Physical and Chemical Properties of FINEMET-Type Amorphous Alloys

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Influence of composition variations on the physical and chemical properties of rapidly quenched NANOPERM-type, FeNbCuB, and FINEMET--type, Fe(Ni)NbCu(Si)B, alloys in amorphous states, is investigated by Mössbauer spectroscopy, magnetic and electrochemical methods. While the partial substitution of Si for B leads to weak effects, that of Ni for Fe results in pronounced changes of both magnetic properties and chemical stability.

PACS numbers: 75.50.Kj, 75.60.Nt

1. Introduction

Nanocrystalline alloys attract interest due to their exceptional soft magnetic properties [1] making them useful for numerous technical applications [1, 2]. They can be prepared by various methods either directly in one process, e.g, by mechanical alloying [3], or indirectly through an amorphous precursor with a subsequent controlled heat treatment [2]. The present contribution is focused on one NANOPERM- and two FINEMET-type alloys prepared by the latter method. Our main aim is to get complex view on these alloys; here we summarize results obtained for their as-quenched amorphous states by using a broad spectrum of experimental techniques.

2. Experimental details

The planar flow casting was used for production of samples in the form of ribbons approximately 9 mm wide and 29 μm thick with the nominal compositions of $Fe_{80}Nb_3Cu_1B_{16}$ (FM1), $Fe_{80}Nb_3Cu_1Si_6B_{10}$ (FM2), and $Fe_{33.5}Ni_{40}Nb_3Cu_1Si_{13.5}B_9$ (FM3). The conversion electrons Mössbauer spectroscopy (CEMS) was used to check the amorphous structure of ribbon surfaces ($\approx$ 300 nm) from both sides while the γ-ray Mössbauer spectroscopy in transmission geometry was applied for bulk measurements. The ribbon surfaces are visually distinguished. The surface which was in direct contact with cooling wheel is matt and will be denoted by "m" while the other surface exposed to surrounding atmosphere is shiny and will

be denoted by "s". The spectra were taken at room temperature (RT) using
^{57}Co/Rh source and evaluated using CONFIT program package [4]. Velocity scale
was calibrated with standard pure α-iron foil at RT.

The magnetic measurements were done by a vibrating sample magnetome-
ter. The coercivity and magnetic polarization data were obtained from the RT
hysteresis curves ($H_{\max} = \pm 1.2$ MA/m). The thermomagnetic curves were mea-
sured in temperature interval of $(300 \div 1000)$ K in vacuum using temperature
sweep of 4 K/s and external field of 4 kA/m.

The corrosion resistance was studied by means of potentio-dynamic polar-
ization measurements. They were performed in 3.5% NaCl solution (pH 6.5) in a
330 ml cell with standard three electrode arrangement (working, Ag/AgCl refer-
ence and Pt counter electrode). The exposed area was 0.5 cm^2. After recording
the free corrosion potential for 30 min, the polarization scan was started at 250 mV
relative to the free corrosion potential with a scan rate of 0.2 mV/s.

3. Results and discussion

The transmission Mössbauer spectra (Fig. 1, bottom) were analyzed using
two Gaussian distributions of hyperfine induction, which corresponds to varying
local environments of resonating iron atoms in amorphous systems. No traces
of crystallization were observed. The hyperfine parameters of amorphous phase
are related to the iron near neighbors. The partial substitution of Si for B leads
to negligible changes in hyperfine parameters as documented by nearly identical
values of the isomer shifts (IS), the quadrupole splittings (EQ) and the mean
values of hyperfine induction (B_{mean}) for the FM1 and FM2 samples: $IS = 0.040 \pm$
0.001 mm/s, $EQ = 0.010 \pm 0.001$ mm/s, $B_{\mathrm{mean}} = 21.0 \pm 0.7$ T. On the other hand,
the partial substitution of Ni for Fe (FM3) causes significant changes: $EQ =$
0.020 ± 0.002 mm/s, $IS = 0.164 \pm 0.005$ mm/s, $B_{\mathrm{mean}} = 14.0 \pm 0.5$ T, in good
agreement, e.g., with Ref. [4]. The same model was used also for evaluation of
the CEMS spectra of shiny and matt surfaces of the samples, except for the FM2
sample where discrete sextuplets had to be added for a crystalline bcc-Fe(Si) phase
(Fig. 1, top and middle). The presence of the crystalline phase is more pronounced
at the shiny surface (Fig. 1, FM2, s).

The results obtained from magnetic measurements are summarized in Table.
The transition of amorphous phase from the ferromagnetic into a paramagnetic
state occurs below the onset of crystallization for all samples. In analogy to the
hyperfine parameters, the Curie temperatures T_{C} of the FM1 and FM2 samples
nearly coincide whereas that of the FM3 sample deviates significantly. This is in
good agreement with observations of other authors [5]. The same is also valid
for the crystallization temperature T_{cr} as well as for the saturation and remanent
polarization J_{s}, J_{r}, respectively. Let us note that the trend of J_{s} corresponds
roughly to variations of B_{mean}. On the contrary, the coercivity H_{c} is fairly sensitive
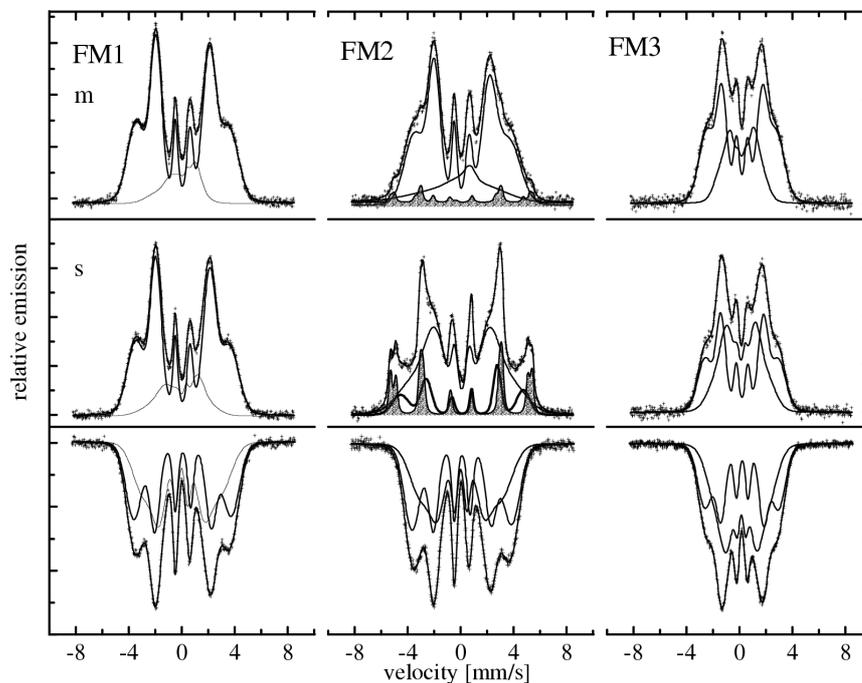to both substitutions.

Fig. 1. CEMS spectra of the FM1, FM2, and FM3 samples: matt (m) and shiny (s) surfaces. The bottom parts show the γ-rays Mössbauer spectra.

TABLE

Properties of the FM1, FM2, and FM3 samples: Curie (T_C) and crystallization (T_{cr}) temperatures, coercivity (H_c), magnetic polarizations — saturated (J_s) and remanent (J_r), and corrosion rates on matt (r_{corrm}) and shiny (r_{corrs}) surfaces.

Sample	T_C	T_{cr}	H_c	J_s	J_r	r_{corrm}	r_{corrs}
	[K]	[K]	[kA/m]	[T]	[T]	[mm/year]	[mm/year]
FM1	530	693	0.89	1.506	0.149	0.629	0.285
FM2	528	703	1.46	1.559	0.148	0.737	0.865
FM3	404	773	1.08	0.735	0.080	0.006	0.002

The electrochemical data (Table) show that Ni alloying (FM3) results in a marked decrease in the corrosion rates and improvement of chemical stability in agreement with cyclic voltammetry experiments [6]. The reactivity of the matt surface is higher as compared to the shiny surface for the FM1 and FM3 samples, whereas the opposite relation is observed for the FM2 sample, most probably owing to the observed surface crystallization (see Fig. 1). This explanation can be correlated with the Mössbauer phase analysis of the FM2 sample which re-

sulted in a higher degree of crystallization of the shiny surface. The formation of nanocrystals in the amorphous structure contributes to a larger inhomogeneity accompanied by enhanced probability of interphase corrosion.

4. Conclusions

The investigations of three FINEMET-type alloys, FM1, FM2, and FM3, in the as-quenched amorphous states have revealed weak influence of the substitution of silicon for boron on the hyperfine parameters, the Curie temperature and the magnetic polarization; the only magnetic property sensitive to this alloying is the coercivity. On the other hand, the substitution of nickel for iron leads to pronounced changes not only in all magnetic parameters but it has also an outstanding effect on electrochemical stability.

Acknowledgments

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