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The Effects of PN spacing of Vertical Electrodes on Betavoltaic Characteristics

Byoung Gun Choi, Sung Weon Kang, and Kyung Hwan Park*

Electronics and Telecommunications Research Institute (ETRI), Daejeon, 305-700, Republic of Korea
**Corresponding author: cbgun@etri.re.kr*

1. Introduction

Betavoltaic cell converts nuclear energy to electric energy. Because of their long half-lives and high power density, radioisotope batteries can be used for the military sensors, space exploration application, and the environment monitoring systems installed to inaccessible infrastructures such as bridges, tunnels, polar areas, and internal of nuclear reactors. Many efforts have been concentrated on improving output power density of the betavoltaic batteries for decades. Using wide band gap semiconductors such as GaN and SiC may increase the conversion efficiency of the betavoltaic cells and decrease radiation tolerance. C. Honsberg *et al.* showed the design rules and efficiency calculations for GaN betavoltaic converters, and demonstrated the radiation tolerance [1]. Chandrashekhar *et al.* and Eiting *et al.* demonstrated that using SiC significantly enhance the radiation resistance and efficiency of the betavoltaic cells [2],[3]. Meanwhile, the three dimensional betavoltaic batteries have attracted attention due to conversion efficiency improvement compared to the planar cells. However, artificial manipulations on a semiconductor's surface inevitably increase defects, which limits the conversion efficiencies. To solve this problem, we focused on vertical *pn* junction silicon betavoltaic cell without appreciable damage on semiconductor's surface.

In this research, three different silicon betavoltaic cells were fabricated with vertically designed *pn* junction structure. Each cell has different *pn* spacing such as 50, 110, and 190 μm. We explore the effects of different *pn* spacing on betavoltaic characteristics.

2. Experimental Technique

The betavoltaic cell consists of multiple vertical *pn* junctions generated by the vertical *p*-electrodes. The beta-particles from beta-emitting radioisotopes such as Ni-63, Pm-147 and H-3 are directly incident to the space charge region of vertically generated *pn* junctions without passing the neutral *n* or *p* region. The energy conversion from nuclear power to electric power occurs at the vertically generated space charge region.

Figure 1 shows the vertically generated *pn* junction with vertical polysilicon *p*-electrode, which describes how the energy conversion occurs in the space charge region. The beta-particles radiated from radioisotope source enter the space charge region, and generate electron-hole pairs (EHPs) until they lose their energies.

The EHPs generated only in the space charge region and within one minority carrier diffusion length of the space charge region contribute to producing electric power. The vertical p^+ electrodes are formed with deep reactive ion etched (DRIE) holes. The holes are filled with undoped polysilicon layer as a p^+ electrode in future and BSG layer as a *p*-type doping source material sequentially. The boron ions in BSG layer are diffused into *n*-type silicon substrate passing through the polysilicon grain boundary by annealing process at 1100℃ for 180 minutes, and finally making *n*-type region to *p*-type region and undoped polysilicon to a p^+ electrode.

The vertical p^+ electrodes are placed every 50μm in series and the unit spacings between *p* and *n* electrodes are split to 50, 110 and 190μm in order to examine the efficiency dependence on the spacing distance. Figure 2 shows the different *pn* spacing, each of which area of unit cell is 1.2 × 1.2mm^2.

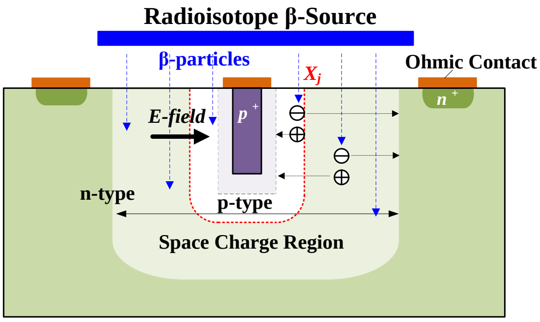

Fig. 1. Cross sectional view of a vertical *pn* junction betavoltaic cell.

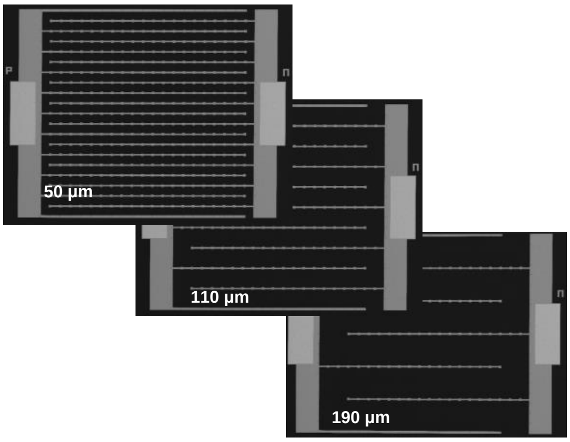

Fig. 2. Betavoltaic cells with different *pn* spacing.

The electrical characteristics of the three different betavoltaic cells with different *pn* spacing are extracted by using electron beam irradiation in a scanning electron microscope (SEM) in place of Ni-63. Exploiting an electron beam instead of hazardous radioisotopes makes it possible to easily predict the effects of *pn* spacing differences on the performance of the betavoltaic cells. The betavoltaic I-V characteristics are measured under two different e-beam source currents and acceleration voltages, i.e., 6.14nA @17keV and 7.27nA @30keV. This is because the average energy of Ni-63 is 17.4keV, and the maximum available electron beam energy from SEM is 30keV.

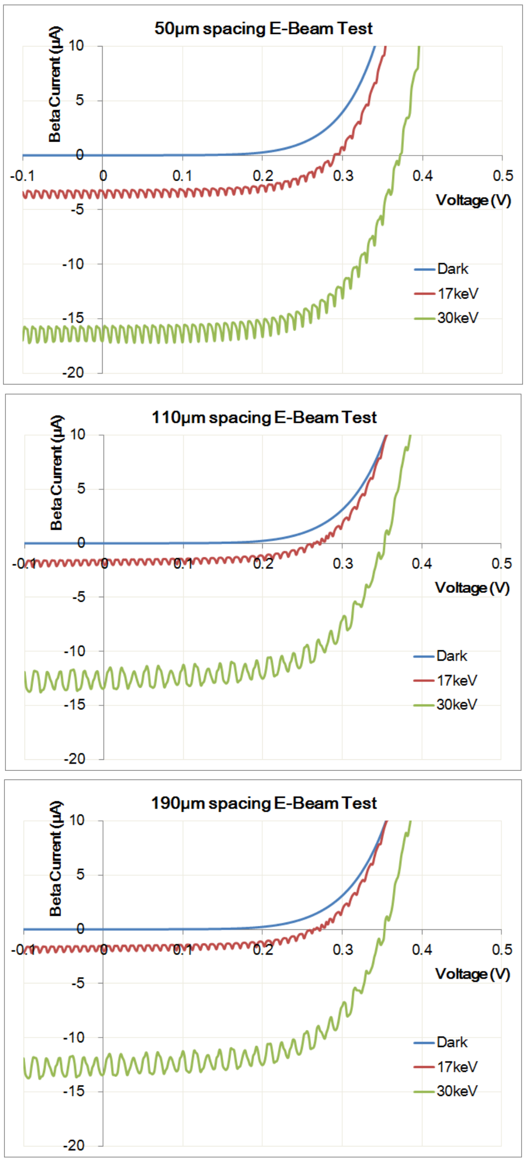

Fig. 3. I-V characteristics under electron beam illumination on 1.2×1.2 mm^2 area.

3. Results and discussion

Figure 3 shows the I-V characteristics of the betavoltaic cells with three different *pn* spacing. All types of betavoltaic cells result higher V_{oc} and I_{sc} at 30keV than under 17keV. This is because e-beam with higher energy makes more EHPs. Both at 17keV and 30keV e-beam energy, betavoltaic cell with a 50µm spacing shows better performance than those with 110 µm and 190 µm. As the *pn* spacing increases, the more electrons can be incident to silicon surface, because the metal electrodes do not screen the incident beta particles. Simultaneously, the generated EHPs travel the longer path as *pn* spacing increases. Furthermore a part of incident beta particles is absorbed in the neutral *n*-region, thus does not contribute to the output current. If the *pn* spacing is chosen to be slightly larger than the width of the space charge region, output power of the betavoltaic cell will be maximized.

4. Conclusions

We explore the effects of *pn* spacing of vertical electrodes of the betavoltaic cell on the electrical characteristics with varying the *pn* spacing to as 50, 110, and 190 µm. In a consequence, short distance of the charge carrier's path shows the better performance in V_{oc} and I_{sc} of betavoltaic cells. To derive the optimum *pn* spacing, the screen effects of the metal electronodes and the width of both space charge region and the neutral *n*-region should be taken into consideration.

Acknowledgement

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REFERENCES

[1] Christiana Honsberg, William A. Doolittle, Mark Allen, Chris Wang, GaN betavoltaic energy converters, IEEE Photovoltaic Specialists Conference, pp. 102~105, 2005.

[2] M. V. S. Chandrashekhar, Christopher I. Thomas, Hui Li, M. G. Spencer, and Amit Lal, Demonstration of a 4H SiC betavoltaic cell, Applied Physics Letters, Vol. 88, pp. 33506-1~3, 2006.

[3] C. J. Eiting, V. Krishnamoorthy, S. Rodgers, T. George, J. David Robertson, and John Brockman, Demonstration of a radiation resistant, high efficiency SiC betavoltaic, Applied Physics Letters, Vol. 88 , pp. 64101-1~3, 2006.