>450wh/kg Li/CFx Technology with Low Temperature Capability at -70°C

Hisashi Tsukamoto, PhD, CEO/CTO Quallion LLC

Powering Life.
Key Business Metrics:

- Diversified across medical, military, vehicle and aerospace markets, 104 employees. More than 60,000 cells produced annually
- Quallion is fiscally sound with cash reserves and profitable. Quallion is not reliant on the external credit markets for expanding production
- Unique knowledge of Li ion chemistry as technology is rooted in Material science
- Active large Li ion battery programs include: USG Title III, Aircraft Retrofit, NASA Orion program (new space shuttle), Blackhawk Helicopter Retrofit, APUs for HMMWV, UAVs, Launcher Vehicle Batteries, Satellite Systems, USAF X-51 Scramjet
- In-house battery electronics design capability
- 5year/$40M United States Military contract to establish 30 year supply of materials and cells for satellite and military applications
- Strong Li ion battery IP Position with over 60 chemistry, cell and battery patents issued and numerous patents pending
- Operations contained within 52,000 sq ft production facility in Los Angeles, CA, with an option to expand to 200,000 sq ft of contiguous manufacturing space

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Company Milestones

1998
- Company established in Southern California, USA

2001
- Entered Aerospace/Defense market with OGA and CECOM Contracts
- Initiated Development of Primary Chemistries

2002
- Developed 7 new cell designs (4 implantable grade); shipped 30,000 production units; plant reached 6,000 unit per month volume

2003
- Zero-Volt™ technology patented

2004
- SaFE-LYTE™ technology patented
- Registered under ISO 9001 & 13485; Zero-Volt™ technology patented (recertified in December 2004)
- Title III Award; Registered AS9100

2005
- Frost & Sullivan Award for Lithium Ion Power Sources
- Registered AS9100

2006
- Boeing Technology Supplier Award

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Y2004: Proof of Concept >500wh/kg Li/CFx Cell (D-size, Aluminum Can)

- Thin film coating to create flexible electrodes that can be easily wound into a jellyroll.

- The high surface wound jellyroll design enables high power discharge of the cells.

**ISSUE**
Safety was concerned because of large exothermic reaction during high rate and high temperature discharge.
Y2007: Small Cell Approach with Advanced Safety and Low Temperature Capability

<table>
<thead>
<tr>
<th></th>
<th>Base line cell</th>
<th>Prototype (C-HE)</th>
<th>Base line cell</th>
<th>Prototype (AAK-LT)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemistry</strong></td>
<td></td>
<td>Li/CFx</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nominal Voltage (V)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nominal Capacity (mAh)</strong></td>
<td>5000</td>
<td>6500</td>
<td>2500</td>
<td></td>
</tr>
<tr>
<td><strong>Dimension (diameter x height)</strong></td>
<td>D26mm, H50.5mm</td>
<td>D14.5mm, H50.5mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Weight (g)</strong></td>
<td>42</td>
<td>42</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td><strong>Energy density (Wh/kg)</strong></td>
<td>357</td>
<td>464</td>
<td>468</td>
<td>468</td>
</tr>
<tr>
<td><strong>Typical operating rate (C-rate)</strong></td>
<td>&lt;C/20</td>
<td></td>
<td>&lt;C/5</td>
<td></td>
</tr>
<tr>
<td><strong>Typical operating temperature (.C)</strong></td>
<td>-40C to +85C</td>
<td></td>
<td>-70C to +85C</td>
<td></td>
</tr>
</tbody>
</table>

• Quallion is developing the Half-5590 pack with Li/CFx AA-size cells. The pack has 15Ah, 12V with 2.3lb.
Comparison of SOA Li/CFx AA cell and Quallion low temperature AA cell (NASA application)
Room temperature discharge characteristic

![Graph comparing LT cell and BRAAK cell discharge characteristics with labels for Temperature: RT and Discharge rate: C/20]
Comparison of SOA Li/CFx AA cell and Quallion low temperature AA cell
-40 C temperature discharge characteristic
Comparison of SOA Li/CFx AA cell and Quallion low temperature AA cell for NASA application
-70°C temperature discharge characteristic
Quallion low temperature LI/CFx AA cell performance
- NASA application -
SINCgars to JTRS Radio Transition

**JTRS Program:** Produce a family of interoperable, affordable software defined radios to provide, secure, wireless, networking capabilities for Joint services.

- SINCgars (over 250,000 units produced)
- ASIP
- Falcon
- MBITR
- ATCS

**Legacy Systems**
- HMS (Handheld & Manpack Systems)
- GMR (Ground Mobile Radios)
- AMF (Airborne Maritime)

**Li/SO2 BA-5590**
95% market saturation against primary and rechargeable solutions

*Reduced envelope, lighter weight with same mission profile*

**Quallion Li/CFx Half-5590**

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Quallion Half BA pack with unique wide temperature Li/CFx chemistry

- Small cell approach (AA-size)
- -40 to 71ºC Operational
  - Quallion Medical Li/CFx cell is capable 150 degree C Autoclave
- 85ºC Storage Capable
- C/20 to C/3 Discharge Capability
- The Half BA pack with 15Ah, 12V and 2.3lb
Cell Design
Quallion Wide Temperature Primary Battery with 966 Wh/L Capability

<table>
<thead>
<tr>
<th>Cell type</th>
<th>Li/CFx AA</th>
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</thead>
<tbody>
<tr>
<td>Nominal Voltage</td>
<td>3V</td>
</tr>
<tr>
<td>Nominal Capacity</td>
<td>2.5Ah</td>
</tr>
<tr>
<td>Standard Discharge</td>
<td>2.5mA</td>
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<tr>
<td>Current</td>
<td></td>
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<tr>
<td>Weight</td>
<td>16g</td>
</tr>
<tr>
<td>Electrolyte</td>
<td>Quallion Low Temperature electrolyte</td>
</tr>
</tbody>
</table>

**NOTE:** D (D34.2 xH61.5mm) size Li/CFx cell with 15Ah has 798 Wh/L energy density. The 2.5Ah AA (D14x H50.5mm) size Li/CFx has 20% larger energy density than 15Ah D size Li/CFx.
C/3 Discharge Curves at -40°C

C/3 Discharge at -40°C for Tested Electrolytes

Discharge: C/20A to 1.0 V at -40°C

Control cells showed less than 1% of their room temperature capacity.

Chemistry: Li/CFx

AA Cell

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Capacity Retention After 1 Month
+71° or +85°C Temperature Storage

AA Cell
Chemistry: Li/CFx
Storage: +71°C or +85°C/1 Month
Capacity Check:
Discharge: C/20 mA to 1.0V at RT

RT Discharge Capacity Retention (%)

<table>
<thead>
<tr>
<th></th>
<th>CTL-1</th>
<th>Q6</th>
</tr>
</thead>
<tbody>
<tr>
<td>85°C % Retention</td>
<td>98</td>
<td>104</td>
</tr>
<tr>
<td>71°C % Retention</td>
<td>98</td>
<td>105</td>
</tr>
</tbody>
</table>
C/20 Discharge Rate Data of Q6-AA Cell

C/20 Discharge at Various Temperature

Discharge: C/20A to 1.0 V at -40°, -30°, -20°, 0°, RT, +71°, & +85°C
LCF Technology: Discharge Curve after 4 months Storage

Note: After storage, the cell again showed LVO discharge curve at initial discharge period. This proved that LVO was charged during storage by CFx which has higher OCV. Stored cell and Non-stored cell showed comparable discharge capacity. This indicates that LVO did not accelerate self discharge of the cell.

0.02C constant current discharge until 50% DOD at 37°C
Storage 4 months at 60°C and discharge again at 0.02C at 37°C
LCF Technology: No voltage Delay after 60 degree C, 3 weeks at SOC 45% Storage

Pulse discharge at 37°C at 1.5C before and after storage 3 weeks at 60°C at 45% SOC, then discharge until 1.7V at 37°C
LCF: Discharge Curve after Storage at Various DOD

0.02C Constant current discharge with 3 weeks storage at different DOD then until 1.7V, 37°C
Quallion Li/CFx Summary

- Improved Low temperature performance of Li/CFx cells through low temperature electrolyte formulation
- Removed voltage delay issue by Quallion unique LCF technology
- The half BA pack with **15Ah, 12V and 2.3lb**
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