Low temperature magnetic properties and stress effects in glassy Fe-B alloys: the eutectic region

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The magnetic properties of glassy $Fe_{100-x}B_x$ ($x = 14, 16, 17, 20$) alloys under a low mechanical stress (up to 68 MPa) at temperatures 10–300 K, in magnetic fields up to 40 Oe, have been studied. Low temperature anomalies of magnetic susceptibility, as well as substantial differences in the effects of stresses on the low field magnetic characteristics of alloys with various boron contents, have been revealed. The eutectic alloy $Fe_{83}B_{17}$ was found to be the least sensitive to applied stresses, magnetic fields, and temperature changes: it possesses the lowest magnetic induction in the reversibility fields region and the highest local anisotropy fluctuations. The hypoeutectic $Fe_{84}B_{16}$ alloy is the most sensitive to applied stresses at room temperature, but its sensitivity substantially reduces with increasing load, as well as with decreasing temperature. The results obtained reflect the special character of the alloys electronic structure at the eutectic point.

The amorphous alloys $Fe_{100-x}B_x$ are soft magnetic materials with a wide field of applications [1–3]. In particular, much attention has focused on the alloys in the region of $x = 17$ (the eutectic composition), due to the possibility of special interatomic interactions in these alloys [4,5]. We have used the effect of stress on the magnetic properties to study the nature of differences of the alloys properties.

Experimental procedure

The studied samples $Fe_{100-x}B_x$ ($x = 14, 16, 17, 20$) were prepared from 30 μm thick and 6 mm wide amorphous ribbons, obtained by the planar flow casting technique.

The effect of tension as well as pressure on the magnetic induction B, was measured. The pulse-induction technique was used, with longitudinal magnetic fields $0 \le H \le 40$ Oe, temperatures 300 and 77 K, and tension stresses σ near 22 and 63 MPa in the 1st kind experiments, as well as the SQUID magnetometer, normal to the ribbons surface external magnetic field 20 Oe (the effective field in the samples was substantially reduced by the demagnetization factor N ~10), temperatures

$10 K \le T \le 230$ K, and the normal to the ribbons surface uniaxial pressure of about 20 MPa in the 2nd kind experiments.

Results and discussion

Magnetic characteristics

Longitudinal field. It was revealed that the eutectic alloy $Fe_{83}B_{17}$ possesses the lowest value of B in fields above 5 Oe at all studied temperatures and stresses. This is in agreement with the opinion, that fluctuations of the local anisotropy field in this alloy are the highest in the considered system [6]. The $B(H)$ curves (Fig. 1) suggest that the $Fe_{83}B_{17}$ alloy has the smallest saturation induction. This result corresponds to the saturation magnetization measurements of Bengus et al. [4].

At 300 K the hypoeutectic alloy $Fe_{84}B_{16}$ possesses the highest magnetic permeability μ, and the lowest coercivity H_c and magnetic remanence B_r (Table). At 77 K the difference between the μ of $Fe_{84}B_{16}$ and other alloys decreases.

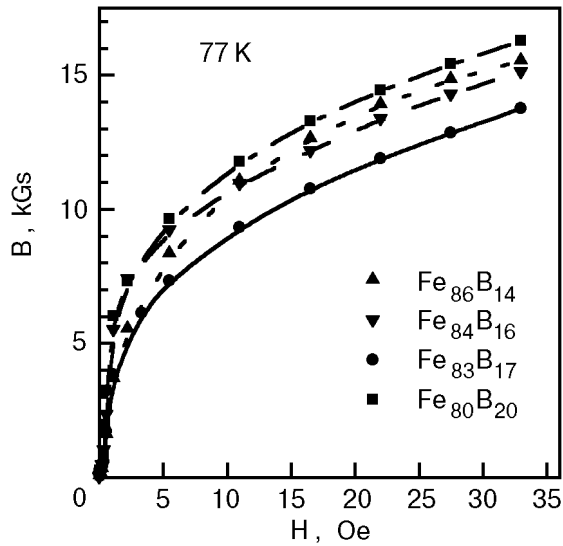*Fig. 1.* The magnetic induction field dependences of $Fe_{100-x}B_x$ (x = 14, 16, 17, 20) amorphous alloys under zero load at 77 K.

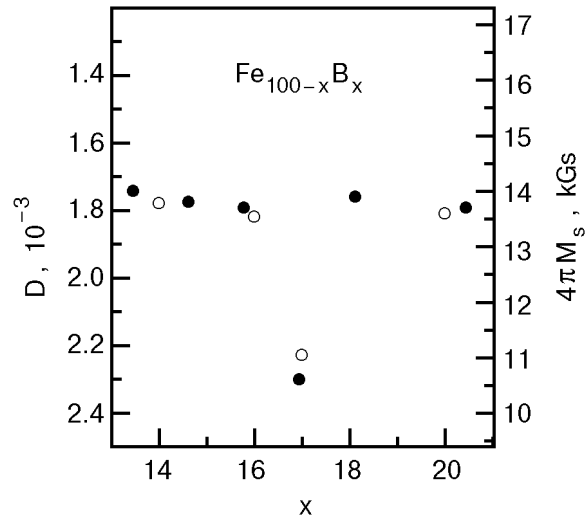*Fig. 2.* The parameter D (○) from Eq. (2), reflecting the local magnetic anisotropy fluctuations in the amorphous alloys $Fe_{100-x}B_x$ under zero load at 77 K, and saturation magnetization (●) [4] at 4.2 K versus x.

Table

The maximum magnetic permeability μ_{max} , coercivity H_c , and magnetic remanence B_r of glassy Fe-B alloys at nitrogen (77 K) and room (300 K) temperatures.

Alloy	μ_{max}		B_r , Gs		H_c , Oe	
	77 K	300 K	77 K	300 K	77 K	300 K
$Fe_{86}B_{14}$	2957	7228	980	1358	0.495	0.231
$Fe_{84}B_{16}$	4600	12651	303	756	0.165	0.132
$Fe_{83}B_{17}$	3235	7478	419	1496	0.341	0.264
$Fe_{80}B_{20}$	3802	8357	1566	1804	0.418	0.308

Transversal field. The effective magnetic susceptibility of the samples χ_{eff} measured in the 2nd experiment slowly decreased with decreasing temperature almost in the whole temperature range. There was a sharp slope at about 20 K, which was evidently connected with a magnetic phase transition to the disordered asperomagnetic phase [7]. The χ_{eff} curve of the eutectic alloy $Fe_{83}B_{17}$ was substantially lower than that of the other alloys. This may be considered as an evidence of the highest local magnetic anisotropy in the alloy.

Local anisotropy. The analysis of the field dependence of magnetization $\mathbf{M} = (\mathbf{B} - \mathbf{H})/4\pi$ in the region approaching saturation is carried out in the framework of the local anisotropy model. The parameters A_i of the equation

$$M = \sum_{i=0}^{6} A_i H^{-0.5i} \qquad (1)$$

in the region of longitudinal magnetic fields 16 Oe $\leq H \leq$ 40 Oe were evaluated by the least

squares method. The validity was analyzed of the sum (1) as a whole, as well as of its separate components. It was found that the best approximation of experimental data corresponds to the equation

$$M = M_\infty [1 - (DM_\infty/H)^{0.5}] , \qquad (2)$$

describing the zero-dimensional violations of the translation symmetry [8] of the system. The parameter D in Eq. (2) characterizes the local magnetic anisotropy fluctuations value.

As one can see in Fig. 2, the concentration dependence of parameter D shows a singularity at the eutectic point $x = 17$, which correlates well with the analogous singularity of the low temperature high field magnetization M_s from [4].

The results obtained agree with work by Iskhakov et al. [6], who reported that the eutectic alloy had the maximum value of mean square fluctuations of local magnetic anisotropy.

Tension effects

Applied tensile stresse leads to a growth in magnetic induction B, magnetic permeability μ and remanence B_r , and to a decrease in H_c (but no H_c decrease for $Fe_{84}B_{16}$).

Permeability. The increase of magnetic induction is mainly seen in fields up to about 30 Oe. At both room and liquid nitrogen temperatures, the growth of the maximum value of magnetic permeability μ_{max} of all the studied alloys under load is very sharp and range up to 1.5–3 times at about
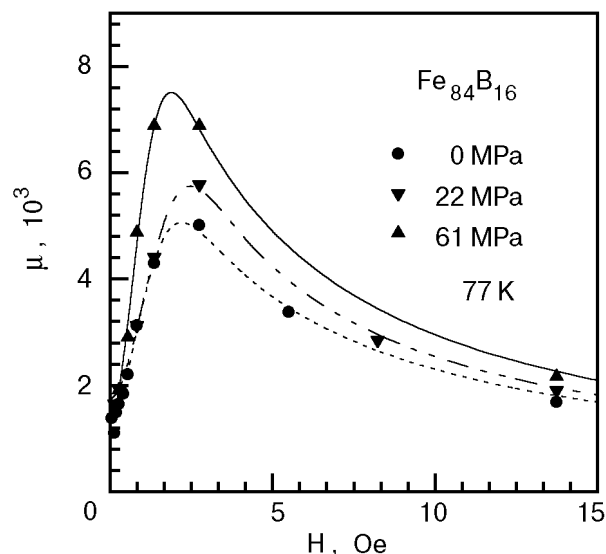
Fig. 3. Magnetic permeability μ of amorphous $Fe_{84}B_{16}$ alloy at liquid nitrogen temperature under the various tensile loads (22 and 61 MPa) versus magnetic field H.

63 MPa. This can be seen at Fig. 3, where the load effect is shown for the alloy $Fe_{84}B_{16}$.

At 300 K the smallest value of $\Delta\mu_{max}$ /$\Delta\sigma$ is exhibited by the eutectic alloy $Fe_{83}B_{17}$. When the temperature is lowered to 77 K, μ_{max} decreases about 2 times. The smallest value of $\Delta\mu_{max}$ /$\Delta\sigma$ at 77 K is for the $Fe_{84}B_{16}$ alloy.

Magnetic remanence. The applied loads lead to 1.6–3.6 times growth in remanence; the change in remanence per unit stress ΔB_r /$\Delta\sigma$, is nearly equal for all studied alloys and temperatures, except for the hypoeutectic alloy $Fe_{84}B_{16}$. This alloy exhibits

the smallest remanence without load at both studied temperatures, the largest value of ΔB_r /$\Delta\sigma$ at 300 K and the smallest at 77 K (Fig. 4).

Coercivity. The coercivity H_c of all the alloys decreased with increasing applied load, except for $Fe_{84}B_{16}$, which increased. But its coercivity remains the smallest at all the studied temperatures and loads. At the same time the coercivity of the eutectic alloy $Fe_{83}B_{17}$ is nearly independent of the applied load, its ΔH_c /$\Delta\sigma$ value is rather small.

The obtained data show that the eutectic alloy $Fe_{83}B_{17}$ is the least sensitive to changes in temperature and applied load: the changes per unit stress of its coercivity ΔH_c /$\Delta\sigma$, remanence ΔB_r /$\Delta\sigma$ and permeability $\Delta\mu_{max}$ /$\Delta\sigma$ are comparatively small at both studied temperatures. The threshold (i.e. separating the unchanged and changed electronic structures) $Fe_{84}B_{16}$ alloy is the most sensitive to applied load at room temperature, and its properties are the most sensitive to temperature as well. When the temperature decreases its sensitiveness to the load drops sharply.

Uniaxial pressure effects

The data obtained in the uniaxial pressure and the tensile experiments are in a good agreement. The magnetic susceptibility drops under pressure at all the temperatures studied, but the temperature dependence is not monotonic.

When lowering the temperature all the alloys showed an increasing value of $\chi^{-1}d\ln\chi/dP$ in the range 230–150 K (for alloy $Fe_{84}B_{16}$ the increase was only small), a maximum at 110–140 K, a decrease at 110–30 K, and an abrupt growth at tem-
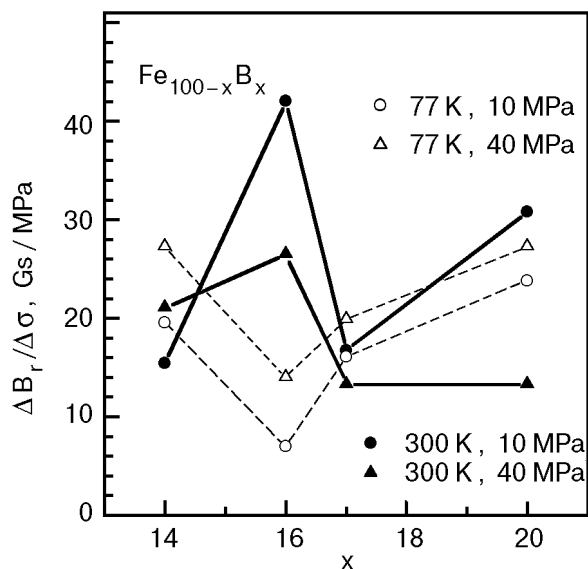

Fig. 4. The average derivative ΔB_r /$\Delta\sigma$ of amorphous Fe-B alloys at temperatures 77 and 300 K under tension stresses of 10 and 40 MPa.
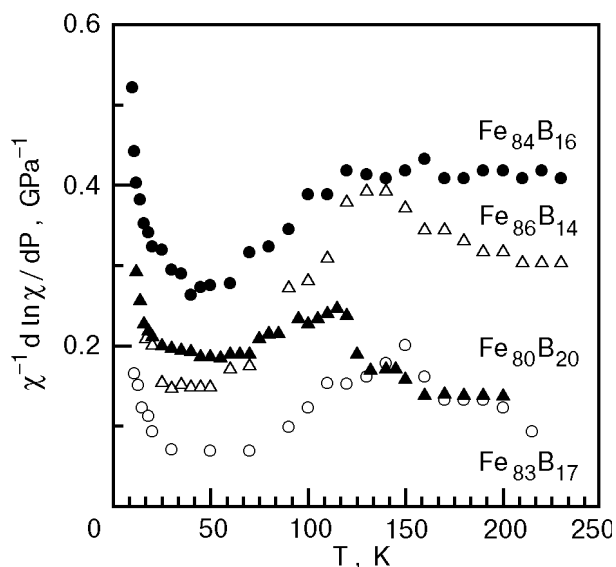

Fig. 5. The temperature dependence of the value $\chi^{-1}d\ln\chi/dP$ for amorphous Fe-B alloys under the normal to the ribbons surface uniaxial pressure of 20 MPa.

peratures lower than 30 K (Fig. 5). The $\chi^{-1} d\ln \chi / dP$ value was chosen for the analysis, because it is independent of the demagnetization factor: $\chi^{-1} d\ln \chi / dP = \chi_{\text{eff}}^{-1} d\ln \chi_{\text{eff}} / dP$. The main features of the temperature behavior of this value are determined by the behavior of $d\chi_{\text{eff}} / dP$, because χ_{eff} comparatively slightly depends on the temperature.

Since the interatomic distances weakly change with temperature (the studied alloys possess invar-type properties [9]), the presence of $\chi^{-1} d\ln \chi / dP$ maxima means a change in electronic structure. The growth of $\chi^{-1} d\ln \chi / dP$ at temperatures lower than 30 K is evidently connected with the formation of an asperomagnetic structure in this temperature region [7].

The smallest value of $\chi^{-1} d\ln \chi / dP$ corresponds to the eutectic composition ($x = 17$). This is in a good agreement with the concentration dependence of the failure stress of the studied alloys [4], as well as with our data on tension stress effects.

Conclusion

The results obtained confirm that the eutectic alloy $Fe_{83}B_{17}$ possesses a special and most stable atomic and electronic structure with the highest local anisotropy. It has the lowest magnetic induction and permeability, and it is the least sensitive to applied load and decreasing temperature. The results are in good agreement with the idea of an extremely disordered structure of intercluster boundaries of eutectic alloy $Fe_{83}B_{17}$, in which the clusters are supposed to have a quasicrystal structure [4].

The hypoeutectic $Fe_{84}B_{16}$ alloy exhibits the highest value of magnetic permeability and the lowest remanence and coercivity. It is the most sensitive to the applied loads at room temperature, and its properties are also the most sensitive to changes in temperature. Therefore, it possesses the smallest local magnetic anisotropy and the least stable electronic structure.

Dedication

Authors dedicate this paper to the memory of Boris Ieremievich Verkin, Scientist and Organizer of Science, who has founded and for thirty years Directed the Institute for Low Temperature Physics and Engineering of the Academy of Sciences of Ukraine, where authors have good luck to work.

1. F. E. Luborsky, *Amorphous Metallic Alloys*, Butterworths, London (1983).
2. R. Hasegawa and R. Ray, *J. Appl. Phys.* **49**, 4174 (1978).
3. R. Hasegawa, *J. Magn. Magn. Mat.* **100**, 1 (1991).
4. V. Z. Bengus, P. Duhaj, E. B. Korol'kova, E. D. Tabachnikova, A. V. Golik, and S. I. Tarapov, *Fiz. Nizk. Temp.* **20**, 1082 (1994) [*Low. Temp. Phys.* **20**, 853 (1994)].
5. A. B. Beznosov, E. L. Fertman, V. A. Desnenko, V. Z. Bengus, and V. A. Ushakov, in: *Novye Magnitnye Materialy Mikroelectroniki*, Pt. 1, 212, MGU, Moskva (1998).
6. R. S. Iskhakov, M. M. Karpenko, G. V. Popov, and V. P. Ovcharov, *Fiz. Met. Metalloved.* **61**, 265 (1986).
7. V. G. Bar'yakhtar, G. A. Takzei, A. B. Surzhenko, and M. V. Gavrilenko, *Fiz. Tverd. Tela* **34**, 245 (1992).
8. S. V. Vonsovsky, *Magnetism*, Nauka, Moskva (1971).
9. K. Fukamichi, M. Kikuchi, S. Arakawa, and T. Masumoto, *Solid State Commun.* **23**, 955 (1977).