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Study of the electroplated of Ni for betavoltaic battery using PN junction without seed layer

[1]*Young Rang Uhm*,* [2]*Byoung Gun Cho,* [1]*Jong Bum Kim, and* [1]*Kwang Jae Son*

[1]*Radioisotope research Division Korea Atomic Energy Research Institute, 1045 Daeduckdaero, Yuseong-Gu, Daejeon 305-353, Republic of Korea*
[2]*Human Interface SoC Research Section, Electronics and Telecommunications Research Institute, 218 Gajeongro, Yuseong-Gu, Daejeon 305-700, Republic of Korea*
[*]*Corresponding author: uyrang@kaeri.re.kr*

1. Introduction

The power source using the radioactive decay of radioisotopes converted into electricity is able to provide high energy density for several decades, though the device is located in a place unavailable to harvestable energy [1-2]. The mechanism of a nuclear battery is same as the P–N junction diode for solar cell application. The photovoltaic is operated by converting photons into electrical energy in the junction. In a betavoltaic battery, beta particles are collected and converted into electrical energy with a similar principle as a photovoltaic. If a radioisotope (RI) with a long half-life (over 100 years) is used, the lifetime of the power source is extended to as long as the half-life time of the RI. Hence, the power sources we describe could extend a system's operating life by several decades or even a century, during which time the system can gain learned behavior without worrying about the power turning off. The beta spectrum of ^{63}Ni is below the radiation damage threshold (approximately 200 keV for Si) of semiconductors such as Si and SiC. For this reason, it is suitable for a power source of betavoltaic battery within nano to micro watt range [3-4]. In this study, a beta voltaic battery using a ^{63}Ni/Ni substrate attached on a single trenched P-N absorber was fabricated using electroplating. The power output was measured from the I-V curves. The thickness dependent self-shielding effect of the radioisotope layer was investigated [5]. In addition, the beta voltaic battery was newly designed and suggested to increase the power output of the battery.

2. Experimental Technique

To fabricate the P-N absorber, new type of 3D single trenched P-N absorber for easy trenching and doping process was developed by the Electronic Telecommunications Research Institute (ETRI). The process of electroplating using radioactive ^{63}Ni in a hot cell (Bank-2, HANARO research reactor in KAERI) was carried out using a two-step process: the preparation of an ionic solution including ^{63}Ni, and electroplating on a substrate. Nickel (Ni) coatings were deposited by DC electroplating at current densities of 20 mA/cm^2. The deposit condition for the 63Ni is explained in [6]. The basic composition of the bath was 0.2 M Ni and boric acid (H_3BO_3). Ni metal powders were dissolved in a mixture of HCl and distilled water. Boric acid is used in nickel-plating solutions for buffering purposes. The pH of the bath was adjusted to 4.0 ± 0.2 by the addition of KOH. The dimension of deposit layer on a P-N junction is 4 × 4 mm^2 as an anode.

The thickness dependent self-shielding effect of the radioisotope layer was studied using a Geant4 Monte Carlo code [7]. The IV characteristics of a ^{63}Ni-coated semiconductor were investigated using a Probe Station of the Precision Source/Measure Unit, B2911A.

3. Results and discussion

To evaluate the P-N junction prepared by ETRI, the electron beam induced current technique has been employed to experimentally simulate the beta emission of ^{63}Ni and to estimate the total device current [5]. From the e-beam illumination test, we confirmed the good operation of PN absorber. A Ni-plating solution is prepared by dissolving metal particles, and the deposition conditions have been optimized by studying the influence of the current density in a previous study. In addition, the proposed prototype condition was applied to radioactive ^{63}Ni electroplating. The electroplating was carried out through two-step processes such as the preparation of an ionic solution including ^{63}Ni, and coating processes on the substrate. The prototype of electroplating ^{63}Ni was carried out in a glove box in a hot cell (Bank-2, HANARO Reactor in KAERI). The specific radioactivity of the electroplated Ni on the foil with dimension (1 × 1 cm^2) including ^{63}Ni was estimated to be about 2.5 mCi. The nominal specific activity was measured by a portable activity meter (PAM 1704). In addition, we prepared electroplated ^{63}Ni with the specific activity of 0.45 mCi for the characteristics of a nuclear battery. The current density was determined as 20 mA/cm^2. The proposed prototype for the synthesis can be applied to the electroplating radioactive ^{63}Ni. An accurate measurement for the specific radioactivity electroplated ^{63}Ni will be carried out in a future study. The range of the beta particles and the location of their deposited energy are deep within the silicon substrate. The penetration depth of the particles in the silicon device was reported in a Katz-Penfold range equation [7]. This equation considers only the density of the materials and energy of the particles. From the equation, the maximum range of the average beta particles energy from 63Ni into silicon is 2.2 μm. This effectively determines the depth of the depletion region required. We modeled the energy deposition as a function of the depth in the silicon using the Monte Carlo code. We attached prepared beta source on the P-N junction using vacuum. The I-V curves of both dark and deposited ^{63}Ni show almost the same values. The difference between the pre-deposition (dark) and deposited ^{63}Ni can be obtained through a magnification of the I-V curve. The difference of the short circuit current between the pre-deposition and post deposition of 63Ni on foil with a thickness of about 3 μm was found to be 5.03 nA. This value of a single cell operated at the nominal specific radioactivity, 0.45 mCi was approximately same comparing with previous measured a single cell with seed layer on the P-N junction at 2.5 mCi. In this study, ^{63}Ni particles were coated on Ni-foil as a beta source, and directly attached on P-N junction without seed layer. So that, the self-shielding effect of beta particles due to seed layer was erased. Though a power output was enhanced, a very low current with range from nano to micro ampere was generated in the devices. Adjusting the P–N junction and depletion region depths are keys to higher device performance. Once a parametric study on the effect of these parameters on the performance of the planar P–N device is conducted, a newly designed device with a sandwich structure will be suggested. To fabricate a betavoltaic, ^{63}Ni should be coated on the double side of the substrate. Figure 1 represents a SEM image of electroplated Ni on double side of a Ni-foil. A schematic of the device with sandwich structure is shown in Fig. 2.

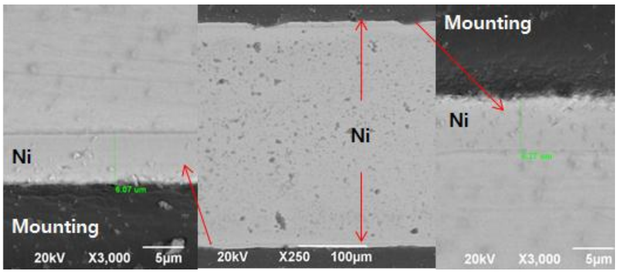

Fig. 1 SEM image of the cross section for electroplated Ni on double side of a Ni-foil.

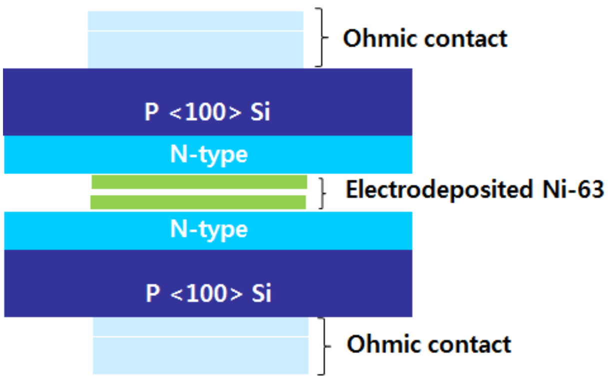

Fig. 2 Cross-sectional schematic of ^{63}Ni on the P–N junction in RI battery with a sandwich structure

4. Conclusions

Beta particles of 63Ni were deposited by electroplating on the Ni-foil substrate and attached on the trench P-N absorber with a spacing of 50 μm. The optimum total thickness of the 63Ni layer was determined to be about 2 μm, when regarding the minimum self-shielding effect of the beta-ray (β-ray). The optimum condition of the electroplating ^{63}Ni was determined at current density of 20 mA/cm^2. The difference in the short circuit current between the pre-deposition and post deposition of ^{63}Ni (0.45 mCi) on Ni foil with a thickness of about 3 μm was found to be 5.03 nA. In this study, a relatively enhanced power output at a single cell was achieved, though the specific radioactivity of power source was lower value than those prepared by other groups [8].

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