Journal of Korean Magnetics Society, Volume 5, Number 5, October 1995

EFFECT OF THE ADDITION OF Ni ON GIANT MAGNETORESISTANCE OF Cu-Co AGED RIBBONS

I. J. Kim, J. Echigoya, K. Fukamichi and Y. Shimada#)

Department of Materials Science, Faculty of Engineering,
Tohoku University, Sendai, 980, Japan

#)Research Institute for Scientific Measurements,
Tohoku University, Sendai, 980, Japan

Abstract- Giant magnetoresistance (GMR) of $Cu_{85-X}Co_{15}Ni_X$ melt-spun ribbons is closely correlated with the microstructure produced by the spinodal decomposition. The solid solution range is extanded by the replacement of Cu by Ni in the as-quenched state. The wavelengths obtained by subsequent isothermal aging in Cu-Co-Ni ribbons are shorter than those in Cu-Co binary ribbons, resulting in the increase of the surface-to-volume ratio. The largest MR ratio of 8 % in high field has been achieved in the $Cu_{80}Co_{15}Ni_5$ aged ribbon. The field dependence of MR ratio in low fields becomes larger with the Ni content.

I. INTRODUCTION

Giant magnetoresistance (GMR) effect is not restricted to multilayer structures. Recently, GMR effect has been observed not only in granular thin films[1-3], but also in ribbons[4-7] and bulks[8-10] comprising insoluble magnetic and nonmagnetic metals and/or alloys. Depending on the quenching rate, the samples become granular alloys consisting of ferromagnetic clusters or homogeneous metastable alloys. The magnetic granular size can be increased by subsequenting aging and GMR is considered to originate in the spin dependent scattering at the interface between the magnetic granulars and the matrix. A close relation between the interface area of granulars and GMR has been given by both theoretical calculations[11] and experimental results[12]. GMR in granular magnetic materials is influenced by the heat treatment condition, as well as by the additional element. Therefore, the detailed study on the microstructures is necessary to discuss the GMR effect. On the other hand, the structural investigations caused by the spinodal decomposition during aging for Cu-Co supersaturated solid solution ribbons[13] and Cu-Co-Ni alloys[14] have been reported.

The observation of GMR in $Cu_{85-X}Co_{15}Ni_X$ melt-spun ribbons has been reported by Kataoka et al[6]. According to their results, a small amount of replacement of Ni improves both the magnetresistance (MR) ratio and the differential MR at low magnetic fields. In the present paper, we have investigated the relation between MR and the microstructure for $Cu_{85-X}Co_{15}Ni_X$ melt-spun ribbons.

II. EXPERIMENTAL

The alloy ingots were prepared using 99.9% pure Cu, Ni and Co by arc melting in an argon gas atmosphere. The ribbon samples were made in an argon gas atmosphere by a single-roller melt spinning method. A copper roller with a diameter of about 200 mm was rotated at 6000 rpm. The isothermal aging at 723 K was carried out in a vacuum-sealed quartz tube. The structures were examined by X-ray diffraction and transmission electron microscopy (TEM). The specimens for TEM were electropolished in a 20% nitric acid in metyle.

The wavelength of the modulated microstructures was estimated from Dainel-Lipson's equation[15]. The magnetic measurements from 4.2 to 360 K were made using a SQUID magnetometer. The magnetoresistance (MR) at room temperature was measured up to 15 kOe by a conventional D C four point probe method.

III. RESULTS AND DISCUSSION

Figure 1 shows the concentration dependence of the lattice constant in the as-quenched state for $Cu_{85-x}Co_{15}Ni_x$. The dotted straight line indicates Vegard's law of the lattice constants between $Cu_{85}Co_{15}$ and $Ni_{85}Co_{15}$. The lattice constant of the $Cu_{85}Co_{15}$ is deviant from Vegard's law. This is different from the result for the sputtered specimen[16]. Therefore, these results depend on the quenching rate. By replacement of Cu by Ni, the lattice constant approachs to Vegard's law above about 10 at.% Ni. This is due to the Ni atoms dissolve in both the Cu matrix and the Co particles, and Ni contributes to the increase in the solubility of Co(–Ni) into the Cu–rich matrix.

Figure 2 shows the magnetic cooling curves for the as–quenched $Cu_{85}Co_{15}$, $Cu_{80}Co_{15}Ni_5$ and $Cu_{75}Co_{15}Ni_{10}$ alloys. The thermal hysteresis between the zero–field cooling (ZFC) and the field cooling (FC) in 100 Oe is observed. The hysteresis much above the broad peak for the $Cu_{85}Co_{15}$, indicates the distribution of the blocking temperature, associated with the particle size distribution. As the Ni content increases, the peak in the zero field cooling curve shifts to higher temperature. However, the hysteresis begins at somewhat lower temperatures, indicating the decrease in the average particle size. Therefore, these behaviours imply that the Co particles with a small radius are appreciably dissolved in the Cu matrix by replacement of Cu by Ni, accompanied by the increase in the solubility in the Cu matrix.

Figures 3 from (a) to (f) show the TEM micrographs of the $Cu_{85}Co_{15}$ and $Cu_{80}Co_{15}Ni_5$ ribbons, together with the diffraction spots given above rigth in the figures (c)~(f). The as–quenched $Cu_{80}Co_{15}Ni_5$ shows no larger precipitations, due to the higher solubility in the matrix, resulting in the decrease in the Co particles as shown Fig. 3 (b), although the as–quenched $Cu_{85}Co_{15}$ exhibits large precipitations as seen from Fig. 3 (a). In the ribbons aged at 723 K, the modulated structures and the satellites are observed as given in Figs. 3 (c, d), which show that a phase decomposition takes place along to the ⟨100⟩ directions and that the satellites in the diffraction pattern also extend to the ⟨100⟩ directions. According to Cahn's spinodal theory[17, 18], the modulated structure propagates in the ⟨100⟩ directions to minimize the coherency–strain energy. On further longer aging, the particle growth is observed and the satellites approach to the main spot as shown in Figs. 3 (e, f). The wavelength λ of the modulated structure produced by the spinodal decomposition in the ⟨100⟩ directions has been measured by Daniel–Lipson's equation[15] using the angular distance between the satellites and the main spot. The value of λ against the aging time is

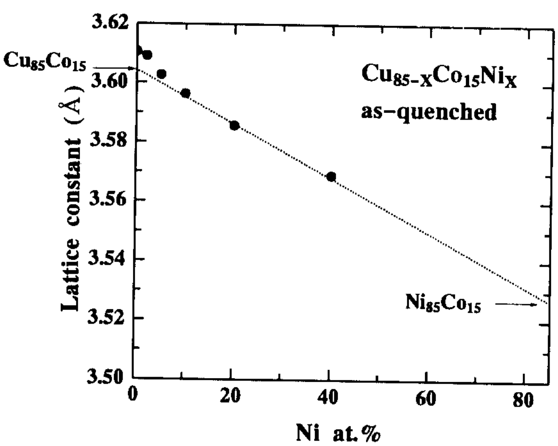

Fig. 1 Concentration dependence of the lattice constant of the as–quenched $Cu_{85-x}Co_{15}Ni_x$ ribbons. The dotted straight line stands for Vegard's law.

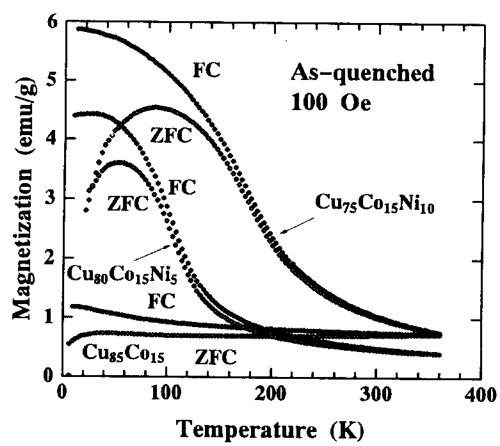

Fig. 2 Magnetic cooling curves for $Cu_{85}Co_{15}$, $Cu_{80}Co_{15}Ni_5$ and $Cu_{75}Co_{15}Ni_{10}$ ribbons.

plotted in Fig. 4. The kinetic of the wavelength of modulated structure at the early stage occurs slowly[19, 20], which is considered that the particles decompose along to the amplitude and no coarsening of the decomposed phase takes place till the equilibrium composition is attained in the decomposed phase[21]. On longer aging, the wavelength growth is caused by the coleracence of the particles. On the other hand, the shorter wavelength as well as the slower kinetic of wavelength growth are observed as the Ni content incerases. These facts may arise from the wider solid solution range in the Cu-Co-Ni system[14] than that in the Cu-Co system in the as-quenched state. The replacement of Cu by Ni would produce a lower elastic coherency-strain than that in the Cu-Co

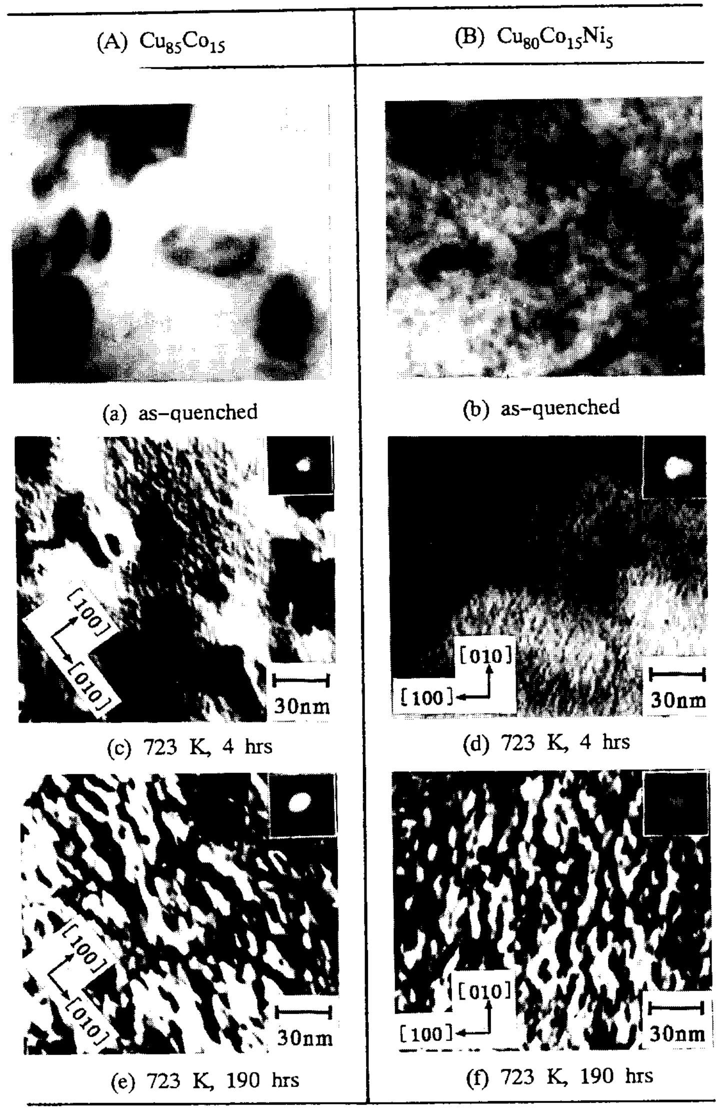

Fig. 3 Bright-field (TEM) images and selected-area diffractions for (A) $Cu_{85}Co_{15}$ and (B) $Cu_{80}Co_{15}Ni_5$ ribbons.

system. Therefore, the phase decomposition by the replacement of Cu by Ni occurs slowly with a shorter periodic compositional fluctuation of Co(-Ni), resulting in the smaller particles.

Figure 5 shows MR vs. the isothermal aging time for the $Cu_{85}Co_{15}$, $Cu_{80}Co_{15}Ni_5$ and $Cu_{75}Co_{15}Ni_{10}$ ribbons aged at 723 K. A noteworthy relation between the change in the MR ratio and the wavelength, λ, of modulated structure has been obtained. The MR ratio increases when λ is almost constant and it decreases with increasing λ. On aging, the MR ratio first increases and then decreases with increasing particle size, suggesting the exsistence of an optimum particle size which makes GMR maximum. When the phase seperation first occurs in the regime of the constant wavelength, the magnetic particles are small and hence the distance between the particles is enough larger than the mean-free-path. Therefore, the electron spin dependent scattering at the interface is infrequent, resulting in a small GMR. On the other hand, GMR increases as the amplitude of the Co concentration increase on aging time in the regime of the constant wavelength. The important point to note that the largest GMR is obtained at the point where the wavelength begins to increase. This means that the spin dependent scattering is increased with the increase in the surface-to-volume ratio[22]. However, on further longer aging, the MR ratio decreases with the growth of wavelength. This decrease is correlated with the progressive coalescence of the magnetic precipitates, which reduces of both the surface-to-volume ratio and the magnetic fluctuation. The MR ratio in the $Cu_{80}Co_{15}Ni_5$ indicates a maximun value of 8 % at the optimum aging time, and the particles are smaller than those in the $Cu_{85}Co_{15}$. Therefore, the increase in the MR ratio would be attributed to the increase in the surface-to-volume ratio.

Figure 6 shows the magntic field dependence of the MR for these samples. The MR ratio at 15 kOe for $Cu_{80}Co_{15}Ni_5$ is larger than that for $Cu_{85}Co_{15}$, while the differential MR in low fields becomes more significant with the increase in the Ni content. Usually, when the particles size becomes smaller, the particles will behave as superparamagnetic particles. However, the rapid increase in the MR ratio in low fields implies that the magnetic interactions among neighboring magnetic particles are effective. This behaviour is correlated with the wavelength, λ, as shown in Fig. 4, where the shorter wavelength means the shorter distance between the particles as well as the finer particle size. The shorter distance would attribute to make the interaction of particles strong, resulting in the reduction of the scattering due to the magnetic fluctuation which depends on the applied magnetic field.

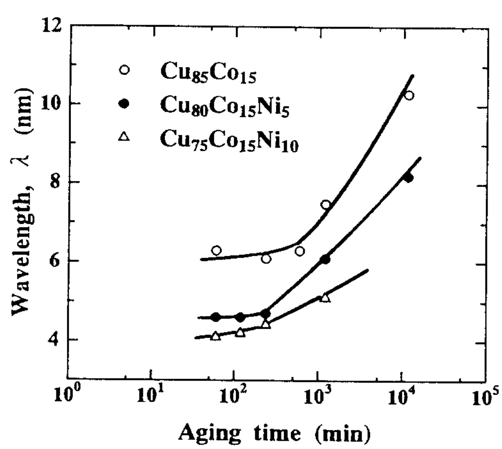

Fig. 4 Aging time dependence of the wavelength of the modulated structure by a spinodal decomposition for $Cu_{85}Co_{15}$, $Cu_{80}Co_{15}Ni_5$ and $Cu_{75}Co_{15}Ni_{10}$.

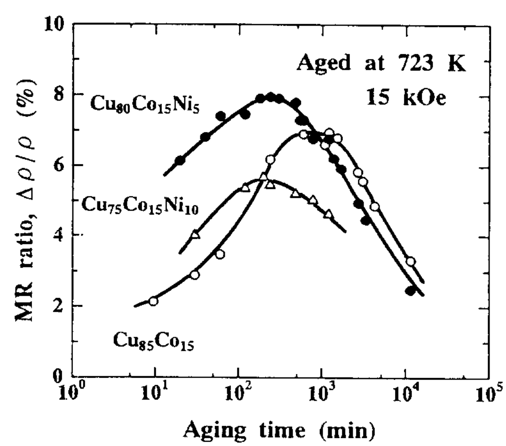

Fig. 5 Aging time dependence of MR ratio at 15 kOe for $Cu_{85}Co_{15}$, $Cu_{80}Co_{15}Ni_5$ and $Cu_{75}Co_{15}Ni_{10}$.

In conclusion, the microstructure for $Cu_{85-x}Co_{15}Ni_x$ melt-spun alloys has been correlated with GMR. A small amount of the replacement of Cu by Ni increases in the MR ratio. The contribution of the magnetic fluctuation due to the fine particles is affected by the distance between the particles. Namely, the shorter distance leads to the stronger interaction, accompanied by the larger field dependence of MR ratio in low fields for higher Ni concentration alloys.

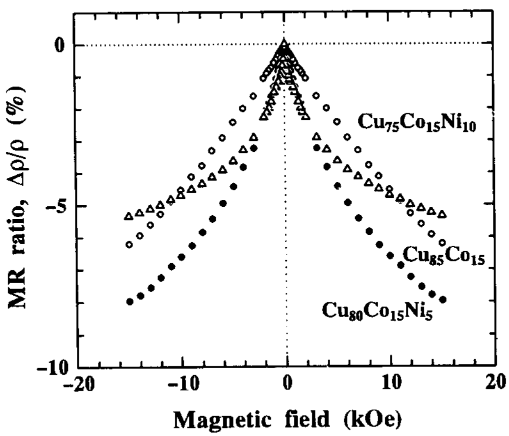

Fig. 6 Magnetic field dependence of the MR ratio for $Cu_{85}Co_{15}$, $Cu_{80}Co_{15}Ni_5$ and $Cu_{75}Co_{15}Ni_{10}$ aged at 723K for 4 hrs.

ACKNOWLEDGEMENT

The authors are indebted to the late Professor N. Kataoka of Tohoku University for his interest and encouragement.

REFERENCES

[1] A. E. Berkowitz, J. R. Mitchell, M. J. Carey, A. P. Young, S. Zhang, F. E. Spada, F. T. Parker, A. Hutten and G. Thomas, Phys. Rev. Lett. **68**, 3745 (1992).

[2] J. Q. Xiao, J. J. Samuel and C. L. Chien, Phys. Rev. Lett. **68**, 3749 (1992).

[3] A. Tsoukatos, H. Wan, G. C. Hadjipanayis and Z. G. Li, Appl. Phys. Lett. **61**, 3059 (1992).

[4] J. Wecker, R. von Helmolt and L. Schultz, Appl. Phys. Lett. **62**, 1985 (1993).

[5] B. Dieny, A. Chamberod, J. B. Genin, B. Rodmacq, S. R. Teixeira, S. Auffret, P. Gerard, O. Redon, J. Pierre, R. Ferrer and B. Barbara, J. Magn. Magn. Mater. **126**, 433 (1993).

[6] N. Kataoka, I. J. Kim, H. Takeda, K. Fukamichi and Y. Shimada, Mater. Sci. Eng. **A181/182**, 888 (1994).

[7] N. Kataoka, H. Endo, K. Fukamichi and Y. Shimada, Japan. J. Appl. Phys. **32**, 1969 (1994).

[8] H. Takeda, N. Kataoka, K. Fukamichi and Y. Shimada, Japan. J. Appl. Phys. **33**, 102 (1994).

[9] H. Takeda, N. Kataoka, K. Fukamichi and Y. Shimada, J. Phys. Condens. Matter. **6**, 3527 (1994).

[10] N. Kataoka, H. Takeda, J. Echigoya, K. Fukamichi, E. Aoyagi, Y. Shimada, H. Okuda, K. Osamura, M. Furusaka and T. Goto, J. Magn. Magn. Mater. **140–144**, 621 (1995).

[11] S. Zhang and P. M. Levy, J. Appl. Phys. **73**, 5315 (1993).

[12] N. Kataoka, H. Takeda, I. J. Kim and K. Fukamichi, Sci. Rep. RITU. **39**, 121 (1994).

[13] T. Kozakai, S. Mizuno, M. Doi and T. Miyazaki, J. Japan. Inst. Metals. **48**, 1138 (1984).

[14] V. W. Dannöhl and H. Neumann, Z. Metallkd. **30**, 217 (1938).

[15] V. Daniel and H. Lipson, Proc. Roy. Soc. **A181**, 368 (1943).

[16] J. R. Chirderss and C. L. Chien, Phys. Rev. **B43**, 8089 (1991).

[17] J. W. Cahn, Acta. Met. **9**, 795 (1961).

[18] J. W. Cahn, J. Chem. Phys. **42**, 93 (1965).

[19] S. S. Brenner, P. P. Camus, M. K. Miller and W. Soffa, Acta. Met. **32**, 1217 (1984).

[20] A. R. Forouhi and D. de Fontaine, Acta. Met. **35**, 1863 (1987).

[21] N. Sano, Y. Hasegawa, K. Hirono, T. Sakurai and H. W. Pickering, Scripta. Met. **23**, 231 (1989).

[22] B. Dieny, S. R. Teixeira, B. Rodmacq, C. Cowache, S. Auffret, O. Redon and J. Pierre, J. Magn. Magn. Mater. **130**, 197 (1994).