Performance and Safety of Lithium Ion Cells

Wright-Patterson Air Force Base, Dayton, OH
R. Marsh

Jet Propulsion Laboratory, Pasadena, California
B. V. Ramesh, M. C. Smart, L. Whittemore and S. Surampudi

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Thermal characterization
• Electrical characterization by a.c. impedance
• VT charge characterization tests
• Storage characterization tests (cruise conditions)
• Accelerated LEO tests
• Capacity retention tests
• Charge rate characterization (at 40, 25, 0, and -20°C)
• Discharge rate characterization (at 40, 25, 0, and -20°C)
• Cycle life at alternating temperatures (40 and -20°C)
• Cycle life performance at low temperature (-20°C)
• Cycle life performance at room temperature (25°C)

Evaluation of Lithium-Ion Cells at JPL
### Technology Drivers

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### Objectives

- LEO Missions by 2003
- Aircraft by 2004
- Military Terrestrial
- Aviation/UAV’s by 2001
- GEO Missions by 2003
- Rovers by 2003
- Lander by 2001

**Sources**

- Establish US production of Batteries
- Long Cycle Life Li-Ion
- Develop High Specific Energy

**NASA-DOD Interagency Li-Ion Program**
Cycle Life of Li Ion Cells

- Temp = -20°C
- Temp = 23°C
Cycle Life of Li-ion Cells - Energy Efficiency
Accelerated LEO
Cycle Life of Li Ion Cells to Partial DOD
Temperature = 23°C
5.0 Amp Discharge Current top 3.0 V
Total Charge time = 24 Hours
Constant Voltage Charging at 4.1 V to 0.001 A Cut-Off
5.0 Amp Charge Current (C/5) to 4.1 V

Discharge Capacity (AHr)
Cycle Number
Tolerance to Extended Tapered Charge
Charge on Cycling

Charge Capacity (Ahr)

Charge Time (Hours)

23°C

4.1 V (Taper to C/50)
5.0 A Charge Current (C/5)

Cycle #400
Cycle #300
Cycle #200
Cycle #100
Cycle #10
Temperature = -20 °C

Low Temperature Discharge

Specific Energy (Watt-Hr/Kg)

Cell Voltage (V)

- 3.5 Amp Discharge Current (C/2)
- 2.212 Amp Discharge Current (C/3.3)
- 1.40 Amp Discharge Current (C/5)
- 0.70 Amp Discharge Current (C/10)
- 0.140 Taper current cut-off (C/50)
- 0.700 A Charge current to 4.1 V
Temperature = 20°C

Charge Capacity (Ah)

Time (Hours)

Low Temperature Charge

Constant potential charge to C/50

Cell charged to 4.1 V

Legend:
- 4.50 A Charge current (C/2)
- 2.725 A Charge current (C/3.3)
- 1.80 A Charge current (C/5)
- 0.900 A Charge current (C/10)
Storage Characteristics

Discharge Capacity (Ah)

Cell Voltage (V)

Recent capacity after prolonged storage at 0°c (3/00)
Capacity after 2 month storage (12/98)
Capacity prior to 2 month storage (10/98)
Initial capacity after conditioning (9/98)

D = 3.951 Ah (92.4% of Initial)
C = 3.991 Ah (93.4% of Initial)
B = 4.055 Ah (94.9% of Initial)
A = 4.274 Ah (5th cycle of conditioning)
Need to define specific conditions under which lithium plating can occur (rate

- Are higher charge voltages justified at lower temperature?

<table>
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<th>Charge Voltage (V)</th>
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Charge Capacity (Ah)
Electrochemical Technologies Group

EIS of a Li Ion Cell
Impedance in a Li Ion Cell
DC Polarizations in Li Ion Cell

Anode Potential (mV vs Li+/Li)

Cathode Potential (mV vs Li+/Li)

Temperature = 23°C

1.0 M LiPF6 EC+DEC+DME (1:1:1)
Li Reference Electrode

MCM Carbon-LiNiCoO2 Cell

Current (amps)

(Z') (Ohms)
EIS During Cycling

$\text{Z}''$ (Ohms)

Cell Fully Charged Prior To Measurements

OCV = 4.07V

$23^\circ\text{C}$
Variable Temperature Cycling

Discharge Capacity (Ahr)

Cycle Number

Cell 1 (4.0 V @ 40°C) - 90% of Initial
Cell 2 (4.1 V @ 40°C)

RT Capacity 45.6% of Initial
EIS During Variable Temperature Cycling

Effect of Variable Temperature Cycling

After 15 cycles
After 55 cycles

Cell Changed to 4 h V Cycling All Cycling

23°C

After 40 cycles at 40°C

Cell 50210

Cell 50210

Cell 50210

Cell 50210
Heat Generation Rates on Discharge
- No damage to equipment
- Venting of a pouch (Polymer) cell
- No damage to equipment
- No injuries to personnel

10 Ah

Li Ion Cell Venting on Extended LT Cycling (5-)

Li Ion Cell Venting upon Inadvertent External Short (20-35 Ah)

Safety Events at JPL
AC Impedance

Mars Mission Profile

Extended Storage at 0°C

10 Month on OCV Stand.

2 Month Storage in Open Circuit

History of the Cell

Short Circuit Incident
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<th>Ten Month Storage</th>
<th>Two Month Storage</th>
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<td>25 Air Generation</td>
<td>Lithium-Ion Cells</td>
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Storage
Such safety events.

Further improvements in cell design will minimize

Hundreds of lithium ion cells of 1-35 Ah sizes

Period of three years of testing more than five

Three minor safety incidents occurred over a

Good storage characteristics

Excellent low temperature performance (-20°C operation)

Long cycle life (over 1000 cycles)

(300 Wh/l)

High specific energy (>120 Wh/kg) and High energy density

DOE/NASA consortium were found to exhibit

Lithium ion cells developed under the

Summary