Demonstration of a 4H SiC Betavoltaic Cell

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Silicon carbide (SiC) is a wide bandgap semiconductor that has been used for high power applications in harsh conditions due to its temperature stability, high thermal conductivity, radiation hardness and good electronic mobility. Furthermore, owing to the wide bandgap of the 4H hexagonal polytype (3.3eV), it provides very low leakage currents. This is advantageous for extremely low power applications as well.

Radioactive isotopes emitting low energy β-radiation such as Ni-63 and Tritium have recently attracted attention as viable power sources for low power applications. Work has been done to harness this power. Their long half lives, insensitivity to climate, and relatively benign nature make them very attractive candidates for nano-power sources. Furthermore, the radiation hardness of SiC ensures the stability of a power source fabricated from it for the proposed isotopes. In this work, we propose and demonstrate the use of a 4H SiC p-n diode as a betavoltaic radiation cell. Due to its wide bandgap, the expected open circuit voltage and thus realizable efficiency are higher than in narrower gap materials such as silicon (Si).

The operation of a radiation cell is very similar to that of a solar cell. Electron-hole pairs are generated by high energy β electrons instead of photons. These generated carriers are then collected in and around the depletion region of a diode and give rise to usable power.

The device structure implemented is illustrated in Figure 1. The devices were electrically isolated by etching. Charge collection experiments under scanning electron microscope (SEM) illumination as well as under 1mCi Ni-63 illumination were performed. The Ni-63 source had a measured current density of 6 pA/cm^2. The SEM beam current of 1.1 nA was kept constant, with the magnification changed to alter the incident electron current density. An energy of 17keV was used to simulate a Ni-63 source with mean β- electron energy of 17keV. Current-voltage characteristics were used to correlate the open circuit voltage and short circuit currents measured under electron illumination. The results are illustrated in Figure 2.

Under monochromatic SEM illumination, the charge collection was limited by surface recombination as seen in Figure 2b). Under Ni-63 irradiation, charge collection was substantially better. This is believed to be due to the higher energy electrons in Ni-63 which penetrate deeper into the junction, thus generating carriers further away from the surface.

An open circuit voltage of 0.95V and a short circuit current density of 8.8nA/cm^2 were measured under Ni-63 β-electron illumination. An efficiency of 3.7% was obtained. No short-term aging from the Ni-63 source was seen. A simple photovoltaic type model with constant electron-hole pair generation modeled the results well. The biggest discrepancy was seen in the fill factor which was believed to have been degraded by unoptimized contacts. Figure 2d) shows the correspondence between the measured and extracted parameters of the radiation cell.

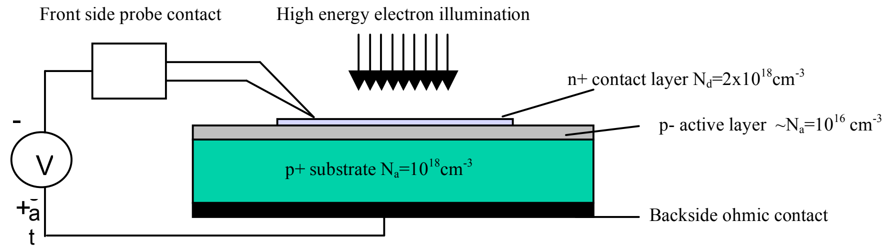
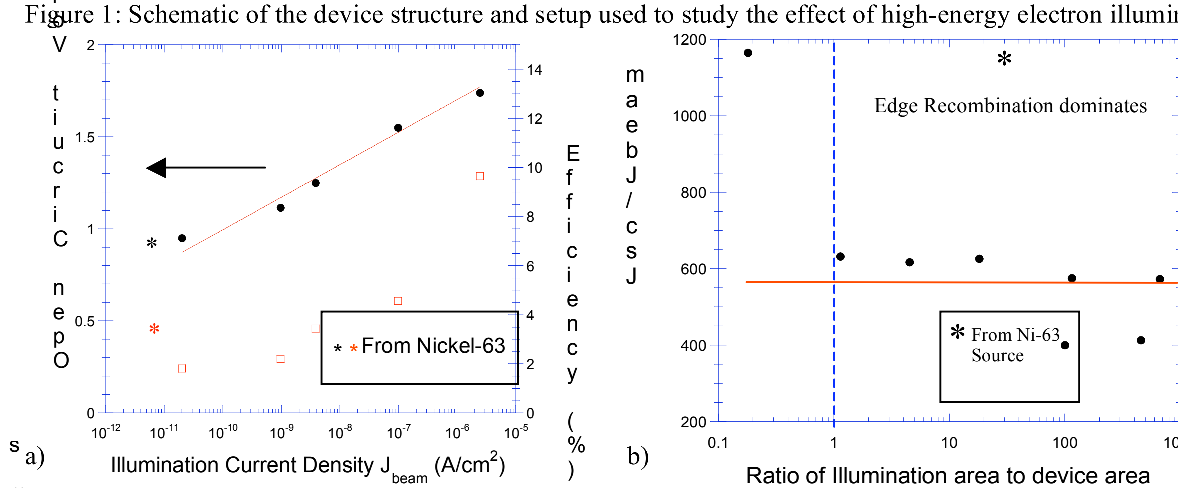
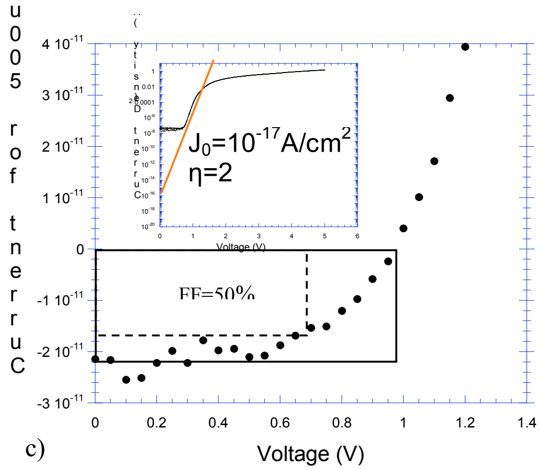


Figure 1: Schematic of the device structure and setup used to study the effect of high-energy electron illumination.





d)

Parameter	Measured	Model
Jo (A/cm2)	10^{-17}	*used measured value*
η	2	*used measured value*
Jsc (A/cm2)	$8.8*10^{-9}$	*used measured value*
Voc (V)	0.95	1.05
Vp (V)	0.68	0.81
Jp (A/cm2)	$6.4*10^{-9}$	$8*10^{-9}$
FF (%)	50	70

Figure 2. a) Open Circuit Voltage (Voc) and efficiency as a function of illumination current density (J_{beam}). b) Current multiplication factor as a function of illumination area for the same 500μm square device. c) IV characteristic of the same 500um device under 1mCi Ni-63 β-electron illumination. The inset shows the normalized semi-log unilluminated current-voltage (IV) characteristic of the diodes. d) Various radiation cell parameters fit to the photovoltaic type model.