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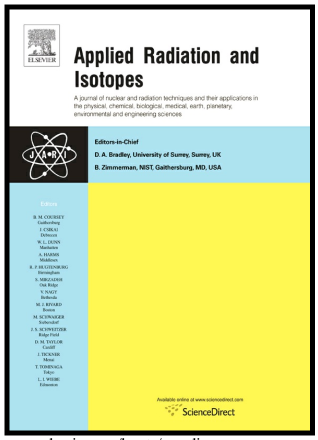

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PII: S0969-8043(17)31441-0
DOI: https://doi.org/10.1016/j.apradiso.2018.09.017
Reference: ARI8487

To appear in: *Applied Radiation and Isotopes*

Received date: 20 December 2017
Revised date: 6 September 2018
Accepted date: 13 September 2018

Cite this article as: Meng Wu, Shumin Wang, Yi Ou and Weibing Wang, Optimization design of betavoltaic battery based on titanium tritide and silicon using Monte Carlo code, *Applied Radiation and Isotopes,* https://doi.org/10.1016/j.apradiso.2018.09.017

Optimization design of betavoltaic battery based on titanium tritide and silicon using Monte Carlo code

Meng Wu[a], Shumin Wang[a], Yi Ou[b], Weibing Wang[b]

[a]Institute of Microelectronics, Peking University, Beijing, 100871, P. R. China
[b]Institute of Microelectronics of Chinese Academy of Sciences, Beijing, 100029, P. R. China

Abstract

This article presents the optimization design and simulation of a betavoltaic battery composed of a silicon p-n junction converter and a titanium tritide film as an isotope source. The self-absorption of β particles emitted from the tritium radioisotope in the titanium tritide film and the energy deposition of β particles in the silicon converter are investigated by the Monte Carlo simulation with the Geant4 radiation transport toolkit. The relationships between doping concentrations and basic parameters such as depletion region width, minority carrier diffusion length and leakage current of the PN junction are discussed through the calculation formulas. By optimizing the doping concentrations in the P-type and N-type regions, the optimized betavoltaic battery can maximize the output power and the conversion efficiency based on the energy deposition in the silicon. The results show that the optimal thickness of the titanium tritide film is about 0.7 um and the optimal doping concentrations of the battery with a PN junction depth of 50 nm are $N_a = 5.75\times10^{19} cm^{-3}$, $N_d = 2.95\times10^{18} cm^{-3}$. Under these parameters, the size $1mm\times1mm$ proposed battery with 2.9mCi/mm^2 ^{3}H can achieve the output power 0.902 nW and the conversion efficiency 0.91%. The open circuit voltage, short circuit current and fill factor of the battery are 0.389V, 3.03nA and 0.766, respectively.

Keywords: Betavoltaic battery; Titanium tritide; Geant4; PN junction; Self-absorption; Optimization design.

1. Introduction

In recent years, betavoltaic batteries are increasingly studied by many research institutions for powering wireless sensor networks due to their high energy density, long working life and anti-interference. Summing up previous studies of betavoltaic batteries, Stanford University proposed to improve the energy conversion efficiency by reasonably matching the range of absorption of β particles and the diffusion length of electron-hole pairs in converters (Coso et al., 2015). A power output of 1.52nW/cm^2 betavoltaic battery with an efficiency of 1.68% was achieved by National University of Science and Technology in Russia (Krasnov et al., 2016). Korea Atomic Energy Research Institute fabricated 3D silicon PN junction betavoltaic batteries with vertical electrode structure and studied the effect of PN electrode spacing on battery performance (Choi et al., 2015). Betavoltaic batteries can convert kinetic energy of β particles emitted from radioactive isotopes into electrical energy with p-n junction converters. Numerous electron-hole pairs (EHPs) are produced in the junction as β particles entering the converters. The build-in electric field of the junction’s depletion region separates EHPs, holes drifting to the P region, while electrons drifting to the N region. The separated holes and electrons are collected to produce voltage and current by the electrodes (Rappaport, 1954).