Pressure effect on the transport properties in heavy-fermion semimetal $CeRu_4Sb_{12}$

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Abstract

We have investigated the effect of pressure on the transport properties in the heavy-fermion semimetal $CeRu_4Sb_{12}$. A characteristic temperature T_m, below which the electrical resistivity $\rho(T)$ shows a steep decrease, is found to increase with hydrostatic pressure (P_h). Non-Fermi-liquid (NFL) behavior in ρ is suppressed with an extension of Fermi-liquid regime under P_h even in absence of a magnetic field. Under the uniaxial pressure, considerable change of NFL behavior is observed in presence of magnetic fields.

Key words: heavy-fermion semimetal; filled skutterudite $CeRu_4Sb_{12}$; Non-Fermi-Liquid; pressure effect.

The filled-skutterudite compounds ($RETr_4Pn_{12}$: RE= rare earth, Tr= Fe, Ru, Os, and Pn=pnictogen) have attracted much attention for their novel physical properties. $CeRu_4Sb_{12}$ exhibits metallic conductivity in contrast with other Ce-skutterudites which show semiconducting behaviors [1–3]. Our studies on the transport, Shubnikov-de Haas (SdH) [3], and the de Haas-van Alphen (dHvA) [3,4] experiments have revealed small semi-metallic Fermi surface (FS) at low temperatures with highly enhanced effective mass. NFL behavior has been reported in the electrical resistivity (ρ), though no clear explanation has been made [1,2]. Takeda *et al.* [1] suggested that the ferromagnetic fluctuation near the quantum critical point (QCP) associated with the coherency of Ce sublattice plays an important role in the NFL behavior based on the La-substitution study. However, the pressure experiment, which has a merit over the substitution experiment that may introduce complications due to random lattice distortion, is more suitable for studying the quantum critical phenomena. In order to understand the NFL and exotic behaviors, we have investigated the effect of pressure on the transport properties including the direct observation of FS through the SdH effect.

Single crystals of $CeRu_4Sb_{12}$ were grown by Sb-self-flux method [5]. A single crystal of basically the same quality with that used in Refs. [3,4] was used for the present experiment. Electrical resistivity was measured by the standard dc four-probe method. The hydrostatic pressure was produced by using a piston cylinder type CuBe pressure cell. The uniaxial pressure was generated by using a piston cylinder type CuBe pressure cell, newly designed and constructed [6]. The pressure was determined at low temperatures by measuring the superconducting transition temperature of Sn.

Figure 1 shows the temperature (0.5-290 K) dependence of resistivity (ρ) under several hydrostatic pressures (P_h). At ambient pressure (P_h =0), ρ decreases very slowly down to $T_m \sim 75$ K, below which it shows a steep decrease signaling the onset of coherent Kondo scattering. ρ tends to saturate around 10 K below which it shows NFL behavior, i.e, a deviation from $\rho \propto T^2$ [see fig. 1(b)] in close agreement with Refs. [1–3]. With increaseing P_h, T_m shifts to higher temperatures

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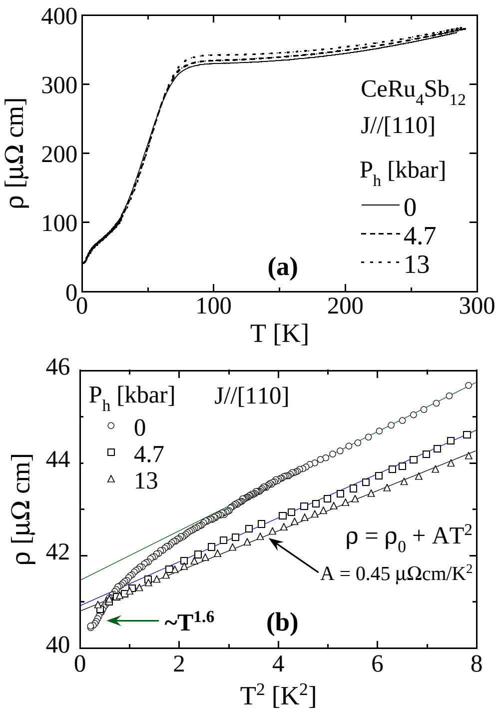

Fig. 1. (a) Temperature (T) dependence of electrical resistivity (ρ) in $CeRu_4Sb_{12}$ under several hydrostatic pressures. (b) ρ at the low temperature region is ploted as a function of T^2.

in contrast to the shift to lower temperatures by La substitutions reported in Ref. [1]. These responses of T_m are similar to those in the Kondo system $CePd_3$ [7], indicating an enhancement of spin fluctuation energy with P_h in $CeRu_4Sb_{12}$. At low temperatures, NFL behavior tends to disappear with increasing P_h with an extension of the Fermi-Liquid (FL), i.e., $\rho \propto T^2$ regime to lower temperatures, as indicated by the deviation from the linear lines drawn for guides to the eyes [see Fig. 1(b)]. At 13 kbar, $\rho \propto T^2$ behavior is extended down to the lowest temperature of the present experiment 0.5 K; ρ can be fitted as $\rho = \rho_0 + AT^2$ with $A = 0.45\mu\Omega\text{cm}\text{K}^2$. These facts indicate a pressure induced enhancement of hybridization, leading the system away from the QCP.

We have also investigated the effect of uniaxial pressure (P_u) on the NFL behavior. The effect of small P_u ($\sim$ 0.6 kbar), applied perpendicular to the current, on ρ is found to be not so large in zero field. However, under a magnetic field there is a considerable effect of P_u on the transverse magnetoresistance (MR) as shown in Fig. 2. In ordinary metals at this temperature a positive MR from cyclotron motion of electrons should dominate over negative MR from field induced suppression of magnetic fluctuations. However, MR at ambient pressure below 4T is anomalous; it is nega-

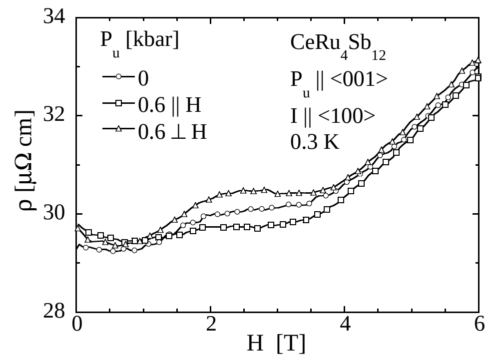

Fig. 2. Magnetic field dependence of transverse magnetoresistance ($I \perp H$) in $CeRu_4Sb_{12}$ at ambient and uniaxial pressure.

tive at the low field region and then it shows a faint peak near 2T, which might be correlated with the magnetic instability related with the NFL behavior. The FL behavior recovers from NFL across the field range 2-4T, i.e, temperature dependence of ρ changes from $\sim T^{1.6}$ at $H = 0$ to T^2 at 2T [1]. Above 6T, Shubnikov de-Hass (SdH) oscillation is observed [3,8] which is another evidence of the FL state at higher fields. Under P_u, the faint peak near 2T tends to be suppressed for H applied parallel to P_u ($P_u \parallel H$), while, in contrast, the peak tends to be enhanced when H is applied perpendicular to P_u ($P_u \perp H$). The origin of this anisotropic response is not clear yet. However, it should be noted that, as we inferred from the change of the frequencies of the SdH oscillations under $P_u \parallel H$ and $P_u \perp H$, the Fermi surface (FS) is elongated along the uniaxial pressure direction [8]. This change of FS topology may be related with the anisotropic change of NFL like anomaly.

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