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ULTRASONIC ATTENUATION FROM DISLOCATIONS IN A MAGNETIC FIELD

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Abstract - The attenuation of longitudinal ultrasonic waves has been measured in high purity Cu monocrystal in a magnetic field at the liquid helium temperature. The magnetic field dependence of dislocation damping has been observed. The dislocation damping force factor B has been evaluated by employing Granato-Lücke theory. The obtained results show that the magnetic field effected on dislocation drag force.

I - INTRODUCTION

The problem of dislocations in a magnetic field was studied both theoretically and experimentally by many authors /1,2,3,4,5,6/. In these experiments the flow stress was measured during plastic deformation of samples. The strain rate was constant. The magnetic field was switched off or on at a very fast rate and the change in flow stress was recorded. The correlation between magnetic field and stress was observed in many metal samples in low temperatures. If the magnetic field changes the dislocation drag force in plastically deformed metals, as it was supposed, it should change that drag force when dislocations are moved by ultrasonic waves as well. In order to resolve this problem the attenuation of ultrasonic waves of frequency 10, 30, 50 and 70 MHz was measured in a magnetic field.

II - EXPERIMENTAL PROCEDURE

The sample was selected from a set of high purity /5N/ copper monocrystals <1,1,1> oriented, carefully lapped and vacuum annealed /3 h at 680 °C/. They were γ-ray irradiated and the sample with the smallest background attenuation at room temperature was selected. For this sample the background attenuation in the range of temperature from 240 K to 360 K was measured. The sample was mounted in a cryostat containing a superconducting magnet. Fast cooling of the sample caused unpinning its dislocations by thermal stresses. The attenuation of longitudinal ultrasonic waves in the <1,1,1> direction, normal to the magnetic field was recorded. Matec equipment was used. For generation and detection of the ultrasonic pulses a X-cut quartz transducer /10 MHz fundamental frequency/ was bonded by 4-methyl-1-pentene for measurements at
the liquid helium temperature and by nonaq stopcock grease for higher temperatures. The sample was then deformed /E=0.47%/ by compression along <1,1,1> direction. After annealing 0.5 h at 80 C the measurements of the attenuation in presence of the magnetic field were repeated.

III - RESULTS AND EVALUATIONS

At low temperatures the coefficient of attenuation of ultrasonic waves can be separated into three contributions: background attenuation $\alpha_B$, dislocation damping $\alpha_P$ and damping caused by phonon-electron interaction $\alpha_{PE}$/7/.

$$\alpha = \alpha_B + \alpha_P + \alpha_{PE}$$

III.1

For small free electron path $\bar{I}$ and low frequencies when $q\bar{I}<1$ / q- wave vector / the $\alpha_{PE}$ contribution can be evaluated from the formula:

$$\alpha_{PE} = \frac{8 \pi^2 N m^* V_F \bar{I}}{\bar{I}^2} f^2 = \delta f^2$$

III.2

where $m^*$ - electron mass, $V_F$ - Fermi velocity, $\bar{I}$ - density of the sample, $V_F$-velocity of the wave. If the sample is in a magnetic field normal to the wave vector the $\alpha_{PE}$ attenuation will vary /8/:

$$\alpha_{PE}(H) = \frac{\delta}{1 + \beta H^2} f^2$$

III.3

For the longitudinal wave

$$\beta = \frac{2 \mu I h e}{m^* V_F}$$

III.4

Here $\mu$ is permeability of the sample, $H$ is magnetic field strengh.
The background attenuation for 4.2 K can be evaluated by extrapolation to that temperature of the results obtained in higher temperatures.

For different frequencies $f_1$, $f_2$ we have from III.1,III.2,III.3:

$$\frac{[\alpha(H,f_2) - \alpha_B(f_2)]/f_2^2}{[\alpha(H,f_1) - \alpha_B(f_1)]/f_1^2} = \frac{\alpha_B(f_2,H)/f_2^2 + \delta / [1 + \beta H^2]}{\alpha_B(f_1,H)/f_1^2 + \delta / [1 + \beta H^2]}$$

III.5

A new function $\mathcal{Z}$ can be introduced:

$$\mathcal{Z}_{f_2} = \frac{1}{\alpha_{PE}(f_2)} = \frac{1}{\alpha_{PE}(f_1)} = \frac{1}{\alpha_B(f_2,H) - \alpha_B(f_1,H)}$$

III.6

Influence of the magnetic field on $\mathcal{Z}$ can indicate that there is an interaction between magnetic field and dislocations since here $\mathcal{Z}$ is only a combination of the coefficient of dislocation damping. The results of calculations of $\mathcal{Z}$ are shown on Fig. 1. From the Granato-Lücke theory /9/ it was possible to obtain relative values of the dislocation damping force factor $B$.

IV - DISCUSSION

Fig. 2 shows the dependence of $B$ on the magnetic field for the sample before and after plastic deformation. The major change of the value of $B$ takes place only in 0-3 kOe range. For stronger magnetic field $B$ becomes a constant. This result is quite from the results obtained during the plastic deformation of the crystals /1,2/ where the $B$ was proportional to the square of the magnetic field in range from 0 to several kOe. Most of the theoretical works predict a linear dependence of the drag force acting on a dislocation upon the increase of the magnetic field /3,4,5,6/ especially for the very high intensities. Moreover it should be noticed that the theoretical works and experiments as well concern the situation when dislocations move through the crystal on account of the plastic deformation passing across its lattice.
Fig. 1 - Dependence of $\xi$ on the magnetic field.

Fig. 2 - Relative dislocation damping force factor vs magnetic field.
In the experiment described here dislocations oscillated around the equilibrium points and their velocities changed harmonically. However the dependence of $B$ on the length of electron free path is in accordance with these theoretical works which predict:

$$B(H) \sim B(0) \omega_c \tau$$

Where $\omega_c$ is cyclotron frequency, $\tau$ is relaxation time of electrons. This makes clear that $B/H : B/0/ \tau$ is greater for the sample before deformation. Only the theory of the inductive drag of dislocations by electrons in metals proposed by Griščin /10/ predicts a square dependence of the drag force on the magnetic field for some range of its values. This force increases like a square function for weak fields and goes asymptotically to a constant value for strong fields. It is worth to notice that the value of $\omega_c \tau$ for undeformed sample was $\sim 1$ for $H=3$ kOe. For this value of the magnetic field was observed the maximum of quotient $B/H : B/0/ \tau$. The relaxation time was estimated from formula III.2.

REFERENCES

/10/ Griščin A. M. Pisma v ZETF vol. 31 (1980) 525.