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INFLUENCE OF DISSIPATIVE PROCESSES ON DISLOCATION DYNAMICS IN METALS

by

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ABSTRACT

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PRIORITY

Rough progress in the field of materials treatment has triggered off the development of the physics of plasticity and strength.

It is well known that the plasticity of materials is caused by the moving elementary "carriers" of plastic deformation, namely by dislocations. Therefore, the explanation of many physical phenomena connected with the plasticity, such as the effect of superconducting softening, photoplastic effect, has been made on the basis of dislocation models.

Moving dislocations, representing the lattice formations, strongly interact with other elementary excitations of a crystal: phonons, conduction electrons, magnons, etc., which may serve the source of their kinetic energy loss. Aforementioned problems have been discussed by several authors. However, the substantial circumstance of this question connected with the vortex nature of the screw dislocation has been passed unnoticed. It should also be emphasized that this circumstance is not taken into account when the external magnetic field is applied.

In crystals with high Peierls barriers the motion of dislocations is realized by means of kinks on dislocation lines. Kinks can be pinned on impurities and pass there the major part of time. It is clear that the type of impurity should play an important role when the probability of depinning is determined. However, the questions connected with the kink mobility in crystals with various types of doping impurities stay yet uninvestigated today.

AIMS AND SCOPE

The main goal of present thesis is investigation of the effect of dissipative processes on the dynamics of dislocations and kinks. There were solved the following problems:

1. Calculation of velocity dependence of dislocation electronic damping to revise the efficiency of electron interaction with short-wave dislocation phonons.

2. Determining the velocity- and field dependence of dislocation electronic damping in an applied magnetic field.

3. Calculation of kink depinning probability from the point obstacle at various values of the medium viscosity coefficient to determine in each case the particular depinning mechanism.

CONTENTS

Introduction substantiates the priority of the problem stated. The aims and main problems of dissertation are defined. The brief review of literature is presented.

In Chapter 1 the velocity dependence of the screw dislocation electronic damping is obtained whereas the simplest model of isotropic electron gas with parabolic dispersion law is taken into consideration. Then the displacement field of moving dislocation represents itself as an elastic wave packet, for which the linear dispersion relation $\omega = kV$ holds, where ω and k are the frequency and wave vector of the given Fourier component, and V is the dislocation velocity. The main distinction of present problem lies in exclusively transversal nature of the elastic field forming the screw dislocation. These waves generate in a metal the electromagnetic waves, the length of which is of the order of the skin layer depth δ. While the length of the induced electromagnetic wave is less than that of elastic one, the attenuation coefficient for such a wave is known to be proportional to its frequency. However, in the case $k\delta \gg 1$ it is no longer linear and asymptotically tends to zero at high frequencies. This nonlinear frequency dependence of the attenuation coefficient constant, where the main contribution to the energy dissipation is introduced by the shortest waves, means that the damping force dependence on the screw dislocation velocity must differ from that obtained using of the linear dependence, where the attenuation constant was assumed to be proportional to the elastic wave frequency. The analytic relation of the damping force has been obtained, which has the form

$$f = \frac{R\, n\, p_f\, b^2\, \omega_p V^{3/2}}{6\pi^2 c\, v_f^{1/2}}$$

where R is a constant of the order of unity, n is the density of electron gas, ω_p is the Langmuir frequency, c is the light velocity, v_f is the Fermi velocity of the electrons.

In Chapter 2 the problem of dislocation electronic damping in an applied nonquantizing magnetic field is considered. The physical reasons resulting in change of the electron trajectory are presented. The generalized expression of attenuation coefficient in case of complex conductivity tensor is obtained. It is shown that at any orientation of the magnetic field and dislocation line the absorbed power decreases with increase of the magnetic field strength. The physical cause of such behavior consists in the change of the electron trajectory. In the absence of the magnetic field the trajectory represents a straight line, while in an applied magnetic field it is transformed into the trochoid, which effectively extends the mean free path of the electron. The expression for relative absorption power in the case of weak field $\omega_c\tau \ll 1$ is obtained (ω_c is the cyclotron frequency and τ is the relaxation time):

$$\frac{W^{H=0} - W}{W^{H=0}} = \exp\left(-\frac{2\pi}{\omega_c\tau}\right)$$

representing the Dingle factor.

The case of strong magnetic field $\omega_c\tau \gg 1$ is also considered. Taking into account two possible relations between the relaxation time τ and the period of elastic wave $1/\omega$, we have obtained the following expressions for the relative absorption for two limiting cases $\omega\tau \ll 1$ and $\omega\tau \gg 1$:

$$W/W^{H=0} \sim H^{-1/2}$$

$$W/W^{H=0} \sim H^{-3/2}$$

In Chapter 3 the problem of kink depinning from fluctuating point obstacle in a viscous gas of quasiparticle excitations of a crystal is considered. It is assumed that the kink exists in a parabolic potential of the point obstacle, carrying out fluctuational oscillations. Simultaneously two equations of motion are solved, namely for the kink and the point obstacle. Moreover the right-hand sides of these equations involve uncorrelated stationary forces. It is significant that the viscosity coefficient is presented not only in the dissipative term, but also in the random force. The main inequalities allowing to separate the physically various situations, when the fluctuations of either kink or obstacle are prevalent, are presented. The main result of this Chapter is the inclusion of the impurity mass into a set of problem parameters, which will allow to analyze the influence of various impurities doping the same crystal.

The main results of Dissertation are published in the following papers:

1. R.A.Vardanian and T.V.Zakarian. On Electronic Damping of Screw Dislocations. - Phys. Lett. A, 1991, v.160, no.5, pp.465-467

2. R.A.Vardanian and T.V.Zakarian. Influence of Impurities on Kink Dynamics in Crystals with High Peierls Barriers. - Solid State Commun., 1993, v.86, no.7, pp.455-458

3. R.A.Vardanian and T.V.Zakarian. Influence of a Magnetic Field on Electronic Damping of Screw Dislocations in Metals. - Preprint IRPhE-94-1, Ashtarak, 1994, 17pp.

4. R.A.Vardanian and T.V.Zakarian. The Damping Force Acting on a Moving Screw Dislocation. - Proceedings of the 29th Conference on Low Temperature Physics, Kazan' (Russia), 1992, v.II, p.E35 (in Russian)

5. R.A.Vardanian and T.V.Zakarian. Dislocation Mobility in Crystals with High Peierls Barriers. - Abstracts of the 3rd European Conference on Materials and Processes, Strasbourg (France), 1992, p.B-IV.3