Simulation on the optimum thickness of Ni-63 for nuclear battery development

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1. Introduction

A nuclear battery is an electrical device to obtain the electrical power using radiations from a radioisotope [1]. The beta-ray emitting radioisotopes such as H-3, Ni-63, Pm-147, Tc-99 were used for producing the nuclear battery. Specifically, long half-life (>50 years) radioisotopes were preferred for developing a long-life battery. Recently, the nuclear battery is considered to be an alternate energy source.

The efficiency of the output power of the nuclear battery can be improved by changing the fabrication process. Designing the shape of the radioisotope and the semiconductor structures, and determining the type of the elements in the battery in manufacturing process were required before the production of the nuclear battery [2]. In this study, the flat Ni-63 sources with various thicknesses were simulated to maximize the efficiency of the transfer of the total energy of beta-rays into the electrical power.

2. Methods

The two dimensional planar geometry was used as a simple nuclear battery in this simulation. Monte Carlo simulations were performed to obtain the energy deposition in the semiconductor region as a function of thickness of the thin Ni-63 layer.

2.1 Geometry

The geometrical configurations in this study were shown in Fig. 1. The primary parts of the nuclear battery, including the thin Ni-63 source and the silicon layer, were shown in the figure. In this figure, the contact layer which consisted of the thin Ni and Ti plates located in between the source and the silicon layers. The contact layer was used to improve the electrical contact with the both layers. The beta-rays from the Ni-63 source were isotropically emitted to random directions. In this geometry, approximately a half of the total beta-rays would go towards the silicon layer [3].

Fig. 1. Geometry for the simulation of nuclear battery.

2.2 Energy spectrum

The maximum energy of the beta-ray from the Ni-63 source was about 67 keV. Due to the lack of the measured energy spectrum data, the ENDF radioactive data from the NNDC (National Nuclear Data Center) database were used in the simulation. The reproduced energy spectrum from the graph of NNDC database was shown in Fig 2.

In this spectrum, a lot of low energy beta-rays were emitted and the emission probability of a beta-ray was inversely proportional to its energy. The low energy beta-ray with a short CSDA range in the contact layer never arrived at the silicon layer.

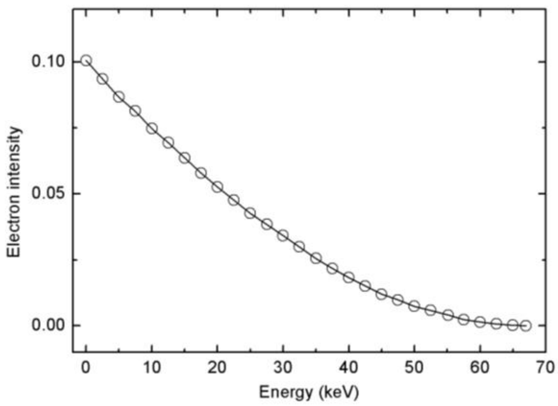

Fig. 2. Energy spectrum of beta-rays emitted from Ni-63 nucleus.

2.3 Simulation

Geant4 (Ver. 9.4.p02) Monte Carlo code, a tool kit for the simulation of the passage of the beta-rays, was used for this simulation. The Livermore physics model, which is specifically designed for the low energy particles, was chosen among the three electromagnetic physics models provided by Geant4. The simulations were performed to calculate the energy deposition in the silicon as a function of the thickness of the source layer. The calculations contained the basic characteristics of the energy deposition along the depth in the silicon for a mono energetic beta-ray. In the simulations, the cut-off range of the electron was 0.001 μm [4].

3. Results

3.1 Penetration depth in silicon

The energy deposition of the beta-rays from the Ni-63 source with the various depths of the silicon layer was shown in Fig. 3. The energy deposition curve decreased exponentially as the most of the low energy beta-rays from the Ni-63 source were deposited within the first few μm of depth. The maximum penetration depth of the beta-rays in the silicon layer was 16 μm.

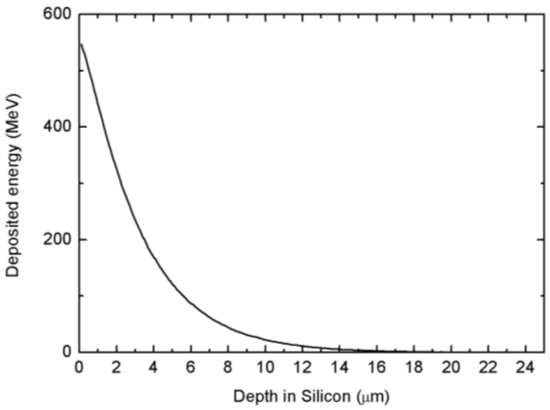

Fig. 3. The energy deposition in the silicon layer.

3.2 Optimum thickness of Ni-63

The beta-ray intensities reached to the silicon layer under the consideration of the self absorption within the Ni-63 sources with various thicknesses were shown in Fig. 4. The beta-ray emission was increased with the thicker source due to the increase in amount of the Ni-63 source at the beginning. However, the increment in intensity started to become slower as the amount of the self absorbed beta-rays increased rapidly from the thickness of 1.6 μm. Therefore, the optimized thickness with regard to the maximum intensity reached to the silicon layer was 2 μm.

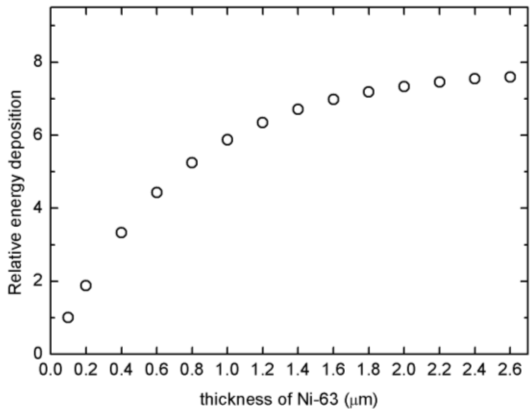

Fig. 4. Monte Carlo calculated energy deposition in silicon as a function of thickness of Ni-63 layer.

4. Conclusions

The minimum thicknesses of the silicon layer and the Ni-63 source in the nuclear battery for the optimized efficiency were determined to be 16 μm and 2.0 μm respectively. This simulation results would be applied to the development in the high efficiency nuclear battery. Further study to determine the geometry and the shape of the radioisotopes and the semiconductors for developing the more efficient nuclear battery would be desired.

Acknowledgement

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