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TEMPERATURE DEPENDENCE OF THE ELECTRICAL RESISTIVITY OF METALS WITH DISLOCATIONS

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Résumé.— On effectue un calcul de diffusion des électrons par les dislocations en prenant en considération l’influence de celles-ci sur le spectre de phonons d’un métal (perturbation linéaire de la matrice de forces) et en supposant que l’amplitude de diffusion des atomes situés sur les lignes de dislocations est différente de celle des atomes non perturbés. On obtient et analyse la dépendance en température de la contribution apportées à la résistivité par les dislocations.

Abstract.— The electron scattering on dislocations is calculated taking into account the influence of dislocations on the phonon spectrum of a metal (line a perturbation of force constant matrix) and on the assumption that the scattering amplitude of atoms located at the dislocation lines differs from that of unperturbed atoms.

The temperature dependence of the dislocation extrasistivity derived is analysed.

Some metals (Cu,Ag,Al,Ni,2n,Al) show a sharp increase in the dislocation extra resistivity in quite a narrow temperature range (20-100 K)/1,4/. The effect observed is rather considerable. The maximum values of the parameter $\rho(T)/\rho(0)-1$ are sometimes as high as 2 or 3. We treat the problem of extrasistivity of dislocated metal by taking into account the mechanism for electron scattering on phonon modes resulting from dislocations /3,4/.

We proceed from the assumption that the dislocation core makes a principal contribution to the electron scattering. Let the atoms of dislocation lines have the scattering amplitude $\alpha_1$, which is different from the amplitude of other atoms $\alpha_0$. The dislocation is assumed to be a local line perturbation of the force constant matrix of the crystal /5/.

The electron scattering probability $W_{kk}$ is calculated taking the total pseudopotential of the dislocated metal as perturbations:

$$W_{kk} = \frac{1}{N} \sum_{n=1}^{N} a_n a_n^* S_{nn} f(E-E_k)$$

Here $m$, $k$, $c$, $\beta$ are the mass, wave vector, and energy of the electron, respectively, $V_0$ is the volume of the unit cell; $f(E)$ is the Fermi distribution function; $E_k$ is the energy of Fermi level. We use the expansion of correlation function $S_{nn}$ in Fourier-series:

$$S_{nn}(E) = \sum_{k} \sum_{\alpha} \sum_{\beta} \rho^{\alpha\beta}(k) f(E-E_k)$$

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As a result we obtain

\[ r(T) = \begin{cases} 
0.5 \frac{T}{\Theta} \text{sign } \Delta a & \Theta > 3.8 \text{ sign } \Delta a - 0.3 \\
\Theta & \Theta \leq 3.8 \text{ sign } \Delta a - 0.3 
\end{cases} \]

The first expression is resulting from the weak, and the second from the strong perturbation of force matrix. The estimates (4) show that it possible to interprete the measurable values of \( r(T) \) in terms of the scattering processes involved.

At the low-temperature limit the main contributions to \( r(T) \) are also due to the phonon and interference processes. The temperature dependence is given both by the power functions (from first to sixth power in \( \Theta \)), and exponential functions, such as \( \exp(-aT^{1/2}) \) and \( \exp(-\frac{\Theta}{T}) \). The contributions from different terms depend on the magnitude of force constants perturbation potential \( U \). The type of transition to the linear high-temperature limit is greatly sensitive to the value of \( U \), namely the stronger \( U \), the steeper transition.

It should be noted that \( r(T) \) is affected by dislocations parallel to the applied electric field in contrast to residual resistivity \( \rho^0(0) \).

References

/4/ Kulesko, G.I., ibid, 72 (1977) 2167.