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MAXIMUM IN THE TEMPERATURE DEPENDENCE OF RESISTIVITY OF SOME CRYSTAL ALLOYS OF THE Cu–Zr SYSTEM

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Temperature dependence of resistivity ρ of crystal Cu–Zr alloys was measured up to 1050 K. For copper-rich alloys, the function $\rho(T)$ turned to have a maximum. This result is discussed in terms of the two-band model.

INTRODUCTION

IT IS WELL ESTABLISHED that for highly disordered metallic systems the electroresistivity value $\rho_{cr} \sim 100 \div 200\,\mu$ohm-cm is a critical one since it corresponds to the electronic mean free path l of the order of the interatomic distance a. If electrons are scattered essentially on static (structural) disorder, temperature variations of resistivity are small, usually of the order of 10%, or even less [1]:

$$\rho_0 \sim \rho_{cr}, \qquad \rho(T) - \rho_0 \ll \rho_0 \tag{1}$$

(ρ_0 is the low-temperature limit of resistivity). There is also another group of metals, in which, though the inequality

$$\rho_0 \ll \rho_{cr} \tag{2}$$

holds, resistivity reaches ρ_{cr} with increasing temperature T. In these metals a small mean free path $l \approx a$ is realized by scattering on dynamic (thermal) disorder. In this case saturation takes place, i.e. with increasing temperature resistivity tends to a constant value $\rho_{sat} \sim \rho_{cr}$ (see e.g. [2]).

We have found that among the metals, for which the inequality (2) holds, there are such, in which the function $\rho(T)$, instead of reaching a saturation limit, has a maximum. We have observed this maximum in Cu_xZr_{1-x} alloys with copper concentration $x \gtrsim 0.5$.

EXPERIMENT

The samples were obtained by recrystallization of an amorphous ribbon used for low temperature Hall effect measurements [3]. The accuracy of definition of ribbon composition did not exceed 2–3%. Strips of dimensions $3.5 \times 25\ \text{mm}^2$ with welded current and potential contacts made from beryllium bronze wire 0.2 mm in diameter were placed into a quartz tube and heated in a vacuum $(3 \div 5) \times 10^{-6}$ Torr. Measurements were carried out using dc method. At each temperature point the sample was kept for 15 min before measurements.

The temperature range up to 1050 K was accessible. At higher temperatures the sample become covered with a film during the time of measurements due to irreversible chemical reactions with residual gases.

The results of measurements for three alloys of different composition are shown in Fig. 1. Crosses correspond to values obtained during initial heating of the amorphous ribbon, whereas dots to measurements after crystallization. Dashed lines correspond to irreversible crystallization. The degree of irreproducibility at reversible parts of the curves is evident from the upper plot, where white and black points are related to different cycles of measurements (the main source of irreproducibility is a redistribution of current density near welded current contacts). Residual resistivity ρ_0 was in the range $10 \div 60\,\mu$ohm-cm. It depended markedly on the initial composition, i.e. on the relative quantity of different compounds in the sample, and on annealing conditions. In the lower part of Fig. 1 it is seen that, the annealing temperature change from 880 K to 1050 K, ρ_0 changes by 20 μohm-cm. However, this does not notably affect the temperature dependence of ρ.

So, two upper plots exhibit a maximum, the resistivity fall for the alloy with $x \approx 0.65$ in the two hundred degree range above the maximum reaching $\Delta\rho/\rho \approx 5\%$. In the curves plotted thermal expansion is not taken into account. If, however, it is allowed for, $\Delta\rho/\rho$ can only increase.

DISCUSSION

In [3] we have already indicated that static and dynamic disorder affect the sign of the Hall constant in a similar way. The experimental facts described above may

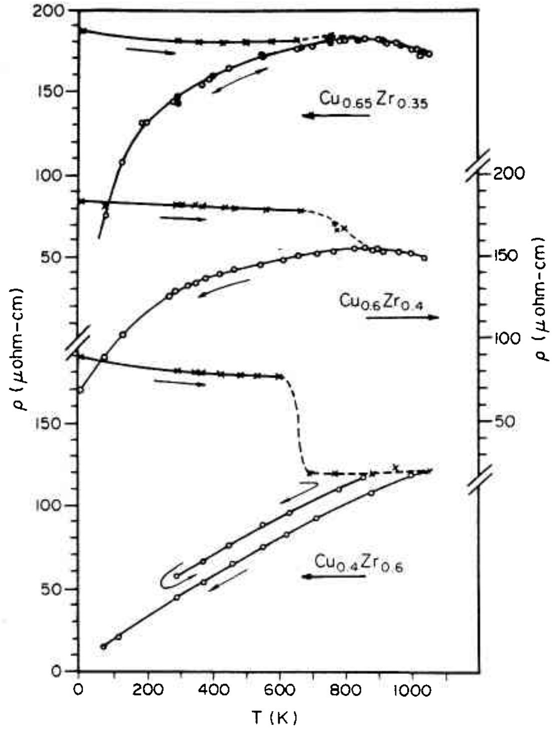

Fig. 1. Electrical resistivity of three Cu–Zr samples with different Cu content.

be interpreted analogously: when with increasing temperature resistivity $\rho(T)$ becomes of order ρ_{am} of the corresponding amorphous alloy, i.e. of the value characteristic for static disorder, the temperature coefficient of resistivity changes its sign.

In [3] a two-band model of the electronic band structure with a narrow d-band has been considered as a specific model, in the framework of which equivalency of scattering on static and dynamic disorder is feasible. It is supposed that

(a) in the narrow d-band at high disorder the criterion $l \approx a$ is realized, so that conductivity in this band resembles hopping conductivity;

(b) metallic character of the alloy is preserved due to the presence of the s-band in which $l > a$;

(c) due to high density of d-states the scattering of s-electrons in most cases is accompanied by their transition to the "localized" d-band.

In the framework of a usually employed model of two parallel resistances [4] it may be suggested that one resistance is associated with s-electrons and the other with d-electrons:

$$\frac{1}{\rho} = \frac{1}{\rho_s} + \frac{1}{\rho_d}. \qquad (3)$$

If for the curve $x \approx 0.65$ ρ_s is represented in the form $\rho_0 + \alpha_s T$ and the values of ρ_0 and α_s are taken from measurements in the range $T \lesssim 150$ K, it appears that at high temperatures $T \gtrsim 400$ K ρ_d may be approximately written as

$$\rho_d = \rho_{sat} - \alpha_d T, \qquad \rho_{sat} = 400\,\mu\text{ohm-cm},$$
$$\alpha_d = 0.15\,\mu\text{ohm-cm K}^{-1}.$$

The decrease of the restricting resistance ρ_d with increasing T is not very surprising. Beginning already with room temperatures d-electrons are in "a limiting regime" $l \approx a$ [3]. If the source of scattering were static disorder, the decrease of ρ_d could be explained in terms of thermally activated hops of localized carriers. A variant of these speculations is believed to be valid also for localization induced by dynamic disorder: phonons strengthen localization at low temperatures and weaken it at high ones. Similar processes for one-dimensional conductors have been discussed in [5]. However, it is possible that due to frequent s–d transitions two terms in equation (3) cannot be associated with s- and d-conductivity separately.

Thus, we again try to use two-band model to explain transport phenomena in crystal Cu–Zr alloys. To verify the theoretical description of such a model (and thereby its validity), there are already two experimental facts to be considered now: a positive Hall constant at room temperatures and a maximum in the temperature dependence of ρ.

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