Journal of ELECTRICAL ENGINEERING, VOL 57. NO 8/S, 2006, 118-121

MEASUREMENTS OF MAGNETOSTRICTION AND CURIE TEMPERATURE OF Fe-B AND Fe-Mo-Cu-B SYSTEMS

Gabriel Vlasák* — Tomáš Kaňúch — Peter Švec* — Marcel Miglierini****

Amorphous rapidly quenched ribbons 6mm wide and 20 microns thick were prepared from $Fe_{100-x}B_x$ and $Fe_{91-x}Mo_8Cu_1B_x$ systems for x=12-25. Dilatation measurements were performed on thermally relaxed samples. Temperature dependencies of dilatation and electrical resitivity were used to estimate the values of the Curie temperatures. The measurements indicate a difference of about 250K between the values for Fe-B and Fe-Mo-Cu-B systems. The same measurements were used to determine also the values of spontaneous volume magnetostriction at 300K. Saturation magnetostriction, volume magnetostriction, and forced volume magnetostriction were determined from direct measurements of linear magnetostrictions in parallel and perpendicular configurations.

Keywords: magnetostriction, Curie temperature, Fe-B, Fe-Mo-Cu-B, amorphous alloys

1 INTRODUCTION

One the most important trends in materials research is the one which leads to novel materials satisfying extreme demands on their physical properties, functionality and performance, reflecting the needs of rapidly growing information and communication technologies. Recent decades of materials research were focused, besides others, quite intensely on alloys prepared by rapid quenching of the melt using quenching rates of ~10^6 K/s. Rapid quenching with quenching rates up to 10^6K/sec frequently improves physical properties or leads to new and unusual ones. Under these preparation conditions the alloy retains to a large extent the structure attained in the melt state. Besides, after transformation, crystalline and frequently nanocrystalline morphology is obtained, especially when using alloy composition consisting of metallic atoms such as Fe, Ni, Co on one side and metalloids such as B, Si, or P on the other side. Small additions of other elements such as Nb, Zr and Cu promote the formation of relatively stable nanocrystalline grains in amorphous matrix leading to enhanced physical properties of such alloys. A vast majority of these alloys are based on Fe and B. For this reason the system $Fe_{100-x}B_x$ in a relatively wide concentration range around the eutectic composition (x = 14, 16, 17, 20, 23, 25) was revisited, concentrating on the magnetic and electrical properties and their structure relationship.

Differences in properties of these materials in amorphous and polycrystalline states (usually enhanced), justify their attractiveness for research [1, 2]. In the present case the focus will be on the Curie temperature T_C, which is an important parameter for ferromagnetic materials, and on magnetostriction in the vicinity of T_C [3].

For metallic glassed and related materials (nanocrystalline alloys), i.e. isotropic systems, a phenomenological description of the magnetoelastic coupling yields the relation for linear magnetostriction [4]

$$\lambda(H) = \Delta l/ l= 1/3\ \omega(H) +3/2\ \lambda_S(H)(\cos^2\Theta - 1/3) + \lambda^F$$

where $\lambda_S(H)$ is the saturation magnetostriction, $\omega(H)= \Delta V/V$ is the volume magnetostriction, λ^F is the bipolar magnetostriction (form effect) and Θ is the angle between the direction of deformation measurement and the direction of the applied magnetic field. Using this relation it is possible to calculate the value of saturation magnetostriction λ_S and volume magnetostriction $\omega(H)$ or the value of forced magnetostriction $\partial\omega/\partial H$, used in technical design. The mentioned quantities are determined from the relations $\lambda_S(H) = 2/3\ [\lambda_{par}(H) - \lambda_{perp}(H)]$ and $\omega(H) = \Delta V/V = [\lambda_{par}(H) + 2\ \lambda_{perp}(H)]$, where $\lambda_{par}(H)$ and $\lambda_{perp}(H)$ are the field dependencies of linear isotropic magnetostrictions. Spontaneous volume magnetostriction ω_{spon} is determined from dilatation measurements.

2 EXPERIMENTAL

The measurements were performed on the $Fe_{100-x}B_x$ system. Phase diagram of binary $Fe_{100-x}B_x$ exhibits eutectic point at the composition of $Fe_{83}B_{17}$. A set of alloys around this composition, namely with x=14, 16, 17, 20, 23, 25, was prepared to investigate selected properties of the Fe-B system. In addition, a system where a portion of Fe was replaced by Mo_8Cu_1, namely, $Fe_{91-x}Mo_8Cu_1B_x$ for x = 12, 15, 17, 20, was investigated as well. The composition of the master alloys, prepared in vacuum induction furnace, was controlled by emission spectroscopy with inductively coupled plasma. Amorphous Fe-B and Fe-Mo-Cu-B ribbons 6 mm wide and 20 microns thick were prepared from these master alloys by planar flow casting; amorphous state was checked by transmission electron microscopy and X-ray diffraction. Field dependencies of linear isotropic magnetostrictions $\lambda_{par}(H)$ and $\lambda_{perp}(H)$, the magnitudes of saturation magnetostriction λ_S, volume magnetostriction $\omega(H)$ and forced volume magnetostriction $\partial\omega(H)/\partial H$ computed from these dependencies were used to identify the effect of composition.

*Institute of Physics, Slovak Academy of Sciences, Dúbravská cesta 9, 845 11 Bratislava, Slovakia, E-mail: fyzivlas@savba.sk
**Slovak University of Technology, Faculty of Electrical Engineering and Information Technology, Department of Nuclear Physics and Technology, Ilkovičova 3, 812 19~Bratislava, Slovakia

ISSN 1335-3632 © 2006 FEI STU

In order to obtain the field dependencies of linear magnetostrictions the samples were prepared by chemical etching of the ribbons to a form of discs with the diameter of 6 mm. The $\lambda_{par}(H)$ and $\lambda_{perp}(H)$ dependencies were measured on a device constructed for this purpose at the Institute of Physics SAS [5, 6]; selected dependencies measured at room temperature are shown in Figs. 1 and 2.

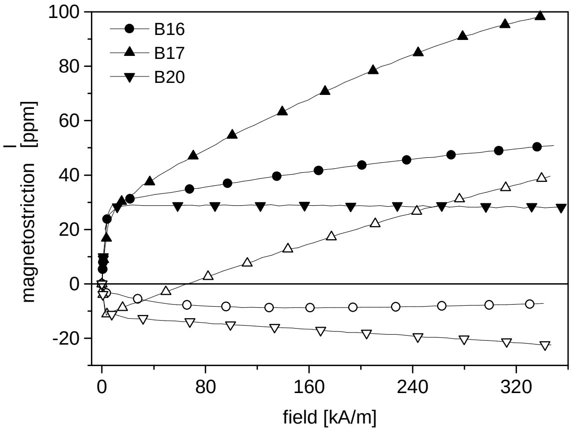

Fig. 1. Measurements of magnetostrictions $\lambda_{par}(H)$ (open symbols) and $\lambda_{perp}(H)$ (full symbols) of selected amorphous $Fe_{100-x}B_x$ ribbons.

Spontaneous volume magnetostriction $\omega_{spon.}$, known also as the invar effect, was also determined from measurements of temperature dependencies of dilatation, using a special dilatometer constructed especially for the use with ribbon samples [7]; ribbon length used was 30 mm.

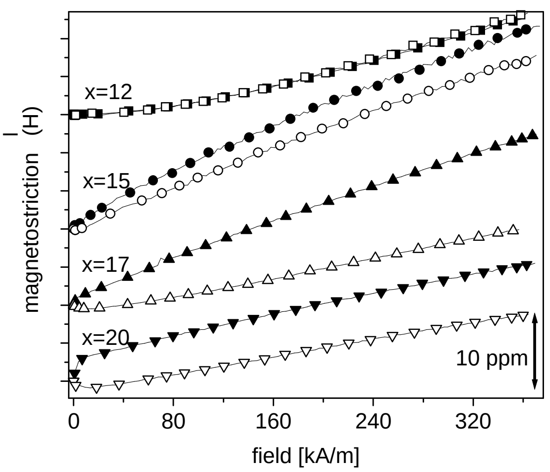

Fig. 2. Measurements of magnetostrictions $\lambda_{par}(H)$ (open symbols) and $\lambda_{perp}(H)$ (full symbols) of selected amorphous $Fe_{81-x}Mo_8Cu_1B_x$ ribbons.

Dilatation measurements were performed either on as-quenched ribbons in the temperature range 300-900K using a linear heating regime or using temperature cycling in order to eliminate relaxation or crystallization effects on the sample structure (Figs. 3 and 4). Cycling regimes 300K – 580K – 300K and 300K – 900K – 300K were used for both Fe-B and Fe-Mo-Cu-B samples.

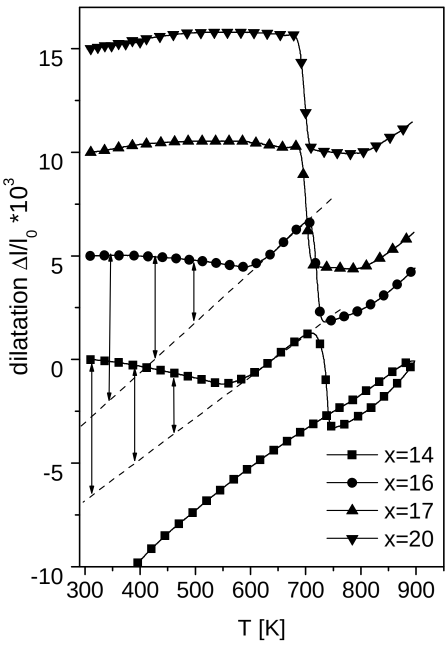

Fig. 3. Dilatation measurements on $Fe_{100-x}B_x$ ribbons after their previous relaxation; suggested dependence of $\omega_{spon.}$ shown by dashed lines.

The Curie temperature T_C was determined as the intersection of the tangents to the temperature dependencies of dilatation below and above T_C, i. e. in the ferromagnetic and paramagnetic temperature regions, respectively; for cases when T_C is above the crystallization temperature, extrapolation according to [3] was used.

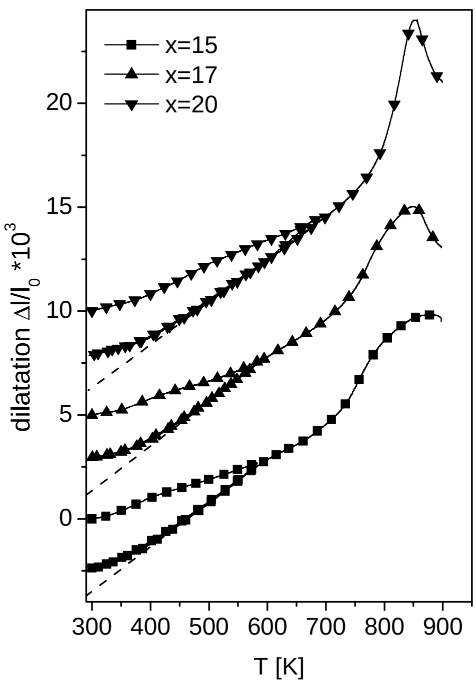

Fig. 4. Dilatation measurements on $Fe_{81-x}Mo_8Cu_1B_x$ ribbons after their previous relaxation (1^{st} heating run 300-580-300K); suggested dependence of $\omega_{spon.}$ shown by dashed lines.

Additional information related to the effect of T_C can be obtained from temperature dependence of electrical resistivity and especially its temperature derivative (inset in the left part of Fig. 5).

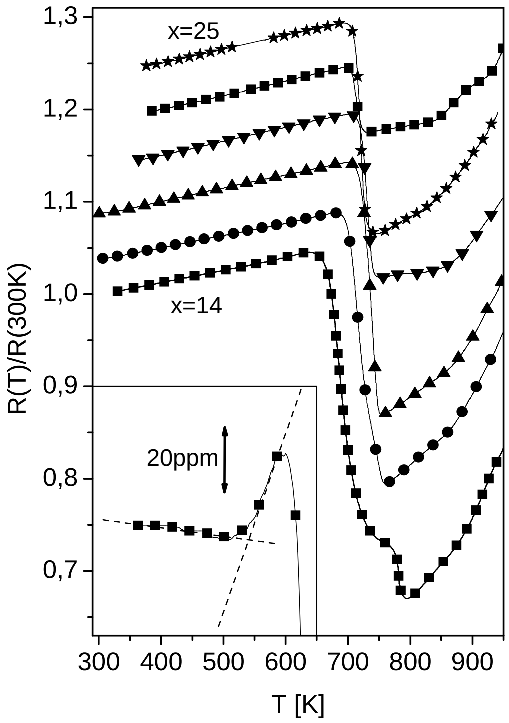

Fig. 5. Temperature dependencies of normalized electrical resistivity R(T/R(300K) of $Fe_{100-x}B_x$ ribbons; the inset shows d[R/R(300)]/dT for x=14, dashed lines indicate the position of the Curie temperature as seen from R(T).

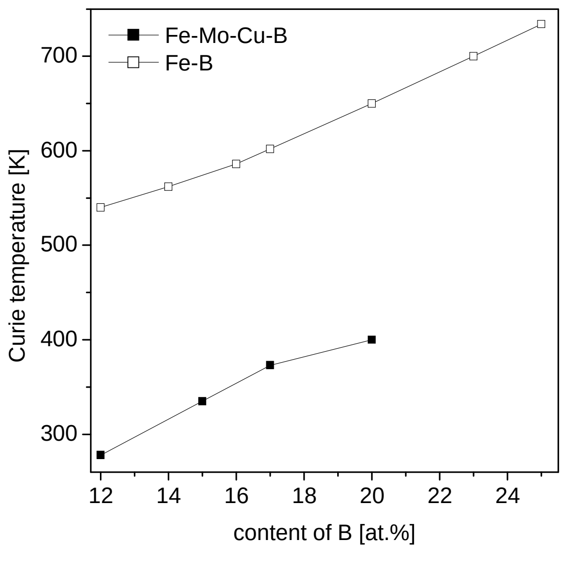

Fig. 6. Concentration dependence of T_C on both Fe-B and Fe-Mo-Cu-B amorphous systems after relaxation.

The increase of T_C with increasing boron content to higher temperatures, thus approaching crystallization temperatures, prevents clear manifestation of the paramagnetic behaviour of the amorphous state for alloys with higher boron content. The values of T_C for Fe-B and Fe-Mo-Cu-B systems are shown in Fig. 6. T_C for the Fe-Mo-Cu-B alloy in as-quenched state are in agreement with those obtained from magnetic measurements [8]. It is to be noted that T_C shifts to slightly higher temperatures after relaxation (see Fig. 3).

Table 1: The values of selected magnetic quantities of $Fe_{100-x}B_x$ and $Fe_{81-x}Mo_8Cu_1B_x$ alloys.

$Fe_{100-x}B_x$								
x	12	14	15	16	17	20	23	25
T_C [K]	540	562	-	586	602	650	700	734
$\lambda_S \cdot 10^6$	-	28	-	27.3	28.6	33.3	36.6	38
$\partial\omega(H)/\partial H \cdot 10^{10}$ [m.A^{-1}]	-	1.47	-	0.58	2.5	-0.7	0.2	0.385
$\omega_{spon} \cdot 10^3$	-	8.11	-	6.01	8.42	5.73	4.56	3.49
Fe_{95-x}-Mo-Cu-B_x								
x	12		15		17	20		
T_C [K] as-q.	278		320		350	375		
T_C [K] after relax.	-	-	350	-	373	400	-	-
$\lambda_S \cdot 10^6$	0	-	1.26	-	1.93	3	-	-
$\partial\omega(H)/\partial H \cdot 10^{10}$ [m.A^{-1}]	0.375/ 1.08	-	2.1	-	1.27	0.904	-	-
$\omega_{spon} \cdot 10^3$	0.2	-	1	-	1.6	1.176	-	-

The dependence of spontaneous volume magnetostriction ω_{spon} below the Curie temperature T_C (Figs. 3, 4) was determined from these measurements as a difference between temperature dependencies of dilatation below T_C and extrapolated temperature dependence of dilatation in paramagnetic state (above T_C) or from the cooling run after crystallization (as indicated in Fig. 3). The results of T_C, λ_S, $\partial\omega(H)/\partial H$, ω_{spon} for both systems after relaxation are listed in Table 1.

3 RESULTS AND DISCUSSION

The Curie temperature T_C determined from dilatation and electrical resistivity as described above, is a function of chemical composition. Replacement of Fe by the Mo_8Cu_1 group for the same content of boron leads to a decrease of T_C by more than 250K. The dependences of T_C on boron content are roughly linear for both systems. The most important influence in this phenomenon can certainly be attributed to the presence of diamagnetic copper. Both atomic species, Mo as well as Cu, play important role in the formation of domains.

The field dependencies $\lambda_{par}(H)$ and $\lambda_{perp}(H)$ reflect the processes related to the behaviour of these atomic species. The alloy $Fe_{79}Mo_8Cu_1B_{12}$ with $T_C \sim 278$K contains no domains at room temperature and only single atoms participate in the magnetostriction effect, thus $\lambda_S \sim 0$. Low-field dependencies of $\lambda_{par}(H)$ and $\lambda_{perp}(H)$ exhibit only a small increase with H due to the presence of diamagnetic Cu atoms. Further increase of magnetostriction values with increasing H is due only to paramagnetic atoms which override the effect of Cu; linear increase of magnetostrictions is observed until saturation is reached at high fields. This corresponds to the theoretical dependence for magnetic polarization $J=\kappa H$, where κ is the magnetic susceptibility of a paramagnetic material.

With T_C approaching (and exceeding) the temperature of measurement more atoms are arranged in domains and the dependencies $\lambda_{par}(H)$ and $\lambda_{perp}(H)$ are then a combination resulting from the action of domains and individual atoms (Fig. 2) resulting in $\lambda_S \neq 0$. The combination of these effects coming from domains and from single (paramagnetic) atoms can be observed also on $\lambda_{par}(H)$ and $\lambda_{perp}(H)$ dependencies for Fe-B and Fe-Mo-Cu-B systems. A decrease of bond strength can be observed at the eutectic concentration $Fe_{83}B_{17}$. Weaker bonds of paramagnetic atoms contribute to the final value of magnetostriction λ_S. Forced volume magnetostriction $\partial\omega(H)/\partial H$ exhibits a maximum in both Fe-B and Fe-Mo-Cu-B systems.

Both systems exhibit also a strong invar effect due to spontaneous volume magnetostriction ω_{spon}. Compositional dependencies for both systems are similar to each other; the values of ω_{spon} at 300K are naturally different because they depend also on the value of T_C.

CONCLUSIONS

The dependencies of $\lambda_{par}(H)$, $\lambda_{perp}(H)$, λ_S, $\omega(H)$, $\partial\omega/\partial H$, ω_{spon} on external magnetic field, temperature and chemical composition as well as the values of the Curie temperature in the investigated rapidly quenched Fe-B and Fe-Mo-Cu-B systems were obtained. The results indicate that these quantities represent important information relevant for technological applications of these magnetic systems.

Acknowledgement

The support of the Slovak Grant Agencies (VEGA 5/5096/25, APVT-51-052702, APVT-99-017904, APVT-20-008404), COST P17 and SAS Centre of Excellence “Nanosmart” is acknowledged.

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Received 6 December 2006

Gabriel Vlasák (RNDr., PhD), senior scientist at IP SAS, born in 1937 in Vinodol (Slovakia), graduated from the Faculty of Natural Sciences of the Comenius University.

Tomáš Kaňuch (Ing.), born in 1980 in Bardejov. He graduated from Slovak University of Technology in Bratislava, in branch Electromaterial Engineering at the Faculty of Electrical Engineering and Information Technology in 2004. Graduation thesis concerned with influence of temperature on magnetic microstructure of $Fe_{76}Mo_8Cu_1B_{15}$ metallic alloy. At present he is a PhD student at the Department of Nuclear Physics and Technology at the Faculty of Electrical Engineering and Information Technology and his field of interest is microstructure and magnetic structure of nanocrystalline alloys.

Peter Švec (Ing., DrSc.), senior scientist at IP SAS, born in Bratislava in 1955, graduated from the Faculty of Electrical Engineering of the Slovak University of Technology in Bratislava, in 1979.

Marcel Miglierini (Prof, Ing, DrSc), born in 1956 in Bratislava. He graduated from the Slovak University of Technology in Bratislava, in branch Experimental Electrophysics in 1981 and received the DrSc degree in 1995. Since 1983 he has worked at the Department of Nuclear Physics and Technology, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava, since 1992 as associate professor, since 1997 as full professor in condensed matter physics. His research activities comprise the study of disordered (amorphous, quasicrystals, nanocrystals) and ordered (steels, minerals, catalysts) materials by nondestructive spectroscopy methods (Mössbauer spectroscopy, electron-positron annihilation, gamma spectroscopy). He is also involved in the investigation of the methodological aspects of Mössbauer spectroscopy.