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Short Communication

Microchannel Structures of Betavoltaic Silicon Convertors

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The paper presents the first results of experimental research on the microchannel structures of betavoltaic silicon converters based on the ^{63}Ni isotope. The areas for further optimization of constructive and technological performance with high conversion efficiency were detected experimentally.

Keywords: Betavoltic effect of power beta source, Design optimization, Silicon converter.

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1. INTRODUCTION

Unlike conventional planar structures [1, 2], on the front surface of the beta voltaic converters (BVC) by a porous layer is formed. The depth of the microchannels is chosen such that the distance from the bottom was far less than the current diffusion path length of minority carriers (L_{MCC}) from the heavily doped p^+ back contact layer. The distance between the pores should be less than ~ 2 L_{MCC}, the pore diameter is chosen for maximizing the area of the front surface. As shown by the experimental results [3, 4], the implementation of these suggestions will significantly reduce the dependence of the photoelectric convertors (PEC) characteristics, to a microchannel structure (MCS) from the L_{MCC} and, as a consequence converters, have shown increasing radiation resistance. According to its principle of operation, as well as the structure of the semiconductor converter BVC is similar to PEC. If for current generation based on PEC it is necessary sources of light (photons), then for the BVC it is necessary beta radiation sources. One of such sources is the ^{63}Ni isotope, with half-life – 100.1 years. ^{63}Ni specific activity is 57 Ci/g, with a range of beta particles energy is limited by energy 67 keV with maximum at 17.4 keV which is several times smaller than the threshold of defect in silicon (~ 200-250) keV.

2. EXPERIMENTAL PROCEDURES

According to the calculated data, the power density of the silicon isotope ^{63}Ni BVC should be higher than 10^{-8} W·cm^{-2}. Therefore, to increase the power source it is appropriate to use the MCS, allowing forming a three-dimensional (3D) structure of silicon BVC with increased more than magnitude area of effectively working surface. The depth of beta particles penetration with an average energy to silicon is 3-4 μm [5], therefore, the wall thickness between adjacent microchannels must not exceed 8 μm. The thickness of the ^{63}Ni radionuclide layer is determined by its self-absorption and is ~ 2.2 μm [5].

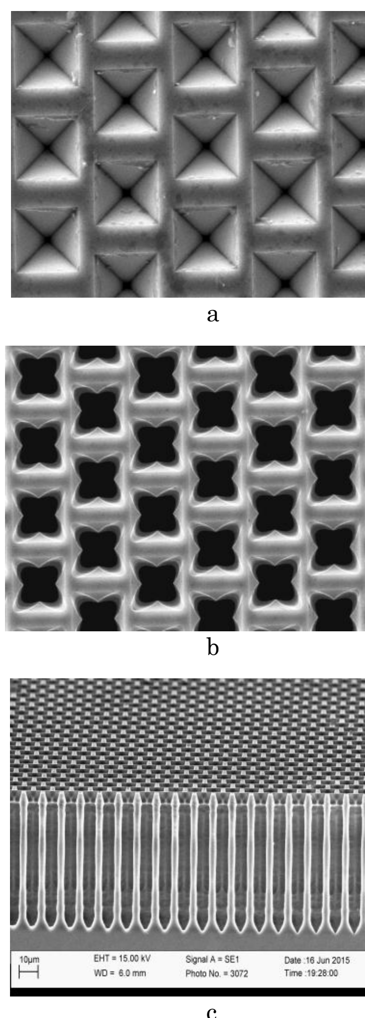

Fig. 1 – SEM image of a silicon structure of BVC. a) type surface of the plates before deep anodic etching. Cellular location of the nucleation centers of pore growth, b) image of the surface after a deep anodic etching, c) image arbitrary cleavage of the MCS

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The most useful way to control a silicon microchannel structure formation with the desired morphology is the method of anodic etching of single crystal silicon. [6] For BVC producing it was used *p*-type silicon with orientation of the surface plates (100) and resistivity of 180-250 Ω cm. Anodic etching plates in a solution of HF: DMF (dimethyl formamide) 1 : 10 at a current constant density of 6 $mA \cdot cm^{-2}$ to make it possible to produce MCS (Fig. 1).

3. RESULTS AND DISCUSSION

Fig. 1a shows the image of the topology and structure of pyramidal seed formed by alkaline etching. The images in Fig. 1 correspond to the surface of (b) and the arbitrary cleavage of plate (c) after anodic etching. The depth of microchannels defined by etching time was varied from 65 to 120 microns. Further processing of silicon wafers with a micro-channel structure corresponds to the standard process of forming a diode structure of PEC. Application of phosphorus for the gas diffusion process allows sufficiently uniformly doping the porous structure throughout the depth with pore diameters from submicrons to several tens of microns and a depth of 500 μm [7]. For PEC and BVC there is no necessity in doping interporous space across the thickness in the lateral direction. On the contrary, the depth of n^+-*p* junction should be as small as possible [1-8]. In our experiment, phosphorus diffusion took place in the standard process at a temperature in the furnace working zone at 900 °C for 10 minutes. The junction depth was 0.4-0.5 μm and was characterized by the required uniformity along the microchannels walls. In contrast to the traditional PEC structure, for BVC there is no need forming *p-i-n* metallization on the front side to the collector. This makes it possible to use the most dense topology and packing microchannels like structure of the "honeycomb" (Fig. 1). Nickel is characterized by an acceptable electrical conductivity and the formation of a continuous metal film with thickness up to 2 μm on the surface of the microchannel supplied an acceptable collector. The role of the metal contact on the front surface layer performs Ti-Ni-^{63}Ni. In the present experiment on the pore surface ^{63}Ni was not precipitated and measuring microchannel BVC characteristics were performed using an external source of beta radiation particles. The source was Ni film with precipitated layer of radioactive ^{63}Ni, covered with a protective Ni film thickness of 1 micron. This multilayer tablet size of 1 cm^2, was placed on the surface of the BVC. Source activity was 2.7 mCi. Battery characteristics were measured by using Agilent 1500 B at room temperature (25 °C) in a light-tight chamber. It can be compared the main electrical parameters I_{sc} and U_{xx} silicon BVC (^{63}Ni) with 3D structures created in this paper and 2D structures [3, 5]: for 3D structures – $I_{sc} = 18$ nA, $U_{xx} = 5$ mV, and, for 2D – 11 nA and 0.8 mV, correspondently.

4. SUMMARY

As follows from the results observed value of energy produced for 3D microchannel BVC structures more than an order of magnitude higher than that of 2D structures produced by a similar process scheme. Further progress to improve the efficiency BVC should be observed after the practical process implementation of forming a continuous layer of radioactive ^{63}Ni on the inner surface of the microchannels. Optimism gives it that technology of nonradioactive nickel deposition in the pores is known and is described in great detail [9].

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