COMPOSITION DEPENDENCE OF MAGNETIC MOMENT AND CURIE TEMPERATURE IN AMORPHOUS $(Fe_xCo_{100-x})_{100-(y+z)}Si_yB_z$ RIBBONS

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ABSTRACT

Composition dependence of the magnetic moment and Curie temperature in amorphous $(Fe_xCo_{100-x})_{100-(y+z)}Si_yB_z$ ribbons has been studied systematically with changing X, Y, and Z. A knee suggesting a peak was found in the magnetic moment vs. metalloid content curve for Fe-Si-B alloys, while the moment of Co-Si-B alloys decreases nearly linearly with increasing metalloid content. The moment of (FeCo)-Si-B alloys decreases monotonously with decreasing iron content. The behavior of the magnetic moment can be explained by the electron transfer from metalloid to the 3d band of transition metal atom. A clear peak in the Curie temperature vs. metalloid content curve was found not only for Fe-Si-B alloys but also for Co-Si-B alloys, contrary to the result for Co-P alloy. The Curie temperature of (FeCo)-Si-B alloys peaks for varying iron content independently of the amount of total metalloid contained in the alloys. These behaviors are discussed in the framework of the Slater-Bethe's curve.

INTRODUCTION

Composition dependence of the magnetic properties in metal-metalloid amorphous alloys has been studied by a number of investigators. It has been reported that the magnetic moment decreases with increasing metalloid content in Fe-Si-B[1], Fe-P-B[2], and Co-P[3] alloys. However, the increasing tendency of the moment with increasing metalloid had been also reported in the range of low metalloid content for Fe-M alloys[4], where M means Si or Ge element. In Fe-Co based alloys, it is known that the moment of $(Fe_xCo_{100-x})_{80}B_{20}$ alloys peaks for varying X, while a peak in the moment vs. X curve was not observed for $(Fe_xCo_{100-x})_{80}P_{20}$ alloys[5]. On the other hand, it has been reported that the Curie temperature peaks for varying metalloid content in Fe-B-Al-P, Fe-Al-P, and Fe-Si-P alloys, and that iron content which gives a peak depends on metalloid elements.[6]

The magnetic moment and Curie temperature of amorphous alloys show complicated dependence on both metalloid elements and their content, as described above. However, systematic investigations on their dependence are not so many, and the machanism of the effects has not been explained clearly.

We have systematically studied the effects in amorphous $(Fe_xCo_{100-x})_{100-(y+z)}Si_yB_z$ ribbons to get understanding of the mechanism.

EXPERIMENTAL

Long ribbons of amorphous alloys (0.5-2.0 mm in width and 10-50 μm in thickness) were prepared by the disc cooling technique[7]. The amorphous state was confirmed by X-ray diffraction. For each specimen, the magnetization in an applied field of 10 kOe was measured continuously with a vibrating sample magnetometer as a function of temperature in the temperature range between 90 K and room temperature. The magnetic moment per transition metal atom at 0 K was determined by extrapolating the measured magnetization vs. temperature curve to 0 K. The Curie temperature was determined by monitoring the magnetization with increasing temperature (5 K/min.). In this measurement a sharp magnetic transition was observed, because all alloys under our study crystallized at higher temperature than Curie temperature except $Co_{79}Si_{11}B_{10}$, $(Fe_{40}Co_{60})_{76.7}Si_{13.3}B_{10}$, and $(Fe_{20}Co_{80})_{76.7}Si_{13.3}B_{10}$ alloys.

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RESULT AND DISCUSSION

A. Magnetic Moment

The magnetic moment, μ, at 0 K per transition metal atom is shown in Fig.1 as a function of total metalloid content. The compositions of alloys shown in the figure are $Fe_{90-y}Si_yB_{10}$ (Alloy-A), $Fe_{88-y}Si_yB_{12}$ (Alloy-B), $Co_{90-y}Si_yB_{10}$ (Alloy-C), and $Co_{88-y}Si_yB_{12}$ (Alloy-D). The magnetic moment vs. metalloid content curve for Fe-Si-B alloys has a knee suggesting a peak at about 21 at.% of metalloid. Beyond 21 at.%, μ of Fe-Si-B alloys decreases nearly linearly with increasing metalloid content. Substitution of 2 at.% Si with B does not cause obvious change of μ. In Co-Si-B alloys, μ decreases monotonously with increasing metalloid content, and μ of Alloy-D is slightly larger than that of Alloy-C. It is clearly seen that the slope for Co-Si-B alloys is steeper than that for Fe-Si-B alloys. The decreases of μ with increasing metalloid content can be explained in the framework of the rigid-band model, assuming the electron transfer from metalloid to the 3d band of transition metal atom. In Fe-Si-B alloys, the contributions of silicon and boron atoms are estimated as about 1.6 electrons per metalloid atom (Si and B) from the slopes at 25 at.% of metalloid for Alloy-A and -B. This value agrees roughly with values obtained

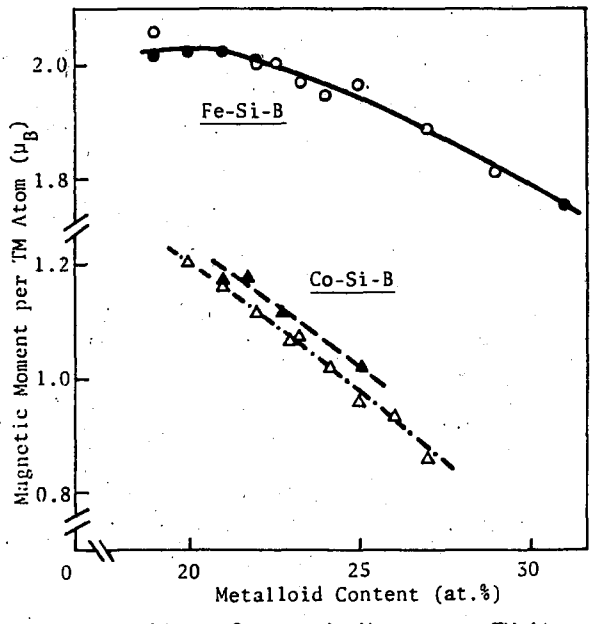

Fig.1 Dependence of Magnetic Moment per TM Atom on Metalloid Content in Amorphous Fe-Si-B and Co-Si-B Alloys. ○ $Fe_{90-y}Si_yB_{10}$ (Alloy-A), ● $Fe_{88-y}Si_yB_{12}$ (Alloy-B), △ $Co_{90-y}Si_yB_{10}$ (Alloy-C), ▲ $Co_{88-y}Si_yB_{12}$ (Alloy-D)

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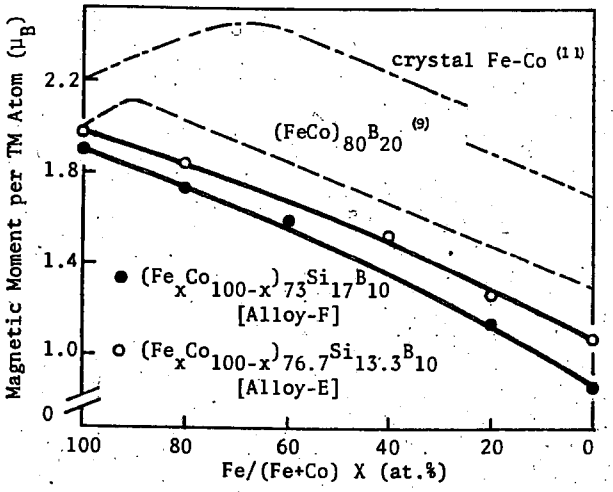

Fig.2 Dependence of Magnetic Moment per TM Atom on Fe Content in Amorphous (FeCo)-Si-B Alloys.

by Yamauchi et al[8] (1 per boron atom and 2 per silicon atom) and by Hasegawa et al[9] (1.6 per boron atom), while a different value was also reported[10]. Using our value, it can be deduced that about 0.4 electron per Fe atom is transfered at the metalloid content (about 21 at.%) corresponding to the knee of the μ vs. metalloid content curve. This is reasonable because Fe atom is considered to have about 7.1 electrons in the 3d band. However, the small value of μ at the knee is puzzling at present. In Co-Si-B alloys, the amounts of the electron transfer are estimated as about 2.8 per silicon atom and as about 1.6 per boron atom from the slopes of the moments and difference between moments of Alloy-C and -D.

Figure 2 shows the magnetic moment per transition metal atom in $(Fe_xCo_{100-x})_{76.7}Si_{13.3}B_{10}$ alloys (Alloy-E) and $(Fe_xCo_{100-x})_{73}Si_{17}B_{10}$ alloys (Alloy-F). The moments of amorphous $(Fe_xCo_{100-x})_{80}B_{20}$[9] and crystal Fe_xCo_{100-x}[11] alloys are also shown in the figure as a reference. As shown in the figure, the moments of Alloy-E and -F decrease monotonously with decreasing X, while the μ vs. X curves show a clear peak for $(FeCo)_{80}B_{20}$ and crystal Fe-Co alloys at X≃90 and X≃70, respectively. It is also seen that μ of Alloy-E is larger than that of Alloy-F in the whole range of X. These results demonstrate that the μ vs. X curves for these amorphous alloys are shifted to the left-hand side from the Slater-Pauling curve of crystal Fe-Co alloy and that the amount of shift is smallest for $(FeCo)_{80}B_{20}$ alloy and largest for Alloy-F. Calculating the number of electrons transfered from metalloid to the common 3d band of transition metal atoms in these amorphous alloys with values obtained from Fig.1, it is deduced that the amounts of the electron transfer show the same tendency with that of the shifts of the μ vs. X curve, that is, the amount of the electron transfer in $(FeCo)_{80}B_{20}$ alloy is smallest. This is reasonable, because the electron transfer causes shift of the Slater-Pauling curve. In addition, it is estimated that about 0.5 electron per Fe atom is transfered from metalloid and cobalt to the 3d band of Fe atom at the composition $[(Fe_{90}Co_{10})_{80}B_{20}]$ corresponding to the maximum of μ. Therefore, it is also reasonable that a peak in the μ vs. X curve is not observed for Alloy-E and -F, if it is taken into account that transfers of about 0.5 and 0.6 electron are estimated in $Fe_{76.7}Si_{13.3}B_{10}$ and $Fe_{73}Si_{17}B_{10}$ alloys, respectively. The value of the electron transfer (about 0.5) at the composition of $(Fe_{90}Co_{10})_{80}B_{20}$ agrees roughly with that estimated at the composition corresponding to the knee of the μ vs. metalloid content curve shown in Fig.1 (about 0.4). This is reasonable in terms of the simple rigid-band model.

B. Curie Temperature

The measured Curie temperature, Tc, is shown as a function of total metalloid content in Fig.3 (a) and (b) for Fe-Si-B and Co-Si-B alloys, respectively. In Fe-Si-B alloys, it is seen that Tc peaks clearly at about 25 at.% of metalloid. The appearance of a peak has been reported for Fe-B-Al-P, Fe-Al-P, and Fe-Si-P alloys by Chen et al[6], while they have not found a peak in the Tc vs. metalloid content curve for Fe-Si-B alloys. The alloys under our study contain larger amount of metalloid than alloys they used. A peak would be observed for Fe-Si-B alloys by them, if Tc were measured in wider range of metalloid content than they did. The behavior of Tc in Fe-Si-B alloys appears to be consistent with the Slater-Bethe's curve as pointed out by Chen et al., considering that metalloid increases the inter-atomic distance of Fe-Fe pair. As shown in Fig.3 (a), substitution of Si with B increases Tc in our alloys, contrary to the result reported by Chen et al.. The magnitude of Tc cannot be explained by that model.

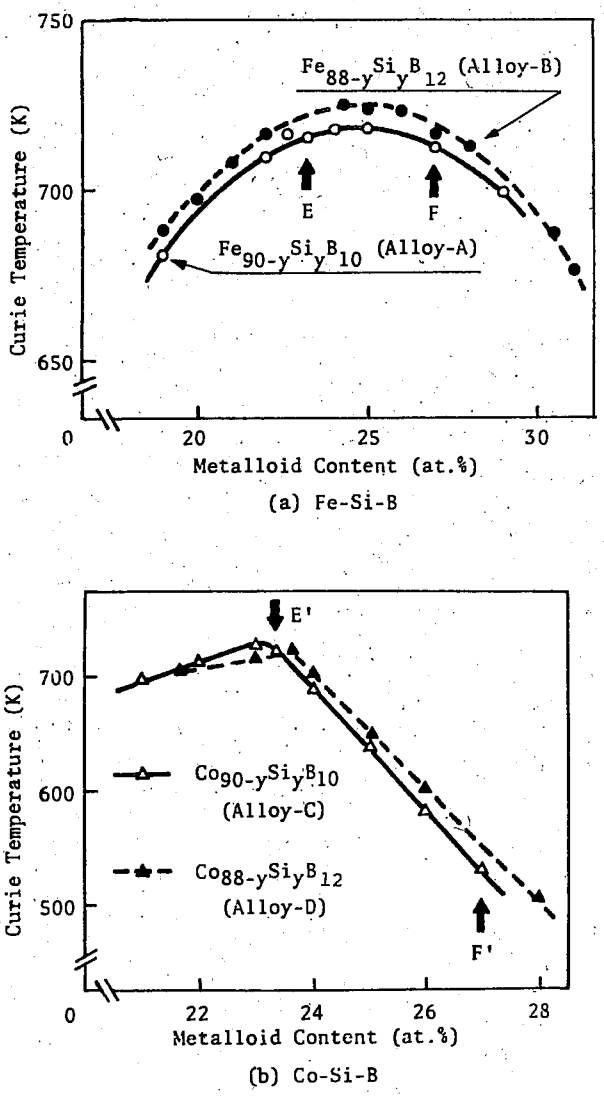

Fig.3 Dependence of Curie Temperature on Metalloid Content in Amorphous Fe-Si-B and Co-Si-B Alloys.

In Co-Si-B alloys, it is found clearly that Tc increases first, reaches a maximum, and then decreases rapidly with increasing metalloid content. This result is quite different from the result reported by Cargill et al[3], in which Tc of Co-P alloy decreases monotonously with increasing P content. Besides, it is seen that substitution of Si with B shifts the Tc vs. metalloid content curve to the right-hand side. In terms of the Slater-Bethe's curve, the appearance of a peak in the Tc vs. metalloid content curve for Co-Si-B alloys suggests that Tc of amorphous pure Co exists in the left-hand side of the peak of the Slater-Bethe's curve. However, it should be mentioned that Tc of crystal Co is considered to exist in the right-hand side of the peak. The Alloy-C contains larger amount of silicon than Alloy-D for fixed total metalloid content. Then, the shift of the Tc vs. metalloid content curve can be understood in terms of the Slater-Bethe's curve, because the iron size of silicon is considered to be larger than that of boron.

Figure 4 shows the Curie temperature of Alloy-E and -F as a function of iron content X. In Alloy-E, the Curie temperatures corresponding to X=100 and X=0 are shown by the arrows E and E' in Fig.3 (a) and (b), respectively. Similarly, the Curie temperatures corresponding to them in Alloy-F are shown by the arrows F and F' in the figures, respectively. In Alloy-E, the compositions corresponding to the arrows E and E' exist in the left- and right-hand side of the peak in the Tc vs. metalloid content curve, respectively. In Alloy-F, the both compositions corresponding to the arrows F and F' exist in the right-hand side of the peak. In addition, the magnetic moments of Alloy-E and -F decrease monotonously with decreasing X, as shown in Fig.2. Then, considering the Slater-Bethe's curve, we expected that Tc of Alloy-E peaks for varying X, and that Tc of Alloy-F does not. However, it is seen in Fig.4 that the Tc vs. X curve shows a peak for Alloy-F as well as for Alloy-E. This result shows that even in Alloy-F, Tc of amorphous Fe-Co based alloys does not accord with average of the Curie temperatures of Fe and Co based alloys having the same metalloid content as the resultant Fe-Co based alloys. This behavior cannot be understood at present stage.

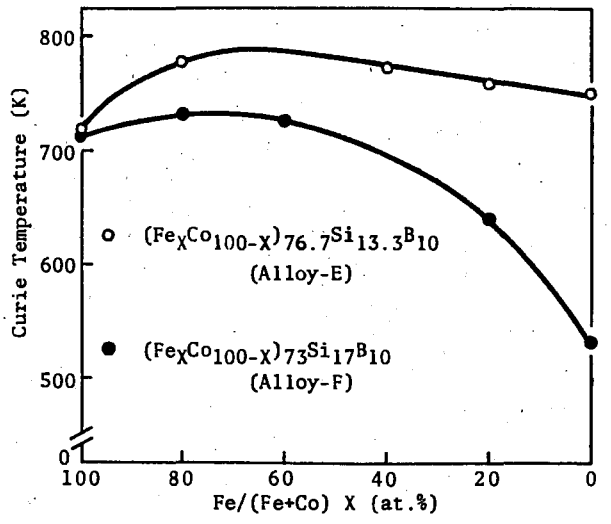

Fig.4 Dependence of Curie Temperature on Iron Content in Amorphous (FeCo)-Si-B Alloys.

CONCLUSION

The magnetic moment vs. metalloid content curve for Fe-Si-B alloys has a knee suggesting a peak at about 21 at.% of metalloid. On the other hand, the moment of Co-Si-B alloys shows monotonous decrease with increasing metalloid content. Substitution of Si with B increases the moment for Co-Si-B alloys, while it does not cause obvious change of the moment for Fe-Si-B alloys. The moment of (FeCo)-Si-B alloys decreases monotonously with decreasing iron content. These behaviors can be understood from the simple rigid band model.

The Curie temperature peaks clearly for varying metalloid content not only in Fe-Si-B alloys but also in Co-Si-B alloys. Substitution of Si with B causes the shift of the Curie temperature vs. metalloid content curve for Co-Si-B alloys. These behaviors can be explained in terms of the Slater-Bethe's curve. Besides, the Curie temperature vs. iron content curve for (FeCo)-Si-B alloys has a peak independently of amount of metalloid contained in the alloys. This behavior cannot be understood at present.

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REFERENCES

1) K.Narita, H.Fukunaga, and J.Yamasaki: Japan J. Appl. Phy. 16, (1977) 2063.
2) J.Durand: IEEE Trans. Mag. Mag-12, (1976) 945.
3) G.S.Cargill and R.W.Cochrane: J. de Phys. Tome 35, (1974) c4-269.
4) W.Felsch: Z. Phys. 219, (1969) 280.
5) R.C.O'Handley, R.Hasegawa, R.Ray, and C.-P.Chou: J. Appl. 48, (1977) 1538.
6) H.S.Chen, R.C.Cherwood, and E.M.Gyorgy: IEEE Trans. Mag. Mag-13, (1977) 1538.
7) H.H.Liebermann and C.D.Graham,Jr.: IEEE Trans Mag. Mag-12, (1976) 921.
8) K.Yamauchi and T.Mizoguchi: J. Phys. Soc. Japan 39, (1975) 541.
9) R.Hasegawa R.C.O'Handley and L.I.Mendelsohn: AIP Conf. Proc. 34, (1976) 298.
10) J.J.Becker, F.Luborsky, and J.L.Walter: IEEE Trans. Mag. Mag-12, (1976) 988.
11) R.M.Bozorth: "Ferromagnetism", Van Nostrand (1968), p441.