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Magnetic properties of $\text{Er}(\text{Fe}, \text{Ni})_{10}\text{Si}_2$ compounds

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Abstract

The magnetic properties of $\text{ErFe}_{10-x}\text{Ni}_x\text{Si}_2$ compounds with $x = 0, 2, 3, 3.5, 4, 4.5$ have been studied by measuring magnetization curves of free-powder samples at 4.2 K in fields up to 38 T and by measuring the temperature dependence of the AC susceptibility in the temperature range 4.2–300 K. In these compounds, the antiparallel alignment of the Er- and 3d-sublattice moments is broken in the applied fields and a bending process of the two sublattice magnetizations is observed. An oscillatory behaviour of the magnetization is found which can be explained by taking into account the magnetic anisotropies of both the Er- and the 3d-sublattice up to K_4 . Below room temperature, a spin-reorientation is observed in all compounds. The spin-reorientation temperature increases with increasing Ni content.

1. Introduction

$\text{RFe}_{10}\text{Si}_2$ compounds (R = rare earth) form in the ThMn_{12} -type tetragonal structure in which the Fe sublattice, according to results on $\text{YFe}_{10}\text{Si}_2$, has uniaxial anisotropy [1, 2]. The competition between the anisotropies of the R- and Fe-sublattices results in a spin-reorientation transition at low temperature for the heavy-rare-earth compounds with $\alpha < 0$ [2]. The R-Fe interaction and also the Fe-Fe interaction have been determined for various $\text{RFe}_{10}\text{Si}_2$ compounds (R = Y, Sm, Gd, Tb, Dy, Ho, Er, Tm) from an analysis of the experimental results by means of mean-field theory [2, 3]. The magnetic anisotropy of the R ions and the spin-reorientation transitions in this type of compounds have been analysed in terms of CEF theory [4, 5]. Higher-order crystal-field parameters are needed to explain the spin-reorientation transition observed in Er compounds. In this paper, we present results on the R-Fe coupling and the complex magnetic anisotropy of

the $\text{ErFe}_{10-x}\text{Ni}_x\text{Si}_2$ compounds derived from the free-powder magnetization and the spin-reorientation transitions in these compounds.

2. Sample preparation and experiments

$\text{ErFe}_{10-x}\text{Ni}_x\text{Si}_2$ compounds with $x = 0, 2, 3, 3.5, 4, 4.5$ were prepared in an arc furnace under purified argon by melting together appropriate amounts of the pure metals. The ingots were wrapped into Ta foil and annealed in a quartz tube filled with purified argon at 1050°C for three weeks. The annealed samples were quenched into water. X-ray diffraction showed the compounds to possess the tetragonal ThMn_{12} structure. Only small amounts of impurity phases were present.

The magnetization of free-powder samples was measured at 4.2 K in fields up to 38 T in the High-Field Facility at the University of Amsterdam. The AC susceptibility was measured on bulk samples in the temperature range 4.2–300 K.

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3. Results and discussion

The free-powder magnetization at 4.2 K of $\text{ErFe}_{10-x}\text{Ni}_x\text{Si}_2$ compounds is shown in Fig. 1. It can be seen in Fig. 1 that, since substitution of Ni for Fe reduces the net magnetization ($M_T - M_{\text{Er}}$), the magnetization values below the first critical field decrease systematically with increasing Ni content. At the same time, since the first critical field is equal to $n_{\text{ErT}}(M_T - M_{\text{Er}})$ if the T-anisotropy is neglected, the values of this field also decrease with increasing Ni content. We can estimate the dependence of the Fe moment on x by assuming that Er has its free-ion value and find that the Fe moment is nearly constant ($\sim 2.0 \mu_B/\text{Fe}$) which indicates that Ni has no magnetic moment in this type of compounds.

Above the first critical field, the magnetization varies either in a discontinuous way or in an oscillatory way for the compounds with $x = 2.0, 3.0, 3.5, 4, 4.5$. Fig. 2 shows dM/dB versus B for these compounds. It can be seen that for $x > 2$, jumps and oscillations occur, and for $x = 2$ only a jump occurs. This complex behaviour may be attributed to the magnetic anisotropy: as mentioned before [6, 7], in this type of compounds the competition between the T- and the Er-sublattice anisotropies may lead to a spin-reorientation. Therefore, the influence of the T-sublattice anisotropy on the magnetization cannot

Fig. 1. Free-powder magnetization at 4.2 K of $\text{ErFe}_{10-x}\text{Ni}_x\text{Si}_2$ compounds.

Fig. 2. Field dependence of dM/dB at 4.2 K for $\text{ErFe}_{10-x}\text{Ni}_x\text{Si}_2$ compounds.

be neglected. As an example, in the following we will describe the magnetization process of the compounds with $x = 2$ by assuming that only two magnetic sublattices (the Er- and the T-sublattice) exist in this compound and by taking into account the magnetic anisotropies of both sublattices.

The free energy of a single-crystalline particle that can freely rotate in an external field can be written as

$$E = K_1^{\text{Er}} \sin^2 \vartheta_{\text{Er}} + K_2^{\text{Er}} \sin^4 \vartheta_{\text{Er}} + K_3^{\text{Er}} \sin^6 \vartheta_{\text{Er}} \\ + K_1^{\text{T}} \sin^2 \vartheta_{\text{T}} + K_2^{\text{T}} \sin^4 \vartheta_{\text{T}} \\ + n_{\text{ErT}} M_{\text{Er}} M_{\text{T}} \cos(\vartheta_{\text{Er}} - \vartheta_{\text{T}}) - B M,$$

where M is the total magnetization in the field direction

$$M = \sqrt{M_{\text{Er}}^2 + M_{\text{T}}^2 + 2M_{\text{Er}}M_{\text{T}} \cos(\vartheta_{\text{Er}} - \vartheta_{\text{T}})},$$

ϑ_{Er} and ϑ_{T} are the polar angles of M_{Er} and M_{T} . The anisotropy within the basal plane is not taken into account here and we used a result obtained earlier [6] that, if the anisotropy within the basal plane is not taken into account, the vectors of the magnetic moment and the external field will lie in the same plane. The magnetization can be derived from the free energy by minimizing it with respect to the angles ϑ_{Er} and ϑ_{T} . The fitted magnetization curve of $\text{ErFe}_8\text{Ni}_2\text{Si}_2$ is shown in Fig. 3. The following values for the magnetic anisotropy constants of the two sublattices and for the intersublattice coupling constant have been obtained, $K_1^{\text{Er}} = -3.22 \times 10^{-22} \text{ J/f.u.}$, $K_2^{\text{Er}} = -1.71 \times 10^{-22} \text{ J/f.u.}$, $K_3^{\text{Er}} = 4.08 \times 10^{-22} \text{ J/f.u.}$ and $K_1^{\text{T}} = 1.12 \times 10^{-22} \text{ J/f.u.}$, $K_2^{\text{T}} = 2.86 \times 10^{-22} \text{ J/f.u.}$ From these values one can derive that at 4.2 K in $\text{ErFe}_8\text{Ni}_2\text{Si}_2$ there is a cone angle between the easy-magnetization direction and c -axis. The cone angle is about 50° . Fig. 3

Fig. 3. Comparison of calculated and measured magnetization curves of $\text{ErFe}_8\text{Ni}_2\text{Si}_2$ and the field dependence of the angles θ_{Er} and θ_{T} .

Fig. 4. Temperature dependence of the AC susceptibility of $\text{ErFe}_{10-x}\text{Ni}_x\text{Si}_2$ compounds.

also shows the field dependences of the angles θ_{Er} and θ_{T} . The intersublattice-coupling constant is about $2.5 \times 10^{23} \text{ T f.u./A m}^2$. This corresponds to an exchange energy J_{ErT}/k (where T refers to the formula RT_{12}) of

about 5.8 K. It can be seen from Fig. 3 that the transition at about 35 T is well reproduced.

The temperature dependence of the AC susceptibility of all compounds is shown in Fig. 4. In all compounds, a spin-reorientation is observed and the spin-reorientation temperature increases with increasing Ni content. This result shows that at 4.2 K the anisotropy constant K_1 ($K_1 = K_1^{\text{Er}} + K_1^{\text{T}}$) is negative in all compounds. This is in agreement with the fitting results above. The increase of the transition temperature with increasing Ni content shows that the T-sublattice anisotropy decreases with increasing x . Below the transition temperature, the easy-magnetization direction departs from c -axis and the cone angle increases with increasing Ni content. Therefore, the easy-magnetization direction of the compounds will tend to lie within the basal plane when x is large enough and, in this case, the anisotropy in the basal plane will play a role and lead to an oscillating magnetization. Due to the different types of magnetic anisotropies of the Er- and T-sublattices, for the compound with sufficiently large Ni content (according to Fig. 2, x should be larger than 2), the bending process of the two sublattice moments will occur in three dimensions, i.e. the two sublattice moments and the external field will not always be confined to one plane. This will be discussed in a forthcoming paper.

References

- [1] K.H.J. Buschow, D.B. de Mooij, M. Brouha, H.H.A. Smit and R.C. Thiel, IEEE Trans. Magn. 24 (1987) 1161.
- [2] Qingan Li, Yi Lu, Ruwen Zhao, O. Tegus and Fuming Yang, J. Appl. Phys. 70 (1991) 6116.
- [3] P. Stefanski, A. Szlaferek and A. Wrzeciono, Phys. Stat. Sol. B 156 (1989) 657.
- [4] P. Stefanski and A. Wrzeciono, Phys. Stat. Sol. B 151 (1989) K195.
- [5] P. Stefanski, A. Kowalczyk and A. Wrzeciono, J. Magn. Magn. Mater. 101 (1991) 97.
- [6] Z.G. Zhao, X. Li, J.H.V.J. Brabers, P.F. de Châtel, F.R. de Boer and K.H.J. Buschow, J. Magn. Magn. Mater. 123 (1993) 74.
- [7] Z.G. Zhao, N. Tang, F.R. de Boer, P.F. de Châtel and K.H.J. Buschow, Physica B 193 (1994) 45.