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SOME MAGNETIC PROPERTIES OF THIN FILMS PREPARED FROM Fe–(M–Nb)–Si–B (M: Cu, Ag, Pt, Pd) ALLOYS*

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Saturation magnetic induction, B_s, and coercive field, H_c, have been studied upon annealing in films flash evaporated from $Fe_{73.5}M_1Nb_3Si_{13.5}B_8$ alloys. The changes in B_s significantly diverged at increasing annealing temperature, T_a, and did not indicate any formation of ultrafine grain phase in the films. H_c measured as an angular function in the plane of the films revealed oscillations due to weak in-plane anisotropy. The coercivity increased in the course of annealing at increasing T_a, while the in-plane anisotropy decreased at the same time.

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1. Introduction

Excellent soft magnetic properties of recently discovered nanocrystalline alloys have stimulated intense investigation of these materials both in the cognitive aspect and in the aspect of their application [1–4]. Production of such soft magnetic materials in the form of thin films would significantly enlarge the scope of their application.

An attempt was made to obtain thin films of nanocrystalline $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ alloy by flash evaporation technique, but it proved only partly successful as, apart from large content of the ultrafine phase, the samples always contained a significant contribution of the phase of larger grains [5]. Certain magnetic properties of the obtained films were also measured [6–8].

In this paper we report new results of our study on the magnetic behaviour of the films obtained.

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2. Experimental

The films were obtained by flash evaporation of $Fe_{73.5}M_1Nb_3Si_{13.5}B_9$ alloys, where M = Cu, Ag, Pt, Pd. The films were deposited onto cooled glass substrates. Electron diffraction study of the films indicates amorphous state of as-deposited samples which crystallize during heat treatment. After annealing for 10 min within the range from about 600 to 823 K, the nanocrystalline phase appeared in a few samples [5, 6].

The Hall effect has been used for determination of the saturation magnetic induction $B_s = 4\pi M_s$ (M_s = saturation magnetization) while for the hysteresis loop tracing and determination of coercive field, H_c, we applied the magnetooptical Faraday effect.

3. Results and discussion

The dependence of the saturation magnetic induction, B_s, on the annealing temperature, T_a, for the alloys with M = Cu, Ag, Pd and Pt shows that, except for M = Pt, the magnetic induction B_s increases with increasing T_a (Table). For M = Ag, B_s oscillates with subsequent annealings and it comes back to the nearly initial value after annealing at 923 K (Table). For the alloy with M = Pt, B_s drastically decreases upon annealing. Thus, although it is clear from our TEM

TABLE

B_s values upon annealing of the samples for different M metals in the alloys.

Sample, M =	Cu	Ag	Pd	Pt
as-depos.	1.62	1.85	1.72	1.80
T_a = 473	–	1.69	1.74	1.75
623	1.58	1.80	1.77	1.43
723	1.63	1.70	1.89	1.31
823	1.68	1.79	2.10	–
923	1.69	1.83	–	–

observation [6] that the nanocrystalline phase is formed during the annealing process, this fact cannot be deduced from the behaviour of $B_s(T_a)$ only. Soft magnetic properties are connected with disappearance of magnetostriction and magnetocrystalline anisotropy. The films studied, when as-deposited, reveal very weak in-plane magnetic anisotropy. This fact makes it impossible to measure the anisotropy directly from hysteresis loops, but the in-plane anisotropy gives periodic oscillations in coercivity, i.e. in H_c measured versus the angle of the applied measuring field. The amplitude of these oscillations, ΔH_c, can be taken as an approximate measure of the latter anisotropy, if exists. Figure 1 shows the angular dependence of H_c for the as-deposited and the annealed, at T_a = 823 K, sample of the alloy with M = Cu. The oscillations of H_c are well apparent for the as-deposited film. After

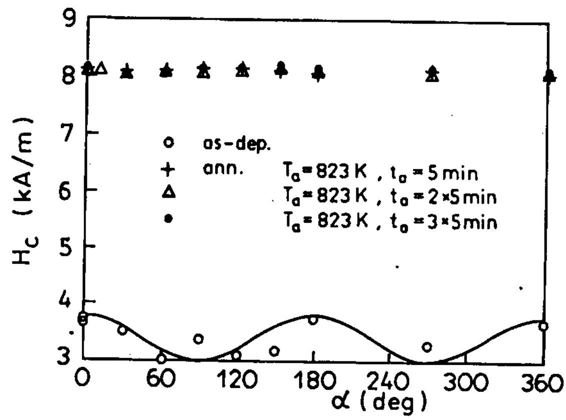

Fig. 1. Angular dependence of coercive field, as measured in the plane of the film: circles — as-deposited sample, stars, triangles and crosses — samples annealed for 5, 10, and 15 min, respectively. Continuous line represents the H_c oscillations corresponding to a reasonable value of uniaxial in-plane anisotropy.

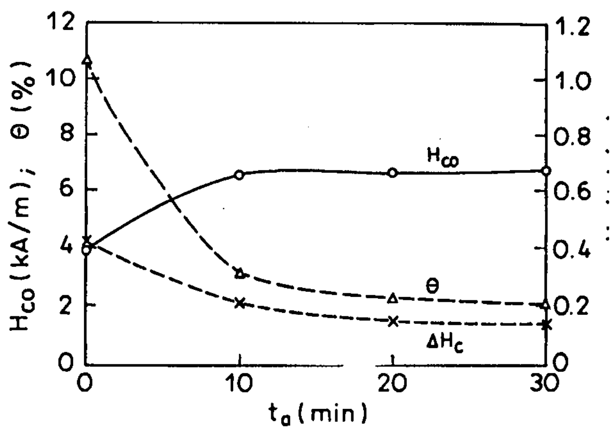

Fig. 2. Easy axis coercive field, H_{co}, amplitude of angular $H_c(\alpha)$ oscillations, ΔH_c, and $\Theta = \Delta H_c/H_{co}$ the supposed measure of the in-plane magnetic anisotropy, as a function of annealing time, t_a.

annealing of this film for only $t_a = 5$ min, H_c increases and already achieves a high value. At the same time, the amplitude of the coercivity, ΔH_c, significantly decreases demonstrating vanishing of the in-plane anisotropy.

Figure 2 illustrates the annealing time dependence, at $T_a = 823$ K, of the (1) easy axis coercivity, H_{co}, (the temperature $T_a = 300$ K has been attributed to the as-deposited samples); (2) oscillation amplitude, ΔH_c; (3) the relative value $\Theta = \Delta H_c/H_{co}$, expressed in percent is the supposed measure of the uniaxial in-plane magnetic anisotropy. This value is almost independent of the applied field direction. This means that upon heating the uniaxial in-plane anisotropy significantly decreased, although at the same time the H_c value increased. The latter value remains constant in spite of subsequent annealings at the same temperature. On the other hand, for many evaporated samples annealed for 10 min in a low temperature range, H_c decreases to a minimum and then strongly increases when the annealing temperature exceeds 600 K. Thus, the increase in the H_c value upon heating is in contradiction to the vanishing of the anisotropy. Such behaviour is, of course, at variance to that found for nanocrystalline ribbons.

4. Conclusion

It is well known that the nanocrystalline phase reveals a low coercivity. Thus, the above discussed results allow us to conclude that apart from a large content of the ultra-fine grain phase the samples contained significant, and increasing on annealing, amount of larger, single-domain grains, which was responsible for the rise in the coercivity of the sample after its annealing.

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