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Magnetoresistance and hyperfine fields in $Sm_xFe_{80-x}B_{20}$ amorphous alloys

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Abstract

The influence of samarium on the magnetic and electron transport properties of amorphous $Sm_xFe_{80-x}B_{20}$, $0 \leqslant x \leqslant 6$, was investigated by Mössbauer spectroscopy and by electrical resistivity and magnetoresistance measurements. The resistivity of the alloys increases by about 5% in the temperature range from 78 to 290 K. For $Sm_6Fe_{74}B_{20}$ ribbons a positive contribution to the magnetoresistance was found. The averaged value of the ^{57}Fe hyperfine magnetic field decreases slightly with increasing samarium content. Variations in the line intensities of Mössbauer spectra recorded for ribbons at 78 K indicate a rotation of magnetization towards the normal to the ribbon via positive magnetostriction.

1. Introduction

Ferromagnetic amorphous metals have received a great deal of attention both from a scientific as well as a technological point of view. Their physical properties depend on their composition. The influence of the rare earth (RE) ion admixtures on the magnetic and electron transport properties of iron-based alloys is caused by the RE–3d exchange interactions and by the crystal field splitting of 4f levels [1]. There is weak dependence of the resistivity on the temperature in amorphous alloys and the change in the resistivity typically does not exceed 10% in the temperature range 4.2–290 K. The scattering of electrons by the structural disorder is the main reason for the high value of the resistivity (100 $\mu\Omega$ cm) of amorphous alloys.

Among other spectroscopic methods, Mössbauer spectroscopy is a particularly suitable technique for studying properties of amorphous metals since it probes the nature of the intermediate surroundings of the resonating atoms. Because of the variety of environments that exist in amorphous alloys for each atomic species, one finds, instead of unique properties, broad distributions of the spectral parameters such as hyperfine field, quadrupole splitting and isomer shift.

This paper presents the results of investigations performed on amorphous alloys of $Sm_xFe_{80-x}B_{20}$ ($0 \leqslant x \leqslant 6$) by Mössbauer spectroscopy and by electrical resistivity and magnetoresistance measurements.

2. Experimental details

Amorphous alloys of $Sm_xFe_{80-x}B_{20}$ were prepared over the composition range $0 \leqslant x \leqslant 6$. The preparation of the samples and their magnetic properties have been described elsewhere [2].

The electrical resistivity and transverse magnetoresistance in constant magnetic fields up to 1.6 T were measured with a relative accuracy of 10^{-5} using a conventional four-point d.c. technique. The magnetic field was parallel to the plane of the ribbons.

The ^{57}Fe Mössbauer absorption spectra of amorphous $Sm_xFe_{80-x}B_{20}$ ($x = 1$, 2, 5 and 6) with the γ rays perpendicular to the absorber plane were recorded at 78 and 295 K. A $^{57}Co(Cr)$ Mössbauer source and a constant-acceleration Mössbauer spectrometer of the Polon type were used. The source was always kept at room temperature. A high purity metallic iron foil was used for calibration of the velocity scale of the Mössbauer spectra. Absorbers of total area 3 cm^2 were formed from powdered alloys or from suitably arranged ribbons 1.5 mm wide. The ribbons were free of external stress. A least-squares computer program was used to derive distributions of the hyperfine field from the Mössbauer absorption spectra. The isomer shift was assumed to be proportional to the hyperfine field when a field distribution was used in the computing procedure.

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3. Results and discussion

The amorphous nature of the $Sm_xFe_{80-x}B_{20}$ alloys was checked by the X-ray diffraction method. The X-ray diffraction patterns of ribbons in the as-quenched state exhibit a diffused broad maximum. From the radial distribution function given elsewhere it follows that the ribbons contain areas with stoichiometry Sm:2Fe and B:3Fe [3]. Stoichiometric and magnetic parameters suggest that the ribbons are composed of Bernal cells which form a deformed Laves phase net of the $MgCu_2$ type [4].

The temperature dependence of the resistivity of the investigated alloys is shown in Fig. 1. The resistivity increases by about 5% as the temperature rises from 77 to 290 K. This behaviour is typical and confirms the amorphous nature of the investigated ribbons.

It is interesting to investigate the influence of an external magnetic field on the transport properties of amorphous alloys. The very small mean free path of the conducting electrons in amorphous alloys suppresses the Lorentz force component of the magnetoresistance and therefore one can obtain information about the magnetic component of the resistivity. The magnetoresistance of amorphous ferromagnetic alloys can be divided into two parts: the magnetoresistance in low magnetic fields and the magnetoresistance in high magnetic fields; the first is caused by the technical magnetization process and the second by the para-process in high magnetic field. The magnetoresistance of the $Sm_xFe_{80-x}B_{20}$ amorphous ribbons measured in constant magnetic fields up to 1.6 T is shown in Fig. 2. The magnetoresistance for the $x=2$ and 4 compositions is typical for ferromagnetic alloys. In fields above technical saturation it decreases almost linearly with increasing magnetic field. For the $Sm_6Fe_{74}B_{20}$ alloy, however, the slope of the magnetoresistance curve changes from negative to positive (Fig. 2) as the external magnetic field increases.

In order to obtain some microscopic insight to the properties of the investigated amorphous alloys, we used Mössbauer spectroscopy since it can distinguish non-equivalent near-neighbour configurations of the resonating atoms. Mössbauer measurements were carried out at 78 and 295 K on powdered samples ($x=1$, 5 and 6) and ribbons ($x=1$, 2, 5 and 6) of the $Sm_xFe_{80-x}B_{20}$ amorphous alloys. A few selected ^{57}Fe absorption spectra are shown in Figs. 3 and 4. The broadening of the spectra is due to a distribution of the hyperfine parameters. The field distribution diagrams derived from the Mössbauer absorption spectra are shown in Fig. 5. The averaged values of the hyperfine magnetic field as well as values of the standard deviation

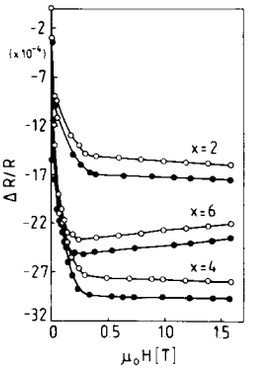

Fig. 2. Transverse magnetoresistance of $Sm_xFe_{80-x}B_{20}$ amorphous ribbons measured at room temperature (○) and liquid nitrogen temperature (●) in constant magnetic fields up to 1.6 T.

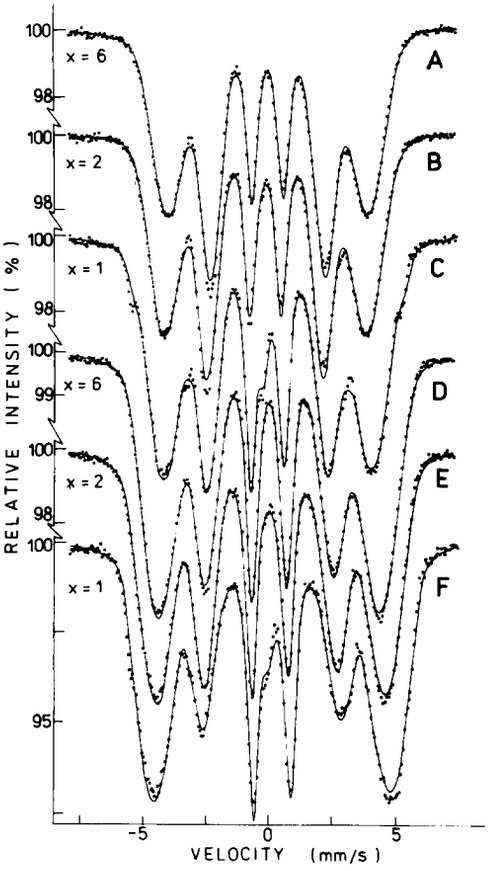

Fig. 3. ^{57}Fe Mössbauer absorption spectra recorded at 295 K (A–C) and 78 K (D–F) for $Sm_xFe_{80-x}B_{20}$ amorphous ribbons.

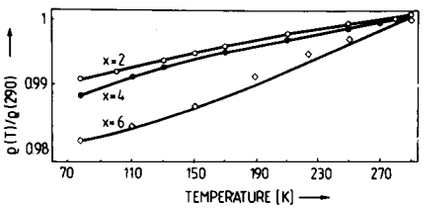

Fig. 1. Temperature dependence of the normalized resistivity of $Sm_xFe_{80-x}B_{20}$ amorphous ribbons.

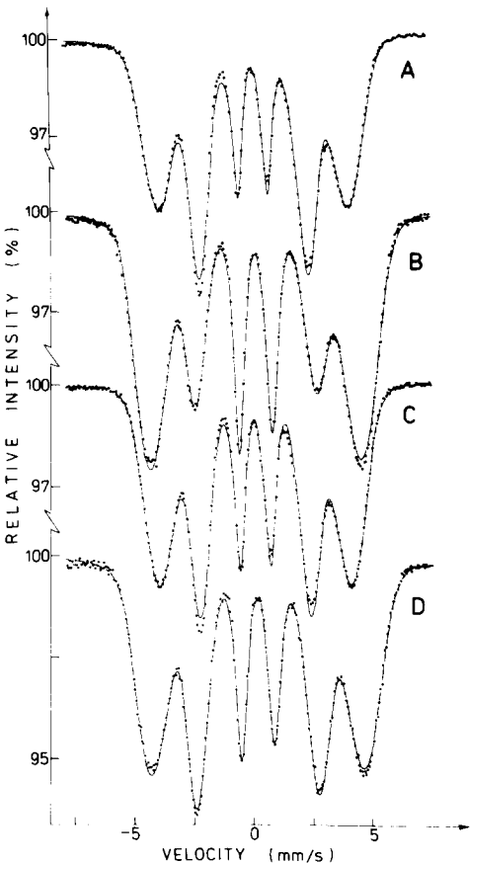

Fig. 4. ^{57}Fe Mössbauer absorption spectra recorded at room (A, C) and liquid nitrogen (B, D) temperatures for $Sm_5Fe_{75}B_{20}$ amorphous alloy: A, B, ribbons; C, D, powder.

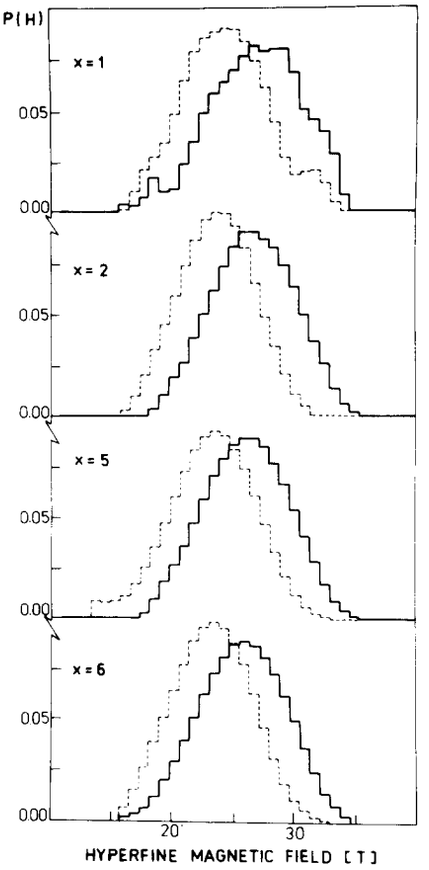

Fig. 5. Diagrams of ^{57}Fe hyperfine magnetic field distributions derived from Mössbauer absorption spectra recorded at 78 K (—) and 295 K (– – –) for amorphous $Sm_xFe_{80-x}B_{20}$ ribbons.

and the asymmetry parameters of the field distribution are compiled in Table 1.

As can be seen from the field distribution diagrams (Fig. 5) and from the corresponding parameters (Table 1), the presence of samarium has only a small influence on the hyperfine fields in the alloys investigated. The mean value of the hyperfine field decreases slightly with increasing samarium content, which might be expected.

The Mössbauer absorption spectra shown in Figs. 3 and 4 possess a small asymmetry in the line intensities. It originates from correlations between the hyperfine parameters [5]. In order to describe this asymmetry, we have assumed that there is a proportionality relation between the isomer shift and the hyperfine field when using the field distribution fitting procedure. The proportionality parameters were found to have positive values at both room (about 0.7×10^{-3} mm s^{-1} T^{-1}) and liquid nitrogen (about 4.4×10^{-3} mm s^{-1} T^{-1}) temperatures.

A very interesting feature of the Mössbauer spectra recorded at 78 K for $Sm_xFe_{80-x}B_{20}$ ribbons is the pronounced decrease in intensity of the second and fifth lines (see Figs. 4 and 5 and the C parameter in Table 1). From the line intensities the average magnetization direction can be determined with no external field applied. This property of Mössbauer spectra is very useful for the amorphous metal–metalloid alloys, which generally have a very small coercivity. For an infinitely thin Mössbauer absorber placed perpendicular to the propagation direction of the γ rays, the ratio of the intensities of the second and fifth lines to the total spectral intensity is given by $C=0.5\sin^2\theta$, where θ is the average angle between the magnetic moments and the direction perpendicular to the plane of the absorber. The largest value of the relative intensity of the second and fifth lines ($C=0.5$) would be obtained if all domain vectors were oriented parallel to the absorber plane, whereas the smallest value ($C=0$) would be obtained if all domain vectors were oriented perpendicular to the absorber plane. A random space distribution of the domain vectors would lead to $C=\frac{1}{4}$.

For macroscopically isotropic materials with low coercivity (such as our ribbons) the net magnetization lies predominantly in the plane, as a result of the demagnetizing field, or can be rotated out of the plane by

TABLE 1. Mean values of ^{57}Fe hyperfine fields (H) and values of standard deviations (S.Dev.) and asymmetry parameters (Asym.) of hyperfine field distributions derived from Mössbauer absorption spectra recorded at 78 and 295 K for amorphous $Sm_xFe_{80-x}B_{20}$

Alloy		T (K)	H (T)	S.Dev. (T)	Asym.	C
$x=1$	R	78	27.3	3.8	−0.31	0.23
	P	78	27.8	3.4	−0.05	0.37
	R	295	24.8	3.6	0.18	0.33
	P	295	24.9	3.8	0.07	0.35
$x=2$	R	78	27.2	3.3	−0.01	0.32
	R	295	24.1	3.0	0.00	0.38
$x=5$	R	78	26.5	3.4	−0.03	0.26
	P	78	26.5	3.4	−0.13	0.35
	R	295	23.6	3.6	−0.20	0.38
	P	295	23.9	3.0	0.00	0.38
$x=6$	R	78	26.1	3.5	−0.17	0.29
	P	78	26.2	3.3	−0.06	0.37
	R	295	23.8	3.1	0.04	0.40
	P	295	23.7	3.1	0.01	0.38
Error		±0.5	±0.3	±0.3	±0.08	±0.03

R, ribbons; P, powder; T, temperature; C, contribution of second and fifth spectral lines to total spectral intensity.

small perturbations. Very often the sign of the magnetostriction determines the magnetization direction of soft ferromagnetic materials in the presence of stress. When the magnetostriction is positive, the domain vectors align in the direction perpendicular to a compressive stress, but when the magnetostriction is negative, the alignment of the domain vectors tends to be parallel to the stress. Tensile stress influences the domain vectors in the opposite manner. In freshly prepared ferromagnetic amorphous ribbons inhomogeneities are common, mainly on the surfaces. During rapid solidification both sides of the ribbon, especially that facing the substrate, freeze much faster than the bulk portion of the ribbon and both of them depart from the stabilized state by a larger amount than the bulk. As a result of thermal contraction on cooling to room temperature, a large tensile stress is exerted on the bulk by the ribbon sides. Thus the preferred plane orientation of domain magnetization indicated by Mössbauer spectroscopy for as-quenched ribbons [6, 7] is not only the result of the demagnetizing field but also of the tensile stress due to quenched surfaces via positive magnetostriction. The stress can be released or even reversed by annealing of the ribbon. When the stress is reversed, an increase in the number of out-of-plane magnetic domains in the bulk of the ribbon can be observed by Mössbauer spectroscopy [7].

In previous studies of $Sm_xFe_{80-x}B_{20}$ ribbons [3] it was shown that the ribbons are magnetostrictive and that the sign of magnetostriction is positive. The ribbons were stored at room temperature for about 2 years before the Mössbauer spectra were recorded. During this long aging process the stress produced in the ribbons by thermal contraction should be released. However, both oxide and crystalline phases must have been formed in the surface layers during storage of the ribbons. The decrease in intensity of the second and fifth lines of the Mössbauer absorption spectra recorded for our ribbons at 78 K (see Figs. 4 and 5 and the C parameter in Table 1) indicates a rotation of the domain vectors towards the direction perpendicular to the ribbon plane. This may be related to the compressive stress exerted on the bulk of the ribbon (via positive magnetostriction) by the formation of higher density crystalline surface layers. A similar phenomenon has been observed previously by other investigators [8–12] at room temperature. Crystallization and oxidation of the surface layers of annealed or aged ribbons were confirmed by conversion electron Mössbauer spectra [9–12]. A completely crystallized sample has a much higher density than the as-quenched sample. Thus even partially crystallized surface layers contract, thereby exerting compressive stress on the bulk of the ribbon. The values of the thermal linear expansion coefficients of our ribbons are not known but are assumed to be smaller than those of the oxide and crystalline surface phases. For amorphous $Fe_{83}B_{17}$, which has a composition close to those of our alloys, the thermal linear coefficient was found to be zero above room temperature [13].

The influence of rotation of the domain magnetization on the shape of the Mössbauer spectra is specific for ribbons. Owing to a random space distribution of the domain vectors in the powdered alloys, the C parameter determined for the powdered absorbers is close to $\frac{1}{3}$ (see Table 1) within experimental error, which might be expected.

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