DEPENDENCE ON METALLOID CONTENT FOR MAGNETIC PROPERTIES OF Fe-Si-B METALLIC GLASSES

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ABSTRACT

On the splat-cooled metallic $(Fe_{.79}Si_{.21})_{1-X}B_X$ glasses the concentration dependence of the magnetic properties has been investigated. For representative specimens, magnetic domain structures have been observed. The crystallization temperature increases and the Curie temperature monotonously decreases from 713 K to 671 K contrary to the result for reported Fe-P-C or Fe-P-B glasses as the metalloid content is increased. The highest value of crystallization temperature (797 K) is about 150 K higher than those for iron-rich glassy alloys reported up to now. The coercive force also depends on the boron content and the lowest value (0.04 Oe) has been obtained at about X=0.10. The magnetization process is discussed in the light of domain patterns observed.

INTRODUCTION

In recent years a number of studies on ferromagnetic metallic glasses have been performed. Most of these glasses have an atomic composition $(TM)_{1-Y}M_Y$ where (TM) and M mean transition metal and metalloid, respectively. However, the dependence of magnetic properties of these metallic glasses on metalloid concentration has not been well investigated; hitherto only a few studies on Fe-P-C[1] and Fe-P-B[2] metallic glasses have been performed. In these metallic glasses, the substitutions of iron with metalloid in the range $0.175 \leq Y \leq 0.23$ for Fe-P-C and $0.17 \leq Y \leq 0.22$ for Fe-P-B, have been found to result in an increase of the Curie temperature and a decrease of magnetic moment. It seems to be of technical as well as fundamental interest to study the effects of the metalloid concentration higher than 25at.% on the thermal stability, the ferromagnetic Curie temperature, and the magnetization process of metallic glasses. We have extented boron content in $(Fe_{.79}Si_{.21})_{1-X}B_X$ metallic glasses in the range $0.06 \leq X \leq 0.14$ and investigated their magnetic properties.

EXPERIMENTAL

The metallic glasses were prepared by the disk cooling technique[3] from a melt of desired composition. The resulting ribbons are 0.5-1.0 mm wide and 10-25 µm thick, and checked to be in amorphous state by X-ray diffractometry in the range $0.06 \leq X \leq 0.14$. Chemically analyzed, the contents of Si and B in each ribbon deviated by less than 0.5 at.% from nominal values.

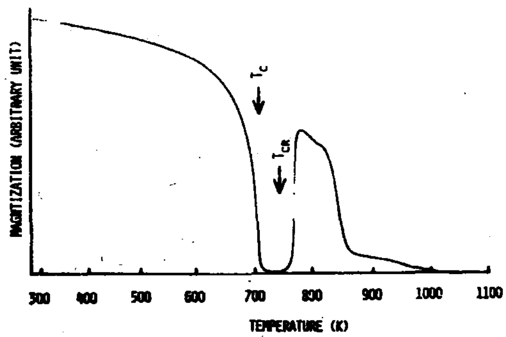
The specific magnetization at room temperature was measured with a vibrating sample magnetometer (VSM-3: Toei Industries Co.) at the field of 15 kOe. The Curie temperature T_C and crystallization temperature T_{Cr} were determined by monitoring the magnetization variation with increasing temperature. The applied field is 150 Oe, which gives a sharp transition temperature on the magnetization versus temperature curve. The hysteresis loop was measured for a set of three ribbons (20 cm long) at the maximum field of 100 Oe. The domain structure observation was performed by the ferromagnetic colloid technique on the free surface without polishing .

All the data shown in this paper are on the as-quenched specimens.

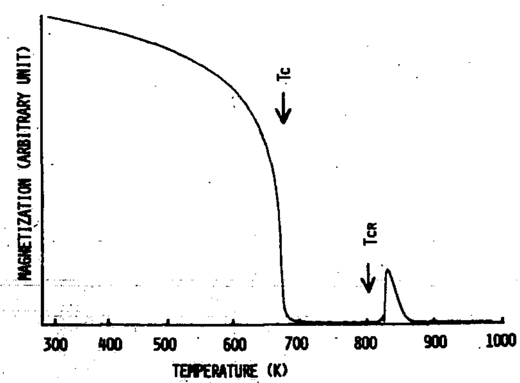
RESULTS AND DISCUSSIONS

A. Crystallization Behaviour

Typical thermomagnetization curves, for X=0.06 and for X=0.13, are shown in Fig.1. The temperature T_{Cr} at which crystallization is estimated to begin is shown by an arrow for each curve. The transformation to the crystalline state for the present metallic



(a) $(Fe_{.79}Si_{.21})_{.94}B_{.06}$



(b) $(Fe_{.79}Si_{.21})_{.87}B_{.13}$

Fig.1. Variation of magnetization with increasing temperature for $(Fe_{.79}Si_{.21})_{1-X}B_X$.

Table I. Magnetic moment µ in μ_B per Fe atom, Curie temperature Tc (K) and crystallization temperature Tcr (K) of iron-rich metallic glasses.

Alloy	µ	Tc	Tcr	Reference
$(Fe_{.79}Si_{.21})_{.94}B_{.06}$	1.86*	713	758	present work
$Fe_{80}B_{20}$	1.99	647	658	5
$Fe_{80}P_{16}C_3B_1$	2.13	565	600	4
$Fe_{80}P_{13}C_7$	2.10	586	690	6

* at room temperature

glass was found to take place at higher temperature than the Curie temperature. In Fig.1(a) for $(Fe_{.79}Si_{.21})_{.94}B_{.06}$ it can be seen that there exist two crystalline phases with different Curie temperatures (about 870 K and 1020 K). The phase with higher Curie temperature is identified as α-Fe phase (T_c=1043 K). In the range 0.11≤X≤0.14 α-Fe crystalline phase was not magnetically detected as typically shown in Fig.1(b). The values of Tcr determined from the thermomagnetization curve are plotted as a function of boron content in Fig.2. The crystallization temperature T_{cr} increases up to about X=0.10 and

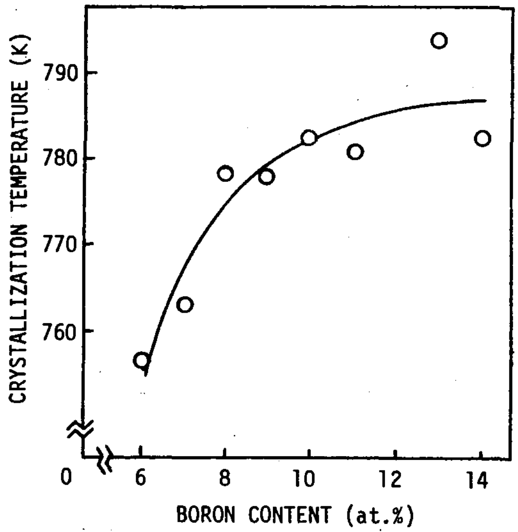


Fig.2. Dependence of crystallization temperature on boron concentration.

tends to saturate. The decreased crystallization temperature for X≤0.10 is consider to be associated with the nucleation of α-Fe phase. The behaviour is quite similar to that of Co-Si-B system reported by Funakoshi et al[7]. They reported that the first stage of crystallization proceeds by the nucleation of hcp cobalt and that the nucleation temperature increases with increasing metalloid content.

The value of T_{cr} for X=0.06 is compared in Table I with those of other iron-rich metallic glasses. In the system of $(Fe_{.79}Si_{.21})_{1-x}B_x$, the highest value of T_{cr}(797 K) is about 150 K higher than that of $Fe_{80}P_{16}C_3B_1$[4] (T_{cr}=600 K) or $Fe_{80}B_{20}$[5] (T_{cr}=568 K). This is favorable in terms of the thermal stability of the material.

B. Magnetic Moment and Curie Temperature

The value of T_c and the magnetic moment μ per iron atom are plotted as a function of the boron content in Fig.3. Both T_c and μ decrease with increasing boron content. The behaviour is quite different from those of Fe-P-C[1] and Fe-P-B[2] amorphous alloys for which increase of T_c and decrease of μ were reported with increaseing metalloid content. The total amount of metalloids is more than about 25.7 at.% for present Fe-Si-B alloys, and less than 23 at.% for Fe-P-C alloys. The difference in T_c is considered to be due to the different metalloid content.

As noticed in Table I, the value of T_c(713 K) for $(Fe_{.79}Si_{.21})_{.94}B_{.06}$, which is maximum in the range 0.06≤X≤0.14, gives the highest Curie temperature among the iron-rich glasses reported up to date. This leads to a smaller temperature dependence of magnetic properties such as the saturation induction around room temperature and gives an advantage for magnetic device application.

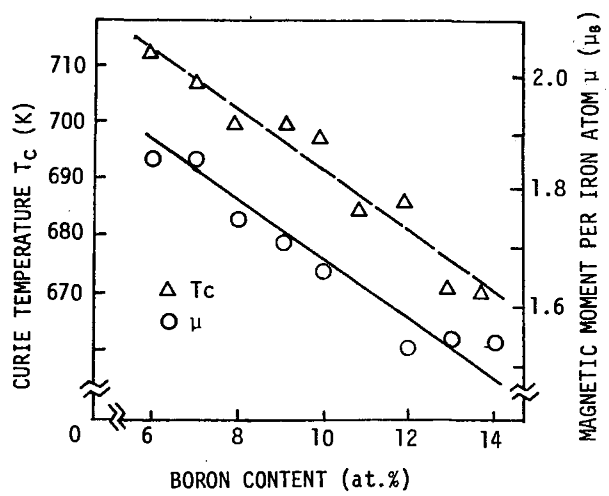


Fig.3. Magnetic moment μ in μ_B per iron atom at room temperature and Curie temperature versus boron content.

C. Magnetization Behaviour

In Fig.4 the value of the specific magnetization σ_s and the coercive force H_c are plotted as a function of the boron content X in $(Fe_{79}Si_{.21})_{1-x}B_x$ glasses. Both the specific magnetization and the coercive force decrease with increasing boron content.

The magnetic behaviour is different between the specimens with X=0.06 and X=0.10 . The hysteresis loops of $(Fe_{.79}Si_{.21})_{.94}B_{.06}$ and $(Fe_{.79}Si_{.21})_{.90}B_{.10}$ are shown in Fig.5. The magnetization is normalized to the value for the applied field of 100 Oe. The former shows remanence ratio of 0.44 and Hc of 0.19 Oe . The latter showing remanence ratio of 0.60 and Hc of 0.04 Oe is superior to the former as a soft magnetic material, but very brittle. Two different behaviours correspond to the change of domain structure in each specimen as described below.

For the specimen with X=0.06 a complicated domain structure as reported in Fe-P-C[8] and Fe-Ni-P-B[9] glasses is shown in Fig.6. The structure suggests the existence of magnetic anisotropy having components perpendicular to the ribbon plane. But a simple domain structure was observed at the demagnetized state of

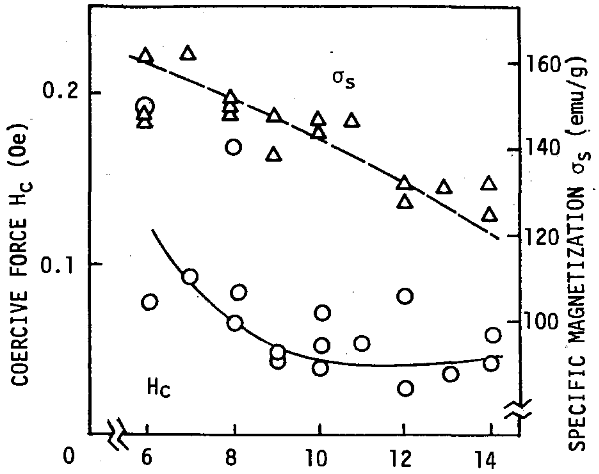
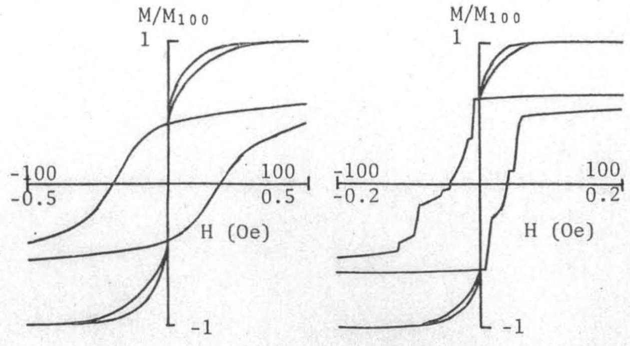


Fig.4. Dependence of specific magnetization and coercive force on boron concentration.



(a) X=0.06 (b) X=0.10

Fig.5. Typical hysteresis loops of as quenched $(Fe_{.79}Si_{.21})_{1-x}B_x$ glasses.

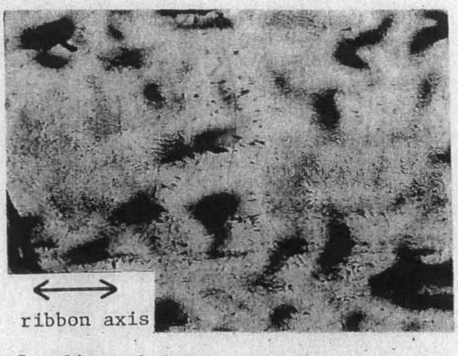
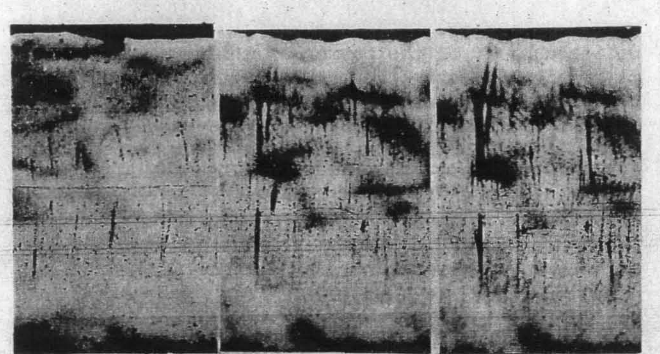


Fig.6. Complicated domain structure at the demagnetized state of $(Fe_{.79}Si_{.21})_{.94}B_{.06}$.



(a) (b) (c)

Fig.7. Typical domain structures in $(Fe_{.79}Si_{.21})_{.90}B_{.10}$. (a) Demagnetized state. (b) Small isolated domain. (c) Movement of small isolated domain under an increasing applied field.

the specimen with X=0.10 as shown in Fig.7(a). A wide domain has the magnetization parallel to the straight wall along the ribbon axis as suggested by the direction of the striation. At the different section of the ribbon, a small isolated domain was observed inside the main domain as shown in Fig.7(b). As the straight wall approaches the small domain under an increasing applied field, the isolated domain moves in the direction normal to the straight wall, and the length does not change as shown in Fig. 7(b) and (c). This suggests that the small domain has the same magnetization component as that of the spreading main domain. The movable isolated domain always appeared at the same position of the specimen. This implies the existence of magnetic non-uniformity in the ribbon.

The difference in magnetic behaviour between two specimens may be due to the variation of magnetic anisotropy with boron content.

CONCLUSION

Typical crystallization behaviour for $(Fe_{.79}Si_{.21})_{1-x}B_x$ has been studied experimentally for boron content more than 6 at.%. The highest crystallization temperature (797 K) was obtained for $(Fe_{.79}Si_{.21})_{.87}B_{.13}$. The decreased crystallization temperature for glasses with X≤0.10 may be attributable to the nucleation of α-Fe phase.

The variation of the Curie temperature with the boron content in the present metallic glasses has a negative slope contrary to that in Fe-P-C and Fe-P-B alloys. From this result, it is expected that the maximum Curie temperature would be obtained at about 25at.% of metalloid content for iron-rich glasses. The high Curie temperature and crystallization temperature of present Fe-Si-B glasses are advantageous from the standpoint of magnetic and thermal stability required in magnetic application.

$(Fe_{.79}Si_{.21})_{1-x}B_x$ exhibits relatively high coercive force for X≤0.08 and lower coercive force for X>0.08. The high coercive force for X≤0.08 may be due to the complicated domain structure. The glass with X=0.10 has a simple domain structure and is suitable for a soft magnetic material.

Further study for glasses with larger ratio of Fe to Si is now in progress.

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REFERENCES

1. H.S. Chen, Phys. Stat. Sol. (a) 17, 561 (1973).
2. J. Durand, IEEE Trans. Mag. Mag-12, 945 (1976).
3. H.H. Liebermann and C.D. Graham, Jr. IEEE Trans. Mag. Mag-12, 921 (1976).
4. R. Hasegawa and R.C.O'Handley, Proc. 2nd Int. Conf. on Rapidly Quenched Metals, Boston, 1975.
5. R. Hasegawa, R.C.O'Handley and L.I. Mendelsohn, AIP Conf. Proc. 34, 298 (1976).
6. C.C. Tsuei, G. Longworth and S.C.H. Lin, Phys. Rev. 170, 603 (1968).
7. N. Funakoshi, T. Kanamori and T.Manabe, Japan J. Appl. Phys. 15, 1833 (1976).
8. Y. Obi, H. Fujimori, and H. Saito, Japan J. Appl. Phys. 15, 611 (1976).
9. J.J. Becker, AIP Conf. Proc. 29, 204 (1975).