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PRESSURE EFFECT ON THE MAGNETISM AND SUPERCONDUCTIVITY IN SINGLE CRYSTAL $CeCu_2(Si_{0.9}Ge_{0.1})_2$*

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The existence of long range magnetic order and superconductivity in single crystals of $CeCu_2(Si_{0.9}Ge_{0.1})_2$ is investigated by measuring the electrical resistivity under pressure. At ambient pressure, antiferromagnetic order coexists with superconductivity. Upon applying pressure, the magnetic order vanishes continuously. Interestingly, we observe two superconducting domains in the T–P phase diagram, where superconductivity is lost inbetween. In the first domain ($0\leq p < 3$ GPa), T_c initially increases with pressure, reaching a maximum value of $T_c^{max_1} \approx 0.39$ K at $p \approx p_{c1}$. Above p_{c1}, T_c decreases with increasing pressure. In the second domain, the maximum T_c ($T_c^{max_2} \approx 0.96$ K at $p_{c2} \approx 5.4$ GPa) is much higher than that in the first domain. Non-Fermi-liquid behavior with resistivity exponent $1\leq n \leq 1.5$ ($\rho = \rho_0 + AT^n$) is observed at pressures $p_{c1}\leq p\leq p_{c2}$.

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1. Introduction

Since the discovery of pressure-induced superconductivity (SC) in the heavy fermion (HF) antiferromagnets (AFM) $CeCu_2Ge_2$ [1], $CePd_2Si_2$ [2] and $CeIn_3$ [2], which occurred in the vicinity of their respective magnetic quantum critical points (QCP: $T_N \to 0$), it is debated whether or not the closeness of the compounds to such a QCP is a prerequisite for SC in these HF compounds [2]. The prototype HF superconductor $CeCu_2Si_2$ is located at the verge of magnetism at ambient pressure [3]. Upon applying hydrostatic pressure, $CeCu_2Si_2$ shows a coherent and broad superconducting region in the temperature-pressure(T–P) phase diagram, starting with a plateau-like region of $T_c \approx 0.65$ K below 2 GPa, which is then followed by a steep increase of T_c ($T_c^{max} \approx 2.3$ K at $p \approx 3$ GPa) upon further increasing

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pressure [4]. A very similar T–P phase diagram was found for the isoelectronic compound $CeCu_2Ge_2$ [1]. The validity of the QCP scenario as an origin for SC is challenged by the observation that SC in these two compounds exists coherently over a much wider range in pressure than found for $CeIn_3$ [2] and for the majority of the samples of $CePd_2Si_2$ [2, 5], *i.e.*, at a much larger distance from the QCP. In this paper, we present a pressure study on the single crystal $CeCu_2(Si_{0.9}Ge_{0.1})_2$, in which the volume effect and disorder effect are important.

2. Experimental

Single crystals of $CeCu_2(Si_{0.9}Ge_{0.1})_2$ have been grown by a Cu-flux method. The resulting ingot was annealed at 800°C for 5 days. It was confirmed that SC and AFM coexist in $CeCu_2(Si_{0.9}Ge_{0.1})_2$ at ambient pressure [6]. The pressure dependence of T_N and T_c has been determined by measuring the electrical resistivity with a low power AC four-terminal method. Two different samples (#1 and #2), cut from the same batch, have been investigated due to the two different methods used to generate pressure. A piston-cylinder cell filled with a 1:1 mixture of iso-pentane and n-pentane providing hydrostatic pressure conditions was employed for $p < 3$ GPa. The pressure was determined to $\triangle p = \pm 0.05$ GPa from the $T_c(p)$ of tin. For $p > 3$ GPa, a Bridgman-type cell was used with steatite as pressure transmitting medium. Absolute values for the resistivity are obtained by scaling the sample resistance to the corresponding value measured at ambient conditions [6].

3. Results and discussion

The temperature dependence of the electrical resistivity at different pressures is presented in Fig. 1(a) for sample #1 ($p < 3$ GPa) and in Fig.1(b) for sample #2 ($p > 3$ GPa). The derivative of the resistivity with respect to temperature at pressures of $p = 0.3$ GPa and 0.5 GPa is shown in the inset of Fig. 1(a). For $p < 1$ GPa, magnetic order (at T_N and $T1$ as shown in the inset) coexists with superconductivity. Neutron scattering results at ambient pressure indicate an antiferromagnetic order below T_N and a probable reorientation of the magnetic moments at $T1$ [6]. Both T_N and $T1$ are suppressed upon applying pressure. However, T_c first increases with pressure and then decreases upon further increasing pressure above $p \approx 1$ GPa (Fig. 1 (a)). At $p \approx 2.8$ GPa, no superconductivity is observed down to $T = 50$ mK. Interestingly, superconductivity recovers at higher pressures above 3 GPa (see Fig. 1(b)). Moreover, the residual resistivity ρ_0 strongly depends on pressure above 3 GPa, and the resistivity exhibits a linear temperature dependence at $p \approx 5.4$ GPa where T_c reaches a maximum value of $T_c = 0.96$ K.

The pressure dependence of T_N ($T1$) and T_c in $CeCu_2(Si_{0.9}Ge_{0.1})_2$ is summarized in a T–P phase diagram (Fig. 2). Both T_N and $T1$ vanish

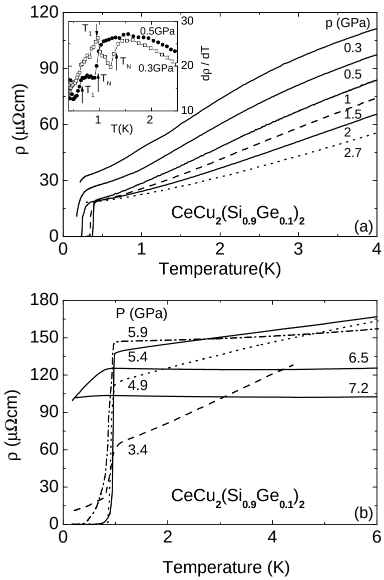

Fig. 1. Resistivity ρ *vs.*T at various pressures. (a) Sample #1 ($p < 3$ GPa). Inset: $d\rho/dT$ *vs.* T for $p = 0.3$ GPa (□) and $p = 0.5$ GPa (•). (b) Sample #2 ($p > 3$ GPa).

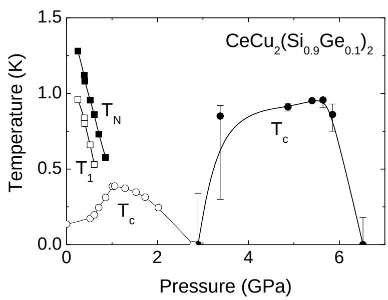

Fig. 2. The T–P phase diagram of $CeCu_2(Si_{0.9}Ge_{0.1})_2$.

in continuous way upon approaching the QCP. T_c is determined at 50% of the drop of $\rho(T)$. The error bar at high pressures reflects the determination of T_c at 20% and 80% drop of $\rho(T)$. In comparison to $CeCu_2Si_2$ (or $CeCu_2Ge_2$) [1, 4], the wide superconducting region obtained in the pure compounds breaks up into two narrow superconduting regimes in case of $CeCu_2(Si_{0.9}Ge_{0.1})_2$. In the low pressure regime ($p < 3$ GPa), T_c reaches a maximum value of $T_c^{\max_1} \approx 0.39$ K just around the magnetic quantum critical point ($p_{c1} \approx 1$ GPa). In the high pressure regime, the maximum T_c ($T_c^{\max_2} \approx 0.96$ K at $p_{c2} \approx 5.4$ GPa) is much higher than in the first regime. This increase may have the same origin as the steep increase of T_c in $CeCu_2Si_2$ [4] and $CeCu_2Ge_2$ [1]. However, both $T_c^{\max_1}$ and $T_c^{\max_2}$ are significantly lower than in pure $CeCu_2Si_2$. We also measured the resistivity of single crystals of $CeCu_2(Si_{1-x}Ge_x)_2$ (x=0.01, 0.05, 0.25) under hydrostatic pressure up to 3.6 GPa which data will be published elsewhere [7]. At larger Ge-substitution ($x = 0.25$), no SC is observed down to $T = 50$ mK even close to the QCP at $p_c \approx 2.2$ GPa. For small Ge-substitution ($x = 0.01$), we could not observe two separate superconducting regions but a minimum at $T_c(p)$ ($T_c^{min} \approx 0.12$ K) around $p = 3$ GPa. This indicates that disorder as introduced by Ge substitution governs the occurrence of SC. Analyzing our resistivity data by fitting $\rho = \rho_0 + AT^n$, we find non-Fermi-liquid (NFL) behavior ($1 \leq n \leq 1.5$) in the pressure range $p_{c_1} \leq p \leq p_{c_2}$ [7]. In particular, a linear temperature dependence of $\rho(T)$ is observed around p_{c_2}. The residual resistivity as extrapolated from $T \geq T_c$ shows a minimum at p_{c1} and a maximum at p_{c2}. Since NFL-behavior is found also in the second regime, the question arises if there exists another QCP whose signature we might have overlooked so far. With regard to this, we like to mention the observation of an additional maximum in $\rho(T)$ just above T_c for $p > p_{c2}$, which is suppressed by applying a magnetic field ($B = 8T$ for $p = 7.5$ GPa) [7].

4. Conclusion

We have investigated the pressure dependence of superconductivity and magnetism in a single crystal $CeCu_2(Si_{0.9}Ge_{0.1})_2$. The large continuous SC regime observed in the T–P phase diagram of $CeCu_2Si_2$ breaks up into two domains by substituting Si by Ge. Based on the similarity of the physical properties observed in both superconducting domains (similar effect of impurity scattering on superconducting, NFL behavior for $p_{c_1} \leq p \leq p_{c_2}$, extrema of the residual resistivity at p_{c1} and p_{c2}, and the possibility for an additional QCP at p_{c2}), we propose that SC in the second domain is of a similar unconventional type as in the first one.

REFERENCES

[1] D. Jaccard, K. Behnia, J. Sierro, *Phys. Lett.* **A163**, 475 (1992).

[2] N. D. Mathur, F. M. Grosche, S .R. Julian, I. R. Walker, D. M. Freye, R. K. W. Haselwimmer, G. G. Lonzarich, *Nature*, **394**, 39 (1998).

[3] F. Steglich, B. Buschinger, P. Gegenwart, M. Lohmann, R. Helfrich, C. Langhammer, P. Hellmann, L. Donnevert, S. Thomas, A.Link, C. Geibel, M. Lang, G. Sparn, W. Assmus, *J. Phys.: Condens. Matter*, **8**, 9909 (1996).

[4] F. Thomas, J. Thomasson, C. Geibel, F. Steglich, *Physica B*, **186-188**, 303 (1993).

[5] A. Demuer, D. Jaccard, I. Sheikin, S. Raymond, B. Salce, J. Thomasson, D. Braithwaite, J. Flouquet, *J. Phys.: Condens. Matter*, **13**, 9335 (2001).

[6] M. Deppe *et al.*, to be published.

[7] H. Q. Yuan *et al.*, to be published.