JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. 7 No 4, 04034(3pp) (2015)
ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том 7 № 4, 04034(3cc) (2015)

Silicon Betavoltaic Batteries Structures

V.N. Murashev[1], S.A. Legotin[1], O.I. Rabinovich[1], O.R. Abdulaev[2], U.V. Osipov[1]

[1] *NUST "MISIS", 4, Leninskiy Prosp., 119040 Moscow, Russian Federation*
[2] *OPTRON, 53, Scherbakovskaya Str. 105187 Moscow, Russian Federation*

(Received 15 July 2015; published online 10 December 2015)

For low-power miniature energy creation sources the particular interest is nickel Ni^{63}. This paper discusses the main types of betavoltaic battery structures with the prospects for industrial application using -isotope of nickel Ni^{63}. It is shown that the prospects for improving the effective efficiency are planar multijunction betavoltaic batteries.

Keywords: Betavoltaic battery, Microelectromechanical systems, Radioisotope.

PACS numbers: 07.05.Tp, 85.60.Jb

1. INTRODUCTION

Nowdays, the field of miniature elements for the electric power suppliers for microelectromechanical systems, as an energy source is rapidly increasing and it is proposed to use the beta isotope nickel-63 [1-5]. The planar structures application with radiation-stimulated batteries is possible in areas where traditional energy sources are not available. For example, gas leak detectors in mines, deep-control elements, underground sensors, but the most attractive applications for such elements are biosensors which for real-time monitor the conditions inside the body. In such conditions, the development of effective and commercially attractive radiation stimulated energy source based on beta-isotopes is a current goal.

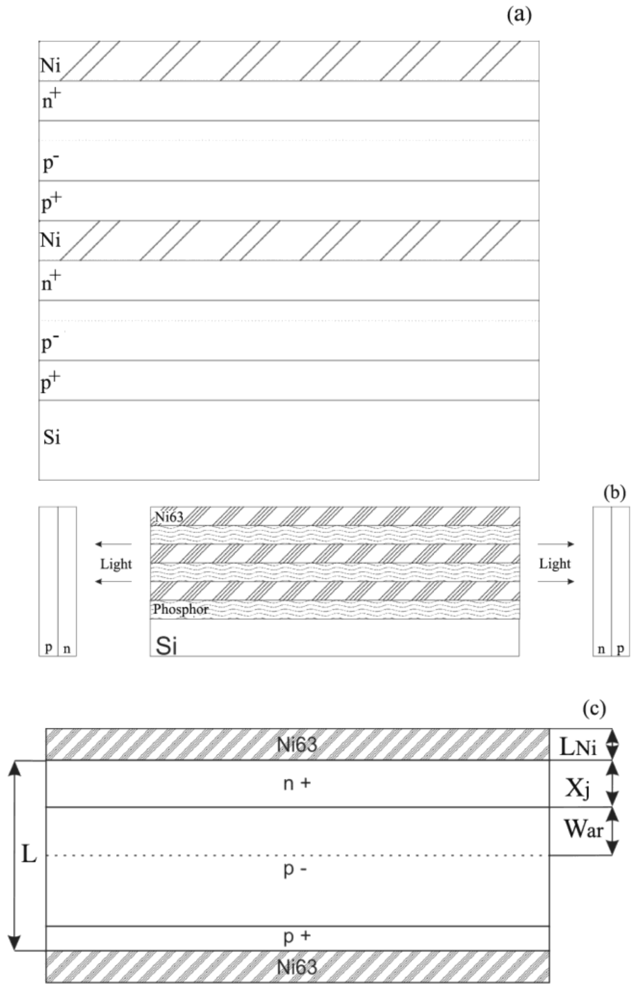
Among the beta-sources the most interesting from the practical point of view it seems to be nickel-63. Firstly, it has a half-life - 100.1 years, secondly, it is not a danger as a non radioactive source, non a toxic substance and thirdly, nickel is a technological material and could be easily integrated into semiconductor structure. The problem for practical nickel-63 structures usage is low energy conversion efficiency beta decay into electricity and not high sources activity [3, 6]. The nickel-63 activity is 1-40 mCi/cm^2, while the energy spectrum of beta particles is limited by energy 67 keV with maximum at 17.4 keV [4]. Integrating the beta particle spectrum by energy it can be obtained that from a Ni-63 source with 10 mCi activity, could be obtained power about 1 μW. Energy conversion efficiency of beta decay currently is quite low and does not exceed 0.3 % [1-4]. Low efficiency is due to several factors: the inelastic beta particles scattering, beta particles absorption in layers, in which there is no electron-hole pairs generation, he of charge carriers recombination and etc. [3-6]. Ways for increasing the efficiency of energy conversion were the selection of structures with wider band gap than in silicon. For example, p-n junctions based on GaN, GaAs and SiC are used [1-3], which offers to increase the structures electromotive force (EMF) compared with silicon structures. Another way for efficiency increasing is the silicon structures usage, in which the p-n junction usable area is increased [6-10]. In this way, there are difficulties with incorporating a radioactive source into microchannels and large leakage current, which greatly reduce the current generation efficiency.

2. EXPERIMENTAL PROCEDURES

In the present paper the goal is to calculate the generation current and silicon structures efficiency betavoltaic elements with the topology, which would collect the maximum of electron-hole pairs quantity. Based on the model developed in previous papers [1-5], the collection coefficient generated charge carriers η was calculated for silicon structures with different space charge region (SCR) and the *p-n*-junction depth based on the beta source isotope ^{63}Ni. At the same time recombination coefficient corresponds to the lifetime of 5.7 μs, and the built-in field varies linearly and was determined by the contact potential difference and the SCR width. Simulation results show that the junction depth influence on generation current is substantially greater than the SCR width, if the SCR width is larger than 4 μm [5-7]. For a structure creation with a maximum charge carriers collecting coefficient is necessary that junction depth was as small as possible, area for carrier generation should be about microns and be in the maximum generation area. Moreover it is clear that the lifetime for different structures will be different, which will make some changes in the values of the generated currents. Besides built-in electric field magnitude in the SCR will depend on the contact potential difference, and also influence on the η value. It is known that the value of the surface charging of the *p-n* junction also affect the η value, which requires steps for drain accumulated charge developed [9]. Taking into account the above mentioned peculiarities it can be assessed the structures efficiency using the obtained dependence.

For silicon structures efficiency analyzing are three structure types corresponding to the semiconductor technology (Fig. 1). The structure must be radiation-resistant for an energy range of Nickel-63 beta source [10]. In order to reduce the base resistance and the charge carriers excitation on both sides it is better to thin the wafer upto 10-40 μm thickness (Fig. 1a). From the other hand, the generated charge carriers collection will be most effective at the structures in which it is the most efficient the radioactive sources usage. Considering that the nickel-63 beta particles are self-absorpted, and the maximum the particle output depth do not exceed then 40 μm, it is good to use a microchannel silicon or forming the cracks up to a thickness 10-40 μm (Fig. 1b).

This raises the technological challenge of filling cracks by radioactive source without voids, which requires additional nickel sub-layer before application [10]. Finally, a third option involves the creation structures with *p-n* junction and has a metal-oxide-semiconductor junction (Fig. 1c).



a) the structure of the electricity source, which consists of series-connected planar monoSi batteries,
b) the slotted design electricity source consisting of parallel vertical *p-n* junctions formed on mono or silicon microchannel,
c) the hybrid design of the SE consisting of layers of phosphor converting electronic radiation to photon radiation

Fig. 1 – Most competing designs BVB

3. RESULTS AND DISCUSSION

For the numerical current generation analysis, efficiency and collection efficiency of generated charge carriers for structures, it is necessary to determine the optimal values of the geometric dimensions of *p*- and *n*- regions in each structure. For this, it is necessary to use the numerical data, which shows that the same carrier collection efficiency can be achieved by various combinations of *p-n* junction depth d and the SCR width of the *w*. By varying only these two parameters for each structure, *d* and *w* values could be calculated, at which developed structures will be most effective. It does not make sense to define the most effective structure; as such structure is with the largest area. It is necessary to calculate the efficiency of the assembly of structures, getting values, normalized to unit volume. Let's call this value as η_V. For clearance let's assume that all the structures area is 1 cm^2 and the thickness is determined by set the parameters of the *p-n* junction depth and SCR width, and the beta-source activity is 10 mCi/cm^2. Selecting the *d* and *w* values was for each structure so that at the one hand the efficiency should be maximum, and the structure thickness – minimum.

Before optimizing parameters it was taken into account the results of [6], which show that due to the self-absorption of beta particles the nickel-63 isotope thickness should be more than 4 μm, and it determines the minimum width of the channels in the structure B. As a result, for all structures it is taken the nickel- 63 layer thickness 4 μm, including a metallization thickness on each side of wall slots in structure B. Taking into account given the data dependence on the collection of charge carriers generated and the diffusion process limit and ion implantation, we take, the following parameters for the structures: the thickness of n$^-$ layer ~ 10 μm, the thickness of the layer n^+ ~ 0.5-1 μm, the thickness of the layer p^+ ~ 0.1-0.3 μm. As a result, the thickness of the structure is obtained ~ 18.6-19.3 μm, and the maximum current generation – 67 nA at the source activity of 10 mCi/cm^2. The calculations show that with further decrease the width of the SCR to 6 μm volumetric efficiency η_V first decreases monotonically, and then at *w* < 4 μm η_V – fast.

For a slit structure was calculated in [6], in which shows that the most effective structures are obtained by crack width of 4 μm, and the distance between the slits – 12 μm, wherein the SCR width is ~ 10 μm. The thickness of this structure may vary, but because as a criterion for the efficiency of current generation is selected based on the size of the structure, to be specific, it can taken a thickness of 100 μm, that will not affect the final result. In this case, generation structure the rated current is 409 nA. Accordingly, for the structure C the substrate thickness. It determines the thickness of the substrate structure as a whole, that together with layer nickel-63 is 14 μm, the current generation will be 69.4 nA.

The calculation results are summarized in Table 1, from which it appears that the most effective structure is the structure S. It should be noted that for the structure of the experimental value of the current generation would be 10-30 % less calculated as isotope nickel-63 will fill the gap by a factor about 0.7-0.9, giving place for cracks. Thus, it is possible, the experimental structures of types A and B can demonstrate about the same efficiency. Efficiency of the structures was calculated as the

Table 1 – Efficiency analysis betavoltaic structures

	A structure	B structure	C structure
Structure width, μm	19	100	14
Generation structure current, nA/cm^2	66.7	409	69.4
Special current per volume, μA/cm^2	350	409	496
Efficiency, %	1.16	1.36	2.43

ratio of the electrical source power to the released per unit time nickel-63 beta source energy, located in the betavoltaic element structure.

4. SUMMARY

The result is that betavoltaic batteries may have relatively high design efficiency factor (up to 30 % based on structure B), but have a low power factor conversion of isotope Ni^{63} power and the effective efficiency of less than 1 %. The main types of structures betavoltaic batteries have prospects for industrial use, and with efficiency of beta radiation conversion into energy and dimensions of existing batteries far from the theoretically possible ones. It is shown that the prospects for improving the effective efficiency are planar betavoltaic batteries.

Thus, on the basis of the numerical calculations for the structures shown the parameters were chosen so that the ratio of the generation current to the structure thickness for them was the highest since the interest is creating three-dimensional assemblies of betavoltaic elements. The highest theoretical efficiency was showed by the assembly based on the structure with efficiency values equal to 2.4 % and the generation current of the order 0.5 mA/cm^3, which can be used commercially to create sensors in the absence of external power sources.

ACKNOWLEDGEMENTS

The current study was supported by the Federal Targeted Program "Research and development on priority directions of scientific-technological complex of Russia for 2014-2020, state contract № 14.575.21.0051 (unique identifier for applied scientific research (project) RFMEFI57514X0051)

REFERENCES

1. M. Lu, G. Zhang, K. Fu, G. Yu, *Energ. Conversion Management* **52** No 4, 1955 (2011).
2. Sh. Yao, Z. Song, X. Wang, H. San, Yu. Yu, *Appl. Radiation Isotope.* **70** No 10, 2388 (2012).
3. H. Chen, L. Jiang, X. Chen, *J. Phys. D: Appl. Phys.* **44** No 21, 215303 (2011).
4. V.V. Svetuhin, V.D. Risovanniy, *Phys. Radiation Effect. Electronic Equip.* **1**, 65 (2011).
5. W. Sun, N.P Kherani, K.D. Hirschman, L.L. Gadeken, Ph.M.A. Fauchet, *Adv. Mater.* **17**, 1230 (2005).
6. A.S. Korolchenko, S.A. Legotin, V.N. Murashev., M.N. Orlova, *Metallurgist* **54** No 5-6, 328 (2010).
7. A.S. Korol'chenko, S.A. Legotin, S.I. Didenko, S.P. Kobeleva, M.N. Orlova, V.N. Murashev, *Russ. Microelectron.* **40** No 8, 620 (2011).
8. V.N. Murashev, A.S. Korolchenko, S.A. Legotin, *Metallurgist* **56** No 3-4, 303 (2012).
9. V.N. Murashev, V.N. Mordkovich, S.A. Legotin, O.I. Rabinovich, A.A. Krasnov, *J. Nano- Electron. Phys.* **6** No 4, 04012 (2014)
10. D.G. Gromov, S.A. Gavrilov, *Phys. Solid State* **51** No 10, 2135 (2009).