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Magnetic, Thermal and Transport Properties of $YbPt_2Si_2$ and $Yb_2Pt_3Si_5$ Single Crystals

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Single crystals of $YbPt_2Si_2$ and $Yb_2Pt_3Si_5$ have been prepared by solvent growth method with Sn flux, characterized by X-ray diffraction and by EDX microprobe analysis and investigated by measurement of magnetization, specific heat and electrical resistivity as functions of temperature and magnetic field. $YbPt_2Si_2$ ($Yb_2Pt_3Si_5$) crystalizes in the tetragonal $CaBe_2Ge_2$-type (orthorhombic $U_2Co_3Si_5$-type) structure. Both compounds exhibit metallic resistivity behavior without visible anomaly, which could be connected with onset of magnetic ordering. Neither the specific heat shows any sign of magnetic ordering down to 0.5 K. The corresponding temperature dependences of the magnetic susceptibility of both compounds behave qualitatively similar, which is reminiscent of spin fluctuation behavior: a broad maximum at high temperatures, a shallow minimum at lower temperatures, followed by an upturn with further cooling the crystal, which can be suppressed by applying a sufficient magnetic field. The rather low values of the γ-coefficients of the specific heat ($\sim 25 \div 35$ mJ·mol·K^{-2}) do not support the mixed valence scenario discussed in literature for $YbPt_2Si_2$.

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1. Introduction

Elemental Yb is a divalent metal with $4f^{14}$ electron configuration yielding no magnetic moment. The 2+ valence is exceptional among lanthanides, which are mostly trivalent. The valence of Yb increases towards 3+ with applied pressure [1]. The magnetic Yb^{3+} ($4f^{13}$) ionic state can be stabilized in some compounds with a specific Yb ion neighborhood [2]. Various Yb^{3+}/Yb^{2+} mixed valence states can be tuned by doping [3]. Only scarce information is known on physics of $YbPt_2Si_2$ from investigations on polycrystals [4, 5]. This motivated us to grow single crystals, which are essential for measurements of intrinsic behavior, including anisotropy. Within our attempts of "flux growth", we were successful in obtaining not only single crystals of this compound but, in some batches, also crystals of a, so far unknown compound of the composition $Yb_2Pt_3Si_5$ have been found. This paper presents results of our structure characterization of the two compounds and the subsequent study of magnetization, specific heat and electrical resistivity as functions of temperature and magnetic field applied along the main crystallographic axes.

2. Experimental details

Single crystals of both compounds were prepared by the solvent growth technique with tin flux and non-stoichiometric amounts of pure elements. Alumina crucibles with the elements were placed into evacuated quartz tubes and heated up to 1450 K. This was followed by a very slow cooling down to 570 K, where crucibles were centrifuged in order to separate the flux from single crystals. The remaining flux was removed from the surface by a solution of hydrochloric acid.

The crystals were checked with a scanning electron microscope MIRA (Tescan) equipped by an EDX detector (Bruker), which confirmed the correct stoichiometry and phase purity. Furthermore, X-ray powder diffraction was measured on powdered crystals by a diffractometer Bruker using Cu-K_α radiation. The crystal structure of $Yb_2Pt_3Si_5$ was also studied on small single crystals with a Single Crystal Diffractometer Rigaku R-Axis Rapid.

Magnetization behavior was inspected by a SQUID magnetometer MPMS 7 T (Quantum Design) in the temperature range 1.8–400 K and magnetic fields up to 7 T. The specific heat and electrical resistivity were measured in PPMS instruments (Quantum Design).

3. Results and discussion

For the $YbPt_2Si_2$ crystal, the tetragonal $CaBe_2Ge_2$-type crystal structure (space group P4/nmm) has been confirmed with lattice parameters $a = 409.59(2)$ pm, $c = 998.34(4)$ pm, in agreement with literature data [4, 5]. By measurement of single crystal diffraction on $Yb_2Pt_3Si_5$, we have determined its crystal structure as orthorhombic of the $U_2Co_3Si_5$-type (space group Ibam) with the lattice parameters $a = 1000.5$ pm, $b = 1133.4$ pm, $c = 595.2$ pm.

The temperature dependence of specific heat (C_p/T vs. T plot) of $YbPt_2Si_2$ is displayed in Fig. 1. It shows an upturn below 2 K, which can be suppressed by magnetic field applied along c. The C_p/T vs. T^2 dependence above 2 K is linear and points to the value of $\gamma = 26.9(2)$ mJ·mol·K^{-2}. Measurements below 0.5 K

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are desired to see whether the upturn is connected with an onset of magnetic ordering or with other low temperature phenomena. The specific heat data of $Yb_2Pt_3Si_5$ (not shown) exhibit neither the low temperature upturn mentioned above for $YbPt_2Si_2$ nor any other anomaly down to the lowest measured temperature (0.5 K), which would indicate a magnetic phase transition. The C_p/T vs. T^2 dependence is linear from 0.5 to 15 K and points to the γ-value of 34.5(5) mJ·mol·K^{-2}. Considering the stoichiometry of the two compounds, the enhanced γ-values may be tentatively attributed to arise mainly due to the density of the Pt 5*d* states.

The temperature dependence of the electrical resistivity of both compounds has metallic character and shows no anomaly down to 5 K. The low temperature data for $Yb_2Pt_3Si_5$ (below 25 K) shows the $\rho = \rho_o + aT^n$ dependence with $n = 1.5$, possibly pointing to non-Fermi liquid behavior. On the other hand, the low temperature resistivity of $YbPt_2Si_2$ (below 30 K) behaves accordingly to the exponent $n = 2.2$, being very close to the standard Fermi-liquid description.

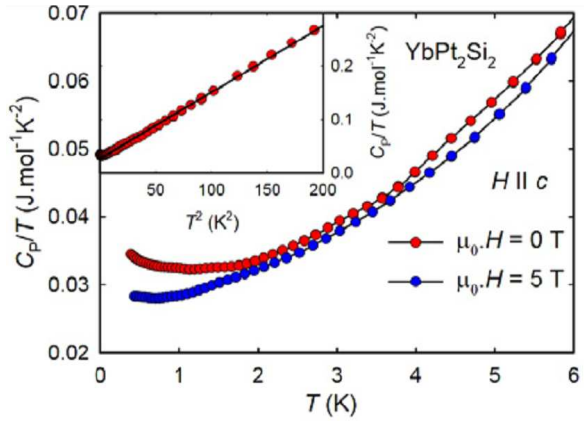

Fig. 1. Low-temperature specific heat of $YbPt_2Si_2$. The inset shows a C/T vs. T^2 fit of zero field data.

The magnetic susceptibility of $YbPt_2Si_2$ (Fig. 2) exhibits considerable anisotropy, the *c*-axis values are much higher than the *a*-axis ones. Both the χ vs. T curves show a broad maximum (reminiscent of spin fluctuation behavior) but at different temperatures for the *a*- ($\sim$ 280 K) and *c*-axis ($\sim$ 130 K) susceptibility. The large low temperature upturn measured in 1 T along the *c*-axis becomes considerably suppressed by the magnetic field of 7 T. This feature may reflect presence of a tiny *c*-axis magnetic moment on Yb site of about 0.03 μ_B/f.u. The χ vs. T curves measured for the $Yb_2Pt_3Si_5$ crystal show qualitatively similar shape, however, the broad maximum is shifted above room temperature. The signal measured along the *b*-axis is about two times larger than that measured along the other two axes, i.e. $Yb_2Pt_3Si_5$ also exhibits considerable anisotropy. For entirely divalent state of Yb ions, Pauli paramagnetic behavior with temperature dependence of susceptibility should be expected. Therefore, we tentatively conclude that the observed susceptibility features indicate that the Yb ions most probably are not entirely divalent, but that a slight admixture of the Yb^{3+} state may occur in both compounds.

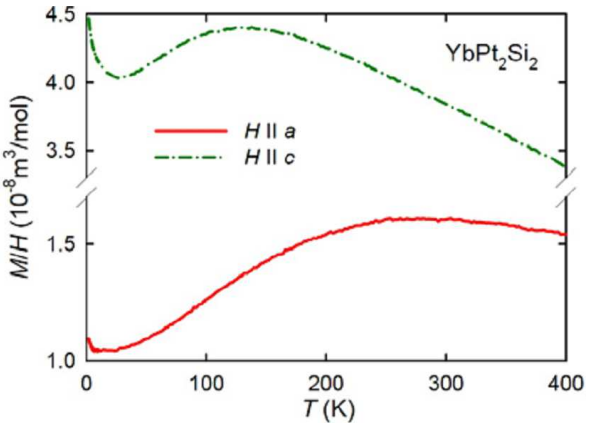

Fig. 2. Magnetic susceptibility measured in the field of 1 T.

4. Conclusions

We have succeeded in growing the single crystals of two ytterbium compounds, $YbPt_2Si_2$ (so far reported on polycrystals) and $Yb_2Pt_3Si_5$ (so far unknown compound). Specific heat, electrical resistivity and magnetization data measured for both compounds manifest: a) lack of magnetic ordering down to the lowest temperature in our experiments (0.5 K). b) The magnetic susceptibility shows features reminiscent of the susceptibility of spin fluctuating systems (maximum in the χ vs. T dependence, anisotropy). This indicates that Yb ions are not entirely in the Yb^{2+} state, but that the trivalent state may be admixed. High-field magnetization measurements are desired to test possibility of metamagnetism, which usually accompanies a maximum in the temperature dependence of magnetic susceptibility.

Acknowledgments

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