Interplay between doping and pressure effects in magnetism of $UCo_{1-x}T_xAl$ (T = Fe, Ni) single crystals

A.V. Andreev [a,1], N.V. Mushnikov [b], T. Goto [b], V. Sechovský [c], Y. Homma [d], Y. Shiokawa [d]

[a] *Institute of Physics ASCR, Na Slovance 2, 18221 Prague 8, The Czech Republic*
[b] *ISSP, Tokyo University, Kashiwanoha 5-1-5, Kashiwa, Chiba 277-8581, Japan*
[c] *Department of Electronic Structures, Charles University, Ke Karlovu 5, 12116 Prague 2, The Czech Republic*
[d] *IMR, Tohoku University, Katahira 2-1-1, Aoba-ku, Sendai 980-8577, Japan*

Abstract

The metamagnetic behavior of UCoAl is easily transformed to ferromagnetism or conventional paramagnetism with doping UCoAl by suitable elements. The new ferromagnetic state is very sensitive to pressure. We demonstrate these phenomena by a magnetization study of the $UCo_{1-x}T_xAl$ (T = Fe, Ni) single crystals. The Ni substitution for Co yields an increase of the critical field for the metamagnetic transition. The transition disappears for x = 0.10. The $UCo_{0.90}Fe_{0.05}Ni_{0.05}Al$ and $UCo_{0.98}Fe_{0.02}Al$ compounds exhibit ferromagnetism, however, a hydrostatic pressure of only 0.3 GPa is sufficient to suppress ferromagnetic ordering and restore the metamagnetic behavior of UCoAl-type. The ferromagnetism in $UCo_{0.95}Fe_{0.05}Al$ is more stable and persists up to 0.8 GPa.

Key words: actinide compounds; itinerant metamagnetism; pressure effects

UCoAl (the hexagonal ZrNiAl-type crystal structure) exhibits no magnetic ordering, but at low temperatures a metamagnetic transition (MT) to a ferromagnetic state is induced at a critical field $B_c < 1$ T. The huge uniaxial magnetic anisotropy is manifest by the fact that the MT is induced only by a magnetic field applied along the c-axis whereas within the basal plane Pauli paramagnetic behavior with no trace of metamagnetism up to 42 T is observed. Also the susceptibility maximum around T_{max}=20 K is observed only in a magnetic field applied along the c-axis. The qualitative similarities with the behavior of the 3d-band metamagnets like YCo_2 lead to the interpretation of the physics of UCoAl in terms of the 5f-band metamagnetism [1–3].

The critical magnetic parameters of UCoAl are very sensitive to external pressure and variation of the chemical environment of the U atom. As known from studies on doped UCoAl polycrystals, substitution of Ni for Co pushes the MT to higher fields, whereas the Fe doping yields an opposite effect. In the latter case, the B_c-value is rapidly reduced to 0 T when a ferromagnetic ground state becomes stable. External hydrostatic pressure works against this trend [4]. In this work, we vary the ground state of the compound by slight substitutions of Ni and Fe for Co and study the impact of external pressure on single crystals, which were grown by a modified Czochralski method in a tetra-arc furnace.

The c axis magnetization curves of the compounds studied at ambient pressure and at 1.2 GPa (Fig. 1) and the temperature dependence of magnetic moment in a field of 0.2 T (Fig. 2) demonstrate the interplay between substitution and pressure effects. Whereas the MT in UCoAl for ambient pressure is observed at 0.67 T, the critical field B_c of the transition is shifted above 2 T by 5% Ni substitution for Co and the magnetization above the MT is reduced by more than 30%. The MT disappears with further increasing Ni content as seen for the $UCo_{0.9}Ni_{0.1}Al$ crystal. On

[1] Corresponding author. E-mail: andreev@mag.mff.cuni.cz

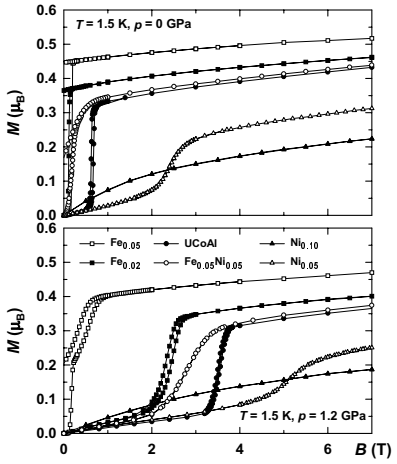

Fig. 1. Magnetization curves along the c axis of the crystals of compounds studied at 1.5 K. Top: at the ambient pressure. Bottom: at the hydrostatic pressure of 1.2 GPa.

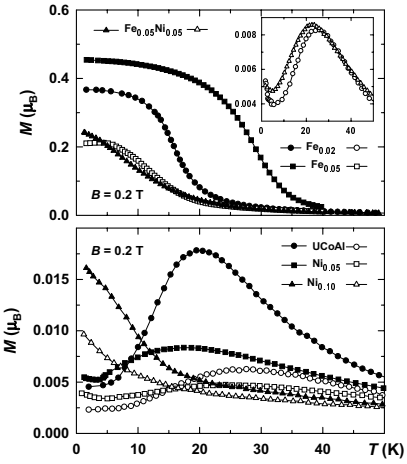

Fig. 2. Temperature dependence of magnetic moment along the c axis of the crystals of compounds studied in a 0.2 T field at ambient pressure (filled symbols) and 1.2 GPa (empty symbols).

the other hand, only 2% Fe doping yields a reduction of B_c down to zero and a stabilization of a ferromagnetic ground state. The $UCo_{0.95}Fe_{0.05}Al$ exhibits a higher spontaneous moment $M_s = 0.46\mu_B$/f.u. For the $UCo_{0.90}Fe_{0.05}Ni_{0.05}Al$, sample with the simultaneously substituted equivalent amounts of Fe and Ni for Co the magnetization isotherm is characterized by a spontaneous moment and a metamagnetic component superimposed on top of it.

A hydrostatic pressure of 0.3 GPa is sufficient to suppress ferromagnetism in $UCo_{0.98}Fe_{0.02}Al$ and $UCo_{0.90}Ni_{0.05}Fe_{0.05}Al$ with a simultaneously reentrant metamagnetism. With further increasing pressure, the MT is shifted to higher fields and the magnetization gain across the transition decreases. The rate dB_c/dp is nearly the same for all samples ($\sim$2.7 T/GPa) with MT. Ferromagnetism in $UCo_{0.95}Fe_{0.05}Al$ is more stable. The metamagnetic features appear at 0.8 GPa, while for the maximum available pressure (1.2 GPa) the sample consists of equal amount of metamagnetic and ferromagnetic components (Fig. 1). In the paramagnetic $UCo_{0.9}Ni_{0.1}Al$, the pressure slightly reduces the magnetic susceptibility.

As can be seen in Fig. 2, the temperature of the susceptibility maximum is slightly affected by 5% Ni doping but the susceptibility values are dramatically reduced and the maximum is strongly smeared out. Application of pressure in the case of $UCo_{0.98}Fe_{0.02}Al$ and $UCo_{0.90}Ni_{0.05}Fe_{0.05}Al$ yields a transformation of the monotonic ferromagnetic-like $M(T)$ dependence to the low-moment curve with a shape characteristic for UCoAl. The changes of the B_c- and T_{max}-values for $UCo_{0.95}Ni_{0.05}Al$ in comparison with UCoAl (B_c increases by a factor of 3.5 whereas T_{max} decreases by 10%) do not obey the B_c vs. T_{max} proportionality, one of the main characteristics of the YCo_2–based metamagnets [5]. Nevertheless, in the same compound this proportionality is valid when both quantities are influenced by external pressure. No susceptibility maximum is observed for $UCo_{0.9}Ni_{0.1}Al$ irrespective to the applied pressure.

The basic magnetic characteristics of the compounds studied at 0 and 1.2 GPa are summarized in Table 1.

Table 1
Magnetic characteristics at ambient and high pressure (0 GPa/1.2 GPa). The M_s and B_c values are at 1.5 K.

Compound	M_s (μ_B)	T_C(K)	T_{max}(K)	B_c (T)
UCoAl	0/0	-	20/28	0.67/3.55
$UCo_{0.95}Ni_{0.05}Al$	0/0	-	18/25	2.35/5.05
$UCo_{0.90}Ni_{0.10}Al$	0/0	-	-/-	-/-
$UCo_{0.98}Fe_{0.02}Al$	0.37/0	16/-	-/25	-/2.4
$UCo_{0.95}Fe_{0.05}Al$	0.46/0.21	30/14	-/-	-/-
$UCo_{0.90}Fe_{0.05}Ni_{0.05}Al$	0.17/0	16/-	-/23	-/2.75

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