UDK 533.9

THE RESEARCHES OF KINETIC ELECTRON EMISSION FOR CREATION OF NEW-TYPE CURRENT SOURCE

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It is suggested that the high energy electrons produced in ionization due to the nuclear particle flow should be used for effective conversion the radioactive decay energy into electrical energy. The conversation of secondary electron emission energy enables one to create a power source with a typical voltage of (10-20) V and a capacity above 2000 KWt×h/kg, this being much higher than for common sources. Moreover, the operation of this type of sources does not require heating to high temperature and use of a refrigerator; this significantly extends their area of application. The experimental studies into secondary emission characteristics of various materials were carried out to optimize binary cell materials of a secondary - emission radioisotope current source. The total current as a function of collector materials was measured. New data on the secondary emission characteristics of certain materials were obtained. It was ascertained that the total binary cell current had an effect upon secondary electron - electron emission. By way of example, a typical power dependence of voltage was investigated for copper collector; the optimum voltage value corresponding to peak power was calculated too.

1. Steady-state nonequilibrium distributions

At present, the development and wide use of powerful sources of particles and energy arouse considerable interest in the nonequilibrium states of various physical systems. The Fermi-Dirac and Maxwellian functions are the thermodynamically equilibrium electron distribution functions in degenerate or classical plasmas, respectively. These functions are, correspondingly, the exact solutions of the quantum or classical Boltzmann collision integral [1].

The steady-state nonequilibrium distributions can be found by exactly solving kinetic equations. This is especially true in regard to the 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. For such distributions to exist, there must be a source and a sink of energy that provide a constant energy flux in the momentum space [2].

These conditions take place when the kinetic secondary electron emission induced by ions occurs. It is well known, that passage of fast ions through substances initiates ionization of medium atoms. As a result of interaction with ions, some electrons leave atoms. They may enter the vacuum if their momentum have a suitable value and direction, i.e. secondary electron emission induced by ions takes place. In this case, a steady-state nonequlibrium electron distribution $N(E)$ with power dependence of electron energy can be formed because of the presence of a source and sink of energy and a constant energy flow in momentum space [2].

The experiments have shown that the energy distributions of fast ion-induced secondary electron emission are the power-law function with power indices differening by various energy intervals [2]. The generalization of the secondary electron emission theory for nonequilibrium electron distribution functions makes it possible to obtain the secondary electron current as a function of retarding potential U:

$$I(U) = \frac{\pi}{2}\sum_{i=k}^{3} A_i \left(\frac{2E_i}{m}\right)^{s_i+2} \cdot \frac{1}{(s_i+1)(s_i+2)} \times$$

$$\times \left\{ \begin{array}{l} (s_i+1)\left[1-\left(\frac{E_{i-1}}{E_i}\right)^{s_i+2}\cdot\Theta(i-k)\right] - \\ -(s_i+2)\left[1-\left(\frac{E_{i-1}}{E_i}\right)^{s_i+1}\cdot\Theta(i-k)\right]\times \cdot \\ \times\left(\frac{E_0+q_eU}{E_i}\right) + \left(\frac{E_0+q_eU}{E_i}\right)^{s_i+2}\left[1-\Theta(i-k)\right] \end{array} \right\}, \quad (1)$$

$$A_i\left(\frac{2E_i}{m}\right)^{s_i} = A_{i+1}\left(\frac{2E_i}{m}\right)^{s_i+1},$$

where $E_0 = E_F + \varphi$ is the minimum energy in the distribution, E_i is the boundary of the energy interval within which the distribution is described by a power-law function with the power index s, m is the electron mass, $\Theta(x)$ is the theta-function, A_i is determined from the recurrent formula, and k is determined from the inequality $E_{k-1} \le E_0 + q_e U < E_k$. [2].

The current-voltage characteristic of such secondary emission source of electrons is sloping considerably slower than that of the thermoemission cathode. A portion of fast electrons of the secondary electron emission is substantially greater than that of the thermoemission [3].

A coefficient of the secondary electron emission (SEE) γ is an integral parameter describing secondary electron emission induced by ions. It is determined by the formula:

$$\gamma = N_e / N_i,$$

where N_e is a total number of the secondary electrons that have left a material; N_i is a number of primary ions.

We consider the secondary-emission coefficient γ to be proportional to the energy loss per atom (i.e., to depend on the atom density N as $N^{1/3}$) and inversely proportional to the excitation potential Φ, which takes into account the collective interaction of a charged particle with the electron subsystem of the material. According to [3], the Sternglass formula can be modified as follows:

$$y = \frac{\varsigma Z_{1eff}^2}{\Phi N^{-1/3}} \left(-\frac{dE}{dx} \right)_p$$

where $(-dE/dx)_p$ is the energy loss by proton whose velocity is equal to the velocity of the incident ion; Z_{1eff} is the effective charge of an ion in the target; ζ is a constant.

The measurements have shown that the γ value can reach a few tens of emission electrons per one bombarding α-particle, as, for example, for beryllium. The presence of a great number of high energy electrons allows one to transform effectively the energy of the nuclear α-particle into electrical one [4].

2. The secondary emission radioisotope source of current

On the basis of the previously obtained results, we propose a secondary-emission radioisotope current source (SERICS) [5]. The source consists of a radioisotope layer 2 placed inside a vacuum container 1 (see Fig. 1). Metallic emitters are arranged on each side of the layer. The emitter thickness is less than the mean path of the charged particle emitted by the radioisotope in the emitter material. Each emitter consists of alternating layers of two different metals 3 and 4 with different secondary-emission coefficients. The layers are electrically isolated by dielectric gaps.

A high efficiency of the radioisotope current source of this type is determined by the fact that secondary electrons are produced along the entire path of charged particle in metal; i.e., the charged particle energy is directly transformed into electron energy; the number and average energy of these electrons are much above those for the thermal electron emission [3].

It has been stated previously that the use of heavy particles in electric-current sources results in a high efficiency of secondary electron production due to a negligibly small scattering of these particles (i.e., they move along almost straight trajectories). The secondary-electron distribution function is nonequilibrium; the average energy of the emitted secondary electrons exceeds 10 eV. The source efficiency increases as a result of an increase in the secondary emission under the action of δ-electrons . As a result, this current source has high energetic parameters proportional to the number of the emitter layers.

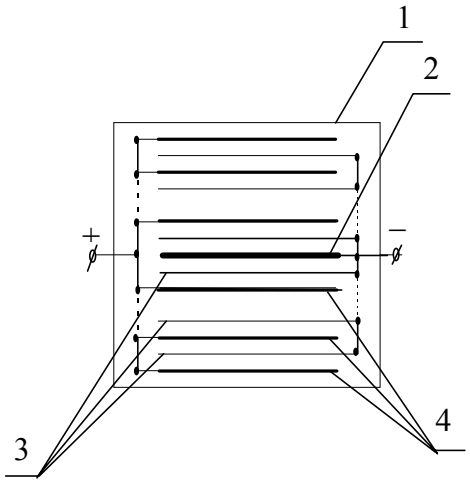

Fig. 1. Schematic diagram of the secondary emission radioisotope source of current: 1- vacuum container, 2- radioisotope layer, 3 and 4- layers of two different metals with different secondary-emission coefficients

Since the total thickness of the emitter does not exceed the mean path of the charged particle emitted by a radioisotope, the number of layers and, consequently, the emitter efficiency can be increased only by making each layer thinner.

However, as the layer thickness decreases, the construction loses its rigidity. This can break the electric insulation between layers. For example, if the layers are bent, the vacuum gaps between them become narrower.

Earlier we have also proposed a secondary emission current source with thinner emitter layers and, at the same time, with a sufficiently high rigidity of the emitter [5].

This problem was solved by developing a SERICS, where the radioisotope and the emitter with a thickness less than the mean path of the charged particle emitted by the radioisotope were placed inside the vacuum-tight case. The emitter consists of alternating electrically insulated layers made of two different materials with different coefficients of secondary electron emission. The dielectric grids, located between the emitter layers, serve to insulate the layers electrically from each other and to improve the rigidity of the emitter construction. The thickness of the dielectric grid is larger than the thickness of the emitter layers. To

attain a better effect, the dielectric grid must be deposited directly on one of the emitter layer. One of the versions uses the ceramic grid, and the other one uses the plastic grid [5].

By using all the technical solutions presented above, one can create a secondary emission radioisotope source of the current with a substantially better energetic parameters, of smaller mass and sizes .

The basic element of SERICS is a binary cell consisting of two thin layers made from different materials. The difference of secondary emission coefficients of these materials (γ_1 - γ_2) is the principal characteristic which determines efficiency of this device. This paper presents the researches of the electrophysical parameters of the binary cell.

3. The experimental setup

The experiments were carried out with the device, schematic diagram of which is shown in Fig. 2.

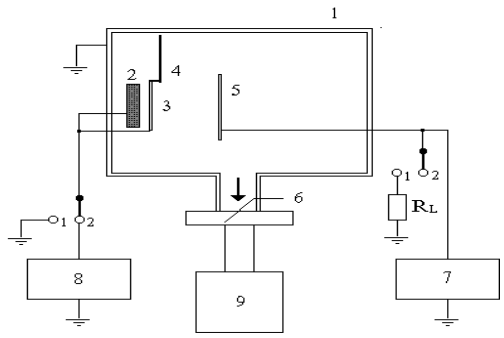

Fig. 2. Schematic diagram of the experimental setup: 1- vacuum chamber, 2- radioisotope source of α-particles, 3- beryllium foil, 4- moveable damper, 5- massive expendable collector, 6- high vacuum valve, 7- electrometric voltmeter, 8- power supply, 9- magnetic discharge pump

The prototype of the binary cell consisting of radioisotope source of α-particles with Pu^{239} isotope 2, the emitter of a beryllium foil 3 and the massive expendable collector 5 were placed in a vacuum cylinder chamber 1. The radioisotope source 2 produced an α-particle beam with intensity of $4{,}64 \cdot 10^6$ particles/sec and an energy of 5,15 Mev. The beryllium foil thickness of 20 μm was chosen to be less than a mean path of α-particle with given energy in this material. The α-particles beam, passing through the emitter 3, induced the secondary electron emission from the outer emitter surface and from the surface of the massive collector 5. The collector current were measured by an electrometric voltmeter 7 with input impedance of 10^{16} Om. Voltage of different polarities was applied to the emitter-collector gap and was changed from 1 to 300V. 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 forevacuum pump with a nitrogen-cooled trap. The plates made from copper, silver and a set of Faraday cups, consist of 33 copper tubes 10 mm in diameter and 100 mm in length, were used as collectors.

4. The experimental results and discussion

The collector current as a function of voltage applied to the emitter-collector gap for the copper collector and the set of Faraday cups is shown in Fig. 3.

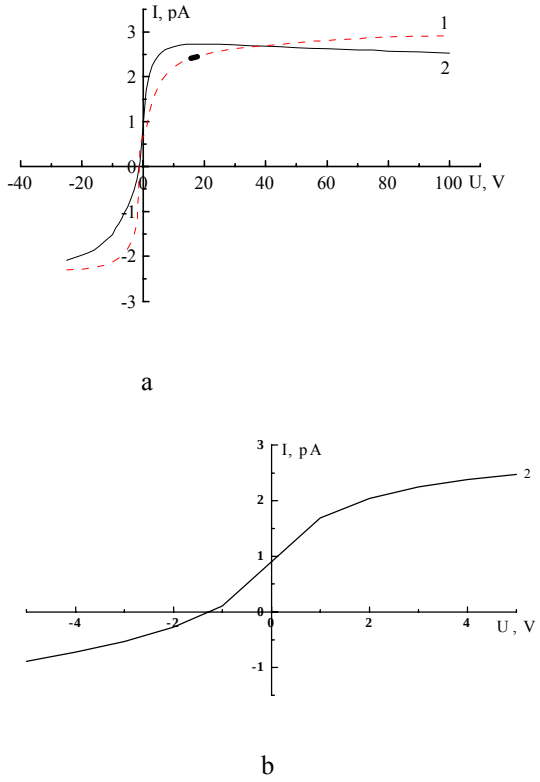

Fig. 3. The experimental current-voltage characteristics for the different collectors: 1- set of Faraday cups, 2- copper collector

It is obvious from Fig.3a that the curve of current-voltage characteristics (CVC) for the set of Faraday cups does not steeply slope up and has no maximum in comparison with one for copper collector. The presence of high energy tail in the secondary electron distribution causes the secondary electron-electron emission (SEEE) of the binary cell materials. Slow SEEE electrons make essential contribution to the total current. This is obvious from the comparison of experimental current-voltage characteristics (CVC) for different collectors. For designing SERICS it is necessary to select the materials, taking into account not only the coefficient γ but also the coefficient of SEEE σ so that a value of electron yield difference $\xi=(\gamma_1+\sigma_1)-(\gamma_2+\sigma_2)$ must be maximum.

The device under review is a current source. That is why, it is very important to know optimum

source power which develops across the load. It has been shown earlier that the energy distributions of electrons of the secondary electron emission induced by fast ions are the power-law functions with different power indices for different energy ranges. Therefore, it is possible to use generalized formula of secondary electron emission theory of nonequilibrium electron distributions to the current of secondary electrons as a function of the retarding potential (1). The nonequilibrium electron distribution for copper sample has the limits of energy range E_1=30 eV and E_2=200 , within which the distribution is described by the power-law function with the power indices of s_1=-4 and s_2=-2.25, respectively [6]. In this case, it is possible to obtain the typical power dependence on voltage. Using the formula (1), we have calculated dependence of source power, which develops across the load, on voltage (Fig. 4).

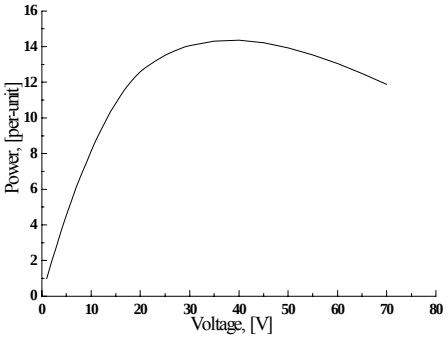

Fig. 4. Theoretical dependence of source power, which develops across the load, on voltage

The optimum value of voltage corresponding to the power maximum, is equal 37 V. This means that the optimum operation of current source will be in case load resistance, which determines output voltage of source, is chosen adequatelly. However, some discrepancy has been found between experimental CVC and theoretical dependence defined by the formula (1) in low energy range [3]. The slow electrons make an essential contribution to the total binary cell current. Formula (1) does not satisfy the binary cell conditions, because, firstly, it does not take account of presence of the second plate; secondly, it does not allow for the secondary electron-electron emission.

In addition, we carried out an experimental study of the dependence of the binary cell power on voltage. For the purpose, the emitter was connected to earth and the load resistance was placed into a collector circuit. In these experiments we measured voltage drop across the load resistor, which value was changed from 56 GOm to 5000 GOm. The plate made from silver was used as the collector. The measured experimental dependence of power on voltage is shown in Fig. 5.

It is obvious that the power which develops across the load has maximum at U=0.67V. The working point lies in narrow voltage range of the current-voltage characteristic for the real binary cell. The maximum working voltage can not be higher than one for point where the total current becomes zero (see Fig.3b). In order to step up this maximum voltage, it is essential to increase the value of ξ..

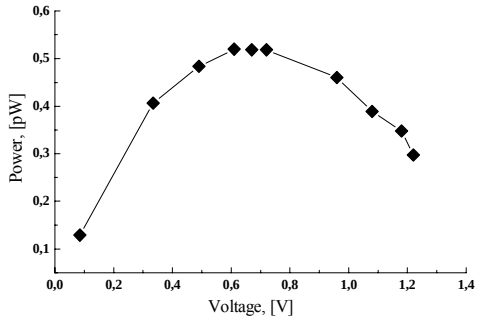

Fig.5. Experimental power dependence on voltage

5. Conclusion

In this paper the investigation of the binary cell electrophysical parameters of the SERICS have been carried out. It was shown that the secondary electron-electron emission from both plates of the binary cell takes great effect on power, which develops across the load. In order to increase this power and to approach the optimum value of voltage to the theoretically calculated one it is necessary to select materials, taking account of both coefficient γ and σ.

6.References

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