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INTERNAL FRICTION AMPLITUDE DEPENDENCE IN SILVER SINGLE CRYSTAL

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ABSTRACT

A careful investigation of the low frequency (~1 Hz) amplitude dependent internal friction, in high purity silver single crystals, was conducted in the 300 - 600 K temperature range. Experimental results, \( Q^{-1} \) versus maximal strain amplitude, at different temperatures, or \( Q^{-1} \) versus temperature for different amplitude , are very close to theoretical curves obtained from the theory developed by BLAIR-HUTCHISON and ROGERS for the thermally assisted unpinning of very long dislocation loops.

The calculated distance between pinning points, according to the B.H.R. theory, \( (10^6) \), being too large for dislocation pinning by impurity atoms, an interpretation involving interactions between long dislocation segments and the trees of the forest is discussed.

I- INTRODUCTION

Theory for thermally activated unpinning mechanisms has been first developed by Teutonico-Granato-Lücke /1/. Later Blair-Hutchison-Rogers /2,3,4,5/ no more restricted the theory to dislocations-impurities interactions but introduced the concept of a generalized pinning force and proposed a model for the predictions of damping variations with strain amplitude and temperature, in the case of very long loops. This model was applied by Ritchie to the case of MgO /6/ and Zr /7/ single crystals.

II - EXPERIMENTAL

High purity (5N) Silver single crystals have been tested in flexion with an evacuated low frequency pendulum. Experiments were carried out between 300 and 450 K, for maximal strain amplitudes ranging between \( 10^{-7} \) and \( 5.10^{-6} \) after the specimens were held for four hours at each measurement temperature.

III - RESULTS

According to the B.H.R. model, the temperature strain diagram can be divided in five regions (figure (1)), in the case of very long dislocation loops:
- in regions A and E, unpinning occurs simultaneously in several pinning points, whereas it is initiated at a single point in regions B, C and D.
- only some dislocations can break away during one cycle in regions A and B, and inversely, all the dislocations can break away in regions C and E.
- in region D, the activation energy for unpinning remains constant.

In the temperature-strain diagram the temperature \( T_0 \), corresponding to the intersection of regions A, D and E, is given by the equation:

\[
k T_0 (\nu/\omega) = U_0 \tag{1}\]
where \( v \) is the attempt frequency for unpinning, \( \omega \) the angular frequency of the applied stress and \( U_0 \) the binding energy between the dislocations and the pinning points.

The binding energy \( U_0 \) is related to the applied stress \( \sigma_S \) by the relation:

\[
\sigma_S = (4 C U_0 b^2 L_c^3)^{1/2}
\]

where \( C = G b^2 / 2 \) is the line tension, \( G \) the shear modulus and \( L \) the spacing between pinning points. Using the B.H.R. theory, it is also possible to predict the shape of the damping-strain amplitude or damping-temperature curves. Figures 2 and 3 show the good agreement between the theoretical and the experimental curves obtained in a silver single crystal annealed at 700 K.

From these experimental curves, it is possible to deduce the \( T - \varepsilon \) diagram (figure 4) and consequently the values for \( T_0 \) and \( \varepsilon_S \):

\[
T_0 = 380 \text{ K} \quad \varepsilon_S = 2.10^{-7}
\]

The binding energy and the mean spacing between pinning points can be obtained from equations (1) and (2). Assuming \( G = 27.10^9 \text{ Pa}, \nu = 10^{11} \text{ s}^{-1}, \sigma_S = 5\varepsilon_S = 15200 \text{ Pa} \) and \( b = 2.5 \text{ Å} \), we obtain:

\[
U_0 = 0.8 \text{ eV} \quad L_c = 3 \mu
\]

IV- DISCUSSION

These values do not correspond to dislocation pinning by impurity atoms but our results can be compared with those obtained at 300 K in copper single crystals by Dralla and Bilello /8/ : they obtained an activation energy of 1 eV and interpreted their results with a mechanism based on the interaction of very long dislocation loops with the trees of the forest. A pair of jogs is formed each time a tree is cut by a loop (one on the tree and one on the loop). In the case of repulsive trees, jog formation can be thermally activated below a critical temperature \( T_c \). For trees interacting elastically with moving loops (as for F.C.C. structures) Friedel /9/ obtained, for a repulsive junction, the relation:

\[
T_c = 2 U_c / k \text{ Log} (\rho b^2 \nu / 3 \varepsilon_a)
\]

Where \( U_c \) is the energy for jog formation, \( \rho \) the mobile dislocation density, \( \nu \) the attempt frequency and \( \varepsilon_a \) the anelastic deformation rate. The damping level \( Q^{-1} \) is related to the total and anelastic deformations:

\[
Q^{-1} = \varepsilon_c / \varepsilon_T \quad \text{and the deformation rate to the vibration frequency} \ N : 
\]

\[
\varepsilon_c = \varepsilon_M N / 4 \\
\text{With} \ N = 1 \text{ Hz}, \varepsilon_M = 10^{-6} \text{ and} \ Q^{-1} = 10^{-3} \text{, we obtain} \varepsilon_a = 10^{-9}.
\]

For a split dislocation, the jog formation energy \( U_j \) is given by:

\[
U_j = \mu b^2 d / 30 \text{ when} \ d > b
\]

When a widely split dislocation is pushed against a tree, the width of the stacking fault ribbon is reduced /9/ and assuming \( d = 5b \), we obtain for silver:

\[
U_j = 0.44 \text{ eV} \quad (G = 27,500 \text{ MPa}), \text{ a value very close to the experimental one (0.4 eV).}
\]

Taking \( \rho = 10^4 \text{ cm}^{-2} \) and \( \nu = 10^{11} \text{ s}^{-1} \), it can be seen that the critical temperature \( T_c = 500 \text{ K} \) is higher than the measurement temperature indicating that interactions between mobile dislocations and trees of the forest should be thermally activated for the experimental temperature range and the very low deformation rates corresponding to internal friction tests.
CONCLUSION

It has been shown that the amplitude dependent internal friction observed above room temperature in silver single crystal can be assigned to elastic interactions between extended moving dislocations and repulsive trees. The experimental activation energy is about twice the jog formation energy in silver (0.44 eV) assuming \( d = 5b \). To explain that damping remains constant during cycling one has to assume that equal numbers of jogs of both signs are continuously created and that annihilation between jogs of opposite signs can occur.

REFERENCES

/7/ RITCHIE, I.G. and SPRUNGMANN, K.W., Atomic Energy of Canada limited report AECL 6810-1981

Figure 1 - T-\( \sigma \) diagram after B.H.R. model.
Figure 2 - Damping versus strain amplitude for different temperatures theoretical (a) and experimental (b) curves.

Figure 3 - Damping versus temperature for different strain amplitudes theoretical (a) and experimental (b) curves.

Figure 4 - Experimental T - ε diagram