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High-field magnetization of a $Dy_2Fe_{14}Si_3$ single crystal

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ABSTRACT

The magnetization of a $Dy_2Fe_{14}Si_3$ single crystal was measured at 4.2 K in pulsed fields up to 51 T along the principal axes. The compound orders ferrimagnetically at 500 K, has a spontaneous magnetic moment of 8 μ_B/f.u. (at 4.2 K) and exhibits a very large magnetic anisotropy, ⟨1 0 0⟩ being the easy axis. In fields applied along the ⟨1 0 0⟩ and ⟨1 2 0⟩ axes, field-induced phase transitions are observed at 33 T and at 39 T, respectively. The *c*-axis magnetization curve crosses the easy-axis curve at 19 T. At higher fields, for all directions, the magnetization continues to increase due to further bending of the sublattice moments. Temperature evolution of magnetic anisotropy and magnetic hysteresis are discussed as well.

1. Introduction

Dy_2Fe_{17} belongs to the R_2T_{17} family of rare-earth (R = Ce–Lu) intermetallic compounds with late 3d transition metals T. It has the hexagonal crystal structure of the Th_2Ni_{17} type characteristic for heavy R. As found from single-crystal measurements, the spontaneous magnetic moment M_s = 16.8 μ_B/f.u. (per formula unit) in the ground state is located in the basal plane along the *a* axis [1–3]. The compound is a collinear ferrimagnet. In such compounds, field-induced phase transitions are expected from the collinear ferrimagnetic structure through canted structure to final collinear ferromagnet. This has indeed observed in Ho_2Co_{17} [4] and later been shown to occur in many other ferrimagnetic R_2Fe_{17} and R_2Co_{17} compounds with easy-plane type of anisotropy. The high-field magnetic transitions, that take place in these compounds if the field is applied within the basal-plane directions, are based on the competition between the Zeeman energy (strength of the applied field) and the strength of the 4f–3d exchange interaction. For Dy_2Fe_{17}, the transitions at 54 T for magnetic field *H* along the *a*-axis [1 0 0] and at 70 T along the *b*-axis [1 2 0] have been predicted [5]. To observe both transitions, one needs magnetic field up to 75 T which is currently not available for magnetization measurements of metallic systems. However, if the strength of the intersublattice coupling is reduced, for example, by dilution of the Fe sublattice, the transitions can be observed at still high but achievable fields.

A study of the Si solid solutions in R_2Fe_{17}, $R_2Fe_{14}Si_3$, performed on polycrystalline samples [6], has revealed a strong modification of both the intra- and inter-sublattice interactions compared to R_2Fe_{17}. The effect is rather complicated, because the Fe-sublattice moment is weakened by the dilution with the non-magnetic Si, whereas the Fe–Fe exchange interaction is unexpectedly enhanced (T_C is 370 K in Dy_2Fe_{17} and 500 K in $Dy_2Fe_{14}Si_3$). Our single-crystal study of $Dy_2Fe_{14}Si_3$ [7] has shown that the transition fields indeed decrease, to 33 and 39 T, along the *a* and *b* axis, respectively. In the present paper we show experimental results in more detail and perform their theoretical analysis absent in [7].

2. Experimental

The single crystal of $Dy_2Fe_{14}Si_3$ of 20 mm length and 4 mm diameter has been grown by a modified Czochralski method in a tri-arc furnace from a stoichiometric mixture of the pure elements (99.9% Dy, 99.98% Fe and 99.999% Si). The lattice parameters determined by X-ray powder diffraction, *a* = 840.8 pm, *c* = 826.8 pm, are in good agreement with the literature [6]. The magnetization was measured along the [1 0 0] (*a*), [1 2 0] (*b*) and [0 0 1] (*c*) axes by extraction method in steady fields up to 5 T at 4.2–300 K using a commercial SQUID magnetometer (Quantum Design). The high-field magnetization has been measured in the Center for Quantum Science and Technology under Extreme Conditions (KYOKUGEN) at Osaka University, at pulsed

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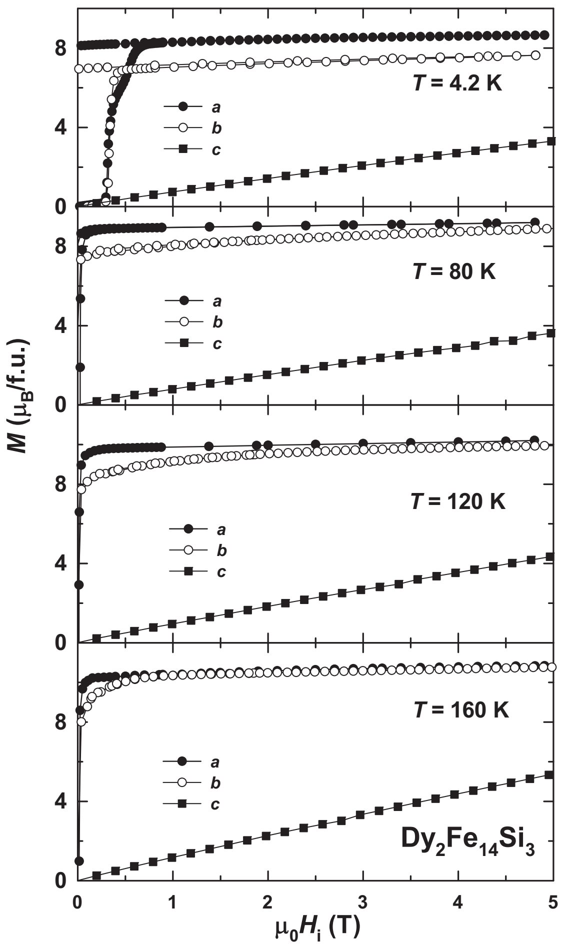

Fig. 1. Magnetization curves of a $Dy_2Fe_{14}Si_3$ single crystal measured along the principal axes at $T = 4.2–160$ K.

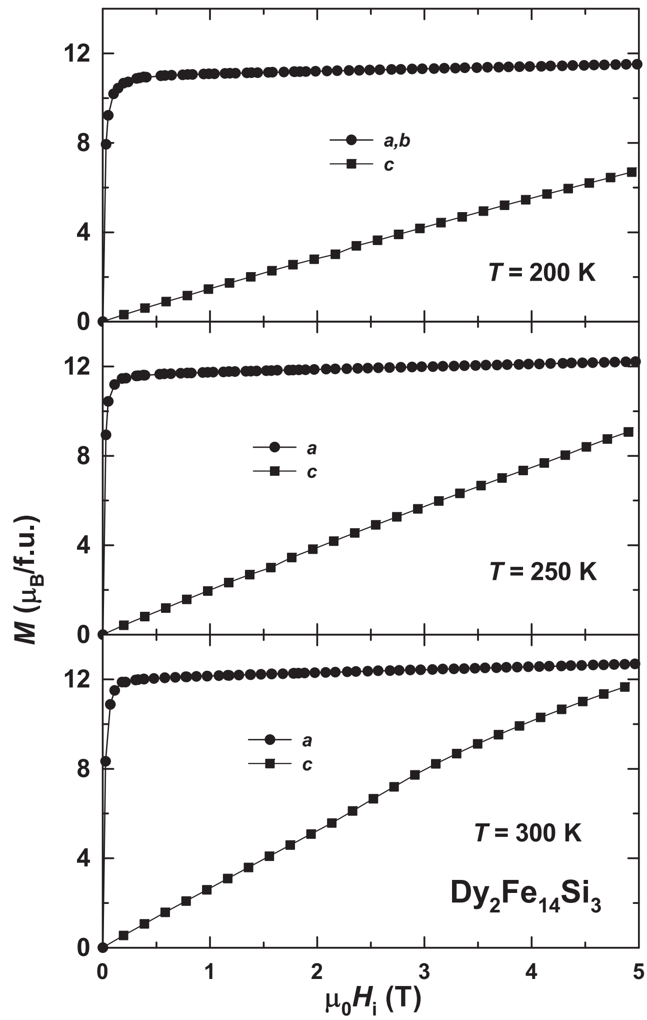

Fig. 2. The same as Fig. 1, for $T = 200–300$ K.

fields up to 52 T with pulse duration of 20 ms at 4.2 K. The magnetization curves presented in this paper have been corrected for demagnetizing field.

3. Results and discussion

Figs. 1 and 2 show the magnetization curves measured along the principal axes at different temperatures. It is seen that $Dy_2Fe_{14}Si_3$ is a highly anisotropic ferrimagnet with the easy *a* axis. The ferrimagnetic arrangement of the Dy and Fe sublattices is manifest in Figs. 1 and 2, where M_s grows with temperature. It is also seen in Fig. 3, where temperature dependence of magnetization of $Dy_2Fe_{14}Si_3$ in 1 T measured along the easy axis is compared with that for $R_2Fe_{14}Si_3$ with non-magnetic Y and Lu [8]. The magnetic isotherm measured with the field applied along the *a*-axis exhibits $M_s = 8\ \mu_B$/f.u. at 4.2 K. If one subtracts this value from $M_s = 26\ \mu_B$/f.u. for $Y_2Fe_{14}Si_3$, which can be considered as the magnetic moment of the Fe sublattice M_{Fe} in $Dy_2Fe_{14}Si_3$, the magnetic moment of the Dy sublattice M_{Dy} is equal to 18 μ_B/f.u., in fair agreement with 2 free-ion values of Dy^{3+} (20 μ_B).

As seen from Figs. 1 and 2, a pronounced anisotropy within the basal plane vanishes above 160 K, where the *b* and *a* axis magnetization curves coincide. The anisotropy between the basal plane and the *c* axis persists at much higher temperatures; the anisotropy field still exceeds 5 T at 300 K.

At low temperatures, the basal-plane magnetization curves of $Dy_2Fe_{14}Si_3$ exhibit a characteristic strong hysteresis with a very low initial susceptibility, an abrupt saturation in narrow field inter-

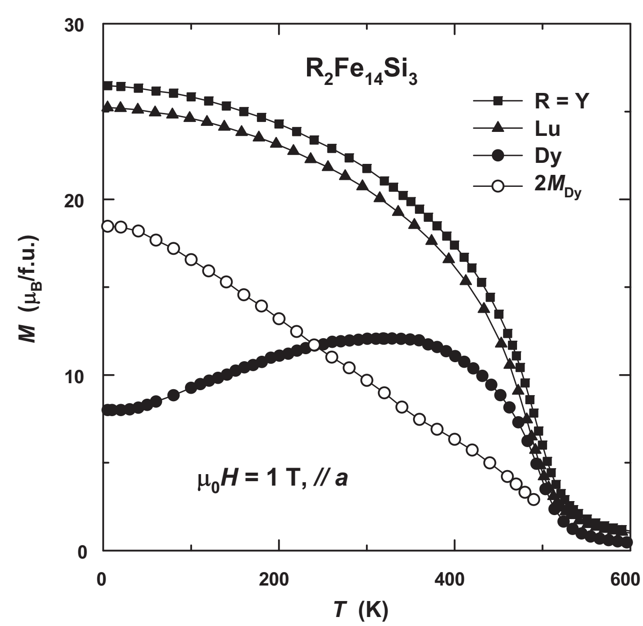

Fig. 3. Temperature dependence of magnetization of $R_2Fe_{14}Si_3$ single crystals measured along the *a* axis in field of 1 T.