Pressure influence on magnetism of UCo$_{1-x}$T$_x$Al solid solutions with T = 3d- and 5d-metals

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Abstracts

UCoAl belongs to a large UTX group of uranium intermetallics (T is a late transition metal of 3d, 4d or 5d series, X is a p-metal Al, Ga, In or Sn) with the hexagonal crystal structure of the ZrNiAl type. Compounds of this group exhibit very diverse magnetic properties from temperature-independent paramagnetism to ferromagnetism or antiferromagnetism [1,2]. UCoAl is a unique itinerant 5f electron metamagnet which exhibits a field-induced transition from the paramagnetic to the ferromagnetic state at a critical field $H_c = 0.7 \pm 0.1$ T applied along the c-axis [2,3]. Due to so low $H_c$, UCoAl is extremely sensitive to any influence, such as off-stoichiometry, dilution of the U sublattice, substitution within the Co or Al sublattices, external pressure, temperature and magnetic field. A magnetic moment at the transition is induced only on U [4], but the state of the 5f electrons depends very drastically on the interaction with ligands, especially with late d-metals.

In the present work we compare influence of hydrostatic pressure on magnetic properties of UCoAl-based compound with the same content of either 3d or 5d metals. Magnetization was measured in the temperature range 2-60 K using MPMS-7 cryomagnetic installation in fields up to 7 T applied along the c-axis on single crystals. A miniature CuBe clamp pressure cell was used to apply hydrostatic pressure up to 0.83 GPa. The crystals were grown by the modified Czochralski method from 8 g stoichiometric mixtures of the pure elements (99.9% U, 99.99% Co and other d-metals, and 99.999% Al) in a tri-arc furnace with a water-cooled copper crucible.

Figure 1 shows magnetization curves of compounds with 2% Fe or Os in the Co sublattice. At ambient pressure both compounds are ferromagnetic with very similar magnetization curves with slightly higher magnetic moment in the case of Os (the Curie temperature $T_C$ is 17 K for the Fe compound and 26 K for the Os one). However, under pressure they behave in very different ways. In the case of Fe substitution, metamagnetic transition characteristic for UCoAl restores at 0.2 GPa and moves to higher field with increasing pressure. The magnetization curve at the transition is slightly wider than in UCoAl. The broadened metamagnetic magnetization curve of UCo$_{0.98}$Fe$_{0.02}$Al for 0.8 GPa can be described well in the assumption of Gaussian distribution of the critical field values $H_c$ with respect to the average critical field $H_c^0$. The distribution is characterized by the probability

$$P(H_c) = \frac{1}{w\sqrt{2\pi}} \exp[-(H_c - H_c^0)^2/w^2]$$

with $H_c^0 = 1.34$ T and the distribution width $w = 0.35$ T.

The compound with Os demonstrates under pressure a mixture of the spontaneous ferromagnet and paramagnet. Ferromagnetic part almost disappears at 0.8 GPa (Fig. 1). Paramagnetic part does not demonstrate clear magnetization jump like in UCoAl or UCo$_{0.98}$Fe$_{0.02}$Al. However, the magnetization curve might be described by a very wide distribution of $H_c$ over crystal volume. Best fit of the magnetization curve of UCo$_{0.98}$Os$_{0.02}$Al at 0.8 GPa gives the value of the average critical field $H_c^0 = 0.8$ T and the distribution width $w = 1.7$ T.

The difference in the distribution width of the metamagnetic transition between the Fe and Os substituted UCoAl can be due to difference in the atomic radii. The metallic radius of Os (135 pm) is considerably larger than that of Co (125 pm). Therefore, random
substitution of Os for Co leads to significant local distortions of the lattice, which produce local variations of the 5f-d hybridization and distribution of parameters of the metamagnetic transition. On contrary, the metallic radius of Fe (126 pm) is almost the same as that of Co, and variation of the critical field of metamagnetic transition is moderate.

In Figure 2 we compare pressure behavior of the compounds in which 5% of Co is substituted by Ni and its 5d analogue Pt. In UCo0.95Ni0.05Al the metamagnetic transition is shifted at ambient pressure to 2.5 T compared to 0.7 T in UCoAl. Under external pressure the transition moves to higher field. Magnetization gain over transition decreases. Extrapolation gives 3 GPa as a critical pressure where the transition disappears and the compound becomes usual paramagnet. Magnetization curve of UCo0.95Pt0.05Al at ambient pressure might be described by very wide distribution of \( H_c \) over crystal volume, similar to that of UCo0.98Os0.02Al. It includes even zero value which means that the compound has small (0.03 \( \mu_B \)) but non-negligible spontaneous moment (which was not observed on random polycrystal [9]).

This ferromagnetic component has \( T_C = 7 \) K. The crystal becomes forced ferromagnet at approx. 1.4 T, so the average \( H_c \) is close to 0.7 T as in UCoAl. At external pressure 0.33 GPa the ferromagnetic component (with \( M_s = 0.15 \mu_B \) and \( T_C = 5 \) K) is still observed. It vanished at 0.58 GPa. The magnetization curve at 0.83 GPa does not exhibit any trace of field-induced transition, the compound behaves as usual paramagnet.

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