Research Tool to Evaluate the Safety Response of Lithium Batteries to an Internal Short Circuit

Authors: Matthew Keyser, NREL
Eric Darcy, NASA-JSC
Ahmad Pesaran, NREL

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Background

- Li-ion cells provide the highest specific energy and energy density rechargeable battery with the longest life.
- Electrode/electrolyte thermal instability and flammability of the electrolyte of Li-ion cells make them prone to catastrophic thermal runaway under some rare internal short circuit conditions.
- Despite extensive QC/QA, standardized industry safety testing, and over 18 years of manufacturing experience, major recalls have taken place and incidents still occur.
- Many safety incidents that take place in the field originate due to an internal short that was not detectable or predictable at the point of manufacture.

Motivation

Lithium Ion Battery Field Failures– Mechanisms

- Latent defect (i.e., built into the cell during manufacturing) gradually moves into position to create an internal short while the battery is in use.
  - Sony concluded that metallic defects were the cause of its recall of 1.8-million batteries in 2006
- Inadequate design and/or off-limits operation (cycling) causes Li surface plating on anode, eventually stressing the separator

Both mechanisms are rare enough that catching one in the act or even inducing a cell with a benign short into a hard short is inefficient.

Current abuse test methods may not be relevant to field failures

- Mechanical (crush, nail penetration)
  - Cell can or pouch is breached; pressure, temperature dynamics are different
- Thermal (heat to vent, thermal cycling)
  - Cell exposed to general overheating rather than point-specific overheating
  - Not a valid verification of "shutdown" separators
- Electrical (overcharge, off-limits cycling)
  - Not relevant to the latent-defect–induced field failure

To date, no reliable and practical method exists to create on-demand internal shorts in Li-ion cells that produce a response that is relevant to the ones produced by field failures.

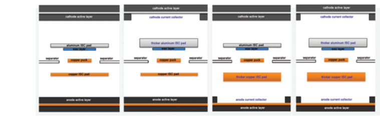
Objectives

- The internal short circuit (ISC) is capable of simulating all four types of shorts.
- Produces consistent and reproducible results.
- Cell behaves normally until activated – cell can be cycled as needed.
- Provides relevant data to verify abuse models.

Design

- Small, low-profile and implantable into Li-Ion cells, preferably during assembly.
- Key component is an electrolyte-compatible wax.
- Triggered by heating the cell or ISC above the wax melting temperature. NREL has developed an ISC that triggers at 47°C and 57°C.
- In laboratory testing, the activated device can handle currents in excess of 300 amps to simulate hard shorts. The impedance of the device is less than 2mΩ.

Design of Battery Internal Short Circuit Device (BISCD)



Short Circuit Type	1	2	3	4
Short Circuit Description	Cathode – Anode	Collector – Anode	Cathode – Collector	Collector – Collector
Relative Resistance	High	Low	High	Low
Severity of Short Circuit	Soft	Hard	Soft	Hard

Battery ISC Designations – Types 1 through 4

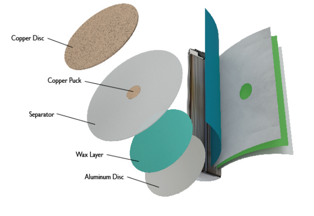
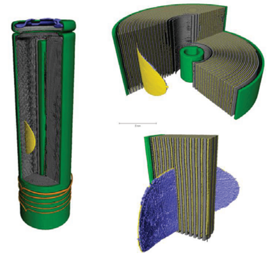
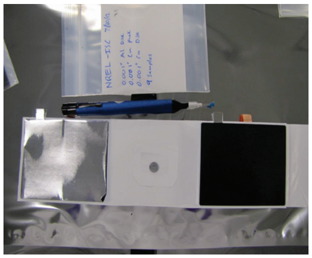


Diagram illustrating the components of the Battery ISC Device and its implantation in a battery cell.

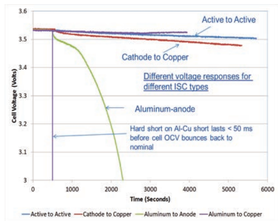


Computerized tomography (CT) rendering of Battery ISC Device inside an 18650 Li-ion battery. Yellow represents copper and blue represents aluminum discs. Credit: Donal Finegan and Paul Shearing, University College London

BISCD used for all Four Types of Shorts in Dow Kokam 8 Ah Cell

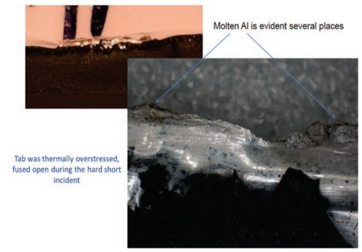


Electrode stack design with BISCD. Credit Ben McCarthy, Dow Kokam

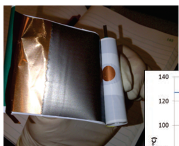


Dow Kokam 8 Ah cell activation at 10% SOC. Voltage response shows dependence on type of BISCD used.

Macro image of fused cathode tab after testing with Type 4 BISCD. Photo Credit: Eric Darcy, NASA-JSC

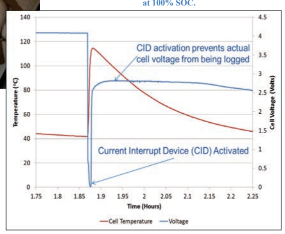


Shutdown Separator Study with Type 4 BISCD

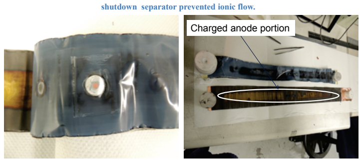


BISCD implantation in 18650 cell. Photo Credit: Mark Shoesmith, E-One Moli

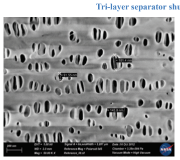
Type 4 BISCD Voltage and Temperature Response at 100% SOC.



DPA of 18650 Cell after BISCD activation at 100% SOC – shutdown separator prevented ionic flow.



Tri-layer separator shut-down when tested with Type 4 BISCD



"Before BISCD activation" - PP/PE/PP separator extracted from unwetted jellyrolls

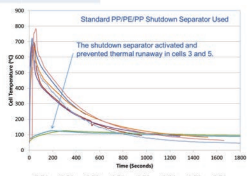
"After BISCD activation" - PP/PE/PP separator extracted from cell with activated ISC device showing reduced "shutdown" porosity

Repeatability Study with Shutdown Separator in 18650 Cell with Type 2 BISCD

Cell	Successful Formation	Successful Activation?	Thermal Runaway?
1	Yes	Yes	Yes
2	Yes	Yes	Yes
3	Yes	Yes	No
4	Yes	Yes	Yes
5	Yes	Yes	No
6	Yes	Yes	Yes
7	Yes	No	-
8	Yes	Yes	Yes
9	Yes	Yes	Yes
10	Yes	No	-

Type 2 ISC – 8 out of 10 ISCs Activated

18650 Cell after BISCD activation at 100% SOC.



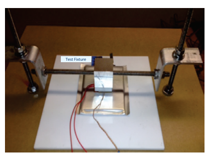
Conclusions

- US Patent #9,142,829
  - NREL – Matt Keyser, Dirk Long, and Ahmad Pesaran
  - NASA – Eric Darcy
- Effective tool for studying the safety features of:
  - Separators
  - Electrolytes
  - Additives
  - Fusible Tabs
  - Propagation
  - Gas generation

Acknowledgements

- DOE VTO – Dave Howell and Brian Cunningham
- E-One Moli – Mark Shoesmith
- Dow Kokam – Ben McCarthy

Non-Flammable Electrolyte Study with Type 2 BISCD



Test Fixture for 20 Ah pouch cells

- Both the control and non-flammable electrolyte caught fire and the cell temperature exceeded 300°C
- The non-flammable electrolyte showed no improvement over the control electrolyte.
- A type 4 (current collector to current collector) BISCD was also tested with similar results.

Visual and infrared images of pouch cell