is valid at 77.3 K. Such a drastic reduction in the large gap energy (~3000–6000 K) by a slight increase of T (~80 K) reflects the strongly correlated nature of the explored Kondo f electron system.

The largest gap of $2\Delta = 0.5$ eV is very consistent with the other Kondo-lattice semiconductors by giving the common gap ratio $2\Delta/k_B T_\chi = 12 \pm 3$ [4]. Although this ratio is similar to that of the frequently observed charge-density-wave gap [5], the emerging gap is not the order parameter of the II-kind phase transition. Specifically, at least three characteristic temperatures (energy scales) might be relevant: (i) the above defined T_χ, (ii) a familiar Kondo one, T_K, exponentially dependent on the coupling constant $-|g|$; (iii) a much higher energy $T_0 \sim g^2 D$, where D is a cut-off energy [6]. Hence, it should be an unconventional gradual thermal filling of the effective energy gap. Since a thorough many-body theory is still lacking, we cannot make an unambiguous interpretation. Nevertheless, when our large gap values are associated with T_0, these three energy scales could explain the discrepancies with the gaps inferred from transport measurements.

The research is supported by the Grant-in-Aid for COE Research (No. 13CE2002) and for Scientific Research (No. 15540346) of the Ministry of Education, Culture, Sports, Science and Technology of Japan.

References

[1] T. Sasakawa, et al., Phys. Rev. B 66 (2002) R041103.
[2] T. Ekino, et al., Physica B312-313 (2002) 221.
[3] K. Shimada, et al., Phys. Rev B66 (2002) 155202.
[4] T. Ekino, et al., Phys. Rev. Lett 75 (1995) 4262.
[5] T. Ekino, J. Akimitsu, Jpn. J. Appl. Phys 26 (1987) 62.
[6] Yu.N. Ovchinnikov, A.M. Dyugaev, UFN 171 (2001) 565.