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THE INFLUENCE OF THE INITIAL ENERGY OF IONS ON THE REGULARITIES OF ION SCATTERING BY CRYSTALS

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1. It is known that in the energy distributions of ions scattered by crystal surfaces, along with peaks corresponding to singly scattered ions and to recoil atoms ionized in the collision process, there are also peaks corresponding to ions that have undergone multiple scattering by target atoms (see, for example, (^{1})).

In (^{2}) an estimate* was given of the relative intensity of the "double-scattering" peak

$$\frac{I_2}{I_1} = R \sim Z_1 Z_2 \frac{1}{l^2} \frac{1}{\vartheta_0^{2.5}} \frac{1}{E_0}, \tag{*}$$

where Z_1 and Z_2 are the atomic numbers of the ion and the target atom; l is the distance between the atoms at which the successive scatterings of the ion occur; ϑ_0 is the total scattering angle; E_0 is the ion energy. The derivation of this formula was based on the simplest diatomic model of scattering. In addition, it was assumed that the interaction of the ion with the target atom is described by the Firsov potential, and that the deflection angles ϑ_1 and ϑ_2 of the doubly scattered ion in scattering by the two target atoms are small, identical, and equal to one half of the total scattering angle ϑ_0. The experimental data presented in (^{2}, ^{3}) indicate that the relation written above qualitatively correctly conveys the character of the dependence of the relative intensity of the double-scattering peak on Z, l, and ϑ. The present work was undertaken in order to trace the character of the dependence of the relative intensity of this peak on the energy of the incident ions.

2. The scheme of the experimental setup and the angular and energy resolution of the analyzer were the same as in (^{2}). The only difference was that in the present work, for recording the energy distributions of the scattered ions, an oscillographic method was used (see (^{4})): the voltage from the output of the

Fig. 1

Figure 1: Fig. 1

ion-current electrometric amplifier was fed to the input of the vertical-deflection amplifier of the beam of a C—1—18 oscilloscope, and part of the voltage applied to the plates of the electrostatic analyzer (which is proportional to the energy of the ions being analyzed) was fed to the input of the horizontal-deflection amplifier. Thus, on the oscilloscope screen, dependences of the number of ions that had passed through the analyzer on their energy were obtained, i.e., the energy distributions of the ions. These distributions were photographed in the usual way. The described method made it possible to increase many times the rate at which the distributions were recorded. The target was the (100) face of a copper crystal. During the experiment the target and analyzer were rotated about two different crystallographic directions—[100] and [110], so that the scattering planes were the crystallographic planes (100) and (110), respectively.

* Performed by Yu. V. Martynenko.

The targets were irradiated with argon ions whose energy was varied from 10 to 20 keV. The grazing angles were 10, 15, and 20°, and the scattering angles were varied from 25 to 42°. To make it convenient to compare different distributions, the gain of the oscillograph was set each time so that the height of the peak having the greater intensity (either the left, "single," peak or the right, "double," peak) was the same throughout all measurements.

Fig. 1. *I* —rotation of the target and analyzer about the [100] axis; *II* —rotation about the [110] axis. Ion energies (keV): 1 —20; 2 —18; 3 —16; 4 —14; 5 —12; 6 —10. Scattering angles (deg.): *a* —25, *b* —28, *v* —30, *g* —35, *d* —40.

3. The experimental results relating to a grazing angle of 20°, to various scattering angles, and to ion energies are presented in Fig. 1. It is seen that in the case when the scattering plane is the (100) face

target, at all scattering angles studied, a decrease in the ion energy leads to an increase in the relative intensity of the double-scattering peak (the right-hand peak). Thus, for example, for a scattering angle of 35°, at an ion energy of 20 keV the double peak is several times smaller than the single peak. When the ion energy decreases, its relative intensity increases; at 12 keV the intensities of the two peaks become equal, and already at 10 keV the double peak is larger than the single peak.

In the case where the scattering plane is the (110) face of the target, for scattering angles of 40 and 35° a qualitatively similar dependence is observed. However, at smaller scattering angles (30—25°) this dependence is no longer observed over the entire investigated range of ion energies. For example, at a scattering angle of 28°, decreasing the ion energy from 20 to 16 keV leads to an increase in the relative intensity of the double peak; in the energy range 16–14 keV the rela-

Fig. 2

Figure 2: Fig. 2

tive intensity of the double peak is approximately constant, and with a further decrease in energy it begins to decrease.

Fig. 2. Dependence of I_1/I_2 on ion energy. Rotation about the [100] axis. Scattering angles: 1—33°; 2—40°.

4. The experimental results obtained indicate that, in any case under certain conditions, the relative intensity of the double-scattering peak increases as the ion energy decreases, which is in qualitative agreement with (*). Unfortunately, carrying out a sufficiently correct quantitative comparison of the experimental results with the dependence given by (*) is difficult. This is due to the fact that relation (*) includes the intensities of the single and double peaks, whereas the experiment gives not these intensities, but only the envelope of at least three more or less superposed distributions: the single peak, the double peak, and the background caused by multiple collisions of ions with target atoms. Present theories of the interaction of ions with solid surfaces still do not make it possible to decompose the total distribution into its components with sufficient justification; therefore any comparison of experimental distributions with the results of calculations based on consideration of the simplest scattering models contains a fundamental error, the magnitude of which is difficult to estimate. Nevertheless, one should expect this error to be minimal in the case when the overlap of the contours of the single and double peaks is minimal, i.e., when the distance between the single and double peaks is greatest. At a glancing angle of 20°, this occurs for scattering angles of 40 and 35°.

If one measures the ordinates of the experimentally obtained distributions at points corresponding to the single (I_1) and double (I_2) peaks at different ion energies, and plots the dependence of the ratio (I_1/I_2) (which, in the absence of background and overlap of the single and double peaks, would coincide with $1/R$ from (*)) on the energy of the primary ions, the results shown in Fig. 2 are obtained. It can be seen that the dependences are almost linear. This is a certain quantitative argument in favor of (*).*

On the other hand, there are experimental data for which dependence (*) is not satisfied even qualitatively. Turning to the scattering schemes presented in Fig. 1, one can note that this occurs in cases where both the distances between atoms are small and the distances between the atoms

of the atomic chain lying in the scattering plane, and the angles of emergence of the ions with respect to the axis of this chain.

The very fact that, in the case of small interatomic distances and emergence angles, discrepancies are observed with the predictions obtained on the basis of considering such an idealized model of the scattering process as a two-atom model is not unexpected—according to Lindhard (§ 2 in (5)), at small interatomic distances and angles formed by the ion trajectories with the axes of atomic chains, the consideration of collisions as strictly individual events is no longer correct. In this case it is more appropriate to consider the scattering of ions by atomic chains. Unfortunately, the only theoretical work of this kind known to us (6) was carried out using numerical integration, so that it does not appear possible, on the basis of that work, to trace the character of the dependence of the form of the energy distributions of scattered ions on the energy of the primary ions.

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REFERENCES

1. E. S. Maschkova, V. A. Molchanov et al., Phys. Lett., **18**, 7 (1965).
2. E. S. Mashkova, V. A. Molchanov, FTT, **8**, 1517 (1966).
3. E. S. Mashkova, V. A. Molchanov, DAN, **172**, 813 (1967).
4. V. M. Chicherov, In VIII Intern. Conf. on Phenomena in Ionized Gases, Vienne, 1967, p. 49.
5. J. Lindhard, Mat. Fys. Dan. Vid. Selsk., **34**, No. 14 (1965).
6. V. M. Kivilis, E. S. Parilis, N. Yu. Tyraev, DAN, **173**, No. 4 (1967).