THE ENERGY SPECTRA OF SECONDARY ELECTRON EMISSION INDUCED BY FAST IONS

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It is shown that the distribution function of secondary electrons of ion-induced emission from the front and back surfaces of thin Ag, Cu, Ni foils can be approximated by the power-law function with different power indices in the corresponding energy ranges. The increases of ion energy losses caused the power index to decrease in the first energy interval, while in the second energy interval the power index showed the trend to lessening.

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INTRODUCTION

At present, the development and wide use of powerful sources of particles and energy attract considerable interest to the non-equilibrium states of various physical systems. Steady-state non-equilibrium distributions can be found by exact solving kinetic equations. It is peculiar to physical systems for which the interaction of waves or particles can be described by the kinetic equations for waves, quasi-particles, and particles. The universal steady-state non-equilibrium power-law distributions in the form:

$$N(E) = A \cdot E^{-s},$$

where s is the power index, A is constant are the exact solutions of the Boltzmann collision integral. In order such distributions to exist there must be a source and sink of energy that provide a constant particle flux in momentum space [1].

These conditions take place when the kinetic secondary electron emission induced by ions occurs. Ionisation of atoms arises as ion pass through the substance. The power-law distribution function of secondary electrons can be formed in this nonequilibrium case [1]. Some part of these electrons passed through surface of a solid into vacuum (i.e. emission takes place

The secondary electrons are the storage medium of the information about internal processes. The distribution function of secondary emission electrons was shown previously to have power-law dependence [2-5]. The ion emission problems have been studied inadequately by now, and, therefore, some effects not sufficiently clear. This assertion is particularly true for both experimental and theoretical aspects of the kinetic ion-electron emission.

The emission energy spectra have been investigated carried out very actively during last time. These spectra are a more informative characteristic than the electron yield γ. It was shown in several experimental studies that the secondary emission electrons were distributed by the power low [2-5]. The authors of ref. [5] have shown that the energy

distributions may be approximated by the power low $N(E) \sim E^{-s}$, where **E** is the energy of the secondary electrons, s is the power index. The energy E was measured starting from the vacuum level. The power index s was 1.5 - 3 for different ion-target pairs and different projectile energies. In this work, the energy distribution **N(E)** normalized on the electron yield, that is $\int N(E)dE = \gamma$. These authors have indicated that the power index s depends on the ion energy in such a way the relative part of fast secondary electrons increases with the growth of ion energy [5]. Earlier, by using proton beams, we have demonstrated that the distribution function of secondary electrons is approximated by the power-law with different power indices in the corresponding energy ranges [3]. Furthermore, it was shown there that the function dependences of secondary electron distributions were the same for different angles of emission current measurements. It is necessary to stress that in this case the distribution is the function of the total energy, namely, $E = E_F + e\varphi + eU$, where E_F is the Fermi energy, $e\varphi$ is the work function of the target material, U is the retarding voltage. Therefore studies of influence of various factors upon the power index in different energy ranges are needed.

1. EXPERIMENT

The investigations of electron spectra from the ion-electron emission were carried out on the experimental setup (see Fig. 1). The target 3 of materials under study was situated in a vacuum interaction chamber 1. The ion beam passed through the target. A 5 MeV electrostatic ion accelerator was the beam source. Collimators 2 limited the geometrical dimension of the He+ ion beam of energies from 1 to 3 MeV. The diameter of the beam on the target was equal to 1 mm. The ion current density was up to 1.0 μA/cm^2. A Faraday cup 4 detected the current of ions, which passed through the target.

The targets were made from Ag, Cu, Ni, which were the polycrystalline thin foils of high purity (99.9%). Their thickness was 2.0 μm, 2.07 μm, and 1.1 μm for Ag, Cu, and Ni respectively. All experiments were carried out with normal incidence of beam on the target. The residual gas pressure was equal to 10^{-4} Pa.

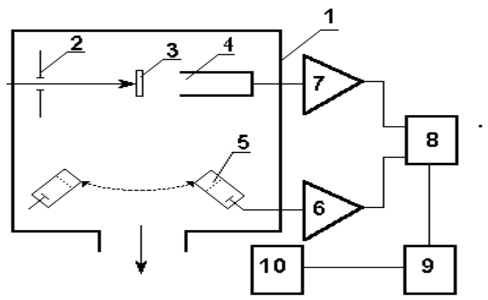

Fig. 1. The experimental setup

The measurements of energy distributions were carried by means of a three–grid electrostatic analyzer 5 with a little aperture ($4\cdot10^{-4}$ ster.). The retarding field method was used in the experiments. The retarding gap was situated between the first and second grids. The first grid was connected to earth. The retarding voltage with 50 V amplitude was applied to the second grid and varied linearly with time. All analyzer grids and the collector were placed into an earthed cylinder copper shield. In this case, the electric field in the analyzer differed by more then 1% from the spherical one. The analyzer was placed at an angle of 45° (.135°) with respect to the beam direction. The energy spectra were studied from both sides of the target, i.e. for forward and backward emissions.

The electrons, which have passed through the retarding potential of the second grid hit the analyser collector. The electrometric amplifier 7 enhanced the electron current. The output voltage of amplifier 7 was applied to the first input of the analogue divider 8. The voltage, which was proportional to the beam current, was applied to the second input of the divider. The ion beam current preamplifier 6 fed this voltage. The use of the analogue divider 8 permitted one to reduce the spurious noise and the oscillations of the beam instability. The error of energy spectra measurements was not more than 1%. The pulse analyser 9 accumulated the information obtained. The analyser data went to the computer 10.

In our case, the dependence of electron current $\boldsymbol{I_e}$ on the retarding voltage $\boldsymbol{U}$ was given by

$$I_e = \int N(E) E\, dE \qquad (1)$$

where $E = E_F + e\varphi + eU$.

The secondary electron emission coefficient γ was proportional to the output voltage of the analog divider, therefore $\gamma = I_e/I_i = A\cdot U_{out}$, where Ii is the ion current and A is constant. The derivative of U_{out} with respect to U corresponded to the distribution function $N(E)$ ***in*** view of (1), because the ion current did not depend on the retarding voltage. In the case of power-law dependence of the distribution function on the electron energy, the obtained relation can be written as

$$U_{out}/dU = B \times E^{s+1}, \qquad (2)$$

where B is constant. The dependence (2) is shown as a straight line in log-log scale.

2. EXPERIMENTAL RESULTS AND DISCUSSIONS

The dependences of the analyzer collector current on the retarding voltage were measured in our experiments. The distribution functions obtained for all He^+ ion energies used and for both sides of all targets showed the power-law dependence on the electron energy.

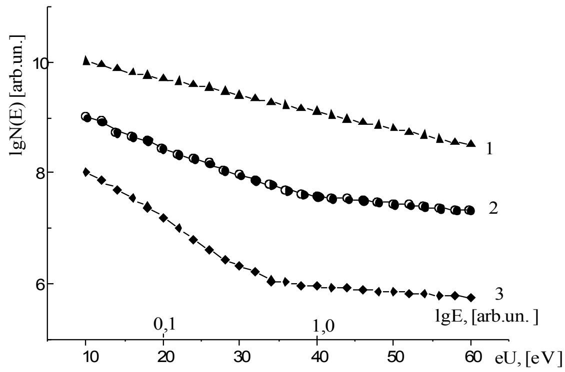

Fig. 2. The energy distributions of secondary emission electron from exit surface of silver target by He^+-ions bombardment. The used energy were 1, 2 3 MeV (curve 1, curve 2, , curve3, correspondingly)

The energy distribution of forward secondary emission electrons is shown in Fig. 2 in log-log scale for the silver target. It can be seen from Fig 2, that the energy distribution for 1 MeV ions (curve 1) is well approximated by the power - law dependence with one power index for the entire energy interval. The electron distributions show bends at He^+ energies of 2 MeV (curve 2) and 3 MeV (curve 3), i.e., the distribution functions are approximated with different power indices for various energy intervals.

In the bend region the power index changes substantially. This region is small and is estimated to be within 2 eV. The power index was equal to 3.5 - 4.0 for 0–35 eV and 1.5-2.0 for 35–50 eV. The analysis of experimental data has shown that the existence and position of bends depend on the ion energy E_1, more precisely, on specific energy losses. The 1 MeV ion that has passed through Ag or Ni target had energy approximately equal to 10.0 KeV. There is no bend of the distribution function at this energy.

The power index in the first interval s_1 depends on the specific energy losses by projectiles in a substance. The dependence of s_1 on the stopping power $S(E_1)$ is shown in Fig. 3 for all forward (Fig. 3a) and backward (Fig. 3b) emission experiments. As is seen from on these figures, the power indexes decrease with an increasing stopping power.

This rigorous dependence was not found for the power index in the second energy interval s_2 . However, it is necessary to note that there is a tendency of s_2 to decreases with an increase in the ion energy (decrease in stopping power). Therefore, the bend on the distribution function of secondary emission electrons arises with ion energy increase. The power index s_1 decreases and s_2 increases in this case.

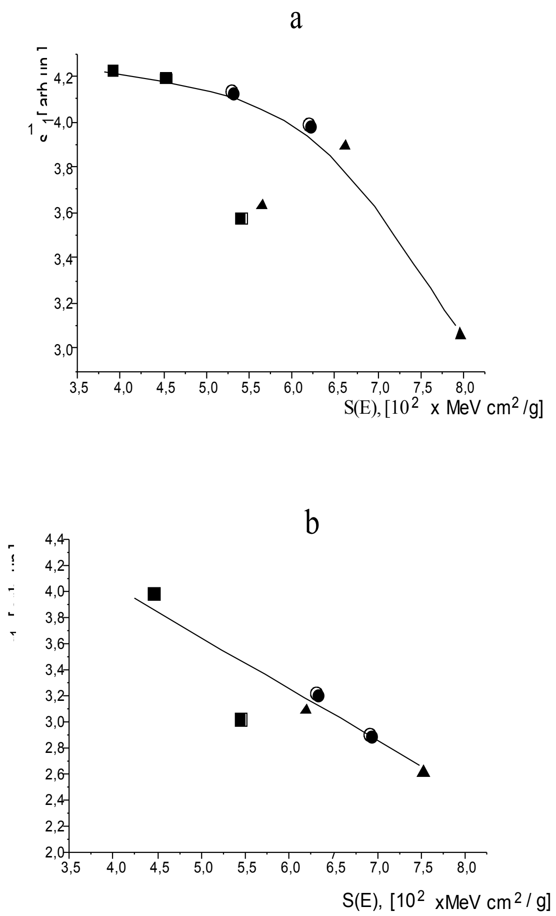

Fig. 3. *The dependences of power indices from the stopping power for backward (a) and forward emission (b). (Squares – Ag, circles – Cu, triangles – Ni)*

Comparison of the secondary electron distribution for the forward and backward emissions permitted us to determine the following characteristic property. The power index for the backward emission was greater that for the forward emission at equal effective ion energies (including energy losses of ions in target substance [6]). This characteristic property was observed in all our experiments.

We know only one paper, where the energy spectra were measured for the forward and backward emission using somewhat inadequate method [2]. The authors of that work noted that the electron distribution function of backward emission decreases quicker with electron energy than in the forward case. The experiments were carried out with a thin carbon foil at a projectile energy 0.25 MeV.

The present results have permitted us to conclude that the power index in the first energy interval increases with increasing energy losses by fast ions. The differences between the forward and backward cases correspond to this statement, too. The energy flux in the forward direction is higher than the one in backward direction for ions moving in a substance. This can be explained by the fact that delta - electrons and convoy electrons transport an essential part of energy only in the forward direction.

3. CONCLUSION

The experimental investigations of He^+ ion-induced emission from front and back surfaces of the thin Ag, Cu, Ni foils were carried out It is shown that the distribution function of secondary electrons can be approximated by the power-low function with different power indices in the corresponding energy intervals. The increases of ion energy losses caused the power index to decrease in the first energy interval, while in the second energy interval the power index showed the trend to lessening.

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