environmental • failure analysis & prevention • health • technology development

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.
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
18650 Cell
Windings

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

- **Discharge Li⁺**
- **Charge Li⁺**
- Copper
- Graphite
- Separator
- Cathode
- Aluminum

100μm
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.
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

Cathode Material
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
3. Electrode Design (Anode Overhangs Cathode)
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
Electrode Point Defects

- Coating non-uniformity (scratch / crack)
Electrode Point Defects

- Coating delamination spots or voids
Electrode Point Defects

- Contaminants
Acknowledgements

- Celina Mikolajczak, P.E.
- Michael Kahn, Ph.D.
- John Harmon, Ph.D., P.E.