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Journal of Alloys and Compounds 408–412 (2006) 241–243

Journal of ALLOYS AND COMPOUNDS

www.elsevier.com/locate/jallcom

Pressure induced Kondo coherence effect in $Ce_2Pd_3Si_5$

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Available online 1 June 2005

Abstract

$Ce_2Pd_3Si_5$ is a new Kondo lattice compound that shows antiferromagnetic ordering at 8.4 K. We have performed the resistances measurement of $Ce_2Pd_3Si_5$ under pressure up to 8 GPa in the interval 2.5–300 K. The hydrostatic pressure was generated by employing a cubic anvil cell. The quantum critical point (QCP) exists around 6 GPa for this system, but the superconductivity is not observed. However, the result reveals the Kondo temperature increases after vanishing the magnetic ordering at around QCP due to the Kondo coherence effect under pressure.

PACS: 75.30.Mb; 75.20Hr; 75.50.Er; 71.27.+a

Keywords: Magnetic ordering; Kondo effects; High pressure; QCP

1. Introduction

It is well known that the phase diagrams of strong correlation system of RM_2N_2 or RMN_5 (R: rare earth; M: Co and Pd; N: Si or Ge) under pressure, exhibit a very interesting behaviour [1]. This is due to the fact that the external pressure could directly change the exchange-coupling strength J, which depends on the lattice parameters of the system. Usually, the J dependence of the ordering temperatures gives the ground states information like whether Rudermann–Kittel–Kasuya–Yoshida (RKKY) or Kondo effects are dominant in the system [2]. The compound $CePd_2Si_2$ [3,4] is a typical example which orders antiferromagnetically below $T_N = 10$ K under ambient pressure and becomes superconductor around QCP near 2.8 GPa. In this regard, it is worthwhile to note that the compound $Ce_2Pd_3Si_5$ crystallizing in the orthorhombic $U_2Co_3Si_5$-type structure with the lattice parameters $a = 9.953$ Å, $b = 11.810$ Å and $c = 5.976$ Å [5]. Actually, this crystal structure is unique like that of the $CePd_2Si_2$ unit cell sandwitched by Pd–Si layers [6]. As we mentioned above, the $CePd_2Si_2$ is an interesting compound that shows non-Fermi liquid behaviour at low temperature and shows superconductivity under pressure. Therefore, it is tempting to make clear how these anomalous things will be in the cases that blocs of Ce–Pd–Si slabs related to the $CePd_2Si_2$ [5,7] seperated, and closer again by using the external pressure. In this study, we have carried out the electrical resistances measurement of $Ce_2Pd_3Si_5$ under pressure up to 8 GPa in the temperature interval 2.5–300 K.

2. Experiment

The polycrystalline sample prepared by arc melting method [5] was used in the present study. The electrical resistivity ρ measurements up to 8 GPa in the temperature interval 2.5–300 K were carried out employing a cubic anvil pressure cell and the dimension of the specimen was 0.5 mm × 0.6 mm × 0.8 mm. Nearly hydrostatic pressure was produced in the teflon cell filled with a fluid pressure-transmitting medium of 1:1 mixture of Fluorinert FC70 and FC77. Four-probe method was used for the electrical resistivity measurements and the electrical contacts with the specimen were made with 20 μmϕ gold wire using a conducting silver paste.

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0925-8388/$ – see front matter
doi:10.1016/j.jallcom.2005.04.029

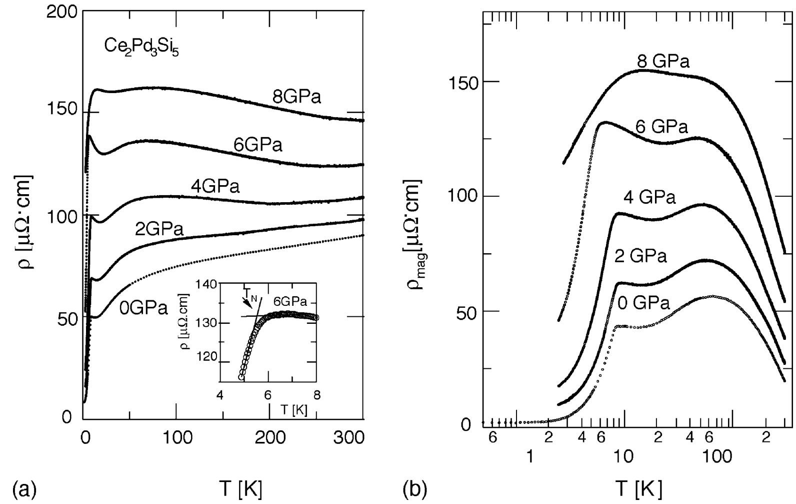

Fig. 1. (a) Temperature dependence of the resistivity of $Ce_2Pd_3Si_5$ under pressure using the cubic anvil cell method. At low temperatures, the resistivity plot shows a shoulder in the vicinity of the antiferromagnetic transition. The way of determining T_N is shown in the inset for one pressure. (b) Temperature dependence of the magnetic contribution to the resistivity of $Ce_2Pd_3Si_5$.

3. Results

In Fig. 1(a) we have shown the ρ data as a function of T under ambient pressure conditions. We have measured ρ for the La compound as well to enable us to obtain the 4f contribution ρ_{mag}. It is clear from Fig. 1(b), that $\rho_{mag}(T) = \rho_{Ce}(T) - \rho_{La}(T)$ exhibits a double-peaked structure arising from an interplay between the Kondo and crystal-field effects [8]. The ratio of the high and low temperature slopes in the plot of $\rho_{mag}(T)$ in the ranges 9–20 and 200–300 K, respectively, is close to the value 0.029 expected for the doublet ground state. There is a sharp fall in ρ at 8.2 K as the T is lowered, which has been established as the onset of antiferromagnetic ordering [6,7]. As the pressure is increased, we note that the overall features are qualitatively the same up to 6 GPa. However, the absolute value of ρ increases with increasing pressure. This behaviour is not expected for a Ce-based Kondo system [5]. The phase diagram of magnetic ordering under pressure is shown in Fig. 2(a). The curve shown in Fig. 2(a) clearly establishes that this compound is placed at the peak of Doniach's magnetic phase diagram, but definitely not at the right side of the peak [2]. The resistivity results of pressure to 8 GPa shows a peak at about 20 K. We believe that such an upward shift of this peak cannot arise from magnetic ordering judged by the pressure dependence of T_N at lower pressures. The estimated Kondo temperatures at 1 bar, by using the double peak temperature, are about 7.6 K [9]. However, it is difficult to distinguish the Kondo and antiferromagnetic ordering tem-

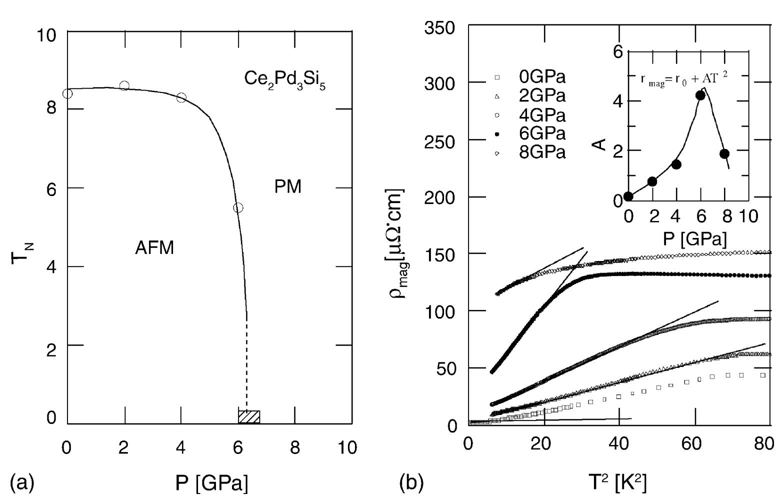

Fig. 2. (a) Pressure dependence of T_N inferred from resistivity data. A line is drawn through the points. PM and AFM refer to 'paramagnetic' and 'antiferromagnetic', respectively. (b) The expanded form of resistivity for low temperature region. The straight line is the T-square fitting results as $\rho = \rho_0 + AT^2$. The pressure dependence of T-square coefficients of A is shown in the insert up to 8 GPa.

peratures at 1 bar. But, note that the low temperature slopes in the plot of $\rho_{mag}(T)$ in the range below antiferromagnetic ordering temperatures are increasing with pressure up to 6 GPa and then decrease sharply. This is considered to be due to the Kondo temperature increasing with pressure. Therefore, we attribute this 20 K-peak at 8 GPa to the onset of coherent scattering among Kondo centers. It would be worthwhile to perform magnetization studies under pressure to confirm this. In any case, the trend in T_N, shown in Fig. 2(a), reveals that the pressure required (6–8 GPa) to bring the present compound to QCP is much larger than that for $CePd_2Si_2$ (2.8 GPa) [4]. Fig. 2(b) shows the T-square fitting results of resistivity as $\rho = \rho_0 + AT^2$. The pressure dependence of A coefficient is shown in insert of Fig. 2(b). It is clear that A coefficient reveals a peak around 6 GPa at the considered QCP of $Ce_2Pd_3Si_5$ in this study. But, the superconductivity that should appear at around the QCP has not been observed at present experiment. However, it would be an expected investigation for superconducting transitions if it is capable of decreasing the temperature below 2.4 K at around QCP for $Ce_2Pd_3Si_5$. Finally, we mention that the ratio of the resistivity slopes under pressure still falls in the range expected for the doublet ground state (that is, around 0.1) [8].

4. Conclusion

To conclude, features attributable to a transformation from antiferromagnetism to Kondo lattice behaviour could be observed in the pressure dependent ρ data of $Ce_2Pd_3Si_5$. The present results establish that the compound $Ce_2Pd_3Si_5$ lies at the peak of Doniach's magnetic phase diagram. The QCP has been expected to occur near 6 GPa from the phase diagram or A coefficients under pressure. It is worthwhile to extend the measurements to mK range to look for superconductivity at QCP as in the case of $CePd_2Si_2$ [4].

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