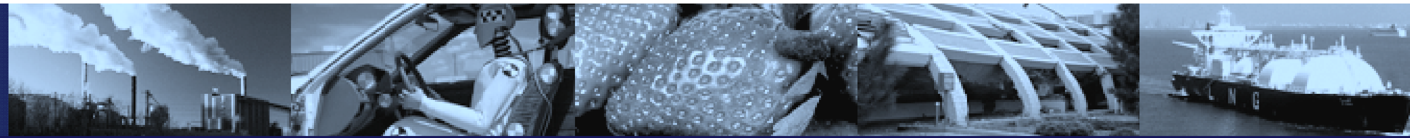
environmental • failure analysis & prevention • health • technology development

Exponent®

A leading engineering & scientific consulting firm dedicated to helping our clients solve their technical problems.

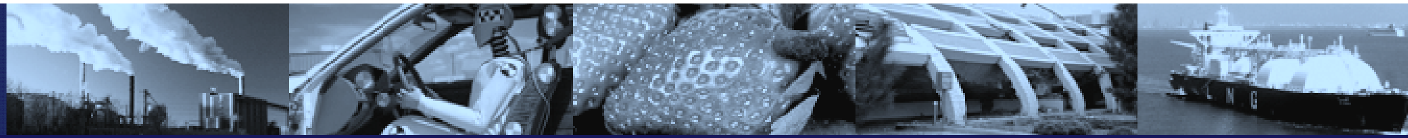
Li-Ion Batteries Basics

Mikhail Kislitsyn, Ph.D.

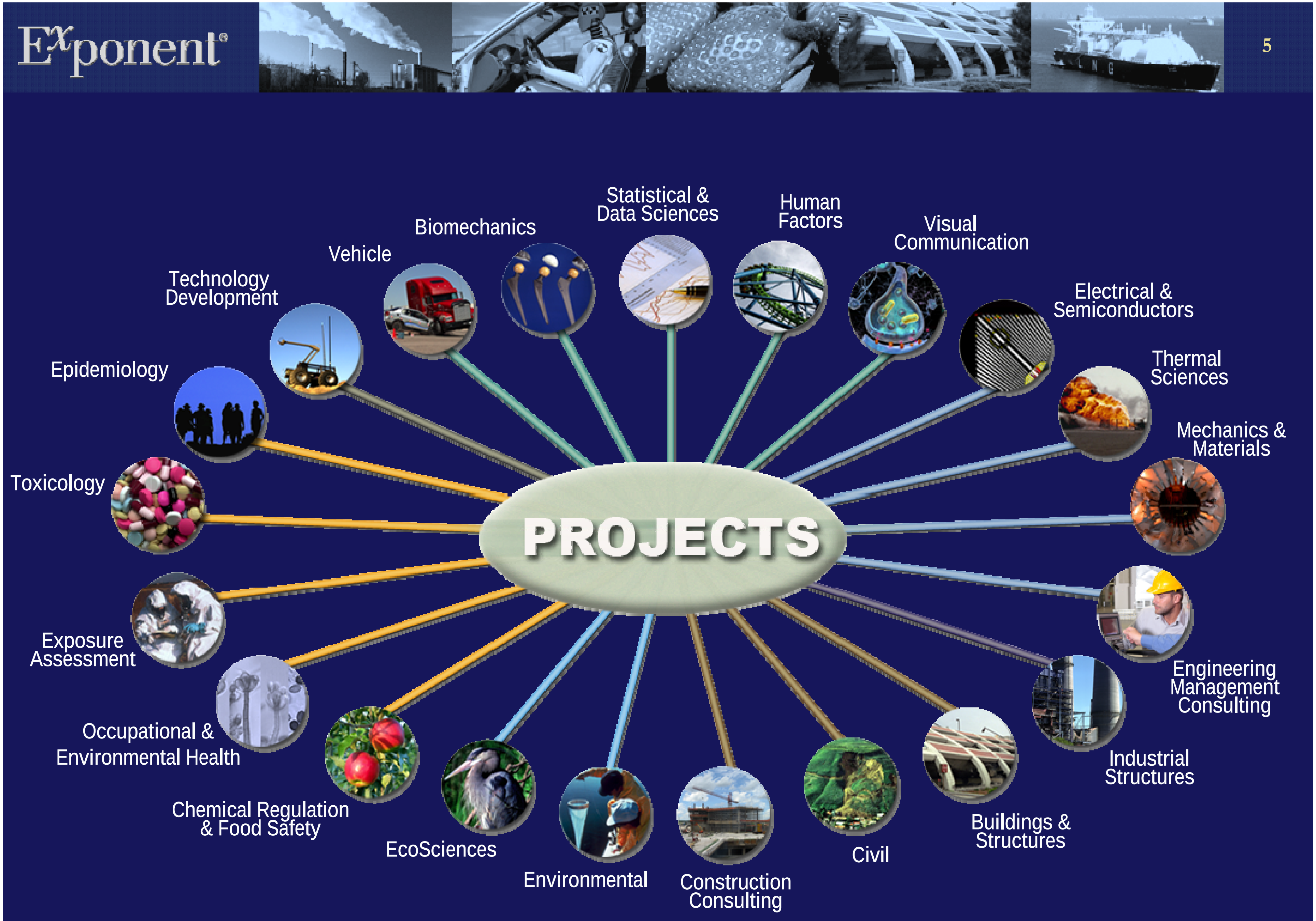


Who We Are

Exponent is a multi-disciplinary consulting firm dedicated to solving important science, engineering and regulatory issues for clients



Exponent Offices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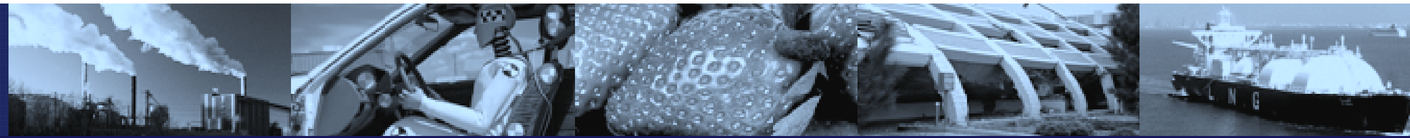
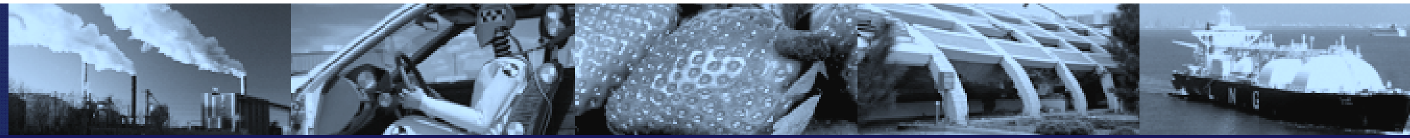


Battery Support Services

- Cell design review & assessment
- Pack design review & assessment
  - Electronics & BMU consulting
  - Thermal management
  - Structural evaluation
- Pre-compliance testing (UN, UL, BAJ, vendor specific)
- Verification & safety evaluation testing
- CTIA testing
- Failure analysis & corrective action recommendations
- Recall support
- Manufacturing auditing
- Cell cross-section analysis
- CT scanning
- Micro-reference electrode testing
- Accelerating rate calorimetry (ARC)
- Thermal analysis of materials (TGA/DSC)
- Materials characterization (SEM-EDS, XRD, FTIR, GC-MS)
- Custom abuse and service testing
- Fundamental electrochemical analysis
- Accelerated life testing and prediction
- Gas analysis
- Vent and CID activation

Objectives

- Review batteries technologies fundamentals
  - General construction,
  - Components,
  - Design
- Overview of the coating processes to apply active material on the anode and the cathode
- Examples of the coating defects



Li-ion Battery Technologies

- Different form factors -
  - Cylindrical
  - Prismatic (flat rectangle)
  - Pouch (Li-ion polymer, soft-pack polymer, lithium polymer, Li-Po cells)
- Different winding enclosure (hard or soft)
- Electrode construction (wound or stacked)
- Focus on the cylindrical 18650 Li-ion cell

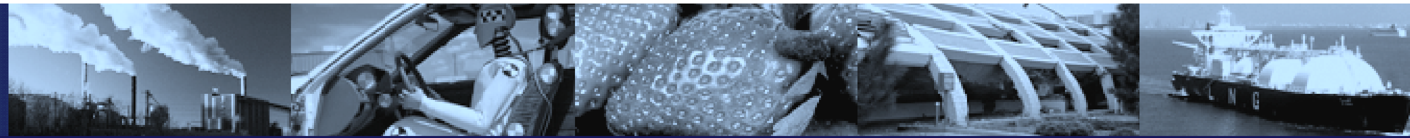
General Battery Design

- Review 18650 cell format:
  - 18650 cylindrical cell: diameter of 18 mm, length of 65.0 mm
  - Design
  - Anode, Cathode and Separator Construction
  - Safety Features
- Coating technologies overview

Cell Pack Typical Configuration

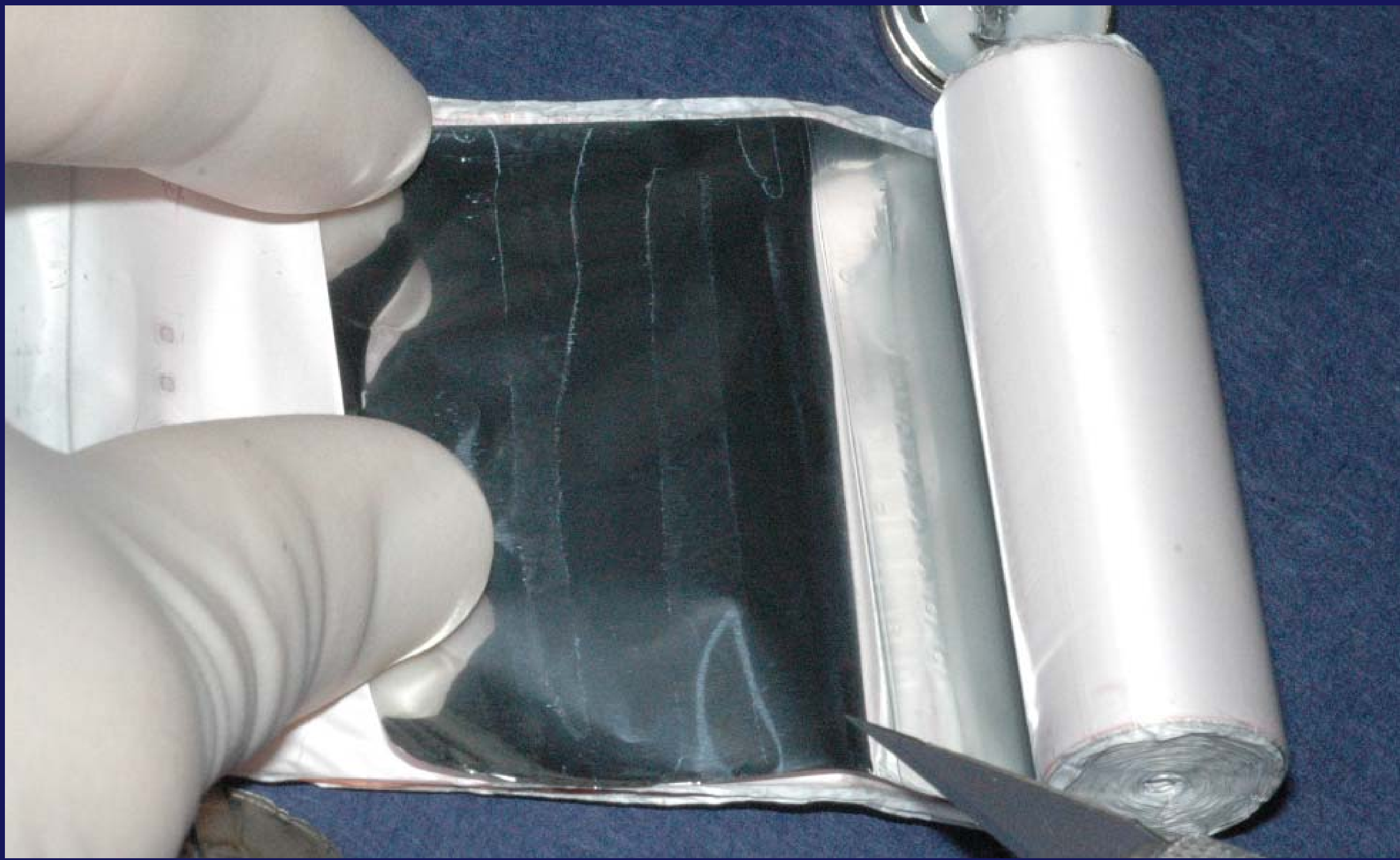
Cell Pack Typical Configuration

- Typical Pack consist of –
  - An enclosure
  - Cells
  - Protection electronics



Typical Cell (18650) Construction

Typical 18650 Roll



Mikolajczak C, Kahn M, White K, Long RT. Lithium-ion batteries hazard and use assessment, The Fire Protection Research Foundation, July 2011. http://www.nfpa.org/assets/files/PDF/Research/RFLithiumIonBatteriesHazard.pdf

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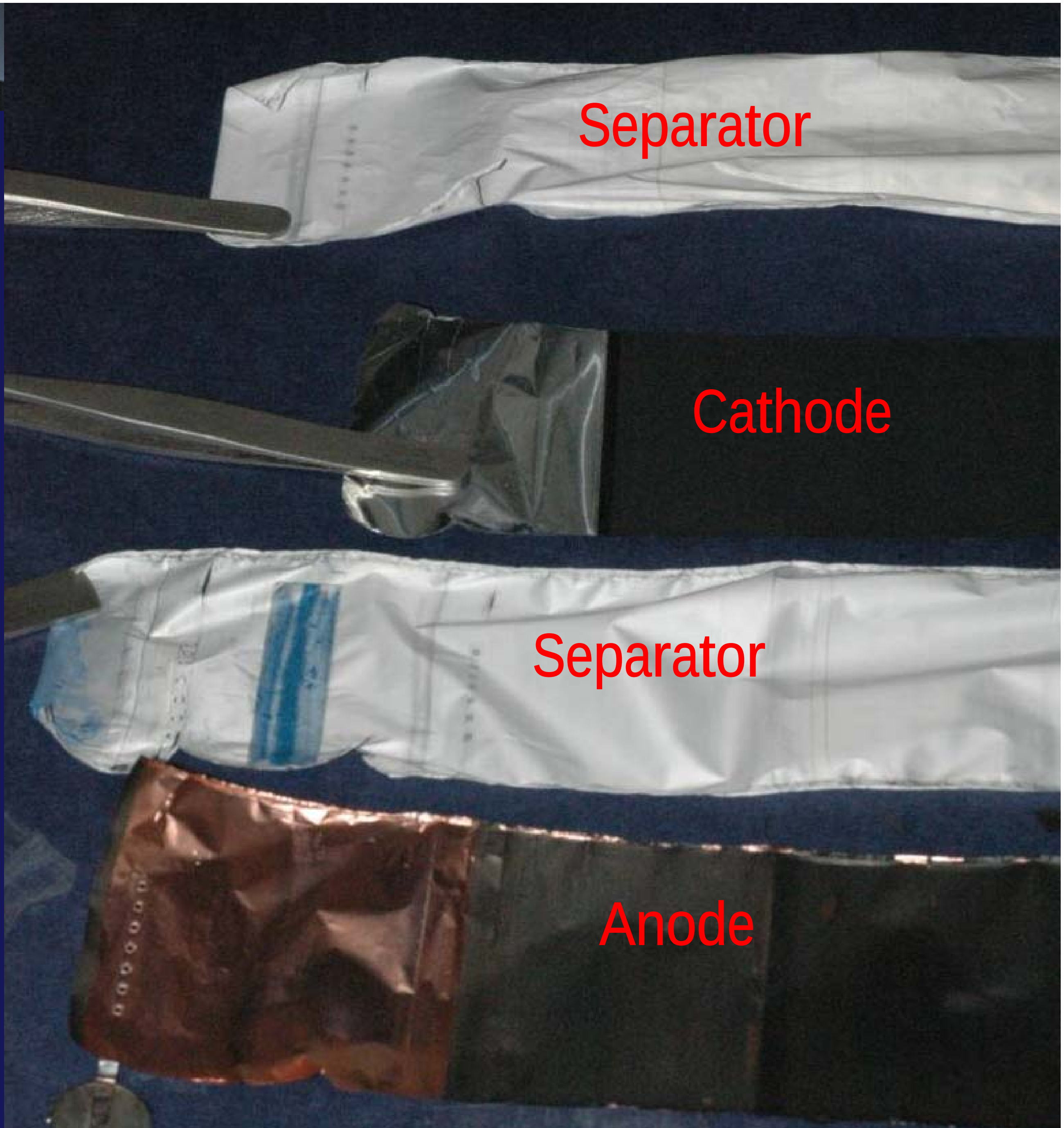
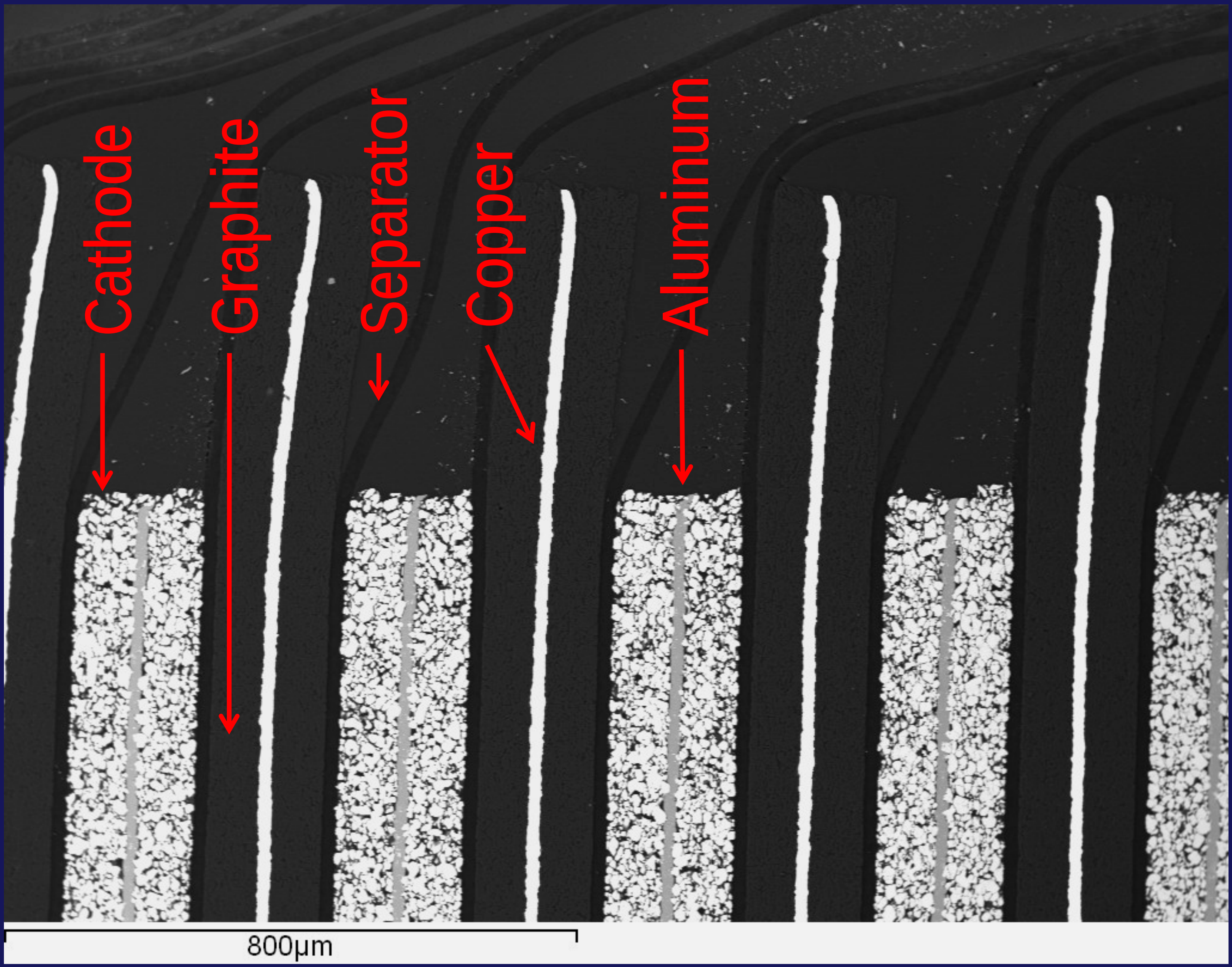
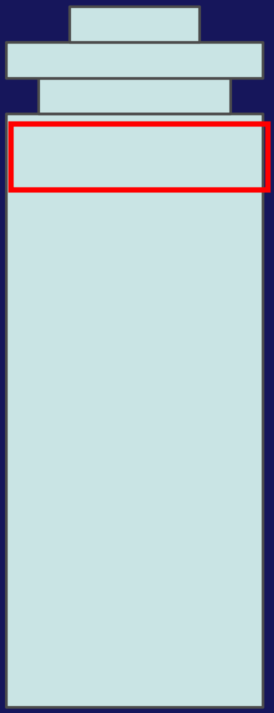
18650 Cell Windings

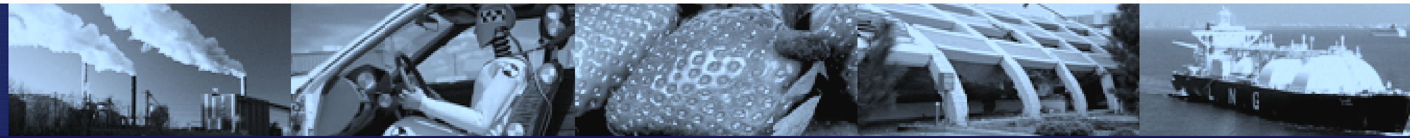


Mikolajczak C, Kahn M, White K, Long RT. Lithium-ion batteries hazard and use assessment, The Fire Protection Research Foundation, July 2011. http://www.nfpa.org/assets/files/PDF/Research/RFLithiumIonBatteriesHazard.pdf


Cathode
Graphite
Separator
Copper
Aluminum
800µm



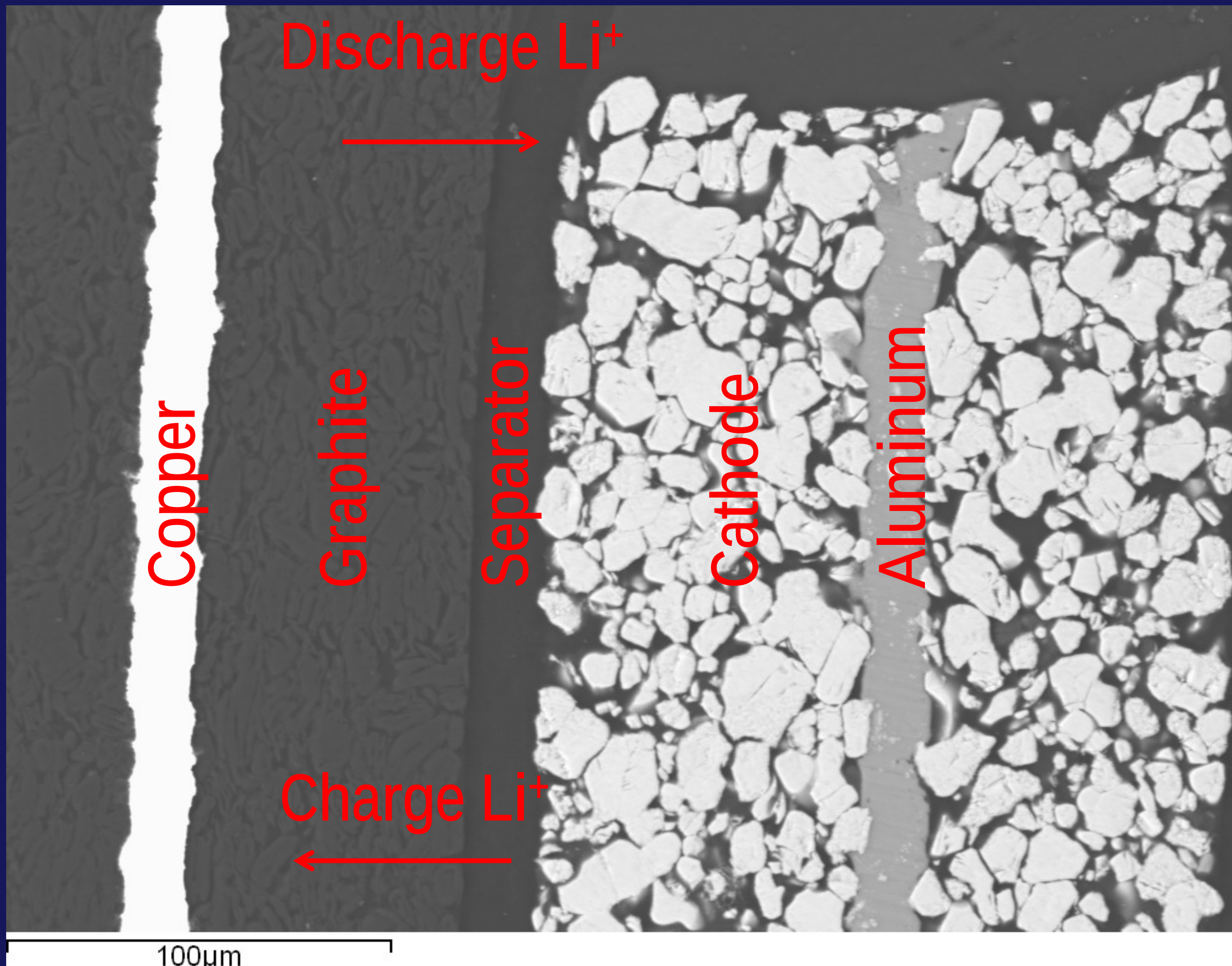
Cell Principle of Operation



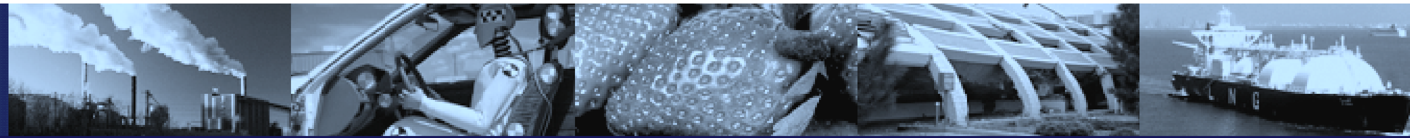
Cell Components

- Anode – stores Li in the interplanar space between graphite layers
- Cathode – stores Li^+-ions
- Separator – electrically insulating the cathode from the anode
- Electrolyte – Li-salt for Li-ion transport

Li-Ion Battery Operation Diagram



Anode, Cathode, and Separator



Separator

- Polymeric film
  - Most commonly, specially processed polyethylene, polypropylene, or polyethylene/polypropylene laminate
  - Ceramic coatings may be applied
  - Some non-woven ceramic based separators (specialty applications)
  - Typical thickness below 25 µm and towards 10 µm for high energy applications
  - Average pore size below 1 µm
- Prevents electrical contact between electrodes
- Allows transfer of Li-ions by electrolyte

Separator

- Thermal Properties:
  - HDPE 135°C, no mechanical integrity above the melting temperature
  - Laminating PP-PE mechanical integrity up to 165°C
  - Polymeric based separators have shutdown behavior
  - Ceramic non-woven maintain dimensional stability but do not have shut-down properties

Separator - Microstructure

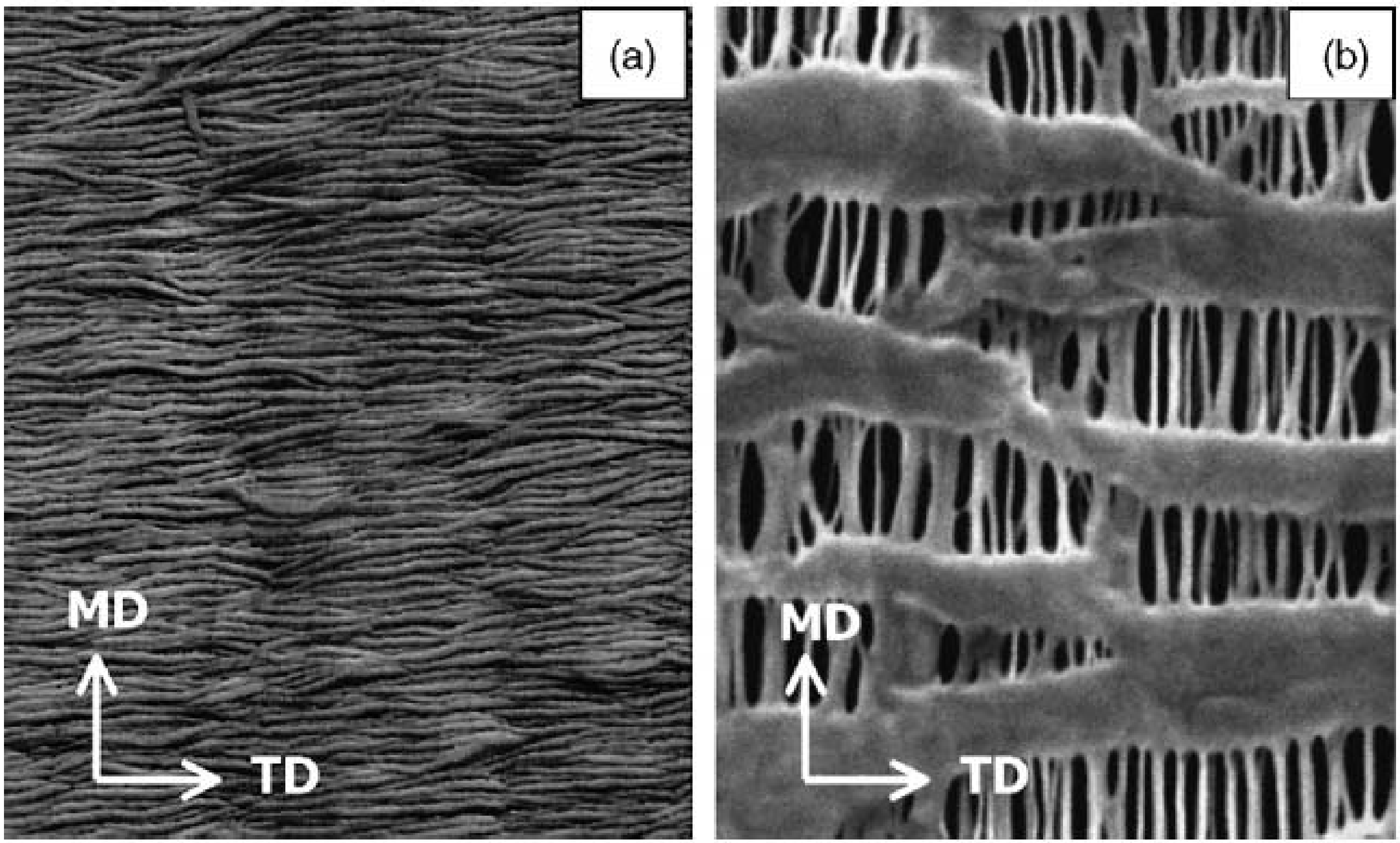
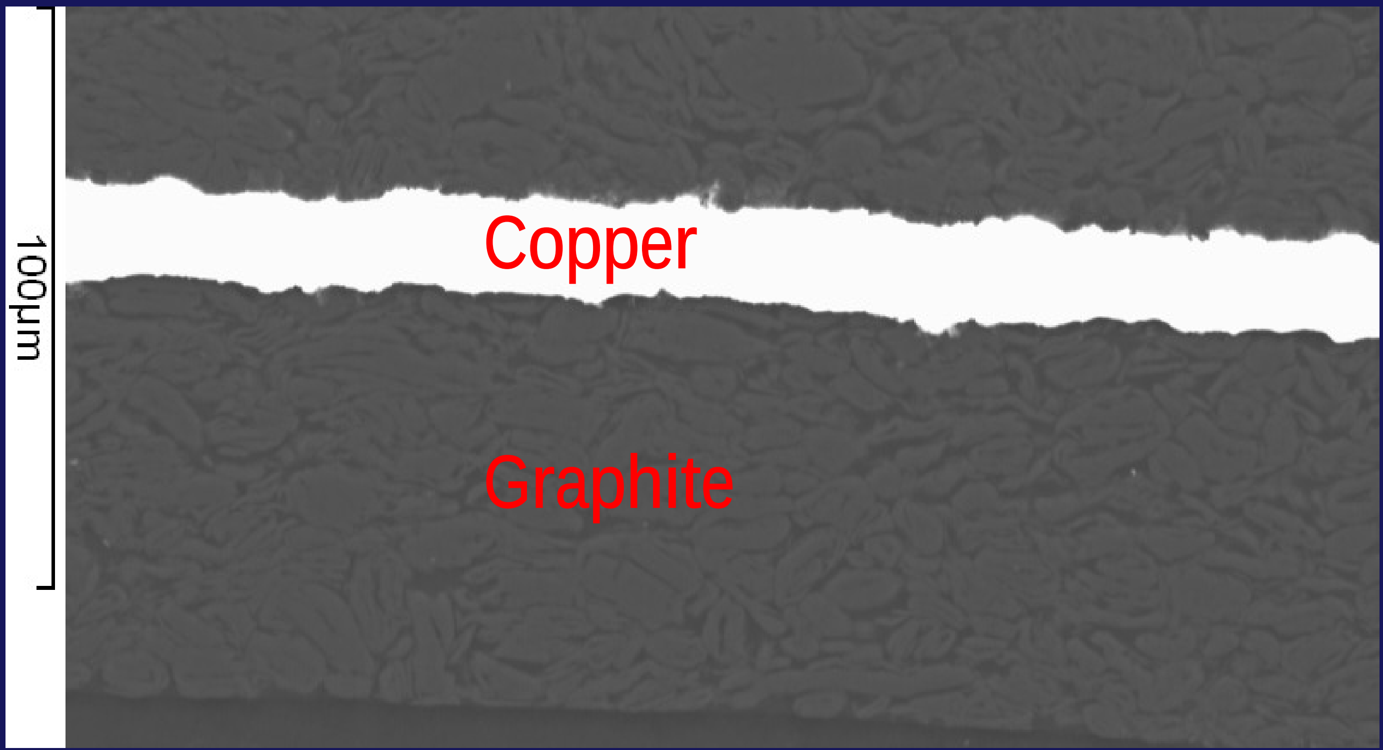


Fig. 2. Microstructure of a uniaxially oriented HDPE film before (a) and after (b) uniaxial stretch.

A review on the separators of liquid electrolyte Li-ion batteries, Zhang S.S. Journal of Power Sources 164 (2007) 351–364

Anode Material

- Carbon coated onto a metal current collector
  - Graphite powder combined with binder



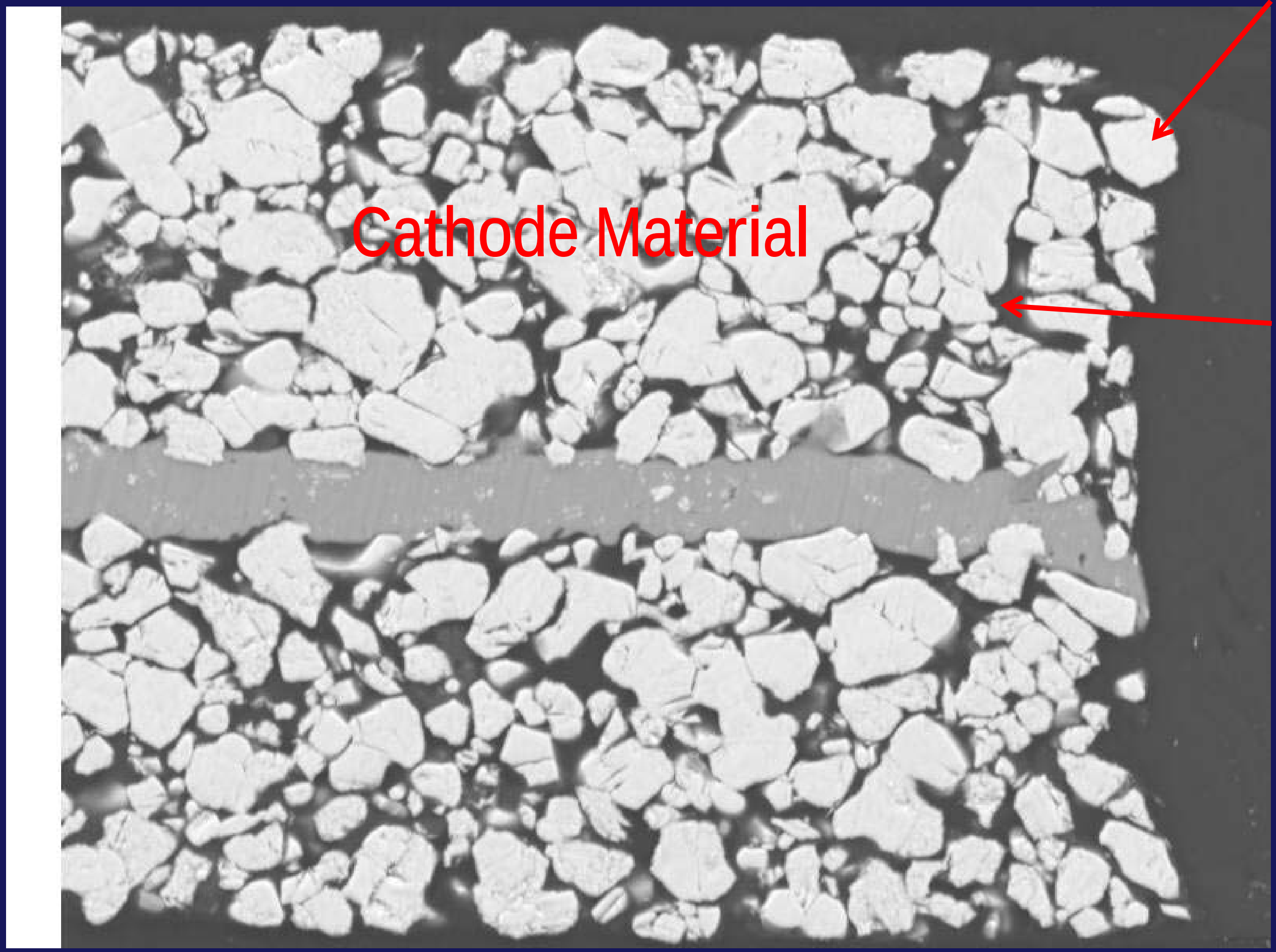
Anode Material

- Passivation layer on carbon (Solid Electrolyte Interface or SEI) forms on a surface at room temperature
- Complex passivation layer growth, composition and formation
- SEI layer breaks down at elevated temperatures

Cathode Material

- Material types: cobalt oxide, iron phosphate, etc.
- Powders combined with conductivity enhancers (carbon) and binder

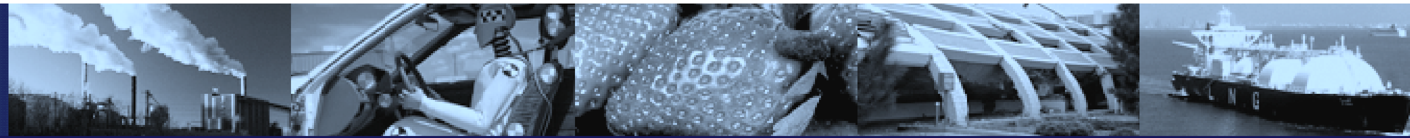
Cathode Material



$LiCoO_2$

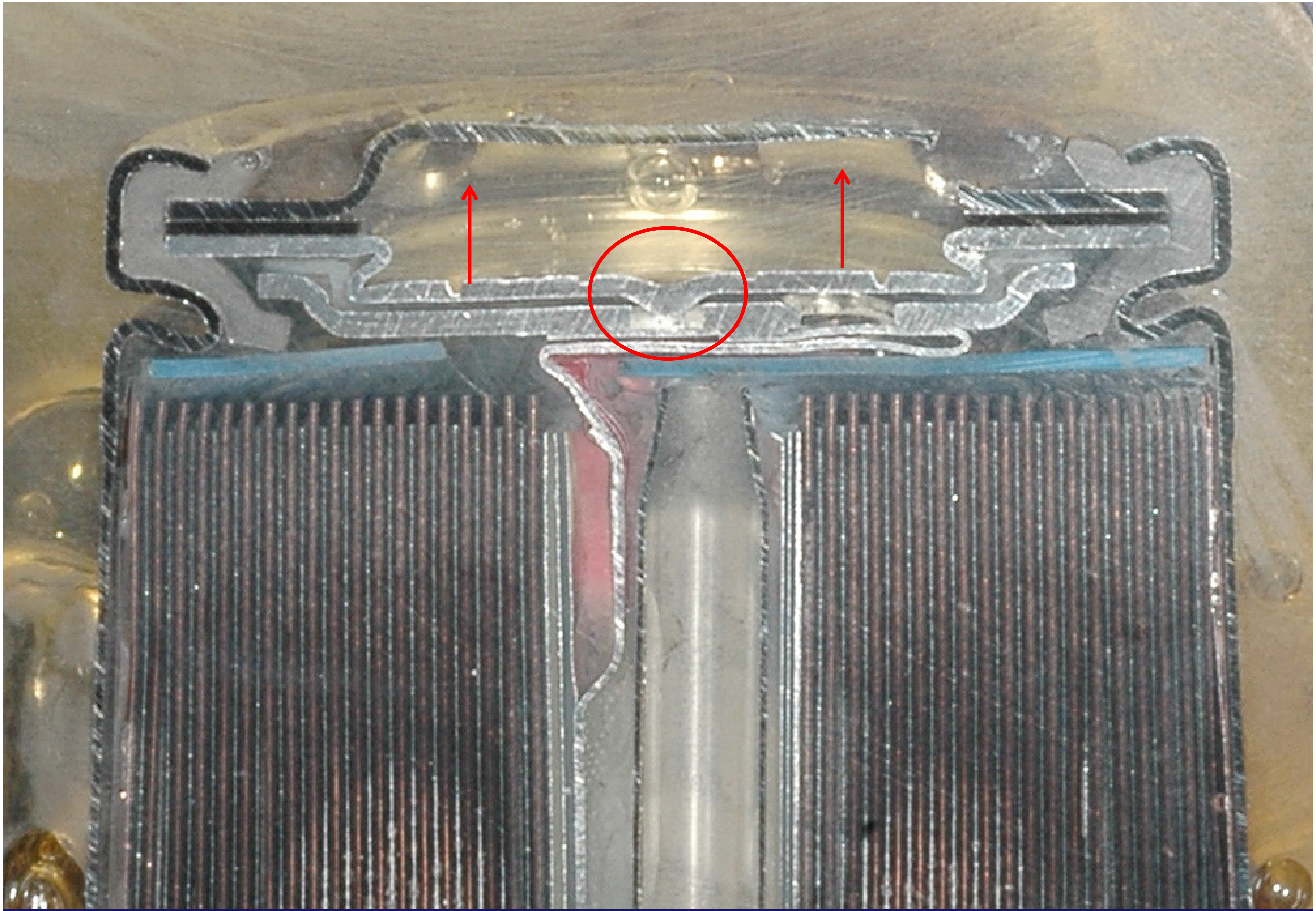
Binder + Carbon

Selected Safety Devices in 18650



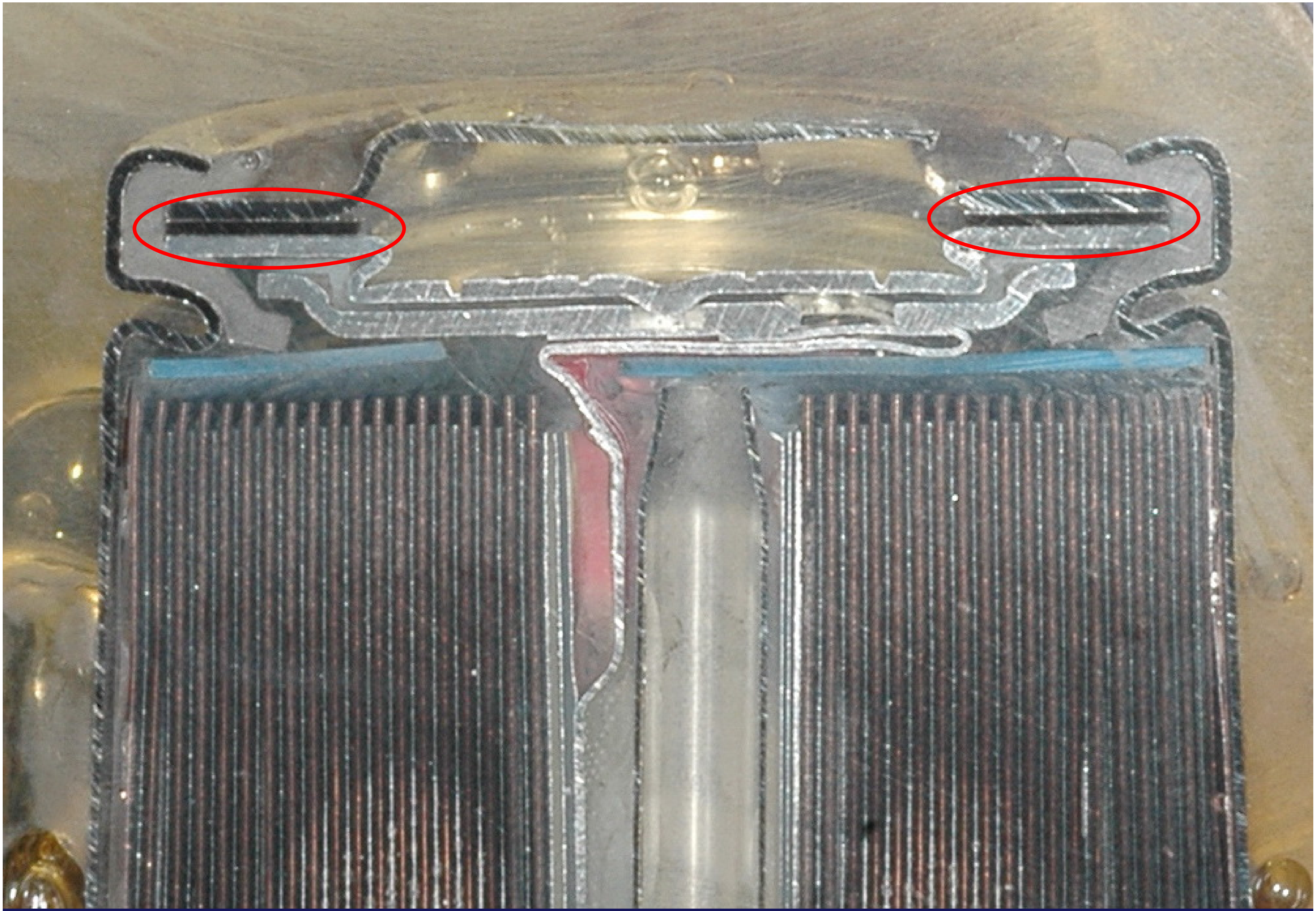
1. Charge Interrupt Device (CID)

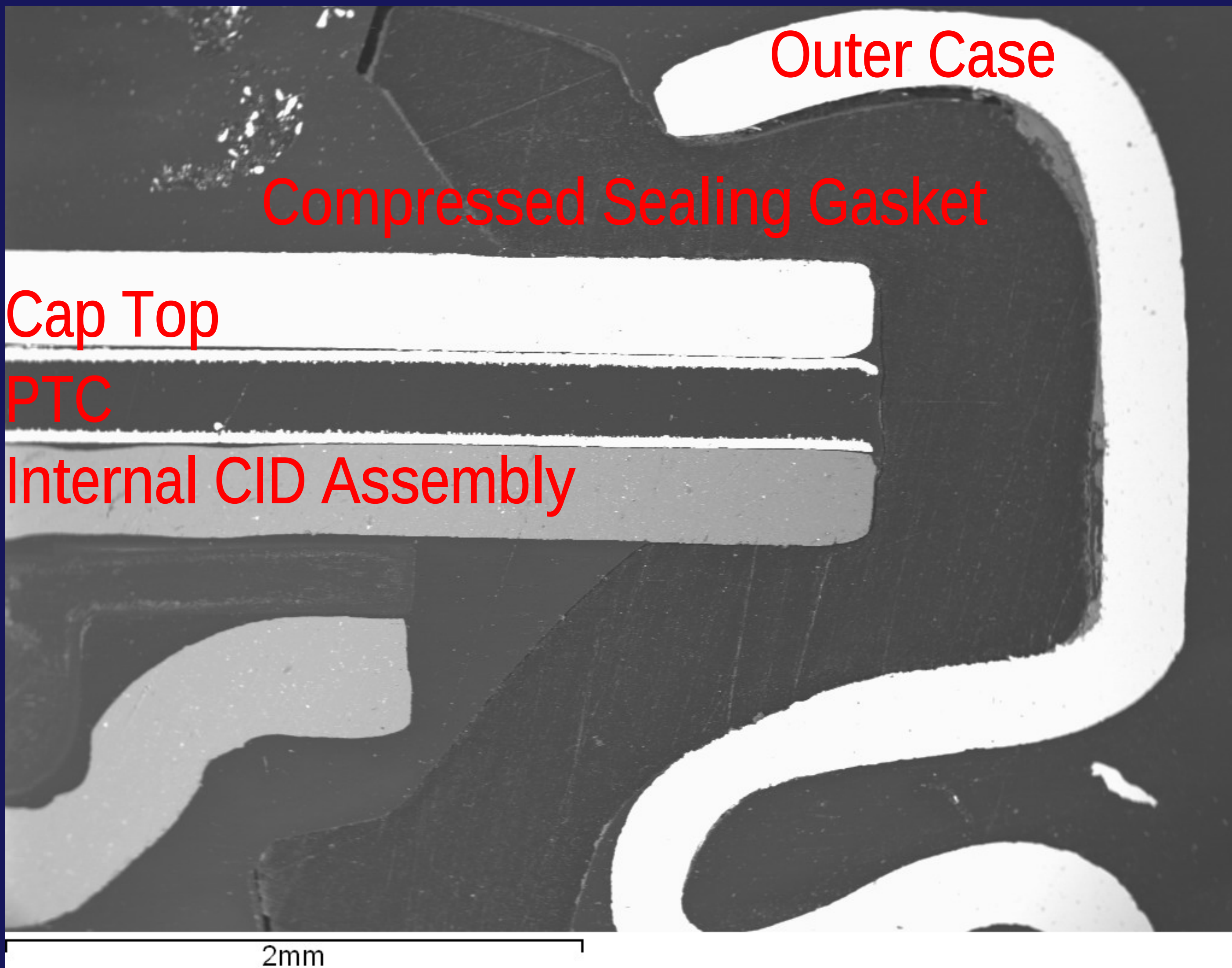
- Increase in the internal gas pressure –
  - Cell overcharge
  - Cell heating due to increased internal impedance
  - Lithium plating due to anode degradation
- Creates mechanical break in the cathode lead preventing current flow



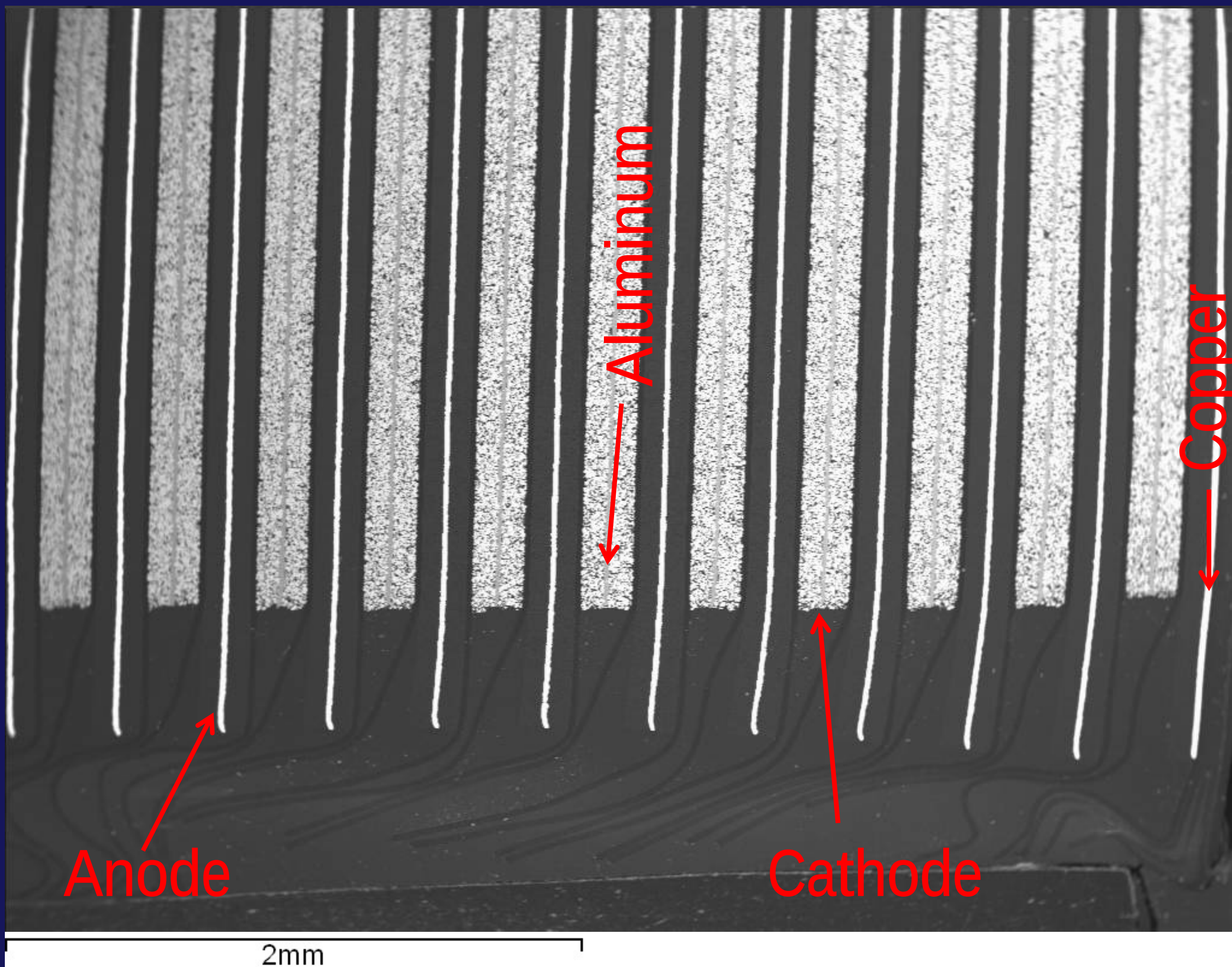
2. Positive Temperature Coefficient (PTC) Device

- Conductive polymer layer in the cap assembly
- Becomes resistive upon heating.
- High discharge (or charge) current –
  - Polymer will heat up
  - Become resistive
  - Stop current from (to) the cell
  - Resistivity is reversible upon cooling




Outer Case
Compressed Sealing Gasket
Cap Top
PTC
Internal CID Assembly
2mm

3. Electrode Design (Anode Overhangs Cathode)



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Active Material Coating Technologies

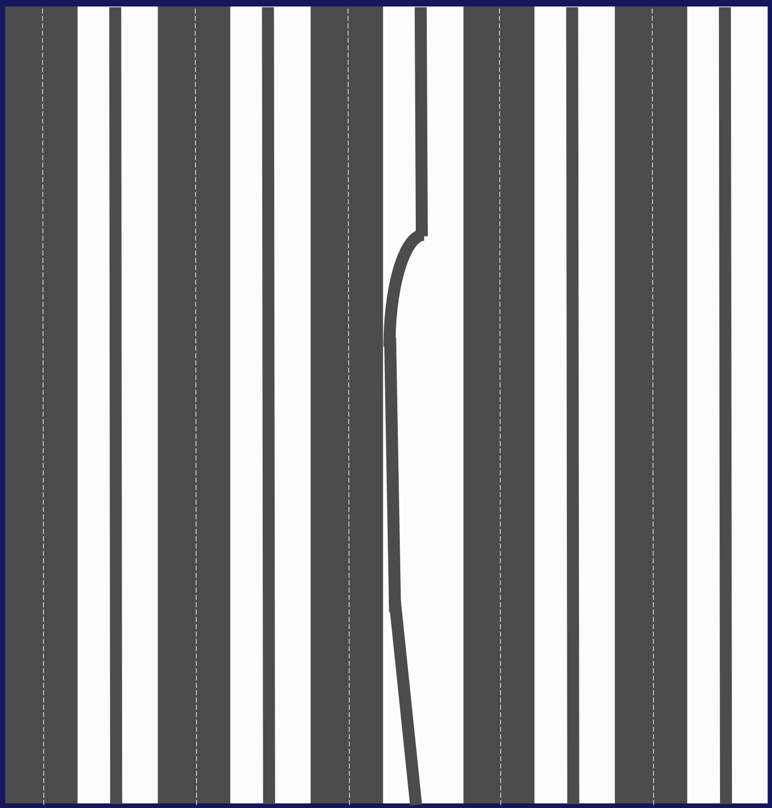
Coating Uniformity

- Both anode (copper) and cathode (aluminum) are coated with complex mixtures during coating process
- Cell and pack lifetimes are strongly related to electrode coating uniformity
- Uniform coating
  - Cell perform and age in the same way
  - Allows tight matching of cells based on capacity and impedance

Coating Defects

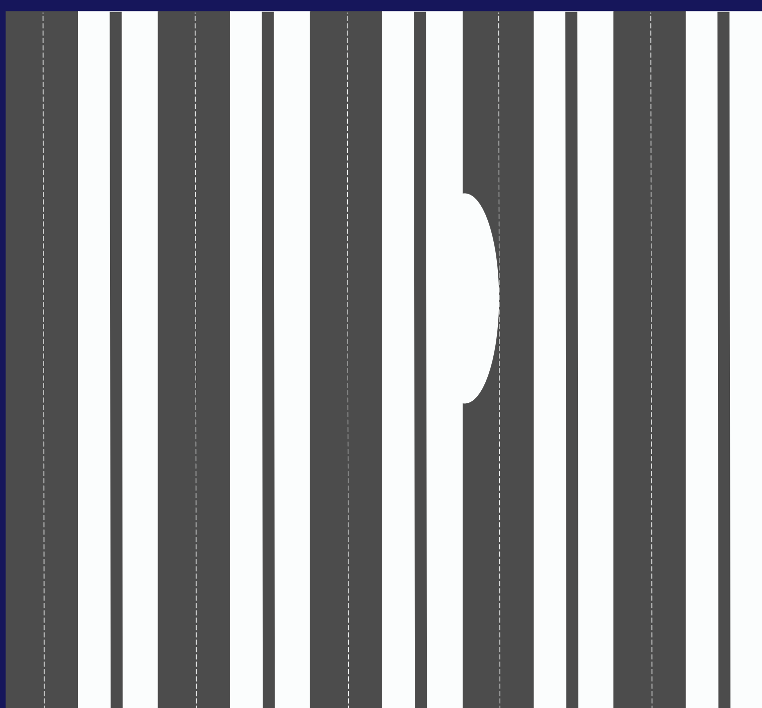
Electrodes Point Defects

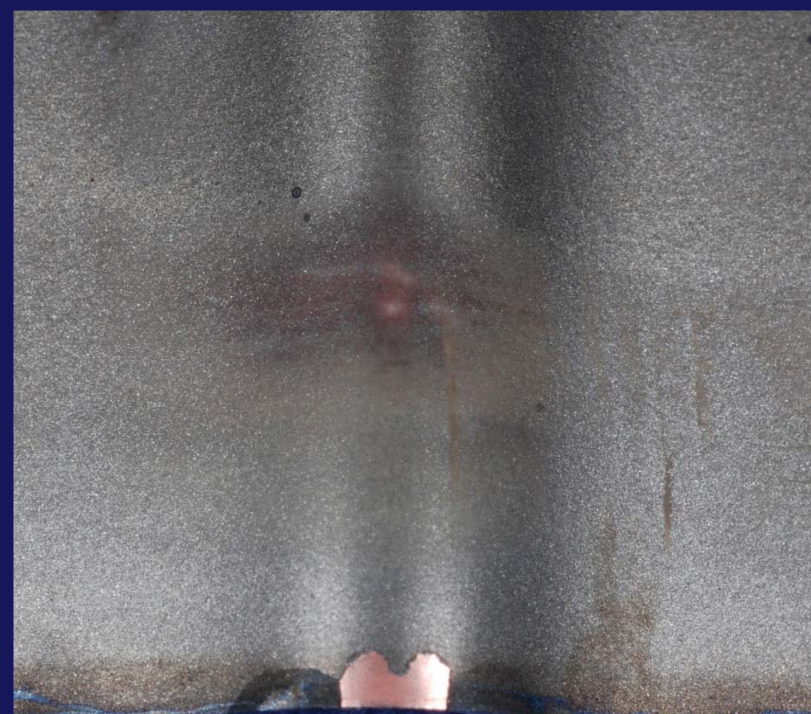
- Coating non-uniformity (scratch / crack)



Electrode Point Defects

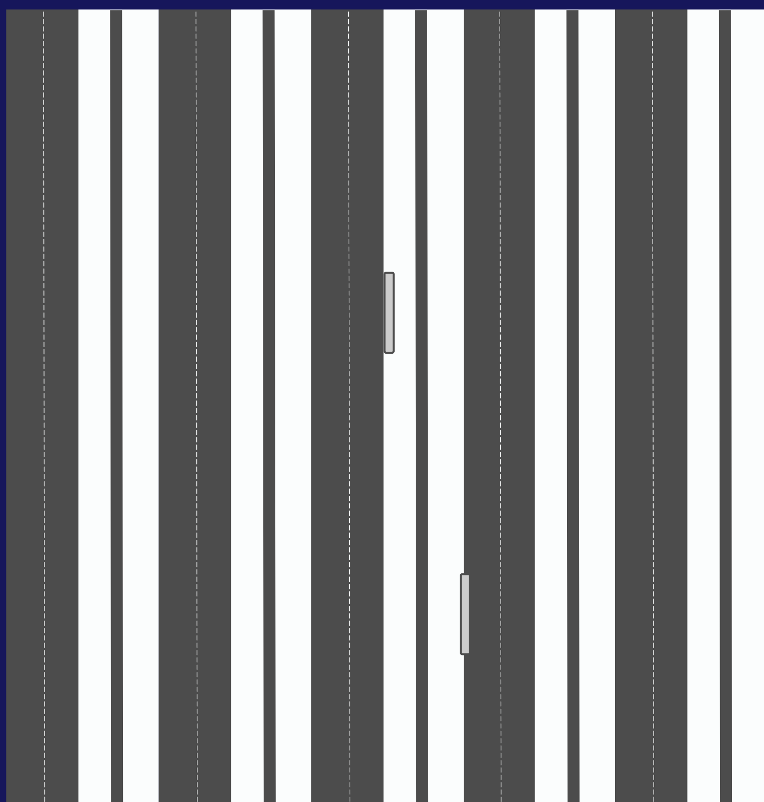
- Coating delamination spots or voids

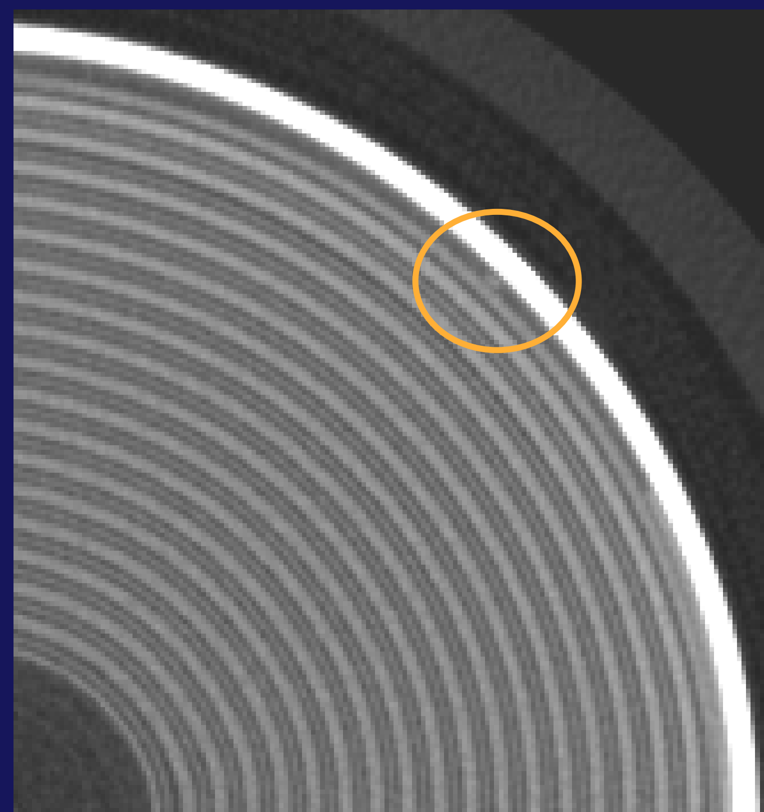




Electrode Point Defects

- Contaminants





Acknowledgements

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