phys. stat. sol. (b) 160, K133 (1990)
Subject classification: 61.70 and 72.15; S4

Institute of Solid State and Semiconductor Physics,
Academy of Sciences of the Belorussian SSR, Minsk[1])

On the Anisotropy of Electron-Dislocation Scattering in Aluminum in Charge Transport

By
V.I. GOSTISHEV, S.E. DEMYANOV, V.R. SOBOL, and D.V. PASHIK

For more than two decades investigations of the dislocation contribution to the electrical resistivity in metals, mainly aluminum and copper, have been carried out both experimentally and theoretically /1, 2/. Recently a theory has been advanced that predicts a strong dependence of the resistivity per dislocation on the dislocation density, where the authors assert that electron-dislocation scattering is essentially a small angle anisotropic process /3, 4/. In other works it was found that the contribution to the electrical resistivity is many times greater than the strain field. Low temperature deviations from Matthiessen's rule (DMR) for the electrical resistivity have been the subject of extensive investigations. It was found that a metal with larger residual resistivity value ρ_0 also has a larger temperature dependent part of the resistivity, arising from electron-phonon scattering /5 to 7/. The monotonic increase of the temperature dependent part of the resistivity ρ_T with ρ_0 at fixed temperature is a characteristic feature of DMR. Recently, however, some marked exceptions to this general behaviour have been reported. Rowland and Woods /8, 9/ have measured ρ_T for a strained sample of Al and found that it decreased by approximately a factor of 2 with increasing ρ_0. In /3, 4/ it was shown that the negative DMR can be explained quantitatively by the effect of anisotropic electron dislocation scattering.

In this report the results of our experimental investigations on the temperature dependent part of the resistivity in highly pure Al will be discussed. The aluminium specimens were plastically elongated at 4.2 K. After each act of deformation the electrical resistance $\rho(T)$ of the specimens was measured and after that all the specimens were kept at room temperature during five days, for the annealing of the deformation point defects to take place. The electrical resistance was measured at temperatures from 4.2 to 20 K. The temperature dependent part of the resistivity ρ_T and the temperature independent residual resistivity ρ_0 combine to give $\rho(T) = \rho_0 + \rho_T$. In practice the assumption was made that $\rho(4.2\ \mathrm{K}) = \rho_0$.

[1]) P. Brovki 17, SU-220726 Minsk, USSR.

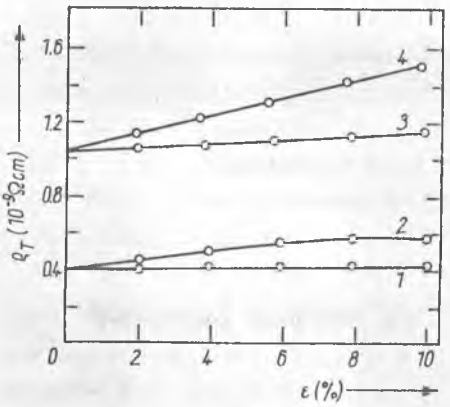

Fig.1

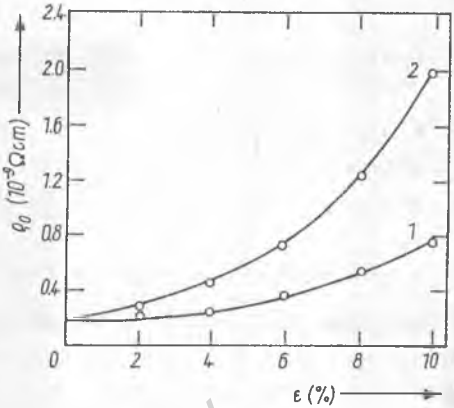

Fig.2

Fig. 1. Temperature dependent part of the resistivity as a function of deformation for two different temperatures: (1), (2) T = 16 K and (3), (4) T = 20 K; curves 1, 3, and 2, 4 after and before the annealing of point defects, respectively

Fig. 2. Residual resistivity at T = 4.2 K as a function of deformation: curves 1 and 2 are after and before the annealing of point defects, respectively

Fig. 1 shows the variation of ρ_T as a function of deformation for two different temperatures (16 and 20 K). The dependences for ρ_0 are presented in Fig. 2. It is noteworthy that ρ_T does not depend on the degree of deformation in the annealed state at T = 16 K. The dependence is stronger at T = 20 K, that is ρ_T grows monotonically with deformation. In the unannealed state the temperature dependent part of the resistance is more complicated. The analysis of the ρ_T dependence on the defect density was carried out in accordance with the theoretical model /10, 11/, where the authors write down the resistivity $\rho(T)$, which is a function of the impurity concentration and temperature, in terms of the two-moment scattering operator P_{ik} which can be written as the sum of $P_{ik}^{(o)}$ and $P_{ik}^{(1)}$ $P_{ik} = P_{ik}^{(o)} + P_{ik}^{(1)}$ where $P_{ik}^{(o)}$ the matrix element of the phonon scattering operator, $P_{ik}^{(1)}$ the matrix element of the defect scattering operator which depends linearly on their concentration. $P_{ik}^{(1)} = cR_{ik}^{(e)} + cR_{ik}^{(i)}(T)$ where c is the concentration of defects, $R_{ik}^{(e)}$ the elastic scattering on the core, $R_{ik}^{(i)}(T)$ the inelastic scattering on the dynamical perturbance, $cR_{ik}^{(i)}(T) \ll cR_{ik}^{(e)}$. In accordance with /10, 11/

$$\rho_T = j^{-2}\left[cR_{ik}^{(i)}(T) + \frac{P_{12}^{(o)2}(T)}{P_{22}^{(o)}(T)}\,\frac{cR_{22}^{(e)}}{P_{22}^{(o)}(T) + cR_{22}^{(e)}} + P_{11}^{(o)}(T) - \frac{P_{12}^{(o)2}(T)}{P_{22}^{(o)}(T)}\right].$$

At small density of defects when $cR_{22}^{(e)} < P_{22}^{(o)}(T)$,

$$\rho_T = j^{-2}\left[P_{11}^{(o)}(T) - \frac{P_{12}^{(o)2}(T)}{P_{22}^{(o)}(T)}\left(1 - \frac{cR_{22}^{(e)}}{P_{22}^{(o)}(T)}\right)\right]$$

and ρ_T increases together with the defect concentration c. If $cR_{22}^{(e)} << P_{22}^{(o)}(T)$,

$$\rho_T = j^{-2}\left[P_{11}^{(o)}(T) - \frac{P_{12}^{(o)2}(T)}{P_{22}^{(o)}(T)}\right].$$

That means ρ_T is the "ideal" resistivity of the metal without impurities. In terms of this approximation it is difficult to understand the cause of the possible negative DMR.

The increase of ρ_T becomes progressively smaller with decreasing temperature and when $\rho_o > \rho_T$ the variational principle first proposed by Kohler has been used in the discussion. According to this principle $\rho(T)$ can be represented as $\rho(T) \geq \rho_o + \rho_{ph}$ (where ρ_{ph} is the phonon resistivity). Also in this approach ρ_o and ρ_{ph} in dirty ($\rho_o >> \rho_{ph}$) and pure ($\rho_o << \rho_{ph}$) limits are variables, that is:

$$\rho_o^{dirty} \leq \rho_o^{pure} \quad ; \quad \rho_{ph}^{dirty} \geq \rho_{ph}^{pure} \quad ;$$

ρ_{ph} increases with increasing defect concentration /5, 12/ as $\rho_{ph} > \rho_o$. This relation between ρ_{ph} and ρ_o is confirmed by the experimental results in Fig. 1. One can see, that the values $\rho_T \approx 4\times10^{-10}$ Ωcm and 10^{-9} Ωcm without deformation at 16 and 20 K, respectively, are larger than ρ_o at least to 6 %. Therefore the addition to ρ_T increases with the increase of ρ_o, that corresponds to /8, 9/.

The dependences of ρ_T in both cases are easily explained by elastic scattering on lattice defects. Moreover the $\rho_T(\varepsilon)$ curves both in the presence of vacancies and in their absence are qualitatively similar and do not need for their interpretation the anisotropic mechanism of scattering. Therefore Brown's calculations /1/ identifying the dislocation core as the most effective source of electron scattering fits perfectly to our considerations.

References

/1/ R.A. BROWN, Canad. J. Phys. 60, 766 (1982).
/2/ D. TRATTNER, M. ZEHETBAUER, and V. GROGER, Phys. Rev. B 31, 1172 (1985).
/3/ M. KAVER and N. WISER, J. Phys. F 13, 953 (1983).
/4/ M. KAVER and N. WISER, J. Phys. F 11, 1740 (1981).

/5/ E.S. BOROVIK and v.G. VOLOTSKAYA,
Zh. eksper. teor. Fiz. 48, 1554 (1965);
Soviet Phys. - J. exper. theor. Phys. 21, 1041 (1965).
/6/ J. BASS, Adv. Phys. 21, 431 (1972).
/7/ M. CIMBERLE, G. BOBEL, and C. RIZUTTO,
Adv. Phys. 23, 630 (1974).
/8/ J.A. ROWLANDS and S.B. WOODS,
J. Phys. F 6, L100 (1976).
/9/ J.A. ROWLANDS and S.B. WOODS,
J. Phys. F 8, 1929 (1978).
/10/ A.F. BARABANOV and L.A. MAKSIMOV,
Fiz. Metallov i Metallovedenie 29, 471 (1970).
/11/ YU. KAGAN and A.P. ZHERNOV,
Zh. eksper. teor. Fiz. 60, 1838 (1971).
/12/ A.D. CAPLIN and C. RIZUTTO,
J. Phys. C 3, L117 (1970).

(Received January 10, 1990; in revised form May 2, 1990)