Magnetic properties of a URhSi single crystal

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Abstract

The ferromagnetic behavior of URhSi (TiNiSi-type orthorhombic crystal structure) resembles its isostructural analogue URhGe, the well-known "ferromagnetic superconductor". We report on first results of magnetization measurements of a URhSi single crystal with respect to a magnetic field and temperature. The magnetization data and specific-heat behavior point to a Curie temperature T_C = 10.5 K. At lower temperatures we observe a strong magnetic anisotropy with the dominant spontaneous magnetic moment (0.47 μ_B) along the *c*-axis (similar to URhGe). Along the *a*- and *b*-axis, much smaller components are indicated. A strong anisotropy is observed also in paramagnetic range.

Key words: URhSi; single crystal; magnetization; magnetic susceptibility; specific heat

The ferromagnetic compound URhSi [1] is a close analogue of URhGe, which has recently attracted strong interest because of coexistence of ferromagnetism and superconductivity at low temperatures [2]. Both compounds crystallize in the orthorhombic structure of the TiNiSi type. Whereas URhGe was studied also in the single-crystal form [3], for URhSi up to now only polycrystalline data were available (for review, see [4]). Characteristic features of the electronic structure of URhSi were also a subject of theoretical studies [5,6]. The bulk electronic properties of this compound point to a ferromagnetic order below T_C = 9.5 K. A spontaneous magnetic moment $M_s \approx 0.3\mu_B$/f.u. was derived from magnetization data measured on an oriented-powder sample at 4.2 K [7]. The low-temperature neutron powder-diffraction results were interpreted in terms of a collinear ferromagnetic structure with U moments oriented along the *c*-axis [8,9]. We have grown a single crystal of URhSi and present first magnetization data obtained on this crystal.

The single crystal of URhSi was grown from a stoichiometric melt in a tetra-arc furnace by a modified Czochralski method under Ar atmosphere. No subsequent heat treatment was given to the crystal. The crystal quality was checked by the Laue X-ray technique and by the electron microprobe analysis. The magnetization and the magnetic susceptibility along the principal axes were measured in the PPMS magnetometer (Quantum Design) in fields up to 9 T in the temperature range 2 - 300 K. Arrott-plot analysis of magnetization data was used to determine the spontaneous moment and Curie temperature.

The top and bottom parts of the crystal were found to be single phase and homogeneous by the electron -probe microanalysis. A composition of the crystal was determined as U 35.5 at.% , Rh 34.4 at.% and Si 30.1 at.% that corresponds to the notation $U_{1.06}Rh_{1.03}Si_{0.91}$ with 3 atoms per formula unit.

The Magnetization curves measured in a field applied along the principal axes of the crystal at 2 K are shown in Fig. 1. In the inset, the temperature dependence of the magnetization in a field of 2 T along the principal axes and of the *c*-axis spontaneous moment determined from Arrott-plots are shown. One can see that this relatively low field induces a large magnetic response far above T_C determined in our case as 10.5 K.

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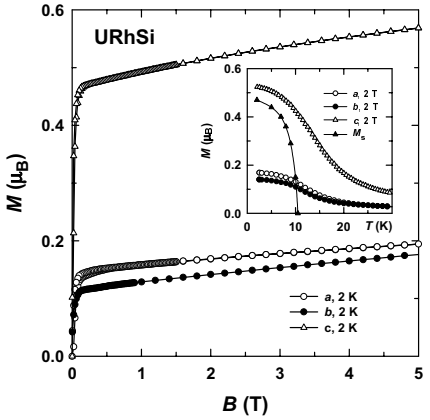

Fig. 1. Magnetization isotherms of a URhSi single crystal along the principal axes at different temperatures. The inset: Temperature dependence of magnetic moment along the principal axes at a 2 T field and of the spontaneous moment along the easy c-axis (determined from the Arrott plots).

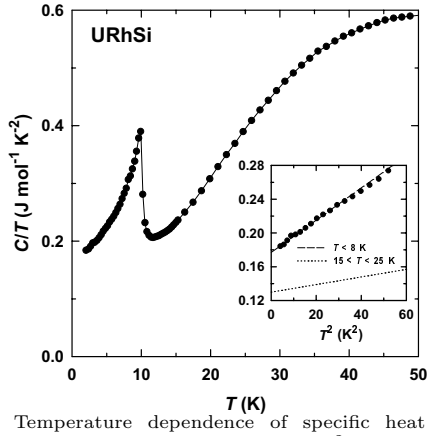

Fig. 2. Temperature dependence of specific heat in the $C_{\rm p}/T(T)$ form. The inset shows the $C_{\rm p}/T(T^2)$ plot at low temperatures. The linear extrapolations to $T = 0$ from low temperatures (dashed line) and from the range above the magnetic ordering (15-25 K).

The difference to previously reported $T_{\rm C} = 9.5$ K may be tentatively attributed to the above mentioned Si deficiency in the crystal. The highest magnetic moment ($M_{\rm s} = 0.47\ \mu_{\rm B}$ at 2 K) is observed for the c axis. Much smaller but non-negligible values of the spontaneous moment are indicated along the a and b-axis (0.14 and $0.12\ \mu_{\rm B}$, respectively). These results may be considered in first approximation in terms of the uniaxial magnetic anisotropy with the easy c-axis, which contradicts previous conclusions about the easy-plane anisotropy based on high-field magnetization data of de Boer et al. [7] done on field-oriented and random fixed-powder samples, respectively. On the other hand, the easy c axis agrees with results of neutron diffraction studies on powder [8,9] and crystal (the present work).

As in many other uranium intermetallics, the magnetic anisotropy energy of URhSi is very high but its quantitative estimate is difficult because the easy-axis magnetization curve shows no tendency to saturation up to the highest applied field. Moreover, the c-axis high-field susceptibility in 9 T (8.2×10^{-8} mol/m^3) exceeds considerably that along a and b axes (4.9×10^{-8} and 7.1×10^{-8} mol/m^3, respectively). The large easy-axis high-field susceptibility probably reflects the itinerant character of $5f$ magnetic moment.

The temperature dependence of the inverse magnetic susceptibility below 180 K strongly deviates from the Curie-Weiss (C-W) behavior at higher temperatures. The C-W fit at 200-300 K gives reasonable value 3.0-3.1 $\mu_{\rm B}$ of effective magnetic moment $\mu_{\rm eff}$. It is considerably smaller than the expectation value for the $5f^2$ or $5f^3$ localized configuration ($3.6\ \mu_{\rm B}$). On the other hand it is a typical value for the UTX family of uranium intermetallics (T is a late transition metal, X is a p-metal) [4]. The observed difference between the paramagnetic Curie temperature $\Delta\Theta_{\rm p}$ along the principal axes ($\Theta_{\rm p}^a$ = -305 K, $\Theta_{\rm p}^b$ = -200 K, $\Theta_{\rm p}^c$ = -120 K) is a sort of measure of the magnetic anisotropy energy, which in case of URhSi amounts 185 K. This value can be considered as moderate in comparison with the hexagonal UTX compounds. For example, in UPtAl, $\Delta\Theta_{\rm p} = 420$ K [10].

Temperature dependence of specific heat, presented in Fig. 2 in the $C_{\rm p}/T(T)$ form, exhibits a sharp maximum at $T_{\rm C}$. The value of electronic specific-heat coefficient γ is determined as 177 mJ mol^{-1} K^{-2} and 130 mJ mol^{-1} K^{-2} by extrapolation from low-temperature range and above $T_{\rm C}$, respectively (inset in Fig. 2). A more detailed study of specific heat is in progress.

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