Implantation, Activation, Characterization and Prevention/Mitigation of Internal Short Circuits in Lithium-Ion Cells

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Internal shorts created by metal particle contamination are the primary cause of failures of Li-ion cells in the field.

- TIAX has worked directly with major battery companies and their computer and mobile phone customers to carry out detailed audits of a large number of these safety incidents.
- We and others have found that while internal shorts are not the only cause of safety incidents, they are overwhelmingly found to be the cause of safety-related failure in the field.

Photographs from field-failure events showing significant damage to electrodes, and cells. Also showing condensed beads of aluminum.

Safety in lithium-ion cells/batteries requires deliberate strategies to deal with the possible occurrence of internal shorts.

- Safety incidents that take place in the field almost always originate due to an internal short (that was not detectable or predictable at the point of manufacture).
- Thermal runaway from internal shorts cannot be prevented by typical protection components because the shorts can be driven and sustained inside the cell.
- The battery industry does not have safety tests that "predict" safety in the field, nor reflect/anticipate the reality of how safety incidents occur in the field.
- Safety incidents take place on the order of **one in 10 million cells *for the most experienced manufacturers* (well beyond six sigma)**.
- Thermal runaways in safety incidents occur during normal operation in the field, after some time in the field, are not detectable at the point of manufacture, and usually occur without warning.
- Internal shorts will never be completely eliminated.

Many mechanisms have been proposed as being responsible for initiating an internal short circuit from foreign metal particle contamination in cells:

1. Dissolution of foreign metal present in the cathode → growth of metal deposit from anode surface to cathode → shorting of cell
2. Dissolution of foreign metal present in the cathode → plating at the anode → promotion of Li deposition → Li-dendrite growth → shorting of cell
3. Metal particle moves during cycling to a position close to separator → punctures separator after several cycles → shorting of cell
4. Unintentional overcharge due to faulty BMU → Li deposition on anode → repeated overcharging results in Li dendrite growth → shorting of cell

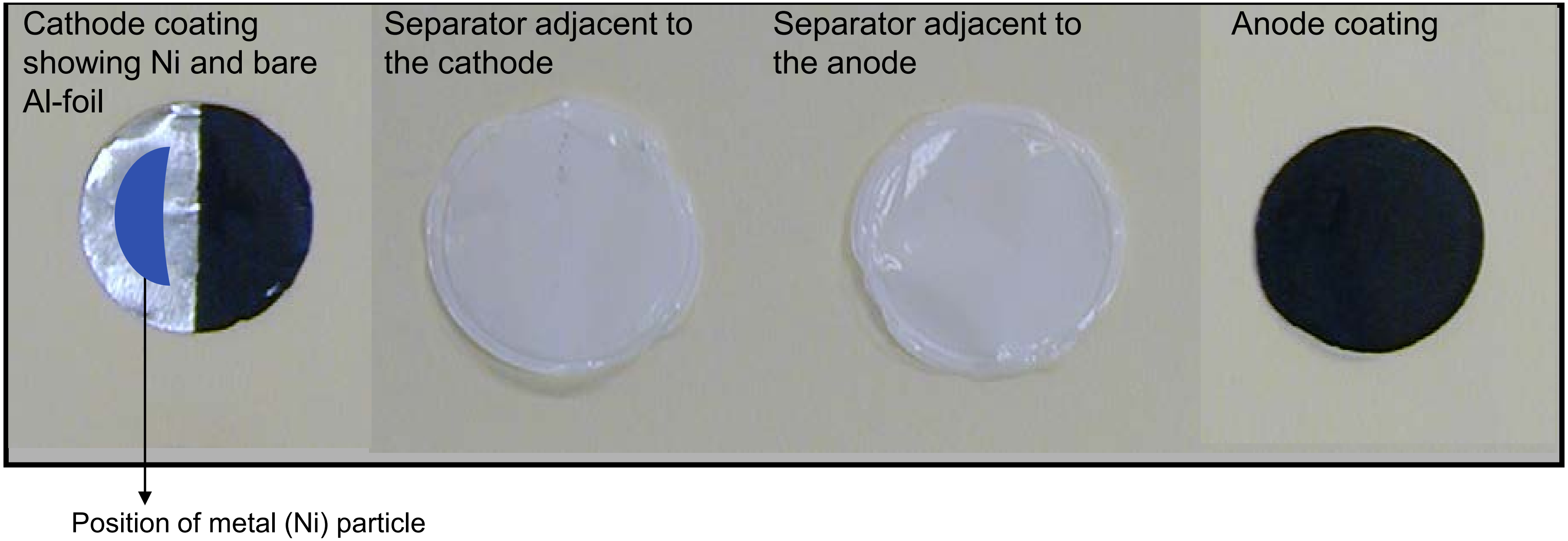
Our work to-date suggests that pathway 1 is the most likely mechanism for the formation of an internal short from foreign metal contamination.

The overall objective is to identify signals that can be used to detect the growth and maturation of internal shorts in Li-ion cells during normal operation.

- Internal shorts from foreign metal contamination have been linked to safety incidents of Li-ion batteries in the field.
- In previous work, we demonstrated a particle implantation method that can result in the formation of internal shorts, and subsequent thermal runaway of a Li-ion cell during normal charge/discharge cycling.
- Induction of thermal runaway by internal shorts required particular combinations of external heat transfer environment, external electrical environment, and internal short resistance.
- We are now focusing on further refining the particle implantation method in order to afford a better opportunity to identify precursor signals.
- We also benchmarked the particle method in comparison with a standard internal shorting-based abuse test method – nail penetration.

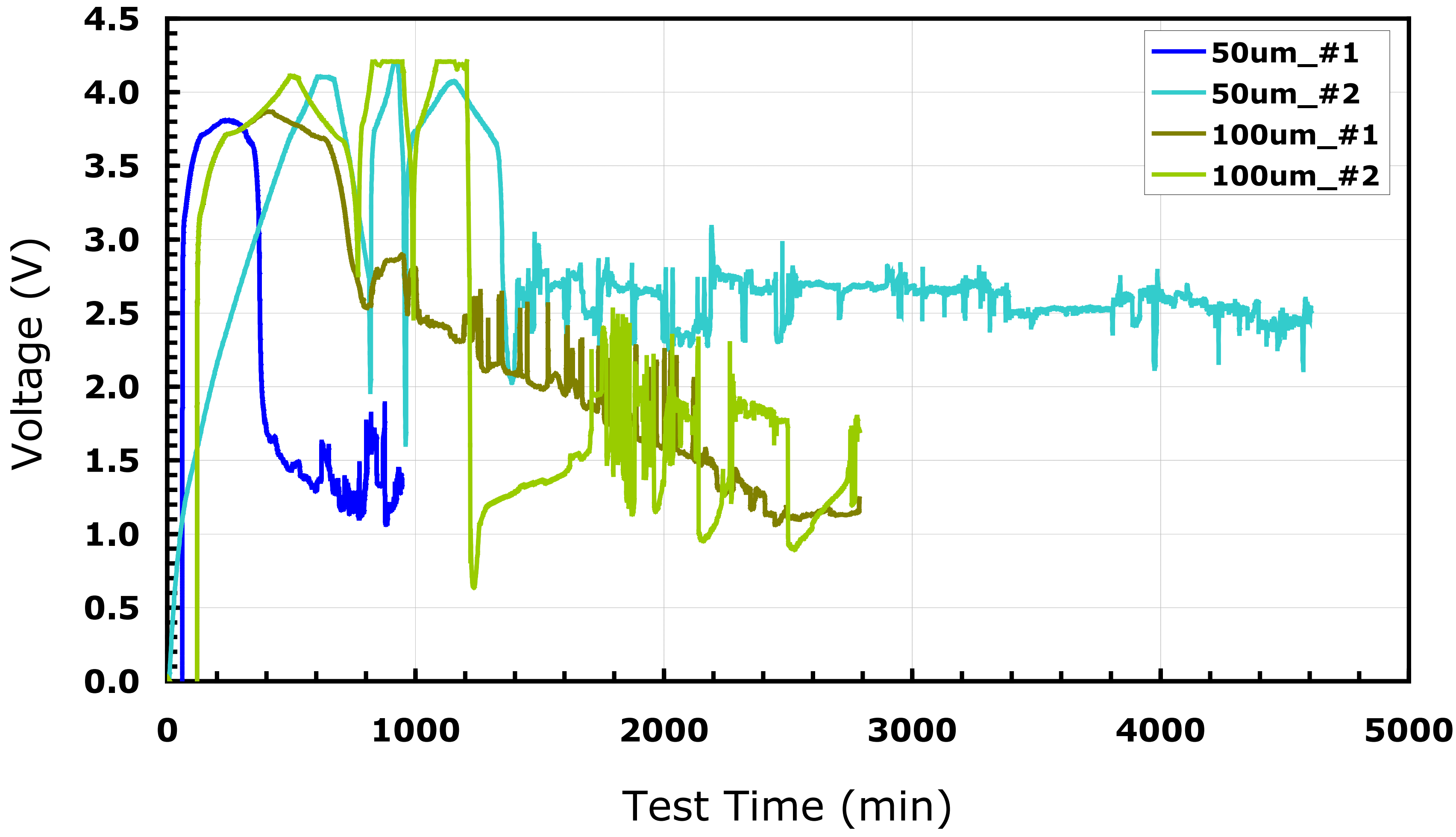
We designed and constructed a coin cell-based experimental configuration to study the mechanism of internal short circuit formation by strategically placing metal particles.

Coin cell construction with two-layers of Celgard® separator



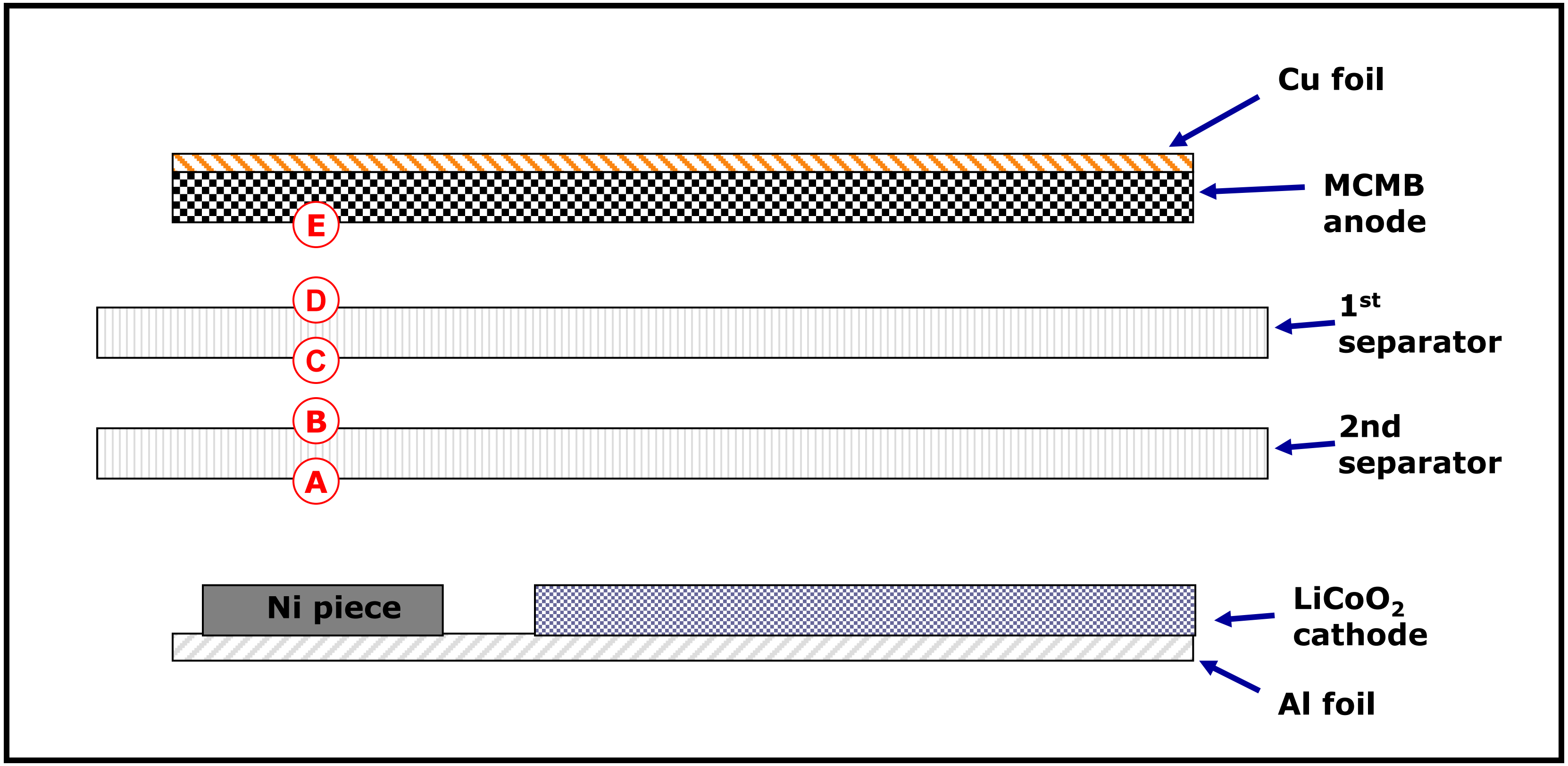
- Half of cathode coating removed
- Two Celgard 2325 separators
- 1.98cm^2 of electrode

These cells developed an internal short-circuit within the first few cycles.



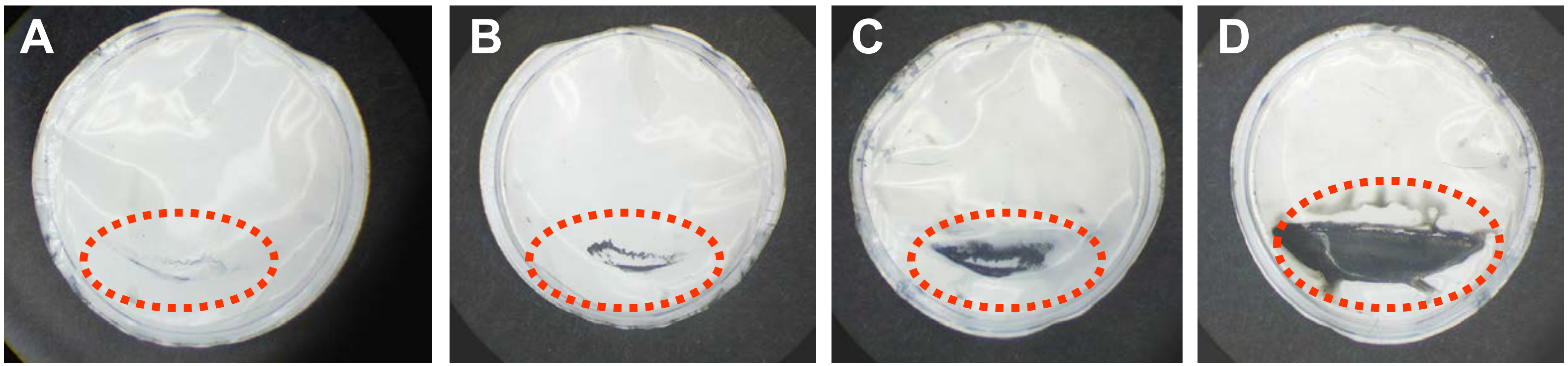
Short-circuited coin cells were disassembled for post-mortem analysis by optical microscopy and EDS.

Materials from regions (A~E) in the figure below were analyzed :

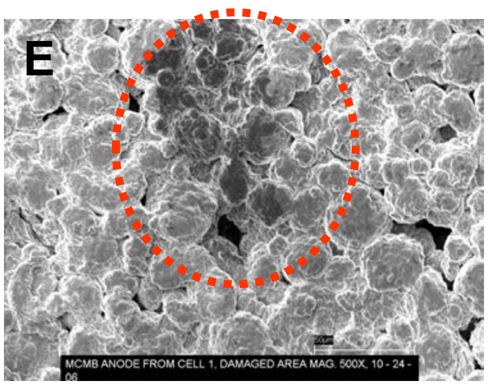


Post mortem analysis clearly showed the formation of a metal deposit: the deposit on anode side of the separator was larger than that on the cathode side, implying non-uniform growth of the deposit.

cathode



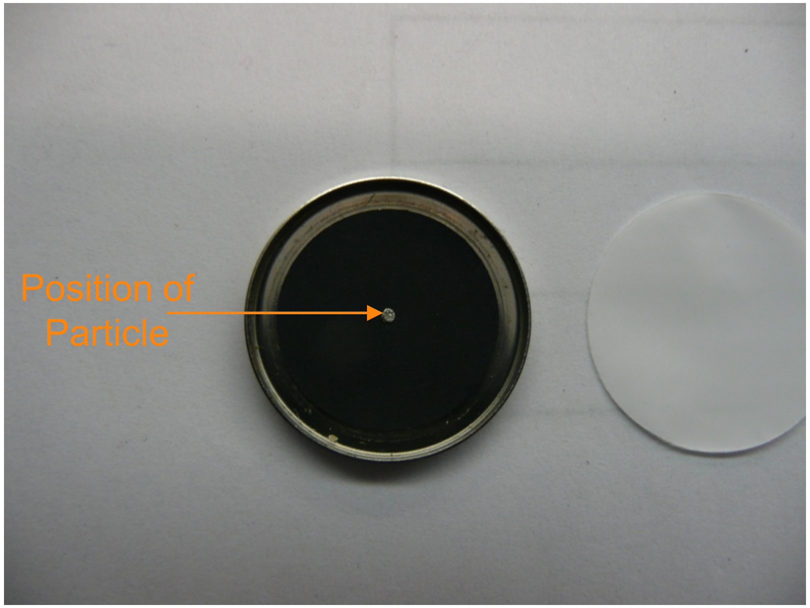
anode



EDS analysis

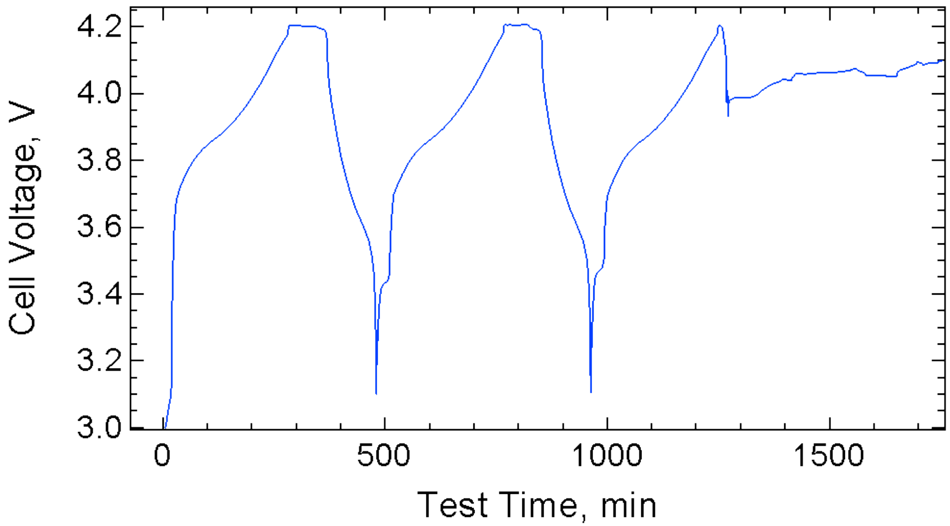
Note) EDS chart showed is for spot E on anode, but EDS charts for the spots A through D are very similar to this.

Utilizing coin cells with particles implanted in the center of full cathode coatings, tests were conducted for a series of different metals.

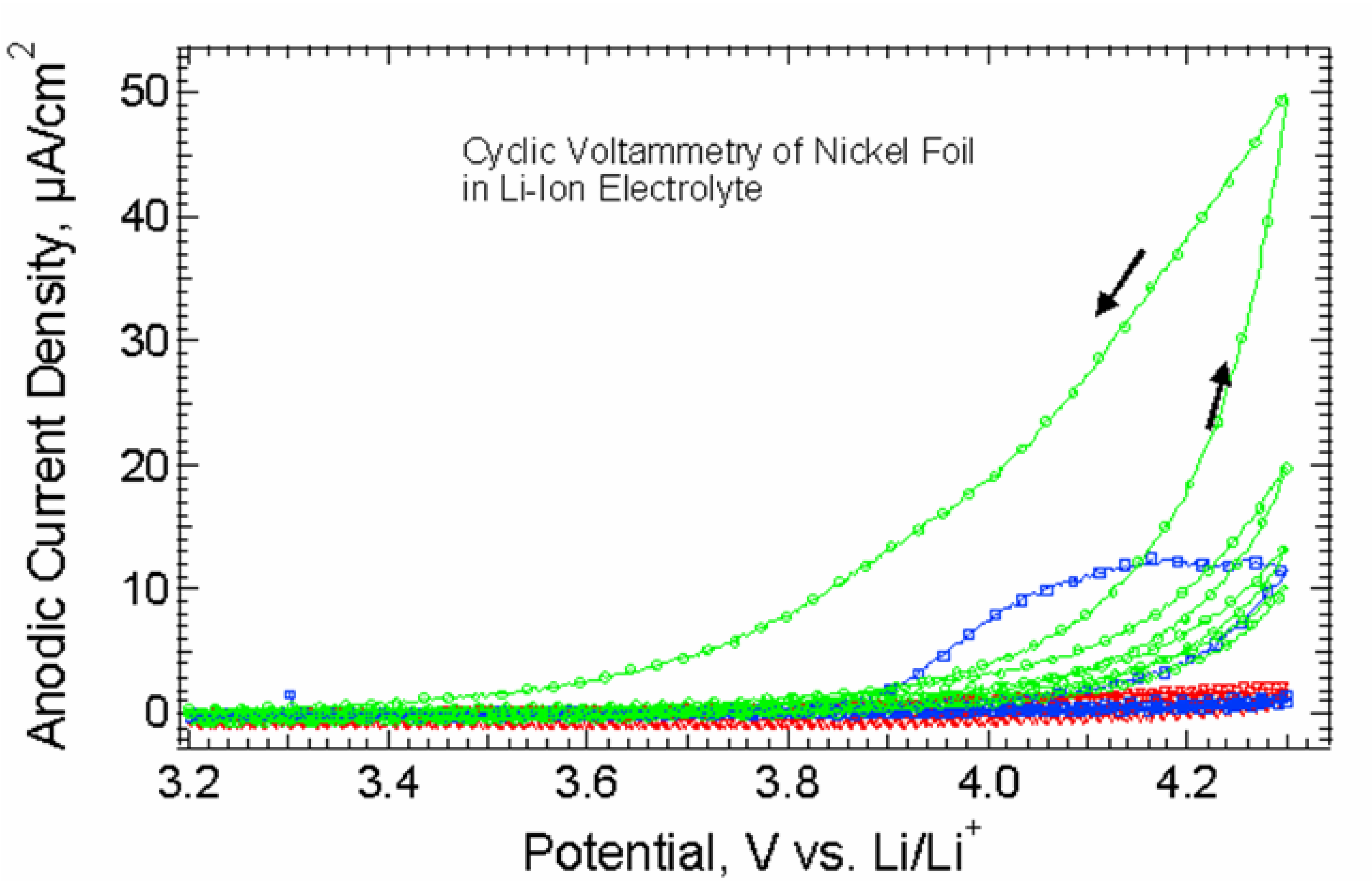


Coin cell test configuration with full cathode coating and center placement of particle

- Particle positioned at center of cathode, either on coating, or on scraped current collector
- 1mm diameter or 2mm x mm particles punched from metal foils
- Particles prepared using two different treatments prior to implantation

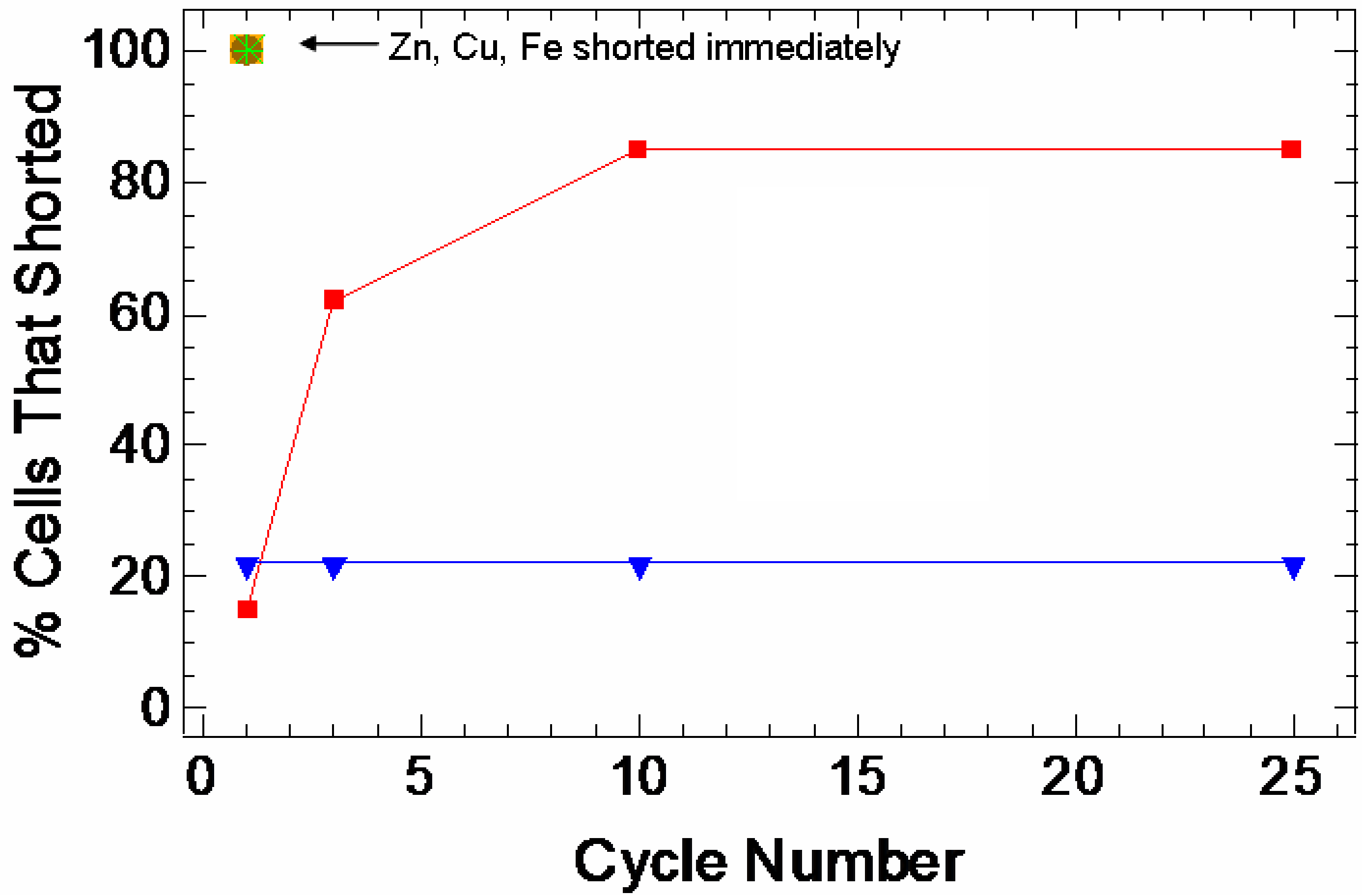


The oxidative dissolution of some metals occur at potentials corresponding to typical cathode operating potentials.

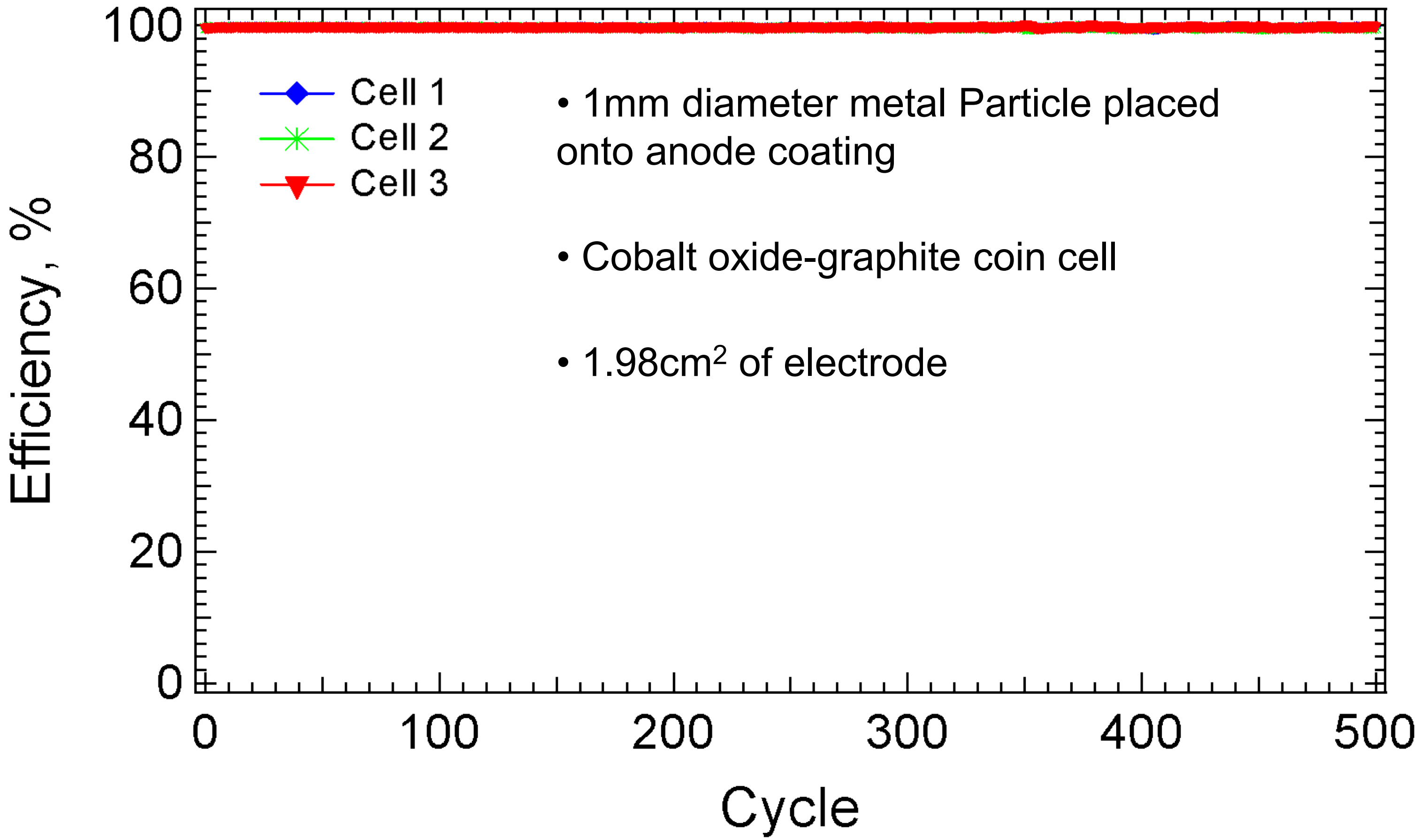


Cyclic voltammetry for metal foils scanned over the operational range experienced inside a lithium-ion cell, with a lithium metal anode. For all foils, current decreases with increasing scan number.

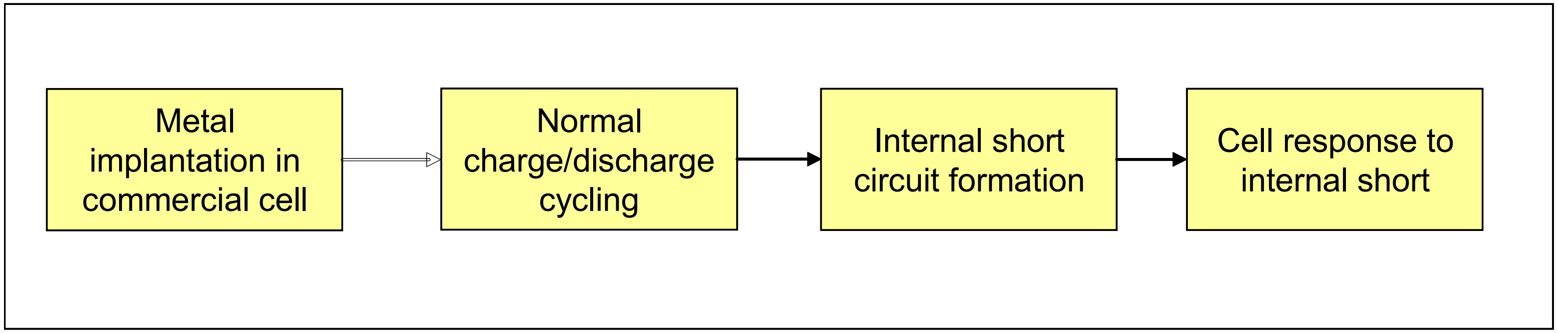
The propensity for cells implanted with metallic particles to short showed dependence on the type of metal.



In tests where a metal particle was placed on the *anode* coating, no shorting was observed in over 500 cycles

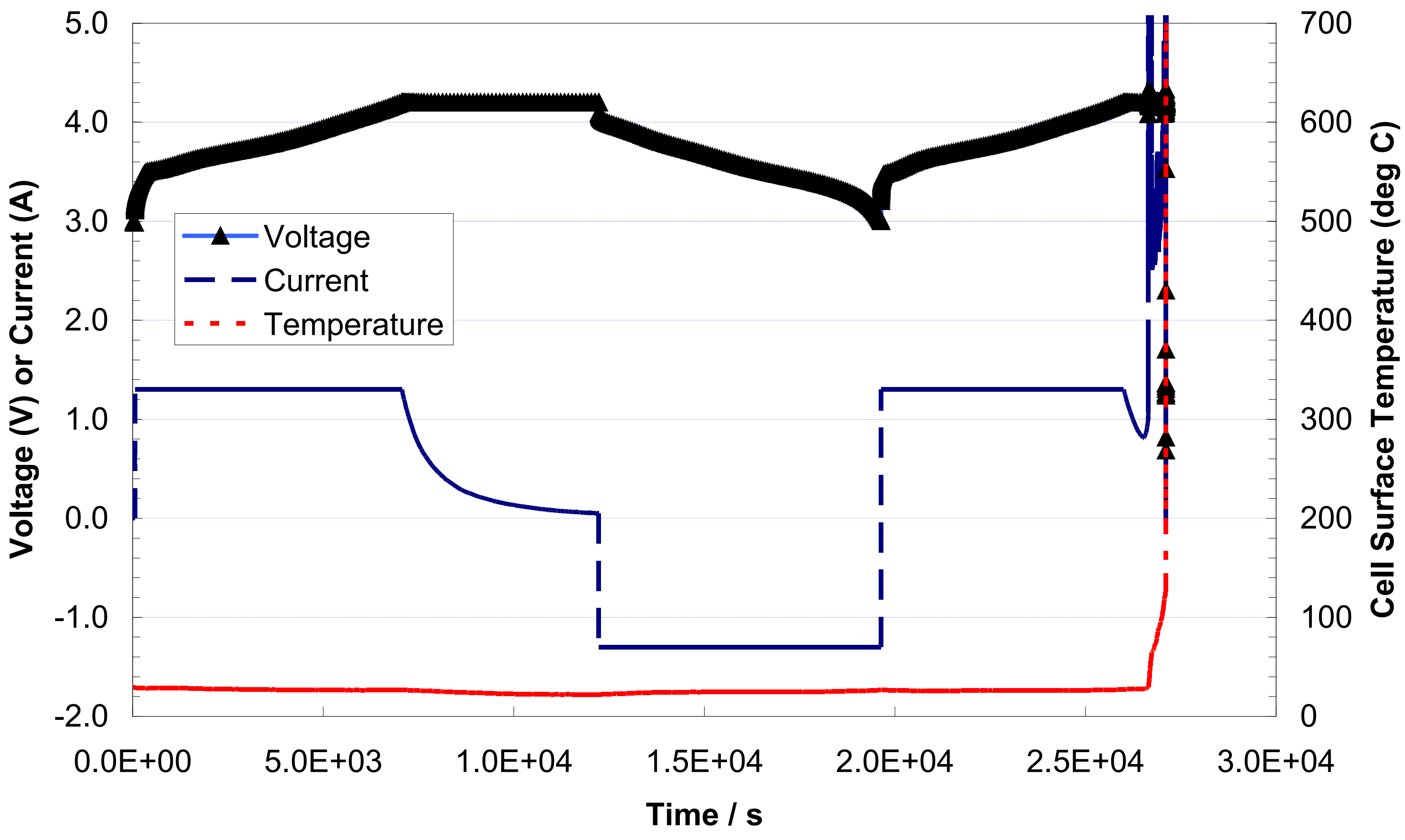


We also developed a technique for introducing a latent flaw involving the following steps.



- Implantation of metal particles in 18650 cells:
  - Disassembly of the cell
  - Unwinding of the jelly roll
  - Placement of a foreign metal particle in contact with cathode or cathode substrate
  - Rewinding of the jelly roll
  - Sealing of the jelly roll into a test fixture
- Normal charge/discharge cycling to cause metal dissolution, plating, and shorting through deposit growth

Implantation of metal particle induced an internal short during normal operation of an 18650 cell (≥ 2.6 Ah).



Summary

- We have found evidence for a mechanism for the formation of internal short circuits in lithium-ion cells in which metallic particles undergo oxidative dissolution at the cathode, plate onto the anode, and grow back to the cathode through the separator, forming a short.
- A procedure has been developed to implant particles in 18650 cells in such a way that the impedance and rate capability of the cell is preserved.
- Internal shorts have been created in 18650 cells, during normal conditions of voltage, current, and temperature.
- We are developing monitoring methods to follow the initiation and growth of internal shorts in lithium ion cells, and to detect shorts with enough sensitivity to provide early warning of impending cell failures.
- Improved understanding of the fundamental processes in metal dissolution and plating in non-aqueous electrolytes will greatly help advance novel safety technologies

Acknowledgments

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