Magnetic Anisotropy of UFe_6Al_6

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$RFe_{12-x}Al_x$ intermetallic compounds (R is a rare-earth or actinide metal) with the tetragonal crystal structure of the $ThMn_{12}$ type attract much attention due to their interesting magnetic properties. In particular, an extensive study of a UFe_6Al_6 single crystal (the refined composition was $UFe_{5.8}Al_{6.2}$) by X-ray and neutron diffraction, ^{57}Fe Mössbauer spectroscopy and magnetization measurements has shown that it is a ferromagnet with spontaneous magnetic moment $M_s = 10.4\ \mu_B$/f.u. and Curie temperature $T_C = 300$ K [1]. It was also shown that the compound exhibits large magnetic anisotropy of the easy-plane type. In the present work, the magnetic anisotropy of UFe_6Al_6 was studied in detail, such as the temperature evolution in the ferromagnetic and paramagnetic state, the anisotropy within the basal plane and a comparison with $LuFe_6Al_6$, Lu being a non-magnetic analogue of U.

Single crystals of UFe_6Al_6 and $LuFe_6Al_6$ were prepared by arc melting the pure elements (99.9% U, Lu, 99.98% Fe and 99.999% Al) in a tri-arc furnace on a water-cooled copper crucible under a protective argon atmosphere. The single crystals were grown from these molten buttons by the Czochralski method using a tungsten rod as a seed with 10 mm/hour pulling speed. X-ray Laue patterns showed good quality of the crystals. Phase purity and lattice parameters were determined by standard X-ray diffractometry with CuK_α radiation on powders prepared from the single crystals. Both compounds crystallize in the $ThMn_{12}$-type crystal structure with lattice parameters $a = 8.663$ Å, $c = 5.009$ Å and $a = 8.593$ Å, $c = 5.021$ Å for UFe_6Al_6 and $LuFe_6Al_6$, respectively. The slightly smaller lattice parameters than in Ref. 1 for $UFe_{5.8}Al_{6.2}$ ($a = 8.674$ Å, $c = 5.014$ Å) correlate well with a slightly higher Fe content at the expense of Al (with larger atomic radius than of Fe). Magnetization curves were measured at 2–600 K along the principal axes of the single crystals using a PPMS-9 magnetometer (Quantum Design) in fields up to 9 T.

Results of magnetization measurements are presented in Figs. 1–5. The values of $M_s = 9.7\ \mu_B$/f.u. and $T_C = 320$ K agree roughly with Ref. 1. The very strong magnetic anisotropy of easy-plane type can be described by the anisotropy constants $K_1 = -7.3$ MJ m^{-3}, $K_2 = 1.25$ MJ m^{-3} at 2 K, determined in a Sucksmith-Thompson analysis of the c-axis curve. $K_1 = -5.7$ MJ m^{-3} and $K_2 = 1.5$ MJ m^{-3} are extracted in the same way from the c-axis curve at 5 K presented in Ref. 1. So, the large anisotropy originates clearly from the U sublattice because in $LuFe_6Al_6$ K_1 equals only –0.73 MJ m^{-3} and K_2 does not exceed 0.04 MJ m^{-3} (Figs. 4 and 5). The very strong anisotropy of UFe_6Al_6 persists in the paramagnetic state up to 500 K, i.e., far above T_C (Fig. 1), again due to the U sublattice because it is not observed in $LuFe_6Al_6$. Other evidence for the U contribution to the magnetism is the observed modest but clear anisotropy in the basal plane with the [110] axis as easy-magnetization direction, the [100] curve saturates in fields above 1 T (Fig. 2). The in-plane anisotropy vanishes at T_C. On the other hand, direct comparison of M_s of UFe_6Al_6 and $LuFe_6Al_6$ (Fig. 3) gives a practically zero U magnetic moment M_U. This is in accord with impossibility to determine the M_U value by neutron diffraction [1] and suggests a mutual cancellation of the spin and orbital components.

References

[1] A.P. Gonçalves, P. Estrela, J.C. Waerenborgh, J.A. Paixão, M. Bonnet, J.C. Spirlet, M. Godinho, M. Almeida, J. Magn. Magn. Mater. **189** (1998) 283.

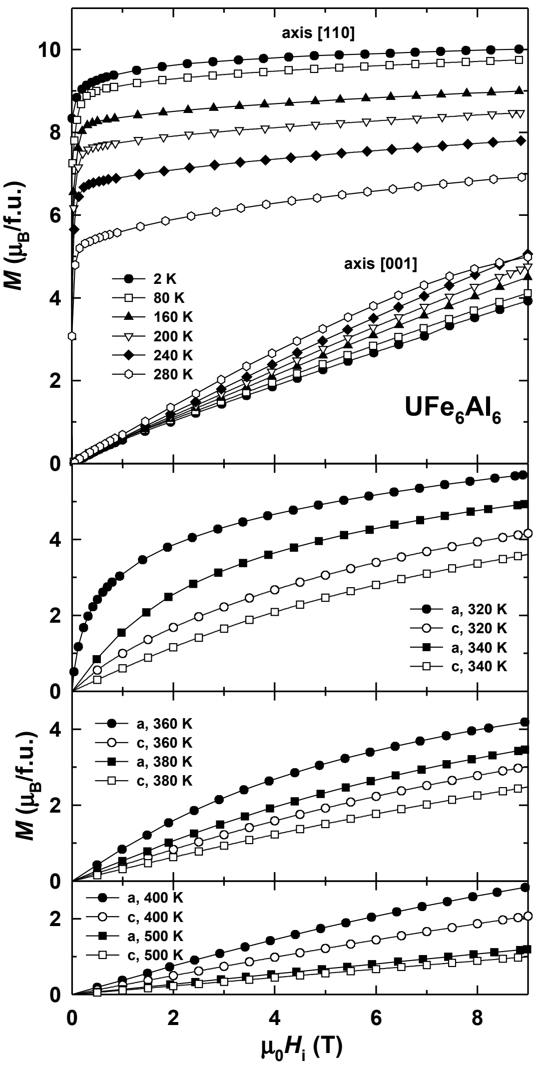

Fig. 1. Magnetization isotherms in fields applied in the basal plane and along the *c* axis of UFe_6Al_6.

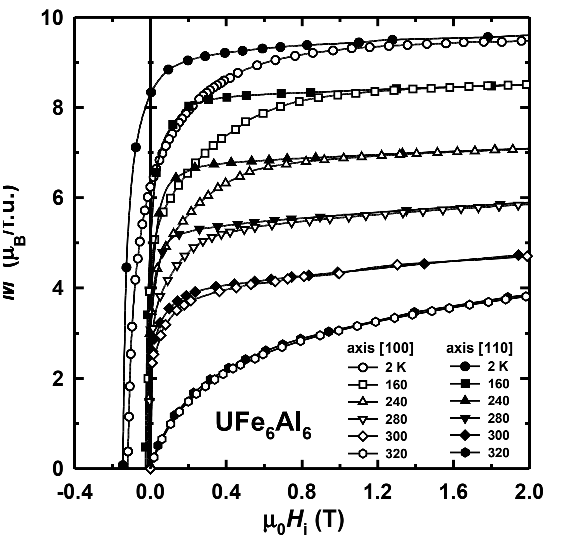

Fig. 2. Magnetization isotherms in fields applied along the *a* and *b* axes in the basal plane.

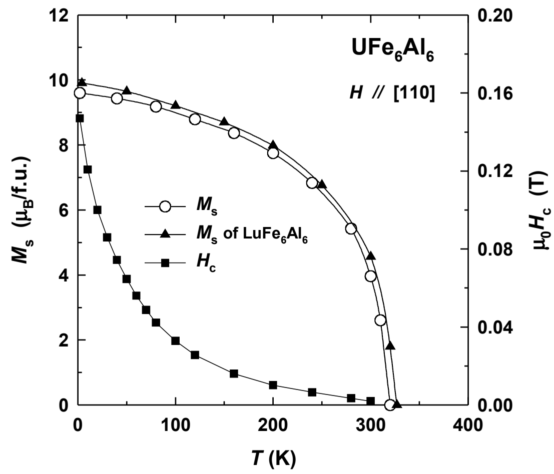

Fig. 3. Temperature dependence of M_s of UFe_6Al_6 and $LuFe_6Al_6$ and coercive field of UFe_6Al_6.

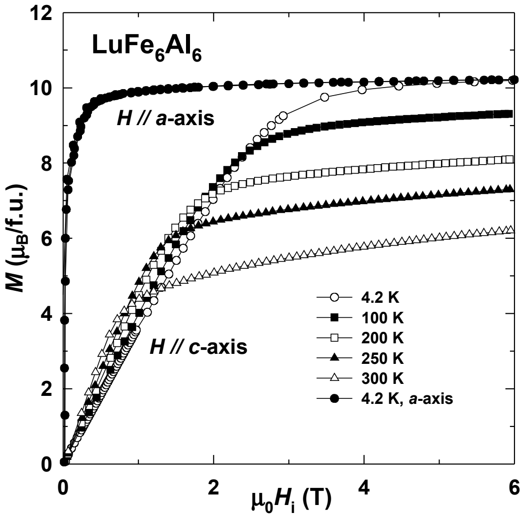

Fig. 4. Magnetization isotherms in fields applied in along the *c* axis of $LuFe_6Al_6$. The *a*-axis curve at 4.2 K is presented as well.

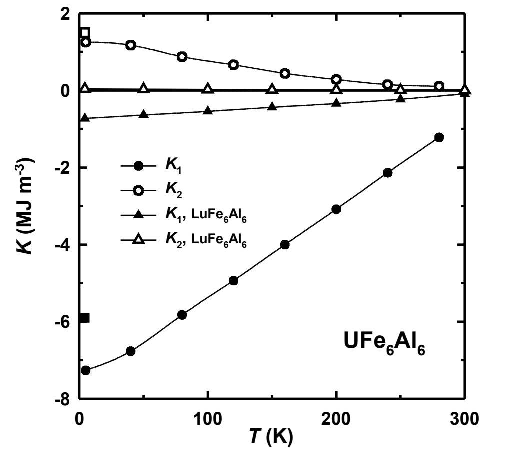

Fig. 5. Temperature dependence of anisotropy constants of UFe_6Al_6 and $LuFe_6Al_6$. Squares represent K_1 and K_2 values calculated from *M*(*H*) of Ref. [1].

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