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Electrical resistivity and effect of pressure on the thermal expansion of a single crystal of YbCu_2Si_2

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Electrical resistivity $\rho(T)$ and thermal expansion $\Delta l/l$ were measured for the intermediate valence compound (IVC) YbCu_2Si_2 and its counterpart LuCu_2Si_2 between 4.2 K and 300 K. It was found that the thermal expansion coefficient $\alpha(T)$ has a negative minimum around 31 K ($=T_{\min}$) at atmospheric pressure and $T_{\min}$ decreases with increasing pressure at the rate $\partial T_{\min}/\partial T = -0.45 \text{ K/kbar}$.

1. Introduction

Ytterbium (Yb) intermetallic compounds show a wide variety of interesting physical properties such as heavy fermion behavior, intermediate valence, etc. [1]. Yb compounds are considered to be hole analogues to heavy fermion Ce compounds, because the valence of Yb^{3+} has a hole relative to the fully occupied 4f shell Yb^{2+} . YbCu_2Si_2 crystallizes in the tetragonal body-centered ThCr_2Si_2 -type structure [2] and is characterized as an intermediate valence compound reflecting the strong hybridization between the 4f localized electrons and the conduction band electrons [3]. YbCu_2Si_2 is shown to be a nonmagnetic compound down to 0.05 K [4] with a large γ -value of 210 mJ/mol K² [5]. It is well known that the hybridization is very sensitive to external forces such as pressure, temperature and magnetic field. It is worthwhile to investigate the physical properties of YbCu_2Si_2 at high pressure because considerable change in the electronic structure is expected.

In this paper, we report the measurement of the electrical resistivity $\rho(T)$ and thermal expansion $\Delta l/l(T)$ of a single crystal of YbCu_2Si_2 up to 20 kbar in order to study the effect of pressure on the electronic state of Yb compounds.

2. Experimental

Details of the sample preparation and characterization were reported previously [5]. The electrical resistivity was measured by the standard four-probe method in the temperature range from 4.2 to 300 K at atmospheric pressure. The thermal expansion was measured by means of the standard strain gauge method (Kyowa Dengyo, KFL02-C1-11, gauge factor 2.03) in the temperature range from 4.2 to 300 K under high pressure up to 20 kbar. The sample was placed in a Cu–Be cylinder vessel (8 mm plain diameter) and loaded by a 20 ton hydraulic press using a W–C piston. A 1:1 mixture of Fluorinert, FC70 and FC77, was used as a pressure transmitting medium. The pressure inside the cylinder was kept constant throughout the experiment by controlling the oil pressure of the hydraulic press. Temperature was measured with a calibrated Cu(Fe)–Chromel thermocouple. Details of the high-pressure apparatus were reported previously [6].

3. Results and discussion

3.1. Electrical resistivity ρ of single crystals of YbCu_2Si_2 and LuCu_2Si_2

Figure 1 shows the temperature dependence of the electrical resistivity $\rho(T)$ of YbCu_2Si_2 and LuCu_2Si_2 in the current along the *a*-axis. Here $\rho(T)$ of YbCu_2Si_2 increases with increasing temperature up to around

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Fig. 1. Temperature dependence of the electrical resistivity of YbCu_2Si_2 and LuCu_2Si_2 single crystals. ρ_{mag} is also shown as a function of temperature.

100 K and becomes nearly constant above 150 K. No maximum is observed in $\rho(T)$. This result is in good agreement with recent studies by Müller et al. [7]. The $\rho(T)$ of LuCu_2Si_2 was measured to estimate the phonon contribution in the $\rho(T)$ of YbCu_2Si_2 , because the 4f shell of nonmagnetic Lu has 14 electrons. The $\rho(T)$ of LuCu_2Si_2 shows a smooth variation against temperature, which is the same as that of normal metal. The magnetic contribution to $\rho(T)$, $\rho_{\text{mag}}(T)$, is defined as $\rho_{\text{mag}}(T) = \rho(\text{YbCu}_2\text{Si}_2) - \rho(\text{LuCu}_2\text{Si}_2)$. This $\rho_{\text{mag}}(T)$ exhibits a broad maximum at $T = 112$ K and $\ln T$ dependence above 200 K, which is characteristic behavior due to Kondo scattering of conduction electrons as observed in many Ce compounds [8]. There is no T^2 -dependence in the $\rho_{\text{mag}}(T)$ at low temperature. This suggests that YbCu_2Si_2 does not behave as a Fermi liquid in the temperature range of the present work ($T > 4.2$ K).

3.2. Effect of pressure on the thermal expansion coefficients of YbCu_2Si_2

The thermal expansion of YbCu_2Si_2 is shown in fig. 2 as a function of temperature at various pressures. Linear thermal expansion $\Delta l/l(T)$ at atmospheric pressure is found to decrease with increasing temperature up to around 50 K and then begins to increase above 70 K after showing a minimum at 60 K ($= T_{\text{min}}$). This anomalous temperature dependence of $\Delta l/l(T)$ may originate from instability in the valence of Yb at low temperature such as IVC YbCuAl [3,9]. The minimum value of $\Delta l/l(T)$ at T_{min} decreases with increasing pressure.

In order to obtain the linear thermal expansion coefficient, $\alpha(T) = (1/l)(\partial l/\partial T)$, the $\Delta l/l(T)$ curve was differentiated by temperature. The thermal ex-

Fig. 2. Temperature dependence of the linear thermal expansion $\Delta l/l$ in YbCu_2Si_2 single crystal at various pressures.

pansion coefficient $\alpha(T)$ of YbCu_2Si_2 is shown in fig. 3 at various pressures up to 20 kbar. The value of $\alpha(T)$ at atmospheric pressure is found to be negative below 60 K with a minimum around 31 K due to Yb valence instability. The negative value of $\alpha(T)$ at low temperature was also observed in YbCuAl [3] at atmospheric pressure. The minimum centered 31 K with the value of $-3.7 \times 10^{-6} \text{ K}^{-1}$ shifts to 24 K at 20 kbar with $-1.6 \times 10^{-6} \text{ K}^{-1}$. It should be noted that the pressure derivative of T_{min} has a negative sign, which is opposite to that of Ce compounds [10].

Figure 4 shows T_{min} of YbCu_2Si_2 as a function of pressure. T_{min} decreases with increasing pressure in an

Fig. 3. Thermal expansion coefficients of YbCu_2Si_2 defined as $\alpha = (1/l)(\partial l/\partial T)$.

Fig. 4. Pressure dependence of $T_{\min}$.

approximately linear fashion at a rate $\partial T_{\min}/\partial P = -0.45 \text{ K/kbar}$. $T_{\min}$ may be related to the Kondo temperature T_K [11]. By assuming that $T_{\min}$ is approximately proportional to T_K , the value of the pressure derivative of T_K is estimated to be $(1/T_K)\partial T_K/\partial P = (1/T_{\min})\partial T_{\min}/\partial P = -1.45 \times 10^{-2} \text{ kbar}^{-1}$. The absolute value of $(1/T_K)(\partial T_K/\partial P)$ is of the same order magnitude as that of the intermediate valence compound CePd_3 [12]. The negative pressure derivative of $T_{\min}$ or T_K of YbCu_2Si_2 , which is in sharp contrast with the case of Ce compounds, may be one of the distinctive characteristics of Yb compounds.

The pressure dependence of $\Delta l/l$ along the a -axis of YbCu_2Si_2 is shown in fig. 5 up to 10 kbar at room temperature. The a -axis decreases linearly with increasing pressure. The linear compressibility along the a -axis is $\kappa_a = 4.18 \times 10^{-4} \text{ kbar}^{-1}$, which is the same order of magnitude as those of Ce compounds [12]. The Grüneisen parameter Γ_a for the a -axis may be

Fig. 5. The relative change $\Delta l/l$ in the a -axis of YbCu_2Si_2 as a function of pressure at room temperature.

defined as $\Gamma_a = -\partial(\ln T_{\min})/\partial(\ln V) = (1/\kappa_a)(1/T_{\min}) \times (\partial T_{\min}/\partial P)$ [13]. Γ_a is estimated as -35 , which is the same as that of YbCuAl , $\Gamma = -35$ [3], and comparable to $\Gamma_p = -29$ estimated [5] from the low temperature T^2 -coefficient of resistivity of YbCu_2Si_2 .

4. Conclusions

Thermal expansion coefficient $\alpha(T)$ of YbCu_2Si_2 has a negative minimum around 31 K ($=T_{\min}$) at atmospheric pressure and $T_{\min}$ decreases with increasing pressure with the rate $\partial T_{\min}/\partial P = -0.45 \text{ K/kbar}$. The Grüneisen parameter Γ_a is estimated to be -35 . The negative pressure dependence of T_K and the Grüneisen parameter Γ_a of YbCu_2Si_2 may be some of the distinctive characteristics of Yb compounds.

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References

- [1] W.C.M. Mattens, H. Hoisher, G.J.M. Tuin, A.C. Moleman and F.R. de Boer, *J. Magn. Magn. Mater.* 15–18 (1980) 982.
- [2] W. Rieger and E. Parthe, *Monatsh. Chem.* 100 (1969) 444.
- [3] R. Pott, R. Schefzyk, D. Wohlleben and A. Junod, *Z. Phys. B* 44 (1981) 17.
- [4] P. Bonville and J.A. Hodges, *J. Magn. Magn. Mater.* 47&48 (1985) 152.
- [5] J.D. Thompson, H.A. Borges, Z. Fisk, S. Horn, R.D. Park and G.L. Wells, in: *Theoretical and Experimental Aspects of Valence Fluctuations and Heavy Fermions*, eds. L.C. Gupta and S.K. Malik (Plenum Press, New York, 1987) p.151.
- [6] Y. Uwatoko and G. Oomi, *J. High Press. Inst. Jpn.* 29 (1991) 318 (in Japanese).
- [7] D. Müller, S. Hunssain, E. Cattaneo, H. Schneider, W. Schlätz and D. Wohlleben, *Valence Instabilities*, eds. P. Wachter and H. Boppert (North-Holland, Amsterdam, 1986) p.463.
- [8] N.B. Brandt and V.V. Moshchalkov, *Adv. Phys.* 33 (1984) 373.
- [9] B.C. Sales and O.K. Wohlleben, *Phys. Rev. Lett.* 35 (1975) 1240.
- [10] Y. Uwatoko, H. Okita, G. Oomi, I. Umehara and Y. Ōnuki, *J. Alloys Compounds* 181 (1992) 293.
- [11] T. Kagayama and G. Oomi, *Physica B* 186–188 (1993) 624.
- [12] G. Oomi, Y. Ōnuki and T. Komatsubara, *Physica B* 163 (1990) 405.
- [13] T.H.K. Barron, J.G. Collins and G.K. White, *Adv. Phys.* 29 (1980) 609.