The Mössbauer study of magnetic permeability enhancement effect in the $Fe_{86-x}Nb_xB_{14}$ (x=5, 6) amorphous alloys

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It is well known that soft magnetic properties (initial magnetic permeability, coercive field) of amorphous alloys based on iron can be significantly improve by applying a suitable thermal annealing at temperatures close to the crystallization temperature. The magnetic permeability enhancement effect is usually explained by formation of a nanocrystalline phase i.e. by formation of nanograins of αFe and/or αFe(Si) embedded in amorphous matrix [1-6]. Especially interesting is an enhancement magnetic properties effect without forming a nanostructure because it makes possible to obtain very a good soft magnetic material essentially free of embrittlement - a typical disadvantage of nanostructured materials.

The aim of the presentation is to study the mechanism of the soft magnetic properties enhancement effect for two amorphous alloys of nanoperm family - namely $Fe_{81}Nb_5B_{14}$ and $Fe_{80}Nb_6B_{14}$ [7]. As-quenched ribbons were annealed for one hour in temperature range T_a from 300 to 900 K, and for annealed samples the following measurements were carried out at room temperature:

Fig.1 shows initial magnetic permeability μ determined at room temperature plotted versus 1-h annealing temperature T_a. In both cases $\mu(T_a)$ passes by a distinct maximum situated at the so-called 1-h optimization annealing temperature T_{op}.

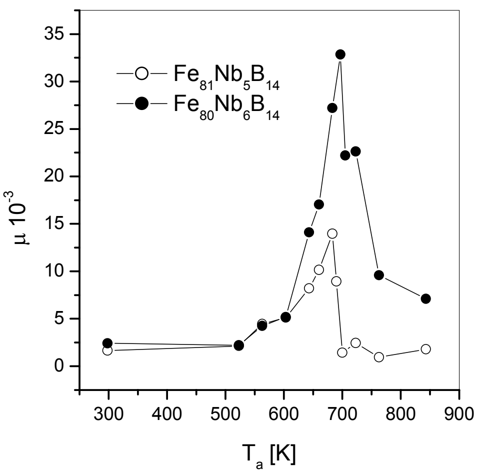

Fig. 1. Initial magnetic permeability determined at room temperature for samples annealed for 1-h at temperatures T_a

From Fig.1 it can be recognized that T_{op}=680 K and 700 K for the $Fe_{81}Nb_5B_{14}$, and $Fe_{80}Nb_6B_{14}$ alloys, respectively. In samples annealed at temperature T_{op} coercive field has a minimum value (about 2 A/m) and thermal/time instabilities (typical for amorphous state) monitored by magnetic after-effect $\Delta\mu/\mu$, practically disappeared. The observed dependences are characteristic features of the crystallization already occurred. Similar results were obtained for the second examined alloy.

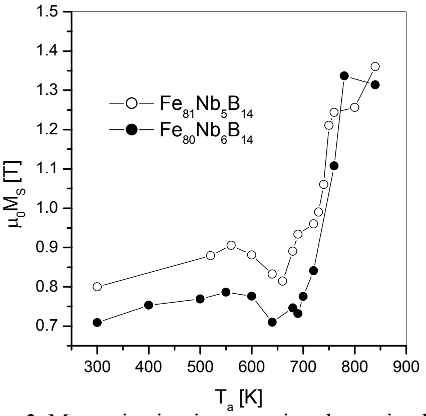

Fig. 2. Magnetization in saturation determined at room temperature for samples preliminary annealed for 1-h at temperatures T_a.

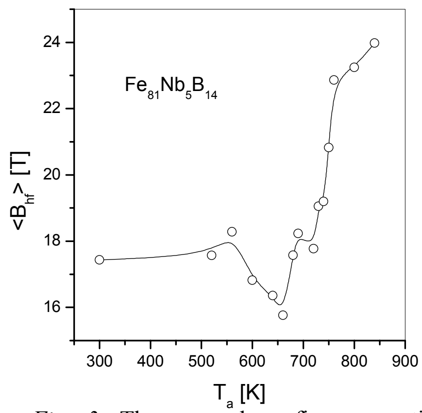

Fig. 3. The mean hyperfine magnetic field determined at room temperature for samples preliminary annealed for 1-h at temperatures T_a.

Figure 2 presents the magnetization in saturation M_S determined at room temperature for samples after 1-h annealing at temperatures T_a plotted versus T_a. Two characteristic features are important i.e. a deep in M_s observed in the range $600<T_a<700$ K and a strong increase for $T_a>750$ K. While the increase in magnetization is due to nanocrystallization, the significant decrease in M_S occurs in amorphous phase and precedes the enhancement permeability effect.

The Mössbauer spectra determined for preliminary annealed samples were numerically analyzed by means of hyperfine field distribution method [8]. In order to take into account the observed asymmetry of lines, a linear relation between isomer shift (IS) and hyperfine magnetic field B_{hf} was assumed in fitting procedure. The mean value of field $<B_{hf}(T_a)>$ determined from hyperfine magnetic field distribution $P(B_{hf})$ for the $Fe_{81}Nb_5B_{14}$ alloy is shown in Fig. 3. Fig.4 presents a plot $<B_{hf}>$ versus the average magnetic moment of iron atoms $<\mu>$ calculated from the data presented in Fig. 3. As it should be expected a good linear correlation $<B_{hf}>$ vs. $<\mu>$ is obtained. The slope of the straight line from Fig. 4. is $d<B_{hf}>/d<\mu>=(11.3\pm0.7)$ T/μ_B. This value is very close to the values reported in [9] for amorphous iron ($d<B_{hf}>/d<\mu>=10$ T/μ_B).

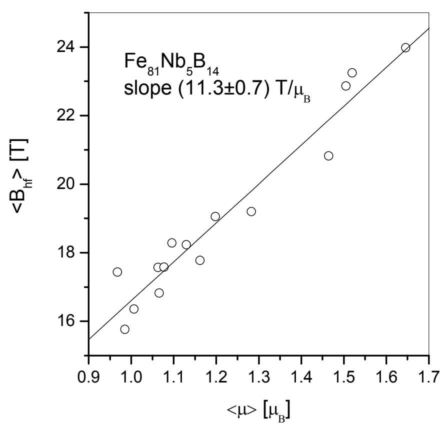

Fig. 4. The mean hyperfine magnetic field *versus* average iron magnetic moment calculated for the data from Fig. 2

Figure 5 present Mössbauer spectra obtained for samples annealed at temperatures closed to T_{op} for the $Fe_{81}Nb_5B_{14}$ alloys. In the inset the velocity range appropriate to the detection of the outer absorption line for α-Fe Mössbauer spectrum is shown. From this figure it can be recognized that optimization annealing (at T_{op}) essentially does not lead to formation of any αFe nanocrystallites. The first traces of nanocrystallites are detected after annealing at T_a=720 K for the $Fe_{81}Nb_5B_{14}$ alloy (T_{op}=680 K) and at 760 K for the $Fe_{80}Nb_6B_{14}$ alloy (T_{op}=700 K).

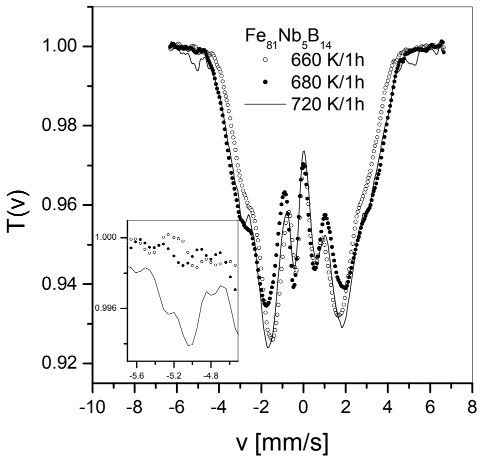

Fig. 5. Mössbauer spectra determined for samples annealed at temperatures closed to the temperature of 1-h optimization annealing (T_{op}=680 K) for the $Fe_{81}Nb_5B_{14}$ alloy; in the inset the velocity range appropriate to the detection of the outer absorption line for αFe Mössbauer spectrum

Experimental results show that the observed magnetic permeability enhancement effect (or magnetic properties optimization effect) in both examined alloys takes place in amorphous phase. In any way we conclude that for annealing temperatures T_a just preceding the optimization annealing temperature T_{op} a characteristic atomic rearrangement occurs which leads to a decrease of the average magnetic moment of iron atoms. As a hypothesis we propose a formation of small iron clusters consisting of more or less ten - fifteen Fe atoms. It results from an estimation of the Mössbauer spectroscopy sensitivity to detect the already formed iron clusters in amorphous phase. The magnetic permeability enhancement effect is due to diffusion of free volume (coagulation and annealing out) leading to a formation of small iron clusters.

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