THE INFLUENCE OF CRYSTALLINE STRUCTURE ON THE ANGULAR AND ENERGY DISTRIBUTIONS OF IONS SCATTERED BY A SINGLE CRYSTAL

PHYSICS

1969

SovietRxiv

Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

UDC 537.534.8

PHYSICS

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THE INFLUENCE OF CRYSTALLINE STRUCTURE ON THE ANGULAR AND ENERGY DISTRIBUTIONS OF IONS SCATTERED BY A SINGLE CRYSTAL

Theoretically ([1]) and experimentally ([2,3]) it has been shown that, in the energy distribution of ions scattered by a single crystal, along with peaks corresponding to singly scattered ions and recoil atoms, there are observed peaks corresponding to ions that have undergone multiple collisions with target atoms. In ([4,5]) the angular regularities in the positions of the peaks of single and double collisions were investigated. The dependence of the position and intensity of these peaks on the energy and type of the primary ions, on temperature, and on the type of target was also studied ([6,7]). In addition, a number of effects associated with channeling of the incident particles in the crystal lattice, as well as with their multiple collisions with atoms of the crystal ([8,9]), have been investigated. These results were obtained mainly in studies of the distribution, by angles and energies, of secondary ions as a function of the angles: incidence Φ of the primary ions, emission θ, and scattering β.

Fig. 1. Oscillograms of the energy distribution of secondary ions obtained during bombardment of the (100) face of Mo ($T = 1800°$) with Rb^+ ions of energy $E_0 = 500$ eV at $\varphi = 0°$ (1) and $\varphi = 45°$ (2) ($\Phi = \theta = 50°$).

To understand the mechanism of interaction of atomic particles with a solid, it was important for us to investigate changes in the character of the angular and energy distributions of secondary ions as a function of the azimuthal angle of rotation of the target φ.

The investigation was carried out on the apparatus described in ([10]), in which provision was made for bombarding the target at different angles Φ by means of a movable ion source. Energy analysis of secondary particles leaving at different

Fig. 2

Figure 2: Fig. 2

angles θ and β was performed with the aid of a special device that led to a change in the orientation of the target. The angles Φ, θ, β, and φ in the instrument were varied externally by means of magnets, which made it possible to follow changes in the character of the angular and energy distributions of ions under the same conditions of the target surface ($T = 1600 \div 1800$°K) and vacuum $(1 \div 2) \cdot 10^{-7}$ mm Hg.

An electrostatic capacitor of the Yuz-Rozhansky type with a resolving power served as the energy analyzer of the secondary ions.

$\Delta E/E \approx 0.7\%$. To amplify the current at the analyzer output, an ion-electron multiplier with a gain of $\sim 10^8$ was used.

Measurement results

Figure 1 shows two oscillograms of the energy distributions of secondary ions obtained in the bombardment of the (100) face of a Mo single crystal, annealed to 1800°K, by Rb^+ ions with energy $E_0 = 500$ eV. Both oscillograms were obtained at $\Phi = \theta = 50°$. However, oscillogram 1 was obtained with such an orientation of the target that the incident and scattered beams lay in the plane of incidence passing through the [110] axis of the target (crystal), whereas oscillogram 2 was obtained after rotating it about the [100] axis lying in the plane of incidence by an angle $\varphi = 45°$.

The peaks with index [000] in the oscillograms correspond to ions that have undergone single collisions, while the peaks with indices [010] and [021] correspond to ions scattered twice on the corresponding atoms.

It is seen that, on going from the principal scattering chain [110] to [100], which corresponds to rotation of the crystal about the [100] axis by an angle $\varphi = 45°$, the maximum energy of the secondary ions E_m increases. (Here, the maximum energy of secondary ions E_m emitted at a definite emission angle is taken to be the extreme, high-energy point of the spectrum (see Fig. 1).) At the same time, oscillogram 2 in Fig. 1 shows that when the principal scattering chain is formed by atoms located along the [100] direction of the crystal, the energy spectrum is rich in peaks ([021], [010], etc.) of multiple collisions; moreover, this leads to an increase in the intensity of the peaks of multiple collisions.

Fig. 2. Oscillograms of the energy distributions of secondary ions obtained for Rb^+ on Mo (110); $E_0 = 500$ eV at $\varphi = 0°$ (1) and $\varphi = 45°$ (2) ($\Phi = \theta = 70°$).

The observed features of the energy spectra of secondary ions scattered along different crystallographic directions can be explained by multiple collision of the ion on an atomic chain, taking into account the increase in the probability of

Fig. 3

Figure 3: Fig. 3

the ion entering the field of the next atom of the close-packed cell ([11]).

There are works ([12,13]) in which calculations performed with a computer showed that a decrease in the distance between atoms of the principal scattering chain leads to an increase in the relative probability of double scattering of the ion. If this is taken into account, it is not difficult to explain the change in the maximum energy of secondary ions scattered along close-packed directions of the crystal.

As is known, for the (100) face of a body-centered cube (W, Mo), the [100] atomic chain is more closely packed than the [110] chain. It was shown that further rotation of the crystal about the [100] axis by angles $\varphi = 45, 90, 135, 180°$ leads to a periodic change in the energy distribution, which is explained by the ordered structure of the target. It was further shown that rotation of the crystal about the [100] axis by an angle $0 < \varphi < 45°$ and $45° < \varphi < 90°$ leads to a certain smoothing of the peaks of multiple collisions, which is explained by a decrease in the relative probability of mult—

collisions of the ion because of the large distance between the atoms of the chain. It was also observed that the transition of the main scattering chain from a more close-packed direction to a less close-packed one leads to a sharp change in the ratio between the number of ions that have undergone single and multiple collisions. In this case the intensity of the single-collision peak [000] in the spectrum increases, while the intensities of the double-collision peaks [021] and [010] decrease. This is explained by an increase in the relative probability for the number of ions undergoing single collisions, in accordance with the theory ([12,13]).

Figure 2 shows two oscillograms of the energy distributions of secondary ions obtained upon bombardment of the (110) face of a molybdenum single crystal, heated to 1800°K, by Rb^+ ions with energy $E_0 = 500$ eV. Here both oscillograms were obtained with the same target orientations as the oscillograms in Fig. 1, but at angles $\Phi = \theta = 70°$. Since here the angles Φ and θ are large, the intensities of the multiple-collision peaks [031], [010] predominate over the intensity of the single-collision peak [000], which is explained by an increase in the number of multiply colliding ions as a result of successive impacts of the incident ions with atoms of the surface chains ([4–6]). Because of the large values of the angles $\Phi = \theta$, the distances between the single- and multiple-collision peaks are small.

Fig. 3. Dependences of $\eta_{[000]}$, $\eta_{[010]}$, and η_m on the azimuthal angle of rotation of the target φ, obtained for Rb^+ on Mo (110), $E_0 = 500$ eV, $\Phi = \theta = 70°$.

It is seen that in the oscillograms of Fig. 2 rotation of the crystal about the [110] axis by an angle $\varphi = 45°$ did not lead here to an increase in the maximum

Fig. 4

Figure 4: Fig. 4

energy of the secondary ions E_m, but, on the contrary, to its decrease. This is connected with the fact that, in the case of bombardment of the [110] face of Mo, the atomic chain [110] is packed more densely than the atomic chain [100]. This also explains the decrease in the intensities of the multiple-collision peaks in the case of oscillogram 2 of Fig. 2. It was shown that further rotation of the crystal about the [110] axis by angles $\varphi = 45, 90, 135, 180^\circ$, etc., leads to patterns the same as in the case of bombardment of the (100) face of Mo.

Fig. 4. Dependence of the intensity of the double-collision peak [010] on the angle φ, in arbitrary units, for Rb^+ on Mo (110). 1—$E_0 = 300$, 2—$E_0 = 600$, 3—$E_0 = 1000$ eV, $\Phi = \theta = 70^\circ$.

Figure 3 gives the dependences of $\eta_{[000]}$, $\eta_{[010]}$, and η_m on the azimuthal angle of rotation of the target φ. Here $\eta_{[000]}$, $\eta_{[010]}$ are the ratios of the energies of secondary ions that have undergone single and double collisions to the ener-

of the primary ions E_0, and η_m is the ratio of the maximum energy E_m of the secondary ions to E_0.

It is evident that the dependence of η_m on φ exhibits anisotropy. The value of η_m is maximal at those angles φ for which the principal scattering chains are the most densely packed atomic rows [100], [110], and minimal for the chains [120], [130]. Figure 3 also shows a certain anisotropy for $\eta_{[010]}$. The observed anisotropy of η_m, as mentioned above, is explained by multiple collisions. The probability of collision of an ion with a large number of atoms in a chain is greater if it is scattered along a closely packed chain and, accordingly, it will have a larger energy E_m.

Figure 4 shows the dependence of the intensity of the double peak [010] on the azimuthal angle of rotation of the target φ, in arbitrary units. Here the measurements refer to an oscillogram of the energy distribution of secondary ions, obtained during bombardment of the (110) face of Mo ($T = 1600^\circ$K) by Rb^+ ions with energies of 300, 600, and 1000 eV.

It is evident that the maximum intensity of the double peak is observed in the same directions [100] and [110] as the maximum energy of the secondary ions (see Fig. 3). Minima are found between these directions. It was shown that in the region of small $E_0 < 500$ eV, secondary maxima appear in the directions [120], [130]. The presence of these maxima is explained by an increase in the probability of double scattering of ions as E_0 decreases [11]. This is also supported by the very character of the change in the anisotropy of the intensity of the double peak [010] with E_0 (Fig. 4). It increases as E_0 decreases, which apparently indicates a nonuniform increase in the probability of double scattering of an ion along different crystallographic directions.

Similar results were obtained in bombardment of the (100) and (110) faces of a tungsten single crystal by K^+, Rb^+, and Cs^+ ions.

The results of the present work confirm the previously drawn theoretical conclusions concerning the features of the angular and energy distribution of ions scattered by a single crystal. In addition, they confirm the applicability of the one-dimensional-chain model considered in (11, 13) for explaining the influence of crystal structure on the character of the angular and energy distribution of ions scattered by a single crystal. At the same time, the results of the study indicate the practical possibility of using the scattering (reflection) of ions to study the structure of a solid.

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Received
15 VII 1969

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