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Performance evaluation of Ni-63 betavoltaic battery

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1. Introduction

A betavoltaic battery is a device that converts the decay energy of radioisotopes into electric energy [1,2]. It is widely used in low-power applications such as medical applications and power sources for MEMS because they can operate effectively under extreme environmental conditions [3]. Ni-63, a pure beta emitter, has a low energy (E_{avg} = 17.4 keV) and a significantly long half-life (100.1 years). For this reason, Ni-63 is suitable for the power source of a betavoltaic battery [4,5].

In this study, the fabrication process of a Ni-63 foil as the energy source of a radioisotope battery was developed using 0.05 M Ni-63. A procedure for forming a Ni-63 thin flim(a micrometer level) onto a Ni sheet was established using acid-based buffer (pH 4) containing boric acid, sodium chloride, saccharin and tween 20. And an electroplating bath for small-scale Ni-63 electroplating was manufactured. These procedures and the manufactured electroplating bath was applied to radioactive Ni-63 electroplating for the fabrication of a Ni-63 foil after finishing the fundamental experiment using stable isotope Ni. The radioactivity of fabricated Ni-63 foil is about 37.37 mCi/cm^2. It was bonded to the Si-based semiconductor, and then short circuit current (I_{sc}) and open circuit voltage (V_{oc}) were measured.

2. Methods and Results

2.1 Fabrication of Ni-63 foil

Table I: Composition and condition of Ni electroplating

Bath composition	
$^{63}NiCl_2$	0.05M
H_3BO_3	0.4 M
NaCl	0.7 M
Saccharin	0.00829 M
Tween 20	0.5 %
Bath condition	
Temperature	40 °C
Substrate dimension	1 × 1 cm^2
Current density	15 mA/cm^2
Cathode	Ni foil
Anode	Pt-coated Ti mesh
pH	4.0

The Ni coatings were deposited by DC electroplating at current densities of 15 mA/cm^2. The basic composition of the bath was 0.05 M Ni and 0.4 M boric acid (H_3BO_3). The pH of the bath was adjusted to 4.0. The composition and condition of Ni electroplating are shown in Table 1. A nickel foil with dimensions of 17 × 17 × 0.125 mm^3 was used as a cathode and a Pt-coated Ti mesh with dimensions of 10 × 10 × 1 mm^3 was used as an anode. A Ni foil with a high purity of 99.99 % was used as the substrate. The deposition time was adjusted to achieve an average thickness of 3 μm based on Faraday's law [6].

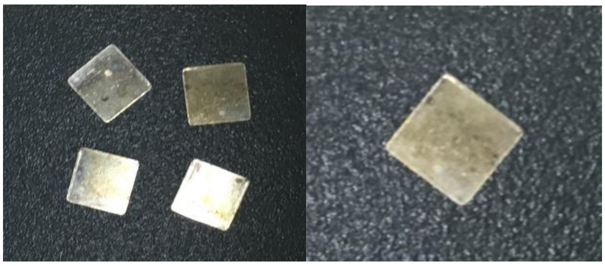

Fig. 1. Image of fabricated Ni-63 foil at current density of 15 mA/cm^2. The size of Ni-63 foil is 4 x 4 mm^2.

Figure 1 presents images for electrodeposited Ni on the Ni foil at current densities of 15 mA/cm^2. The thickness of the Ni-coated Ni foil was estimated 2.5 ~ 3.0 μm, and the size of single foil is 4 × 4 mm^2.

2.2 Radioactivity measurement of Ni-63 foil

Fig. 2. Liquid Scintillation Counter (LSC)

The radioactivity of fabricated Ni-63 foil is measured by Liquid Scintillation Counter (LSC, Tri-Carb 2910 TR, Perkin Elmer). Ni-63 standard source was purchased from Eckert & Ziegler Isotope Products, and its specific activity is 20.12 μCi/ml. Ultima gold was used as LSC cocktail. For radioactivity measurement of Ni-63 onto Ni foil, the plating buffer before electroplating was compared with the buffer after electroplating. The CPM and DPM values of Ni-63 are shown in table 1. An average DPM value of buffer before plating was 309,556 and buffer after plating was 106,414, respectively. It means that approximately 66% of the Ni-63 in buffer before plating(56.625 mCi) was deposited onto Ni foil, therefore, the radioactivity of Ni-63 on Ni foil is about 37.37 mCi/cm^2.

Table Ⅰ: The values of CPM and DPM of before and after the Ni-63 electroplating

	Time (m)	CPM	DPM
Before electroplating	30	239,359	303,321
	30	242,161	311,091
	30	246,559	314,256
After electroplating	30	82,355	106,036
	30	82,835	106,594
	30	82,744	106,613

2.3 Measurement of power output

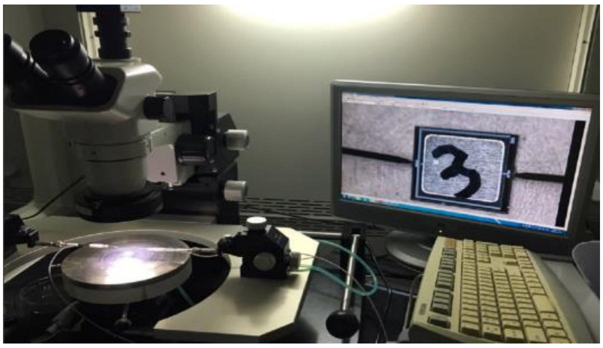

Fig. 3. Probe Station of the Precision Source/Measure Unit, B2911A

The IV characteristics of a Ni-63 foil placed onto Si-based semiconductor were investigated using Probe Station of the Precision Source/Measure Unit, B2911A (Fig. 3). As shown in Fig. 4, the open circuit voltage was found to be 48 mV, and the short circuit current was 8.7 nA. The power output was found to be 0.42 nW, and maximum output power density was 2.62 nW/cm^2. These results mean that the power output value increased about twice as compared with the Ni-63 foil manufactured earlier.

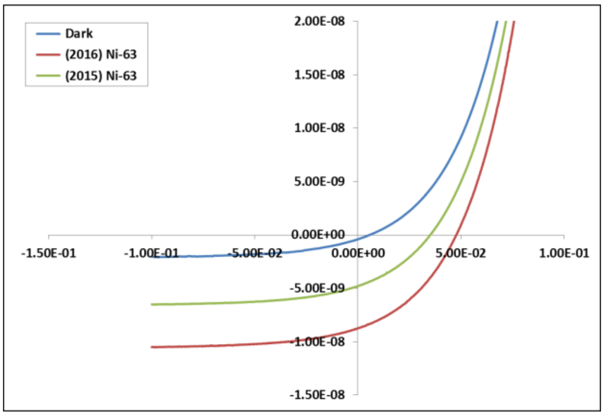

Fig. 4. IV characteristics for Ni-63 foil placed onto Si-based semiconductor.

3. Conclusions

In this study, the fabrication process of a Ni-63 foil as the energy source of a radioisotope battery was developed using 0.05 M Ni-63. And an electroplating bath for small-scale Ni-63 electroplating was manufactured. These procedures and the manufactured electroplating bath was applied to radioactive Ni-63 electroplating for the fabrication of a Ni-63 foil after finishing the fundamental experiment using stable isotope Ni. The radioactivity of fabricated Ni-63 foil is about 37.37 mCi/cm^2. It was placed onto the Si-based semiconductor, and then short circuit current (I_{sc}) and open circuit voltage (V_{oc}) were measured. The output power density was 2.62 nW/cm^2.

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