Bipolar Rechargeable Lithium Battery
For High Power Applications

Presented to the
NASA Aerospace Battery Workshop
NOVEMBER 17–19, 1992
U.S. Space and Rocket Center
Huntsville AL
S. Hossain, G. Kozlowski and F. Goebel

Yardney Technical Products, Inc.
82 MECHANIC STREET, PAWCATUCK CT 06379
<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode or Negative Electrode</td>
<td>Li</td>
</tr>
<tr>
<td>Cathode or Positive Electrode</td>
<td>CuCl₂</td>
</tr>
<tr>
<td>Electrolyte</td>
<td>SO₂ based LiAlCl₄</td>
</tr>
<tr>
<td>OCV</td>
<td>3.45V versus Li</td>
</tr>
</tbody>
</table>
NO organic electrolytes offer as high conductivity as SO$_2$-based electrolytes

**Conductivity of LiAlCl$_4$/SO$_2$ Electrolytes at Various Temperatures**

Vapor-pressure lower than atmospheric pressure can be achieved with SO₂-based electrolytes.

SO$_2$ based Li–ion conducting electrolytes offer several advantages

- High ionic conductivity ($1 \cdot 1 \times 10^{-2}$ Scm$^{-1}$)
- Excellent electrochemical voltage window
- Limited overcharge tolerance
- Very low shelf–discharge rate (<0.1% per month)
- Insignificant Li–anode passivation
Bipolar Rechargeable Lithium Battery: REACTION MECHANISMS

The use of high surface area carbon and SO₂-based LiAlCl₄ electrolyte provides extra capacity before SO₂-reduction occurs.

**Discharge**

Anode: \( \text{Li} \rightarrow \text{Li}^+ + \text{e}^- \)

Cathode:

1. \( \text{Cu}^{++} + \text{e}^- \rightarrow \text{Cu}^+ \) (\( \sim 3.4 \) versus Li)

2. \( \text{LiAlCl}_4 \cdot 3\text{SO}_2 + x\text{C} + 3\text{e}^- \rightarrow \text{LiClAl} \text{OSO} \rightarrow \text{OSO} \rightarrow \text{Cx} + 3\text{Cl}^- \text{OSO} \rightarrow \text{OSO} \)

3. \( 2\text{SO}_2 + 2\text{e}^- \rightarrow \text{S}_2\text{O}_4^{2-} \) (\( \sim 2.8\text{V} \) versus Li)

4. \( \text{Cu}^+ + \text{e}^- \rightarrow \text{Cu}^0 \) (\( \sim 2.5\text{V} \) versus Li)

**Charge**

Anode: \( \text{Li}^+ + \text{e}^- \rightarrow \text{Li} \)

Cathode: \( \text{Cu}^+ \rightarrow \text{Cu}^{++} + \text{e}^- \) (\( \sim 3.5\text{V} \) versus Li)

\( \text{LiClAl(OSO)}_3 \cdot x\text{C} + 3\text{Cl}^- \rightarrow \text{LiAlCl}_4 \cdot 3\text{SO}_2 + x\text{C} + 3\text{e}^- \) (\( \sim 3.65\text{V} \) versus Li)

\( \text{LiAlCl}_4 \rightarrow \text{Li}^+ + \text{AlCl}_3 + \frac{1}{2}\text{Cl}_2 + \text{e}^- \) (\( \sim 3.9\text{V} \) versus Li)
Discharge/charge behavior of a Li/CuCl₂ cell in LiAlCl₄ • 6SO₂ electrolyte at 1mA/cm²
Li/CuCl₂ Rechargeable Cells: CYCLING BEHAVIOR

Discharge/charge behavior of a Li/CuCl₂ cell in LiAlCl₄•6SO₂ electrolyte at 1mA/cm²
Li/CuCl₂ Rechargeable Cells: CYCLING BEHAVIOR

Discharge behavior of a Li/CuCl₂ rechargeable cell in LiAlCl₄·6SO₂ electrolyte at 1mA/cm²
Charge behavior of a Li/CuCl₂ cell in LiAlCl₄·6SO₂ at 1mA/cm²
Coulombic efficiency of 1 shows excellent cycling behavior

Coulombic efficiency of a Li/CuCl$_2$ cell at 1mA/cm$^2$ discharge/charge rate
Discharge/charge behavior of a Li/CuCl₂ cell at 40mA/cm² discharge for 20 seconds and 4.44mA/cm² charge for 180 seconds.
Cycle number vs capacity of a Li/LuCl$_2$ cell at 40mA/cm$^2$ discharge for 20 seconds and 4.44mA/cm$^2$ charge for 180 seconds. Voltage limits 2.5–4.0 V.
Discharge/charge behavior of a Li/CuCl₂ cell at 50mA/cm² discharge for 20 seconds and 5.56mA/cm² charge for 180 seconds.
Discharge/charge behavior of a Li/CuCl$_2$ cell at 50mA/cm$^2$ discharge for 20 seconds and 5.56mA/cm$^2$ charge for 180 seconds.
Cycle number vs capacity of a Li/CuCl₂ cell at 50mA/cm² discharge and 5.56mA/cm² charge for 180 seconds. Voltage limits: 2.5–4.0 V.
Coulombic efficiency of a Li/CuCl$_2$ cell discharged at 50mA/cm$^2$ for 20 seconds and charged at 5.56mA/cm$^2$ for 180 seconds
Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR

Discharge/charge behavior of a Li/CuCl₂ cell at 50mA/cm² discharge for 20 seconds and 5.56mA/cm² charge for 180 seconds.
Discharge/charge behavior of a Li/CuCl$_2$ cell at 50mA/cm$^2$ discharge for 20 seconds and 5.56mA/cm$^2$ charge for 180 seconds
Cycle number vs capacity of a Li/LuCl$_2$ cell at 50mA/cm$^2$ discharge for 20 seconds and 5.56mA/cm$^2$ charge for 180 seconds. Voltage limits 2.5 – 4.0 V.
Coulombic efficiency of a Li/CuCl₂ cell discharged at 50mA/cm² for 20 seconds and charged at 5.56mA/cm² for 180 seconds
1. Nickel substrate
2. Carbon/TFE undercoat
3. Tefzel insulator
4. Anode and cathode
5. Fill tube and separator
6. Stack sealed except in fill tube area, then activated. Final.

BIPOLAR STACK ASSEMBLY SEQUENCE
Discharge/charge behavior of a bipolar Li/CuCl₂ battery (4-cell stack) at 50 mA/cm² discharge for 20 seconds and 5.56 mA/cm² charge for 180 seconds. Voltage limits 10.0–16.0 V.
Bipolar Rechargeable Lithium Battery

Based on the present state-of-the-art of bipolar rechargeable lithium batteries, a cumulative specific power of 1mW/kg and specific energy of 6kWh/kg can be achieved

Development of a 270V bipolar rechargeable battery

REQUIREMENTS:

Discharge: 20 seconds at 50mA/cm² (Total = 30A)
Average operating voltage: 270 V
Charge: 180 seconds at 5.56mA/cm² (Total=3.33A)
Charge cut-off voltage: 360 V
Total number of cycles: 800 cycles

TOTAL WEIGHT OF BIPOLAR BATTERY: 6 kg

\[
\text{Specific Power} = \frac{270 \times 30}{6} \text{ w/kg} = 1.35 \text{kW/kg}
\]