Bipolar Rechargeable Lithium Battery
For High Power Applications

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Bipolar Rechargeable Lithium Battery: CELL CHEMISTRY

Anode or Negative Electrode : Li
Cathode or Positive Electrode : CuCl₂
Electrolyte : SO₂ based LiAlCl₄
OCV : 3.45V versus Li
NO organic electrolytes offer as high conductivity as SO$_2$-based electrolytes

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 SO$_2$-based LiAlCl$_4$ electrolyte provides extra capacity before SO$_2$-reduction occurs.

**Discharge**

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

Cathode:

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

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

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

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

**Charge**

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

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

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

\[ \text{LiAlCl}_4 \; \rightarrow \; \text{Li}^+ + \text{AlCl}_3 + \frac{1}{2}\text{Cl}_2 + e^- \; (\sim 3.9\text{V} \text{ versus Li}) \]
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/CuCl$_2$ rechargeable cell in 
LiAlCl$_4$ $\cdot$ 6SO$_2$ electrolyte at 1 mA/cm$^2$
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/CuCl₂ cell at 1mA/cm² discharge/charge rate
Discharge/charge behavior of a Li/CuCl$_2$ cell at 40mA/cm$^2$ discharge for 20 seconds and 4.44mA/cm$^2$ charge for 180 seconds.
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/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/CuCl$_2$ cell at 50mA/cm$^2$ discharge for 20 seconds and 5.56mA/cm$^2$ charge for 180 seconds
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Bipolar Lithium Rechargeable Batteries: CELL ASSEMBLY

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 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/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

\[
\text{SPECIFIC POWER} = \frac{270 \times 30}{6} \text{ W/kg} = 1.35 \text{kW/kg}
\]