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Figure 1

Figure 1: Figure 1

Abstract

Full Text

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PHYSICS

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ON THE DEPENDENCE OF THE ION-ELECTRON EMISSION OF SINGLE CRYSTALS ON THE TARGET TEMPERATURE

(Presented by Academician L. A. Artsimovich, 12 XII 1964)

In the work of E. S. Mashkova and V. A. Molchanov (1), the influence of the temperature of a bombarded copper single crystal on the angular dependence of ion-electron emission was investigated. It turned out that an increase in temperature leads to a smoothing of the curve of the dependence of emission on the angle of incidence of the ions.

The magnitude of electron emission upon variation of the angle of incidence of ions on a single crystal, as shown in (2), is satisfactorily described by a formula obtained under the assumption that the number of emitted electrons is proportional to the energy lost by the ion in its first collisions with atoms of the surface layers. This approximation is based on the assumption that the overwhelming number of fast electrons arising in the interaction of an ion with a crystal is due to the transfer of ion energy not to free but to bound electrons (see also (3)).

Fig. 1. Change in the positions of atoms due to thermal displacements. For convenience of representation, a particular case has been chosen in which all vectors lie in one plane. The arrow *a* denotes the direction of incidence of the particles.

In work (2), in deriving the formula for the coefficient of ion-electron emission γ, the thermal motion of atoms was not taken into account. Since the collision time of an argon ion with an energy of 30 keV with a lattice atom is much less than the period of thermal vibrations, the change in the atom' s position during the collision may be neglected. Thermal vibrations will lead only to distortion of the crystal lattice and thus affect its transparency, i.e., the probability of the first collision of the ion with atoms of the single crystal (in a polycrystal, where averaging over orientations takes place, this effect should not occur). The distortions are substantial, and they should be taken into account when calculating the average energy transferred to an atom only in those cases where part of the atom is shielded by the atom lying above. The average energy $\overline{E_i}S_i$, transferred in such collisions, is expressed by the formula

$$\overline{E_i}S_i = E_{\max}R^2 F\left(\frac{\delta}{R}\right) = E_{\max}R^2\left[\frac{\pi}{2}\left(\frac{\delta}{R}\right)^2 - \frac{2}{3}\left(\frac{\delta}{R}\right)^3 + \frac{29}{15\cdot 2^7}\left(\frac{\delta}{R}\right)^5 + \sum_{k=0}^{\infty}\frac{(2k+1)!(\delta/R)^{2k+7}}{2^{4k+5}k!(k+2)!(2k+5)(2k+7)} \quad (1)$$

where the same notation is used as in work ([4]).

As is seen from (1), the average energy $\overline{E_i}S_i$ is determined by the quantity δ– the projection of the vector connecting the centers of the atoms onto the plane perpendicular to the direction of incidence of the particles (see Fig. 1). When thermal displacements are taken into account, $\vec{\delta} = \vec{\delta}_0 + (\vec{\rho}_1 - \vec{\rho}_2)$, where $\vec{\delta}_0$ is the projection of the vector connecting the nodes of the ideal lattice, and $\vec{\rho}_1$ and $\vec{\rho}_2$ are the projections of the thermal displace-

of the shielding and shielded atoms, respectively. To calculate $F(\delta/R)$ (R is the radius of the collision sphere), it is necessary to find the mean values of the second and higher odd powers of $\vec{\delta}$. Taking into account that the mean values of the odd powers of the thermal displacements (and, consequently, of their projections) are equal to zero, we find

$$\overline{\delta^2} = \delta_0^2 + \overline{(\vec{\rho}_1 - \vec{\rho}_2)^2}, \qquad \overline{\delta^3} = \delta_0^3 + 3\delta_0\overline{(\vec{\rho}_1 - \vec{\rho}_2)^2},$$

$$\overline{\delta^5} = \delta_0^5 + 10\delta_0^3\overline{(\vec{\rho}_1 - \vec{\rho}_2)^2} + 5\delta_0\overline{(\vec{\rho}_1 - \vec{\rho}_2)^4}, \text{ etc.}$$

In the Einstein approximation (i.e., without taking correlations into account),

$$\overline{(\vec{\rho}_1 - \vec{\rho}_2)^2} = \frac{4}{3}x_l^2.$$

Taking correlations into account at $T \gg \Theta$ (see (5)),

$$\overline{(\vec{\rho}_1 - \vec{\rho}_2)^2} \simeq \frac{4}{3}x_l^2(1 - 1/2\eta n),$$

where x_l^2 is the mean square of the amplitude of thermal vibrations, Θ is the Debye temperature for copper (345° K), $\eta = \sqrt[3]{6\sqrt{2}}/\pi$, and n is the distance between atoms in units of d, the shortest distance between lattice nodes.

The quantity $\overline{(\vec{\rho}_1 - \vec{\rho}_2)^4}$ can be determined approximately as

$$\overline{(\vec{\rho}_1 - \vec{\rho}_2)^4} = A \int_{-\infty}^{\infty} x^4 \exp\{-x^2/\alpha\overline{(\vec{\rho}_1 - \vec{\rho}_2)^2}\}\, dx$$

with constants A and α satisfying the conditions

$$A \int_{-\infty}^{\infty} x^2 \exp\{-x^2/\alpha\overline{(\vec{\rho}_1 - \vec{\rho}_2)^2}\}\, dx = \overline{(\vec{\rho}_1 - \vec{\rho}_2)^2},$$

$$A \int_{-\infty}^{\infty} \exp\{-x^2/\alpha\overline{(\vec{\rho}_1 - \vec{\rho}_2)^2}\}\, dx = 1.$$

Since the sum in (1) is appreciable only for large δ, and under all conditions its contribution is less than 10%, the quantity $\overline{(\vec{\rho}_1 - \vec{\rho}_2)^4}$ was taken into account only in the term preceding it in the sum, while we neglected the mean values of higher powers of the displacements.

Within the framework of the scheme described above, γ was calculated for a copper single crystal by the formula given in (2). In accordance with the experimental conditions ([1]), it was assumed that bombardment by argon ions with an energy of 30 keV was carried out along the (100) face at different angles of rotation of the single crystal about the [110] direction and at target temperatures $T = 0.9\Theta$ and $T = 3.4\Theta$. In the calculations the following parameter values were used: $\beta_{1,2} = \beta_{3,4} = 5/3\beta_{5,6} \simeq 0.176$ keV^{-1}*, the shadow radius, i.e., in the present approximation the radius of the collision sphere, $R = 0.2d$.

The calculated curves are shown in Fig. 2 together with the experimental values of E. S. Mashkova and V. A. Molchanov ([1]). The agreement is satisfactory, especially if one takes into account that the constancy of the shadow radius assumed in the calculation** should lead to an increase in the difference between the calculated curves, chiefly in the minima corresponding to large distances between the shielding and shielded ato-

* In ([2]), instead of the numerical value of $\beta_{1,2}$, the quantity $\beta_{1,2} \cdot \pi/2$ was given by mistake. It should be $\beta_{1,2} = 0.148$ keV$^{-1} \simeq 0.15$ keV^{-1}.

** As shown by Yu. M. Martynenko ([6]), the shadow radius increases somewhat with increasing distance between the shielding and shielded atoms.

(for example, a minimum at 19.5°). This apparently permits the conclusion that, in the case considered, the effect of a change in temperature on the angular dependences of ion-electron emission is due mainly to a change in the transparency of the crystal by thermal vibrations, and not to the effect of temperature on the escape of electrons from the crystal. Above, as in work ([2]), it was assumed that the electrons arising

Fig. 2

Figure 2: Fig. 2

Fig. 2. Dependence of γ on φ—the angle between the normal to the surface and the direction of incidence of the particles. Calculated curves: 1—for $T = 0.9\Theta$ (parameters are indicated in the text), 2—for $T = 3.4\Theta$ (without using additional parameters). Points are experimental data ([1]) for temperatures $\sim 40^\circ$ (a) and $\sim 900^\circ$ (b)

during the second and subsequent collisions of the argon ion with atoms of the lattice do not make a noticeable contribution to the emission. The agreement between the calculations and the experimental data apparently confirms this assumption. Further refinement of the experiments would help to clarify the role of collisions in deep layers and to reveal the main mechanisms ensuring the transfer of energy from deep layers to the surface. In this connection it would also be possible to judge the role of plasmons in ion-electron emission (in this connection see also ([7,8])).

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CITED LITERATURE

1. E. S. Mashkova, V. A. Molchanov, *Fiz. tverd. tela*, **6**, 3704 (1964).
2. E. S. Mashkova, V. A. Molchanov, D. D. Odintsov, *DAN*, **151**, 1074 (1963).
3. E. S. Parilis, L. M. Kishinevskii, *Fiz. tverd. tela*, **3**, 1219 (1961).
4. D. D. Odintsov, *Fiz. tverd. tela*, **5**, 1144 (1963).
5. R. S. Nelson, M. W. Thompson, H. Montgomery, *Phil. Mag.*, **7**, 1385 (1962).
6. Yu. V. Martynenko, *Fiz. tverd. tela*, **6**, 2003 (1964).
7. E. S. Mashkova, V. A. Molchanov, D. D. Odintsov, *Fiz. tverd. tela*, **5**, 3426 (1963).
8. V. M. Agranovich, *Atomnaya energiya*, **17**, 152 (1964).

Note: Figure translations are in progress. See original paper for figures.