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MAGNETIC AFTEREFFECTS IN $(Co_{1-x}Fe_x)_{75}Si_{15}B_{10}$ METALLIC GLASSES

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The paper deals with the influence of the magnetostriction λ_s on the quantity (RMA) of reversible magnetic aftereffect (MAE) in the $(Co_{1-x}Fe_x)_{75}Si_{15}B_{10}$ metallic glasses system. The RMA slightly increases with the $|\lambda_s|$. The micromechanisms of the (MAE) and of the changes of magnetic properties due to low-temperature annealing of Co-rich and Fe-rich alloys are discussed. It was found that the annealing at $T = 150\,°C/3h$ causes the most significant changes of AC susceptibility χ_{30}, coercive force H_c, MAE and perminvar critical field H_{CR} in Co-rich alloys with near-zero λ_s.

I. INTRODUCTION

The behaviour stability of amorphous ferromagnets is an important criterion of their applicability in technical utilization. Magnetic relaxation of amorphous structure is a factor which influences this stability [1–3]. Magnetic relaxation can be characterized as a sort of rearrangement of uniaxial two-level atomic units with respect to the direction of local magnetization.

On the other hand, the authors of [4] explain the MAE in amorphous alloys by a magnetoelastic interaction between magnetization and shear-stresses fluctuations.

Almost all soft magnetic metallic glasses applicable in technique contain Co and/or Fe as their basic elements. Our $(Co_{1-x}Fe_x)_{75}Si_{15}B_{10}$ system is intensively studied because of its wide range of magnetostriction in dependence on the Fe content. Its magnetostriction approaches near-zero value for $x = 0.06$ [5].

The aim of this work is to show influences of the magnetostriction λ_s on the MAE and of the low-temperature annealing on the MAE, the coercivity H_c, the AC susceptibility χ_{30} and the perminvar critical field H_{CR} [6] of the $(Co_{1-x}Fe_x)_{75}Si_{15}B_{10}$ amorphous system with $x = Fe/Fe + Co = 0, 0.06, 0.12, 0.5, 0.79, 1$.

II. EXPERIMENT

The CoFeSiB glassy alloys were prepared by the melt-spinning technique under the same technological conditions in the TUD, Lyngby. The samples had a form of 10 cm long and 0.5 mm wide straight ribbons.

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The AC susceptibility was measured by a mutual-inductance bridge at the frequency of $f = 1.5\,kHz$ and at various intensities of the measuring field. To determine the initial susceptibility values the measuring magnetic field intensity of $H = 25\,mA\,m^{-1}$ was used. The specimens were demagnetized by the AC magnetic field of the 50 Hz frequency and of the first amplitude of $H = 2\,kA\,m^{-1}$, continuously decreased to zero within 3 s. The MAE (disaccommodation) is represented by a relative change of reluctivity

$$\frac{\Delta r}{r} = \frac{r(t_2) - r(t_1)}{r(t_1)} = DA = \frac{RMA}{I_s} \qquad (1)$$

measured between two fixed times t_1 and t_2 after demagnetization (in our case $t_1 = 30\,s$, $t_2 = 30\,min$), I_s saturated magnetization. The perminvar critical field H_{CR} was determined from dependences of the AC susceptibilities on measuring magnetic field amplitude as the critical fields for the irreversible susceptibility beginnigs [6] after a 30 min long stabilization. During stabilization the measuring field was switched off. The coercive field was measured by the pull-down method in an arrangement with an electronic fluxmeter.

III. RESULTS AND DISCUSSION

Magnetic relaxation causes an increase of the domain structure stability and a decrease of the domain walls mobility. This fact is manifested by a characteristic time decay of susceptibility in a certain interval of temperatures and by an increase of critical magnetic field intensity H_{CR} required for stimulation of the irreversible movement of domain walls. The time development of the MAE is well illustrated by dependences of the inversed susceptibility, i.e., reluctivity. The time dependences of reluctivity measured at room temperature showed, in our case, a good agreement with log-time kinetics [1] almost in all of the $(Co_{1-x}Fe_x)_{75}Si_{15}B_{10}$ specimens. Here the MAE of reversible type was prevailing. It was manifested by the same value of reluctivity after repeated demagnetization of a specimen.

Our set of specimens is characterized by a wide range of magnetostrictions. We have found (see Fig. 1) that $RMA = I_s \cdot DA$ as a quantity of the initial (reversible) reluctivity MAE (1) increases with an increasing absolute value of the magnetostriction of individual specimens, similarly as in [4]. The mathematical description of the RMA dependence on the magnetostriction looks similarly like in the case of the MAE of irreversible susceptibility [4, 6, 7]. In our case in the first aproximation the power dependence of reversible MAE on magnetostriction $RMA = a \cdot |\lambda_s|^b$ ($a = 0.6\,T$, $b = 0.2$) could be valid.

Subsequently, an influence of the domain structure stabilization during 30 min at the elevated temperature $T = 150\,°C$ on the MAE and the perminvar critical fields H_{CR} in amorphous alloys with different Fe content x was investigated. As it is seen in Fig. 2, both $\Delta r/r$ and H_{CR} behave very similarly. At low x-values they slowly increase. It might be caused by the increase of the Co-based atomic couples

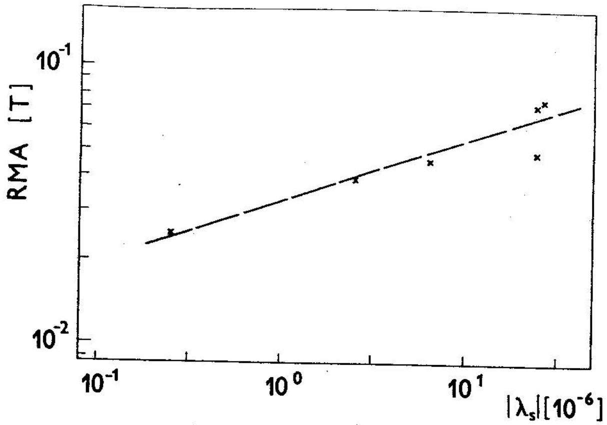

Fig. 1. Dependence of magnetic aftereffect on magnetostriction of the $(Co_{1-x}Fe_x)_{75}Si_{15}B_{10}$ amorphous alloys $RMA = f(\lambda_s)$ measured at room temperature.

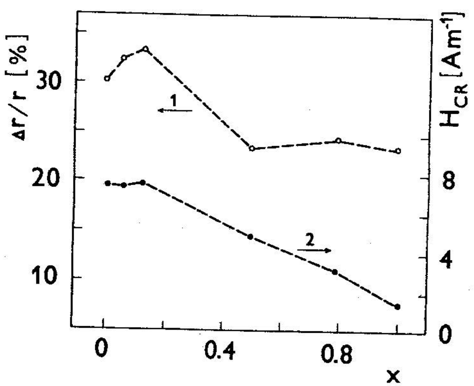

Fig. 2. Dependence of the MAE $\Delta r/r$ and the critical field H_{CR} on Fe content x measured at $T = 150\,°C$

concentration. At $x = 0.12$ they reach their maximum and with the subsequent increase of the Fe content the intensities of the MAE and H_{CR} decrease. It can be connected with the increase of the magnetic relaxation times [1] as well as with the decrease of Co-based pairs and cluster concentrations. They contribute to the induced anisotropy and also to the stabilization of the domain structure much more than Fe-based pairs and clusters [8].

Magnetic materials annealing is, as a rule, accompanied by many complicated atomic processes that often influence their properties in a contradictory way. These processes may have both reversible and irreversible character concerning the temperature character. The results of our investigations of the influence of

Table 1
Influence of low temperature annealing at $T = 150\,°C/3\,h$ on relative changes of the AC susceptibility χ_{30}, coercive force H_c, MAE $DA = \Delta r/r$ and perminvar critical field H_{CR} measured at room temperature before and after annealing

Composition	$\Delta\chi_{30}/\chi_{30}$ (%)	$\Delta H_c/H_c$ (%)	DA_2/DA_1 (%)	$\Delta H_{CR}/H_{CR}$ (%)
$Fe_{75}Si_{15}B_{10}$	+1.1	+28.3	0.91	-18.7
$(Co_{.21}Fe_{.79})_{75}Si_{15}B_{10}$	+4.2	+31.2	0.97	-13.3
$(Co_{.5}Fe_{.5})_{75}Si_{15}B_{10}$	-6.7	+2.5	0.85	-2.7
$(Co_{.88}Fe_{.12})_{75}Si_{15}B_{10}$	-42.6	+14.0	0.50	-25.5
$(Co_{.94}Fe_{.06})_{75}Si_{15}B_{10}$	-48.4	+314.0	0.51	-56.3
$Co_{75}Si_{15}B_{10}$	-45.2	+44.4	0.43	-29.0

low-temperature annealing at $T = 150\,°C$ for 3 h on the initial susceptibility (χ_{30}), on the coercive force (H_c), on the $MAE(DA)$ and on the perminvar critical field (H_{CR}) are presented in Tab. 1. Individual measurements before and after annealing without magnetic field have been performed at room temperature. The low-temperature annealing causes a change of all the mentioned properties. As it is seen in Tab. 1 the relative magnitude of these changes depends on the Fe content in CoFeSiB alloys.

By a sign of the relative change of initial susceptibility caused by annealing one can detect the result of a competition at least of two basic annealing mechanisms. These are the magnetic relaxation of atom pairs and the recombination of $n-$ and $p-$ defects [9]. The magnetic relaxation produces the local atom-pair-ordering induced anisotropy and the lower domain walls mobility, which is reflected in lower susceptibility. The n–p recombination produces the homogenization of amorphous structure and the release of the local internal-stress-induced anisotropy, which is reflected in a higher susceptibility. In Co-rich alloys the susceptibility χ_{30} decreases (Tab. 1) and the dominant atomic process of annealing seems to be the magnetic relaxation. In Fe-rich alloys the susceptibility χ_{30} increases. That indicates the dominant processes of annealing are the n–p recombinations. It is remarkable that there are no extreme χ_{30} changes at margine concentrations of Co and Fe, respectively.

Changes of both the coercive field H_c and the critical field H_{CR} are caused by changes in distribution functions of the domain walls pinning fields due to low-temperature annealing. The increase of the amorphous alloys coercivity (Tab. 1) reflects the shift of the pinning fields maximum to higher values owing to the deepening of the domain walls potentials caused by magnetic relaxation. The decrease of the critical fields H_{CR} might be connected with partial shifts of pinning fields to lower values. This is in agreement with the conception of internal stress release at low-temperature annealing [10].

As seen in Tab. 1, the low-temperature annealing causes the decrease of the

MAE amplitude, DA, in every $(Co_{1-x}Fe_x)_{75}Si_{15}B_{10}$ composition. The higher the Co content, the larger the DA change. This could be connected with the more significant mobility decreasing of Co-based atom pairs caused by the free volume homogenizing. Amorphous alloys near extreme Co or Fe concentrations need a more detailed study.

IV. CONCLUSIONS

1. Reversible MAE in $(Co_{1-x}Fe_x)_{75}Si_{15}B_{10}$ seems to be increased with magnetostriction.

2. At the 150 °C temperature the MAE and the perminvar effect, as manifestations of magnetic relaxations, are more apparent in Co-rich alloys. They decrease with the Fe content increase. These indicate that the influence of Co-based atom pairs ordering on the domain walls mobility is higher than the influence of Fe-based pairs ordering.

3. The low-temperature annealing at 150 °C/3 h causes the decrease of the MAE and of the perminvar critical fields, as well as the increase of the coercive field which are more apparent for a higher Co content. The above mentioned annealing causes initial susceptibility decreasing in a Co-rich alloy and its increasing in Fe-rich alloys.

4. Two different annealing processes with different micromechanisms take parts in CoFeSiB amorphous alloys. The dominant influence of annealing on magnetic properties is changed by the Fe content in amorphous alloys. The higher the Fe content, the lower the influence of low-temperature annealing. In Co-rich alloys the magnetic relaxation seems to be the main low-temperature annealing micromechanism. In Fe-rich alloys the dominant micromechanism of annealing is the recombination of $n-$ and $p-$ defects of amorphous structure. The extremal influence of annealing on magnetic properties does not always correspond with the extreme Co and Fe content in $(Co_{1-x}Fe_x)_{75}Si_{15}B_{10}$ amorphous alloys.

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МАГНИТНОЕ ПОСЛЕДЕЙСТВИЕ В МЕТАЛЛИЧЕСКИХ СТЕКЛАХ $(Co_{1-x}Fe_x)_{75}Si_{15}B_{10}$

Приведены результаты исследований влияния магнитострикции λ_s на величину (RMA) обратимого магнитного последействия (MAE) в системе металлических стекол $(Co_{1-x}Fe_x)_{75}Si_{15}B_{10}$ Обратимое магнитное последействие слабо растет с $|\lambda_s|$. Обсуждаются микромеханизмы магнитного последействия и изменения магнитных свойств при низкотемпературном отжиге сплавов Co и Fe. Определено, что отжиг при 150 °C/3 ч приводит к значительным изменениям магнитной восприимчивости переменного тока χ_{30}, коэрцитивной силы H_c, магнитного последействия DA и перминварного критического поля H_{CR} в сплавах богатых на Co с λ_s близкими нулю.