Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Simulation of Ni-63 based nuclear micro battery using Monte Carlo modeling

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1. Introduction

Nuclear battery research was started from 1960s by USA and the Soviet Union as a center. At that time, the selected sources of radioisotope battery emitted high level of radiation. Therefore, the application range was limited to extreme environment like space exploration or ocean exploration.

Until now, the battery that widely used in human life has been lithium ion battery. However, it has the limitation of specific energy and energy density. The radioisotope batteries have an energy density of 100-10000 times greater than chemical batteries[1]. Also, Li ion battery has the fundamental problems such as short life time and requires recharge system. In addition to these things, the existing batteries are hard to operate at internal human body, national defense arms or space environment. Since the development of semiconductor process and materials technology, the micro device is much more integrated. It is expected that, based on new semiconductor technology, the conversion device efficiency of betavoltaic battery will be highly increased. Furthermore, the radioactivity from the beta particle cannot penetrate a skin of human body, so it is safer than Li battery which has the probability to explosion.

In the other words, the interest for radioisotope battery is increased because it can be applicable to an artificial internal organ power source without recharge and replacement, micro sensor applied to arctic and special environment, small size military equipment and space industry. However, there is not enough data for beta particle fluence from radioisotope source using nuclear battery. Beta particle fluence directly influences on battery efficiency and it is seriously affected by radioisotope source thickness because of self-absorption effect.

Therefore, in this article, we present a basic design of Ni-63 nuclear battery and simulation data of beta particle fluence with various thickness of radioisotope source and design of battery.

2. Experiment and Data Analysis

2.1. Battery Design

A nuclear battery is mainly consisted of 2 parts. First part is radioisotope part and the second part is conversion device part. In this simulation, we used Ni-63 as the radioisotope source, and silicon based semiconductor is used for conversion device[2]. The sample design of battery is like following.

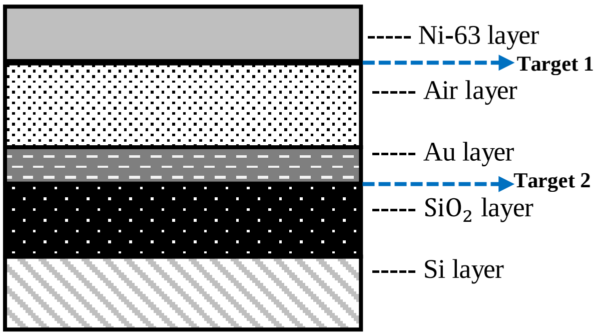

Fig. 1. Schematic design of nuclear battery

We design nuclear battery simulation model as 2 types, one is a rectangular parallelepiped structure and the other one is cylinder type. In the rectangular type, the length and width are both 1cm and height is changed by increasing the radioisotope source thickness. In the cylinder type, the diameter is 1cm and the other dimension of nuclear battery is demonstrated in following table.

Table 1. Dimension of nuclear battery simulation model

Layer Type	Thickness
Ni-63 Layer	0.1μm ~ 1.5μm
Air Layer	1mm
Au Layer	30nm
SiO_2 Layer	2nm
Si Layer	1.3mm

Top layer is Ni-63 radioisotope source and it is the most important part in this simulation. With changing the thickness of Ni-63 layer from 0.1μm to 1.5μm. The fluence data is measured at Target 1 and Target 2 layer. Target 1 fluence means the number of beta particle which emits from radioisotope source toward –Z direction and Target 2 fluence means the number of beta particle which goes into semiconductor layer.

2.2. MCNP Simulation

MCNP Simulation is conducted by 2 different cases. We design battery sample model as rectangular model and cylinder model. The total radioactivity of rectangular shape nuclear battery is 5.06 ~ 75.9 mCi, and this change is caused by the radioisotope source thickness difference. Also the radioactivity of cylinder shape nuclear battery is from 3.97 ~ 59.6 mCi. In addition, we consider dopant concentration is so lower than Si concentration, that we neglect the dopant during the MCNP simulation.

3. Result

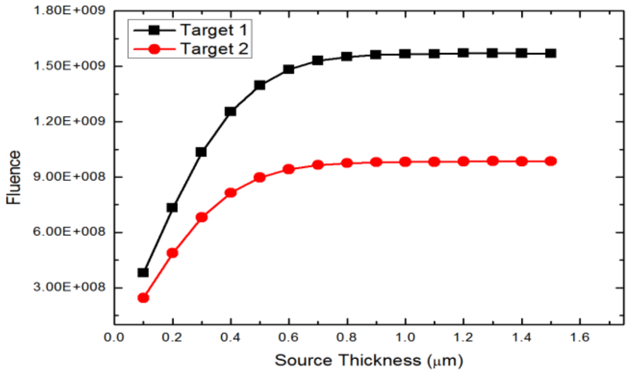

Fig. 2. Rectangular model MCNP simulation result

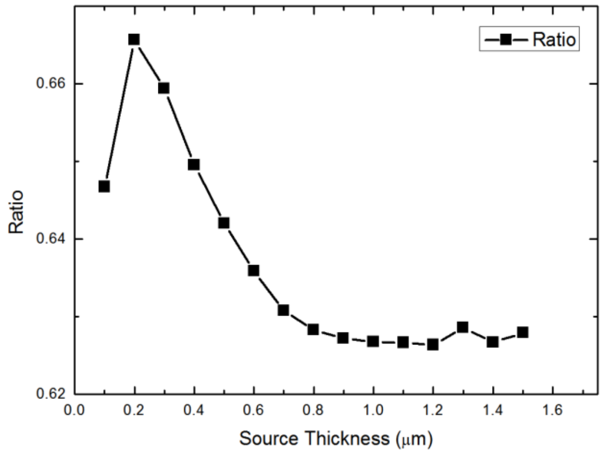

Fig. 3. Efficiency of beta particle in rectangular model

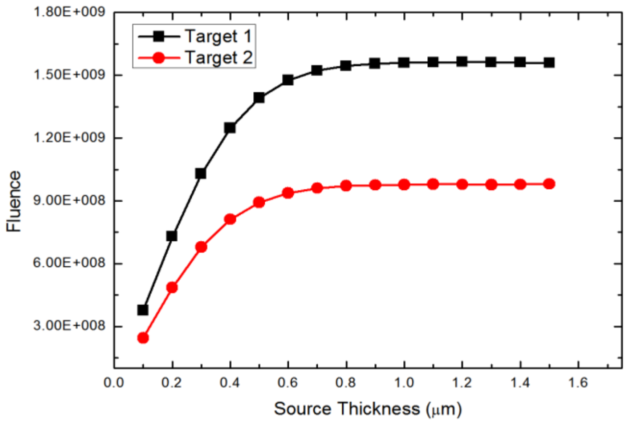

Fig. 4 Cylinder model MCNP simulation result

4. Discussion

This study is focused on how source thickness and shape affect the beta particle fluence.

As shown in the result data, the fluence of beta particle which is emits from source layer is increased while the source thickness is near 0.8μm, and the after this thickness the fluence is converged. The total electron fluence is increased because radioactivity is increase, but also the self-absorption effect is dominant when the source thickness is above 0.8μm.

Likewise, the shape of nuclear battery influences to beta particle fluence. The total radioactivity is smaller in cylinder type than rectangular type because of volume difference (about 78.5%). However, the absolute value of beta particle fluence is almost same and the efficiency of the beta particles going into semiconductor device is increased by reducing the ratio of beta particle going out through surface. The surface area is smaller in cylinder shape than rectangular shape, so the probability of leaving beta particle is decreased.

5. Summary

In this study, the thickness and the shape of nuclear battery is changed and the beta particle fluence at bottom of source layer and top SiO_2 layer. From MCNP simulation, we can figure out that the optimum thickness of source layer is about 0.8 μm and the cylindrical shape has the better efficiency than rectangular shape.

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