Bipolar Rechargeable Lithium Battery
For High Power Applications

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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.

Vapor Pressures of LiAlCl₄/SO₂ Electrolytes at Various Temperatures

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

- High ionic conductivity ($1 \cdot 1 \times 10^{-2}$ S cm$^{-1}$)
- 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. \( \text{Cu}^{++} + e^- \rightarrow \text{Cu}^+ \text{ (\sim 3.4 versus Li)} \)

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

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

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

**Charge**

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

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

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

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

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/Cl\textsubscript{2} cell at 1mA/cm\textsuperscript{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/CuCl₂ cell at 50mA/cm² discharge for 20 seconds and 5.56mA/cm² 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
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
Bipolar Lithium Rechargeable Batteries: CYCLE LIFE

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/CuCl₂ cell discharged at 50mA/cm² for 20 seconds and charged at 5.56mA/cm² for 180 seconds
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/CuCl$_2$ battery (4-cell stack) at 50mA/cm$^2$ discharge for 20 seconds and 5.56mA/cm$^2$ 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

Develpment 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

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