Magnetoresistance of aluminum on plastic deformation

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An increase in the relative transverse magnetoresistance as a function of deformation, produced by small angle electron scattering by extended defects in the crystal lattice, was found in galvanomagnetic measurements on aluminum. Two forms of small angle scattering are compared: electron–phonon and electron–dislocation.

Many effects in the low-temperature characteristics of the electrical resistivity and magnetoresistance of aluminum have a common form, as shown by Kagan and Flerov,[1] associated with the fact that the electron distribution function in the pure metal has an anisotropy, brought about, in particular, by the anisotropy of processes of scattering by phonons. A correlation has been established[2] between the temperature dependences of the electrical resistivity and magnetoresistance of aluminum containing static crystal lattice defects of different kinds. It was shown experimentally that the effect of extended defects (dislocations) on the temperature dependence of the relative transverse magnetoresistance ρ_H/ρ_0 is qualtatively similar to the influence of impurities and quenching defects; i.e., it leads to a deduction in the scale of the anisotropy in the distribution function. The possibility of small angle scattering of electrons by dislocations was not then studied in detail, but conclusions about the existence of such a scattering mechanism were based on qualitative calculations or on indirect measurements.

In the present work experimental results are given of a study of the transverse magnetoresistenace of aluminum in the process of low-temperature plastic deformation. Two mechanisms of small angle scattering, associated with scattering of electrons by phonons and dislocations, are analyzed.

Cylindrical specimens of polycrystalline aluminum of diameter 1.4 mm with RRR = 10,000 in the initial state were used in the experiment. Measurements were carried out in the temperature range 4.2–40°K in magnetic fields of strength up to 85 kOe. The specimens were deformed by uniaxial extension at 4.2°K in the deformation range 0–30% in steps of 3%. After the required degree of deformation had been reached, the specimen was unloaded and maintained at room temperature for 170 h in order to anneal out point defects[3] and then cooled at 4.2°K, and after the measurements underwent the next stage of low-temperature deformation.

From the form of the work-hardening curve with characteristic jumps in the region of high loads, it can be concluded that twinning is absent in the deformation process, and that extended and point defects are preferentially generated.[4] The density of extended defects introduced can be estimated easily[5] from the change in the electrical resistivity $\Delta\rho$: $\Delta\rho = 3.7 \cdot 10^{-19}\ \Omega \cdot cm^3$ per unit dislocation.

The dependence of ρ_H/ρ_0 on deformation is shown in Fig. 1 for several values of the magnetic field at 4.2°K. As can be seen, the relative magnetoresistance increases with an increase in ε, i.e., in the dislocation density, reaches a maximum at $\varepsilon \cong 10\%$ ($N_D \cong 3 \cdot 10^9\ cm^{-2}$) and then falls, being smaller than the value of ρ_H/ρ_0 at $\varepsilon = 0$ for $\varepsilon \sim 20\%$. The increase of ρ_H/ρ_0 is already observed at $\varepsilon \sim 0.2$–0.3%, i.e., immediately after the elastic deformation leads to an approximately linear increase in ρ_H/ρ_0, and its rate stays roughly the same for different deformations, which is determined by the strong linear growth in ρ_H with magnetic field. The shape of the $\rho_H/\rho_0(\varepsilon)$ curve is similar to the temperature dependences obtained

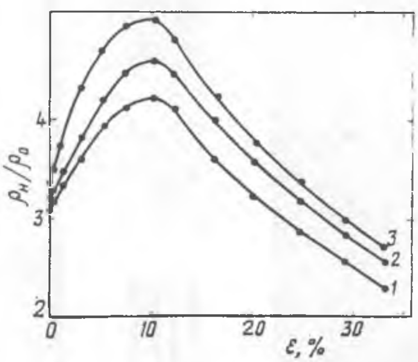

FIG. 1. Dependence of the relative magnetoresistance of aluminum on deformation for magnetic field strengths 1) H = 15; 2) 40; 3) 85 kOe at T = 4.2°K.

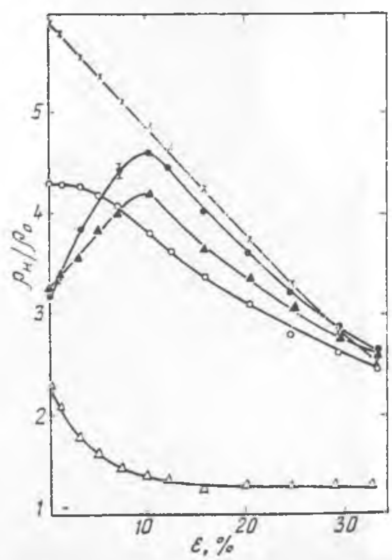

FIG. 2. Change in ρ_H/ρ_0 with deformation at a temperature ●) 4.2; ▲) 7.5; ×) 17 △) 40°K at H = 40 kOe.

earlier[2,6] and by us in the present work, and is evidence of the existence of a scattering mechanism similar in its effect to small angle scattering by long wavelength phonons. In other words, the generation of extended defects on plastic deformation up to 10% increases the anisotropy in the distribution function, and on further deformation decreases it. It is probable that for large densities of extended defects, local sources of short-range strain are formed in the aluminum structure, from which electrons are elastically scattered.

The $\rho_H/\rho_0(\varepsilon)$ curves shown in Fig. 2 at different temperatures give an indication of the relative contribution of phonon and dislocation scattering mechanims for electrons. Scattering by impurities and extended defects are the dominant mechanisms at 4.2°K. An increase in the concentration of the latter leads to a sharp growth in the scale of the anisotropy in the distribution function. Raising the temperature to 7.5°K does not lead to qualitative changes in the dependence of the relative transverse magnetoresistance on deformation, although the reduction in the value of ρ_H/ρ_0 is evidence that the distribution function becomes more isotropic. At T = 12°K in the region of small deformations, inelastic electron—phonon scattering becomes more effective than electron—dislocation scattering, and the maximum in ρ_H/ρ_0 shifts to the region of $\varepsilon \sim 0$ ($N_D \cong 10^8$ cm^{-2}). An increase in the dislocation density leads to the distribution function becoming more isotropic over the whole ε range. At 17°K, i.e., at a temperature at which a strong departure from Matthiessen's rule is observed, ρ_H/ρ_0 is at a maximum. The anisotropy of the distribution function decreases linearly over the whole deformation range, with the scale of the anisotropy in the distribution function produced by electron—phonon scattering mechanisms being greater than that produced by small angle electron—dislocation scattering. Raising the temperature to 40°K leads to complete suppression of both anisotropic scattering mechanisms.

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NOTATION

Here ρ_H is the low-temperature magnetoresistance, ρ_0 is the low-temperature resistance, ρ_H/ρ_0 the relative transverse magnetoresistance, ε the plastic deformation, N_d the dislocation density, T the temperature.

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