Bipolar Rechargeable Lithium Battery
For High Power Applications

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Bipolar Rechargeable Lithium Battery: CELL CHEMISTRY

<table>
<thead>
<tr>
<th>Anode or Negative Electrode</th>
<th>Cathode or Positive Electrode</th>
<th>Electrolyte</th>
<th>OCV</th>
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<tr>
<td>Li</td>
<td>CuCl₂</td>
<td>SO₂ based LiAlCl₄</td>
<td>3.45V versus Li</td>
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</table>
NO organic electrolytes offer as high conductivity as SO₂-based electrolytes

Conductivity of LiAlCl₄/SO₂ Electrolytes at Various Temperatures

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

SO₂ based Li–ion conducting electrolytes offer several advantages

- High ionic conductivity \((1 \times 10^{-2} \text{ Scm}^{-1})\)
- Excellent electrochemical voltage window
- Limited overcharge tolerance
- Very low shelf–discharge rate \((<0.1\% \text{ per month})\)
- 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: \( Li \rightarrow Li^+ + e^- \)

Cathode:

1. \( Cu^{2+} + e^- \rightarrow Cu^+ \) (\(~3.4 \text{ versus Li}\))

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

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

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

**Charge**

Anode: \( Li^+ + e^- \rightarrow Li \)

Cathode: \( Cu^+ \rightarrow Cu^{2+} + e^- \) (\(~3.5 \text{V versus Li}\))

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

\( \text{LiAlCl}_4 \rightarrow \text{Li}^+ + \text{AlCl}_3 + \frac{1}{2}\text{Cl}_2 + e^- \) (\(~3.9 \text{V versus Li}\))
Li/CuCl₂ Rechargeable Cells: CYCLING BEHAVIOR

Discharge/charge behavior of a Li/CuCl₂ cell in LiAlCl₄ • 6SO₂ electrolyte at 1mA/cm².
Discharge/charge behavior of a Li/CuCl₂ cell in LiAlCl₄•6SO₂ electrolyte at 1mA/cm²
Discharge behavior of a Li/CuCl₂ rechargeable cell in LiAlCl₄ • 6SO₂ electrolyte at 1mA/cm²
Charge behavior of a Li/CuCl\textsubscript{2} cell in LiAlCl\textsubscript{4} \cdot 6SO\textsubscript{2} at 1mA/cm\textsuperscript{2}
Coulombic efficiency of 1 shows excellent cycling behavior

Coulombic efficiency of a Li/CuCl₂ cell at 1mA/cm² 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.
Bipolar Lithium Rechargeable Batteries: CYCLE LIFE

Cycle number vs capacity of a Li/LuCl₂ cell at 40mA/cm² discharge for 20 seconds and 4.44mA/cm² 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.
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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/CuCl₂ cell discharged at 50 mA/cm² for 20 seconds and charged at 5.56 mA/cm² 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
Discharge/charge behavior of a Li/CuCl₂ cell at 50mA/cm² discharge for 20 seconds and 5.56mA/cm² charge for 180 seconds
Cycle number vs capacity of a Li/LuCl₂ cell at 50mA/cm² discharge for 20 seconds 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: CELL ASSEMBLY

BIPOLAR STACK ASSEMBLY SEQUENCE

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.
Discharge/charge behavior of a bipolar Li/CuCl₂ battery (4-cell stack) at 50mA/cm² discharge for 20 seconds and 5.56mA/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/cm\(^2\) (Total = 30A)
- **Average operating voltage:** 270 V
- **Charge:** 180 seconds at 5.56mA/cm\(^2\) (Total = 3.33A)
- **Charge cut-off voltage:** 360 V
- **Total number of cycles:** 800 cycles

**TOTAL WEIGHT OF BIPOLAR BATTERY:** 6 kg

\[
270 \times 30 \\
6 \text{ w/kg} = 1.35 \text{kW/kg}
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