EXPERIMENTAL STUDY OF SECONDARY EMISSION RADIOISOTOPE CURRENT SOURCE PROTOTYPE

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The results of experimental investigations of prototype of secondary emission radioisotope current source are presented. Novel physical idea of nuclear particle energy conversion into electricity by means of secondary ion induced electron emission underlies this autonomous power supply. As primary particles we used H^+ ion beam from Van de Graff accelerator with megaelectronvolt energy. Some possible regimes of the prototype operation were studied. It was shown that load curve of the prototype had maximum. Output power up to 10 μWatt was obtained. It was experimentally shown realizability of the energy conversion idea.

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1. INTRODUCTION

Fast ions passing through a substance loss the energy due to processes of atom ionization [1]. At that part of substance electrons can leave the surface leading to a secondary ion-induced electron emission [2-4]. The integral characteristic of the emission is coefficient γ frequently termed in the literature as an electronic yield [2-4]. 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:

$$\gamma = N_e/N_i. \quad (1)$$

Coefficient γ can change depending on ion energy, target substance and a number of other parameters [2-4].

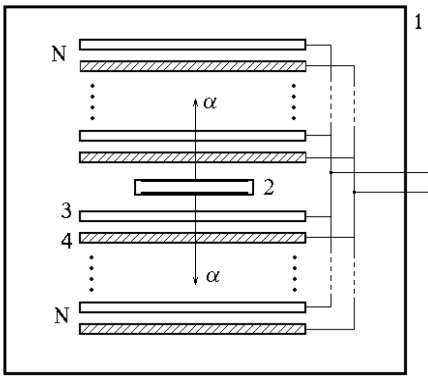

Fig.1. Schematic diagram of SERICS: 1 – vacuum container, 2 - α-radioisotope, 3 and 4 – emitting thin layers with different emission coefficients

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) [5-7].

SERICS schematic diagram is presented on Fig.1. Radioisotope 2 emitting α-particles towards two half-spheres 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 [5].

The paper deals with the results of experimental study of SERICS prototype, which consisted of one emitter with 5 binary cells. The experiments were carried out with H^+ ion beam because we have studied normal incident of primary particles. Dependences of emission parameters on incident angles are well known [3, 4]. In electrical engineering when some cells are in parallel connection, important question is internal resistance matching. In SERICS internal resistance of the binary cells are not defined. Mismatch of binary cells can give rise to low efficiency of the device. Thus, the first purpose of the study was to clear up a question of electron current growth in the prototype by means of increase of binary cell quantity (hereinafter referred to as current additivity). The second purpose was study and optimization of load characteristics of this electricity source.

2. PROTOTYPE DEVELOPMENT AND MEASUREMENT PROCEDURE

Doubled SERICS prototype containing two converters was developed. The converters were identical in construction but differ in composition (Al-Ni and Al-Cu). The prototype was mount on sector-shaped metal plate where two mentioned above emitters were arranged down arc of circle. The construction enabled to put one of the converters to the beam without vacuum failure and to measure beam current at the entry of converter before each experiment. When ion path length in the materials being used was greater than total thickness of foils in the set, transmitted ion beam was collected by Faraday cup.

Each converter included 5 binary cells, i.e. 10 parallel emitting layers (thin foils of 13 mm effective diameter) made from two consecutively alternate materials

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“A” and “B”. For the first converter “A” is aluminum and “B” is nickel, for the second - aluminum and nickel, correspondently. All of the foils were electrically insulate from each other and the other constructional elements and each of them was fixed in separated holder with reliable electric and heat contact. Distance between foils was 4 mm.

The experiment were performed on Van de Graf accelerator at NSC “KIPT” with H^+ ions of 1.5, 1.7 and 1.96 MeV energy. Ion beam of 3 mm diameter impinged on converter. Beam current varied in the range of 0.14…1.21 μA. Residual gas pressure was no more than 10^{-4} Pa.

We used program SRIM 2003 [8] for simulation processes which take place in the converters under passage of protons with different primary energy. Having analyzed proton path lengths in the materials under study we calculated necessary foil thickness for both variants of converter so that minimal primary energy of protons would be 1.5 MeV. Thus foil thickness varied in the range of 0.58…6 μm, at that nearly all ions for primary energy of 1.5 MeV would slow down by the last foil of the set (about 99.3%). For 1.7 and 1.96 MeV energy almost all of ions pass through the last foil (for 1.7 MeV – 98.85%, 1.96 MeV – 99.85%).

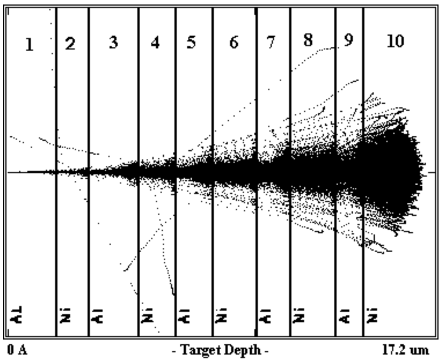

Fig.2. Simulation of H^+ ion scattering in the prototype multilayer structure

Simulation showed that nearly 99.81% of ion energy was connected with electronic stopping power, while energy losses for recoil atoms, phonon excitation and sputtering of the foils were negligible. 1.5 MeV proton trajectories in Al-Ni converter are shown on Fig.2.

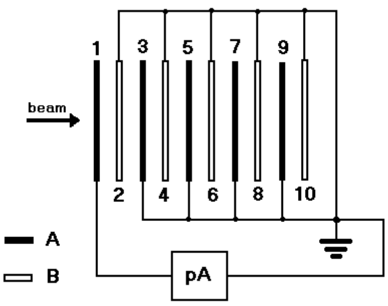

Fig.3. Electric circuit for study of current additivity in the SERICS prototype

Prototype study was performed in two main directions:

1. *Current additivity*. At first we measured current of each separated foil, while the others were grounded (see Fig.3). Then current measurements of two, three and so on foils connected in parallel were carried out, while vacant foils were grounded.

2. *Electrophysical characteristics*. Output characteristics such as current, voltage, power depending on load resistance were measured.

We used Keithley 6487 picoammeter and digital voltmeter for electrical measurements. Measuring circuits were electrometric. Resistance set overlapped range of 10 kΩ…500GΩ.

Three operating modes of the prototype were examined.

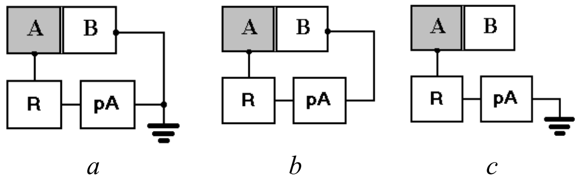

Fig.4. Electric circuits for load curve measurements: a - the first operating mode; b – the second mode (floating scheme); c – the third mode (unipolar circuit)

At the first operating mode “A”-foils were connected in parallel and loaded by resistance R (Fig.4,a). One pole of picoammeter and “B”-foils were grounded.

The second mode is a floating scheme (Fig.4,b). In this case “A”-foils were connected in parallel as well as “B”-foils. “A” and “B” connection terminals were closed by resistance R, picoammeter operated in floating mode.

The third operating mode (unipolar circuit) repeated the first scheme but “A”-foils were connected in parallel and ungrounded, i.e. “A” connection terminal was under floating potential (Fig. 4c).

All of the operating modes were realized twice, it means symmetry with regard to “A”- and “B”-foils.

3. RESULTS AND DISCUSSION

The experiments showed that total current of each converter was exact sum of each separated foil currents independently of ion energy and beam current. Thus current additivity was observed. By the example of Al-Ni converter with aluminum current-carrying foils the current dependence of a set on the number of binary cells are shown on Fig.5 for 0.91 μA beam current and 1.7 MeV ion energy. As it can be seen from the Fig.5, strong additivity are fulfilled.

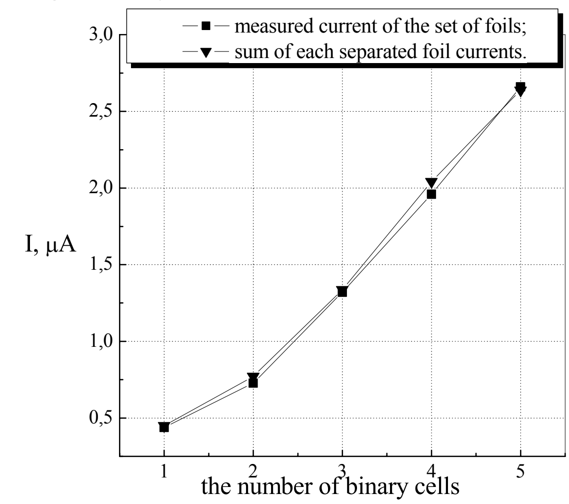

Fig.5. Al-Ni prototype current as a function of the number of binary cells for 1.7 MeV ions and 0.91 μA beam current

One of the basic characteristics of electricity source is a load curve. Power developed across the load by Al-Ni converter under the first operating mode as a function of load resistance is presented on Fig.6 for 1.5 MeV ions and different beam currents. As it can be seen, the power has maximum, i.e. there is optimal value of load resistance. For all of ion energy and beam currents as well as for both variants of load connection (Al grounded or Ni grounded) the optimal load resistance is equal to 300…500 kΩ. The output power of the prototype is proportional to beam current.

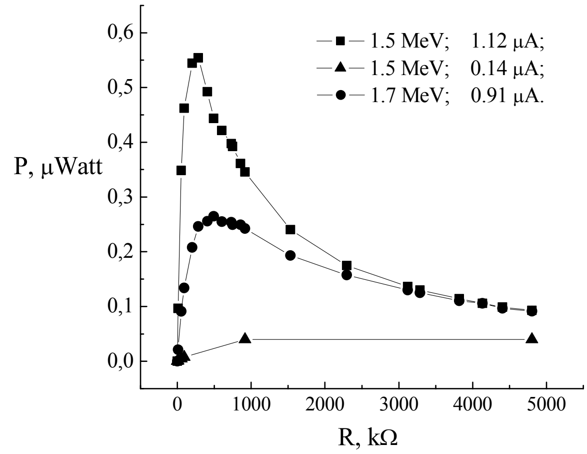

Fig.6. Load curve of Al-Ni prototype under the first operating mode for 1.5 MeV ions and different beam currents

Fig.7 shows load voltage dependence on resistance value for the first operating mode. Voltage does not exceed 0.5 V at the power maximum point and is no more than 0.7 V at R=5 MΩ.

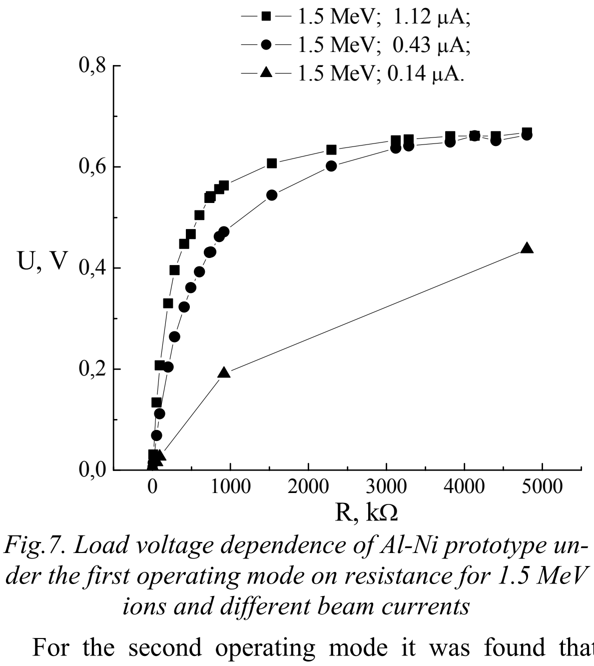

Fig.7. Load voltage dependence of Al-Ni prototype under the first operating mode on resistance for 1.5 MeV ions and different beam currents

For the second operating mode it was found that load curve and load voltage dependence on resistance were similar to the ones observed for the first operating mode (taking into account normalization to beam current).

Having studied the third mode with various beam currents and ion energy we found that sign and value of prototype current did not depend on fact what sort of foils ("A" or "B") was under floating potential. Load curves obtained for the unipolar circuit of Al-Ni SERICS prototype operation (Ni foils were under floating potential) are presented on Fig.8.

First of all let us give attention to the 1.5 MeV load curves on Fig.8. As we mentioned above, passing through the set of foils, practically all ions with such primary energy slowed down in the last foil. In this case, as it can be seen, the power is proportional to beam current. The power is monotonically grows along the whole range of load resistance. The load curve for 1.12 μA beam current reaches 9 μWatt value at 5 MΩ resistance. For such resistance value load voltage amounts 6.5 V.

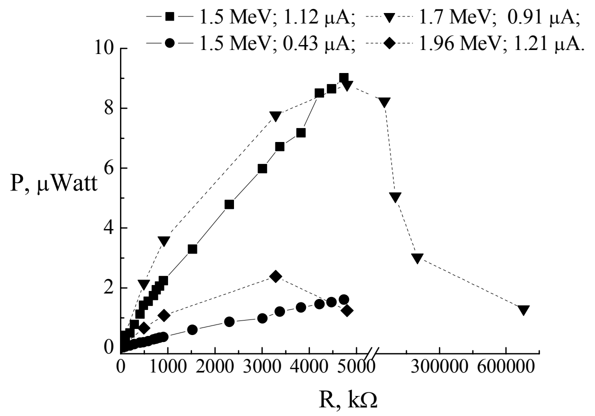

Fig.8. Load curve of Al-Ni prototype under unipolar mode (Ni under floating potential) for different beam currents and ion energy (1.7 and 1.96 MeV curves are normalized to 1.12 μA beam current)

When ions pass through emitter and hit the Faraday cup (load curves for 1.7 and 1.96 MeV) power has maximum. For 1.7 MeV ions the power maximum corresponds to resistance value of some tens MΩ (for such energy part of ions pass through the last foil, but not all of that). For 1.96 MeV (almost all ions pass through the last foil) the power maximum shifts to lower part of the resistance range.

The SERICS construction should include a large amount of consecutive elementary cells. Therefore, primary energy of α-particles inducing electron emission would be different for each consecutive emitter layer in real SERICS. As it was shown above, power maximum in load curve depended on ion energy. In this connection, it is necessarily that load resistance for real SERICS construction would be optimized.

CONCLUSIONS

Realizability of idea of the energy conversion by means of secondary ion induced electron emission has been demonstrated. Two variants of the prototype Al-Ni and Al-Cu were experimentally studied with MeV energy proton beam. Current additivity of binary cell operation in the prototype was verified. Presence of this effect enables to enlarge output power of the source significantly by means of increase of emitting pair quantity (foils).

It was found that the prototype could work on load under two operating mode:

1) one pole (i.e. all of emitting layers of one sort with high or low emission coefficient) is grounded;

2) one pole is under floating potential.

The highest output electrical power (up to 10 μWatt) of the prototype was reached under the latter operating mode.

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ПРОТОТИПА ВТОРИЧНО-ЭМИССИОННОГО РАДИОИЗОТОПНОГО ИСТОЧНИКА ТОКА

С.И. Кононенко, О.В. Калантарьян, В.П. Журенко, В.Т. Колесник, В.И. Муратов, В.И. Карась, В.Е. Филиппенко

Представлены результаты экспериментальных исследований прототипа вторично-эмиссионного радиоизотопного источника тока. Этот автономный источник питания основан на новой физической идее преобразования энергии ядерных частиц в электрическую энергию с помощью вторичной ионно-электронной эмисии. В качестве первичных частиц мы использовали пучок ионов H^+ мегаэлектронвольтных энергий, который был получен на ускорителе Ван де Граафа. Было изучено несколько возможных режимов работы прототипа. Показано, что нагрузочная кривая прототипа имеет максимум. Получена выходная мощность до 10 мкВт. Экспериментально показана осуществимость идеи преобразования энергии.

ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ПРОТОТИПУ ВТОРИННО-ЕМІСІЙНОГО РАДІОІЗОТОПНОГО ДЖЕРЕЛА СТРУМУ

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Представлено результати експериментальних досліджень прототипу вторинно-емісійного радіоізотопного джерела струму. Це автономне джерело живлення базується на новітній фізичній ідеї перетворення енергії ядерних частинок в електричну енергію за допомогою вторинної іонно-електронної емісії. За первинні частинки ми використовували пучок іонів H^+ мегаелектронвольтних енергій, який було отримано на прискорювачі Ван де Граафа. Було вивчено кілька можливих режимів роботи прототипу. Показано, що навантажувальна крива прототипу має максимум. Отримано вихідну потужність до 10 мкВт. Експериментально показана здійснюваність ідеї перетворення енергії.