ENERGY SPECTRUM OF THE ELECTRON EMISSION OF A KCl SINGLE CRYSTAL BOMBARDED WITH HELIUM IONS

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Abstract

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ENERGY SPECTRUM OF THE ELECTRON EMISSION OF A KCl SINGLE CRYSTAL BOMBARDED WITH HELIUM IONS

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It is known that, when refractory metals are bombarded by inert-gas ions with energy $E_0 \leq 400$ eV, only potential ejection of electrons occurs, and the coefficient of ion-electron emission γ is almost independent of E_0 (see [1]), and also the review [2]). A different situation is observed when dielectrics are bombarded by these ions. The study of ion-electron emission from single crystals of alkali-halide compounds showed [3, 4] that, when they are bombarded by He^+ ions, electron emission depends substantially on the kinetic energy of the ions even at $E_0 \leq 100$ eV. Extrapolating the dependence of the coefficient γ on ion energy to the value $E_0 = 0$, one can estimate the quantity $\gamma|_{E_0 \to 0}$ and assume that, as in the case of metals, it is due to potential ejection of electrons ($\gamma|_{E_0 \to 0} \simeq \gamma_n$). Direct proof of the existence of potential ejection of electrons from dielectrics can be obtained from a study of the energy spectrum of secondary electrons.

If one assumes that, qualitatively, the mechanism of potential ejection of electrons from dielectrics is the same as from semiconductors and metals (Auger neutralization), then one should expect [5, 6] that the maximum energy of the emitted electrons $E_{\max}$ will be close to $eV_i - 2W$, where eV_i is the ion neutralization energy, and W is the minimum energy required to remove an electron from a solid. For dielectrics and semiconductors, W is determined by the sum of the forbidden-gap width and the electron affinity of the substance under study. For some alkali-halide compounds, W is $6 \div 8$ eV, while the width of the valence band does not exceed $2 \div 3$ eV. Therefore, when they are bombarded by He^+ ions, the maximum energies of electrons released at the expense of the ion neutralization energy would seem to have to reach ten electronvolts, and a comparatively large number of fast particles should be observed. At the same time, the most probable energy of electrons excited by transfer to them of the kinetic energy of the ions should be smaller.

In the present work, the energy distribution was studied for electrons emitted from a KCl single crystal by He^+ ions directed normal to the (100) face. The experimental apparatus is described in [4]). To obtain the distribution curves,

Fig. 1. Retarding curves of the emission current from a KCl crystal bombarded by He+ ions with energies: 1—20 eV; 2—40; 3—100; 4—200; 5—400 eV.

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the retarding-field method was used. A quasi-spherical capacitor with an antidynatron grid was employed. The retarding field was determined by the potential difference between the target and the grid. The Earth' s magnetic field at the location of the capacitor was compensated. An ion beam with a current intensity of 10^{-10} A was used; measurements were carried out at a target temperature of $\sim 400^{\circ}$, which precluded any appreciable charging of it. Before the measurements, the cleaved crystal was heated at this temperature in vacuum for 8 h. Control measurements performed with an ion beam modulated in intensity made it possible to estimate, from the difference in flight times of electrons and sputtered negative ions, the contribution of the latter to the total emission; under the conditions of these experiments it proved negligibly small. Indirectly, the small ···

values of the sputtering coefficient in the form of ions are also indicated by measurements of positive ion emission.

Figure 1 shows the dependence of the ratio of the collector current to the primary ion current on the potential difference between the target substrate and the analyzer grid V_{m}. It is seen that saturation of the electron current to the collector occurs at $V_{\text{m}} \simeq -2$ V. The zero value of the retarding potential corresponds to the target potential at which the current to the collector is the algebraic sum of the saturation currents of electrons and positive ions. Since the emission coefficient of the latter did not exceed 0.05, the zero electron energy corresponds to $V_{\text{m}} = -(2 \pm 0.25)$ V. In Fig. 1, the arrows show on the left the position of the zero retarding potential, and on the right the "saturation" points of the positive-ion current (complete blocking of the electron current) to the collector.

Fig. 1. Retarding curves of the emission current from a KCl crystal bombarded by He^{+} ions with energies:
1—20 eV; 2—40; 3—100; 4—200; 5—400 eV.

The latter were estimated as the values of V_{m} at which the collector current differed from the current at $V_{\text{m}} = +12$ V by no more than 0.005.

The electron energy distributions obtained by differentiating the retarding curves are shown in Fig. 2. It is seen that an increase in the ion energy leads to a substantial deformation of the distribution curve. In particular, the number of slow electrons ($E \leq 3$ eV) increases sharply. Similar changes were observed ([1]) during bombardment of metallic targets by He^{+} ions with $E_0 \geq 400$ eV, when kinetic ejection of electrons appears.

Fig. 2. Energy spectra of electrons obtained by differentiating the retarding curves in Fig. 1. The designations are the same.

Figure 2: Fig. 2. Energy spectra of electrons obtained by differentiating the retarding curves in Fig. 1. The designations are the same.

At the same time, the number of fast electrons ($E \geq 4$ eV) depends relatively weakly on E_0, and this portion of the distribution curve undergoes no substantial changes. It may be thought that the appearance of these electrons is due to potential ejection. If so, then the value of W could be estimated from the maximum electron energy.

Fig. 2. Energy spectra of electrons obtained by differentiating the retarding curves in Fig. 1. The designations are the same.

As Fig. 2 shows, the distribution curves asymptotically approach the abscissa axis, and an exact determination of $E_{\max}$ is difficult. Their value can be estimated conditionally in two ways: either by using the "saturation" points of the retarding curves shown in Fig. 1 (we shall denote the maximum values obtained in this way as

electron energy $E'_{\max}$), or by approximating portions of the distribution curves in the region $E = 4 \div 6$ eV by straight lines and extending them to their intersection with the abscissa axis ($E''_{\max}$). From the distribution curves for the minimum kinetic energy of the ions, $E_0 = 20$ eV, one can obtain the values $E'_{\max} = 9 \pm 1$ eV and $E''_{\max} = 7.5 \pm 1$ eV. If it is assumed that the energy levels of the helium atom do not shift as it approaches the surface, so that $eV_i = 24.5$ eV, then the values $W = (7.8 \pm 0.5)$ eV and $W = (8.5 \pm 0.5)$ eV are obtained using $E'_{\max}$ and $E''_{\max}$, respectively. Because of a possible decrease in the ionization potential of the helium atom near the crystal surface, the obtained values of W may be somewhat overestimated. These values are in full agreement with the literature data on the magnitude of W for a KCl crystal: 8.2 eV according to ([7]) and 7.5 eV according to ([8]).

It is seen from Fig. 2 that an increase in the kinetic energy of the ions leads to a certain broadening of the electron distribution and to an increase in the values of $E_{\max}$. This qualitatively resembles the broadening of the energy distribution under potential ejection of electrons, observed for metallic and semiconductor targets when E_0 is increased ([1],[9]).

Thus, the obtained energy spectra of secondary electrons convincingly indicate the existence of potential ejection of electrons from a KCl crystal. At the same time, the kinetic energy of the bombarding ions affects the shape of the distribution curve even at $E_0 \sim 40$ eV. Measurements at smaller E_0 should provide information on potential ejection that is independent of the velocity with which the particle approaches the surface. They will probably make it possible to judge the energy structure of the valence band of crystals, similarly to how this was done in ([5]) for germanium and silicon. However, in our opinion, the

study of electron energy-distribution curves under bombardment of alkali-halide crystals by slow ions of inert gases also opens up new possibilities for investigating electronic processes during ion neutralization at surfaces. The point is that the expected electron energy spectrum is very specific: a group of comparatively fast particles should be observed, with energies from $E_{\max} \simeq eV_i - 2W$ to $E_{\min} \simeq eV_i - 2(W + \Delta)$, where Δ is the width of the valence band. There is no doubt that analysis of the shape of the experimental electron energy distribution will make it possible to judge more clearly the nature of the shift of the energy levels of the bombarding particle near the surface, the energy losses by excited electrons, and, possibly, the depth of electron excitation in crystals during neutralization of Ože ions.

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