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Ultrasonic Measurements of Interaction between Dislocations and Point Imperfections*

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The measurements of the resonance damping of dislocations permits the possibility of determining the free loop length of the vibrating dislocation strings. Point imperfections created by radiation damage, plastic deformation or quenching, are able to migrate to the dislocations, and to act there as additional pinning points. This leads to a reduction of the free loop length so that it becomes possible to study the production and migration of the point imperfections by measuring the time dependence of the dislocation damping.

Results of such measurements will be described and discussed.

COMMENT

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Ultrasonic Attenuation of Aluminum Single Crystal

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The objective of our study is to investigate about the dynamic behavior of dislocations in high purity aluminum single crystal which is annealed or slightly cold worked. High purity aluminum which contains 0.0005% silicon, 0.0006% iron and 0.0010% copper was used. A single crystal (20 mm in diameter) was prepared by Bridgemann method with reactor grade graphite crucible. The single crystal was cut into specimens of 15 mm length, and then annealed at 500°C for 1 hr in vacuum of 10^{-5} mm Hg and electrolytically polished. Its orientation is shown in Fig. 1. The dislocation density, obtained from etch pits on the plane perpendicular to {111} and parallel to ⟨011⟩ by Lacomb's solution, is 6.3 $\times 10^5$ lines/cm^2.

Quartz (of X-cut, 6 mm in diameter) was attatched to the specimen with "Sarol" and then ultrasonic attenuation was measured. The apparatus, for the measurement is "Ultrasonic Comparator" of Sperry's Products, the frequency range of which is from 5 Mc/s to 200 Mc/s.

In the case of annealed crystal the result of frequency dependence of attenuation is shown in Fig. 1, curve 1. The measured decrement decreases with frequency and shows minimum and then gradually increases. After 0.63% cold working in compression, the time dependence of attenuation was measured within the range from 5 Mc/s to 55 Mc/s. The value at 35 Mc/s is plotted in Fig. 2.

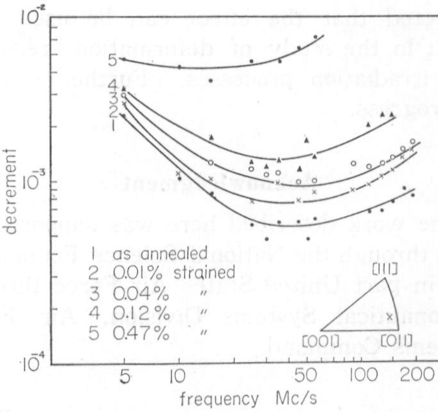

Fig. 1. Frequency dependence of the decrement of annealed and strained crystals.

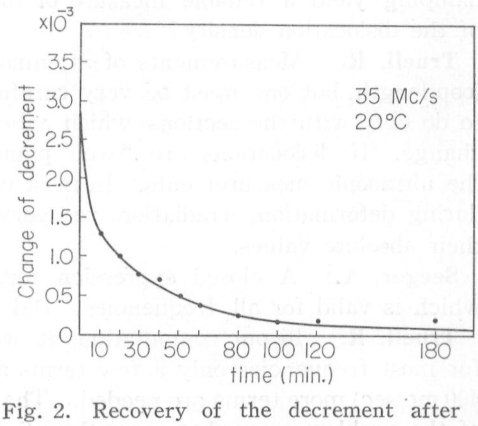

Fig. 2. Recovery of the decrement after cold work (0.63% strained) and its theoretical curve.

* A full manuscript could not be received in time.

The curve shows the Granato-Hikata's relation[1] which is based on the Granato-Lücke's theory. The equation for the curve is

$$\Delta=3.17\times10^{-3}\frac{1}{\{1+2\cdot44\times10^{-2}t^{2/3}\}^4}$$

where Δ is decrement and t is aging time in minutes.

As seen in the Fig. 2 it fits very well for $t<120$min, but for $t>120$min the data deviates from the theoretical curve. To investigate the effect of cold work in compression, attenuation was measured 180 min after cold work. Fig. 1 shows the data of the specimens which were compressed 0.01%, 0.04%, 0.12% and 0.47%, respectively. The difference between the decrements before and after compression is plotted in Fig. 3. It increases almost proportionally to the frequency. This can be

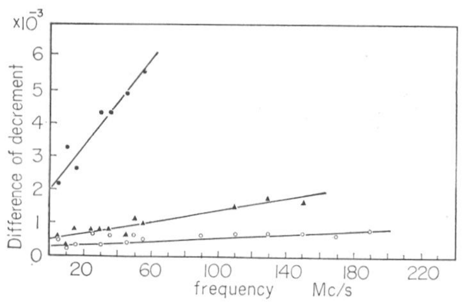

Fig. 3. The difference of the decrement before and after cold work.

interpreted in one of the two mechanisms, *i.e.* relaxation mechanism and resonance mechanism. But considering other investigators' results[2),3),4)] which are measured at low temperature, the former can be excluded. It would be concluded, therefore, that this increase which is proportional to the frequency is the resonance damping as Granato-Lücke theory predicts. Recently the decrement maximum was found in aluminum single crystal at about 250Mc/s[5)]. As we have no data above 200Mc/s, we assumed that $f_{max}\simeq 200$ Mc/s and Δ_{max} is nearly equal to Δ at 200 Mc/s, and we tried to calculate loop length L_c and dislocation density Λ. The results are as follows. The dislocation density is somewhat higher than the value obtained from the etch pit density.

L_c cm	Λ lines/cm^2
3.8×10^{-5}	1.8×107

References

1 A. Granato, A. Hikata and K. Lücke: Acta Met. **6** (1958) 470

2 T. S. Hutchson and A. J. Filmer: Canad. J. Phys. **34** (1956) 159; *ibid.* **34** (1956) 1498, *ibid.* (1958) 82

3 A. Shibata: Thesis Cornell Univ. (1959)

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5 C. Elbaum and R. Truell: Private Communication

DISCUSSION

Truell, R.: It seems interesting to note the very large differences between the behavior of copper and aluminum under the conditions mentioned by Dr. Lücke. Recovery does occur at lower temperatures (−78°C) in aluminum. This moreover appears to be a behavior of a single pinning component because the "$t^{2/3}$" recovery law seems to be very well obeyed. It might also be noted here that there is a critical (small) amount of deformation below which no recovery occurs and above which recovery does occur.

Lücke, K.: The measurements of the recovery of aluminum in the temperature range around and above room temperature which have been conducted in our laboratory show mostly a two-component behavior. However, by choosing an appropriate defect concentration (*i.e.* deformation) or temperature, one can make the first component die out so fast that only one component, namely the slow one, is observable. As mentioned above, these experiments tend to favour the exponent $n=1/2$ rather than $n=2/3$.

Sosin, A.: In agreement with Prof. Lücke, we have irradiated copper at 4°K. Warming between 25°K ond 60°K show a $t^{2/3}$ dependence obviously for interstitials. Another question: at what temperature do the depinning of dislocation occur in silver following quenching?

Lücke, K.: As far as I remember, this temperature is about 500°C.

Nowick, A. S.: I would like to ask whether you think it reasonable that following deformation there should be no dislocation rearrangement, with dislocation only sitting in place waiting for point defects to come to them.

Lücke, K.: There is, of course, a dislocation rearrangement when the load is changed. In the case of constant load, however, the good agreement between theory and experiment leads us to believe that under this condition such an eventual small rearrangement has only negligible influence upon the increase of the density of pinning points with time. At present we do not see any theoretical difficulties connected with this view.

Girifalco, L. A. and Kuhlmann-Wilsdorf, D.: The question as to why recovery of dislocation pinning by point defects takes only place at fairly high temperatures might be fruitfully discussed further in connection with the lecture* at the Kyoto Conference. There a theory will be given to suggest that the equilibrium vacancy concentration in the vicinity of a dislocation divided by that in the unstressed material attains a minimum at intermediate temperatures, being higher, both, at low and at high temperatures.

* *Proc. Int. Conf. Cryst. Latt. Def. (1962)*: J. Phys. Soc. Japan **18** Suppl. II (1963).

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Evidence for Vacancy Clustering in Dislocations of Copper as Measured by Internal Friction Techniques

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Measurements of the internal friction and Young's modulus of a copper single crystal have been made after a series of light neutron bombardments ($3-40\times10^{10}$ nvt) at 375°K. The measurements were made after each bombardment as a function of temperature from approximately 200°K back up to the bombardment temperature. In terms of the Koehler-Granato-Lücke theory of internal friction due to dislocation motion, the results indicate that bombardment-produced pinning points are lost as the temperature is lowered, and recovered upon warming. It is shown that the pinning point behaviour for small doses can be described by a second order equation with a binding energy of just under 0.3 eV. After larger doses the loss in pinning points upon cooling is relatively more severe, but again, all can be recovered by annealing.

The results are presently attributed to the interaction of vacancy pinning points with each other in the dislocation cores.

Introduction

It was recently suggested that the dislocation pinning point distributions as introduced by room temperature neutron bombardment in dislocations of copper and as measured by internal friction techniques might be temperature as well as concentration dependent[1]. This suggestion resulted from an observed temperature hysteresis in the internal friction of copper following a fast neutron bombardment of about 10^{14} nvt. In addition, it was found that it was possible to cool the sample rather rapidly from approximately 350°K to the neighborhood of 270°K–300°K and observe a series of repeatable transient phenomena in the internal friction and modulus of the crystal as thermal equilibrium was attained. It was thought that a possible contribution to these effects might be a change in state of the dislocation pinning point distribution as the temperature was changed, and consequently a change in the number of pinning points as a function of temperature after a given bombardment. In an effort to study these results further, it was decided to make measurements of the dislocation internal friction and modulus upon the same crystal after a series of smaller neutron doses and as a function of temperature. Measurements of the strain amplitude dependence of the internal friction were included in these studies

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