Search for a quantum critical end-point in CeRu$_2$(Si$_{1-x}$Ge$_x$)$_2$

F. Weickert$^{a,*}$, P. Gegenwart$^a$, J.A. Mydosh$^{a,1}$, F. Steglich$^a$, C. Kanadani$^b$, Y. Tabata$^b$, T. Taniguchi$^b$, S. Kawarazaki$^b$

$^a$Max-Planck Institute for Chemical Physics of Solids, D-01187 Dresden, Germany
$^b$Osaka University, Toyonaka 560-0043, Japan

Abstract

We use high-resolution dilatometry and electrical resistivity down to 20mK 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 6.8T, respectively. We do not find any evidence for QCEP since (i) the peak height and FWHM of the magnetostrictive anomaly saturate below 0.2K and (ii) the thermal expansion and the electrical resistivity indicate the formation of a Landau–Fermi liquid (LFL) state below 0.3K even at $B_m$. We speculate that the metamagnetic crossover represents a Fermi surface reconstruction that is fully completed below 0.2K.

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$_2$Si$_2$ [2], Sr$_3$Ru$_2$O$_7$ [3]), there has been a “resurrection” of the CeRu$_2$Si$_2$ [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 7.8T, 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 20mK on CeRu$_2$(Si$_{1-x}$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
the tri-arc Czochralski method for \( x = 0.02 \). Residual resistivities (RR) are very similar: 1.6 and 1.8 \( \mu \Omega \) 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 \( \lambda = (1/L)\partial L(T, B)/\partial B \) 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 \( \alpha = (1/L)\partial L(T, B)/\partial T \) of the undoped system is shown for magnetic fields very close to the MMT. For temperatures below 0.3 K the coefficient \( \alpha \) displays a linear temperature dependence, thus \( \alpha/T \) is constant—a hallmark of Landau–Fermi liquid (LFL) behavior. By fine-tuned magnetic fields we can demonstrate that \( \alpha \) 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 \( \alpha \)-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\(_2\)Si\(_2\) is smaller (\( T \leq 0.3 \) K) than that for the doped system (\( T \leq 0.5 \) 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
($T \leq 0.3 \text{ K}$) 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 $B_m$.

We acknowledge Huang Ying Kai and T.J. Gortenmulder for their help in the sample preparation and analysis.

References