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Magnetic properties of $Y(Co_{1-x}Fe_x)_{10}Si_2$ compounds

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Abstract

The magnetic properties of $Y(Co_{1-x}Fe_x)_{10}Si_2$ ($x = 0.0, 0.2, 0.4, 0.6, 0.8, 1.0$) compounds have been studied. All compounds crystallize in $ThMn_{12}$ type structures. The lattice parameters a and c increase with increasing iron content, while the Curie temperature has a maximum at about $x = 0.6$. The easy magnetization direction at room temperature changes from basal plane to the c-axis at about $x = 0.2$. The anisotropy field obtained by the SPD technique reaches a maximum at $x = 1.0$, with values of 2.1 T at room temperature and 2.6 T at 77 K respectively.

Keywords: Magnetocrystalline anisotropy; Singular point detection; Uniaxial anisotropy

1. Introduction

The R–Co compounds which have suitable magnetic properties for permanent magnet materials, such as RCo_5 and R_2Co_{17}, have been extensively investigated [1,2], but the main components of these compounds are comparatively expensive. Many attempts were made during the 1970s to use iron-based compounds [3]. Since the $Nd_2Fe_{14}B$ compound was discovered as a permanent magnet material, research on iron-rich rare earth transition-metal intermetallic compounds has attracted much attention. Rare earth transition-metal intermetallic compounds of different transition-metals show many similar structural properties, but different magnetic properties, for example Curie temperature and magnetocrystalline anisotropy. However, in different structures a given transition-metal element may show different magnetic properties. For example, the cobalt sublattice anisotropy in the R_2Co_{17} structure proved not to be uniaxial, while there is an extremely large magnetocrystalline anisotropy in the RCo_5 structure due to the cobalt sublattice. It is well known that fairly accurate measurements of critical fields can be made using polycrystalline specimens and the singular point detection of discontinuous magnetization processes (SPD) technique [4]. The anisotropy fields for compounds of uniaxial anisotropy at room temperature can also be obtained from the intersection point of two magnetization curves, measured in the magnetic fields applied parallel and perpendicular to the alignment direction of the powder samples.

In order to investigate the effects on magnetic properties due to the substitution of Co for Fe, we have studied the magnetic properties of the $Y(Co_{1-x}Fe_x)_{10}Si_2$ compounds. The anisotropy fields of these compounds have been obtained by the two different methods noted above.

2. Experimental process

Alloys of the stoichiometric composition $Y(Co_{1-x}Fe_x)_{10}Si_2$ compounds were prepared by arc-melting of 99.9% pure materials in a purified argon atmosphere. An additional amount of Y was added to compensate for loss in the melting and annealing processes. The ingots were annealed at 1173–1473 K for 4–10 h in an argon atmosphere, followed by quenching to room temperature. X-ray diffraction with Cu Kα radiation was employed to determine the phases present in the alloys and the lattice parameters.

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X-ray diffraction patterns of the magnetically aligned powder samples obtained at room temperature were used to determine the easy magnetization direction of these compounds. The thermomagnetic analysis ($\sigma(T)$) in a low field strength of 0.04 T was performed from room temperature to 900 K. The Curie temperature T_c was determined from $\sigma^2 - T$ plots by extrapolating σ^2 to zero.

The magnetic isotherms were recorded with the external field applied either parallel or perpendicular to the alignment direction of the cylindrical samples. The latter were prepared by aligning powder particles at room temperature in a magnetic field strength of 1 T, applied parallel and perpendicular to the cylinder axis, and by fixing their direction with epoxy resin. The anisotropy fields at room temperature were determined from the intersection point of two magnetization curves measured in the magnetic field applied parallel and perpendicular to the alignment direction of the cylindrical samples. We also determined the anisotropy fields at room temperature by means of the singular point detection technique.

3. Results and discussion

X-ray diffraction patterns and thermomagnetic analysis show that all compounds crystallize in $ThMn_{12}$ type structures with α-Fe as impurity phase. The movement of the diffraction peaks towards the smaller angles shows that there is expansion of the unit cell volume on going from $x = 0$ to 1.0. From Fig. 1 and Table 1 it can be seen that the lattice parameters increase with increasing Fe content, due to the larger radius of iron. The unit cell volume increases by about 5.6% at $x = 1.0$.

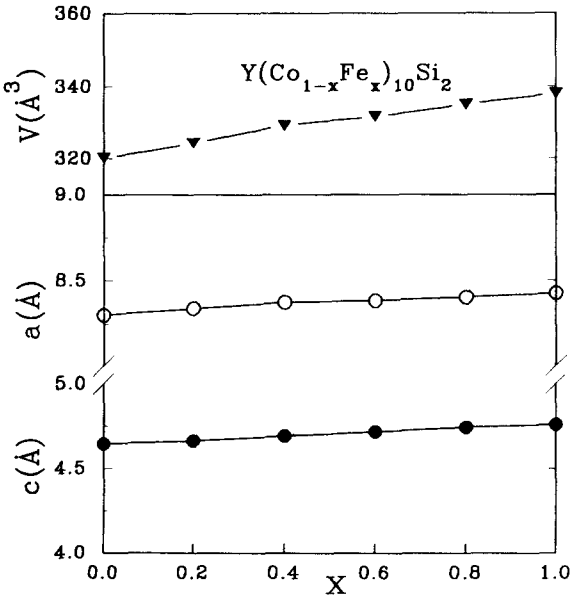

Fig. 1. Lattice parameters of the $Y(Co_{1-x}Fe_x)_{10}Si_2$ compounds.

Table 1
Lattice parameters a, c and V, Curie temperature T_c and anisotropy field B_a of the $Y(Co_{1-x}Fe_x)_{10}Si_2$ compounds at 77 and 300 K

x	a (Å)	c (Å)	V (Å^3)	T_c (K)	B_a(300 K) (T)	B_a(77 K) (T)
0.0	8.30	4.64	320.19	709	—	—
0.2	8.34	4.66	324.36	743	—	—
0.4	8.38	4.69	329.24	—	0.746	0.726
0.6	8.39	4.72	331.67	764	1.315	1.279
0.8	8.40	4.74	335.08	670	1.904	2.091
1.0	8.43	4.76	338.01	554	1.970	2.565

X-ray diffraction patterns of the magnetically aligned powder samples are shown in Fig. 2. It can be seen that when $x > 0.2$ the (002) peak of the diffraction patterns of the aligned samples is dominant, which shows that the easy magnetization direction is along the c-axis. The change of easy magnetization direction with decreasing Fe content is a consequence of the fact that the Fe sublattice magnetization has its preferred direction parallel to the c-axis while the Co sublattice magnetization prefers a direction perpen-

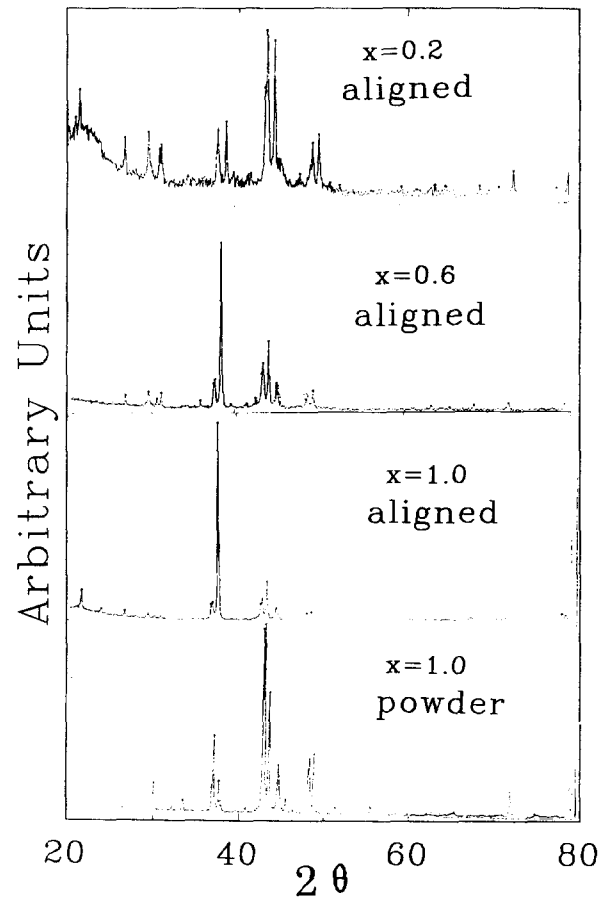

Fig. 2. X-ray diffraction patterns of $YFe_{10}Si_2$ powder and $Y(Co_{1-x}Fe_x)_{10}Si_2$, $x = 0.2$, 0.6, 1.0 aligned powder samples.

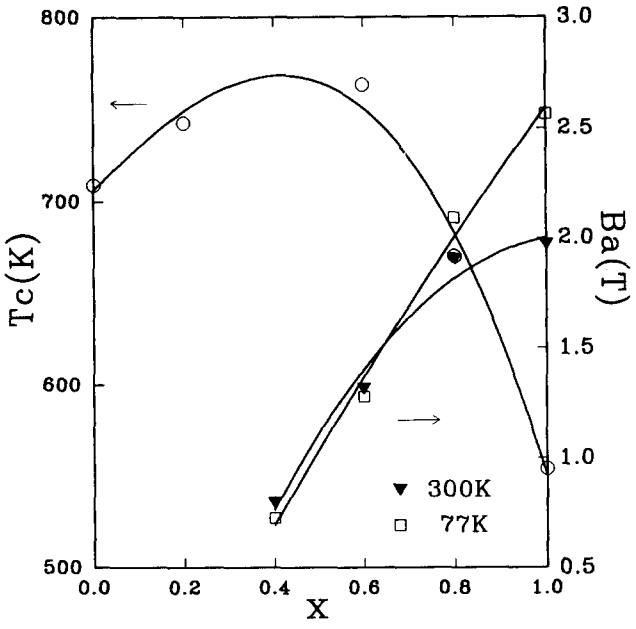

Fig. 3. Curie temperature, anisotropy fields at 77 and 300 K, of $Y(Co_{1-x}Fe_x)_{10}Si_2$ compounds.

dicular to the c-axis. This result is similar to that observed in the $R_2Fe_{14-x}Co_xB$ system [5]. From Fig. 3 it can be seen that the Curie temperature at first increases with Fe content, reaches a maximum at about $x = 0.6$, then decrease with further increasing Fe content. It is well known that the iron moment is larger than the cobalt moment in a given type of compounds. Generally, the opposite is true with regard to the case of exchange coupling constants J_{TT} acting on the spins. So, according to the mean field analysis of the Curie temperature it can be understood that the T_c increase for $x < 0.6$ is the result of an enhancement of the 3d exchange interactions, as the iron atoms have larger magnetic moment than the cobalt atoms. For $x > 0.6$ the decrease of T_c may be due to the smaller J_{TT} for iron-rich compounds.

The SPD patterns of aligned samples at room temperature are shown in Fig. 4. A discontinuous rise can be found in the first derivative dM/dH for $x > 0.2$, which indicates that these compounds have uniaxial anisotropy at room temperature. These results are in agreement with those from X-ray diffraction of aligned samples. We have obtained the anisotropy fields B_a at room temperature and 77 K from the intersection point of two magnetization curves measured in the magnetic field applied parallel and perpendicular to the alignment direction of the cylindrical samples, and by means of singular point detection technology respectively. The tendencies of B_a obtained by the two methods are similar, but the values show a small difference. The values derived from the SPD data are shown in Fig. 3. It can be seen that the anisotropy fields at room temperature and 77 K increase with

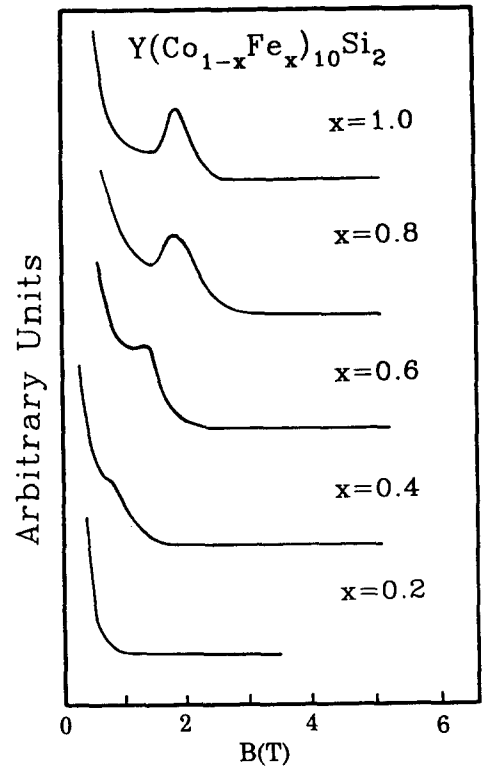

Fig. 4. SPD patterns of the $Y(Co_{1-x}Fe_x)_{10}Si_2$ compounds at 300 K.

increasing iron content. The anisotropy fields of these compounds at 77 K and room temperature are also listed in Table 1. It can easily be seen that the anisotropy fields at 77 K are larger that those at room temperature for $x > 0.6$ samples, in contrast to the $x \leq 0.6$ samples. The results may be associated with a different temperature dependence of the iron and cobalt sublattice magnetizations. It is well known that, in this system, the contributions of iron and cobalt to the magnetocrystalline anisotropy field are opposite. The Fe sublattice magnetization has its preferred direction parallel to the c-axis while the Co sublattice magnetization prefers a direction perpendicular to the c-axis. From the experimental results it can be seen that the anisotropy contribution of cobalt increases more rapidly than that of iron in these compounds.

4. Conclusion

All compounds crystallize in $ThMn_{12}$ type structures. The lattice parameters increase with increasing iron content while the Curie temperature has a maximum at about $x = 0.6$. The basal planar anisotropy of the cobalt atoms can be maintained only for small Fe concentration, and leads to a change in the easy magnetization direction at $x = 0.2$. The anisotropy field at room temperature and at 77 K increases with increasing iron content.

Acknowledgement

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