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MEAN ENERGY OF ELECTRONS EMITTED FROM SOLIDS UNDER SWIFT LIGHT ION BOMBARDMENT

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In this paper energy distributions of secondary electron emission induced by 1-2.5 MeV H^+ and He^+ ions from GaAs, CdTe, Ge and Ti samples were analyzed. Dependences of mean electron energy on electronic stopping power of ions in the substances were obtained. The semiconductors had small dependence of mean electron energy in the range of ion energy being investigated. Mean electron energy decreased with growth of electronic stopping power of ion for titanium sample. We concluded that the semiconductors would be more preferable materials in comparison with titanium to use as emitting layers in the secondary emission radioisotope current source.
KEY WORDS: secondary electron emission, energy distribution function of electrons, mean electron energy, electronic stopping power of ions

At current state of science and technology development there are great demands for autonomous sources of energy. They must meet the requirements of energy capacity, reliability, safety and cost. Secondary emission radioisotope current source (SERICS) is nonthermal converter of α-particle energy to electricity [1]. The unique emission characteristics of metals and semiconductors during ion bombardment are the base of SERICS operation. Formation of power-law energy distribution function is the reason of anomalous secondary electron emission under action of α-particle flows [2-4].

SERICS is converted energy of α-particles from alpha decay into secondary emission current. This source consists of isotope (α-source) and multilayer emitter, which are contained in vacuum chamber. Emitter is a set of alternating thin layers made from two different materials. These materials have a various coefficients of ion induced secondary electron emission.

The elementary cell of SERICS emitter is the pair of thin layers from two different materials. The energy conversion coefficient of one cell is defined as $\eta = (\gamma_1 + \sigma_1 - \gamma_2 - \sigma_2)\cdot E_{mean}/E_\alpha$, where γ_1 and γ_2 are coefficients of secondary ion-electron emission (SIEE), σ_1 and σ_2 are coefficients of secondary electron-electron emission for both material of the cell, E_{mean} is mean energy of emitted electrons, and E_α is energy of α-particles projectiles [1]. The mean energy of emitted electrons is one of important characteristics, which defines SERICS energy conversion efficiency.

It is well known, that moving charged particle loses energy in a substance due to some processes. Ionization of substance atoms is a main channel of stopping power for ions when projectile velocity is more than the one for each atom electrons of the material [5]. This process takes place in elementary cell of the source under passage of fast α-particles. As we mentioned above SERICS construction includes set of consecutive elementary cells. Therefore, primary energy of incident α-particles is different for each consecutive emitter layer. As a result the mean electron energy for SIEE distribution can be various for each emitting layer. This dependence is very important for simulation of secondary-emission processes, which take place in set of elementary cells under α-particle irradiation.

D. Hasselcamp et. al. had studied energy distributions of backward SIEE from metal samples in 0÷200 eV electron energy range for different energy of bombarding light ions [6]. They concluded that the relative part of secondary electrons with energy above 50 eV increased with growth of ion energy. It was shown that, in the SIEE spectra for gold target mean electron energy increased with growing ion energy from 75 keV to 900 keV [6].

Semiconductors are considered to be perspective materials from standpoint of its use in SERICS emitter construction [7]. Information about SIEE electron energy distribution for these materials is practically absent. The question of mean electron energy dependencies on electronic stopping power of ions (ion energy) is still opened too. The purpose of our work is to found mean energy of electrons emitted from some semiconductors and titanium during fast light ions bombardment and to determine its dependency on materials, ion species and energy etc.

ENERGY DISTRIBUTION FUNCTIONS OF ELECTRONS

The measurements of the energy distributions of secondary electrons induced by fast light ions were carried out on experimental setup described in detail in [4]. The experiments were performed with Van de Graaf accelerator for H^+ and He^+ ions of 1.00 – 2.25 MeV energy with 0.25 MeV step. The ion beams were collimated by means of diaphragm system so as the diameter of ion spot on target was 3 mm. Backward secondary electron emission induced by ions was studied. Target surface was perpendicular to the beam axis. Ion beam current density was less than 30 μA/cm^2. Residual gas pressure was not more than 10^{-6} Torr.

Secondary electron energy distributions were measured in 0 - 100 eV range by means of electrostatic spherical analyzer with retarding field. Diameter of the targets was 10 mm and thickness was greater then ion path length in the substance. Energy distribution functions for GaAs, CdTe, Ge and Ti targets were measured.

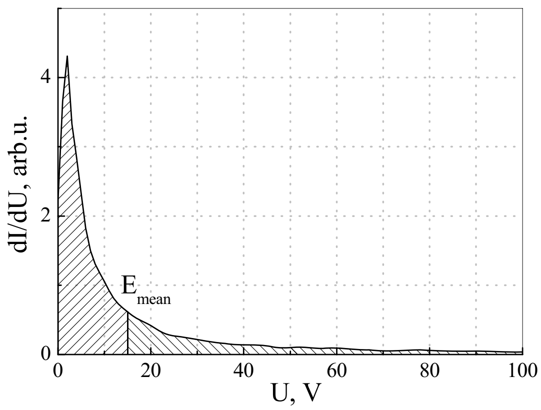

Fig. 1. Energy spectra of electrons for GaAs and 1.26 MeV He^+ ions.

The experimental investigation of SIEE energy spectra have shown, that distribution functions of electrons in 5 - 100 eV energy range have nonequilibrium dependence for H^+ and He^+ ions with mentioned above energy. They can be approximated by piecewise-power law $f(E) = A \cdot E^{-s}$, where A is a constant, s is power index, $E = E_F + \varphi + eU$ is total energy of electrons in the solid, φ is work function, E_F is Fermi energy, U is retarding potential [4]. Fig. 1 shows typical electron energy spectrum for GaAs induced by 1.26 MeV He^+ ions. Presence of maximum in SIEE spectra at low energy is usually explained by overcoming of the surface potential barrier by electrons [7].

In double logarithmic scale distribution function of electrons represents linear dependency, i.e. straight line that slope ratio is equal to s+1 (Fig. 2). For semiconductors distribution has one power-law area in the whole electron energy interval of 5÷100 eV in vacuum [4]. At that power index of the distribution function depends weakly on projectile energy.

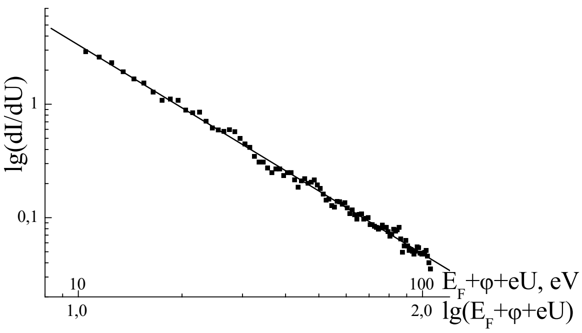

Fig. 2. Distribution function of electrons for GaAs and 1.26 MeV He^+ ions in double logarithmic scale.

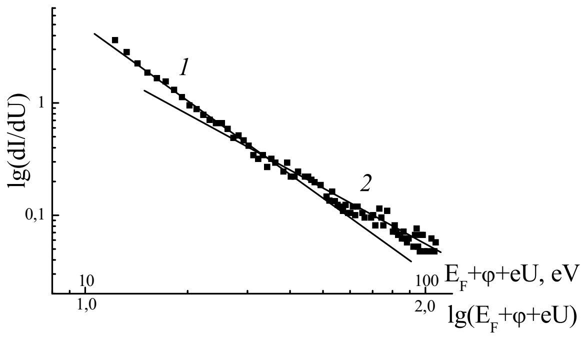

Fig. 3. Distribution function of electrons for Ti and 1.26 MeV He^+ ions in double logarithmic scale.

For titanium distribution functions have piecewise power-law character, namely there are two areas with different power indexes on energy intervals of 5÷30 eV and 30÷100 eV (Fig. 3). It was found that in the case of He^+ ions power index depended on projectile energy on the first energy interval of 5÷30 eV, namely, power index value decreased (increased) with growth of projectile energy (electronic stopping power of ion).

MEAN ENERGY OF SECONDARY ELECTRONS

We have analyzed the experimental distribution data for some semiconductors [4] and titanium on purpose to reveal character of mean electron energy dependence on ion energy or electronic stopping power.

It is well known, that in the case of point source of emission for spherical energy analyzer current is defined by expression $I = B_1 \int_{\varphi+E_F+eU}^{E_{max}} E^* \cdot f(E^*)dE$, where B_1 is a constant, $f(E^*)$ is distribution function [8]. Then, for power-law distribution function $f(E) = A \cdot E^{-s}$ the derivative of electron emission current with respect to retarding potential can be written in the form [8]:

$$dI/dU = B \cdot E \cdot f(E). \quad (1)$$

Mean energy in the distribution can be determined as:

$$E_{mean} = \frac{\int_0^{100} Ef(E)\sqrt{E}dE}{\int_0^{100} f(E)\sqrt{E}dE}. \qquad (2)$$

Using (1) the expression (2) can be rewritten in the form:

$$E_{mean} = \frac{\int_0^{100} \sqrt{E}\frac{dI}{dU}dU}{\int_0^{100} \frac{dI}{dU}\frac{1}{\sqrt{E}}dU}. \qquad (3)$$

Integral in the expression (3) was taken between the limits 1 and 100 over retarding voltage of energy analyzer.

Hydrogen and helium ions with the same energy have significantly different (up to 10 times) electronic stopping powers in target material. It is reasonable to plot mean energy dependence on electronic stopping power of fast ions in material for comparison of experimental results for ions of both species. Fig. 4 shows mean electron energy dependence on electronic stopping power of H^+ and He^+ ions in GaAs, CdTe and Ge semiconductors. Electronic stopping power of ions were calculated by means of SRIM 2003 program [9]. Analogous dependence for titanium and He^+ ions is presented on Fig. 5.

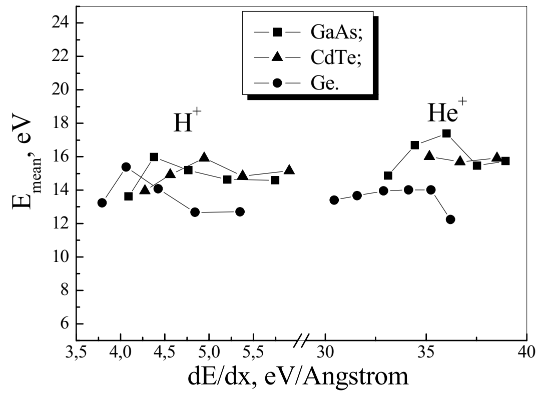

Fig. 4. Mean energy in the low-energy spectra of secondary electron emission induced by fast H^+ and He^+ ions from semiconductors as a function of electronic stopping power.

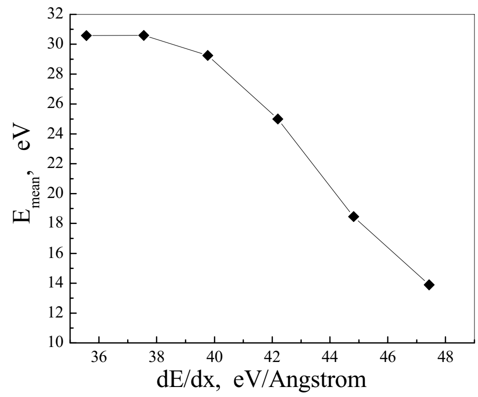

Fig. 5. The dependency of mean energy in electron distribution on electronic stopping power of He^+ ion for titanium.

As it can be seen from Fig. 4, for semiconductors mean energy of emitted electrons weakly depends on electronic stopping power and the values of E_{mean} are close for both species of projectiles. As it can be seen from Fig. 5, for titanium mean energy is decreased with growth of electronic stopping power of ions. The last is in accordance with the result of abovementioned work of Hasselkamp D. et. al. [6].

CONCLUSIONS

Thus, for semiconductors and titanium under study we observed clear differences in electron energy distributions and in mean energy dependences on electronic stopping power of ion.

The semiconductors can be characterized as:

- one power-law area in the energy distribution with power index, which has weak dependence on electronic stopping power of ion;
- small dependence of mean electron energy in the ion energy range being investigated on electronic stopping power.

The following can be concluded for titanium:

- two power-law areas in the energy distribution; power index for the first energy interval of 5-30 eV increased with growth of electronic stopping power of ion;
- decrease of mean electron energy with growth of electronic stopping power.

Reasons for the differences observed can be underlain in presence of two channels of energy dissipation by moving ion in a substance:

1) energy transfer from ion to electron subsystem by means of direct collisions;

2) excitation of long-living collective electron oscillations (plasmons) with subsequent energy transfer to electrons. In the case of semiconductors contribution of the second channel of energy transfer is probably small because energy of plasmons, which propagate on free conduction electrons, is much more lower then ionization potential of substance atoms.

In respect to mean energy of emitted electron, we concluded that semiconductors under study were more preferable materials in comparison with titanium to use as emitting layers in the SERICS. Weak dependence of mean electron energy on electronic stopping power of ion can provide more effective operation of the whole set of elementary cells in the SERICS.

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СРЕДНЯЯ ЭНЕРГИЯ ЭМИТИРОВАННЫХ ИЗ ТВЕРДЫХ ТЕЛ ЭЛЕКТРОНОВ ПРИ ОБЛУЧЕНИИ БЫСТРЫМИ ЛЕГКИМИ ИОНАМИ

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В этой работе проанализированы энергетические распределения вторичной электронной эмиссии, индуцированной ионами H^+ и He^+ с энергиями 1-2,5 МэВ из образцов GaAs, CdTe, Ge и Ti. Были получены зависимости средней энергии электронов от электронных потерь энергии ионами в веществах. Полупроводники имеют слабую зависимость средней энергии электронов в исследуемом интервале энергий ионов. Для титанового образца средняя энергия электронов уменьшалась с ростом потерь энергии ионами. Мы пришли к выводу, что рассмотренные полупроводники являются более предпочтительными материалами по сравнению с титаном с точки зрения их использования в качестве эмитирующих слоев во вторично-эмиссионном радиоизотопном источнике тока.

КЛЮЧЕВЫЕ СЛОВА: вторичная электронная эмиссия, функция распределения электронов по энергиям, средняя энергия электронов, электронные потери энергии ионами.