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MAGNETOOPTICAL INVESTIGATION OF THE MICROMAGNETIC STRUCTURE OF Fe-ENRICHED AMORPHOUS RIBBONS

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The results of magnetooptical investigation of the micromagnetic structure of amorphous $Fe_{73}Co_{12}B_{15}$ ribbons are presented. A strong dispersion of magnetic anisotropy on a macro- and microscale in the initial state of the ribbons is detected. As a result, their local magnetic properties are rather heterogeneous, an irregular ripple-structure forms on remagnetization of the ribbons, and blocking of magnetization processes, accompanying this structure is observed. The influence of thermomagnetic annealing on the micromagnetic structure of the ribbons is investigated.

Since the moment they were first prepared, the interest in amorphous alloys has almost not eroded because their unique magnetic properties are widely used in practical applications. Recently a gigantic magnetic impedance has been revealed in these materials. This phenomenon attracted attention of researchers as to its possible use in high-sensitivity magnetic field detectors and in magnetic recording heads. The gigantic magnetic impedance value was shown to depend strongly on the amorphous alloys micromagnetic structure [1].

In this paper, we present the results of our magnetooptical investigation of the near-surface micromagnetic structure (MMS) and of the processes of magnetization of magnetically soft amorphous $Fe_{73}Co_{12}B_{15}$ ribbons, as well as of the effect of the thermomagnetic annealing (TMA) temperature t and time T on them. Measurements were carried out on a magnetooptical micromagnetometer described in detail in [2]. Magnetization curves and magnetization distribution curves on contact and free sides of the ribbon were measured with the help of the equatorial Kerr effect δ_e and the meridional intensity effect δ_m which we had discovered earlier [3]. The use of the meridional intensity effect and the equatorial Kerr effect makes it possible to measure simultaneously for each micro-region of the sample surface the planar magnetization components directed both parallel ($M_{\|}$) and perpendicular ($M_{\perp}$) to the applied field H. In the field H normal to the light incidence plane, it is possible to measure $\delta_e/\delta_s \sim \Delta M_{\|}/M_s$; $\delta_m/\Delta_s \sim \Delta M_{\perp}/M_s$. Here ΔM is the change of the planar magnetization component under the effect of the field H; δ_s is the value of δ_e (or of δ_m) at $\Delta M = 2M_s$; M_s is the saturation magnetization. We used a modulation method of recording magnetooptical signals. Therefore, an alternating magnetic field with frequency $f = 80$ Hz was applied to the sample along its length L.

Ribbons were prepared by quenching from a melt. Samples to be studied were 2-mm wide, 10-mm long, and 25-μm thick strips. Sample No. 1 was in the initial state, whereas samples Nos. 2–7 were annealed in the constant magnetic field $H = 2$ kOe normal to the ribbon length. The following TMA conditions were used: $T = 310\,^\circ$C (Nos. 2, 3); $350\,^\circ$C (Nos. 4, 5); $370\,^\circ$C (Nos. 6, 7); $t = 20$ s (Nos. 2, 4, 6) and 60 s (Nos. 3, 5, 7). All the samples were amorphous under X-ray diffraction analysis.

Preliminary investigations showed that the ribbons in the initial state were anisotropic (the easy-magnetization axis parallel to the ribbon length) and featured strong magnetic anisotropy dispersion on a macro- and microscale. It was also established that in studying magnetic inhomogeneities the optimal light

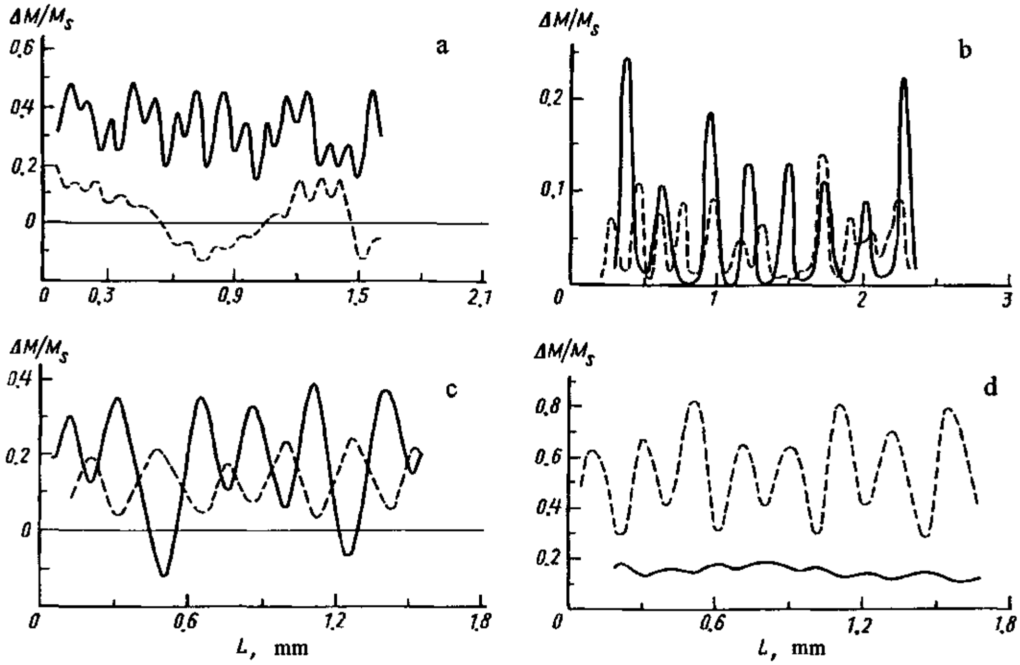

Fig. 1

Typical dependences of $\Delta M_{\parallel}/M_s$ (solid) and $\Delta M_{\perp}/M_s$ (dashed) on the sample length at $H = 1$ Oe for samples (*a*) No. 1, (*b*) No. 2, (*c*) No. 3, and (*d*) No. 6.

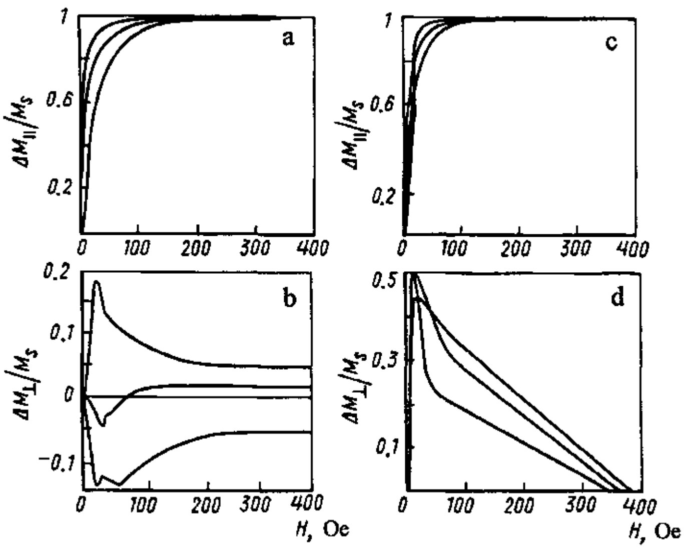

Fig. 2

Typical local magnetization curves for samples (*a, b*) No. 1 and (*c, d*) No. 2.

spot size D on the sample must be ~ 0.03 mm. Figure 1*a* shows typical dependences $\Delta M_{\parallel}/M_s$ (solid) and $\Delta M_{\perp}/M_s$ (dashed) on the sample length, measured on the contact side of sample No. 1 in the field $H = 1$ Oe as the light spot moved along the central line lengthwise. It is apparent that a set of such curves makes it possible to obtain topography of the planar magnetization components and thus to derive information on the near-surface MMS of the sample. Figure 2*a, b* shows typical local magnetization curves $\Delta M_{\parallel}/M_s$ and $\Delta M_{\perp}/M_s$ measured for different micro-regions of sample No. 1. It can be seen that the magnetization distribution curves are irregular and the magnetization curves differ. These data point to heterogeneity of local magnetic properties in sample No. 1, possibly caused by magnetic anisotropy dispersion. It will be appropriate to point out that at $H > H_s$ (H_s, the sample saturation field) the equatorial Kerr effect value was the same over the entire ribbon surface.

Attention should be paid to the dashed curve in Fig. 1*a* and to the shape of the curves in Fig. 2*b*. The magnetization component normal to H is an alternating quantity and has an unusual field dependence: for $0 < H < 50$ Oe it increases as the field grows, and then it decreases to a certain value which remains constant up to high H. At the same time, at high H the magnetization component parallel to H remains almost invariable. Similar results were also obtained for the free side of sample No. 1, but, compared to the contact side, local values of the initial permittivity were greater, and those of the coercive force and saturation field were ~ 1.2 times smaller. The field dependences of $\Delta M/M_s$ suggest that the magnetization processes get blocked as soon as H attains a certain value. The obtained data can be explained as follows. An analysis of magnetooptical signals shows that the dependence of $\Delta M_\perp/M_s$ on L can be alternating if the magnetization orientation of different near-surface micro-regions is described by angles $\pm\chi_i$ read off in the plane of the ribbon from its axial direction, and their remagnetization is effected owing to incoherent rotation of magnetization vectors. When the sample remagnetization occurs due to domain walls displacement and at χ_i with the same sign, the values $\Delta M_\perp/M_s$ do not change the sign or are equal to zero [4]. We notice that the magnetization orientation in the ribbon plane was confirmed by the data obtained in measuring the polar Kerr effect (within the limits of experimental error it was equal to zero). And finally, the blocking of magnetization processes by analogy with [5] suggests the appearance of a *ripple*-structure which, however, is irregular in our case.

Then we studied the effect of the TMA time and temperature on the ribbon MMS. Figures 1*b* and 2*c*, *d* illustrate, respectively, typical magnetization distributions in the field $H = 1$ Oe and local magnetization curves for sample No. 2. It can be seen that in this case the local magnetization curves are almost identical: magnetization processes are not blocked (at $H \sim 350$–400 Oe, $\Delta M_\perp/M_s$ vanishes); the planar magnetization components are of the same sign and sufficiently regular character, this being indicative of the appearance of strip domains normal to the ribbon length. This was confirmed by the magnetooptical contrast pattern due to the meridional Kerr effect. The strip domains were about 200 μm wide. The appearance of the strip domain structure is caused by the induced magnetic anisotropy induced by the sample TMA. The above facts give grounds for asserting that remagnetization of sample No. 2 in the region of small fields takes place due to simultaneous displacement of domain walls and rotation of magnetization vectors in the domains.

Similar measurements were carried out on samples Nos. 3–7. It was established that in samples Nos. 3, 5, 7 blocking of the magnetization processes persists up to high fields; at $H < H_s$, the magnetization distribution is sufficiently regular but on the $\Delta M_\parallel/M_s$ curves (see Fig. 1*c*) there appear reverse magnetization areas whose linear size is ~ 150–200 μm. The latter fact may be explained as follows. It is known [6] that as the sample annealing time increases, the concentration of metalloid atoms near the surface of the ribbon grows. As a result, the influence of scattering fields near nonmagnetic inclusions and of the effects of exchange origin intensify, and this may lead to the appearance of a secondary domain structure [7]. Reverse magnetization areas are a typical attribute of this structure.

It was found that the MMS of samples Nos. 4 and 6 is similar to the MMS of sample No. 2, but $\Delta M_\perp/M_s$ in these samples are zero at $H \sim 500$–600 Oe. It was also established that as the sample number increases, the maximum value of $\Delta M_\perp/M_s$ increases (from 0.2 for No. 1 to 0.9 for No. 7), whereas the values of $\Delta M_\parallel/M_s$ at $H \ll H_s$ become appreciably smaller than $\Delta M_\perp/M_s$ and are almost invariable along L (see Fig. 1*d*). This data suggests that as the time and temperature of the sample TMA increase, the influence of the induced magnetic anisotropy on the MMS of the ribbon intensifies.

On the whole, the obtained information on the MMS of Fe-enriched amorphous ribbons and on its changes under the effect of TMA may be useful in designing magnetic sensors based on the magnetic impedance effect.

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