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# Internal Shorting of Lithium Ion Battery with Charging

## *Problem Statement*

Cell safety simulations using AutoLion 3D™ have been reported in the literature[1,2] and previous case studies. The recent Samsung Note battery incidents show that internal shorting hazards might occur during the battery charging process due to design issues. Here we simulate the internal shorting under the condition of CCCV charging process. It is shown that two different scenarios might occur depending on the magnitude of the shorting resistance (i.e. soft shorting or hard shorting). Results also suggest that internal shorting is very hard to detect by gauging the cell voltage.

## *Setup*

- An 8Ah NCM/Graphite cell with stacked electrode design (SED) is set up in AutoLion 3D™ and the 3D cell mode is used. The internal shorting feature is enabled.
- The cell has a dimension of 70mm X 100mm in cross section and 6mm in thickness. The initial SOC of the cell is set to be 50%.
- The 18th plate of the cell is internally shorted. The shorted area (1.3mm by 1.3mm) is located in the center of the cell. The short resistances used in the simulation are 10 mΩ (hard shorting) and 2 Ω (soft shorting).
- CCCV charging protocol is applied with 1C current.

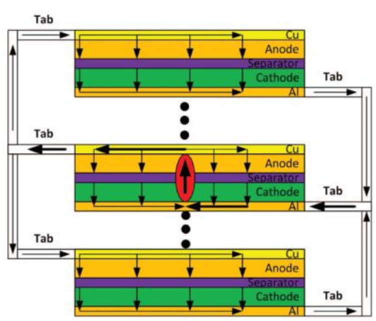


**Figure 1 Current flow path in the internal shorting process**

Figure 1 illustrates the current flow path in the internal short-circuit process, where a short-circuit object (SCO) is embedded within one electrode layer of the cell[2] The SCO creates a short circuit and current loop within the electrode layer where the SCO is located. This electrode layer not only discharges its energy to itself, it also serves as a load to the other electrode layers without a SCO inside. The cases of internal shorting without charging follow the current flow pattern depicted in Figure 1.

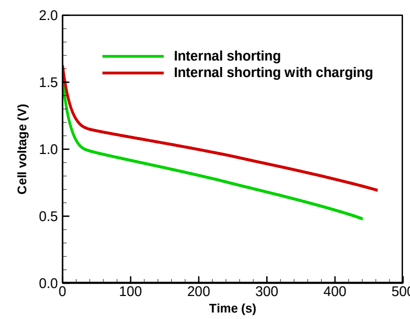


**Figure 2 Voltage responses (10 mΩ)**

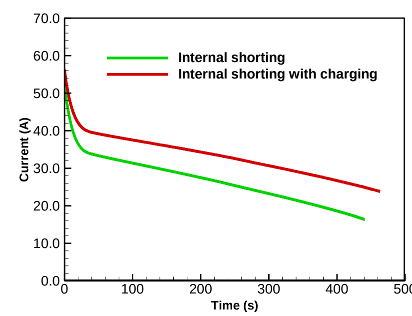


**Figure 3 Current responses (10 mΩ)**

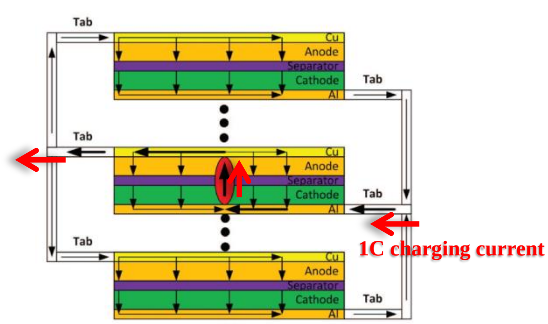


**Figure 4 Current flow path in the internal shorting process with charging for small shorting resistance (10 mΩ)**

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Figure 2 shows the voltage evolution for 10 mΩ cases. It can be seen that the cell voltage is very low for the internal shorting only case. The charging voltage for the charging case is only slightly higher (around 170mV). This higher voltage is required in order to keep the 1C charging current. Figure 3 shows the current responses for 10 mΩ cases. The current is defined as the total current flow through the SCO in all of the figures in this study unless noted. The difference between the two current responses is very close to the 1C charging current (8A). The reason can be easily explained in Figure 4, which shows the current flow path for the internal shorting process with constant current charging for small shorting resistance (10 mΩ). Due to small charging voltage, all of the cell layers are in the discharging mode. The current flow path is the same as the internal short only cases as shown in Figure 1. The charging current is superimposed on the internal-short process. The 1C charging current only flows through the SCO. Figure 5 shows the temperature evolutions for 10 mΩ cases. Due to the additional charging current, the temperature at the shorted location for the charging case is 70K higher than that of the internal shorting only case.

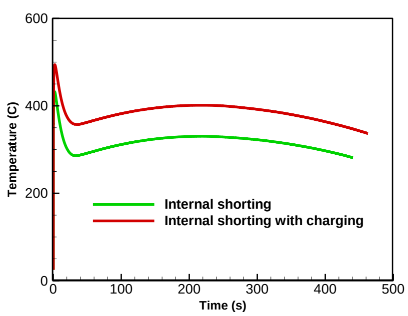


**Figure 5 Temperature responses at shorted location (10 mΩ)**

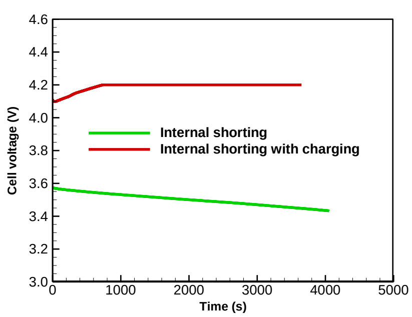


**Figure 6 Voltage responses (2 Ω)**

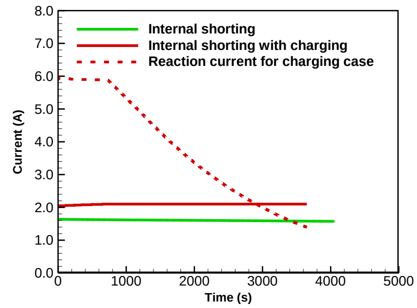


**Figure 7 Current responses (2 Ω)**

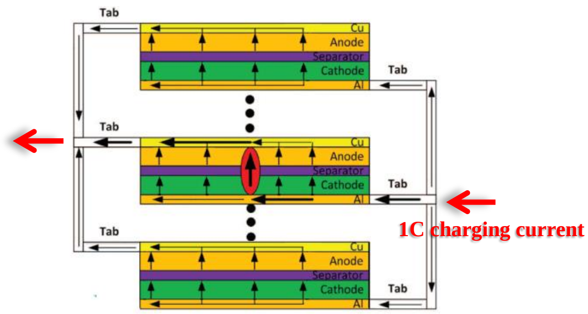


**Figure 8 Current flow path in the internal shorting process with charging for large shorting resistance (2 Ω)**

Figure 6 shows the voltage evolution for 2Ω cases (when there is a loose contact during soft shorting). For the internal shorting only case, the cell voltage shows a typical discharge curve when the load resistance is relatively large. However, the cell voltage for the charging case shows a typical voltage response under CCCV charging process: the cell voltage increases with time initially, and then remains at a constant value (4.2V). Even during the internal shorting process, the cell still can be charged. Figure 7 shows the current responses for 2Ω cases. The current flow through the SCO is about 1.6A for the internal shorting only case. The SCO current (around 2.1A) can be roughly estimated using the charging voltage and shorting resistance for the charging case. Figure 8 shows a clear picture of the current flow path for the charging case with a large shorting resistance (2 Ohm). Like a normal cell charging process, the current flow pattern is totally different from patterns shown in Figures 1 and 4. Only part of the total charging current (around 2.1A) flows through the SCO. The rest of the charging current flows through the cell layers as the reaction current, as shown in Figure 7. Figure 9 shows the temperature evolutions for 2Ω cases. Since the SCO current of the charging case is much larger than that of the case without charging, the temperature at the shorted location for the charging case is much higher than that of the internal shorting only case. It can be seen that the maximum temperature in the case absent of charging is around 125°C, perhaps still within the limit of battery safety without causing deformation of the separator and decomposition of the electrolyte. On the other hand, in the presence of charging, the maximum temperature rises above 170°C, exceeding the limit of battery safety. Here lies a major difference in the consequence of soft shorting with and without charging current. AutoLion3D™ appears to have explained the dramatic effect of charging current on a soft-shorting scenario of a Li-ion cell.

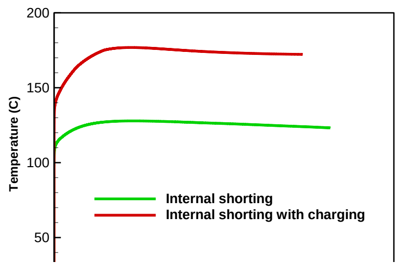


**Figure 9 Temperature responses (2 Ω)**

## *Summary*

- There are two different scenarios for the internal shorting during the charging process: discharging mode for small shorting resistance (hard shorting) and charging mode for large shorting resistance (soft shorting).
- For both scenarios under charging conditions, the temperature at the shorted location is higher than that of the internal shorting only case. The charging condition put the battery in a more dangerous situation during the internal shorting process.
- For the soft shorting case during charging, the cell voltage response behaves like a normal cell. It is very hard to detect the internal shorting by gauging the cell voltage.
- Experimental testing of internal shorting is very challenging, if not impossible at all. In contrast, AutoLion-3D™ provides a time- and cost-saving method to evaluate the impact of internal short on Li-ion cells and the effectiveness of various mitigating strategies.
- AutoLion-3D™ can readily be used for rapid analysis of safety designs to prevent thermal runaway of Li-ion cells undergoing internal shorting. This unique capability is one of many reasons that AutoLion-3D™ easily stands out from all other battery simulation software.

## *References*

[1] Wei Zhao, Gang Luo, and CY Wang, Modeling Nail Penetration Process in Large-Format Li-Ion Cells, *Journal of Electrochemical Society*, 162(1) A207-A217, 2015.

[2] Wei Zhao, Gang Luo, and CY Wang, Modeling Internal Shorting Process in Large-Format Li-Ion Cells, *Journal of Electrochemical Society*, 162(7) A1352-A1364, 2015.