Dislocation Inelastic Effects in Zinc Single Crystals *

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ABSTRACT

Dislocation internal friction, elastic modulus defect and their ratio *r* have been studied in annealed and plastically deformed Zn single crystals in the temperature range of 80 to 300 K in a wide range of oscillation amplitudes. The results obtained are discussed within the present notion about the nature of dissipative elastic oscillation losses in solids.

KEYWORDS: internal friction, elastic modulus defect, dislocation, single crystal, plastic deformation

1. Introduction

Two closely connected phenomena, the Young's modulus defect and internal friction, were revealed in studying inelastic effects [1]. Investigation of the inelastic effects is an important source of information about the crystal dislocation structure and dynamic dislocation behaviour [2]. However, in most cases only the dislocation internal friction has been studied. The elastic modulus defect and the ratio of internal friction to elastic modulus defect, *r* , have been reported in a few papers [3–5]. Granato and Lucke [6] and K.Ishii [7] have given some theoretical considerations in respect to the ratio *r* .

An attempt to investigate the elastic modulus dislocation defect $\triangle M / M$, internal friction δ and their ratio *r* in a wide range of oscillation amplitudes in the temperature range of 80 to 300 K in annealed and plastically deformed Zn single crystals is made in this paper. It was expedient to carry out this investigation in the oscillation frequency range (about 10^5 Hz), where dislocation effects are the determining ones and the contribution of other mechanisms is negligible.

2. Method of Investigation

Investigations of the *r* , δ and $\triangle M / M$ were accomplished in vacuum not worse than 13.3 Pa by a double composed oscillator at the longitudinal oscillation frequencies of about 91 kHz [2,8]. The accuracy of the measurements was: for δ about 6% , for the modulus defect about 2×10^{-3}%. Investigations were carried out in the temperature range of 80 to 300 K at some fixed *T* values. The accuracy of the task and maintenance of the fixed temperature values was not less than 0.1 K. The double composed oscillator was inserted into the evacuated ampule of a cryostat. A furnace was located around the sample. The copper–constantan thermocouple was used as the temperature sensor. The preselected temperature as well as its stabilization was achieved by a VRT–2 temperature regulator.

The investigations were carried out on Zn single crystals grown from the raw material of 99.997% purity. The single crystals were grown as rectangular parallelepipeds of about $4\times 60\times 80$ mm^3 in size from which the samples of rectangular parallelepipeds of $4\times 4\times 35$ mm^3 in size were cut by an electrospark lathe. Then the lateral faces of the parallelepipeds were chemically polished up to the cross–section of 3×3 mm^2 , which is equal to the cross–section of the piezoquartz used in this measurements. The Zn samples prepared in this way were annealed at 380℃ for 8 h then cemented to the

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quartz resonator. The length of Zn single crystals was reduced gradually by the electrospark lathe until the difference in intrinsic frequencies of quartz and sample was reduced to the values lower than 300 Hz. After the double composed oscillator was made the crystallographic orientation of Zn sample was such that the angle between the sample longitudinal axis and the normal to the basal plane was 38 to 40 ° .

The samples were deformed in three–point bending by about 1% . After deformation the samples were returned to the state initially.

3. Results and Discussion

The amplitude dependences of damping decrement and Young's modulus were measured at fixed temperatures and their ratios were calculated:

$$r(\varepsilon_o) = \delta_h(\varepsilon_o) / (\triangle M / M)(\varepsilon_o)$$

where ε_o is the amplitude of the relative cyclic deformation, $\delta_h = \delta - \delta_i$ (δ_i is the amplitude of the independent damping decrement), $\triangle M / M = (M_i - M) / M_i$ (M_i is the elastic modulus measured in the amplitude independent region, M is the current modulus value). Figure 1 shows the ε_o amplitude dependence of δ, $\triangle M / M$ and r measured on a predeformed sample at 220 K. In the region of low ε_o values (10^{-8} to 10^{-6}) the δ decrement is amplitude–independent at the temperature above 220 K, that is, the pronounced segment of the amplitude independent decrement is observed. At the temperatures below 200 K in the region of low ε_o values the decrement of δ increases slightly with ε_o . In the last case by calculating $\delta_h (\delta_h = \delta - \delta_i)$ instead of δ_i the value of δ was used, which was measured at the lowest amplitude (1×10^{-8}). With the increase of ε_o amplitude the value of r decreases abruptly from 10 to 0.3.

The δ and M measurements in the temperature range of 80 to 300 K showed that T increase in the temperature range from 80 to 140 K leads to the shift of $\delta_h(\varepsilon_o)$ and $\triangle M / M(\varepsilon_o)$ dependences towards the lower ε_o values. And this is in agreement

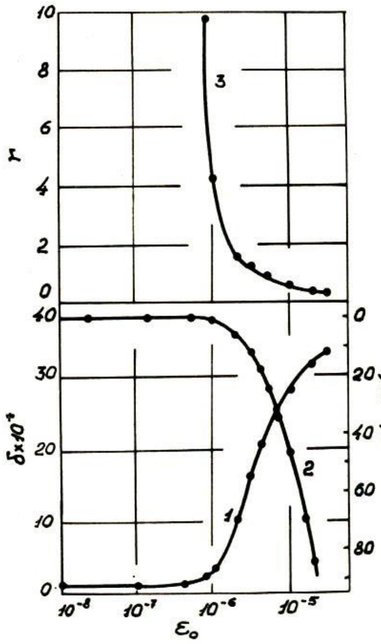

Fig.1 Amplitude dependence of internal friction (1), elastic modulus defect (2) and their ratio (3) at 220 K

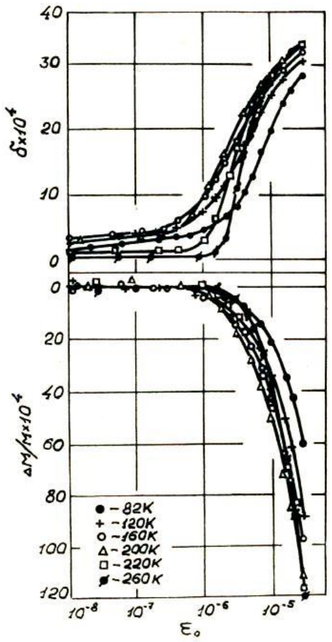

Fig.2 Temperature effect on amplitude dependences of internal friction and elastic modulus defect

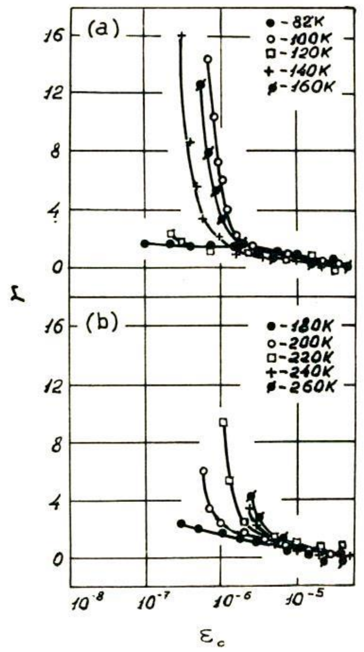

Fig.3 Temperature effect on amplitude dependences of ratio r in annealed single crystals

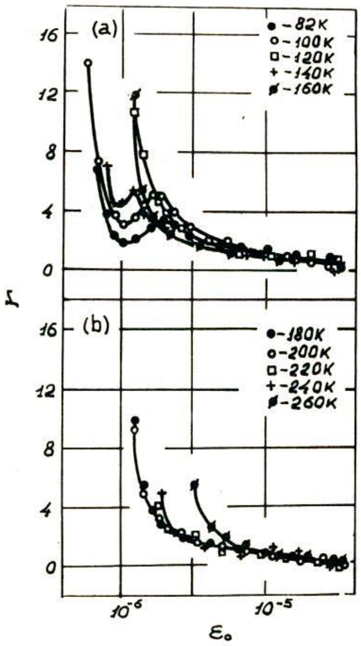

Fig.4 Temperature effect on amplitude dependences of ratio r in predeformed (prestrained) single crystals

with the ideas about the formation of amplitude–dependent dissipative losses due to the thermoactivated hysteresis cyclic dislocation motion [9]. In the temperature range of 140 to 200 K the $\delta_h(\varepsilon_o)$ and $\triangle M/M$ (ε_o) dependences do not practically depend on T. And finally in the temperature range of 220 to 300 K the $\delta_h(\varepsilon_o)$ and $\triangle M/M$ (ε_o) shift towards the higher ε_o value with the increase of T (Fig.2).

Figures 3(a) and (b) show in semilog coordinates the ε_o dependences of r obtained in the range of 80 to 300 K in the undeformed Zn single crystals. It appears that in the region of large ε_o values of the $r(\varepsilon_o)$ dependences, measured at different T, the values of r achieve about 0.4 to 0.5.

Figures 4(a) and (b) show the ε_o dependences of r obtained in the temperature range of 80 to 300 K on the deformed samples. Attention is directed to the fact that during the temperatures below 140 K the curves are not monotonous and in some cases the maxima are observed on them.

The above mentioned measurement cycle was repeated on three samples. In all cases the results obtained coincided qualitatively.

According to present notions [6] the dislocation dissipative losses determine not only the amplitude dependence of δ, but also δ_i to a high degree. Temperature dependences of δ_i were measured for all the samples studied, but the common or even close character of $\delta_i(T)$ dependence for these samples was not established. Though, according to the above–mentioned, the amplitude dependences of δ_h, $\triangle M/M$, r and the character of the preliminary effects of plastic deformation and temperature were the same.

The amplitude independent regions on $\delta(\varepsilon_o)$ and $\triangle M/M(\varepsilon_o)$ curves, exponential change of δ and $\triangle M/M$ with amplitude growth ε_o in the amplitude region (See Fig.1) can be interpreted in the frames of Granato–Lücke mechanism [6] or its modifications [9–11]. However, the $r(\varepsilon_o)$ dependence shown in Fig.1 does not correspond to these notions. Though it was predicted in

Ref.[6] that r did not depend on ε_o and was equal to 1, in our experiments r decreases from 10–15 to 0.4. The ε_o dependence of r was also observed in Zn single crystals [12] at about 2 kHz frequency (torsional oscillations), but in this case r does not exceed 0.9, and with the ε_o increase it decreases to 0.4–0.1.

It should be mentioned that at oscillation excitations in a sample the latter is heated due to energy dissipation from these oscillations, the temperature increment increasing with the growth of ε_o amplitude. Such a heating may lead to a seeming change in the elastic modulus and thus distort the $r(\varepsilon_o)$ dependence. If the seeming change in the elastic modulus is excluded, the r values will grow in the whole amplitude range ε_o . And the r values will exceed 1 even at the highest ε_o values.

The ε_o dependences of δ and $\triangle M/M$ indicated the complicated character of temperature effect on the formation of dislocation hysteresis losses and the dislocation deformation under the crystal cyclic loading. And only in the range of 80 to 140 K the shift of $\delta(\varepsilon_o)$ and $\triangle M/M$ (ε_o) curves at the temperature change corresponds to the assumption on the thermoactivated character of dislocation hysteresis [9]. The anomalous shift of $\delta(\varepsilon_o)$ and $\triangle M/M(\varepsilon_o)$ dependences with the temperature increase in the range of 220 to 300 K does not keep within the frames of such assumptions. It should be mentioned that the anomalous shift of $\delta(\varepsilon_o)$dependence at the temperature change was also observed [13] in the considerably lower region of oscillation frequencies. As to the papers [9–11] where the thermoactivated dislocation hysteresis was discussed, the r ratio, and its change with ε_o , T were not considered.

The elastic modulus change associated with the amplitude dependent internal friction in crystals and r ratio were semiphenomenologically investigated in Ref.[7]. One of the main results of the investigation is that r may be less than 4, which contradicts to the experimental results obtained in this paper.

4. Conclusions

(1) In annealed and predeformed Zn single crystals the amplitude dependence of internal friction relation to the defect of elastic modulus $r(\varepsilon_o)$ is observed.

(2) In a predeformed sample at temperature under 140 K on $r(\varepsilon_o)$ curves the maxima are observed.

(3) In the range of 80–300 K r decreases from 10–15 to 0.4 with the increase of ε_o .

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