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New Findings in Mössbauer Studies of Amorphous FeMoCuB NANOPERM-Type Alloy

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The effect of heat treatments at 603 K (a relaxation of an amorphous structure) and at 723 K (an onset of a bulk nanocrystallization) of a rapidly quenched $Fe_{76}Mo_8Cu_1B_{15}$ alloy is studied. The differences in sample processing are reflected in magnetization direction as seen by room- and low--temperature Mössbauer spectroscopy.

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1. Introduction

Amorphous and nanocrystalline materials attract steady interest and their applications can be found in many types of industrial products [1]. A broad variety of these materials is given by different methods and a wide range of alloy compositions which can be used for their production. The recently investigated NANOPERM-type FeMoCuB system [2–5] is a subject of the present Mössbauer (Ms) study focused on yet unpublished angular dependence of the hyperfine interaction. The intensity ratio of hyperfine lines which reflects magnetization direction with respect to the ribbon plane is followed during cooling the alloy in different structures (as-quenched amorphous, relaxed amorphous and compositionally modified amorphous structure due to a formation of bcc-Fe(Mo) nanocrystals) down to 25 K.

2. Experimental details

Amorphous $Fe_{76}Mo_8Cu_1B_{15}$ ribbon 6 mm wide and 20 μm thick was prepared by the planar-flow casting (sample named FMAQ). The sample denoted as FM603 was subjected to isothermal treatment at temperature of 603 K/1 h/vacuum. The other sample, denoted as FM723, was conventionally nanocrystallized [2, 6] at 723 K/ 1 h/vacuum. Ms measurements were performed at different but fixed absorber (sample) temperatures within the range 25 $K \leq T \leq$ 300 K using γ-rays in transmission geometry and backscattered conversion electrons at room temperature (RT). Both modes employed the RT α-Fe calibration and the CONFIT evaluation program [7].

3. Results and discussion

The Ms spectrum of the amorphous $Fe_{76}Mo_8Cu_1B_{15}$ alloy in the as-quenched state, sample FMAQ, exhibits both the electric quadrupole and magnetic dipole hyperfine interactions (EQ and BC in Fig. 1) as was already shown in previous investigations [3–5]. A two-pattern fit, used as well for Ms spectrum of the sample in the relaxed state (FM603, Fig. 1), is represented by Gaussian distributions of quadrupole split doublets $P(\Delta)$ and magnetically split sextets $P(B)$, respectively. This model reflects the existence of a spatial segregation of finite spin clusters and a ferromagnetic matrix due to either concentration or density fluctuations. The

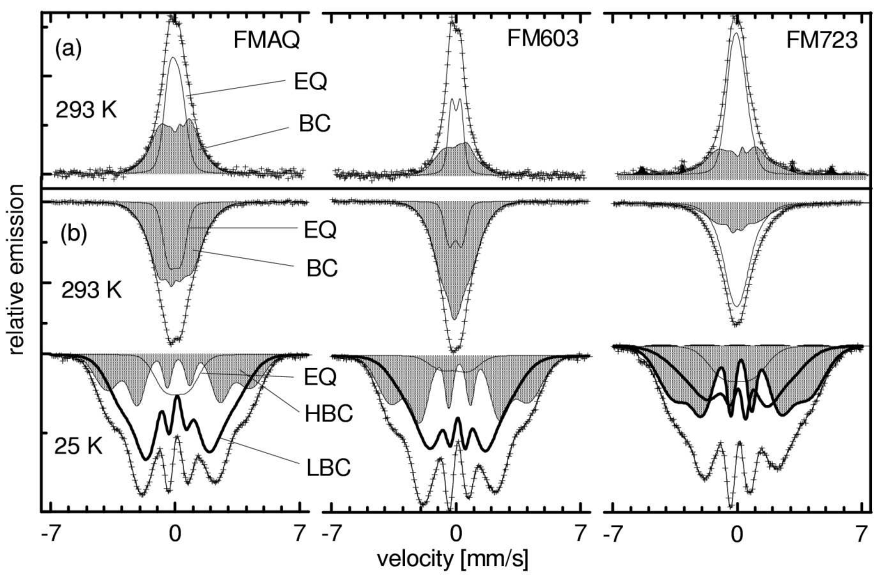

Fig. 1. Mössbauer spectra of $Fe_{76}Mo_8Cu_1B_{15}$ sample in the as-quenched, FMAQ, relaxed, FM603, and nanocrystallized, FM723, states measured using backscattered conversion electrons (a) and by γ-rays in transmission geometry (b).

concentration fluctuations correspond to formation of Fe-rich and Fe-poor regions while the density fluctuations arise from the low- and high-density regions with different ferromagnetic couplings between the spins inside.

After the sample was exposed to the relaxation annealing (603 K), an increase in the intensity of the magnetically split component from 73% (FMAQ) to 82% (FM603) was detected simultaneously with a decrease in the mean hyperfine induction from $B_{\text{mean}} = 8.1 \pm 0.5$ T to $B_{\text{mean}} = 6.1 \pm 0.5$ T, respectively. It reflects an annealing out of stresses and free volumes as known from the studies of relaxation processes of amorphous alloys. As a consequence the amount of low-density regions has decreased and an influence of high-density regions and ferromagnetic coupling between spins became more pronounced. Simultaneously, the intensity of quadrupole split doublets has decreased while the average quadrupole splitting ($\varDelta$) did not change ($\varDelta_{\text{FMAQ,FM603}} = 0.67 \pm 0.14$ mm/s).

The formation of bcc-Fe(Mo) nanocrystals in the sample exposed to the heat treatment at 723 K (FM723, Fig. 1b) is represented by an additional narrow six--line component. Its presence is better distinguished in the Ms spectrum taken from the sample surface using conversion electrons (Fig. 1a). The very low nanocrystallization leads only to a slight reduction of the iron content in the amorphous matrix which is accompanied by a decrease both in the mean hyperfine induction to approximately 5 T and in the relative weight of this component on behalf of the quadrupole split doublets.

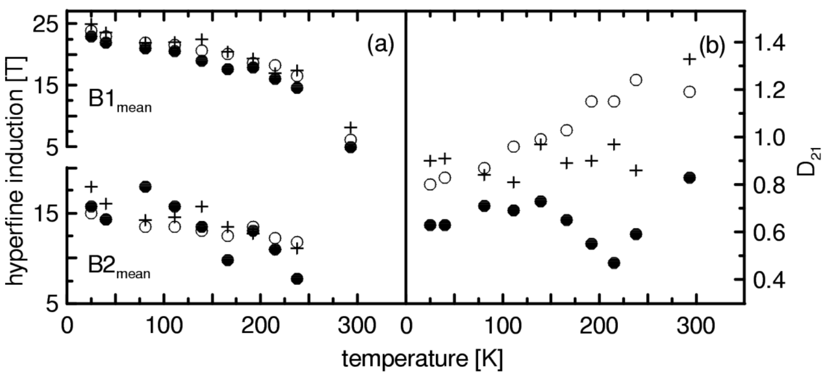

Fig. 2. Temperature dependence of mean hyperfine inductions: $B1$ — high induction component, $B2$ — low induction component (a) and of intensity ratio $I_2/I_1 = D_{21}$ obtained from Mössbauer spectra analysis (b). + FMAQ, ∘ FM603, • FM723.

The transmission spectra measured below RT exhibit substantial broadening which calls for a more complex distribution of hyperfine parameters. For this reason the second Gaussian-like distribution of magnetic inductions, denoted as low-induction component LBC, in addition to previous high-induction HBC (Fig. 1b), was included in the model employed. The mean values of magnetic inductions, $B1_{\mathrm{mean}}$ and $B2_{\mathrm{mean}}$, respectively, increase with decreasing temperature (Fig. 2a). A difference among the amorphous phases can be observed in the D_{21} parameter (Fig. 2b) which represents a relative ratio of intensities of the second and first absorption lines of the sextuplets and simultaneously the orientation of the spins with respect to the ribbon plane. While in the relaxed state of the sample (FM603) this parameter decreases almost linearly with temperature, it exhibits pronounced changes in the states with higher degree of "disorder" originating from either production (FMAQ) or nanocrystallization (FM723) processes.

4. Conclusions

The Mössbauer studies of the NANOPERM-type $Fe_{76}Mo_8Cu_1B_{15}$ alloy below room temperature were focused on changes of magnetization direction, represented by the intensity ratio D_{21} in various structural states of amorphous phase. The relaxed amorphous structure exhibits the smallest variations in D_{21} with decreasing temperature as compared to amorphous structure containing stresses due to the fast cooling or nanocrystallization.

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