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Peculiarities of Betavoltaic Battery Based on Si

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In the paper the description of the optimal geometric dimensions of the structure of beta silicon galvanic battery using radioisotope Ni^{63} is presented.

Keywords: Betavoltaic battery, Microelectromechanical systems, Radioisotope.

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1. INTRODUCTION

Modern society has become increasingly a need for energy to power a wide range of electrical and mechanical devices. Radioisotope power sources are well suited to power microelectromechanical systems (MEMS) due to their high energy density, long life small volume. Radioisotope power sources are used where necessary to ensure the autonomy of the equipment, a significant reliability, light weight and small size. A promising method to convert radioactive decay energy into electric current is the direct conversion of energy, which is carried semiconductor diode and radioisotope source [1]. Semiconductor diodes for converting nuclear radiation into electrical energy were first proposed in 1950 [2]. City Labs company created beta voltaic battery that as a source of beta particles using radioisotope tritium peak voltage idling amounted to 0.7 V and short circuit current of 0.1 mA [3]. Radioisotope ^{63}Ni seems more suitable beta source, because of its pure beta radiation, long half life (100 years) and a high energy beta particles (maximum value of 66.7 keV), but it has a low power density (0.006 W / g) and high self-absorption. Duration of works such batteries depends on the half-life of the radioisotope and is in the range of a few (Pr^{147}) to one hundred years (Ni^{63}) [4].

2. EXPERIMENTAL PROCEDURES

The principle of operation is similar to nuclear batteries with solar panels [5-7], which convert the energy of the photons into electricity with the only difference being that they are working on the effect of generating electricity in the *p-n* junction at the span of beta particles. It is based on electron-galvanic phenomenon, which opened in 1937 Becker and Kruppke for selenium photocells [8]. The principle of operation is shown in Figure 1.

At the absence of any external influence on the semiconductor electric field generated in the space charge region can not perform useful work, as there are no free charge carriers that may be accelerated by the field. However, if the space-charge region will free charge carriers (for example, electron-hole pairs), then due to a static electric field, they begin to move in different directions: the electron - in the direction of the field n, and the hole in the side of the river area. There will be a charge separation, that is, in the chain there electromotive force (EMF) will occur. One of the main processes taking place in the semiconductor when hit it with an electron energy of 1-100 keV, is the ionization of atoms along the electron trajectory. As a result, the semiconductor forming a plurality of electron-hole pairs along the track highenergy electron. At relatively low energy of the outer electron (100 keV), the ejection of electrons from the atoms of the semiconductor and pair production is the dominant process, so the number of pairs is proportional to the energy of the outer electron. Under the action of the static electric field, these pairs form current and its value is proportional to the product of the flow of electrons and their energy.

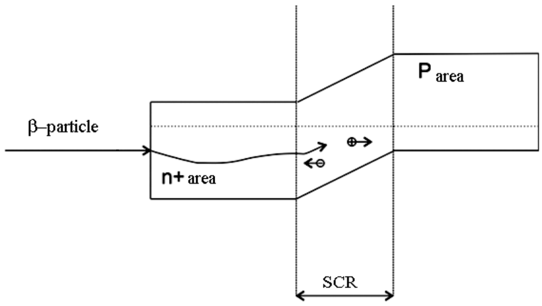

Fig. 1 – Principle of betavoltaic battery work

The main problem of planar design betavoltaic battery is the low conversion efficiency of ionizing radiation, since over 50 % of the beta particles do not contribute to the generation of electron-hole pairs. Thus, in [9, 10] have been proposed three-dimensional structure converter using radioisotopes S^{35} and tritium. The radioactive material emits beta particles with a continuous spectrum of energy in all directions, so to maximize the collection of electrons in the planar structures as necessary in the metallization used Ni^{63} and placing them over one another. Figure 2 shows the structure of a planar transducer ionizing radiation.

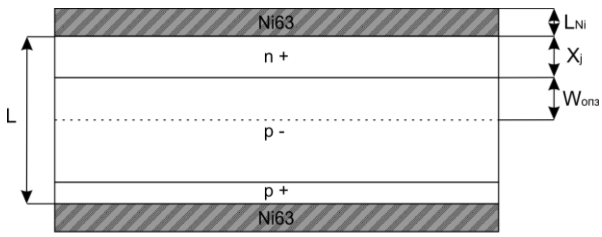

Fig. 2 – The design of silicon betavoltaic battery. L – thickness of the structure, L_{Ni} – metallization thickness, x_j – the depth of the *p-n* junction, W_{opz} – the width of the space charge region

Choosing the best weight and size dimensions betavoltaic batteries it must be guided by the maximum range of ionizing particles emitted from the surface of a radioactive source. The depth of penetration of beta particles emitted by Ni^{63} can be calculated by the formula Kanaya-Okayama.

$$R_{K-O} = \frac{0,0276 \cdot A \cdot E_0^{1,67}}{Z^{0,889} \cdot \rho}, \quad (1)$$

where $R_{K\text{-}O}$ is given in micrometers, A – average atomic weight of the sample, E_0 – energy electrons in keV, Z – the average atomic number of the sample, ρ – density in g / cm^3.

3. RESULTS AND DISCUSSION

Figure 3 shows that the highest-energy particles penetrate into the silicon to a depth of about 35 microns, so the diffusion length of minority carriers must be at least 30-40 microns.

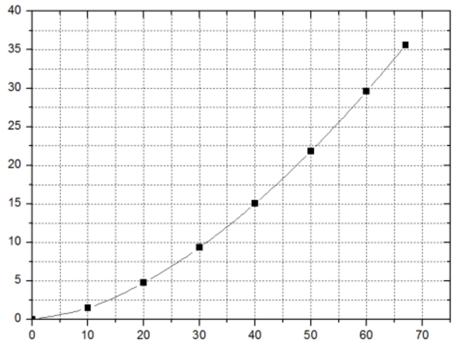

Fig. 3 – The depth of penetration of beta particles in Si

To reduce the series resistance caused by the substrate it is necessary to carry out grinding the back of the battery betavoltaic to 40-50 microns. Also in figure 3 the particles with a mean energy (17.3 keV) penetrate into the silicon to a depth of 3-4 microns, which corresponds to the maximum energy release rate and generation so the space charge region width must be no less than 4 microns, such value can be easily achieved by using high-resistivity silicon.

Since Ni^{63} radioisotope has a high self-absorption, it is necessary to determine the optimal thickness of the metallization, in which the electrons will have sufficient energy to be generated. Assuming that beta decay occurs in the center of the metallization, then the shortest path is perpendicular to the particle surface by using the formula 1 can easily determine that the thickness of the radioisotope should not exceed 1.5 microns.

The current generation of batteries will depend on the depth of the *p-n* junction, as the particles emitted by the isotope will be absorbed in the upper layer, failing to reach the space-charge region. Therefore, to create a structure with a maximum current needed to make the depth as low as possible. Modeling the interaction of the electron beam with the sample, the method of calculating the Monte Carlo and distribution of the electron energy loss, we can determine the optimal depth. For this task, the program CASINO was used. Dependence of the energy loss of electrons from the depth of penetration at different beam energies is shown in Figure 4.

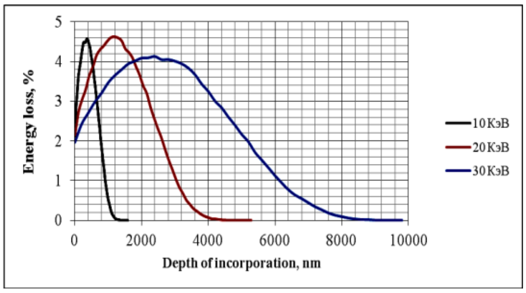

Fig. 4 – Dependence of the energy losses of electrons

Figure 4 shows that particles with energies from 10 keV energy have a maximum at 400 nm, so for the efficient conversion of ionizing radiation energy depth of the *p-n* junction should be done at least 500 nm. Electron-hole pairs generated by particles with energies below 10 keV, will not contribute to the current structure, as they will be formed in the n^+ region and almost immediately recombine.

4. SUMMARY

In this paper it was described the main design features of the planar structure betavoltaic batteries based on silicon using radioisotope Ni^{63}, the optimal thickness of the substrate and the metallization, the depth of the p-n junction and the value of the space charge region were determined.

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