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C-beta energy converter efficiency modeling

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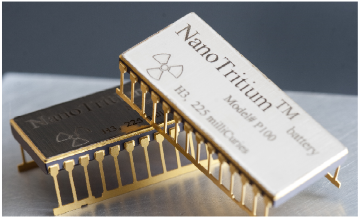
Introduction
Motivation for the study of betavoltaic energy converters

- increase of lifetime
- uninterrupted operation
- miniaturization
- reduced power consumption
- offline work in remote access locations



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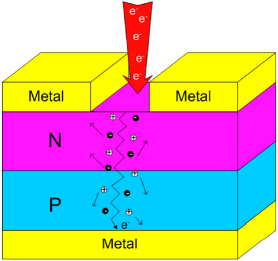


[1] Ehrenberg W., Lang C.-S., West R. The Electron Voltaic Effect. Proceedings of the Physical Society A. 1951. V.64. p.424

[2] Moseley, H.G.J., Harling, J. The attainment of high potentials by the use of radium. Proc. R. Soc. A. 1913. V.88 p.471.

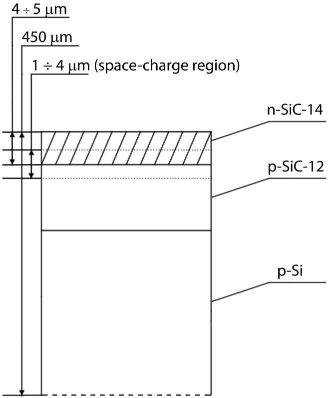
[3] Rappaport P.I., Loferski J.J., Lindery E.G. A study program of possible uses new principle. Nucleonics. 1957. V.15. p.99.

Properties of several radioisotopes

Radioisotope	E_{max} of β-decay (MeV)	half-life (year)
H-3	0,019	12,3
Ni-63	0,067	100,1
Ar-42	0,600	33
Kr-85	0,687	10,6
S-35	0,167	0,24
P-33	0,249	0,07
C-14	0,156	5730

☞ The most radiation-resistant semiconductor structure is SiC!

Beta-converter



Pic.1. The structure of beta-converter.

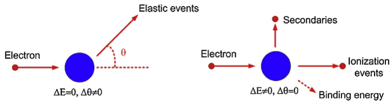
Previous study of the betavoltaic device characteristics

There are several methods of calculating a generation rate:

- Via Bethe-Bloch formula
  $-(\frac{dT}{dx}) = \frac{2\pi e^4 n_e}{m_e v^2}[ln\frac{m_e v^2 T_e}{2I^2(1-\beta^2)} - ln(1-\beta^2) - \beta^2 - \delta - U]$
  (A.A.Gorbacevich et al.//ZHTF, 2016, V.86, no.7, P.94-99.),
- calculating recombination current density
  (Bulyarski S. V. et al. // Fizika i tekhnika poluprovodnikov. 2017. no.51(1). P.68-74.)
- Mone-Carlo method(S.Theirrattanakul, M.Prelas // Applied Radiation and Isotopes. 2017. no.127. P.41–46.; K.Zhang // Sensors and Actuators A 240 (2016) 131–137)
  etc.

Creating a beta-converter model in GEANT4 [4]

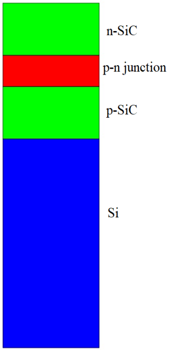
- Calculation electron-hole pairs generation rate inside the space charge region of the p-n junction based on secondary electrons from processes



Following Monte-Carlo algorithm:
- Determine primary electron's initial position, momentum direction and energy based on set probability densities
- Track primary electrons as they fly through the substance and create electron-hole pairs along the way
- If the electron-hole pair is created inside the space charge region, it is separated by the electrical field of the p-n junction
- Repeat this process many times to achieve good statistical accuracy

[4] http://cern.ch/geant4

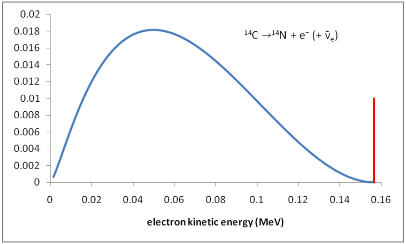
Model in GEANT4



Beta-converter model in GEANT4

This model was created to determine the generation rate of electron-hole pairs inside the space charge region.

Random variables and C14 spectrum

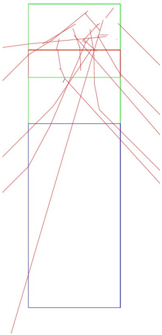


Carbon 14 beta spectrum

The following random variables were used for Monte-Carlo modeling:

- Initial positions of primary electrons. Carbon 14 distribution in substance is known from experimental data.
- Momentum direction of primary electrons. From Fermi's theory of beta decay its probability is considered uniform in any direction.
- Spectrum of primary electrons: $N(T) = C_L(T)F(Z,T)pE(Q-T)^2$

Modeling process

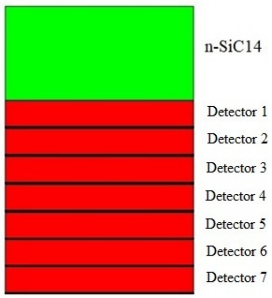


Red trajectories correspond to primary electrons, blue - to secondary electrons (might not be visible due to fast absorption)

Generation rate results

Monte-Carlo simulations in GEANT4 were conducted 10000000 times. Out of 10000000 primary electrons, 6 039 018 electron-hole pairs were separated by the p-n junction. Since generation rate is per unit time, this value scales linearly with radioisotope activity. Considering specific activity of C^{14} $A_{C^{14}} = 5.203 * 10^{18}$ and its mass inside the beta converter 0.1 μg we get the following generation rate value $G = 3.120 * 10^{11}$

Determination of the optimal depth of the p-n junction



In the upper part there was a layer with the radioisotope C14. Beneath it are layers of detectors each 1 μm thick, which register secondary electrons. The decay process was simulated 10 000 000 times, the results are shown in the table.

Optimal depth determination results

Detector number	Registered electrons
1	2109458
2	1679731
3	1474314
4	1310688
5	1177058
6	1061822
7	963735
8	879160
9	800190
10	727735

Conclusions

- A beta-converter model was created in GEANT4
- Generation rate of electron-hole pairs was obtained
- Optimal depth of the p-n junction was determined

Thank you for your attention!