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Galvanomagnetic Measurements of Annealing in Deformed Aluminium

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In (1) we showed the usefulness of combined resistivity and magnetoresistivity measurements for the interpretation of the recovery of quenched-in defects in aluminium. At T>400 K considerable annealing of the resistivity ϱ_o took place. The isochronal recovery was dominated by changes in the structure of the defects. The formation of larger defect aggregates was observed; they contributed only a small resistivity change.

In the following we present measurements on samples with defect aggregates introduced by deforming at concentrations higher than in the previous investigation. In particular, the high field dependence of the magnetoresistivity of defects in the region of self-diffusion is demonstrated.

We used 1 mm thick aluminium wires (99.999%, Degussa, Hanau) 10 cm in length. Cold working was performed during manufacture of the wires. They were annealed at room temperature. Potential leads were attached by spot welding. The resistivity ratio R_{273K}/R_{4K} was approximately 270.

The samples were isochronically step annealed with 2 deg/min and the galvanomagnetic resistivity $\varrho(H)$ and ϱ_o measured with an accuracy of $3\text{x}10^{-13}$ Ωcm.

After each annealing step the galvanomagnetic coefficient P_o was determined:

$$P_o(H/\varrho_o)^2 = \Delta\varrho(H)/\varrho_o = \varrho(H)/\varrho_o - 1 \qquad (1)$$

for $H/\varrho_o = 0.8$ kG/nΩcm where $\omega\tau = 0.2$, ω being the cyclotron frequency and $\tau \sim 1/\varrho_o$ the average time between two scattering events. In addition the normalized high field magnetoresistivity

$$S = \Delta\varrho(H)/\varrho_o \qquad (2)$$

was determined at $H/\varrho_o = 40$ kG/nΩcm where $\omega\tau \approx 10$.

The galvanomagnetic coefficient P_i corresponding to impurity atoms was determined according to equation (1) with the measured values $\varrho(H)$ and ϱ_o of samples which were

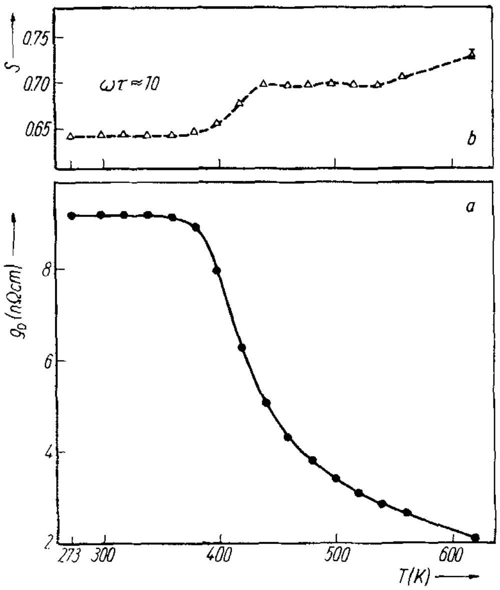

Fig. 1. a) Isochronal annealing curve of resistivity ϱ_o for a deformed Al wire of 1 mm diameter ($\Delta T = 20$ K, $\Delta t = 10$ min). b) Isochronal annealing of the high field galvanomagnetic coefficient S at $\omega \approx 10$

fully annealed at 620 K. It was assumed that the contribution to the magnetoresistivity from impurity atoms considerably exceeds the contribution from dislocations, grain boundaries, and sample size effect (2, 3). The resistivity ϱ_o at 4 K (after annealing at 620 K) was approximately 1.9 nΩcm. (The approximate relations are 1 ppm impurity atoms = 1 nΩcm and 10^9 dislocation lines/cm^2 ≙ 0.1 nΩcm.

The galvanomagnetic coefficient P_d for defects introduced by cold working is determined as follows (4):

$$P_o = P_d(\varrho_d/\varrho_o) + P_i(\varrho_i/\varrho_o) - 0.5\,|P_d - P_i|\,\varrho_d\varrho_i/\varrho_o^2 \,, \qquad (3)$$

where $\varrho_o = \varrho_d + \varrho_i$ and P_d and P_i the galvanomagnetic coefficients for dislocations and impurity atoms, respectively.

Fig. 1 illustrates the annealing behaviour of deformed Al wires. Annealing is complete at 620 K. The annealing of ϱ_o exhibits one distinct revocery stage in the tempreature range of self-diffusion. Analytical checks on the reaction order of the annealing process of ϱ_o definitely exclude first order and second order kinetics. This points to the fact that the annealing between 300 and 620 K cannot be explained by a simple vacancy diffusion mechanism (5).

According to equation (1) we can evaluate the galvanomagnetic coefficient P_i (in the low field region) due to impurity atoms, which yields

$$P_i = 0.451\ (n\Omega cm/kG)^2 \quad \text{at} \quad \varrho_i = 1.932\ n\Omega cm.$$

From cold-worked samples which were annealed at room temperature we find in the low H region

$$P_o = 0.309\ (n\Omega cm/kG)^2 \quad \text{at} \quad \varrho_o = 9.189\ n\Omega cm.$$

Utilizing equation (3) we find for the defects introduced by the cold work

$$P_d = 0.295\ (n\Omega cm/kG)^2 \quad \text{at} \quad \varrho_d = 7.257\ n\Omega cm.$$

Samples with different impurity content, i.e. with different P_i values ranging from 0.4 to 0.55 $(n\Omega cm/kG)^2$ always yield

$$P_d = 0.29 \text{ to } 0.30\ (n\Omega cm/kG)^2.$$

Even at high magnetic fields the various defects (impurities, dislocations, vacancies) have a marked influence on the magnetoresistivity $\Delta\varrho/\varrho_o$ as already mentioned in (1). This is illustrated by the upper curve in Fig. 1. We observe two recovery steps, the first between 300 and 440 K the second between 540 and 620 K.

For impurity atoms we find according to equation (2) a normalized high field coefficient:

$$S = 0.729 \quad \text{at} \quad \omega\tau \approx 10.$$

Defects introduced by cold work show the smaller S = 0.645. Introducing, however, defects produced by quenching results in a higher S between 0.68 and 0.95. Here S = 0.68 the pre-quench value of samples used in these experiments.

At present there is no theoretical calculation about the high field dependence of the magnetoresistivity on defects. It is likely that the investigation of magnetoresistivity annealing provides a simple and effective possibility to cover the region between point defect and large defect aggregates.

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