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MAGNETIC PROPERTIES OF IRON-BASED AMORPHOUS AND NANOCRYSTALLINE Fe-Zr-X-B (X: Cu, Al) ALLOY FILMS

I. GOŚCIAŃSKA^a, T. TOLIŃSKI^b, H. RATAJCZAK^b, P. SOVÁK^c, R. DLUGOŚC^c
AND M. KONČ^c

^aInstitute of Physics, A. Mickiewicz University, Umultowska 85, 61-614 Poznań, Poland

^bInstitute of Molecular Physics, Polish Academy of Sciences
Smoluchowskiego 17, 60-179 Poznań, Poland

^cDepartment of Experimental Physics, P.J. Šafarik University, Košice, Slovakia

Thermal stability and magnetic properties of thin films, of a few Fe-based amorphous and nanocrystalline alloys, have been studied. The alloys belong to the class Fe-M-B, whose representatives are: $\text{Fe}_{87}\text{Zr}_4\text{Cu}_1\text{B}_8$, $\text{Fe}_{87}\text{Zr}_7\text{B}_6$, and $\text{Fe}_{87}\text{Zr}_7\text{Al}_1\text{B}_5$ and are of particular interest because of their wide variety of magnetic properties. The films were prepared by flash evaporation onto liquid nitrogen cooled substrates. Measurements of the Kerr effect, the Hall effect, and ferromagnetic resonance in the films were carried out as functions of the annealing temperature. It was found that the changes in the coercive field H_c , resonance linewidth ΔH_{pp} , effective magnetization M_{eH} , Hall parameters, and resistance were correlated with the structural changes in the studied films.

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1. Introduction

Nanocrystalline and amorphous materials are still widely investigated due to their possible applications based on their soft magnetic properties [1, 2] and the giant magneto-impedance effect [3]. In this paper we continue our studies of structural and magnetic properties of thin nanocrystalline films which belong to the Fe-M-B alloy series. The thermal stability of $\text{Fe}_{87}\text{Zr}_4\text{Cu}_1\text{B}_8$, $\text{Fe}_{87}\text{Zr}_7\text{B}_6$, and $\text{Fe}_{87}\text{Zr}_7\text{Al}_1\text{B}_5$ films is verified. Similar systems were previously investigated using ferromagnetic resonance and Mössbauer techniques [2]. Especially, the ferromagnetic resonance appeared to be a sensitive indicator of the crystallization process.

2. Experimental

The thin films were prepared by flash evaporation of pulverized alloys onto liquid nitrogen cooled glass substrates in the vacuum of 1.5×10^{-9} Torr [4]. The thickness of the samples was determined using the multibeam interference method and was kept at about 30 nm with the accuracy of 20%. The magnetic parameters, namely the coercive field H_c , magnetic induction B_S , spontaneous Hall coefficient R_S , effective magnetization M_{eff} , and resonance linewidth ΔH_{pp} for annealing temperatures $T_a = 623, 723, 773,$ and 823 K were obtained from the measurements of magneto-optical Kerr effect (MOKE), spontaneous Hall effect (SHE), and ferromagnetic resonance (FMR), respectively. Annealing temperatures T_a were extracted from the temperature dependence of resistivity $\rho(T)$. The evolution of the films structure was observed by the transmission electron microscopy (TEM). The ferromagnetic resonance was carried out at the frequency of 18.74 GHz at a room temperature. The effective magnetization is defined as $M_{\text{eff}} = M_S - \mu_0 H_u$, where H_u is the perpendicular anisotropy field ($2K_u/M_S$).

3. Results and discussion

Figure 1 shows an example of the TEM images of $\text{Fe}_{87}\text{Zr}_7\text{B}_6$ alloy for some temperatures T_a . It is seen that already in the as-deposited state the sample is partly nanocrystalline with the grains diameter of about 15 nm. The diameter rises to about 50 nm at the highest T_a .

The development of the crystallization process is confirmed by the temperature dependence of the resistivity (Fig. 2). The above changes in the structure of the films correlate with the behavior of the magnetic properties performed in Figs. 3. and 4. For $\text{Fe}_{87}\text{Zr}_7\text{B}_6$ and $\text{Fe}_{87}\text{Zr}_7\text{Al}_1\text{B}_5$ films both field the coercive H_c

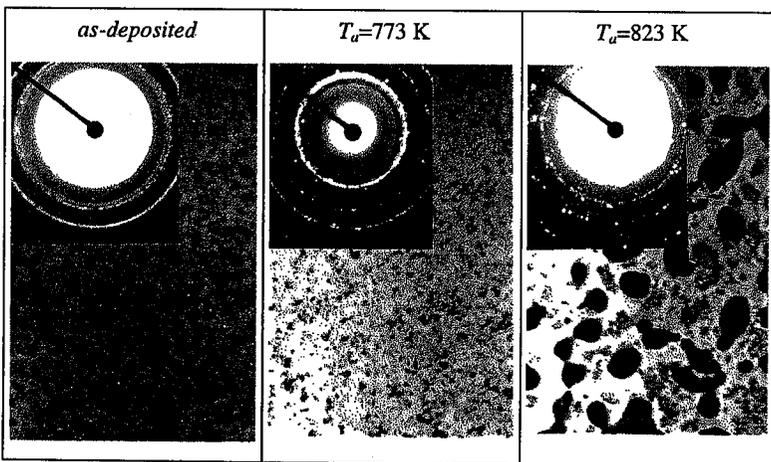


Fig. 1. Example of TEM images for the $\text{Fe}_{87}\text{Zr}_7\text{B}_6$ alloy film (magnification about $22000\times$).

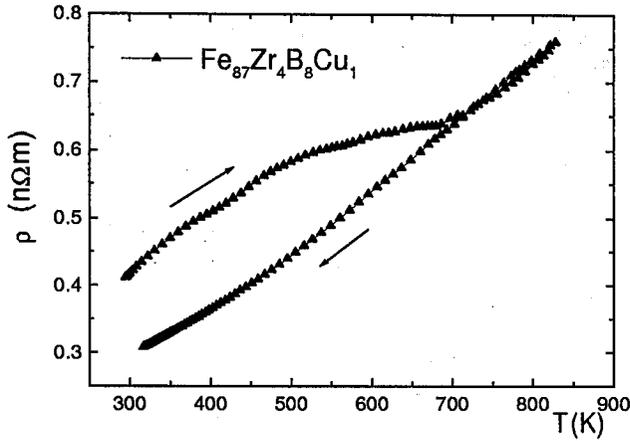


Fig. 2. Resistivity $\rho(T)$ measured with the rate of temperature change $5^\circ/\text{min}$.

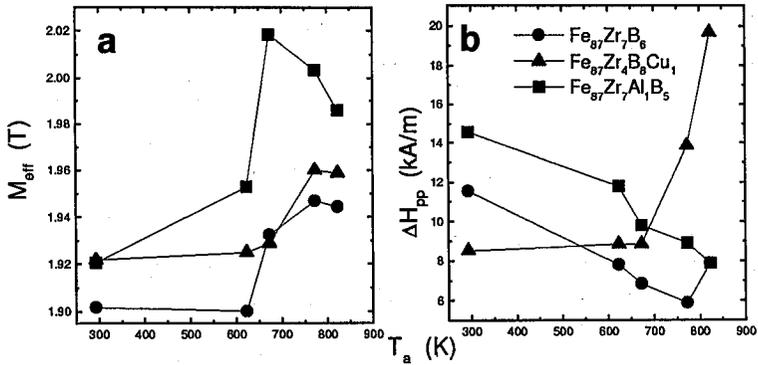


Fig. 3. Effective magnetization M_{eff} (a) and resonance linewidth ΔH_{pp} (b) as a function of annealing temperature T_a .

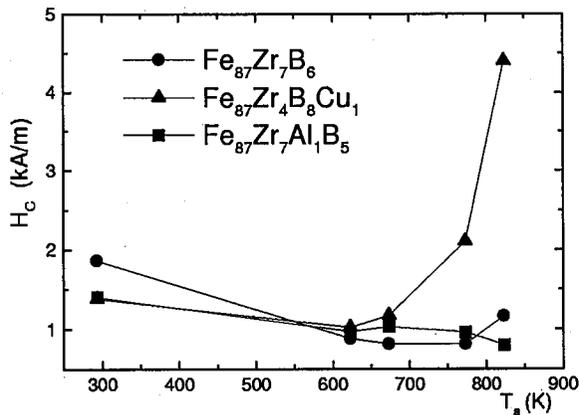


Fig. 4. Coercive field H_c as a function of annealing temperature T_a .

and the resonance linewidth ΔH_{pp} decrease with increasing temperature and eventually have a flat minimum near 700 K. This is a result of the annealing induced enlargement of the grains either by merging of the nanocrystallites or by the proceeding crystallization of the amorphous matrix. The contribution of the surface anisotropy to the crystalline anisotropy is less significant when the grains become larger. In the case of the $\text{Fe}_{87}\text{Zr}_4\text{Cu}_1\text{B}_8$ alloy H_c and ΔH_{pp} are approximately constant up to 600 K and increase above that temperature. The discrepancy in comparison with the previous samples can result from the different course of the crystallization, however the role of copper is not clear yet. The effective magnetization M_{eff} increases slightly above $T_a = 623$ K for all samples.

The Hall coefficient R_S decreases with temperature for all samples. The magnetic induction B_S obtained from MOKE measurements changes from 1.8 T in an as-deposited state to 1.97 T after annealing at 823 K for $\text{Fe}_{87}\text{Zr}_7\text{B}_6$ and from 1.76 T to 1.88 T for $\text{Fe}_{87}\text{Zr}_4\text{Cu}_1\text{B}_8$.

4. Conclusions

The $\text{Fe}_{87}\text{Zr}_7\text{B}_6$ and $\text{Fe}_{87}\text{Zr}_7\text{Al}_1\text{B}_5$ alloy films appeared to be thermally more stable than $\text{Fe}_{87}\text{Zr}_4\text{Cu}_1\text{B}_8$ in the considered temperature range, i.e. they better conserve the soft magnetic properties. The nanocrystalline structure observed at the as-deposited state is present up to 700 K, only the dimensions of the grains slightly change in this range.

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