Anisotropic magnetoresistance in transition metal-boron amorphous alloys

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Anisotropic magnetoresistance ratio (AMR) was measured for binary and ternary (Fe,Co,Ni)-B amorphous alloys over the temperature range from 77K to room temperature varying the composition systematically. The largest AMR at room temperature was 0.45% for $(Fe_{0.95}Co_{0.05})_{84}B_{16}$ alloy, which is smaller by about one order in magnitude than those in crystalline binary transition metal alloys. It was found that AMR in Co-Ni-B alloys exhibits a maximum similar to crystalline Co-Ni alloys. The maximum values were obtained for the alloys having magnetic moment of $0.56\mu_B$ regardless of composition, meaning that the rigid band model is applicable to the anisotropic magnetoresistance in Co-Ni-B amorphous alloys.

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INTRODUCTION

In recent years, many investigations have been made on the galvanomagnetic effects in transition metal-metalloid amorphous alloys. But only a few papers[1-4] are on the anisotropic magnetoresistance effect. It is well known in the crystalline Ni based alloys that the anisotropic magnetoresistance ratio(AMR) exhibits a maximum for the alloy having a magnetic moment of $0.9\mu_B$[5]. On the other hand, it has been reported[1] that AMR in amorphous (Fe,Co)-Si,B and (Fe,Ni)-Si,B alloys does not show such maximum for the alloy having a magnetic moment of $0.9\mu_B$. But AMR in (Co,Ni) based amorphous alloys has not yet been measured.

In the present work, we measured AMR of binary and ternary (Fe,Co,Ni)-B amorphous alloys varying composition systematically to obtain the large AMR in amorphous alloys, and examined a relation between AMR and magnetic moment for ternary (Co,Ni)-B amorphous alloys.

EXPERIMENTAL

Binary and ternary (Fe,Co,Ni)-B amorphous samples in ribbon form were prepared by rapid quenching from the melt using iron or copper roller as a substrate. The cross sectional dimensions of the samples were typically 20μm x 1mm. To check the amorphous structure in the prepared samples, X-ray diffraction data were used. For Ni rich (Fe,Ni)-B and (Co,Ni)-B alloys, thermomagnetization curves were also measured to confirm the absence of fine magnetic crystallites which can not be detected by X-ray diffraction. Anisotropic magnetoresistance ratio(AMR) defined as $(\rho_\parallel - \rho_\perp)/\rho_\perp$ was measured by a dc four-probe method, where $\rho_\parallel$ and $\rho_\perp$ are the resistivities when the magnetization is lined up parallel and perpendicular to the ribbon axis, respectively. Measurements were made on 4cm long sample with pressed contacts over the temperature range from 77K to room temperature. The electric current along the ribbon axis and the maximum external field, which was applied parallel and perpendicular to the ribbon axis, were 80mA and 4KOe, respectively.

RESULTS AND DISCUSSION

A. Binary Fe-B and Co-B alloys

Fig.1 shows the temperature dependence of the anisotropic magnetoresistance ratio(AMR) for some Fe-B and Co-B amorphous alloys. Values of AMR are normalized with respect to those obtained by simple extrapolation toward 0K. It is noted that AMR vs. temperature curves show boron content dependence. AMR of $Fe_{84}B_{16}$ is more sensitive to temperature than that of $Fe_{77}B_{23}$. While in Co-B alloys, this tendency is in the opposite sense against boron content.

Fig.2 shows AMR at 77K and at room temperature in $Fe_{100-x}B_x$ and $Co_{100-x}B_x$ alloys as a function of boron

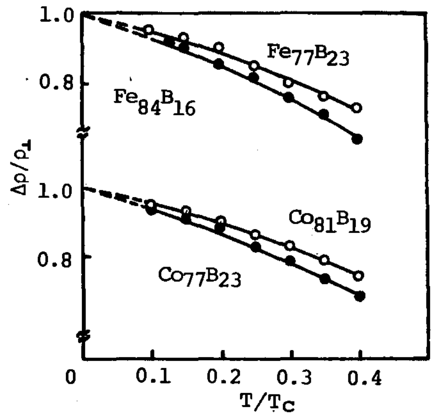

Fig.1 Reduced $\Delta\rho/\rho_\perp$ vs. temperature curves for binary Fe-B and Co-B amorphous alloys.

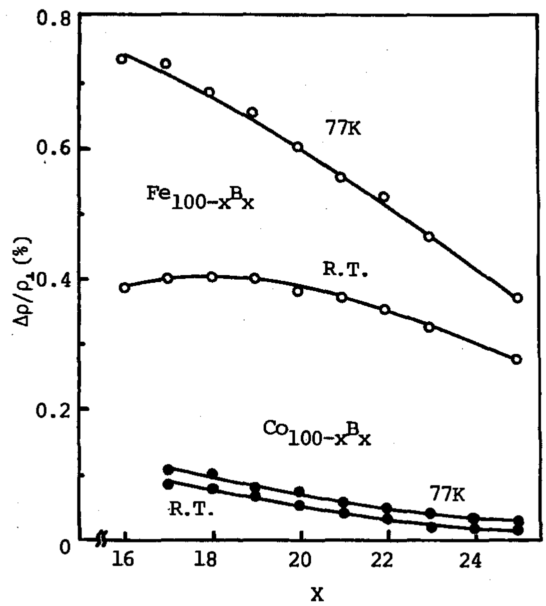

Fig.2 Compositional dependence of $\Delta\rho/\rho_\perp$ in amorphous $Fe_{100-x}B_x$ and $Co_{100-x}B_x$ amorphous alloys.

Table I Comparison of anisotropic magnetoresistance ratio between binary amorphous alloys and crystalline elements.

	Δρ/ρ (%)	ρ (μΩ·cm)	T (K)
$Co_{83}B_{17}$	0.11	120	77
$Fe_{84}B_{16}$	0.73	150	77
Co [6]	1.9	13.0	300
Fe [7]	0.2	0.64	77

content X. AMR at 77K in both alloy systems are positive and decrease monotonically with increasing X, while AMR at room temperature in Fe-B alloys takes a broad peak near X=18. This is a result of the decreased Curie temperature and stronger temperature dependence of AMR in Fe-B alloys with low boron content as is shown in Fig.1. Typical values at 77K are compared with those in crystalline Co[6] and Fe[7] in Table 1. AMR in Co-B alloy is smaller than that in crystalline Co, which is considered to be related to the higher electrical resistivity in the amorphous alloy. But AMR in Fe-B alloy is larger than that in crystalline Fe despite its higher electrical resistivity. It is also found that AMR in $Fe_{78}B_{22}$ and $Co_{78}B_{22}$ are larger than the reported values for $Fe_{78}Si_{10}B_{12}$ and $Co_{78}Si_{10}B_{12}$ alloys[1] containing the same amount of metalloid, from which it can be estimated that boron is more effective than silicon to increase AMR.

B. Ternary Fe-Co-B and Fe-Ni-B alloys

In Fig.3 are shown the reduced AMR vs. temperature curves for ternary Fe-Co-B and Fe-Ni-B alloys. It is to be noted that the substitution of Fe with Co or Ni causes AMR in Fe-B to be more stable against temperature. But the excessive substitution of Fe with Ni causes a rather rapid decrease in AMR with increasing temperature as is shown in the figure. AMR decreases nearly linearly with temperature. Thus alloying small amounts of Co or Ni improves the temperature dependence of AMR in Fe-B, but it also causes AMR at 77K to decrease as shown in Fig.4 and Fig.5 for $(Fe_{1-x}Co_x)_{100-y}B_y$ and $(Fe_{1-x}Ni_x)_{100-y}B_y$ alloys, respectively. It is to be noted that AMR at 77K in both alloy systems decreases steeply with increasing X up to arround X=0.4, beyond which the changes in AMR are relatively small. It is also seen that AMR in Fe-Ni-B alloys are larger than those in Fe-Co-B alloys in the range of X smaller than 0.8. Near this value of X, the Curie temperatures in Fe-Ni-B alloys are low(less than 300K).

On the other hand, AMR at room temperature in both alloy systems with lower boron content shows a maximum near X=0.05, which is attributable to the improved temperature dependence of AMR and to the increase in Curie temperature by alloying Co or Ni. The largest value of AMR at room temperature in the present alloys is 0.45%

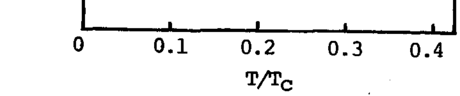

Fig.3 Reduced $\Delta\rho/\rho_\perp$ vs. temperature curves for binary and ternary (Fe,Co,Ni)-B amorphous alloys.

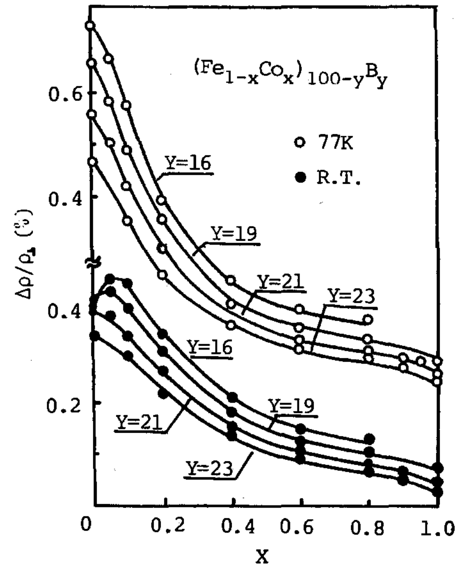

Fig.4 Compositional dependence of $\Delta\rho/\rho_\perp$ in amorphous $(Fe_{1-x}Co_x)_{100-y}B_y$ alloys.

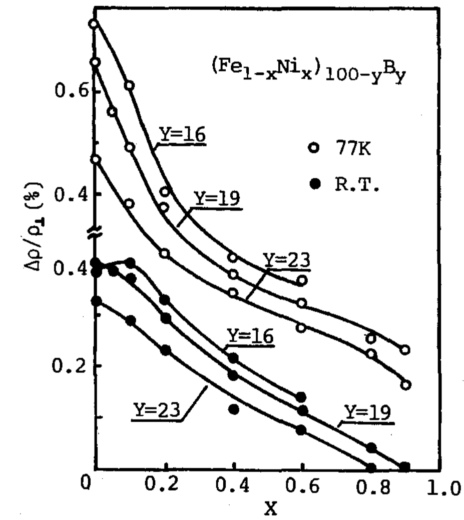

Fig.5 Compositional dependence of $\Delta\rho/\rho_\perp$ in amorphous $(Fe_{1-x}Ni_x)_{100-y}B_y$ alloys.

for $(Fe_{0.95}Co_{0.05})_{84}B_{16}$ alloy. This value is about 10% larger than the peak value of 0.40% in Fe-B alloys. When the ferromagnetic alloy is used in a magnetoresistance effect device, the output signal is proportional to the product of Δρ and electric current, which is also proportional to $1/\sqrt{\rho}$ under the condition of constant power dissipation, so that $\Delta\rho/\sqrt{\rho}$ is a reasonable figure of merit(FM) rather than Δρ. If we assume the FM for crystalline $Ni_{70}Co_{30}$[6] having AMR of 6.6% to be unity, FM for the present Fe-Co-B alloy is evaluated to be about 0.3. Thus the figure of merit of the amorphous alloys is low.

C. Ternary Co-Ni-B alloys.

Reduced AMR vs. temperature curves for ternary Co-Ni-B alloys are shown in Fig.6. It can be seen that the substitution of Co with Ni makes the AMR more temperature sensitive similar to Ni in Fe-Ni-B alloys. AMR decreases nearly linearly with increasing temperature in the temperature range shown. From these linear dependences of AMR, values at 0K were evaluated simply.

The compositional variations of AMR in $(Co_{1-x}Ni_x)_{100-y}B_y$ alloys are shown in Fig.7 as a function of X for Y=19 and 23. Semi-open circles are for partially crystallized alloys. It is to be noted that AMR shows a maximum similar to that in crystalline alloys. But the peak values at room temperature are smaller than that in Fe-Co-B alloys. It is also seen that X where AMR exhibits a maximum sifts toward larger value with decreasing temperature or with decreasing Y. This value of X for fully amorphous $(Co_{1-x}Ni_x)_{77}B_{23}$ alloys is 0.6 at 0K, and is evaluated to be about 0.7 for $(Co_{1-x}Ni_x)_{81}B_{19}$ alloys assuming the crystallization rises AMR due to the decreased resistivity. These values of X are small compared to that in crystalline $Co_{0.2}Ni_{0.8}$[5] having the peak value of AMR.

In the crystalline Fe-Ni and Co-Ni alloys, the maximum AMR is obtained for the alloy having the magnetic moment of $0.9\mu_B$. Near the composition of this alloy, saturatin magnetostrictions λ_s and spontaneous Hall coefficients R_s change their signs. These phenomena have been reported to be based on a commom physical origin, spin-orbit interaction[8,9]. Recently, O'Handley[10] has applied split band model developed by Berger to amorphous Fe-Ni-B alloys, and shown that the charge transfer from boron to the transition metal 3d band causes the composition with $\lambda_s=0$ and $R_s=0$ to shift from the crystalline composition toward Ni rich side. However, the direction of shift in maximum AMR composition for the present Co-Ni-B alloys with increasing boron content is in the opposite sense to that expected by split band model. It is supposed that a commom band is formed in Co-Ni-B alloys as well as crystalline Co-Ni[11] alloys.

Fig.9 shows compositional variations of the magnetic moment μ and the saturation magnetostriction λ_s in Co-Ni-B alloys. λ_s were determined from the tensile stress dependence of anisotropy field[12] at room temperature. The value of μ of $(Co_{0.4}Ni_{0.6})_{77}B_{23}$ alloy is $0.56\mu_B$. This value is nearly equal to $0.55\mu_B$ obtained by extrapolation for $(Co_{0.3}Ni_{0.7})_{81}B_{19}$ alloy. This means that the rigid band model is applicable to the aniso-

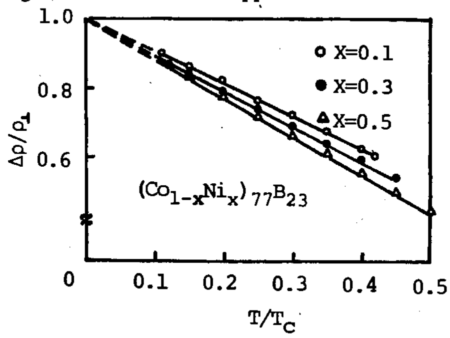

Fig.6 Reduced $\Delta\rho/\rho_\perp$ vs. temperature curves for ternary $(Co_{1-x}Ni_x)_{100-y}B_y$ amorphous alloys.

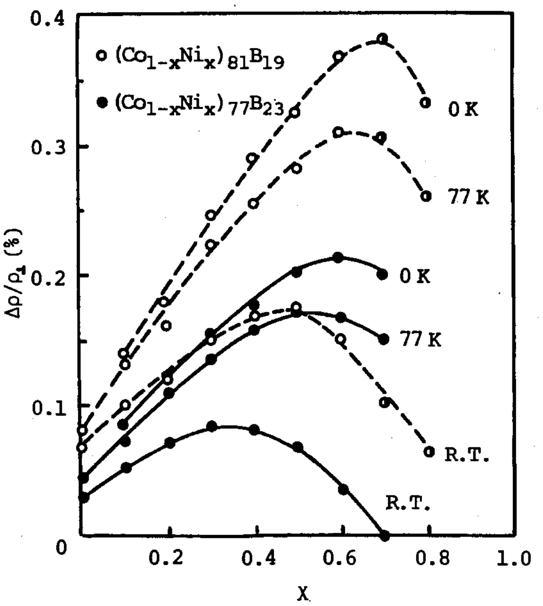

Fig.7 Compositional dependence of $\Delta\rho/\rho_\perp$ in amorphous $(Co_{1-x}Ni_x)_{100-y}B_y$ alloys.

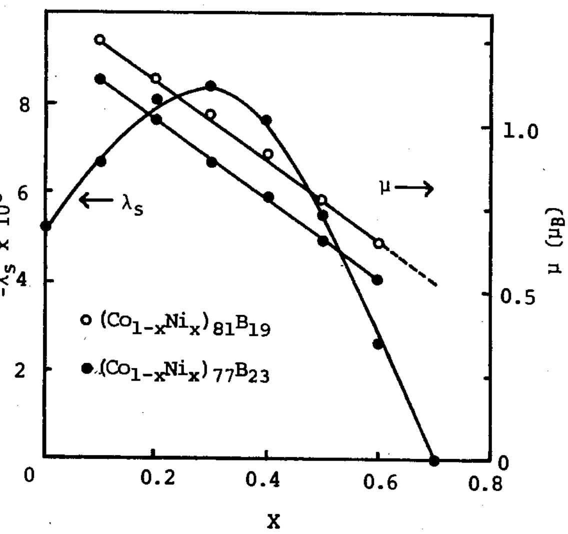

Fig.8 Compositional dependence of magneti moment μ and magnetostriction λ_s in $(Co_{1-x}Ni_x)_{100-y}B_y$ amorphous alloys.

tropic magnetoresistance in Co-Ni-B amorphous alloys. But the value of μ in the present Co-Ni-B alloys is smaller than $0.9\mu_B$ in the crystalline alloys.

On the other hand, λ_s in $(Co_{1-x}Ni_x)_{77}B_{23}$ is negative. Its absolute value decreases rapidly beyond X=0.4. λ_s at X=0.6 is small(-2.3×10^{-6}). Thus the peak of AMR in amorphous Co-Ni-B alloys is associated with the small magnetostriction. While large AMR in Fe-Ni-B alloys is obtained for Fe rich alloy having large magnetostriction. The reason of this is not clear.

CONCLUSION

The largest anisotropic magnetoresistance ratio (AMR) at room temperature was 0.45% for $(Fe_{0.95}Co_{0.05})_{84}B_{16}$ alloy, but its figure of merit is lower compared to that in crystalline binary transition metal alloys. AMR in Co-Ni-B amorphous alloys exhibits a maximum, which is obtained for the alloy having magnetic moment of about $0.56\mu_B$. This means that the rigid band model is applicable to the anisotropic magnetoresistance effect in (Co,Ni) based amorphous alloys.

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