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COMPOSITION AND TEMPERATURE DEPENDENCE OF GIANT MAGNETORESISTANCE IN MELT-SPUN Co_xCu_{100-x} RIBBONS

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Structure, magnetic properties and magnetoresistance in as-quenched and annealed Co_xCu_{100-x} samples were investigated. Homogeneous metastable Co_xCu_{100-x} alloys were prepared by the single-roller technique. The maximum value of magnetoresistance is shifted to higher annealing temperatures with increasing measuring temperature. At higher measuring temperatures the magnetoresistance is not saturated in fields as high as 16 T. Susceptibility measurements showed the formation of hcp-structured Co clusters. For small cobalt concentrations there is a transition from giant magnetoresistance to the normal anisotropic magnetoresistance.

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Giant changes in magnetoresistivity were found at first in thin films containing ferromagnetic granules embedded in a non-magnetic matrix [1, 2]. Later it was found that some bulk heterogeneous systems prepared by rapid quenching or mechanical alloying also show this effect [3, 4]. Many of these granular alloys may have values of the giant magnetoresistance (GMR) effect $MR(H) = [R(H)-R(0)]/R(0)$ as high as or even larger than their counterparts prepared as multilayers or thin films. In this case the effect is due to the spin-dependent scattering of electrons on superparamagnetic clusters embedded in a non-magnetic well conducting matrix. The influence of Co in melt-spun Co_xCu_{100-x} ribbons is described in this paper.

High-purity elements (Cu 99.9, Co 99.998) were used to melt the starting ingots in an arc-furnace. From these Co_xCu_{100-x} master alloys with $x = 0$, 0.5, 1, 5, 8, 10, 12, 15, 20 and 25 metastable ribbons were prepared using the single-roller technique. The liquid alloy was jetted through a quartz nozzle on a Cu wheel (diameter 20 cm) at surface velocities from 30 to 40 m/s in an Ar filled chamber.

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The samples were annealed from temperatures $t_a = 400°C$ to $600°C$ for 30 min to obtain various states of microstructure. The electrical resistivity was measured with the dc four-point method in the temperature range from 5 K to 300 K at magnetic fields up to 16 T. The ac susceptibility of zero-field cooled samples was measured in a Lake Shore susceptometer.

Figure 1a shows the cobalt concentration dependence of GMR of samples after annealing at 420°C measured at 10 K. The greatest GMR values were found for alloys with $x = 10$ and 12. $Co_{10}Cu_{90}$ was chosen for the detailed investigation. For a comparison Cu ribbons have also been investigated (i.e. $x = 0$) which exhibit a normal MR of about 17% at $\mu_0 H = 5$ T (see inset of Fig. 1a). Figure 1b shows that the conditions for optimal GMR values strongly depend on the temperatures of annealing and measurement. E.g. for $x = 10$ the maximum GMR (5 T) values are 34% and 11% for $T = 10$ K and 293 K, where the respective annealing temperatures differ by about 75 K.

Figure 2a shows the well-known field dependence of GMR for $Co_{10}Cu_{90}$ samples. Very small differences between the GMR values measured at 10 K with the applied field perpendicular and parallel to the current directions are typical for granular solids. The temperature dependence of the susceptibility χ shows the typical behaviour of superparamagnetic particles with blocking temperatures $T_B \approx 18$ K in the case of annealing from 420°C to 500°C as shown for $x = 10$ in Fig. 2b. But for higher t_a the peaks were broadened and shifted to higher temperature regions. This is probably due to the change from fcc- to hcp-structure type because of the growth of Co clusters. An increase in the anisotropy constant K_1 due to this structural change [5] causes the shift of T_B according to the proportionality of T_B to the anisotropy energy [6]. The absolute value of χ grows and after structural

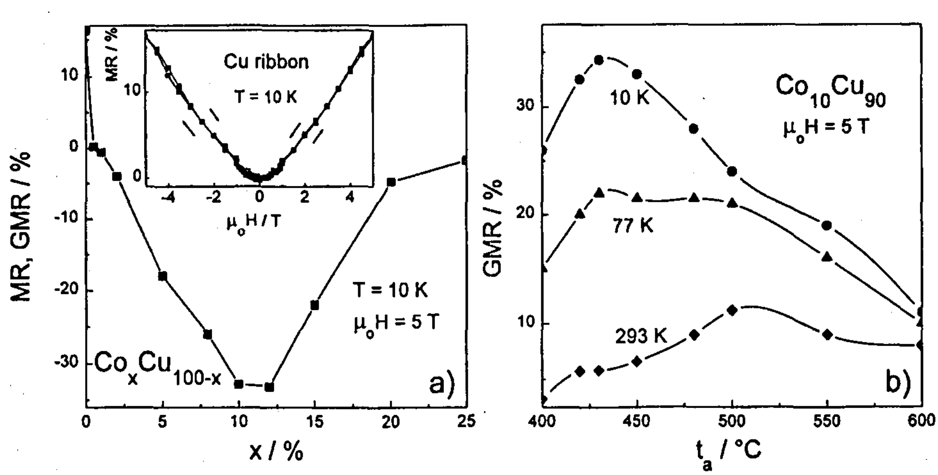

Fig. 1. Giant magnetoresistance of Co_xCu_{100-x} samples (a) in dependence on the Co content after annealing at 420°C (inset: MR vs. field for Cu ribbon) and (b) for $x = 10$ in dependence on the annealing temperature measured at $T = 10$, 77 and 293 K, and $\mu_0 H = 5$ T.

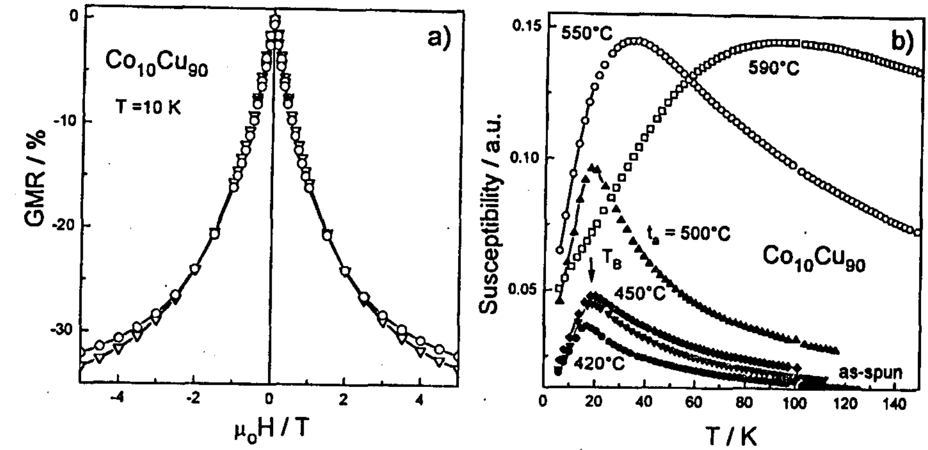

Fig. 2. $Co_{10}Cu_{90}$: (a) giant magnetoresistance vs. external field of samples annealed at 420°C and measured at 10 K with the applied field perpendicular (▽) and parallel (o) to the current direction and (b) temperature dependence of the ac susceptibility for samples annealed at different temperatures.

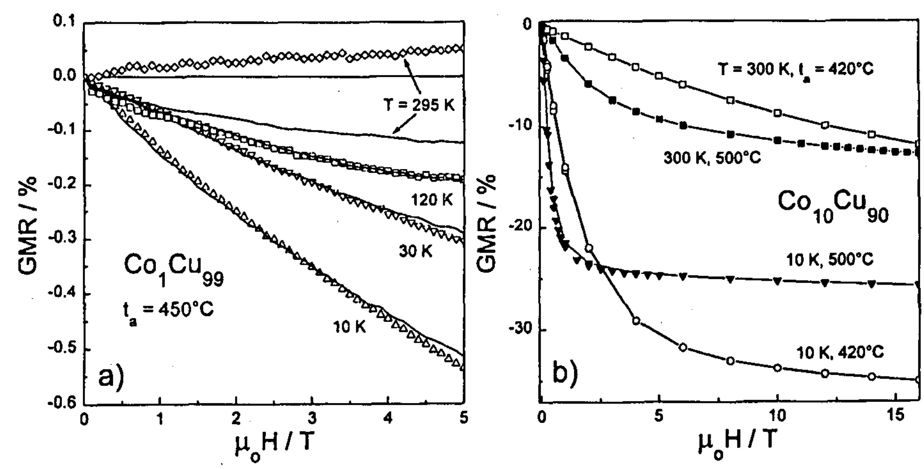

Fig. 3. Field dependence of the magnetoresistance for Co_xCu_{100-x} samples with (a) $x = 1$ measured perpendicular (solid lines) and parallel (symbols) to applied field and with (b) $x = 10$ annealed and measured at different temperatures.

changing of Co grains this value decreases. It could be explained by taking into account a possible solution of Co in the Cu matrix after annealing at t_a between 500°C and 600°C. The mean particle size could be roughly estimated [6] using the formula $30k_BT_B = K_1\langle V\rangle$, where k_B is the Boltzmann constant and $\langle V\rangle$ is the mean volume of superparamagnetic particles. If both or only one of the values of K_1 or $\langle V\rangle$ increase, the blocking temperature also increases. The roughness of a $\langle V \rangle$ estimation is mainly due to the complicated origin of magnetic anisotropy in very small particles [6]. The effective anisotropy constant for such particles is usually larger than for bulk material. $K_1 = -3 \times 10^5$ J m^{-3} and $T_B = 18$ K give the value of cluster diameter of about 3.6 nm.

As shown in Fig. 3a there is a transition from GMR to the normal anisotropic magnetoresistance (AMR) for small cobalt concentrations. Thus a Co_1Cu_{99} sample heat treated at 450° for 30 min shows an isotropic GMR effect from 10 K to 120 K but the behaviour is AMR dominated at 300 K. A similar behaviour was also found for samples with $x = 0.5$.

As seen in Fig. 3b the MR of $Co_{10}Cu_{90}$ is not saturated at higher temperatures in fields as high as 16 T. The GMR effect of samples annealed at 420°C and 500°C and measured at 300 K practically reaches the same value of 13% at 16 T. The high-change rates of MR were obtained for samples with a nearly linear high field behaviour, e.g. up to 0.7%/T for a $Co_{15}Cu_{85}$ sample. The difference in the field dependence may be caused by the variety of Co clusters formed after various heat treatments as discussed above, i.e. the fcc- and hcp-structured clusters show different behaviour at 300 K.

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