Transport properties in UCoAl under uniaxial pressure

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Abstract

We report the first study of uniaxial pressure (P_u) effect on the transport properties in the unique $5f$ electron metamagnet UCoAl. A metamagnetic transition around a critical magnetic field $B_M \sim 0.7$ T applied along the c axis at ambient pressure shifts to higher fields with increasing P_u applied along the a axis. This increase is in contrast to the decrease of B_M under P_u applied along the c axis. The result may be interpreted most likely as an enhancement of $3d$-$5f$ hybridization in the basal plane under P_u along the a axis.

Key words: $5f$-electron metamagnet; ligand hybridization; uniaxial pressure; UCoAl.

UCoAl, crystallizing into the hexagonal ZrNiAl-type hexagonal structure, is an unique $5f$ electron compound which exhibits a metamagnetic transition (MT) from a paramagnetic ground state around a magnetic field $B_M \simeq 1$ T when the field is applied along the c axis [1–4]. As a possible origin of MT, a field-induced ferromagnetism due to the $5f$ band splitting has been inferred. B_M is reported to increase with the hydrostatic pressure (P_h), stabilizing the paramagnetic state [5]. The magnetic behavior in this compound is strongly anisotropic, reflecting the anisotropic $5f$ ligand hybridization in the layered structure. The uniaxial pressure experiment has a merit to provide information on the anisotropy in the hybridization-mediated exchange interaction. In fact, we explored the anisotropic effect under P_u in $CeRu_2Si_2$ that exhibits a metamagnetic anomaly [6]. Recently, magnetization measurements were performed in UCoAl under P_u applied along the c axis in which B_M was found to decrease with increasing P_u, leading to a ferromagnetism in zero field around 0.56 kbar [7]. However, study the effect of P_u along the a axis on B_M as well as the study of transport properties under P_u are essentially important. In this proceedings, we report the preliminary results of the first study of the effect of P_u on the transport property in UCoAl.

Single crystals of UCoAl were grown by Czochralski pulling method in a tetra-arc furnace with an argon atmosphere. The quality of the single crystal was inferred from the residual resistivity ratio ≥ 16, which is close to that used in Ref. [4]. Electrical resistivity was measured by the standard dc four-probe method. Uniaxial pressures were generated by using a piston cylinder type CuBe pressure cell, recently designed and constructed [6]. P_u were determined by measuring the superconducting transition temperature of Sn placed near the sample by an induction method.

Figure 1 shows the effect of $P_u \parallel a$ axis on the magnetic field (B) dependence of the resistivity (ρ) in the $B \parallel J \parallel c$ axis geometry. At ambient pressure, ρ increases with magnetic fields and then shows a steplike increase across a characteristic magnetic field $B_M \simeq 0.7$ T, tracing the metamagnetic transition. The increase of ρ across B_M is attributed to the change of density of states at the Fermi level [3,4]. The presence

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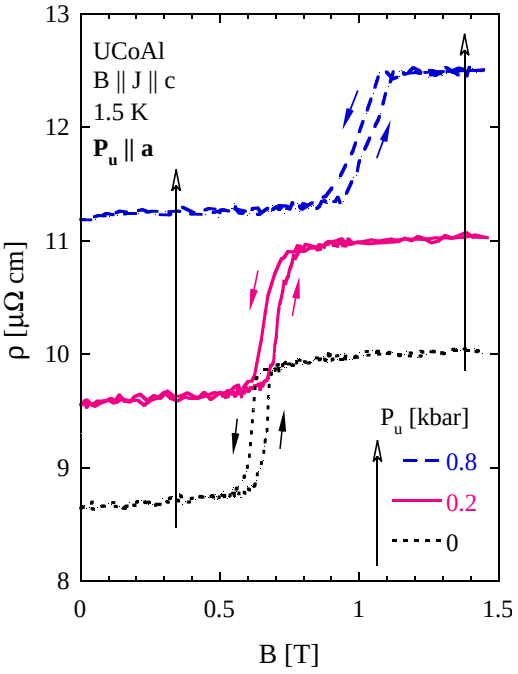

Fig. 1. Magnetic field dependence of the longitudinal magnetoresistance ($B \parallel J \parallel a$ axis, J denotes the current) in UCoAl at 1.5 K under $P_u \parallel a$ axis. The up and down short arrows indicate the data points for increasing and decreasing sweep of the applied magnetic fields across B_M.

of hysteresis between ρ for increasing and decreasing B (as indicated by the up and down short arrows) across B_M indicates the first order type transition. These behaviors at the ambient pressure are in close agreement with those reported in Ref. [4].

With increasing P_u along the a axis, the metamagnetic transition across B_M shifts to higher magnetic fields [see Fig. 2]. This increase is in contrast to the decrease of B_M and hence the appearance of ferromagnetism in the magnetization measurement under $P_u \parallel c$ axis reported in Ref. [7]. The absolute value of ρ increases for all fields both below and above B_M with increasing P_u as indicated by the long upward arrows in Fig. 1. At the present stage, an increase of spin fluctuations and inclusion of microcracks should be taken into account as the possible origins of this increase of ρ with $P_u \parallel a$ axis.

The result may be interpreted qualitatively as follows: The UCoAl crystal structure consists of U-Co and Co-Al basal-plane layers alternating along the c axis. According to Sechovśky *et al.* [8,7], ferromagnetic (F) type U-U exchange coupling is favored along the c axis assisted by $5f$-$3d$ hybridization within the basal plane in UCoAl. The linear compressibility in UCoAl is anisotropic, i.e., a axis is softer than c axis [7]. Under hydrostatic pressure (P_h) an enhancement of $5f$-$3d$ hybridization within the basal plane is

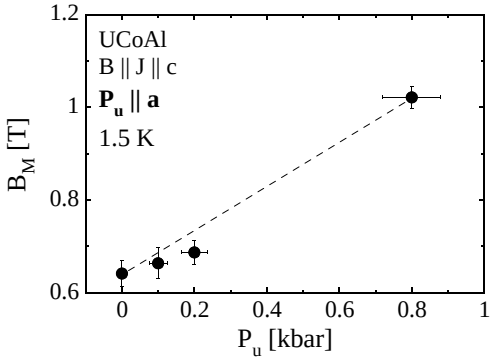

Fig. 2. Uniaxial pressure ($P_u \parallel a$ axis) dependence of the metamagnetic transition field B_M. B_M is defined by the field B that corresponds to 50% of the sharp increase of ρ across the transition. The broken line is a guide to the eyes.

expected to lead to an increase of B_M, as indeed was observed [5]. Under $P_u \parallel c$ axis, c axis shrinks and a axis expands and as a result an enhancement of F-coupling along the c axis assisted by an weakening of $5f$-$3d$ hybridization within the basal plane may lead to ferromagnetism as was also proposed in Ref. [7]. In contrast in the present experiment under $P_u \parallel a$ axis, c axis expands and a axis shrinks, which may cause an enhancement of $5f$-$3d$ hybridization in the basal plane that weaken the F-coupling along the c axis, leading to an increase of B_M; It should be noted that the magnetostriction across the metamagnetic transition in UCoAl are positive along the a axis and negative along the c axis [9]; The scenario is also consistent in the light of the anisotropic magnetoresistance.

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References

[1] V. Sechovský *et al.*, Physica B & C **142B**, (1986) 283.

[2] A. V. Andreev *et al.*, Phys. Rev. B **55** (1997) 5847.

[3] A. V. Kolomiets *et al.*, J. Appl. Phys. **83** (1998) 6435.

[4] T. D. Matsuda *et al.*, Phys. Rev. B **62** (2000) 13 852.

[5] N. V. Mushnikov *et al.*, Phys. Rev. **59** (1999) 6877.

[6] S. R. Saha *et al.*, Phys. Rev. B **65** (2002) 214429.

[7] V. Sechovský, A. V. Andreev, Y. Ishii, M. Kosaka, and Y. Uwatoko (to be published in High Pressure Research, 2002).

[8] V. Sechovský *et al.*, *Hand Book of Magnetic Materials*, edited by K. H. J. Buschow (Elsevier Science B. V., Amsterdam, 1998), p. 1-289.

[9] A. V. Andreev *et al.*, Sov. Phys. Solid State **27** (1985) 1145.