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Electron tunneling experiments on La-substituted Kondo-semiconductor CeRhAs

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Abstract

Polycrystalline $Ce_{1-x}La_xRhAs$ is investigated by means of break-junction tunneling. On Ce substituted by La ($x = 0.01$), a pronounced hump structure is developed at the bias ± 0.25 V with a shallow dip on it. The hump emergence is consistent with a drastic reduction in the resistivity. These facts give direct evidence for the appearance of mid-gap states near the Fermi energy by a small La substitution for Ce in CeRhAs.

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Keywords: Electron tunneling: Break junction; Kondo semiconductor; Energy gap; $Ce_{1-x}La_xRhAs$

CeRhAs is a unique Kondo semiconductor exhibiting successive structural phase transitions at 360, 235, and 165 K below the susceptibility-maximum temperature $T_\chi = 510$ K, at which coherent states due to anisotropic c–f hybridization begin to develop [1]. To understand the nature of these phase transitions as well as the c–f hybridization, effects of atomic substitution in CeRhAs have provided the important evidence [2,3]. In fact, a slightly La-substituted sample $Ce_{0.99}La_{0.01}RhAs$ shows a drastic reduction in the resistivity ρ by a factor of $\sim 10^{-2}$ at low temperatures as compared with CeRhAs [3]. This should be due to a significant change in the electronic states at the Fermi energy. In this paper, we report on tunnel measurements of $Ce_{1-x}La_xRhAs$ polycrystal to see the substitution influence on the gap feature and the overall semiconducting behavior. The tunneling measurements were done using in situ break junction, which successfully probes gap structures of such compounds [4].

Fig. 1 shows the tunneling conductance dI/dV for $Ce_{1-x}La_xRhAs$ ($x = 0$ and 0.01) at 4.2 K. For $x = 0$, well-defined gap-edge peaks appear at ± 0.4 V, which correspond to $\pm 2\Delta/e$ of the semiconductor–insulator–semiconductor junction. This can be attributed to the hybridization gap because the gap ratio $2\Delta/k_B T_\chi = 12 \pm 3$ is common to those of other Kondo semiconductors [4,5]. The V-shaped conductance is seen around zero bias, exhibiting its conductance leakage $\approx 30\%$ of the peak value. This feature is well reproduced among polycrystalline CeRhAs break junctions [5]. For $x = 0.01$, the shape of dI/dV changes essentially, namely, the gap-edge peaks broaden, and a pronounced hump appears within the bias of ± 0.25 V concomitant with a shallow zero-bias dip on it. The gap edges of the size ± 0.6 V, which is the smallest size among the distribution extended up to $\sim \pm 1$ V, are seen in Fig. 1. Such a large gap has never been observed in CeRhAs. Fig. 1 demonstrates a difference between compounds with the gap-edge energy for $x = 0.01$ being larger than that for $x = 0$. A possible origin of such a gap enhancement is due to the stretch of the Ce chain along the a-axis by a La substitution, which could locally optimize the c–f hybridization [3]. The other significant feature for $x = 0.01$ is the above-mentioned pronounced hump-dip structure, where the zero-bias leakage becomes as high as $\approx$ 60% of the peak value. The increased small-bias

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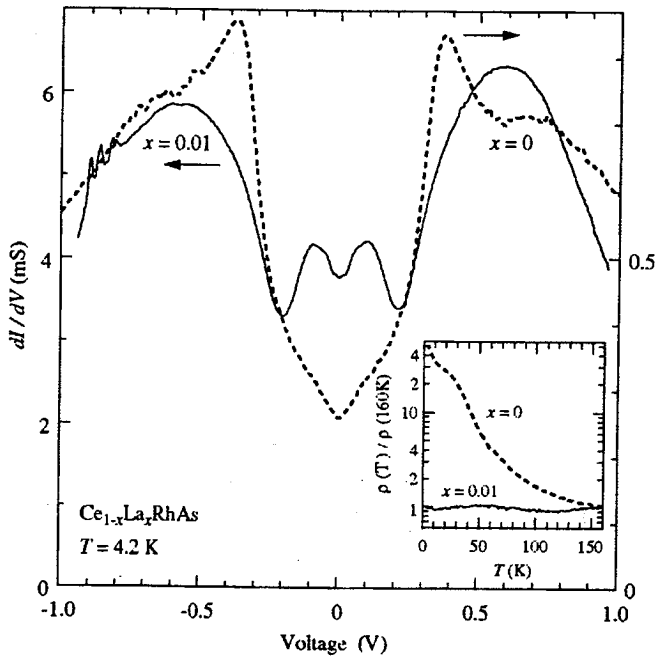

Fig. 1. Tunneling conductance of $Ce_{1-x}La_xRhAs$ at 4.2 K. Inset shows the temperature, T, dependence of ρ normalized by ρ(160 K).

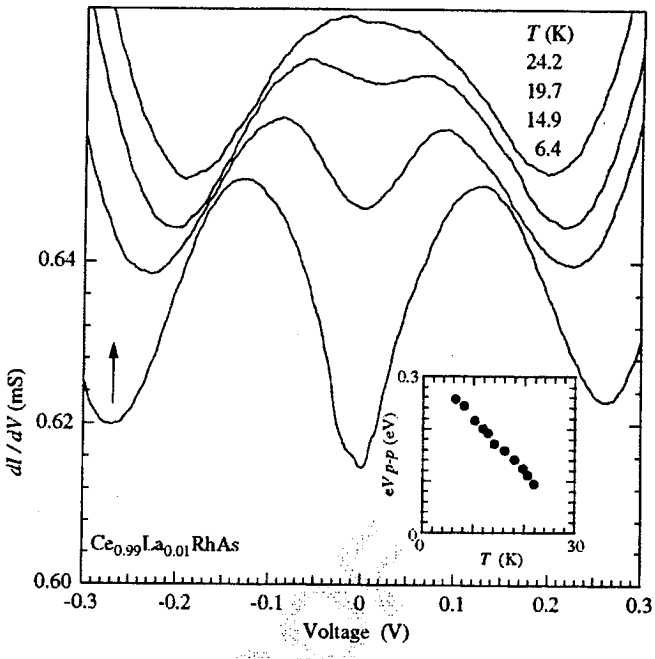

Fig. 2. Temperature variations of the tunneling conductance for $Ce_{0.99}La_{0.01}RhAs$. The values for different T are shifted up for the clarity. Inset shows eV_{p-p} versus T.

onductance for $x = 0.01$ as compared with that for $x \neq 0$ learly correlates with the behavior of ρ(T). Namely, ρ falls ubstantially at low T, and the apparent semiconducting ehavior disappears for $x = 0.01$ as shown in the inset of ig. 1. This is also in line with the growth in the effective harge carrier concentration with x as confirmed by the Iall coefficient measurements [3]. These results strongly uggest that the reduction in ρ for $x = 0.01$ is not due to the ollapse of the huge gap Δ, but due to the *mid-gap* states round the Fermi energy. A similar correlation between unneling and transport data was observed in the defect-ontrolled CaB_6 [6].

We next focus on the dip structure at zero bias for = 0.01. This structure possesses gap- like peaks at :0.15 V, which are well reproduced among the junctions. ig. 2 shows the temperature variations of the dip structure or $x = 0.01$ obtained for the junction different from that f Fig. 1. Only the region inside the gap Δ is shown in Fig. to trace the detailed T evolution of dI/dV around $V = 0$. /ith increasing T, the dip structure is gradually filled, and ie *peak-to-peak* separation eV_{p-p}, being 0.3 eV at 4.2 K, ecreases almost linearly with T, as shown in the inset. bove ~25–30 K, these structures merge into the back-ound conductance, showing a broad zero-bias hump ithin ±0.2 V. The observed behavior may be most probably explained by a "soft" Coulomb gap formation in the random environment actual only for a small group of charge carriers, while other carriers donated by La are itinerant [7]. No conspicuous change in ρ is detected in the relevant range of ~25–30 K, but there is a weak structure at around 30–50 K. Perhaps, a substantial influence of the electronic states buildup near the Fermi energy caused by the La substitution obscures this delicate T dependence. More precise transport measurements below ~50 K are needed to clarify the correlation between dI/dV around zero bias and the bulk electronic properties.

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