Search for a quantum critical end-point in $CeRu_2(Si_{1-x}Ge_x)_2$

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Abstract

We use high-resolution dilatometry and electrical resistivity down to 20 mK and millitesla magnetic field steps to search for a possible quantum critical (end-) point (QC(E)P) in $CeRu_2(Si_{1-x}Ge_x)_2$ with $x = 0.00$ and 0.02 at the metamagnetic transition (MMT), $B_m = 7.8$ and 6.8 T, respectively. We do not find any evidence for QCEP since (i) the peak height and FWHM of the magnetostrictive anomaly saturate below 0.2 K and (ii) the thermal expansion and the electrical resistivity indicate the formation of a Landau–Fermi liquid (LFL) state below 0.3 K even at $B = B_m$. We speculate that the metamagnetic crossover represents a Fermi surface reconstruction that is fully completed below 0.2 K.

Keywords: $CeRu_2(Si_{1-x}Ge_x)_2$; Heavy fermion; Metamagnetism; Quantum critical end-point

Due to the great interest in itinerant electron metamagnetism and its putative quantum critical (end-) point (QC(E)P), exhibited by a variety of different materials (MnSi [1], URu_2Si_2 [2], $Sr_3Ru_2O_7$ [3]), there has been a "resurrection" of the $CeRu_2Si_2$ [4] system. This prototype 4f heavy-fermion compound, long known to exhibit a metamagnetic transition associated with large changes in both Fermi surface and magnetism at 7.8 T, has been proposed as a direct analogue to the above materials [4]. If valid, the low-temperature properties should display the characteristics of a QCP, i.e., diverging experimental and non-Fermi liquid (NFL) behavior or the formation of novel phases.

In this work we determine, systematically and on an ultrafine field scale, the magnetostriction, thermal expansion and resistivity in a narrow field interval spanning the metamagnetic transition down to 20 mK on $CeRu_2(Si_{x-1}Ge_x)_2$ with $x = 0.00$ and 0.02. The single crystal samples were grown by travelling floating zone for $x = 0.00$ and

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the tri-arc Czochralski method for $x = 0.02$. Residual resistivities (RR) are very similar: 1.6 and 1.8 μΩ cm with RR ratios 43 and 37, respectively. Length changes and resistivity were detected utilizing a high resolution capacitive dilatometer and an AC four-point probe, both adapted to a dilution cryostat reaching 15 mK at fields up to 18 T.

In the magnetostriction coefficient $\lambda = (1/L)\partial\Delta L(T,B)/\partial B$ we observe a sharp anomaly at the metamagnetic transition (MMT) for both concentrations (Fig. 1). This maximum shifts for $x = 0.02$ to 6.8 T and broadens. At lower temperatures the anomalies become sharper. However, below 0.2 K the peak height and the FWHM of the maxima saturate according to a T^2 law (solid and dotted lines in the inset of Fig. 1). This means that there is no observable change of the MMT to a first-order or continuous phase transition with decreasing temperature.

In Fig. 2 the linear thermal expansion coefficient $\alpha = (1/L)\partial\Delta L(T,B)/\partial T$ of the undoped system is shown for magnetic fields very close to the MMT. For temperatures below 0.3 K the coefficient α displays a linear temperature dependence, thus

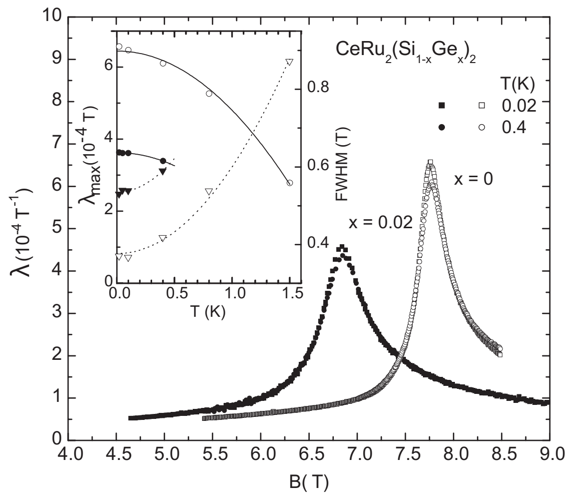

Fig. 1. Coefficient of linear magnetostriction λ along the c-axis of $CeRu_2(Si_{1-x}Ge_x)_2$ for $x = 0$ (open symbols) and $x = 0.02$ (closed symbols) vs. magnetic field $B \| c$ at different temperatures. Inset displays temperature dependence of peak height λ_{max} (circles) and FWHM (triangles). Solid and dotted lines indicate T^2 dependence and the saturation as $T \to 0$.

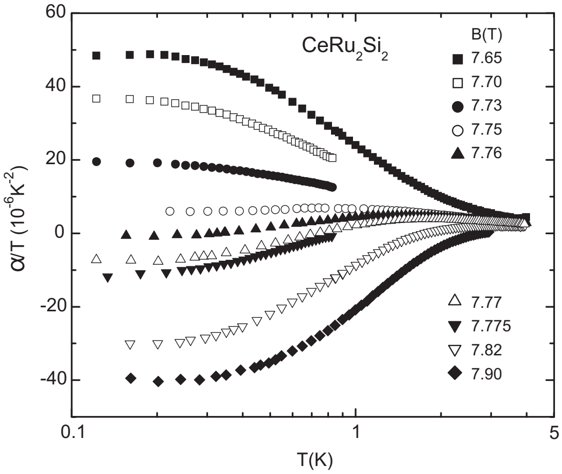

Fig. 2. Coefficient on linear thermal expansion α as α/T vs. T (logarithmic scale) at various magnetic fields $B \| c$ for $CeRu_2Si_2$.

α/T is constant—a hallmark of Landan–Fermi liquid (LFL) behavior. By fine-tuned magnetic fields we can demonstrate that α changes continuously from large positive ($B < B_m$) to large negative ($B > B_m$) values and not suddenly as in previous publications [5,6]. The α-coefficient in the doped system shows generally the same behavior (not displayed) but with about 40% smaller values.

The resistivity of $CeRu_2(Si_{1-x}Ge_x)_2$ (Fig. 3) exhibits LFL behavior for both Ge concentrations (a) $x = 0.00$ and (b) $x = 0.02$. Here the temperature-dependent part of the resistivity has a T^2 behavior ($\Delta\rho = AT^2$). The LFL region of $CeRu_2Si_2$ is smaller ($T \leqslant 0.3$ K) than that for the doped system ($T \leqslant 0.5$ K). From the $T \to 0$ intercept, the A coefficient can be determined which is a measure of the quasiparticle scattering cross section and proportional to the quasiparticle mass. For fields near the MMT (7.75, resp. 7 T in Fig. 3), the A coefficient increases in comparison to lower fields, but does not diverge; after the transition A decreases strongly (e.g. 8.1, resp. 7.5 T).

In conclusion, by studying the thermal expansion and resistivity of $CeRu_2(Si_{1-x}Ge_x)_2$ it is not possible to tune the system from a MMT to a QCEP or even to a first-order phase transition. Thus a different tuning parameter would be needed. Yet, the pseudo-diverging behavior of

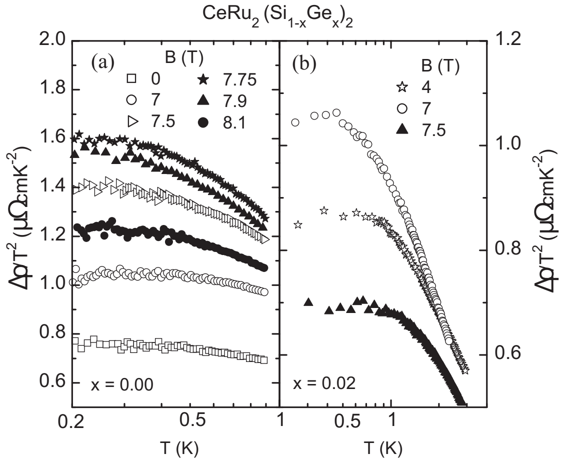

Fig. 3. Temperature dependent part of electrical resistivity $\Delta\rho = \rho(T, B) - \rho_0(B)$ as $\Delta\rho/T^2$ vs. T (logarithmic scale) for (a) $CeRu_2Si_2$ and (b) $CeRu_2(Si_{0.98}Ge_{0.02})_2$ at different magnetic fields $B \| c$.

$CeRu_2(Si_{1-x}Ge_x)_2$ at $T \geqslant 0.5$ K misleadingly suggests that the system appears to be close to a QCP. From our experiments, the low temperature region ($T \leqslant 0.3$ K) of the B–T phase diagram clearly forms a LFL state in strong contrast to the other materials. This, we attributed to a Fermi surface reconstruction [7] that leads to spin polarization and a local-moment ferromagnetism above B_m.

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