PREPARED DISCUSSION

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An Experimental Determination of the Electrical Resistivity of Dislocations in Aluminum*

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Introduction

A recent paper by the author reported of an experimental determination of the electrical resistivity of stacking faults in gold[1]. The change in the electrical resistivity due to the introduction of a high and uniform concentration of stacking-fault tetrahedra[2] was measured. The resistivity specimen was then thinned electrolytically and the resulting electron microscope specimens were used to determine the tetrahedron concentration, the specimen thickness being found by the method by Whelan[1]. The stacking-fault density was computed directly from the concentration of tetrahedra. The present discussion gives a brief description of a similar experiment with 99.995% pure aluminum. Quenching of the latter, followed by annealing at room temperature, produces prismatic dislocation loops free of stacking faults[3], and correlated measurements of the type described above yield a value for the electrical resistivity of dislocations.

Experimental Techniques

The material used in the experiment was nominally 99.995% pure aluminum supplied by Johnson Matthey and Co. Ltd. Each specimen was annealed at about 640°C, in a continuous stream of argon/1% hydrogen, until resistivity reached a constant value. The specimen was then quenched from the same atmosphere into distilled water at room temperature. It was annealed at 70°C for 10 minutes, to ensure completion of the annealing process, and the net change resistivity due to the introduction of the loops was measured. All resistivity measurements were made at −196°C, and the details of the technique were the same as those described previously[1]. The dislocation density was computed

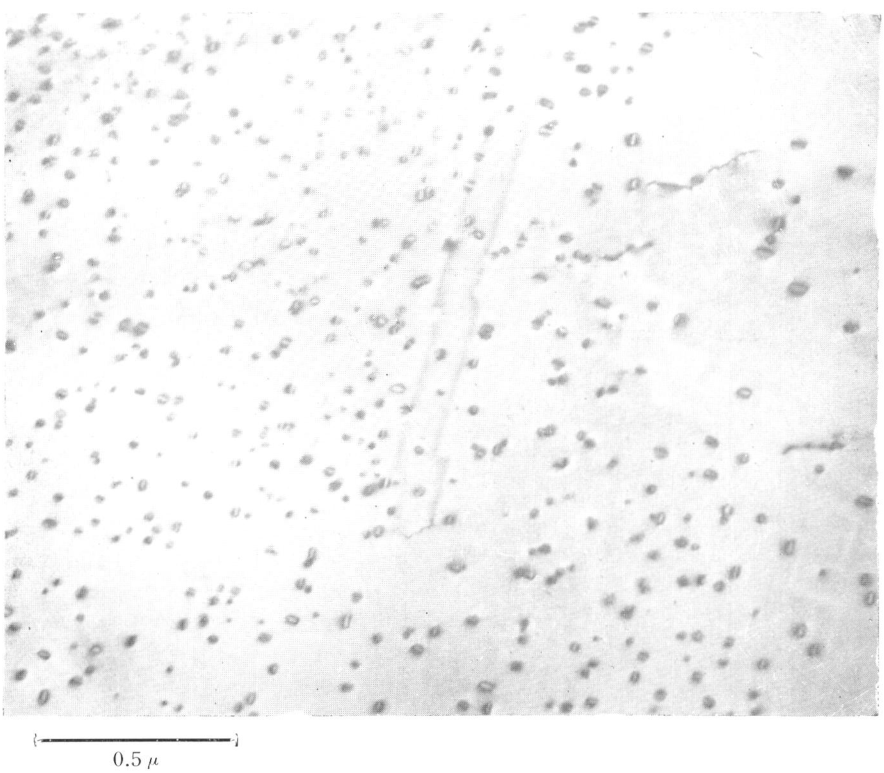

Fig. 1 Prismatic dislocation loops in aluminum. Note the slip traces from which the foil thickness is determined.

* Presented by D. G. Brandon.

Table I

Specimen	T_q $\pm 15°C$	$\Delta\rho$ $\times 10^{-9}$ ohm cm	$\bar{d}$ Å	C_L $\times 10^{14}$ cm^{-3}	C_d $\times 10^{9}$ cm^{-2}	ρ_d $\times 10^{-19}$ ohm cm /unit density
1	600	4.5	440	4.3	5.9	8.0
2	600	4.7	405	4.8	6.0	8.0
3	625	5.2	260	8.7	7.1	7.4
4	650	6.4	225	15.1	10.8	5.7
5	650	5.9	320	8.9	8.9	6.8

from direct transmission electron micrographs (Fig. 1).

Experimental Results

The results of five runs are given in Table I. The quenching temperatures, T_q, were in the range 600°–650°C. $\Delta\rho$ is the change in resistivity due to the loops, $\bar{d}$ is the mean loop diameter, and C_L is the mean loop concentration. The mean dislocation density, C_d, is given by $C_d = C_L \pi \bar{d}$, and the individual values of dislocation resistivity, ρ_d, are given by $\rho_d = \Delta\rho / C_d$. The mean value of ρ_d was

$$\rho_d = [7 \pm 2] \times 10^{-19} \text{ ohms cm/unit density.}$$

Discussion

The determination of C_L involved two corrections. The first of these is due to a contrast effect discussed by Hirsch *et al*[4]. These workers find that for a foil orientation characterised by $\boldsymbol{g}$ (where $\boldsymbol{g}$ is the reciprocal lattice vector corresponding to the strongest reflection), all loops satisfying the condition $\boldsymbol{g}\cdot\boldsymbol{b}=0$ will be invisible. The fraction of loops which satisfy this condition depends on the foil orientation. For a [110]-oriented foil giving a strong [111] reflection it is as high as 0.5, whereas for a [111]-oriented foil with a strong [220] reflection it is only 1/6.

The second correction concerns the interaction of loops with the foil surface. Most of the loops lying within a distance $\bar{d}$ (see above) of the latter will become truncated. If the resultant dislocation configuration were stable, one would expect to see a fraction $2\bar{d}/t$ of all the loops truncated (t is the specimen thickness). For $\bar{d} \sim 300$Å, and $t \sim 2000$Å, which are typical values for the present experiment, the fraction would be greater than 25%. As can be seen from Fig. 1, such a fraction of truncated loops is not observed. One may infer that loops which intersect the foil surface are drawn out of the foil. If this is so, an effective foil thickness equal to $t - 2\bar{d}$ must be used in the calculation of C_L. This correction was used in the present experiment.

Federighi[5] has suggested that some of the resistivity increment $\Delta\rho$ might be due to vacancies not in the loops, which are not observed with the electron microscope. These could exist as small uncollapsed clusters, for instance. The isochronal annealing curves obtained by Panseri and Federighi[6] do in fact indicate the existence of clusters with sizes ranging from a few vacancies right up to several thousand vacancies in the loops. Using the curves given by Panseri and Federighi, and the results of Silcox and Whelan[7] for the annealing out of loops in aluminum, it is not difficult to show that something in the region of 30% of $\Delta\rho$ could be due to unobservable clusters. This would mean that the value of ρ_d given above should be reduced by a similar amount.

The value of ρ_d obtained in the present experiments is about three times the value that can be inferred from the results of Clarebrough *et al.* for copper.[8),9] It is about fifty times larger than the theoretical value given for copper by Hunter and Nabarro[10]. It should be remembered that the results described here are strictly applicable only to dislocation loops.

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