Temperature Dependence on Electrical Performance of Tritium Sourced Betavoltaic Cells

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Abstract

There is an increasing need for devices that can be powered for extended periods of time where it is difficult or impossible to maintain or replace, such as in pacemakers, long term space flight and unattended sensors. Presently, most devices rely on lithium battery chemistries that provide high power densities, but require replacement after 2 to 5 years due to material and temperature degradation. However, betavoltaic cells can last over 20 years in extreme temperatures from -50 C to 150 C. City Labs, Inc. received a general license for commercially available tritium betavoltaic cells that were validated at extreme temperatures without permanent degradation. To fully determine the effectiveness of a betavoltaic cell, the electrical performance (I-V curves) of three betavoltaics were evaluated under temperatures from -30 C to 60 C. A photovoltaic cell was evaluated first to validate the system. Short circuit current, open circuit voltage, maximum power and fill factor were used to compare electrical performance. Results indicate that the open-circuit voltage and maximum power decreased as temperature increased, suggesting that betavoltaic cells are suited for cold environments below 0 C, such as during nightfall when the photovoltaic cell may not be used.

Research Objectives

Research focuses on testing the electrical performance of tritium sourced betavoltaic cells in a temperature cycle.

- Evaluate the electrical behavior of 3 NanoTritium betavoltaics by City Labs; the only commercially available and NRC generally licensed nuclear battery
- Observe trends in electrical behavior after multiple temperature cycles
- Simulate electrical performance in a real world environment

Motivations

- Betavoltaics are an enabling technology providing new capabilities & applications never before possible
- Can operate in more environments than batteries
  - Longer Operational Lifetimes (>20 years)
  - Wider temperature range (-60 C to 150 C)
  - Based on solar cells, but works regardless of sunlight
- Energy density is greater than lithium cells
  - Tritium: 10-150 times greater
  - Promethium-147: 150-400 times greater
- Ideal for low powered application
- Possible Applications:
  - Cardiac Pacemaker
  - Encryption Key Sourcing
  - Sensors in Extreme Environments
  - Communication Systems
  - Cochlear and Intraocular Implants
  - Crosshairs on Armed Weapons

Solar cells vs. Betavoltaics

- Sunlight
  - Photon, uncharged, long penetration depth
  - Energy: 1 eV – 4 eV/1-3 EHPS per photon
  - Intensity: 0.012 W/cm² – 0.16 W/cm²
- Beta radiation
  - Electron, charged, short penetration depth
  - Energy: 10's – 100's keV
  - Intensity: 100 μW/cm² – 0.1 W/cm²

- Current density of a solar cell was used to predict I-V curves at various temperatures due to both devices using a semiconductor diode.

Results

Current Voltage Characterization of BV06 At Various Temperatures

- I-V curve demonstrated that open circuit voltage varied more than the short circuit current at various temperatures

Open Circuit Voltage Over Temperature

- Open circuit voltage falls from 1V to 0.6 V as temperature varies from -30 C to 70 C

Short Circuit Current Over Temperature

- Short Circuit Current does not vary widely with temperature at all

Conclusions

- Many applications suitable for betavoltaic power
- Betavoltaics perform optimally below freezing temperatures
- Betavoltaics still perform in extreme conditions beyond the temperature range of lithium cells
- No drastic short term dropoff in electrical performance

Future Work

- Longer temperature cycles to observe the effects of repeated temperature cycling onto the betavoltaic cell
- Expand the temperature range of the betavoltaic cell to be larger or to reflect environments on Earth and in Outer Space
- Explore the temperature effects onto different manufactured betavoltaic sources

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- GPIB / RS-232 Controller
- Keithley Model 6420
- Keithley Model 7702
- Digital Multimeter (DMM)
- Router/switch
- Laptop computer Running LabView
- Uninterruptable Power Source (UPS)
- Power Source Measurement Unit (SMU)
- Booster Power

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