ELSEVIER

Journal of Alloys and Compounds 218 (1995) L1–L3

Journal of ALLOYS AND COMPOUNDS

Letter

Structure and magnetic properties of $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ ($x=0$–1.0) compounds prepared by arc melting

Shao-ying Zhang, Bao-gen Shen, Bing Liang, Jun-xian Zhang, Zhao-hua Cheng, Fang-wei Wang, Hua-yang Gong

State Key Laboratory of Magnetism, Institute of Physics, Chinese Academy of Sciences, P.O. Box 603, Beijing 100080, People's Republic of China

Received July 12 1994

Abstract

The effects of substitution of Y for Sm on the structure and magnetic properties of $Sm_2Fe_{14}Ga_3C_2$ compounds are studied. Alloys with composition $(sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ ($x=0$, 0.2, 0.4, 0.6, 0.8, 1.0) are prepared by arc melting. X-ray diffraction shows that they are almost single phase compounds of the Th_2Zn_{17}-type structure. The lattice constants, the unit cell volume and Curie temperature decrease with increasing yttrium concentration. The room temperature saturation magnetization enhances from 83.3–103.2 emu g^{-1}, as x increases from 0–1.0. The substitution of Y for Sm decreases the uniaxial anisotropy of the R sublattice, resulting in a monotonous decrease of anisotropy field from 99 kOe for $x=0$ to 20 kOe for $x=0.8$.

Keywords: Magnetic properties; Arc melting; Anisotropy

1. Introduction

The introduction of nitrogen or carbon atoms into the lattice of R_2F_{17} dramatically increases the Curie temperature and the saturation magnetization, as well as modifies the anisotropy [1,2]. In general, the $R_2Fe_{17}N_y$ and $Re_2Fe_{17}C_y$ with high nitrogen or carbon concentration can easily be obtained by gas-solid reaction, however, the major drawback of these nitrides or carbides is their high-temperature unstability. In our previous work, we discovered that the highly stable $R_2Fe_{17}C_x$ compounds with high carbon concentrations can be formed by the substitution of Ga, Si, Al, etc. for Fe [3–5]. We have succeeded in preparing the single phase compounds of high-carbon $R_2(Fe, M)_{17}C_y$ ($M=Ga$, Si, Al) with the Th_2Zn_{17}-type or Th_2Ni_{17}-type structures by arc melting. It was found that the arc-melted $Sm_2Fe_{14}Ga_3C_y$ compounds with $y=0$–2.5 exhibit an easy c-axis anisotropy at room temperature and show an anisotropy field of higher than 90 kOe for $y \geqslant 1.5$ [3]. The substitution of non-magnetic Ga for Fe in $Sm_2Fe_{17}C_y$ compounds, however, results in the decrease of the saturation magnetization. In order to improve the saturation magnetization of $Sm_2(Fe, Ga)_{17}C_y$ compounds, we have studied the effects of the substitution of non-magnetic Y for Sm. In this paper, the structure and intrinsic magnetic properties of $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ compounds with $0 \leqslant x \leqslant 1.0$ prepared by arc melting are studied.

2. Experimental

Iron and carbon were first melted into Fe–C alloys. Samples with the composition $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ ($x=0$, 0.2, 0.4, 0.6, 0.8, 1.0) were prepared by arc melting the elements Sm, Y, Fe, Ga and Fe–C alloy in a high-purified argon atmosphere. All samples were melted four times to ensure homogeneity. Elements used were at least 99.9% pure. The arc-melted ingots were annealed in an argon atmosphere at 1430 K for 48 h. X-Ray diffraction measurements on powder samples were performed using CuKα to determine the crystallographic structure and phase components. The Curie temperatures were determined from the temperature dependence of the magnetization measured by a vibrating sample magnetometer in a magnetic field of 1 kOe. The aligned samples for anisotropy field measurements were prepared by mixing the powder with epoxy resin and then aligning in a magnetic field of 10 kOe. The saturation magnetization was measured by an extracting sample magnetometer in a field of 65

0925-8388/95/$09.50 © 1995 Elsevier Science S.A. All rights reserved
SSDI 0925-8388(94)01405-1

kOe. The anisotropy field was determined from magnetization curves along and perpendicular to the orientation direction by using the extracting sample magnetometer with a magnetic field of up to 65 kOe.

3. Results and discussions

The X-ray diffraction patterns of non-aligned and aligned $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ ($x=0.4$) samples are shown in Fig. 1. All samples of $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ after homogenization annealing are found to be almost single phase compounds of the Th_2Zn_{17}-type structure with a few percent of α-Fe. The substitution of Ga for Fe has a significant effect on the stability of the crystal structure of high-carbon $Sm_2Fe_{17}C_y$ with 2:17-type structure [3]. The lattice constants *a* and *c*, and the unit cell volumes *v* of $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ compounds are listed in Table 1. It can be seen that the lattice constants and unit cell volumes decrease linearly with increasing Y concentration. This behaviour is a result of the smaller ionic radius of Y as compared with Sm.

The Curie temperatures of $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ compounds are found to decrease with the increase of Y concentration, shown in Fig. 2(a). In the rare-earth iron compound, the Curie temperature is mainly determined by the exchange interaction between Fe–Fe atoms, which is strongly dependent on the Fe–Fe interatomic distance. It has been evidenced in the previous studies of the magnetic properties of rare-earth iron compounds that in many cases the enhancement in Curie temperature is primarily owing to the lattice expansion induced by interstitial or substitutional additions [1,6]. The volume effect is also evident in the data shown in Fig. 2(a). As Sm is replaced by non-magnetic Y, the lattice shrinks and the interatomic distance decreases which results in the reduction of the Fe–Fe exchange interaction. In addition, substitution of Sm by non-magnetic Y in $Sm_2Fe_{17}Ga_3C_2$ reduces the R–Fe exchange interaction. These are the reasons of the sharp drop in T_C.

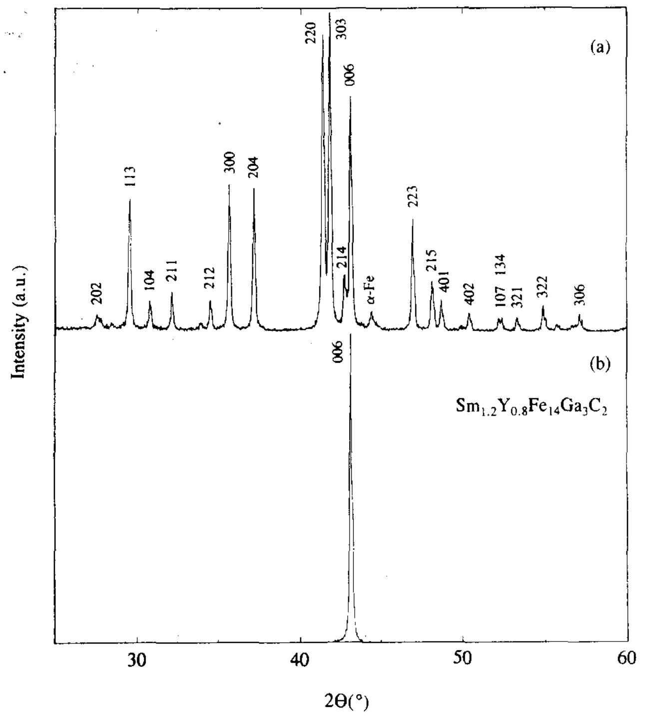

Fig. 1. X-Ray diffraction patterns of (a) non-aligned and (b) aligned $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ samples with $x=0.4$.

Table 1
The lattice parameters *a* and *c*, and unit cell volumes *v* of the $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ compounds

$(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$	*a* (Å)	*c* (Å)	*v* (Å^3)
$x=0.0$ [3]	8.747	12.621	836.2
0.2	8.747	12.614	835.7
0.4	8.737	12.608	833.4
0.6	8.733	12.610	832.9
0.8	8.725	12.613	831.5
1.0	8.715	12.610	829.4

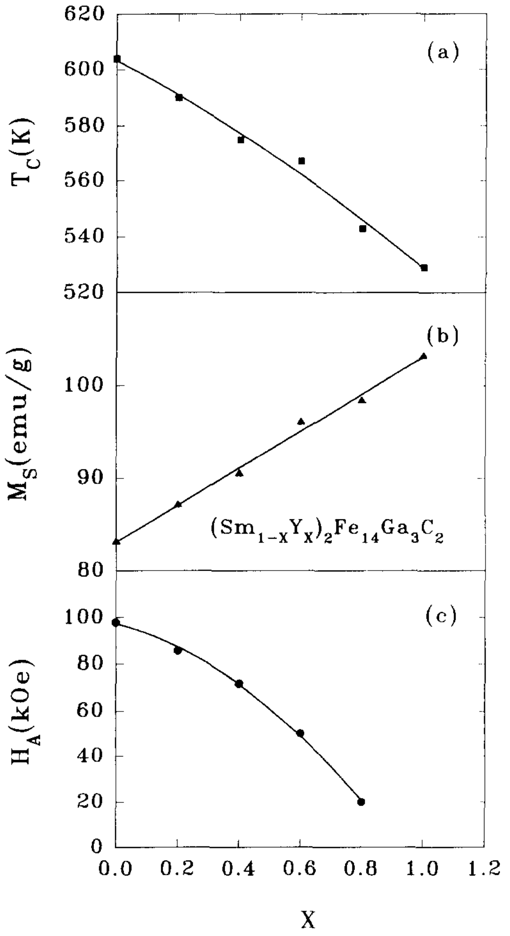

Fig. 2. (a) The Curie temperature T_C, (b) the room temperature saturation magnetization M_s and (c) the room temperature anisotropy field H_A of $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ compounds as a function of Y concentration.

The room temperature magnetizations plotted in Fig. 2 (b) show a large rise as Sm is replaced by Y in $Sm_2Fe_{17}Ga_3C_2$ compounds. The origin of this rise may be a subtle consequence of the crystal-field interaction as discussed by Malik et al. [7]. Under some conditions, specifically, the relative values of the crystal-field interaction and exchange, Sm^{3+} and Co in $SmCo_5$ couple antiferromagnetically. The behaviour displayed in Fig. 2 (b), like the results in $(Sm_{1-x}Y_x)_2Fe_{17}N$ compounds [8], suggest a similar effect. Antiferromagnetic Sm–Fe coupling, and the absence of a moment on Y in the 2:17 compounds, enhance the saturation magnetization.

All compounds investigated in this work exhibit an easy c-axis anisotropy at room temperature, except for $Y_2Fe_{14}Ga_3C_2$. Fig. 1 (b) shows the X-ray diffraction pattern of magnetically aligned powder sample of $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ with $x=0.4$. A strong (0, 0, 6) reflection and the absence of (h, k, 0) indicate the characteristics of a uniaxial magnetocrystalline anisotropy. Fig. 3 shows the magnetization curves of the $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ ($x=0$–0.8) samples measured along and perpendicular to the aligned directions at room temperature. The anisotropy field H_A estimated from magnetization curves are shown in Fig. 2 (c) as a function of Y concentration x. The anisotropy field of $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ compounds decrease monotonically with x. The magnetocrystalline anisotropy in the rare-earth iron compounds results from the competing of the R sublattice and the Fe sublattice. It is observed that planar Sm_2Fe_{17} becames uniaxial when interstitial or substitution additions in the Sm_2Fe_{17} compounds. The addition of interstitial N, C [1,2], or an appropriate amount of Ga, Al [4,6] in the Sm_2Fe_{17} leads to a strong increase of the uniaxial anisotropy of the Sm sublattice. If so, it is expected that diluting Sm with non-magnetic yttrium will reduce the anisotropy field. H_A will be reduced linearly with composition if size difference is ignored and single ion anisotropy theory obtained. The data in Fig. 2 (c), however, show that H_A is not linear with composition. This indicates that Y doesn't act as a mere diluent. The room temperature anisotropy field is found to be higher than 70 kOe for $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ compounds with $x \leqslant 0.4$.

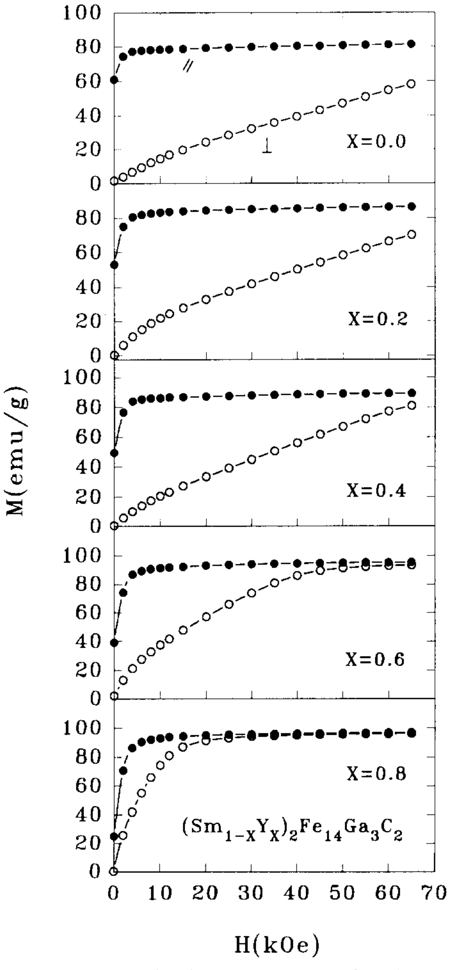

Fig. 3. The magnetization curves of the orientated $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ ($x=0$–0.8) samples measured along and perpendicular to the aligned directions at room temperature.

In summary, the substitution of Y for Sm in $Sm_2Fe_{14}Ga_3C_2$ compounds can improve the saturation magnetization, and result in the decrease of the uniaxial anisotropy. The anisotropy field for $(Sm_{1-x}Y_x)_2Fe_{14}Ga_3C_2$ with $x \leqslant 0.4$ maintains higher than 70 kOe. The lattice constants, the unit cell volume and the curie temperature decrease linearly with x.

Acknowledgements

This work was supported by the National Natural Science Foundation of China. The authors wish to express their gratitude to T.S. Ning and M. Hu for their assistance in the X-ray diffraction experimental, and to S.Y. Fan for his assistance in the magnetic parameter measurements.

References

[1] J.M.D. Coey and Hong Sun, *J. Magn. Magn. Mater.*, *87* (1990) L251.
[2] J.M.D. Coey, Hong Sun, Y. Otani and D.P.F. Hurley, *J. Magn. Magn. Mater.*, *98* (1991) 76.
[3] Bao-gen Shen, Lin-shu Kong, Fang-wei Wang and Lei Cao, *Appl. Phys. Lett.*, *63* (1993) 2288.
[4] Zhao-hua Cheng, Bao-gen Shen, Fang-wei Wang, Jun-xian Zhang, Hua-yang Gong and Jian-gao Zhao, *J. Phys.: Condens. Mater.*, *6* (1994) L185.
[5] Bao-gen Shen, Fang-wei Wang, Lin-shu Kong, Lei Cao and Wen-shan Zhan, *J. Appl. Phys.*, *75* (1994) 6253.
[6] Bao-gen Shen, Fang-wei Wang, Lin-Shu Kong and Lei Cao, *J. Phys.: Condens. Mater.*, *5* (1993) L685.
[7] S.K. Malik, W.E. Wallace and R. Vijayaragrava, *Phys. Rev. B*, *19* (1979) 1671.
[8] M.Q. Huang, Y. Zheng, K. Miller, J.M. Elbicki, S.G. Sankar and W.E. Wallace, *J. Appl. Phys.*, *70* (1991) 6024.