FORWARD AND BACKWARD ELECTRON EMISSION IN BINARY CELL OF RADIOISOTOPE CURRENT SOURCE

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It was shown that ratio of forward and backward yields for Ti-Ti binary cell of the SERICS was close to other materials. Isotropic emission of alpha particles from the surface of radioisotope source led to dependency of projectile effective charge and convoy electron yield on incidence angle. The influence of convoy electrons on total electron yield can be neglected.

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1. INTRODUCTION

1.1. BACKGROUND

An ion propagating through a matter produces free electrons, some of which, with the proper values and directions of momentum, can escape from the medium. This process is called ion induced electron emission (IIEE). At present, it is proved theoretically and experimentally that the IIEE coefficient in the case of light ions is directly proportional to the mean specific ionization loss dE/dx of an ion in a matter [1, 2]. Consequently, the investigation of SEE makes it possible to derive information about the energy lost by an ion as it moved through a solid-state plasma and about how this energy is distributed between different electron groups. The mean specific ionization loss dE/dx of an ion at each point in a medium can be represented as a sum of the losses associated with energy transfer to the electrons that move in the same direction as the primary ion, $(dE/dx)_F$, and with the energy transfer to the electrons that move in the opposite direction, $(dE/dx)_B$: $dE/dx = (dE/dx)_F+(dE/dx)_B$. In our opinion, it is quite natural that the quantities $(dE/dx)_F$ and$(dE/dx)_B$ are proportional to the coefficients of IIEE in the propagation direction of a fast light ion (in the forward direction),γ_F , and in the opposite (backward) direction, γ_B , respectively. Hence, by investigating the kinetic ion-electron emission from a thin film in the forward and backward directions, it is possible to study the anisotropy of energy transfer from a primary ionizing charged particle.

In the energy spectrum of the secondary emission electrons we can distinguish three electron groups:

1. Slow electrons with energies $E < E_p$, where $E_p = h\omega_p$ is the energy of the plasma oscillations with frequency ω_p. These electrons are produced from the ionization by plasma oscillations and from direct collisions with large impact parameters, accompanied by small momentum transfers.
2. Moderate-energy electrons, which are produced exclusively in direct collisions accompanied by moderate momentum transfers.
3. Fast electrons, which move preferentially in the propagation direction of the ion. These are convoy electrons and δ-electrons, which produced from direct collisions with small impact parameters, accompanied by large momentum transfers. The velocity convoy electrons, coincides in magnitude with the velocity of the ion, $v_e = v_p$, and has the same direction. The velocity of the δ-electrons that corresponds to the maximum possible momentum transfer can be defined as $v_\delta = v_p\cos\theta$, where v_p is the velocity of a bombarding ion and the angle θ is measured from its propagation direction.

1.2. SECONDARY EMISSION RADIOISOTOPE CURRENT SOURCE

New technique for nuclear decay energy conversion to electrical was based on the power law distribution of emission electrons induced by ions. This phenomenon was predicted theoretically early [3]. Some differences between the experimental values and theoretical power law indexes were related with the time evolution of the electron distribution function [4]. Main channel of fast ion energy loss in matter is processes of atom ionization [5]. At that part of substance electrons can leave the surface leading to a secondary ion-induced electron emission [6 - 8]. The integral characteristic of the emission is coefficient γ frequently called in the literature as an electronic yield [6 - 8]. Emission coefficient is defined as a relation of a number of secondary electrons N_e emitted to a number of primary incident ions N_i:

$$\gamma=N_e/N_i. \tag{1}$$

Coefficient γ can vary depending on ion energy, target substance and a number of other parameters [6 - 8].

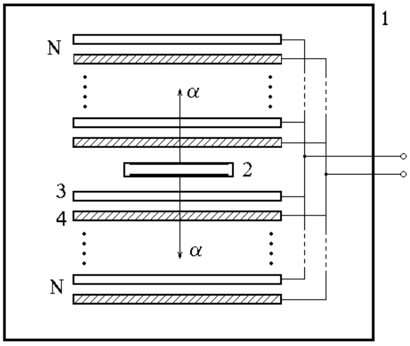

Fig. 1. Schematic diagram of SERICS: 1 – vacuum container; 2 – α-radioisotope; 3 and 4 – emitting thin layers with different emission coefficients

By using α-particles emitted by radioisotope as projectiles and pair of thin emitting layers (insulated from each other) with different coefficients γ it is possible to convert energy of nuclear particles into electricity. This idea underlies secondary emission radioisotope current source (SERICS) [9 - 11].

SERICS schematic diagram is presented on Fig. 1. Radioisotope 2 emitting α-particles towards two halfspheres is situated in vacuum container 1. Two emitters of electrons are located on both sides of the radioisotope. Each emitter is a set of some pairs of thin emitting layers (so-called binary cells) of two different materials 3 and 4. One of the materials should have high emission coefficient, whereas the other should have low one. All of the layers are parallel and insulated with each other. Layers from one material electrically connected in parallel and have own contact. As α-particle passes through emitter, difference of charges between the layers of binary cell arises. By close the circuit with useful load it is possible to use the charge difference as a source of current. Effectiveness of energy conversion is proportional to the number of emitting pairs N and difference of the emission coefficients [6].

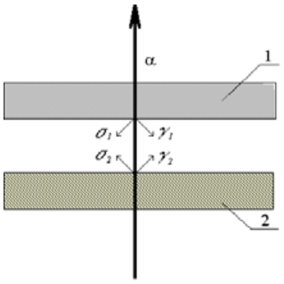

Fig. 2. Binary cell of SERIC: 1 – layer of higher IIEE yield (γ_1); 2 – layer of lower IIEE yield (γ_2); σ_1 and σ_2 SEEE yields respectively

The basis of SERICS is a binary cell which consists of two different materials (Fig. 2). We established that secondary electron-electron emission (SEEE) (tertiary emission) influenced strong at efficiency of SERICS.

Titanium and some other materials have SEEE yield less than one. We carried out forward and backward emission study for Ti-Ti binary cell. The results are presented in this paper.

2. THE EXPERIMENTAL SETUP

The experiments were carried out with the device, which schematic diagram is shown in Fig. 3.

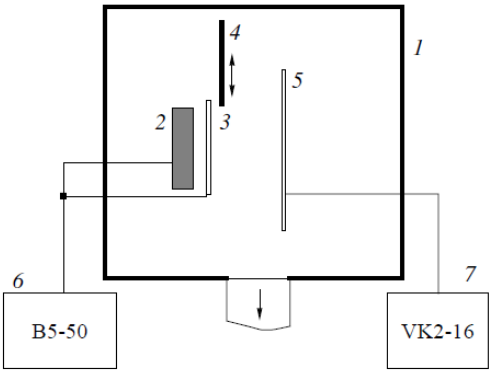

Fig. 3. The experimental device: 1 – vacuum chamber; 2 – Pu239 radioisotope source of α-particles; 3 – target; 4 – movable diaphragm; 5 – collector; 6 – B5-50 dc source; 7 – electrometric voltmeter

The prototype of the binary cell, consisting of radioisotope source of α-particles with Pu-239 isotope 2, the emitter of a titanium foil 3 and the Ti massive collector 5, were placed in a vacuum cylinder chamber 1. The radioisotope source 2 produced α-particle flow with intensity of $4.64 \cdot 10^6$ particles/s and energy of 5.15 MeV. The alpha-particles current I_{c0} was measured of multiple Faraday cylinder collector. The titanium foil thickness of 5.6 μm was chosen to be less than a mean path of α-particle with given energy in this material. The α-particle passed through the emitter 3 and induced the electron emission from the forward emitter surface and from the surface of the massive collector 5. The measurements of a collector current were made by an electrometric voltmeter 7 with input impedance of 10^{16} Ohm. Voltage of different polarities was applied to the emitter-collector gap and was changed from 1 to 300 V. For adjusting the system a moveable damper 4, shutting the flows of α-particles and emitted electrons, was placed between the emitter and the collector. The residual gas pressure in the vacuum chamber was less than 10^{-4} Pa. The chamber was pumped out with a magnetic discharge pump 9 and mechanical rough pump with a nitrogen-cooled trap.

3. THE EXPERIMENTAL RESULTS AND DISCUSSION

The collector current as a function of voltage applied between the titanium foil (as emitter) and titanium plate (as collector) is shown in Fig. 4.

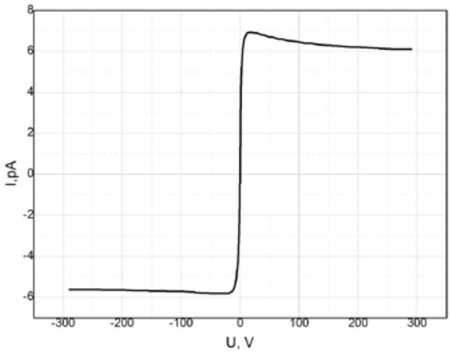

Fig. 4. The experimental current-voltage characteristics for Ti-target and Ti-collector

This coefficient γ for forward and backward cases was calculated by the following formulas:

$$\gamma_F = 2\frac{k_f I_{\alpha 0} + I_c}{k_f I_{\alpha 0}}, \qquad \gamma_B = 2\frac{k_f I_{\alpha 0} - I_c}{k_f I_{\alpha 0}}, \qquad (2)$$

where I_c is the collector current and k_f is the fraction of alpha-particles that have passed through the target. The ratio R of the forward IIEE coefficient γ_F to the backward one γ_B, was measured earlier and was equal to 1.57 for aluminum, 1.69 for copper, and 1.82 for nickel [13]. We found thatR ratio for titanium was equal to 1.62. According to these data, the R ratio for different substances varies insignificantly (lower than 10% of the mean value).

The charge of moving projectile in matter depends on its velocity. In our case, different incidence angles for alpha particles led to various effective charges on the target surface. Analytical formula for effective charge Z_{eff} calculation according to the Bohr model was obtained in [12]:

$$Z_{eff} = Z_1\left[1-\exp\left(-\frac{v_1}{v_0 Z_2^{2/3}}\right)\right], \quad (3)$$

where Z_1 and Z_2 are charges of projectile and target atoms respectively, v_1 is projectile velocity, v_0 is Bohr velocity. The best agreement with experiment is given by the formula obtained in [13]

$$Z_{eff} = Z_1\left[1-\exp\left(-0{,}92\frac{v_1}{v_0 Z_2^{2/3}}\right)\right]. \quad (4)$$

When fast ions penetrate a solid or gaseous medium, they can be accompanied by electrons which move at nearly the same velocity as the ion. These electrons have been called convoy ones [15]. Influence of different interaction parameters on convoy electrons was studied in many investigations (see for example [16, 17]). Authors [17] summarized their experimental results by the empirical equation for yield of convoy electrons:

$$\gamma_c = 1\times10^{-4} C(Z_T) Z_{eff}^{\;2{,}75} E_1^{-2{,}25}, \quad (5)$$

where Z_{eff} is the effective charge of the incident particle with energy E_1 in MeV/amu, and C is a constant depending on the target material; C(Au) = 1.65, C(Ag) = 1.25, C(A1) = C(C) = 1.0. All the values have accuracy 0.15.

Alpha particles were emitted isotropically from the surface of radioisotope source. These projectiles moved at different angles with respect to the target surface and, consequently, passed different path in the matter of the foil. As a result, their energy losses were different too (Fig. 5).

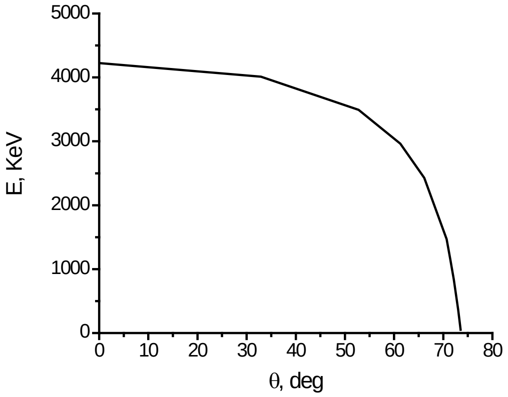

Fig. 5. Dependence of alpha-particle energy at the back surface of the titanium foil

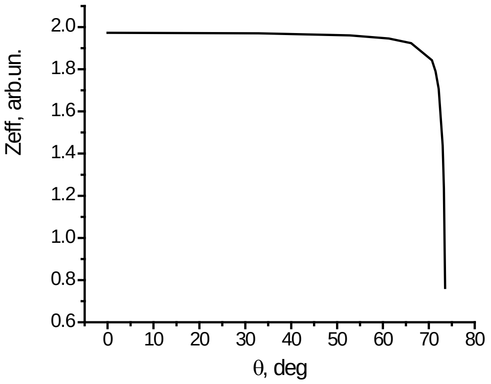

Fig. 6. Effective charge of alpha-particles in the target foil as function of incidence angle

The effective charge is a function of projectile velocity. Consequently, it depends on the incidence angles too (Fig. 6).

In this case, yield of convoy electrons according (5) varied from $5.7\cdot10^{-4}$ (0°) to 0.82 (75°). The influence of convoy electrons on total electron yield can be neglected. However, these electrons have considerable energy from 578 eV (0°) to 71 eV (75°). It means that convoy electrons enable to knock out secondary electrons from the opposite electrode. These additional electrons influence on charge balance between the electrodes and decrease the conversion efficiency of SERICS.

CONCLUSIONS

In this paper the investigation of the forward and backward electron emission in Ti-Ti binary cell of the SERICS induced by alpha-particles have been carried out. It was shown that ratio of forward and a backward yield was close to the other materials. Isotropic emission of alpha particles from the surface of radioisotope source led to distribution of the projectile's energy in binary cell. As a result, the effective charges of projectile and convoy electron yield depend on incidence angle of alpha-particles. The influence of convoy electrons on total electron yield can be neglected.

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REFERENCES

1. E.J. Sternglass. Theory of secondary electron emission by high-speed ions // *Phys. Rev.* 1957, v. 108. № 1, p. 1-12.
2. D. Hasselkamp, S. Hippler, A. Scharmann. Ion-induced secondary electron spectra from clean metal surfaces // *Nucl. Instr. and Meth. B.* 1987, v. 18, p. 561-565.
3. V.I. Karas', S. S. Moiseev, V.E. Novikov. Nonequilibrium stationary distributions of particles in a solid body plasma // *Zh. Eksp. Teor. Fiz.* 1976, v. 71, p. 1421-1433.
4. V.E. Zakharov, V.I Karas'. Nonequilibrium Kolmogorov-type particle distributions and their applications // *Physics - Uspekhi*. 2013, v. 56, p. 49.
5. N.P. Kalashnikov, V.S. Remizovich, I. Ryazanov. *Collisions of fast charged particles in solids*. Moscow: "Atomizdat", 1980, 272 p. (in Russian).
6. D. Hasselkamp. Secondary emission of electrons by ion impact on surfaces // *Comments At. Mol. Phys.* 1988, v. 21, p. 241-255.
7. B.A. Brusilovskiy. *Kinetic ion-electron emission*. Moscow: "Atomizdat", 1990, 184 p. (in Russian).
8. V.P. Kovalev. *Secondary electrons*. Moscow: "Energoatomizdat". 1987, 175 p. (in Russian).
9. V.M. Balebanov et al. Secondary emission radioisotope current source // *Atomnaya energiya*. 1998, v. 84, №5, p. 398-403 (in Russian).

10. V.M. Balebanov et al. Secondary emission radioisotope current source // *Inventors certificate* № 1737559 USSR, 1992.
11. V.M. Balebanov et al. *Secondary emission radioisotope current source*: Patent of Russian Federation. № 2050625. 1993.
12. V.P. Zhurenko, S. I. Kononenko, V.I. Karas’, et al. Dissipation of the energy of a fast charged particle in a solid-state plasma // *Plasma Physics Reports*. 2003, v. 29, № 2, p. 130-136.
13. L.C. Northcliffe. Energy loss and effective charge of heavy ions in aluminum // *Physical Review*. 1960, v. 120, № 5, p. 1744-1757.
14. J.F. Ziegler, J.P. Biersack, U. Littmark. *Software SRIM2003. The Stopping and Ranges of Ions in Solids.* New York: “Pergamon Press”, 2003.
15. W. Brandt, R.H. Ritchie. Velocity spectra of convoy electrons emerging with swift ions from solids // *Physics Letters*. 1977, v. 62A, № 5, p. 374-376.
16. R. Laubert, I.A. Sellin, C.R. Vane, et al. Yield of convoy electrons from solids // *Nuclear Instruments and Methods*. 1980, v. 170, p. 557-560.
17. H.-P. Hülskötter, J. Burgdörfer, LA. Sellin. Exit charge state dependence of convoy electron production in heavy-ion-solid collisions // *Nuclear Instruments and Methods in Physics Research*. 1987, v. B24/25, p. 147-152.

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ЭЛЕКТРОННАЯ ЭМИССИЯ ВПЕРЕД И НАЗАД В БИНАРНОЙ ЯЧЕЙКЕ РАДИОИЗОТОПНОГО ИСТОЧНИКА ТОКА

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Показано, что отношение электронных выходов в прямом и обратном направлениях для Ti-Ti-бинарной ячейки SERICS близко к некоторым другим материалам. Изотропное испускание альфа-частиц с поверхности радиоизотопного источника привело к зависимостям эффективных зарядов и выхода конвойных электронов от угла взаимодействия. Влиянием конвойных электронов на общий выход электронов можно пренебречь.

ЕЛЕКТРОННА ЕМІСІЯ ВПЕРЕД І НАЗАД У БІНАРНІЙ КОМІРЦІ РАДІОІЗОТОПНОГО ДЖЕРЕЛА СТРУМУ

С.І. Кононенко, В.П. Журенко, О.В. Калантар’ян, А.А. Семеренський

Показано, що відношення електронних виходів у прямому і зворотному напрямках для Ti-Ti-бінарної комірки SERICS близьке до деяких інших матеріалів. Ізотропне випромінювання альфа-частинок з поверхні радіоізотопного джерела призвело до залежності ефективних зарядів і виходу конвойних електронів від кута взаємодії. Впливом конвойних електронів на загальний вихід електронів можна знехтувати.