Batteries with Improved Safety Through Thermally Stable Separators

Technology & Features
- Microfiber/Nanofiber Technology Overview
- Separator Thermal Comparisons
- Flame Testing

Applications & Benefits
- High Rate Capability: reduce inactive materials
- Scale-up Case Study
What is a lot of energy packed into a small container called?

A grenade?

Or a battery?

Both?
What does a battery fire cost?

Boeing 787s grounded
January 16 – May 20
4 months at $200 million/month

$800,000,000 mistake
Parts of a Battery

- Electrodes
  - Store Energy
- Current Collector
  - transfer electrons
- Electrolyte
  - transfer ions
- Separator:
  - Keep electrodes isolated
  - Allow ions to pass through
Thermal Runaway in a Lithium-Ion Battery

1. Heating starts.
2. Protective layer breaks down.
3. Electrolyte breaks down into flammable gases.
4. Separator melts, possibly causing a short circuit.
5. Cathode breaks down, generating oxygen.
LIB Cathode Thermal Runaway: 180 – 240 C

Temperature (C)

Normalized Rate (C/min)

LiCoO₂

Gen2: LiNi₀.₉₅Co₀.₁₅Al₀.₀₅O₂

Gen3: Li₁.₁(Ni₁/₃Co₁/₃Mn₁/₃)₀.₉O₂

LiMn₂O₄

LiFePO₄

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SAND # 2009-7319P
Separator Problem: Shrink at 120 and Melt at 140-160 C!
What are Separator Manufacturers Proposing?

Ceramic coating

Cost is more than $1/m² of separator
Or 70% increase in separator cost
What Else?

Polyimide Electroblown Nanofibers

Dendrite detectors

Cost is more than $2/m² of separator
Or 133% increase in separator cost
Dreamweaver Technology

- Nanofiber on microfiber
  - “spider-web-on-Tinkertoy”
- Nanofibers form good barrier
- Microfibers give open structure
  - good window
- Microfibers also add strength
Nanofiber Structure
Dreamweaver Gold™

- Blend of high temperature fibers
- Featuring Teijin Twaron
- Features
  - High rate capability
  - Stable to 300 C
  - Below market price
Separator Features

• Look & feel of paper
  – Fast roll-to-roll processing

• Electrolyte Wet Out
  – Very fast, uniform

• Thermal stability
  – <2% shrinkage up to 300 C

• Open structure
  – Delivers high energy at high rate
**Separator Shrinkage**

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Film</th>
<th>Gold™ 30</th>
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<tbody>
<tr>
<td>TD Shrinkage 90 C</td>
<td>%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MD Shrinkage 90 C</td>
<td>%</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>TD Shrinkage 160 C</td>
<td>%</td>
<td>Melted</td>
<td>1</td>
</tr>
<tr>
<td>MD Shrinkage 160 C</td>
<td>%</td>
<td>Melted</td>
<td>1</td>
</tr>
<tr>
<td>TD Shrinkage 280 C</td>
<td>%</td>
<td>Oxidized</td>
<td>1</td>
</tr>
<tr>
<td>MD Shrinkage 280 C</td>
<td>%</td>
<td>Oxidized</td>
<td>2</td>
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</tbody>
</table>

If thermal stability and nail penetration are primary concern, we strongly encourage you to test Dreamweaver™ Gold

Polyolefin separator
Separator Shrinkage <2% to 300 C

- DMA—measures shrinkage
- Temperature limits:
  - Trilayer: 120 C
  - PP: 140 C
  - Silver: >250 C
  - Gold: >300 C
Separator Melt Stability to 300 C

- DSC—measures phase change
- Features:
  - Trilayer: melt peaks at 130 and 160 C
  - PP: melt peak at 165 C
  - Silver:
    - Water elution at 100 C (non-dried sample)
    - PET melt at 250 C
  - Gold:
    - Water elution at 100 C
    - PET melt at 250 C
Flame Test: Saturated with Electrolyte

- The test nobody would ever do:
  - Saturate separator with electrolyte
  - 5 min soak
  - Light electrolyte
  - Watch burn

- Results
  - PP: melt and burn
  - Silver: some charring
  - Gold: minor charring

After electrolyte burns out, DWI separators retain basic shape and size and ability to continue electrical separation of electrodes.
Flame Test: Saturated with Electrolyte
## Key Benefits

<table>
<thead>
<tr>
<th>Feature</th>
<th>Benefits</th>
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<tbody>
<tr>
<td>Safety</td>
<td>• Better safety at large cell size</td>
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<tr>
<td></td>
<td>• Better ability to withstand excursions in local environment</td>
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<td></td>
<td>• More durable against manufacturing defects</td>
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<tr>
<td>Higher Energy Density</td>
<td>• Lighter, thinner cell phones and laptops</td>
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<tr>
<td></td>
<td>• Power tools that last longer between charges</td>
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<tr>
<td></td>
<td>• Lighter electric vehicles</td>
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<tr>
<td>Higher Power</td>
<td>• Fewer batteries in hybrid vehicles</td>
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<td></td>
<td>• Power tools with more gusto</td>
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<tr>
<td>Longer Lifetime</td>
<td>• Cell phones, laptops and power tools that require a new battery less</td>
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<tr>
<td></td>
<td>frequently</td>
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<tr>
<td></td>
<td>• Lower battery depreciation cost for electric and hybrid vehicles</td>
</tr>
<tr>
<td>Lower Cost</td>
<td>• Lower cost batteries for cell phones, laptops and power tools.</td>
</tr>
<tr>
<td></td>
<td>• Greater acceptance of electric/hybrid vehicles.</td>
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THANK YOU!!

<table>
<thead>
<tr>
<th>Name</th>
<th>Email</th>
<th>Phone</th>
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<tbody>
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