Quallion Matrix Battery Technology for Lithium-ion Lead Acid Replacement & Wide Operating Temperature Range Cells

May 2011

Powering Life.
Employing a core strategy of leveraging R&D, niche focus, complementary and synergistic market entries

Largest manufacturer of Lithium cells in the U.S.

Best-of-breed system level approach for advanced battery technologies involving a core expertise from material selection to cell design and final battery pack configuration

**Products:**
- Materials
- Cells
  - Primary
  - Secondary
  - Polymer
- Batteries
  - Matrix Battery (MBD)
- Intellectual Property Portfolio
  - Zero-Volt
  - SaFE-LYTE

**End Markets**
- Aerospace
- Defense
- Medical
- Utility
- Vehicle

**Headquarters:**
Sylmar, CA

**Founded:**
1998

**Employees:**
161

**Sites**
- Sylmar, California
- Detroit, Michigan
- New York, New York

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Targeting and Dominating Key Niche Markets

Quallion focuses on organic growth within niche markets rather than highly commoditized markets.

- Medical
- Defense
- Aerospace
- Green Technology
Overview of Battery Industry

Battery Market Stratification

- **Materials**
  - Chemistries can be varied for high-energy, power, rate and capacity, safety.

- **Cell Design**
  - Cell configurations include prismatic, cylindrical, flat stack, wound, large, small, polymer (pouch), hard case.

- **Electronics**
  - Cell and battery management, power, safety, interface, communication (e.g., SM/CAN), balancing, state of health monitoring, modeling, grade of board parts.

- **Battery Pack**
  - Pack design: safety, interconnects, spacing of cells, thermal gradients, heat ejection, environmental requirements, interface to application.

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Lithium-ion Challenges for Lead Acid Replacement

- **Cost**
  - Mitigated lifetime use, as long as lead acid is utilized for deep discharges

- **Electronics**
  - Battery must contain power electronics capable of high discharges while managing for external shorts
  - Safety for overcharge, overdischarge and over/under voltage
  - Charge management/regulation to ensure proper system function
Quallion Matrix™ Technology
Balancing Circuit or Connector to balancing circuit

Bus bar

Cell or Battery

Balancing line

Quallion Patents:
US7479346B1
US7573233B1
US7573234B1

Patented Quallion Matrix™ Battery Structure
Quallion Matrix™ Technology
Safety Aspects
Matrix™ Battery: Advanced Safety Feature

Cell: 18650

Apply local heating (>250°C) to Cell No.2
Conventional Battery: Thermal Run-away Propagated to Entire Battery
Matrix™ Battery:
Thermal Run-away Localized to Only Cell #2
Matrix™ Battery:
Cell #3-6 Remain Functional

<table>
<thead>
<tr>
<th>Cell number</th>
<th>Resistance (Ohm)</th>
<th>Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5600</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>0.04</td>
<td>4.14</td>
</tr>
<tr>
<td>4</td>
<td>0.026</td>
<td>4.107</td>
</tr>
<tr>
<td>5</td>
<td>0.03</td>
<td>4.14</td>
</tr>
<tr>
<td>6</td>
<td>0.03</td>
<td>4.08</td>
</tr>
</tbody>
</table>
Partial Penetration Test Conditions

- The module was charged with 53.3V, 3.5A (CCCV method) at room temperature (approximately 25 Deg C).
- The module was charged to 100% RSOC (reported by SMBUS communication).
- The module was penetrated with a 10 mm mild steel (conductive) pointed rod.
- The rate of penetration was approximately 8 cm/sec.
- The module was penetrated twice, once at the center of the outer cell and a second penetration between two outer cells.
- After penetrating the battery module, the test was monitored for one hour.
Partial Penetration Test Results

Penetration at the center of the cell.

Penetration was between two adjacent cells.
Crush Test Conditions

- The module was charged with 53.3V, 3.5A (CCCV method) at room temperature (approximately 25 Deg C).
- The module was charged to 100% RSOC (reported by SMBUS communication).
- The module was crushed between a flat plate and a textured plate as shown.
- Bottom flat plate was electrically isolated from the crush fixture.
- The crush occurred in two stages. In the first stage, crush is applied for 15% of the module’s height, which is held for five minutes.
- In the second stage, crush was limited by a 47% displacement of the module’s height and is held for five minutes.
- The module was observed for one hour after the test.
Crush Test Results
Quallion Matrix™ Technology Survivability
Increased Load Test on Matrix™ Battery

... A cell was removed at every 1000 cycles from pack

LEO cycle continued with no impact on battery voltage after 3750 Cycles with Three Failed Cells

Test Parameters
- 90-minute orbit
- Charge at 6 A to 32 V clamp with a taper to end of the charge period of 60 minutes
- Discharge current 9.6 A for 30 minutes
- DOD: 40%
- Removed one cell at 1000th cycle, second at 2000th cycle and the third at 3000th cycle; to understand the performance of the battery with three failed cells
Survivability Comparison:
Matrix™ vs. Conventional

High Reliability
3P7S test pack

Conventional pack

F1:
self-discharge

F2:
high internal impedance

F3:
decreased capacity

MBD
Conventional Pack: Failed in Overcharge at First Cycle
Matrix™ Battery:
No Overcharge & Survived an Additional 19 Cycles

DOD100% test

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Matrix™ Battery:
Less Balancing Need for Pack after 300 Cycles

Pack I
Matrix Pack

Pack II
Conventional Pack

Quallion confidential and proprietary
Matrix™ Battery: Flexible Power/Energy Ratio

12S-4P with various HE/HP cell Mix

<table>
<thead>
<tr>
<th></th>
<th>HP Cells</th>
<th>HE Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy density</strong></td>
<td>120Wh/kg</td>
<td>200Wh/kg</td>
</tr>
<tr>
<td><strong>Power density</strong></td>
<td>1000W/kg</td>
<td>200W/kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Battery pack</th>
<th>Total number of cells</th>
<th>High power cells (18650 - 1.5 Ah)</th>
<th>High energy cells (18650 - 2.5Ah)</th>
<th>Weight (g) (including heat shrink tube, excluding tab)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4E0P</td>
<td>48</td>
<td>0</td>
<td>48</td>
<td>2208</td>
</tr>
<tr>
<td>3E1P</td>
<td>48</td>
<td>16</td>
<td>32</td>
<td>2176</td>
</tr>
<tr>
<td>2E2P</td>
<td>48</td>
<td>24</td>
<td>24</td>
<td>2160</td>
</tr>
<tr>
<td>0E4P</td>
<td>48</td>
<td>48</td>
<td>0</td>
<td>2112</td>
</tr>
</tbody>
</table>

*Source: Qualiion*
12S-4P Hybrid Quallion Matrix™ Battery

... A matching correlation between design and performance
Quallion HAM™ Technology
Quallion Heat Absorption Material (HAM™) Technology
Overcharge Test with and without HAM™

Test Battery
18650 (1.5Ah high power) - 10 cells in Parallel connection.
Capacity- 15.0 Ah

Overcharge Test Condition
Charge battery pack @6A to 12V, hold voltage @12V till temperature dropping
Thermal Run-away Propagation without HAM™

Connection

After Test

Insulation

After Test

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Thermal Dissipation with HAM™

**HAM™ melted and latent heat stopped thermal run-away**

Connection

After Test

Insulation

After Test
Quallion Matrix™ Technology In Large Lithium-ion Lead Acid Replacements
Quallion 24V, QL072KM 1250A Capable Battery System for HMMWV

Current Lead-Acid Battery
12V x2Series, 65Ah, 59lb x2

Quallion Drop-in Li-ion APU with Safety Circuit and Fuel Gauge
24V, 72Ah, 42lb

Discharge time at various rates
24V, 50Ah Lithium-ion Battery for U2 Vehicle

Li-ion Tech Demonstration Unit using QL038KM unit
- 38 Ah capacity
- Flight Demonstration Fall 2008 with future scale up to 50Ah

QL038KM -30°C, 30A discharge (discharged 98% of nameplate capacity)
24V, 8.25Ah Lithium-ion EBPS for C-17 Aircraft

Qualification Program to Replace Current Ni-Cd System

- Low maintenance & long life
- Fully integrated charge control electronics, battery management electronics & BIT/SOC capability
- -65°F to 160°F (with heaters)
- 8.5lbs
- Full charge in 75 minutes over 21V to 32V input range
- Plug-N-Play
24V, 38Ah Lithium-ion Battery for Little Bird, MH-47 & MH-60 Vehicles

- 24V Lithium-ion/Lead Acid Replacement
- 1100 amp pulse capability
- 38 Ah capacity
- 24 lbs
Wide Operating Temperature Cell Designs
Quallion Q18650-HP

At -40°C, 30C rate discharge capable

<table>
<thead>
<tr>
<th>Cell Specifications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>True Capacity / mAh*</td>
<td>1000</td>
</tr>
<tr>
<td>Energy Density / Wh/kg*</td>
<td>92</td>
</tr>
<tr>
<td>Energy Density / Wh/l*</td>
<td>217</td>
</tr>
<tr>
<td>Dimensions / mm</td>
<td>65 x 18 (H x d)</td>
</tr>
<tr>
<td>Weight / g*</td>
<td>39 ± 0.75</td>
</tr>
</tbody>
</table>

* Calculated values based on design

- **Operating Range** = -40°C to +71°C
- **Heritage Materials**
  - Active materials are the same as Quallion SATELLITE cells
Discharge Rate Data of Quallion HP Cell

Charge: 1.0A, 4.1V CCCV C/20 mA cutoff at RT
Discharge: 0.2, 0.5, 1, 2, 5, 10, 15, 20, 25, 30A to 2.7 V at RT
Discharge Temperature Data of Quallion HP Cell at 30C Rate

- Single cell; 29 cycles at different rates and temperatures

**Charge**: 1.0A, 4.1V CCCV C/20 mA cutoff at RT

**Discharge**: 30CA to 1.5V at -40, -20, 0°C or 2.7V at RT, +40, +60, and +71°C

**Graph Details**:
- **Voltage / V** vs. **Discharge capacity / Ah**
- **Graph Legend**:
  - -40°C
  - 20°C
  - 0°C
  - +25°C
  - +40°C
  - +60°C
  - +71°C

**Notice**:
- 1Ah Q18650-HP
- Chemistry: NCA/C
- Electrolyte: A-1

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Quallion High Power 2.3Ah Cell

- Dimensions (without tabs) – 5.5” x 2.25” x 0.25”
- Weight – 75g
# Pouch Cell

## Cell Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Capacity / mAh*</td>
<td>2300</td>
</tr>
<tr>
<td>Energy Density / Wh/kg*</td>
<td>110</td>
</tr>
<tr>
<td>Energy Density / Wh/l*</td>
<td>205</td>
</tr>
<tr>
<td>Dimensions (H x W x T)</td>
<td>5.3 x 2.1 x 0.25</td>
</tr>
<tr>
<td>Weight / g</td>
<td>75 ± 0.75</td>
</tr>
</tbody>
</table>

- **Operating Range** = -40°C to +70°C
- **Heritage Materials**
  - Active materials are the same as Quallion SATELLITE cells
  - USG T3 program enables Quallion to produce Cathode and Anode material in-house by 2012
Rate Test Summary at RT

Retention of 1C Capacity / %

Prototype 1
Prototype 2
Pre-Production

Charge: 1.0 C A, 4.1 V CCCV C/20 mA cutoff at RT
Discharge: 0.2, 0.5, 1, 2, 5, 10, 15, 20, 25, 30 C A to 2.7 V at RT
1C Discharge Rate Curve at RT

**Charge**: 1.0 CmA, 4.1V CCCV C/20 mA cutoff at RT

**Discharge**: 1 CmA to 2.7V at RT

**Graph Details**
- **Prototype 1**
- **Prototype 2**
- **Pre-Production**
15C Discharge Rate Curve at RT

Charge: 1.0 CmA, 4.1V CCCV C/20 mA cutoff at RT
Discharge: 15 CmA to 2.7 V at RT
30C Discharge Rate Curve at RT

**Charge**: 1 CmA, 4.1V CCCV C/20 mA cutoff at RT

**Discharge**: 30 CmA to 2.7 V at RT
1C Discharge at -40°C

Charge: 1 CmA, 4.1V CCCV C/20 mA cutoff at RT
Discharge: 1 CmA to 1.5 V at -40°C
15C Discharge at -40°C
-40 C Discharge @15C

Charge: 1 CmA, 4.1V CCCV C/20 mA cutoff at RT
Discharge: 15 CmA to 1.0 V at -40 C
C/2 Charge/Discharge Cycling of Prismatic Cell at -20° & -30°C

-20 C Cycling
-30 C Cycling

• Cycles 0, 11, 12 and 23 represent capacity checks at RT

2.30Ah Prismatic Cell
Chemistry: NCA/C
Electrolyte: M-1
Capacity Check:
Charge: 1CmA to 4.1V CCCV C/20 mA cutoff at RT
Discharge: 1C A to 2.7 V at RT

Charge: C/2 A, 4.1V CCCV C/50 mA cutoff at -20 & -30 C
Discharge: C/2 A to 2.5 V at -20 & -30 C
Quallion 10Ah Cell with Wide Operating Temperature

* Calculated values based on design

<table>
<thead>
<tr>
<th>Cell Specifications</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical Capacity / mAh*</td>
<td>10000</td>
</tr>
<tr>
<td>Energy Density / Wh/kg*</td>
<td>82</td>
</tr>
<tr>
<td>Weight / g*</td>
<td>450</td>
</tr>
</tbody>
</table>

- **Operating Range** = -40°C to +71°C
- **Heritage Materials**
  - Active materials are the same as Quallion SATELLITE cells
  - Wide temperature electrolyte
- **5000 DOD 60% to 80% Cycling over Wide Temp Temperature Spectrum**
- **Cell to undergo life testing February 2011**