THE LOW-TEMPERATURE ACOUSTICAL AND THERMAL PROPERTIES OF MATERIALS DUE TO THE DYNAMICS OF LINEAR TOPOLOGICAL DEFECTS

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Summary The specific heat and frequency-dependent loss due to twist disclinations are investigated. The low-temperature internal friction and thermal conductivity due to dipoles of edge dislocations are explored.

TWIST DISCLINATION

In general, the equation of motion of twist disclination has the form [1]

$$m\frac{\partial^2\epsilon(z,t)}{\partial t^2} = \frac{\partial}{\partial z}\left(T\frac{\partial\epsilon(z,t)}{\partial z}\right) - B\frac{\partial\epsilon(z,t)}{\partial t} + F_i, \tag{1}$$

where $\epsilon(z,t)$ is the position of the disclination line in the glide plane, F_i is the external force, m is the mass of twist disclination, T is the line tension, and B is the damping parameter. All these parameters are determined per unit length of the disclination line and they are z-dependent [1,2] The equation (1) means that twist disclination can be represented as a string with the understanding that this is *heterogeneous* string. We calculate the specific heat C and internal friction Q^{-1}, resolving the equation of motion (1). As a result, it was obtained that $C \sim \Lambda T$ [2] and under the low frequency acoustical influence $Q^{-1} \sim \Lambda L^4$ [1], where Λ is the twist disclination density, T is the temperature, L is the length of twist disclination. An important conclusion can be drawn: that the individual(local) properties of linear defects get lost whithin the string model. That is the main physical characteristics(heat capasity, internal friction) are found to be determined only by some general parameters of linear defects (the length of defect line, the density of defects) and elastic body (the density of the solid, sound velocities, the shear modulus).

DISLOCATION DIPOLE

We suggest that a dipole can be modeled by means of two damped interacting vibrating strings. Supposing that all the parameters of the string model are common for both dislocations one can formulate the general equations of damped glide motion for the edge dislocation dipole.

$$\begin{aligned} m\frac{\partial^2\epsilon(z,t)}{\partial t^2} + B\frac{\partial\epsilon(z,t)}{\partial t} - T\frac{\partial^2\epsilon(z,t)}{\partial z^2} &= F_1^{ext+} \\ m\frac{\partial^2\psi(z,t)}{\partial t^2} + B\frac{\partial\psi(z,t)}{\partial t} - T\frac{\partial^2\psi(z,t)}{\partial z^2} &= F_1^{ext-}, \end{aligned} \tag{2}$$

where $\epsilon(z,t)$ and $\psi(z,t)$ are the position of positive and negative dislocations in the glide plane, m is the effective mass, T is the line tension and B is the damping parameter, F_1^{ext+},F_1^{ext-} are the total external forces which exert on the positive and negative dislocations correspondingly, in their glide planes. In our case, the total external force

$$F_1^{ext\pm} = f_1^{\pm} + F_1^{\pm} \tag{3}$$

where $f_1^{\pm}$ is interaction force between the dislocation into dipole and the force $F_1^{\pm}$ due to phonon stress field σ_{ik}. Hereafter, the sign plus (minus) correspond to a positive (negative) dislocation, and the summation over repeated indices is assumed. In the particular case of the linear long-wave approximation, the explicit form of (3) was presented in [3]. Notice that, in general, the force (3) is essentially nonlinear.

Internal friction due to the motion of dislocation dipole

In [4], the amplitude-independent dislocation absorption (internal friction) was investigated under the joint action of constant and random external forces on the dislocation. The action of random forces of different types were considered with due regard for the inertial properties of the dislocation and the effect of the internal (parabolic) potential relief of the crystal. The dependence of the internal friction from the degree of correlation of random forces and the parameters of the dislocation and the medium were obtained. It was revealed that the regularities of the energy loss by excitation of the dislocation structure under random external actions essentially differ from those observed under harmonic actions. Unlike the Granato-Lucke classical case of periodic actions on a dislocation, the internal friction in the low-frequency range for the random actions nonlinearly depends on the frequency. The decrement in this frequency range is considerably larger than that under periodic actions. The dependence of the damping decrement from the dislocation segment length L is governed by the parameters of the dislocation, the medium, and the random force and can exhibit different behavior in contrast with the corresponding dependence observed under periodic actions. We suppose that a similar mechanism of the dissipation due to the random external force is responsible for the explanation of an unexpected high value of low-temperature internal friction in high-purity plastically deformed aluminium experimentally observed in [5]. Actually, we apply the scheme developed in [4] to the dynamics of dislocation dipole and obtain the reasonable value of the decrement Q^{-1} in Al. The theory gives a good agreement with experiment under the appropriate density of dislocation dipoles.

Thermal conductivity

As is well-known, metals in the superconducting state conduct the heat via phonons. At the lowest temperature the thermal conductivity is due to scattering of phonons by the surface of the sample(boundary scattering) and by lattice defects. We suppose that the most part of lattice defects are the dislocation dipoles. In order to obtain the contribution to the thermal conductivity we use the relaxation-time description. In this case, within the framework the Debye approximation and if normal-process scattering is neglected, the lattice thermal conductivity is given by

$$k = (k_B^3/2\pi^2\overline{v}\hbar^3)T^3 \int_0^{\theta/T} x^2\tau(x)C(x)dx \tag{4}$$

where θ the Debye temperature, $\overline{v}$ is the averaged sound velocity, τ is the total phonon relaxation time and C is the specific heat. We will assume that all phonon modes are scattered almost equally by the dislocation dipoles. The total relaxation rate τ^{-1} is

$$\tau^{-1} = \tau_c^{-1} + \tau_d^{-1} \tag{5}$$

where τ_c^{-1} is the relaxation rate of the boundary scattering which is obtained from the data of an undeformed specimen and τ_d^{-1} is the relaxation rate due to the dynamic phonon-dipole interaction.
The calculations shows that in Al below 0.15 K, in Ta below 0.6 K and in Nb below 1.5 K when the influence of the electronic contribution to the thermal conductivity is neglected, our model demonstrates a rather good agreement with experiments.

References

[1] Churochkin D.V., Osipov V.A.: On the disclination-induced internal friction. *Phys. Lett. A* **277**:277–273, 2001.
[2] Churochkin D.V., Osipov V.A.: Contribution of mobile twist disclinations to the specific heat of crystals. *Phys. Lett. A* **96**:96–92, 2001.
[3] Kneezel G.A., Granato A.V.: Effect of independent and coupled vibrations of dislocations on low-temperature thermal conductivity in alkali halides. *Phys.Rev. B* **2866**:2866–2851, 1982.
[4] Kamaeva O.V., Chernov V.M.: Amplitude-Independent Dislocation Internal Friction under Random External Actions. *Physics of the Solid State,* **1608**:1601–1608, 2002.
[5] Liu X., Thompson E., White B.E., Jr., Pohl R.O. : Low-temperature internal friction in metal films and in plastically deformed bulk aluminum. *Phys.Rev. B* **11776**:11776-11767, 1999.