Nuclear Engineering and Technology 48 (2016) 773–777

Available online at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

Study of a Betavoltaic Battery Using Electroplated Nickel-63 on Nickel Foil as a Power Source

Young Rang Uhm [a,*], *Byoung Gun Choi* [b,*], *Jong Bum Kim* [a], *Dong-Hyuk Jeong* [c], *and Kwang Jae Son* [a]

[a] *Radioisotope Research Division, Korea Atomic Energy Research Institute (KAERI), 989-111, Daedeokdaro, Yuseong, Daejeon 34056, South Korea*

[b] *Human Interface SoC Research Section, Electronics and Telecommunications Research Institute (ETRI), 218 Gajungro, Yuseong, Daejeon 34129, South Korea*

[c] *Dongnam Institute of Radiological and Medical Science, 40 Jwadong-gil, Gijang, Busan 46033, South Korea*

ARTICLE INFO

Article history:
Received 7 August 2015
Received in revised form
8 January 2016
Accepted 25 January 2016
Available online 26 February 2016

Keywords:
Betavoltaic Battery with Sandwich Structure
^{63}Nickel
Radioisotope Battery
Electroplating

ABSTRACT

A betavoltaic battery was prepared using radioactive ^{63}Ni attached to a three-dimensional single trenched P–N absorber. The optimum thickness of a ^{63}Ni layer was determined to be approximately 2 μm, considering the minimum self-shielding effect of beta particles. Electroplating of radioactive ^{63}Ni on a nickel (Ni) foil was carried out at a current density of 20 mA/cm^2. The difference of the short-circuit currents (I_{sc}) between the pre- and post-deposition of ^{63}Ni (16.65 MBq) on the P–N junction was 5.03 nA, as obtained from the I–V characteristics. An improved design with a sandwich structure was provided for enhancing performance.

1. Introduction

Electricity generated by the decay of radioisotopes can provide a high energy density for several decades, although the device is located in a place inaccessible to harvestable energy [1,2]. The mechanism of a nuclear battery is the same as that of a P–N junction diode for solar cell application. A photovoltaic battery is operated by converting photons into electrical energy in the junction. In a betavoltaic battery, beta particles are collected and converted into electrical energy by a similar principle to that used in a photovoltaic battery. A very low current, of the order of nano- or microamperes, is generated in the devices [3]. If a radioisotope 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 radioisotope. Some special applications require long-lived compact power sources [4,5].

* *Corresponding authors.*
E-mail addresses: uyrang@kaeri.re.kr (Y.R. Uhm), cbgun@etri.re.kr (B.G. Choi).
http://dx.doi.org/10.1016/j.net.2016.01.010

These include space equipment, sensors in remote locations (space, underground, etc.), and implantable medical devices. The power source of the radioisotope shows that a larger amount of energy released per reaction than that release during the conversion of chemical energy into electricity [6,7]. A radioisotope battery is a novel solution for solving the power needs of these applications [8–10]. For the ^{63}Ni beta source that we used, the half-life is 100.2 years [2]. Hence, the power sources can extend a system's operating life by several decades or even by a century, during which time the system can gain 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 [4]. In addition, ^{63}Ni is easier to handle than other beta particles such as ^{3}H, ^{90}Sr, and ^{147}Pm because of its low energy spectrum and solid-metal form. For this reason, it is suitable for the power source of betavoltaic batteries to be within the nano- to microwatt range [8–10]. There are several methods for forming nickel (Ni) deposits onto a substrate, such as electroplating, electroless plating, and chemical vapor deposition [11]. Among them, the electroplating process is most commonly used for Ni deposition when using ^{63}Ni as a power source for batteries. Radioactive thin-film-based power sources also have energy densities that are several orders of magnitude higher than chemical-reaction-based energy sources. This enables submillimeter-scale power sources, which is significant given the crucial role of the metrics of power and energy density in determining the usefulness of pervasive computing systems' applications with limited size.

The aim of this work is to optimize the method and conditions of electroplating to maximize the electrical efficiency of a betavoltaic battery using radioactive ^{63}Ni. In this study, a betavoltaic battery was fabricated using ^{63}Ni attached on a P–N junction semiconductor, and the *I–V* characteristics were measured using a probe station. The thickness-dependent self-shielding effect of the radioisotope layer was investigated [12]. In addition, a betavoltaic battery was newly designed and is suggested as a means of increasing the power output of the battery.

2. Materials and methods

To fabricate the P–N absorber, a new type of three-dimensional single trenched P–N absorber for easy trenching and doping was developed by the Electronic Telecommunications Research Institute. The P–N spacing was 50 μm. To measure the power output of a single cell, a ^{63}Ni beta source was deposited on the substrate, and the unsealed source was attached on a P–N junction using vacuum.

The process of electroplating using radioactive ^{63}Ni in a hot cell (Bank-2, HANARO research reactor in Korea Atomic Energy Research Institute) was carried out using a two-step process: preparation of an ionic solution including ^{63}Ni and electroplating on a substrate. Ni coatings were deposited by DC electroplating at a current density of 20 mA/cm^2. The deposition condition for ^{63}Ni is explained in the works of Uhm et al [13]. The basic composition of the chloride bath was 0.166M Ni and 0.4M boric acid (H_3BO_3). Ni metal powders were dissolved in a mixture of HCl and distilled water. Boric acid is used in Ni-plating solutions for buffering purposes. The pH of the bath was adjusted to 4.0 ± 0.2 by the addition of KOH. Dimension of the layer deposited as an anode on a P–N junction is 4 × 4 mm^2.

The thickness-dependent self-shielding effect of the radioisotope layer and the penetration depth of the beta particles in Si were studied using a Geant4 Monte Carlo code [14]. The *I–V* characteristics of a ^{63}Ni-attached semiconductor were investigated using a probe station of the Precision Source/Measure Unit, B2911A. Radioactivities were estimated by comparing the measurements of a liquid scintillation counter (Tri-Carb 2910 TR; PerkinEmer Co. Waltham, Massachusetts, USA) for the bath before and after electroplating. The standard solution for ^{63}Ni was 100.6 μCi/5 mL in 0.1N HCl.

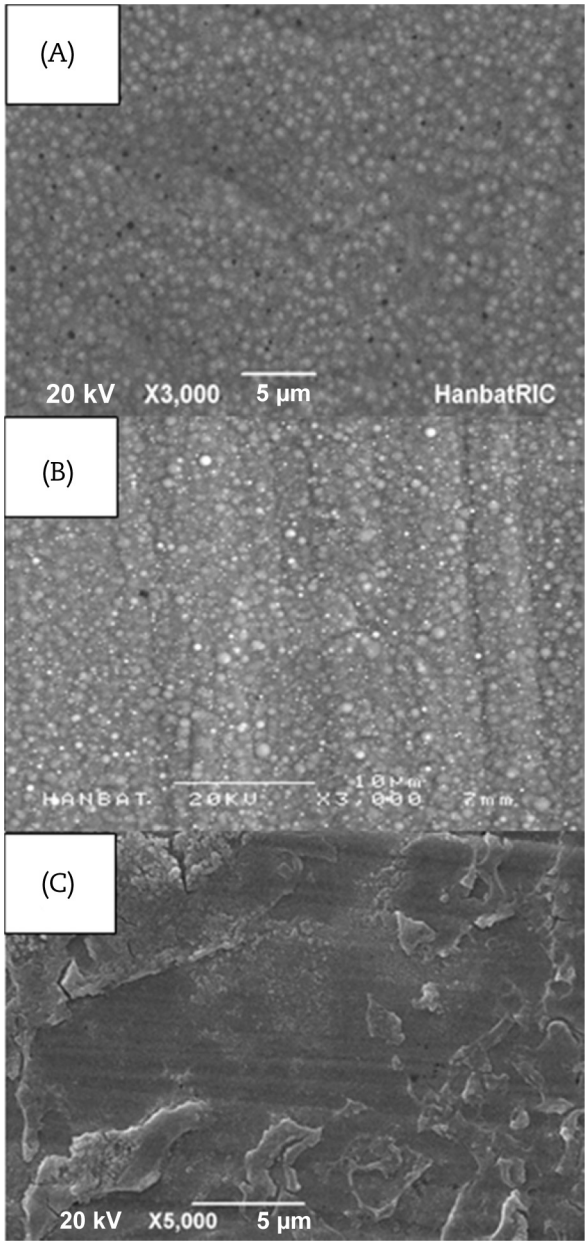

Fig. 1 – SEM images for electroplated Ni on Ni foil. Electrodeposition at a current density of (A) 10 mA/cm^2, (B) 20 mA/cm^2, and (C) 30 mA/cm^2.