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Intriguing Magnetoresistivity of $URh_{0.62}Ru_{0.38}Ge$ in the Non-Fermi Liquid Regime

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Magnetoresistivity of $URh_{0.62}Ru_{0.38}Ge$ solid solution was measured in the temperature range 0.35–300 K and in magnetic fields up to 9 T. For the studied system, which lies on the border of ferromagnetism, we observe positive magnetoresistivity in the non-Fermi liquid regime. The finding is in striking disagreement with scenario predicted for ferromagnetic quantum critical point.

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1. Introduction

Intermetallic compounds containing $4f$ and $5f$ elements exhibit a variety of exotic phenomena, including heavy fermion, non-Fermi liquid, unconventional superconductivity and so on [1]. This is caused by the fact that f shell in these compounds is unstable and competition between Ruderman–Kittel–Kasuya–Yosida (RKKY) and Kondo interaction may lead to the formation of heavy-mass quasiparticle at low temperatures.

Recently, a lot of attention was devoted to investigation of strongly correlated electron systems, in particular these lying on the border of magnetic instability. In the latter systems, significant deviation from renormalised Landau–Fermi liquid (LFL) behaviour is often observed when systems approaches to 0 K. These strongly correlated electron metals are so-called non-Fermi liquids (NFL). Characteristic features of the NFL, among other things, are a logarithmic divergence of the Sommerfeld ratio and resistivity following power law with an exponent close to 1.

UTM family of compounds, where T and M stand for transition metal and p-type metalloid, exhibits a variety of ground states. Among these compounds URhGe, crystallising in an orthorhombic structure, seems to be very appealing due to the coexistence of ferromagnetic ground state ($T_{\mathrm{C}} = 9.5$ K) and superconductivity ($T_{\mathrm{sc}} = 0.25$ K) under ambient pressure [2]. Ru-doping experiments conducted on $URh_{1-x}Ru_xGe$ system have shown that magnetic order vanishes at $URh_{0.62}Ru_{0.38}Ge$ composition [3, 4]. Non-Fermi liquid behaviour was found in specific heat and resistivity behaviour, and conception of ferromagnetic quantum critical point (FQCP) at this particular composition was proposed [3, 5]. To shed more light on the origin of the non-Fermi liquid state in this system we decided to perform magnetoresistivity measurements in a wide field and temperature range.

2. Experimental

Polycrystalline sample of $URh_{0.62}Ru_{0.38}Ge$ was synthesised from pure elements (> 3N) using arc-melting technique under gettered Ar atmosphere and annealed for 66 h at 850°C in evacuated silica tube. Homogeneity and quality of the sample were examined using X-ray diffraction and energy dispersion X-ray spectroscopy (EDXS) magnetoresistivity on the obtained sample was carried out using Quantum Design PPMS device in the temperature range 0.35–300 K and in magnetic fields up to 9 T. The direction of the field was applied perpendicular to the current (≈ 0.1 mA).

3. Results and analysis

The electrical resistivity of $URh_{0.62}Ru_{0.38}Ge$ collected in 0, 4 and 9 T as a function of temperature is depicted in Fig. 1. The overall shape of $\rho(T,\ 0\ \mathrm{T})$ reminds these observed for heavy fermion compounds, with pronounced coherence maximum at 120 K [6]. At temperatures below 2.5 K, we were able to fit zero field resistivity with the power law formula

$$\rho(T) = \rho_0 + AT^n, \tag{1}$$

which yielded residual resistivity $\rho_0 = 454.3\ \mu\Omega$ cm, $A = 10.4\ \mu\Omega\ \mathrm{cm}/K^n$ and $n = 1.18$. The observed value of n, lower than 2 suggests the presence of non-Fermi liquid behaviour and is in good agreement with the previous results reported in [3]. In the theoretical models for the spin fluctuations and the local magnetic moments scenarios of FQCP Moriya and Millis and Hertz [7] have predicted $n = 5/3$. Therefore, disparity between theoretical predictions and our experimental results suggests that in $URh_{0.62}Ru_{0.38}Ge$ FQCP may not be present or it appears in not "pure" form. According to experimental [8] and theoretical [9] results of investigation of URhGe under high pressures, it is not possible to suppress ferromagnetic ground state with chemical pressures available by exchanging Rh with Ru. The key factor seems to be emptying of $4d$ bands of the transition metal, which enhances hybridisation of $5f$ states with conductivity band, exerting evanescence of magnetic order.

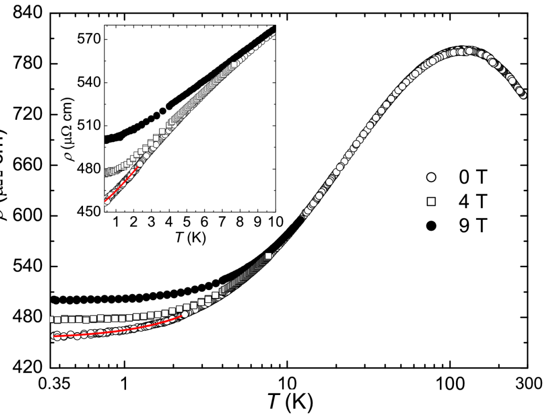

Fig. 1. Resistivity of $URh_{0.62}Ru_{0.38}Ge$ as a function of temperature at 0, 4 and 9 T. Solid line shows the result of fit to Eq. (1). The inset shows low-temperature data.

Effect of applied magnetic field on $URh_{0.62}Ru_{0.38}Ge$ resistivity is very suprising. A split between 0 and 4 and 9 T curves occurs at 12 K and is clearly shown in Fig. 1. Magnetoresistivity defined as

$$\mathrm{MR} = \frac{\rho(B) - \rho(0)}{\rho(0)} 100\% \tag{2}$$

is displayed in Fig. 2. MR is positive in the whole measured temperature range. A large influence of magnetic field on resistivity is found, for instance, at $T = 0.35$ K. MR reaches 9.5% at 9 T. Applying Eq. (1) to the $\rho(B, T)$ gives exponent $n \approx 1.9$ for the data collected at 9 T. This observation indicates LFL recovery. Very interesting and uncommon behaviour is the isothermal MR(B) dependence collected at the lowest temperature measured (see inset of Fig. 2) where MR essentially exhibits a linear function of applied field. Positive and large MR is certainly different from expected negative MR predicted by Moriya and Kawabata for systems with ferromagnetic fluctuations [10]. The latter mechanism is believed to be responsible for a NFL state in this compound [3].

It is worth in this point to mention that MR is a very complex quantity, since consists of a number of different contributions — positive ordinary MR $\sim B^2$ and magnetic component, which may be negative or positive depending on type of occurring magnetic correlations. Usually, external magnetic field enhances antiferromagnetic fluctuations, thus gives a positive rise to MR, whereas fluctuations with ferromagnetic origin should be suppressed by magnetic field, results in negative component of the magnetoresistivity. In the case of $URh_{0.62}Ru_{0.38}Ge$ presence of antiferromagnetic correlations was deduced from the temperature dependence

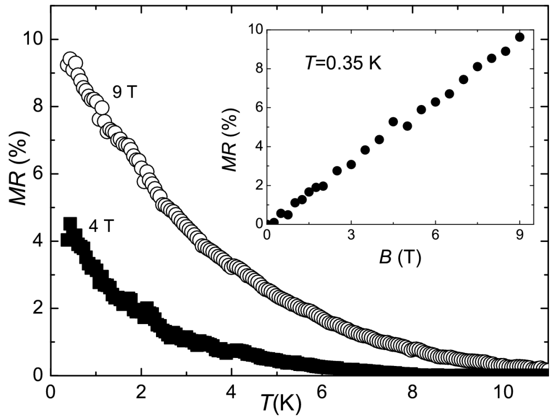

Fig. 2. Magnetoresistivity in function of temperature in 4 and 9 T. The inset shows isothermal magnetoresistivity collected at $T = 0.35$ K.

of χT product [4]. Positive response of resistivity on magnetic field is typical of classic NFL systems such as $CeCu_2Si_2$, $CeNi_2Si_2$ [11] or $U_{0.9}Th_{0.1}Be_{13}$ [12], where applied field is supposed to suppress critical magnetic fluctuations with antiferromagnetic character. However, all these three intermetallics are believed to be close to the antiferromagnetic QCP. Unfortunately, lack of reference systems with "clean" FQCP restricts interpretation of our results. Presence of both types of correlations, antiferro- and ferromagnetic, may be related to large disorder in transition metal sublattice (38% of Rh sites are occupied by Ru). Type of exchange interaction may have local character — depending on the environment of U site. This effect should be strong in combination with large magnetocrystalline anisotropy, often present in uranium compounds. The fact that parent compound URhGe reveals very anisotropic magnetic properties [2] supports this conjecture.

4. Summary

Summarising, we have confirmed non-Fermi liquid character of resistivity in $URh_{0.62}Ru_{0.38}Ge$, reported previously in [3] and [4]. We found positive magnetoresistivity below 12 K in 9 T. The behaviour is in contrary with that expected for the FQCP. The observed MR > 0 is consistent with magnetic susceptibility results, suggesting a presence of antiferromagnetic correlations in this compound. Such coexistence of different types of correlations in this alloy may be related to large disorder in transition metal site — just like it is observed in spin glasses. In order to clarify scenario of a coexisting and/or competing antiferro- with ferromagnetic fluctuations, a more detailed study of magnetoresistivity properties in $URh_{1-x}Ru_xGe$ system is in progress.

Acknowledgments

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