THE EFFECTS PRODUCED BY MOLECULAR IONS ON A SOLID SURFACE

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This work deals with the experimental study of secondary electron emission induced by discusses 1 MeV/a.m.u. hydrogen ions in forward direction from thin argentums, copper and nickel foils. The possible reasons of less effective generation of law energy electrons by molecular ions were discussed. We concluded that realization of collision mechanism of secondary electron production (slow electrons) is complicated by correlative motion of the constituent ions of molecule in the substance. The experiments show, that when fast charged particle passes through substance the production mechanism of ionization electrons through plasma oscillations, apparently, is proved to be more effective for molecular ions, than for atomic ones.

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1. INTRODUCTION

At present, the development and wide use of powerful sources of particles and energy attract considerable interest to the nonequilibrium states of various physical systems. Steady-state nonequilibrium 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 nonequilibrium 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].

Ionization of atoms arises as ion pass through the substance. Some part of these “new-free” electrons can penetrate through the surface of solid into vacuum, i.e. the secondary electron emission takes place. The studies of this phenomenon that induced by fast ions from thin foils are of great interest now [2,3].

These conditions take place when the kinetic secondary electron emission induced by ions occurs. Ionization 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 power-law distribution function of secondary electrons can be formed in this nonequilibrium case [3]. The secondary electrons are the storage medium of the information about internal processes. The distribution function of secondary emission electrons had been shown previously to have power-law dependence [4]. 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 law [2-5]. The authors of ref. [5] have shown that the energy distributions may be approximated by the power law $N(E) \sim E^{-s}$, 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 $\int \mathbf{N(E)dE} = \gamma$. 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, $\boldsymbol{E} = \boldsymbol{E_F} + \boldsymbol{e\varphi} + \boldsymbol{eU}$, where $\boldsymbol{E_F}$ is the Fermy energy, $\boldsymbol{e\varphi}$ 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.

The powerful method for analysis of wake potential oscillations in matter at fast ion passing is study of kinetic emission of secondary electrons emitted from metal surfaces at bombardment by molecular ions. Such experiments were carried out by a number of authors [6-8]. In paper [6] the energy spectra of secondary electrons, knocked out from the massive copper target by ions H_1^+, H_2^+, H_3^+ with energies 200 keV/a.m.u. were studied. From the results, reduced in this paper, it is visible, that the secondary electron spectra in a measured energy interval (≤35 eV) have power-law character, both for atomic, and for molecular ions. The measured total electron yields γ for bombarding ions H_1^+, H_2^+, H_3^+ relate as *1: 2: 3*. This ratio is upset for a differential electron yields $\gamma(E)$, where *E* is secondary electron energy. As mentioned in paper [7] a coefficient $R_\gamma(E)$, defined as:

$$\mathbf{R}_\gamma(\mathbf{E}) = \gamma_{\mathrm{H}_2}(\mathbf{E}) / 2\gamma_{\mathrm{H}_1}(\mathbf{E}) \quad , \qquad (1)$$

is vary depending on secondary electron energy changing from 0 up to 200 eV. The coefficient $R_\gamma(E)$ curve for gold target has two maxima for primary ion energies from 75 KeV/a.m.u. up to 300 KeV/a.m.u. The coefficient $R_\gamma(E)$ is less than *1* for small secondary electron energies. It is necessary to note, that the curve intersection with a straight line $R_\gamma = 1$ and the first maximum are shifted with increasing of primary ion energies in the direction of small energy, and the second maximum in the direction of large energy. The authors point out, that the velocity of electrons at curve maximum is equal to the bombarding ion velocity [7].

A diatomic molecule ion is dissociating in two fragments when it passing through substance. Both of that fragments excite plasma oscillations (plasmons). The authors of [8] studied the kinetic electron emission induced by CO^+, C^+, O^+ ions. The effect of plasma oscillation interference from fragments of molecular ion on electron yield was found.

The diatomic molecule moving through substance loss electrons, i.e. ionization process happens. The Coulomb repulsion between two fragments becomes very strong and “Coulomb explosion” occurs [9]. The separation of molecule fragments occurs on distances not more than a Coulomb screening length *r* for ions generated. For example, for metal this value is equal to 10^{-8} cm. The track diameter is determined by the length of collision cascade and comes to 10^{-6} cm, i.e., in this case, both fragments of a molecular ion move in one track.

2. EXPERIMENT

The investigations of electron spectra from the ion-electron emission were carried out on the experimental setup (see Fig. 1) [10]. 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 H_1^+ or H_2^+ 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.

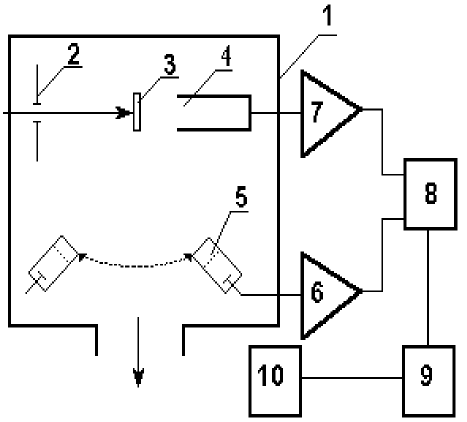

Fig. 1. The experimental setup

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, 2.07μm, and 1.1μm for Ag, Cu, and Ni respectively. All experiments were carried out with normal incidence of beam to the target. The residual gas pressure was equal to 10^{-4} Pa. 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 50V 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° 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 analyzer 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.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The energy spectra of secondary electrons, induced from Ag target by H_1^+ ions with energy 1 MeV and H_2^+ ions with energy 2 MeB are shown at Fig. 2.

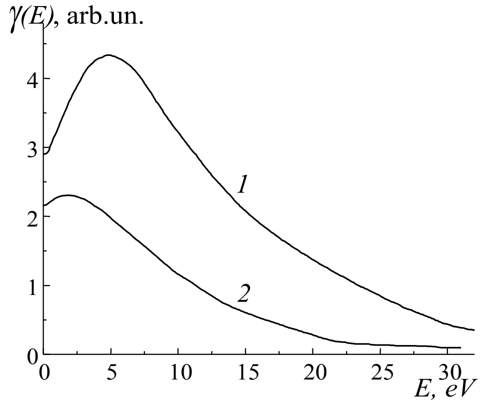

Fig.2. The energy spectra of secondary electrons, induced from Ag target by H_1^+ ions with energy 1 MeV (curve 2) and H_2^+ ions with energy 2 MэB (curve 1)

The distribution function of non-equilibrium electrons have power-law character with power indices nearly to presented early [3]. These results were obtained for all used targets. For definition of differences in power spectra of secondary electrons, which induced molecular and atomic ions, we calculated a differential coefficient *R*

$_{\gamma}(E)$. This coefficient was determined above. The coefficient $R_{\gamma}(E)$ dependences on energy of secondary electrons presented at the Fig. 3 for all three targets used in experiments. As seen from Fig.3, the curves for different targets are similar and differ by amplitudes. The $R_{\gamma}(E)$ maximum for all three targets does not coincide. The energy of secondary electrons which corresponding to a $R_{\gamma}(E)$ maximum decreases with growth specific energy losses dE/dx of ions. The similar curves for a massive gold target presented earlier [7]. In these experiments projectile energies were less than ones in our study.

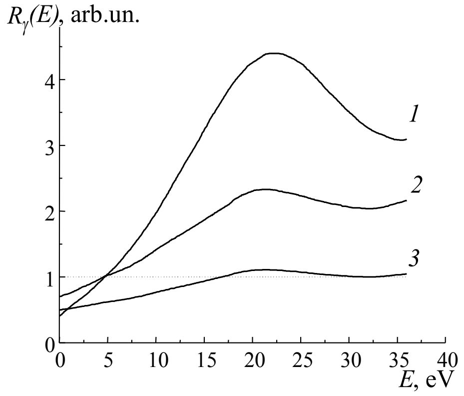

Fig.3. The coefficient $R_{\gamma}(E)$ dependence on energy of secondary electrons for all three targets used in experiments (1- Cu, 2- Ni, 3- Ag)

It is necessary to notice, that there are two features at the experimental curves. This is maximum existence and presence of $R_{\gamma}(E) < 1$ region for energies of secondary electrons less than 10 eV. The existence of a maximum, apparently, can be explained from following reasons. The energy losses of a diatomic molecule are higher, than ones for two atomic ions at passing through matter [10]. The losses related with excitation of wake oscillations of a charge density increase most essentially. Plasma oscillation energy has fixed value for the each matter [11]. The electrons formed through plasma oscillation interaction have the same energy. Therefore, the part of energy electron spectra, where electron energy is less than plasmon one, corresponds these processes. Consequently, we think that the maximum on $R_{\gamma}(E)$ curves have a plasma nature.

Existence of an energy interval in secondary electron spectra, where $R_{\gamma}(E) < 1$ means, that one molecular ion (the diatomic molecule) acts less effectively, than its components individually. We think, that it can be explained from following reasons. The slow electrons from the region $R_{\gamma}(E) < 1$ arise from not only plasmon mechanism, but also direct collisions projectiles with target atoms. In the case of collision mechanism, the first fragment of the diatomic molecule screens from collisions the second one (see above). The back ion is in a shadow of the forward one, that results in decreasing of yield of slow electrons (region $R_{\gamma}(E) < 1$) for H_2^+ ions in comparison with two H^+ ions. Besides, when hydrogen molecule moves through substance the back ion is in the wake track of the forward one. In this case, the addition screening of the back ion by substance electrons can take place. As the law- electrons arise from distant collisions, in this case its number can appear essentially less, than for two independent protons. Therefore, the existence of $R_{\gamma}(E) < 1$ region can be explained as well by the addition screening of the back ion in a diatomic molecule by substance electrons.

CONCLUSION

Arising of slow electrons through collision mechanism is less effective for molecule ions because of correlation motion of fragments. It is followed from both mentioned above reasons.

Our experiments show, when a fast charged particles pass through matter the mechanism of substance atom ionization through plasma oscillations is more effective for molecular ions, than for atomic one.

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ЕФЕКТИ, ЩО СТВОРЮЮТЬСЯ МОЛЕКУЛЯРНИМИ ІОНАМИ НА ПОВЕРХНІ ТВЕРДОГО ТІЛА

С.І.Кононенко, В.І.Муратов

У цій роботі приведені результати експериментального дослідження вторинної електронної емісії, що спричинюється іонами водню з енергіями 1 МеВ/а.о.м.. Емісія вивчалася на прострiл з тонких мішеней зі срібла, міді і нікеля. Обговорюються можливі причини менш ефективної генерації низько енергетичних електронів молекулярними іонами. Ми вважаємо, що механізм створення повільних електронів через зіткнення має певні труднощі, щодо реалізації при корелірованому розльоті фрагментів молекулярного іона в речовині. Проведені експерименти показали, що передача енергії від швидкої зарядженої частинки електронам середовища через плазмові коливання найбільш ефективно для молекулярних іонів, ніж для атомних.

ЭФФЕКТЫ, ПРОИЗВОДИМЫЕ МОЛЕКУЛЯРНЫМИ ИОНАМИ НА ПОВЕРХНОСТИ ТВЕРДОГО ТЕЛА

С.И.Кононенко, В.И.Муратов

В этой работ приведено результаты экспериментального исследования вторичной электронной эмиссии, вызываемой ионами водорода с энергиями 1 МэВ/а.е.м.. Эмиссия изучалась на прострел с тонких мишеней из серебра, меди и никеля. Обсуждаются возможные причины менее эффективной генерации низкоэнергетических электронов молекулярными ионами. Мы считаем, что столкновительный механизм создания медленных вторичных электронов затруднен при коррелированном разлете фрагментов молекулярного иона в веществе. Проведенные эксперименты показали, что передача энергии от быстрой заряженной частицы электронам среды посредством плазменных колебаний более эффективно для молекулярных ионов, чем для атомных.