Simulation and fabrication of an alpha-radioluminescence nuclear battery using Am-241

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Abstract
In this paper we have designed and simulated an alpha-radioluminescence nuclear battery based on Am-241 source and ZnS:Cu phosphor material using MCNP/MATLAB/SILVACO hybrid code and compared it with experimental results. The effective parameters on output of battery include type and activity of source, thickness of phosphor material, thickness of semiconductor and doping concentrations. The experimental parameters include Am-241 source with 1.1 mCi activity, ZnS:Cu with different thicknesses of 50, 100 and 150 micrometers and Silicon semiconductor with thickness of 50 micrometers. To investigate the accuracy of simulation we used same parameters as experimental setup. The obtained values of open circuit voltage from simulation are close to the values from experiment, which shows the great accuracy of the hybrid code for simulation of nuclear batteries.

Keywords: Am-241, Nuclear Battery, Monte Carlo, MATLAB, SILVACO

Introduction
Nuclear batteries are long life energy sources which attracted research interests in recent years. Based on their mechanism, these batteries are divided into direct and indirect conversion types [1]. Betavoltaic and Alphavoltaic batteries are famous examples of direct conversion type where a semiconductor transducer directly converts beta or alpha particles into electricity. While direct conversion batteries usually have higher efficiency than indirect ones, they cause radiation damage to semiconductor crystals, thus decreasing the life time [2,3].
Radioluminescence batteries [4] are an example of indirect conversion batteries which employ a phosphor material to convert the radiation emitted from a radioactive source into light, then use a photovoltaic cell to collect the light and convert it to electricity. These batteries have lower efficiency than direct conversion batteries, however they have longer life time.
As the computer simulations accuracy has improved in recent years, they are being used to save time and cost before setting up an experiment.
In this paper we have designed and simulated a radioluminescence nuclear battery based on Am-241 radioisotope using MCNP/MATLAB/SILVACO [5-7] hybrid code and compared the results with experiments.

Materials and methods
We used Am-241 radioisotope with activity of 1.1 mCi as the source, ZnS:Cu as the phosphor material, and a commercial Silicon PIN diode as the semiconductor. Am-241 is an alpha emitter with a half-life of 432.2 years and its spectrum is listed in Table 1.
The simulation methods are discussed in details in our previous works [4,8]. MCNPX is used to calculate the deposited energy in phosphor layer, MATLAB is used to calculate the spectral intensity of light emitted from phosphor layer, and SILVACO is used to calculate the open circuit voltage.
In experimental section we deposited different thicknesses (50, 100 and 150 um) of ZnS:Cu paste on glass slides using doctor blade method.
The Am-241 disk is placed on top of the phosphor layer and both are placed on the Silicon semiconductor. To measure the open circuit voltage from cell, the output of the semiconductor is connected to a RLC low-pass filter (to reduce noises) and then connected to the oscilloscope.

Table 1. Am-241 alpha spectrum.

Energy (keV)	Probability (%)
5485.6	84.5
5442.8	13.0
5388.23	1.6

Results and discussion

The deposited energy in ZnS:Cu layer is ploted in Fig 1.

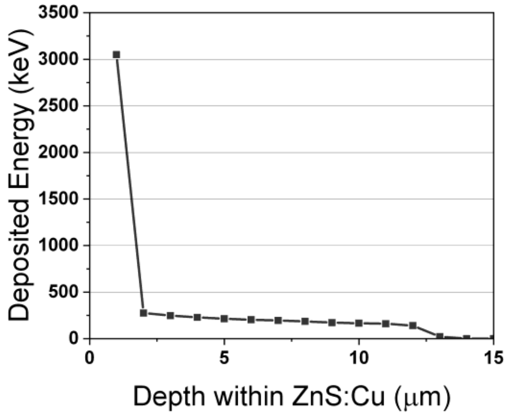

Fig 1. Deposited Energy in the ZnS:Cu phosphor layer.

As one can see the maximum range of alpha particles emitted from Am-241 is 14 um in ZnS:Cu.

More energy is deposited by increasing the thickness t of phosphor material, on the other hand, more thickness cause more self-absorption of photons in the phosphor layer. Thus there is an optimal thickness (Fig 2).

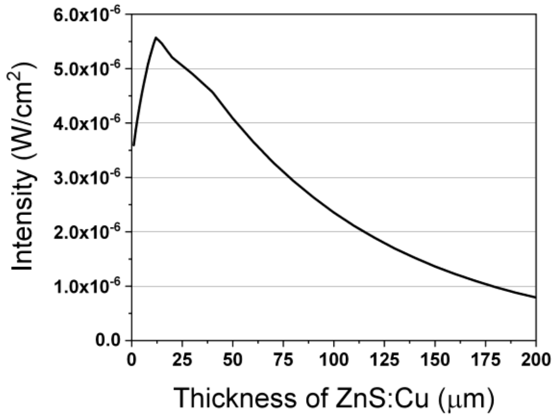

Fig 2. Total intensity of the light emitted from phosphor layer vs thickness.

As it can be seen from Fig 2 the optimal thickness for Am-241 is 12 um.

A limitation of doctor blade method is that we can only deposit ZnS:Cu in thicknesses of integer multiples of thickness of scotch tape (50 um). Thus we deposited three thicknesses of 50, 100 and 150 um and use it in our simulations. For a better comparison we also simulate the optimal thickness of 12 um.

The spectral intensity of emitted light from phosphor layer obtained from simulation in these thicknesses are plotted in Fig 3.

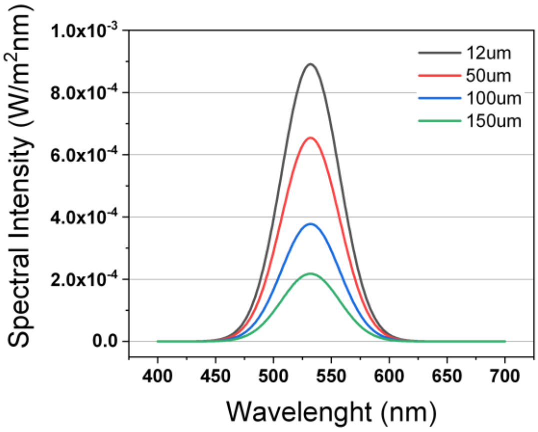

Fig 3. Spectral Intensity of emitted light from phosphor layer in different thicknesses.

As it shows, the thinner the phosphor layer is, the more light exits from the phosphor layer.

In Fig 4 we can see a comparison of the value of open circuit voltage from simulation and experiments. As we expected, the thinner phosphor layer produces more light, which leads to a higher open circuit voltage in the semiconductor.

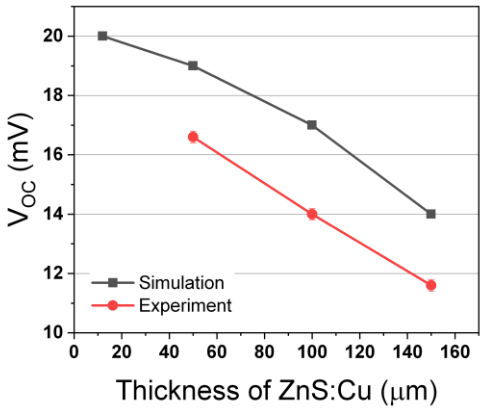

Fig 4. Comparison of results from simulation and experiment.

Although the simulation and experimental data shows the same trend, there is about 20% error in the simulation. The error caused by several not-idealities such as presence of PVA in the phosphor layer which reduces the light intensity.

It worth to note that the open circuit voltage from phosphor layers of 50 um and 12 um are relatively close so that we can consider 50 um as the practical optimal thickness which is also easier to fabricate from practical point of view.

Conclusions

In summary, we designed, simulated, and fabricated an alpha radioluminescence battery based on Am-241 radioisotope and ZnS:Cu phosphor layer. We compared the simulation and experimental results and showed that the results are in agreement. A single cell of this battery can provide up to 20 mV and by combining an array of them in series we can achieve higher voltages.

We had two limitations in this work: 1-Phosphor layer could not be deposited in arbitrary thicknesses 2-We did not have any equipment to measure the current in nA scale.

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