

## Lithium-Ion Cell PTC Limitations and Solutions for High Voltage Battery Applications

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### Problem

Most commercial, cylindrical lithium-ion cell design are equipped with a positive thermal coefficient (PTC) current limiting switch to provide hazard protection against short circuits external to the cell. This device, shown in Figure 1, is thin annulus consisting of a specially irradiated polyethylene laminated with a metal on both sides [1]. When exposed to an overcurrent situation, this normally conductive polymer heats up and changes phases to become several orders of magnitude more resistive. Once the short is removed, the PTC cools down and returns to its electrically conductive state. This device has been a very effective method of providing reliable short circuit protection in low voltage battery assemblies.

However, when 8 or more fully charged cells in series are shorted, the first PTC that trips in the series strings can experience a large voltage drop that exceeds its voltage rating (~30V) and will cause it to fail. Such tests performed at COM DEV and at NASA-JSC have revealed that sparks and flames accompany these failures. The PTC usually fails shorted, becoming a charred substance. In a large series string, then the first cell PTC that fails shorted will transmit the problem to the next PTC to trip and the cascading series of flames and sparks will follow. This occurs because slight manufacturing variances in the resistance and trip points of the PTC prevent them from tripping in unison to distribute the large short circuit voltage drop among them.

### Solution

A simple electrical protection scheme using bypass diodes is proposed to protect the cell PTCs from overvoltage conditions. The idea consists of placing a bypass diode in parallel with groups of 6 cells in series as shown in Figure 2. During a short, the diode in parallel with the first PTC to trip will shunt the current away from the PTC until other cell PTCs in other series group of cells trip and share the voltage drop from the short circuit condition. This scheme protects the PTC from large voltage drop surges until the drop can be equitably distributed along the long series string of cells.

### Verification and Analysis

A number of different tests have been completed and are still underway to characterize and understand the behavior of cell PTCs under high voltage conditions and to validate the diode protection scheme.

Single cell tests with a power supply in series determined that; (a) the PTC fails when exposed to a voltage drop > 31.3V when starting at 65°C, (b) PTC failures cause sparks, flames, and heat that sometimes melts the plastic gasket of the crimp seal, and (c) if the voltage drop is slowly applied the PTC can tolerate much higher voltages without failure. Analysis of high frequency current and voltage data combined with destructive physical analysis of the cells reveal that the overvoltage that the PTC

experiences causes the polyethylene to char and form a low resistance short. The neighboring crimp seal gasket also melts in some cases causing the negative can to bond to the positive lid of the cell, but in some cases the PTC is in the short circuit path and holds down short circuit current until separator shutdown occurs, preventing thermal runaway. The source of the sparks and flames is still under investigation. Cell destructive physical analysis confirmed that the separator porosity clogging was occurring at designed. A detail discussion of the results of these findings and the suspected mechanism for PTC failure will be explained.

A battery submodule consisting of 5 parallel strings of 41 cells in series was assembled with a small 10A Schottky diode in parallel with every six cells in series at Com Dev. This building block cells is the Sony HC 18650 lithium ion cell. The battery submodule was subjected to an external short < 10 mohms. As shown in Figure 3, 40 milliseconds after the short, we recorded a peak current of 312 A and observed that the short was gracefully shutdown in < 0.5 sec by the cell PTC. Thereafter, the submodule was successfully recharged and discharged with very little capacity degradation.

Bundles of 24-cells in series will be used to validate the diode selected for our application under worst case thermal conditions. These results will also be presented.

### REFERENCES

1. Raychem Circuit Protection Handbook.

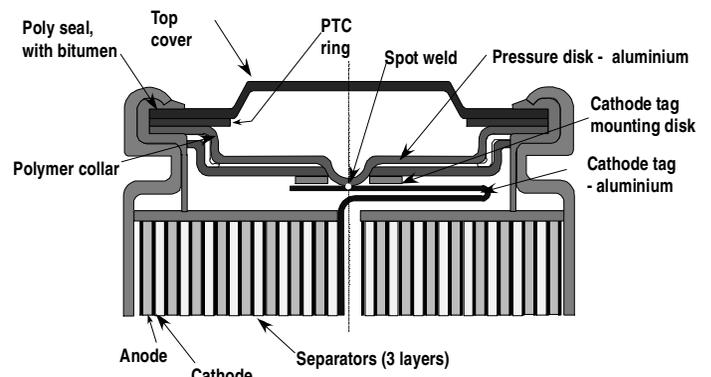


Figure 1. The cathode end of a 18650 lithium ion cell.

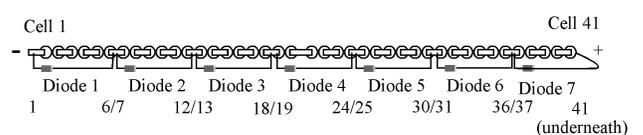


Figure 2. One string of 41 cells with a small diode bypassing every sixth cell.

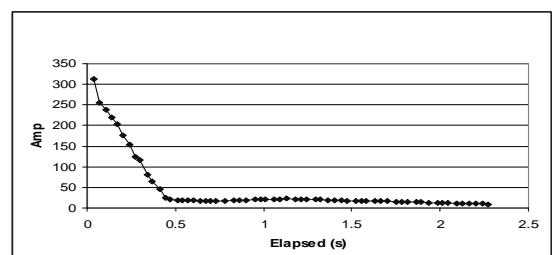


Figure 3. Current vs. time during the short circuit test of a 41S-5P battery submodule with bypass diodes in parallel with every 6 cells in series.

