Primed Al/Cu foils to support the battery market evolution

NAATBatt 2019
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VP Operations
Who are we?

**Mid-size industrial company**
- 1922 established in Nantes, France
- $300 M revenue (2018)
- 1850 employees

**Expert in formulation and high precision coating**
- 1.3 billion SQM of high precision coating produced annually
- 97 years of expertise in chemical formulation

**Global mindset supported by local proximity**
- 80% turnover from export
- 26 manufacturing and logistics sites
En’ Safe® primed Al/Cu foils

- Aluminum or Copper foil with a primer
- Primer coating thickness: typically 1µm
- Improve the interface electrode / metal foil
- Range of 7 primers (different chemistry)
Wide product range required to cope with many applications

En’ Safe® product range

Applications examples:

- Cathodes: NCA, NMC, LFP, LMO/LMNO, LCO
- Anodes: Silicon-based, LTO
- EDLC
- Lithium-Sulfur
- Lithium-ion 4.5 – 5.0V
- Lithium-capacitors
- Etc...
Battery technologies drivers

- Power and Energy Density
- Safety
- Cost
Optimized interface

REINFORCED ADHESION STRENGTH

+100% peeling test at 180°

Bare Al/Cu foil
En' Safe®

CHEMICAL BARRIER AGAINST CORROSION

Significant Corrosion
Standard primed current collector available on the market

0% Corrosion
En' Safe® primed Al/Cu foils

TRIPLE ACTION CURRENT COLLECTOR

LOWER INTERNAL RESISTANCE

-80%
@ 0.5 bar
-60%
@ 5 bar

LFP Battery

-20%
@ 0.5 bar
-15%
@ 5 bar

NMC Battery
Seeking for enhanced system performance

- **Optimized Interface**
  - Current collector
    - Bare foil
    - Existing formulation
  - Cathode
    - Primed foil
    - Existing formulation

- **Fully Optimized System**
  - Primed foil
    - Modified formulation 0 - 1% Carbon Black only

ARMOR patent WO2018220285
Fully optimized system

- **En’ Safe®** primed foil enables the reduction of Carbon Black in the electrode
  - 0% Carbon Black for LFP
  - 1% Carbon Black for NMC 532

- Excellent performance @ 5C (low impedance, no polarization, no capacity loss)

- Longer cycle life (typically +20%)
Wrap up - Savings ( $$ $$)

- Bill Of Material (BOM) -> 0 to 1% Carbon Black instead of 3 to 5%
- Lower price per kWh -> Replacing passive material (Carbon Black) by active material
- Total Cost of Ownership (TCO) -> Thanks to a longer cycle life
Thank you for your attention!

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Auxiliary Slides – Reduction of Carbon Black
## Systems tested

<table>
<thead>
<tr>
<th>Cathode type</th>
<th>Electrode carbon content</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFP</td>
<td>E0 = 0 % Carbon Black</td>
</tr>
<tr>
<td>NMC 532</td>
<td>E1 = 1 % Carbon Black</td>
</tr>
<tr>
<td></td>
<td>E2 = 2 % Carbon Black</td>
</tr>
<tr>
<td></td>
<td>E3 = 3 % Carbon Black</td>
</tr>
<tr>
<td></td>
<td>E5 = 5% Carbon Black</td>
</tr>
</tbody>
</table>
## Test types

<table>
<thead>
<tr>
<th>Topic</th>
<th>Test type</th>
<th>LFP</th>
<th>NMC 532</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impedance (especially for power app)</td>
<td>Electrochemical Impedance Spectroscopy (EIS)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Power curves (especially for power app)</td>
<td>Rate capability 2,1V to 4,2V vs graphite C/5 to 5C</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Charge/discharge cycles (for cycle life)</td>
<td>Cycling @C and 2C</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Specific capacity (especially for energy app)</td>
<td>Specific capacity @5C</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
LFP cathodes
down to 0% Carbon Black
Electrochemical Impedance Spectroscopy (EIS) characterizations

Huge impedance increase (from 40 to 2000 Ohm.cm²) when reducing electrode carbon content

Bare Al foil

@ 50 % SoC (1 hour stand-by)
189 kHz - 10 mHz
ΔV = 5 mV

Primed Al foil
Very small impedance even with 0% Carbon Black in the electrode
Rate performance

Bare Al foil
High polarization and huge capacity loss

Rate capability
2.1V to 4.2V vs Graphite
Previous charge at C/5
Discharge between C/5 and 10C

Primed Al foil
Almost no impact of electrode carbon content on capacity and polarization
Cycling

After 200 cycles @ 2C

Bare Al foil: Drastic loss of capacity retention by reducing electrode carbon content

Primed Al foil: Low impact on capacity retention even with 0% Carbon Black in the electrode
NMC 532 cathodes
down to 1% Carbon Black
Specific capacity (mAh.g\(^{-1}\)) @ 5C

- Bare Al foil E3 (3% CB) + 9%
- Primed Al foil E3 (3% CB) 86
- Bare Al foil E1 (1% CB) + 26%
- Primed Al foil E1 (1% CB) 82

Legend:
- RCC - E3
- PCC - E3
- RCC - E1
- PCC - E1
Cycling @ C (1% Carbon Black in the electrode)

- **Specific Capacity (mAh.g\(^{-1}\))**
  - PCC - E1 (1% CB)
  - RCC - E1 (1% CB)

- **Capacity retention (%)**
  - PCC - E1 (1% CB)
  - RCC - E1 (1% CB)

- **Number of cycles**
  - Bare Al foil
  - Primed Al foil