Simulation about Self-absorption of Ni-63 Nuclear Battery Using Monte Carlo Code

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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.

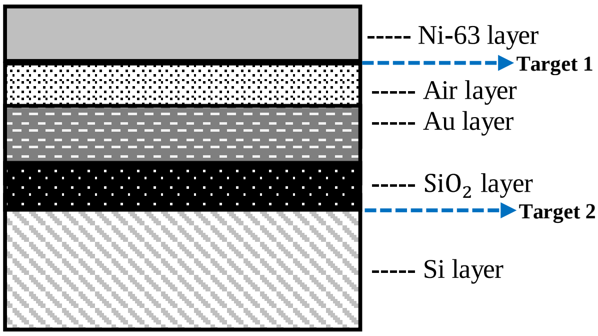

Fig. 1. Schematic design of nuclear battery

The nuclear battery simulation model is designed 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 100µm and height is changed by increasing the radioisotope source thickness.

In the cylinder type, the diameter is 1cm and the other parameters of nuclear battery are 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 20µm. 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 silicon wafer layer.

2.2. MCNP Simulation

MCNP Simulation is conducted by 2 different cases. A sample model is designed as rectangular model and cylinder model. The total radioactivity of rectangular shape nuclear battery is 5.10 ~ 1010 mCi, and this change is caused by the radioisotope source thickness difference. Also the radioactivity of cylinder shape nuclear battery is from 3.97 ~ 794 mCi. In addition, the dopant concentration is so lower than Si concentration, that the dopant is neglected during the MCNP simulation.

The simulation is conducted by the latest version of MCNP, MCNP 6.

3. Result

The error of simulation is controlled and the value of it is under 0.05. Following figures are the results of MCNP simulation.

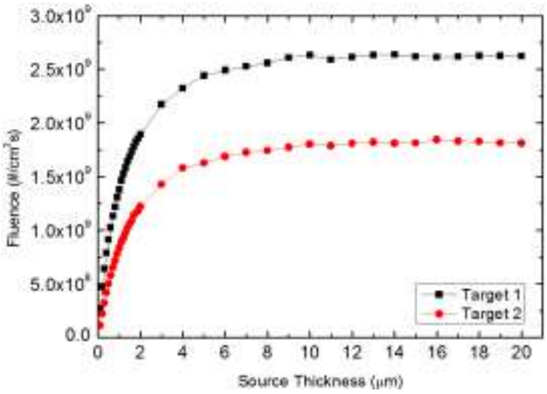

Fig. 2 Rectangular model MCNP simulation result

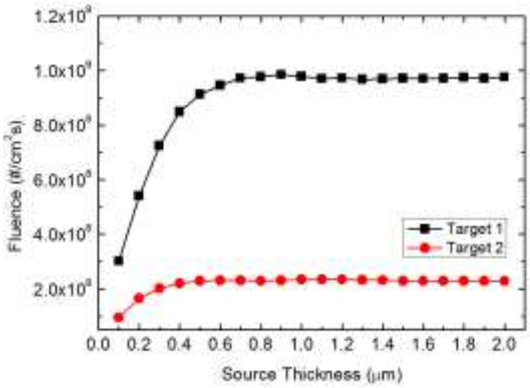

Fig. 3 Cylinder model MCNP simulation result

As the thickness is increased, the total volume of nuclear battery is also increased, and it causes the beta particle fluence enhancement. However, because of the self-absorption effect of metal layer, the fluence is converged when the thickness is around 10μm, in the rectangular simulation case. The following figure shows the effect of beta particle self-absorption in metal.

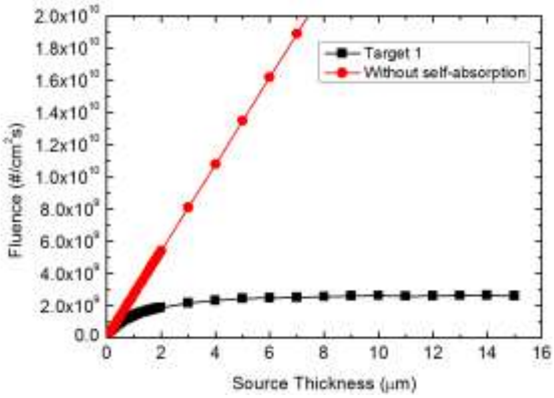

Fig. 4 Self-absorption effect in rectangular model

The empirical formula of self-absorption effect is following.

$$\frac{\text{\# of particle leaving source with self-absorption}}{\text{\# of particle leaving source without self-absorption}} = \frac{1}{t\mu}(1-e^{-t\mu})$$

,when t is the thickness of metal and μ is the attenuation coefficient of Ni-63. In this calculation, the thickness is 10μm, because it is the most suitable value from the simulation result.

$$\mu = 1.7E_{max}^{-1.14} = 1.7(0.066\text{MeV})^{-1.14} = 520.2\text{m}^2/\text{kg}$$

The density of Ni-63 is 8910kg/m^3, therefore the value of tμ is 46.35, and the self-absorption rate of Ni-63 is 0.021.

In cylinder case, the fluence is saturated when the thickness is around 0.8μm, because of self-absorption effect.

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 emitted from source layer is increased while the source thickness is near 10μm. The thickness is over than that value, the fluence is converged. The total electron fluence is increased because radioactivity is increased, but also the self-absorption effect is dominant when the source thickness is above 10μm.

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 SiO2 layer is obtained. From MCNP simulation, the optimum thickness of source layer is about 10μm (rectangular case) and the self-absorption effect of Ni-63 is considered.

Acknowledgements

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