Bipolar Rechargeable Lithium Battery For High Power Applications

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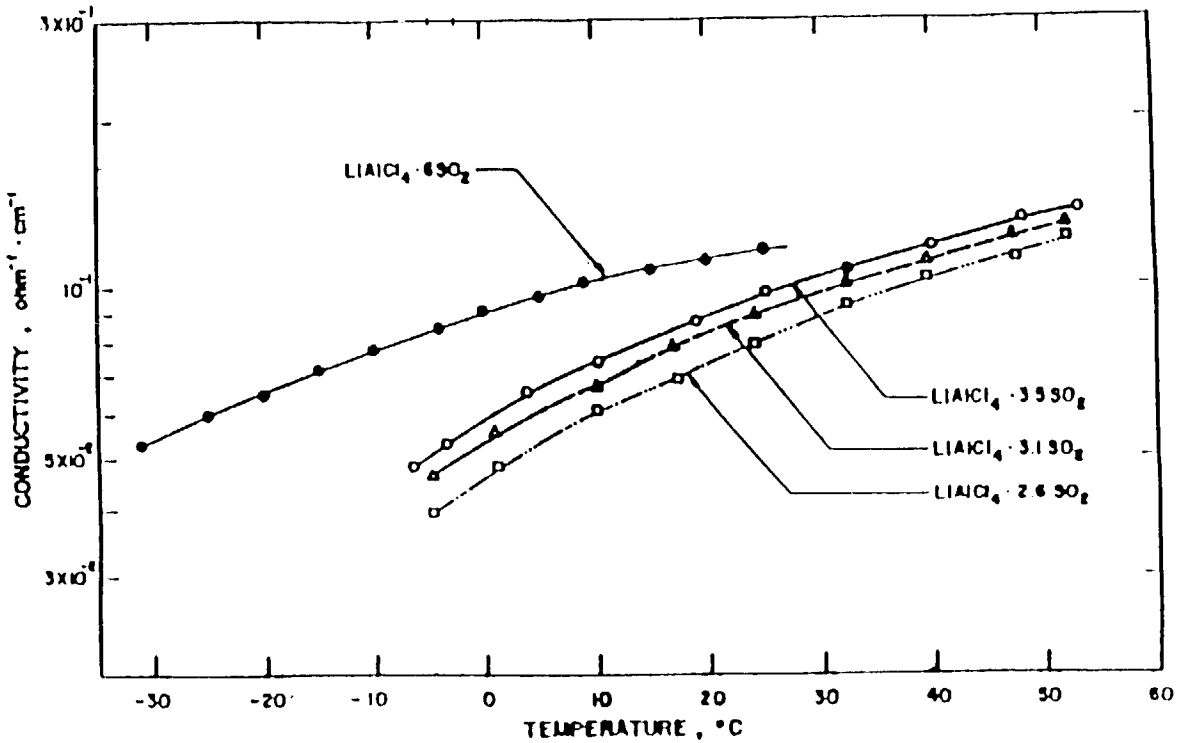
Bipolar Rechargeable Lithium Battery: CELL CHEMISTRY

Anode or Negative Electrode	:	Li
Cathode or Positive Electrode	:	$CuCl_2$
Electrolyte	:	SO_2 based $LiAlCl_4$
OCV	:	3.45V versus Li

NO organic electrolytes offer as high conductivity as SO_2-based electrolytes

Conductivity of $LiAlCl_4/SO_2$ Electrolytes at Various Temperatures

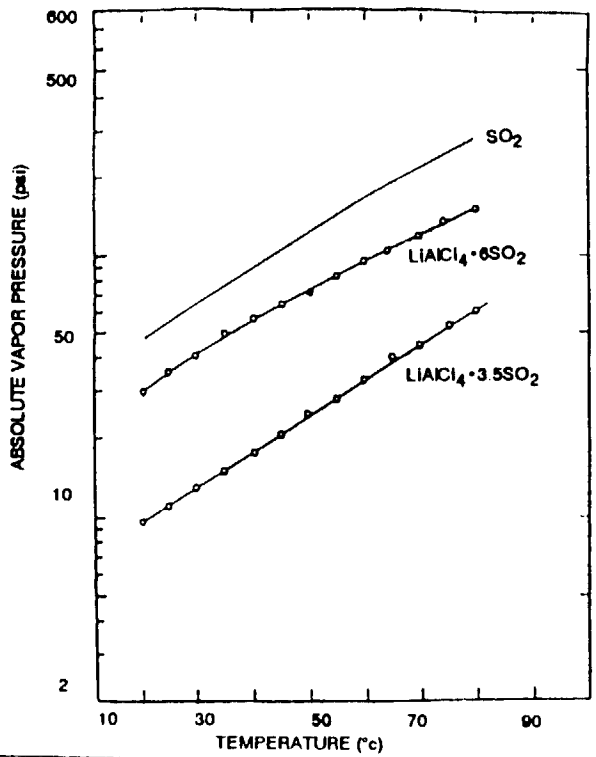


Kuo et al, Duracell Final Report, Contract No. DOE-DE-AC01-80ER-10191 (1985)

Bipolar Rechargeable Lithium Battery: ELECTROLYTE

Vapor-pressure lower than atmospheric pressure can be achieved with SO_2-based electrolytes.

Vapor Pressures of $LiAlCl_4/SO_2$ Electrolytes at Various Temperatures



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Bipolar Rechargeable Lithium Battery: ELECTROLYTE ADVANTAGE

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: $Li \rightarrow Li^+ + e^-$

Cathode:

1. $Cu^{++} + e \rightarrow Cu^+$ (~ 3.4 versus Li)
2. $LiAlCl_4 \cdot 3SO_2 + xC + 3e^- \rightarrow LiClAl$ (OSO, OSO, OSO) $Cx + 3Cl^-$
3. $2SO_2 + 2e^- \rightarrow S_2O_4^=$ (~ 2.8V versus Li)
4. $Cu^+ + e \rightarrow Cu^0$ (~2.5V versus Li)

Charge

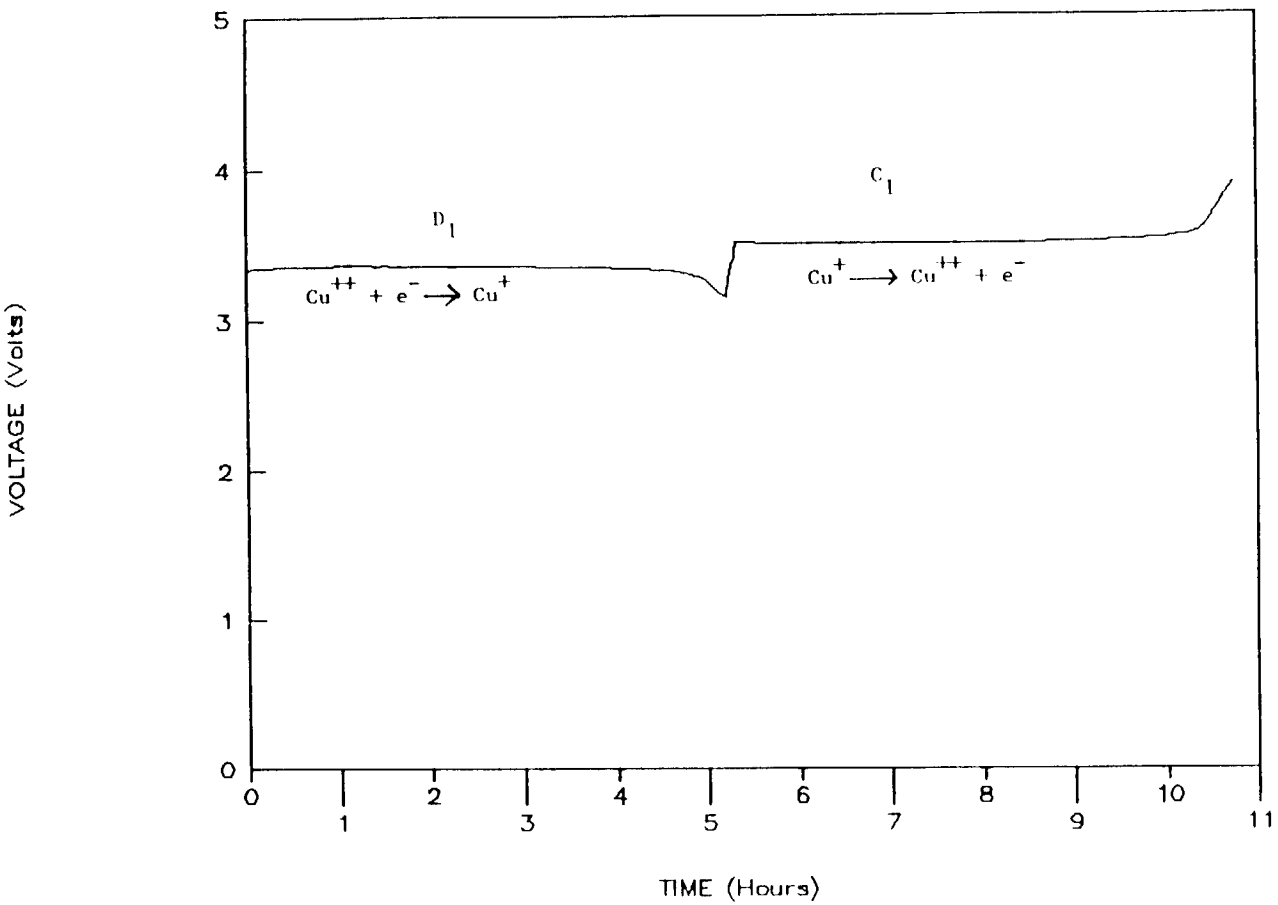
Anode: $Li^+ + e \rightarrow Li$

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

$LiClAl(OSO)_3 \cdot xC + 3Cl^- \rightarrow LiAlCl_4 \cdot 3SO_2 + xC + 3e^-$ (~3.65V versus Li)

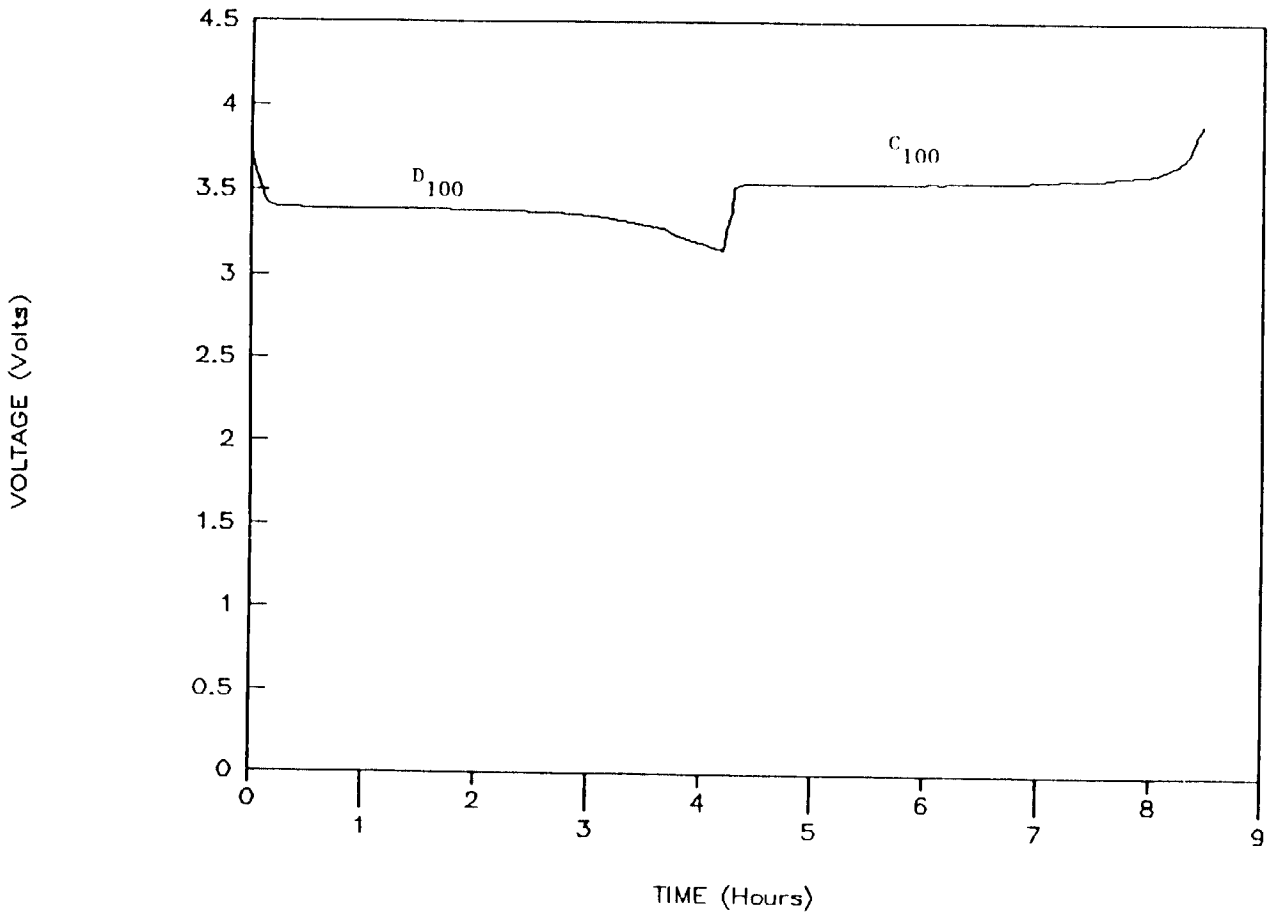
$LiAlCl_4 \rightarrow Li^+ + AlCl_3 + \frac{1}{2}Cl_2 + e^-$ (~3.9V versus Li)

$Li/CuCl_2$ Rechargeable Cells: CYCLING BEHAVIOR



Discharge/charge behavior of a $Li/CuCl_2$ cell in $LiAlCl_4 \cdot 6SO_2$ electrolyte at $1 mA/cm^2$

$Li/CuCl_2$ Rechargeable Cells: CYCLING BEHAVIOR



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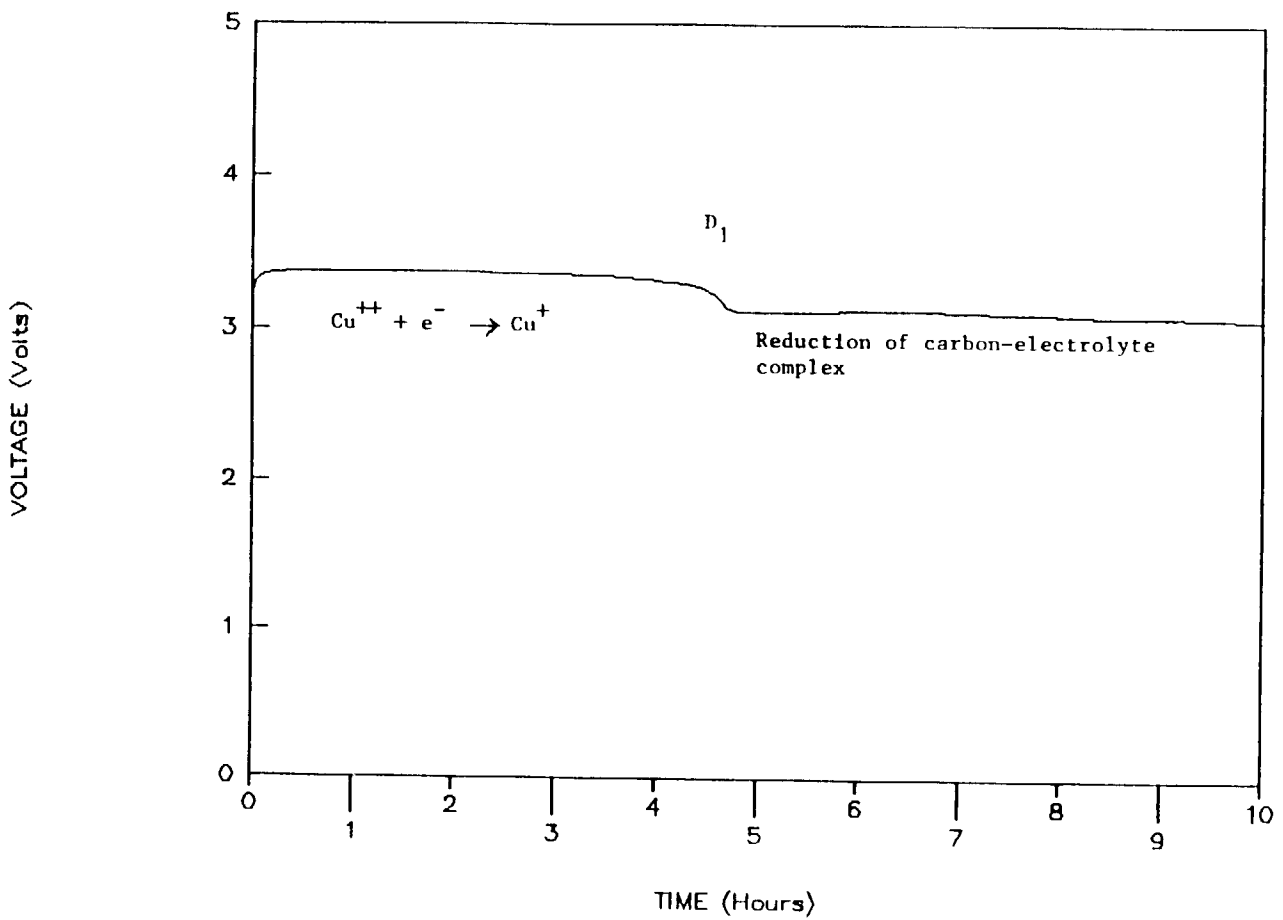

Discharge behavior of a $Li/CuCl_2$ rechargeable cell in $LiAlCl_4 \cdot 6SO_2$ electrolyte at $1 mA/cm^2$

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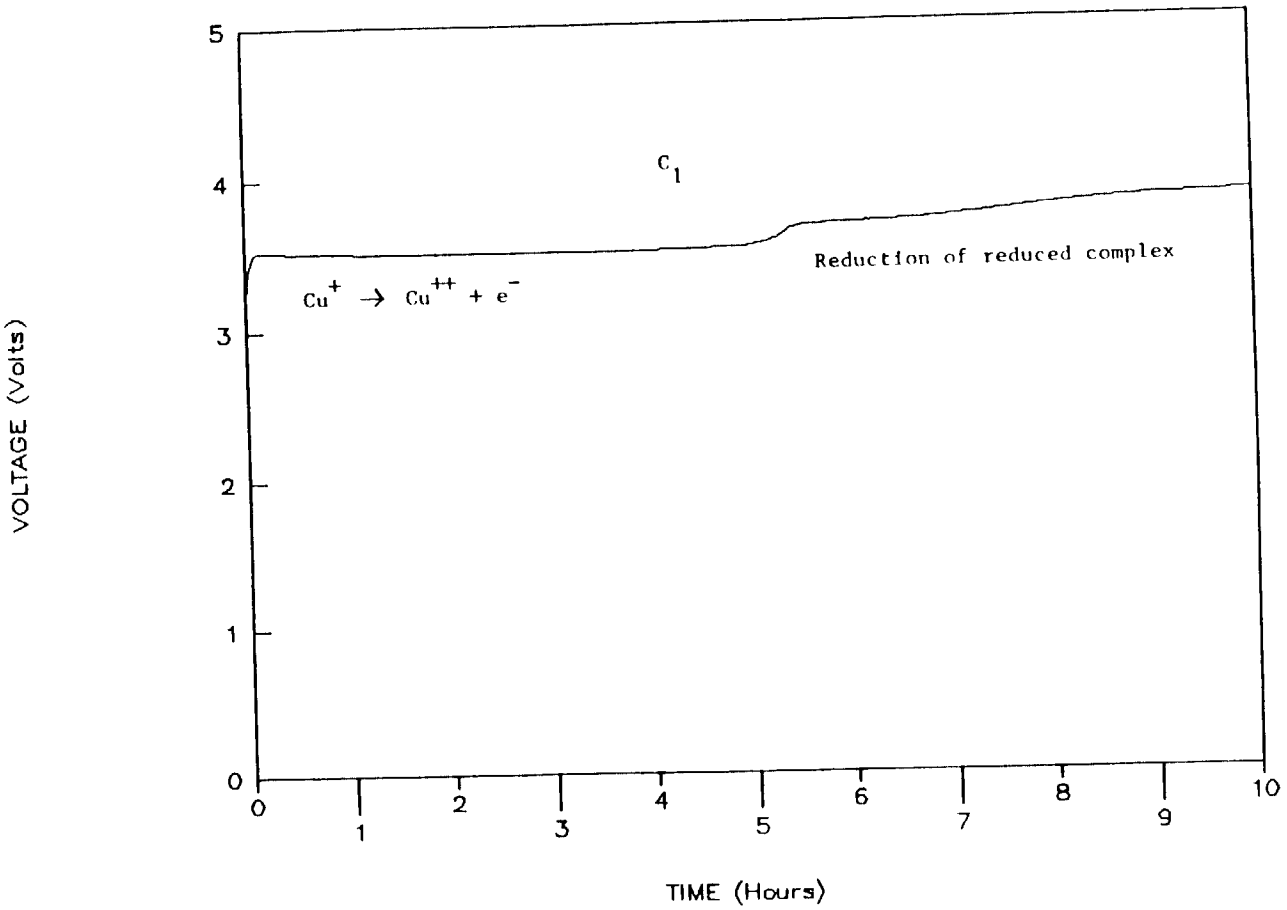
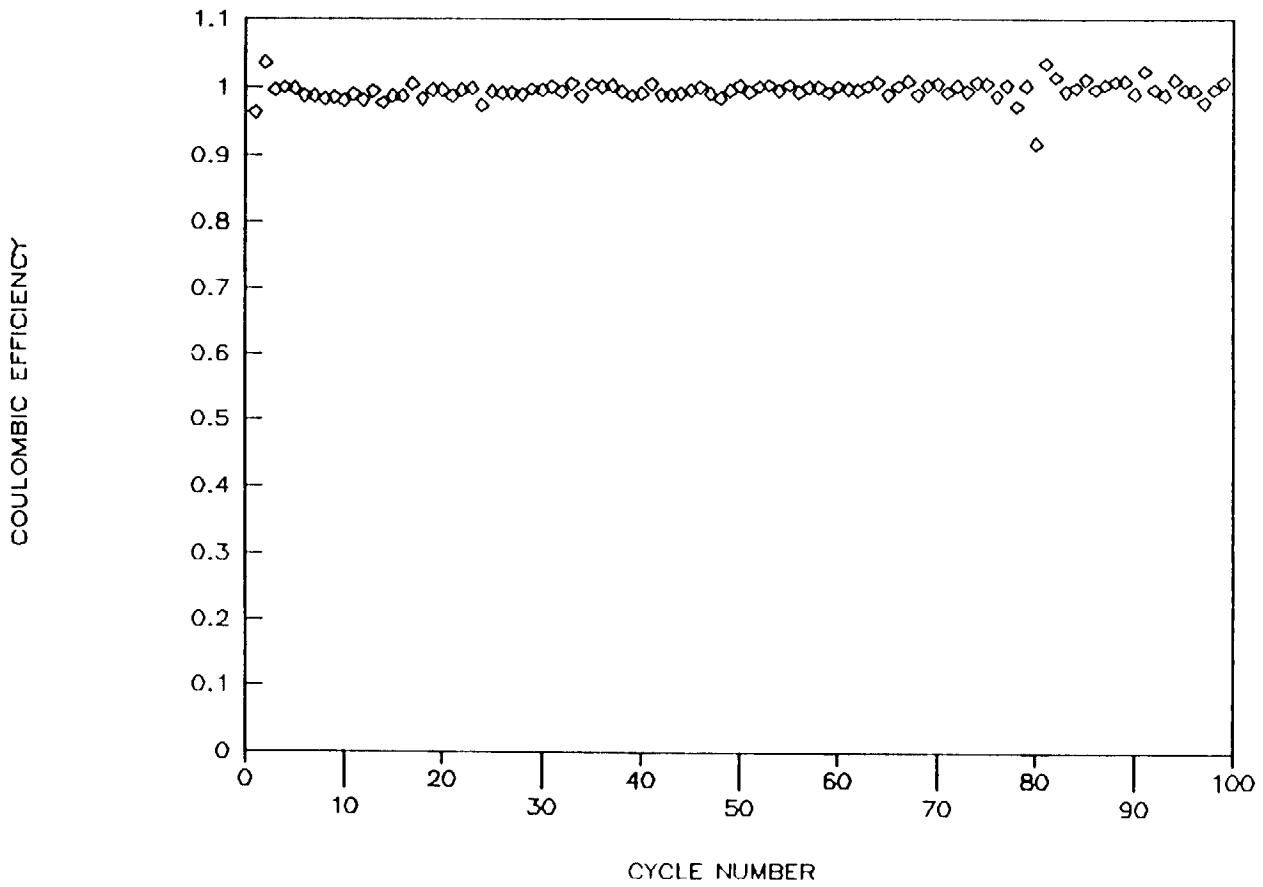


Charge behavior of a $Li/CuCl_2$ cell in $LiAlCl_4 \cdot 6SO_2$ at $1mA/cm^2$

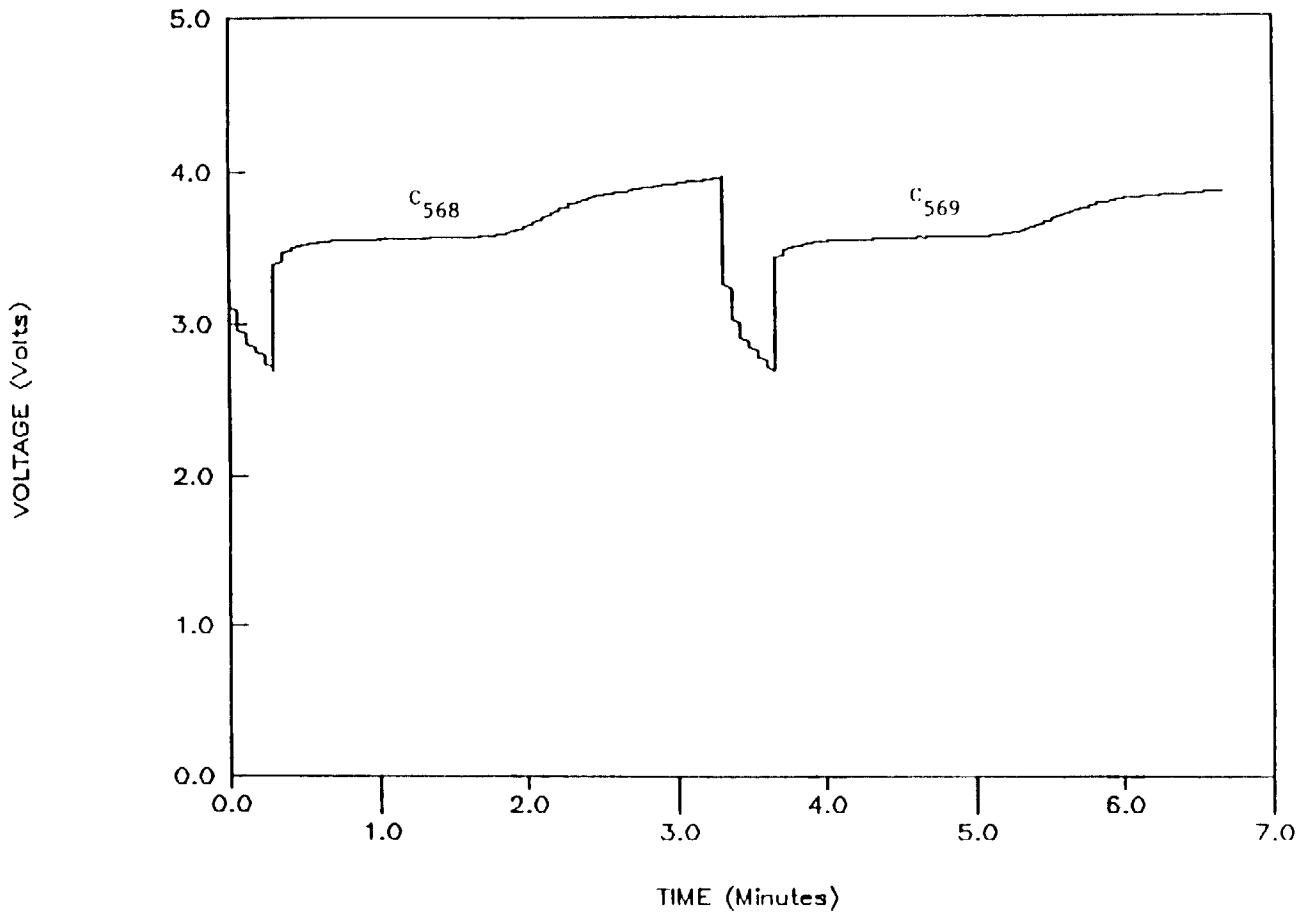
$Li/CuCl_2$ Rechargeable Cells: CYCLING BEHAVIOR

Coulombic efficiency of 1 shows excellent cycling behavior



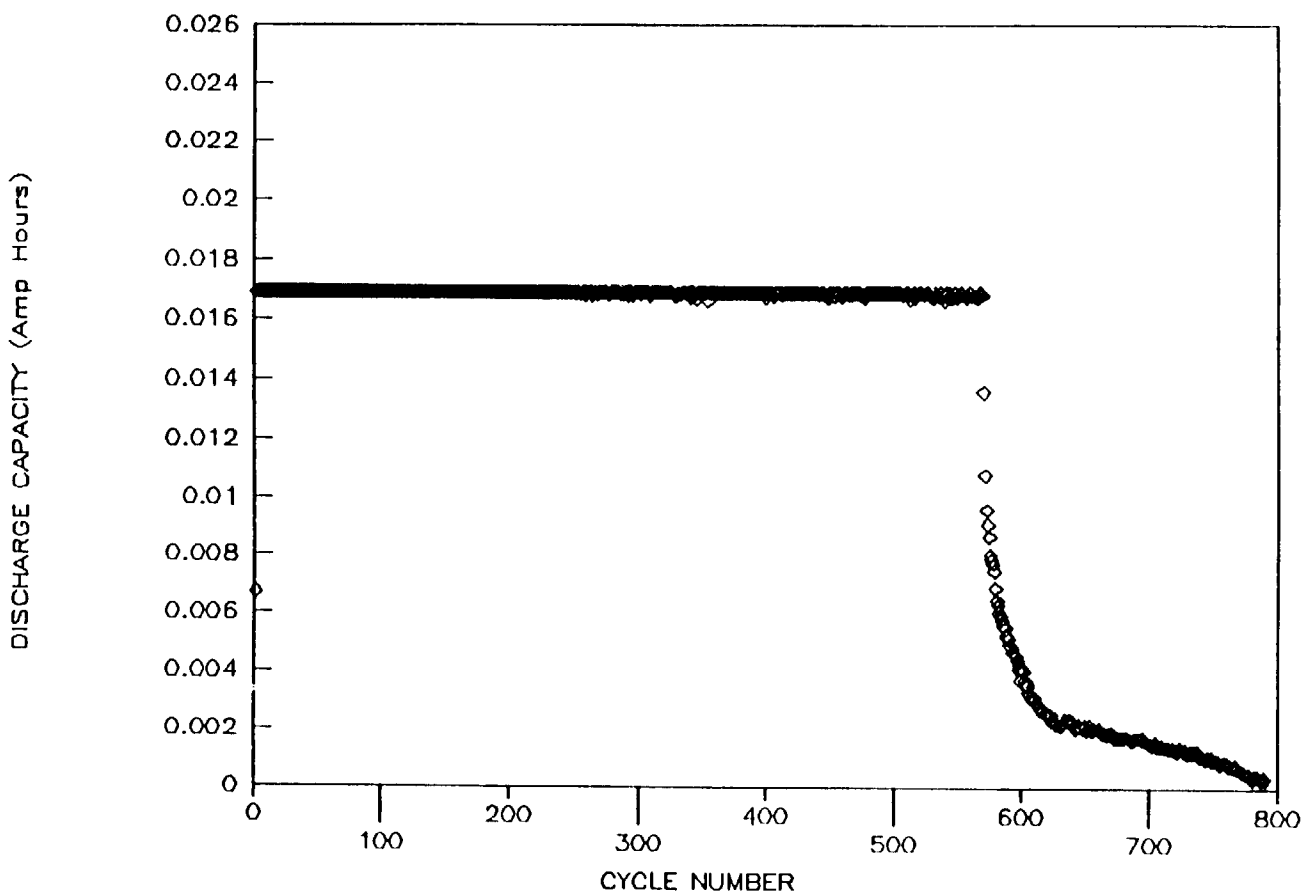
Coulombic efficiency of a $Li/CuCl_2$ cell at 1mA/cm^2 discharge/charge rate

Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR



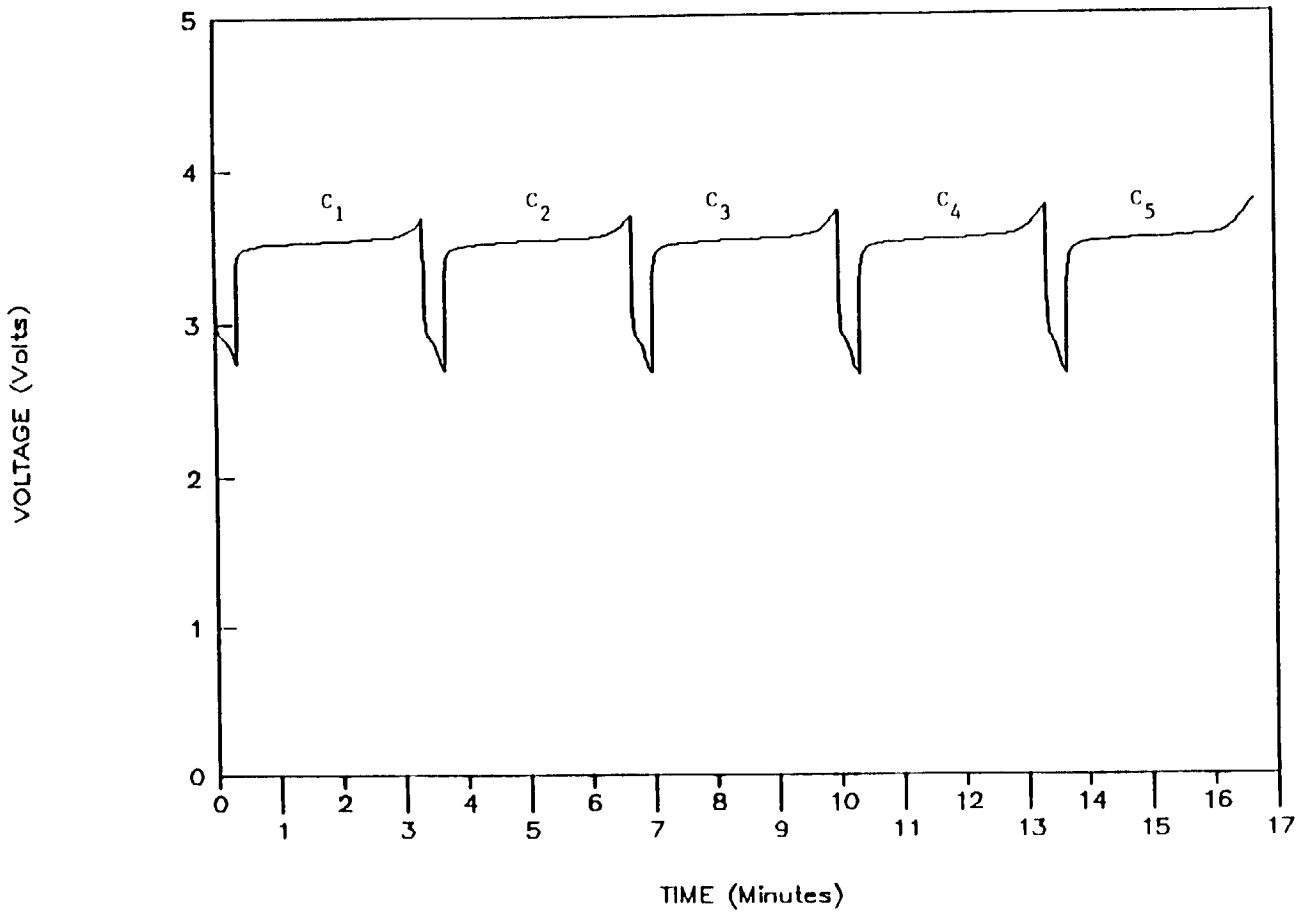
Discharge/charge behavior of a $Li/CuCl_2$ cell at 40mA/cm^2 discharge for 20 seconds and 4.44mA/cm^2 charge for 180 seconds.

Bipolar Lithium Rechargeable Batteries: CYCLE LIFE



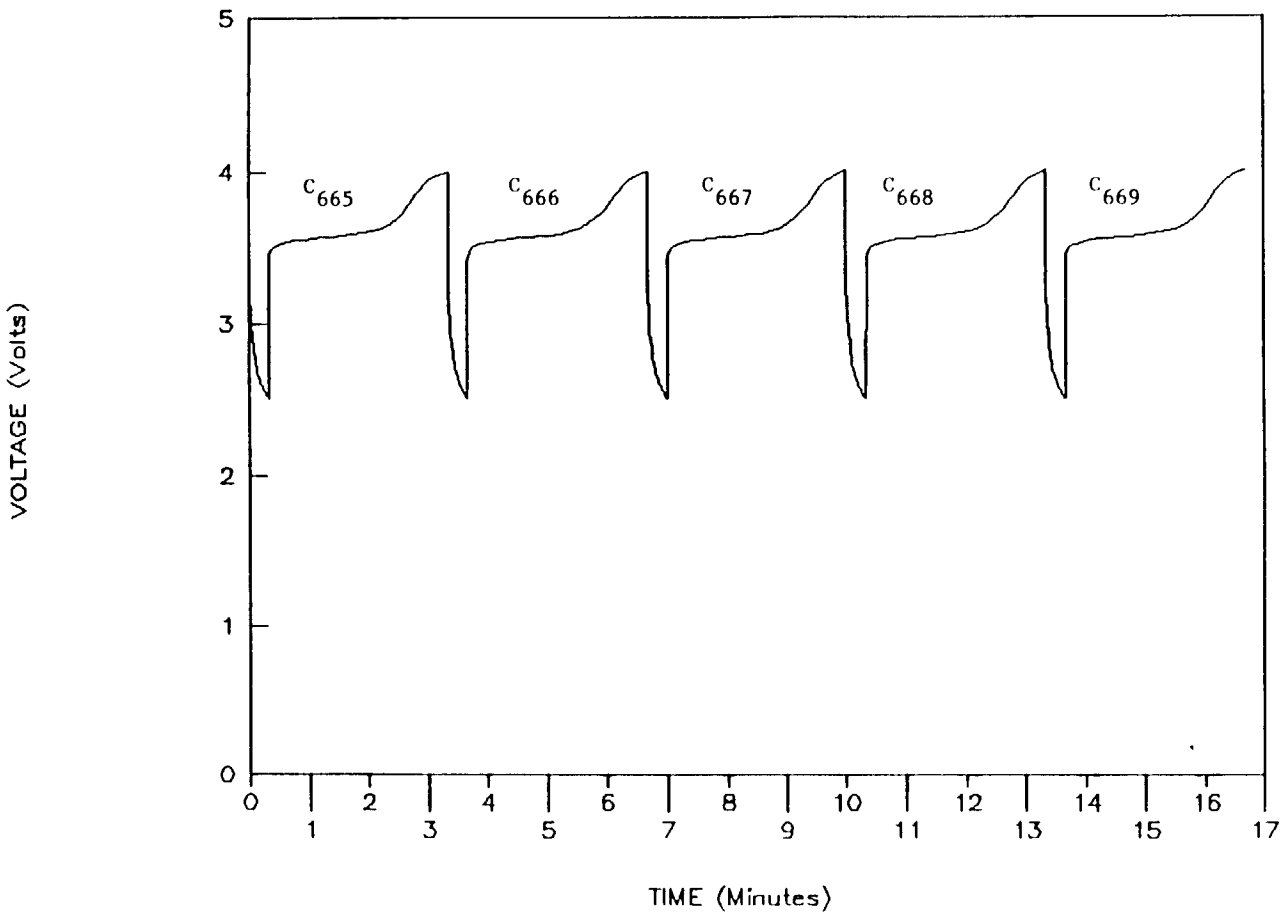
Cycle number vs capacity of a $Li/LuCl_2$ cell at 40mA/cm^2 discharge for 20 seconds and 4.44mA/cm^2 charge for 180 seconds. Voltage limits 2.5–4.0 V.

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.

Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR



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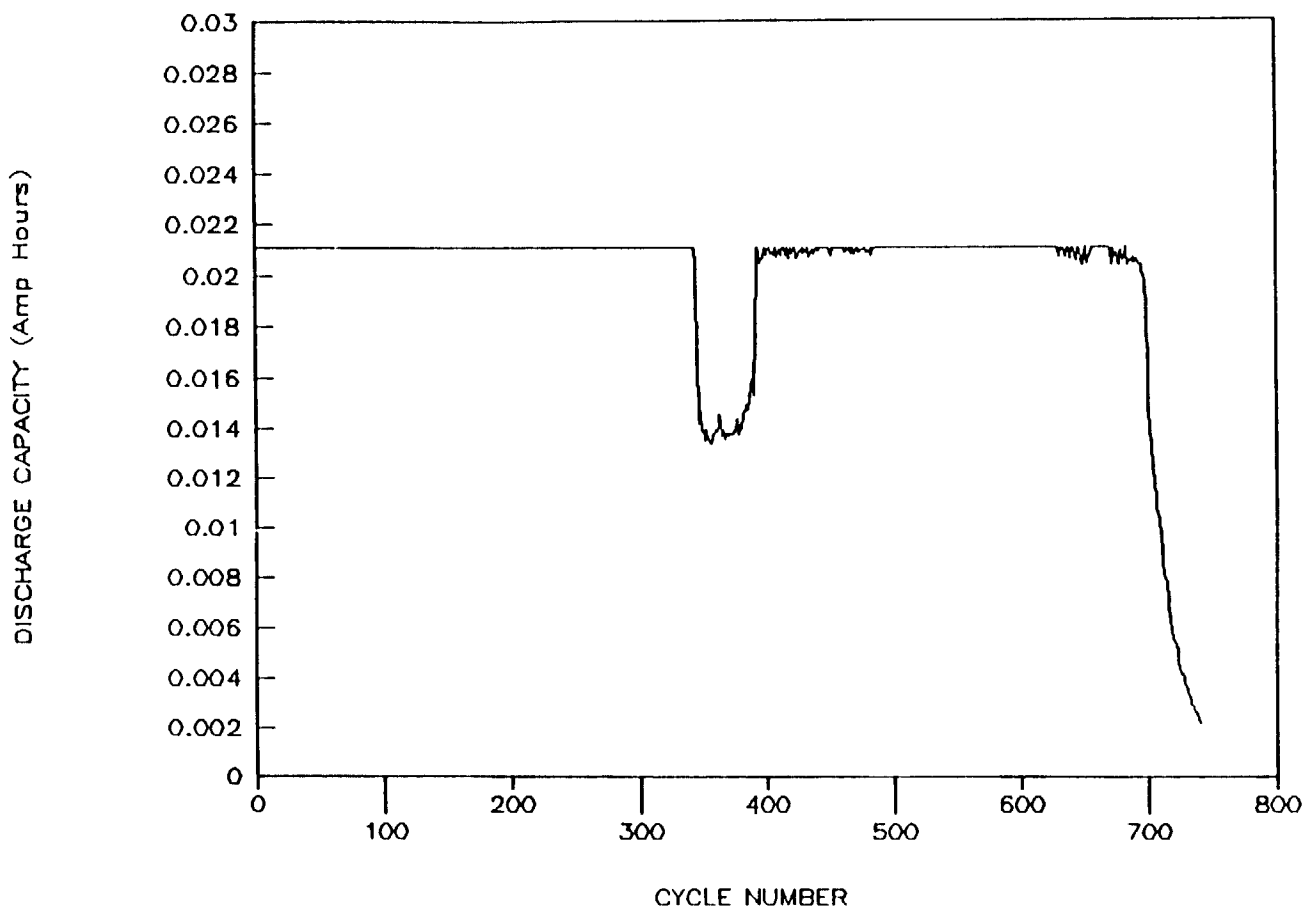
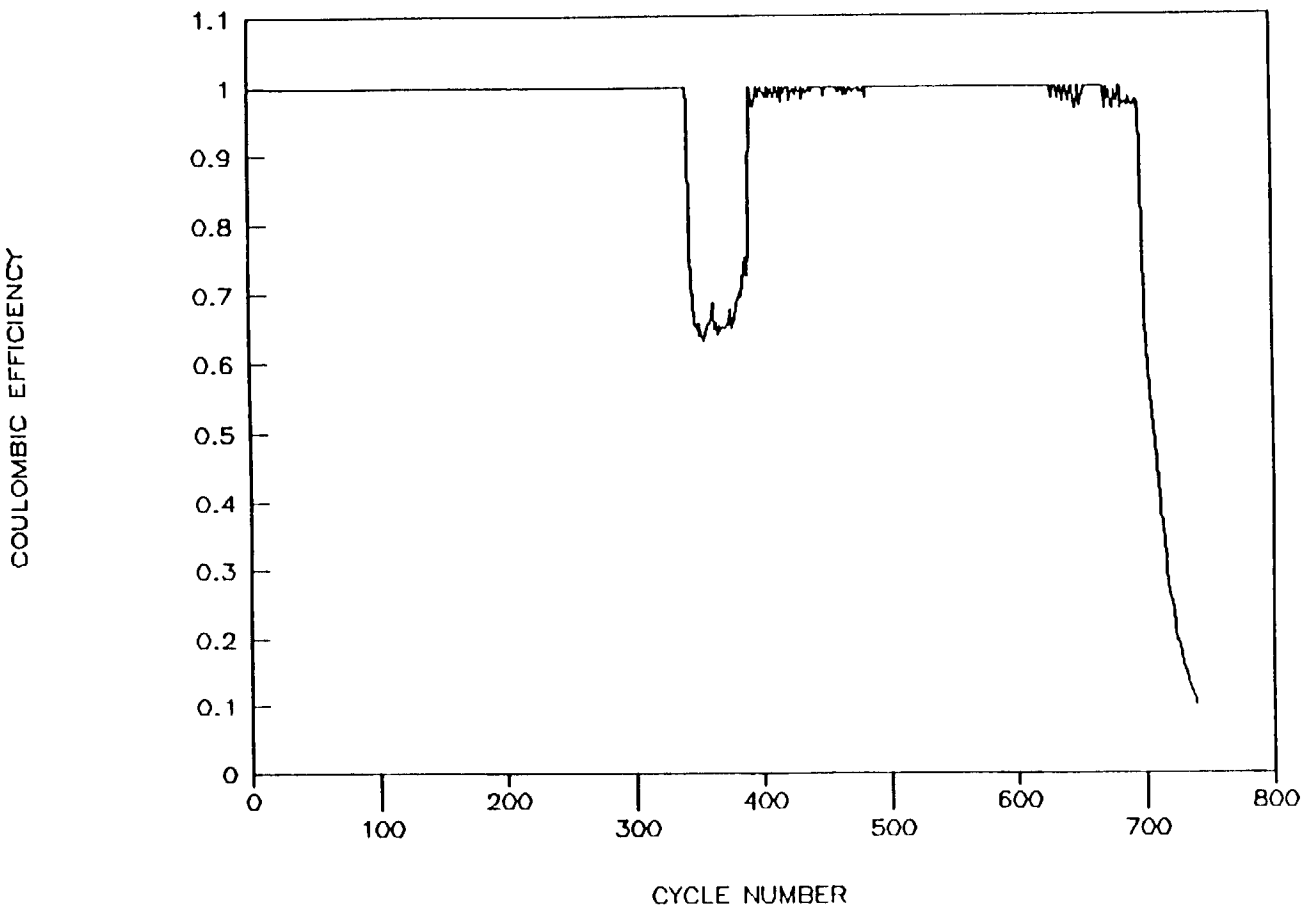


Cycle number vs capacity of a $Li/CuCl_2$ cell at $50mA/cm^2$ discharge and $5.56mA/cm^2$ charge for 180 seconds. Voltage limits: 2.5–4.0 V.

Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR



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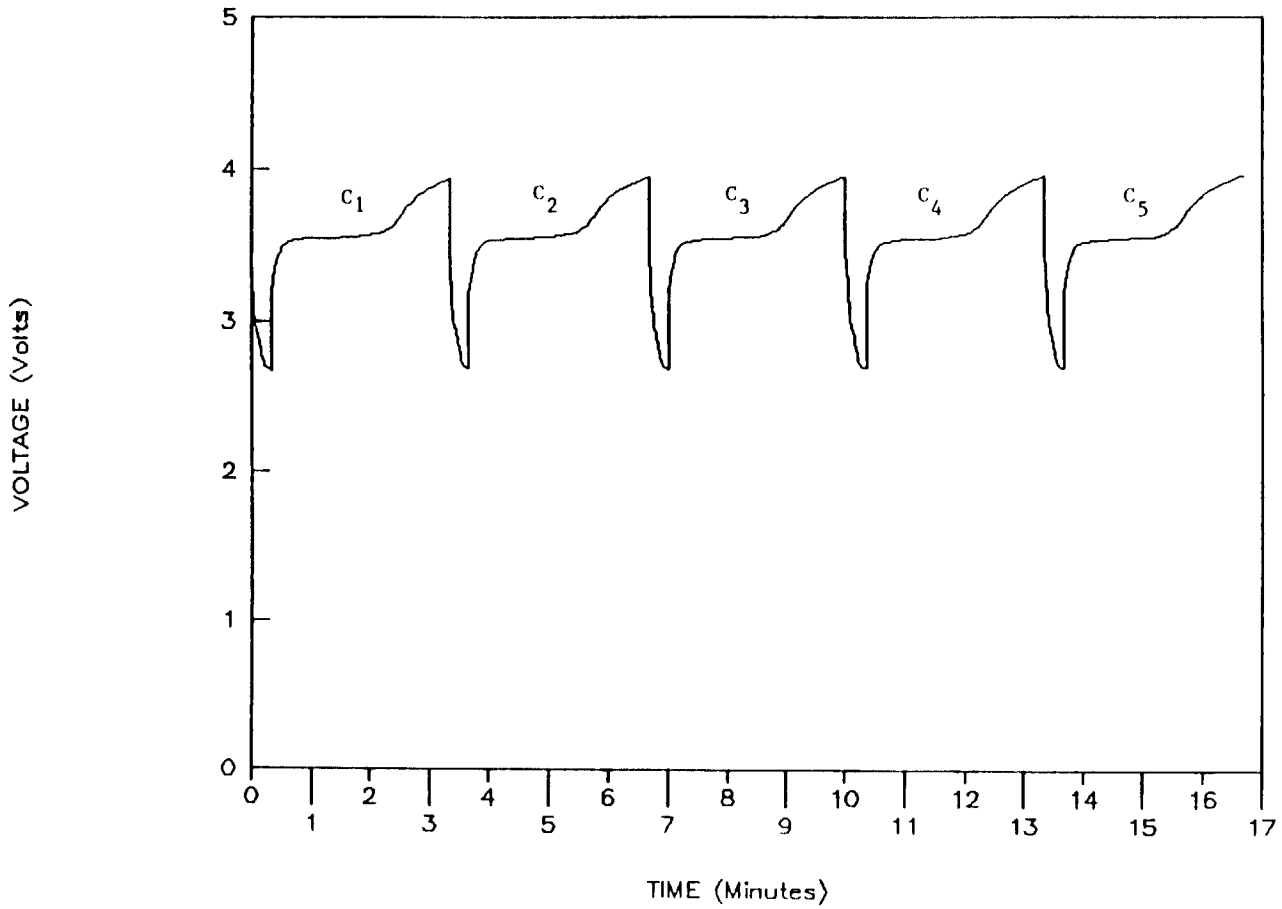

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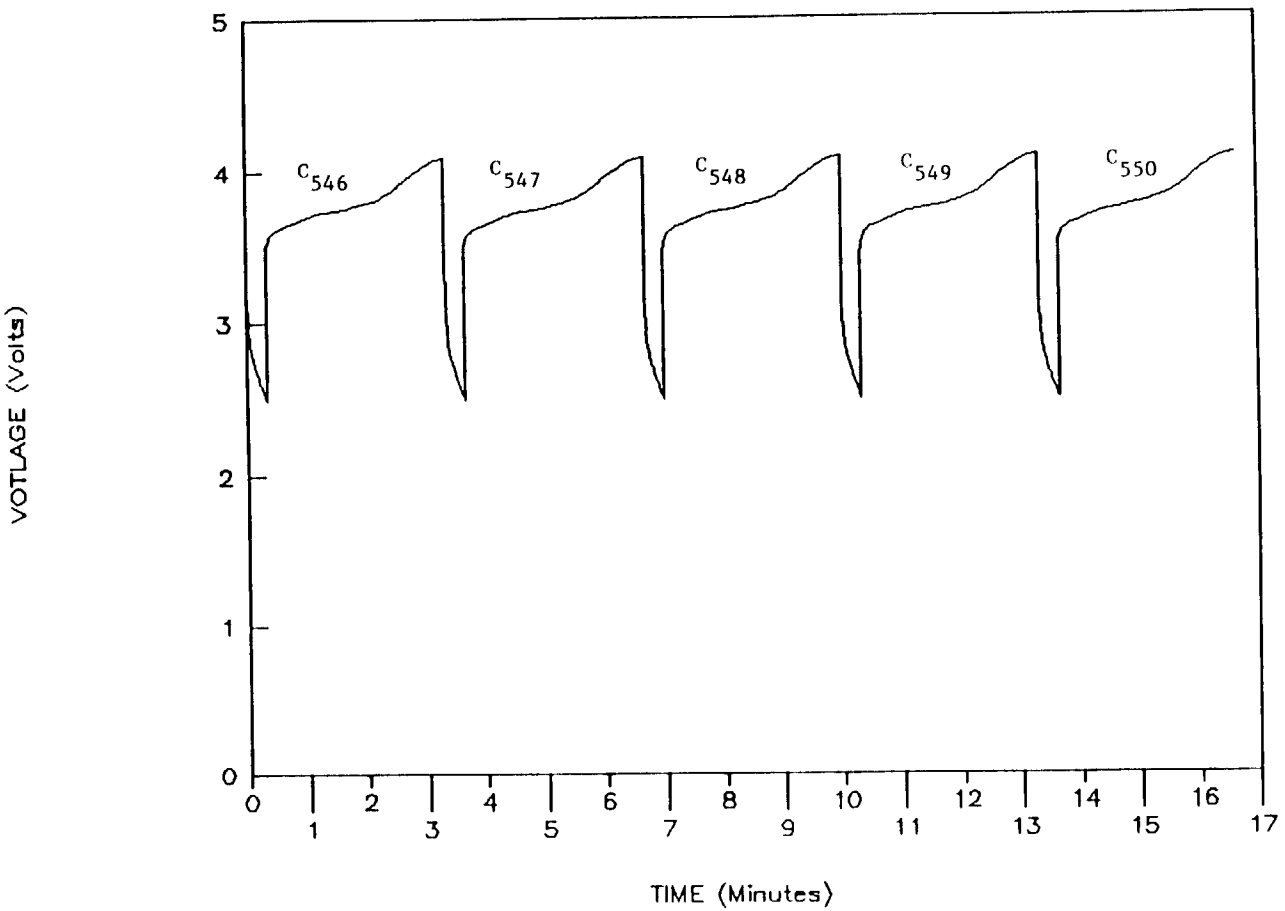
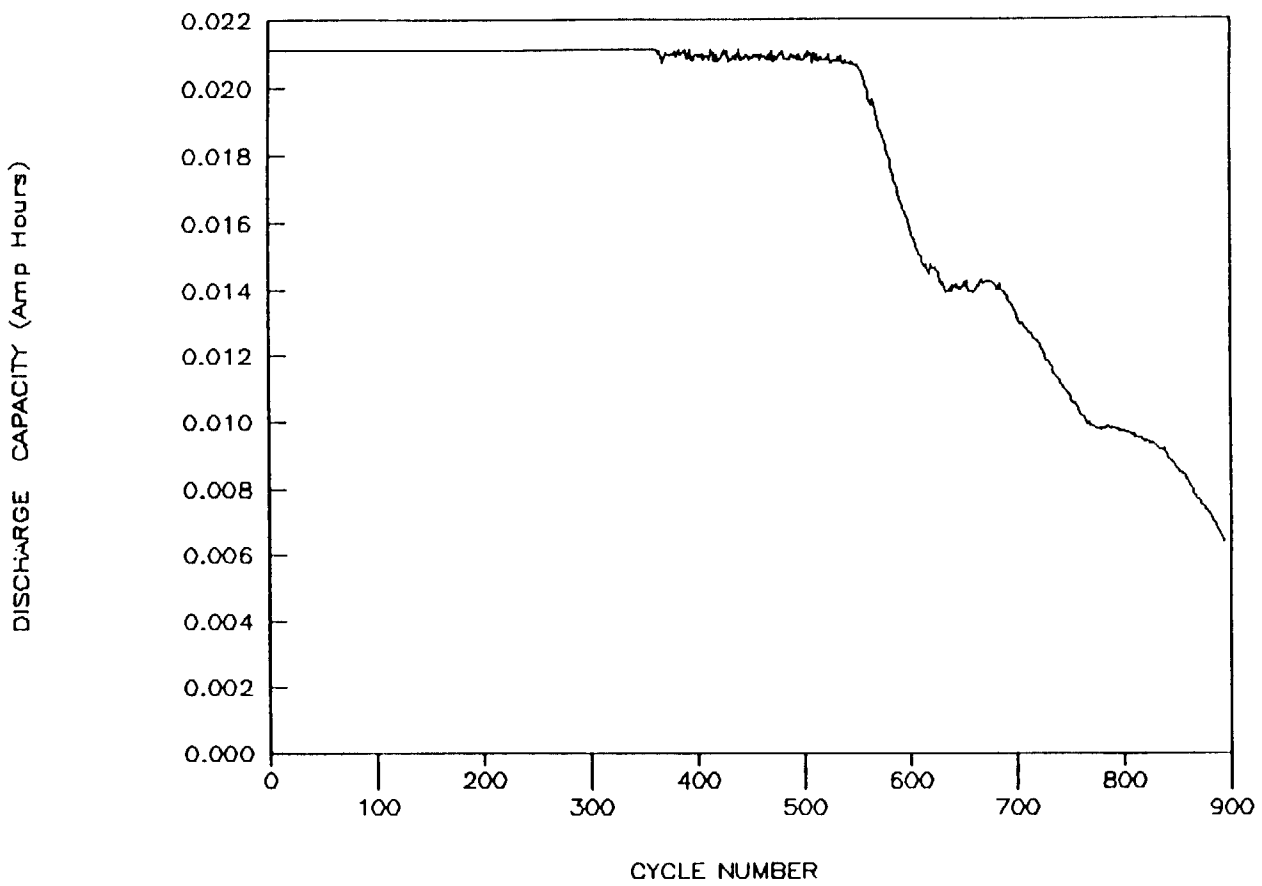


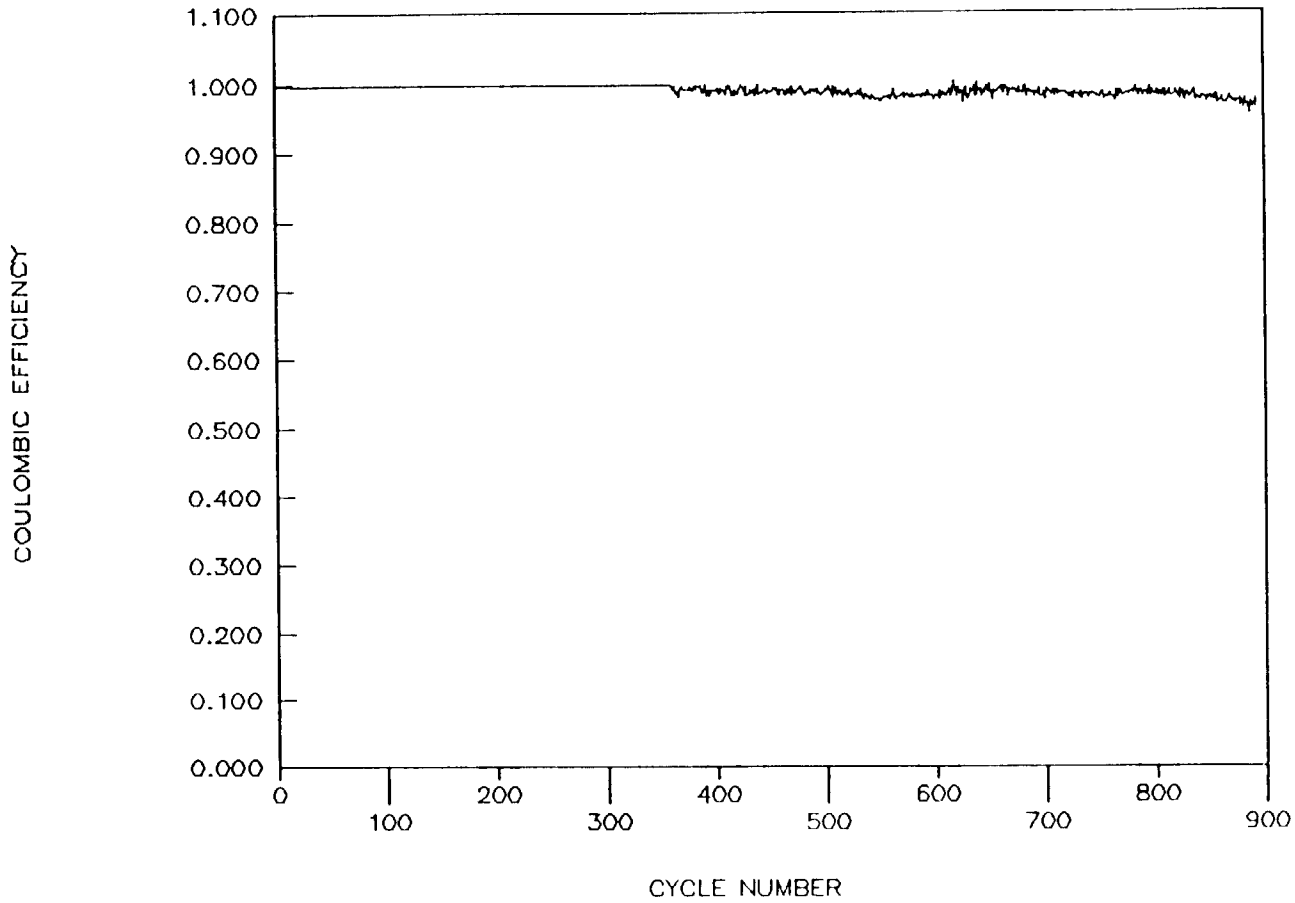
Discharge/charge behavior of a $Li/CuCl_2$ cell at $50mA/cm^2$ discharge for 20 seconds and $5.56mA/cm^2$ charge for 180 seconds

Bipolar Lithium Rechargeable Batteries: CYCLE LIFE



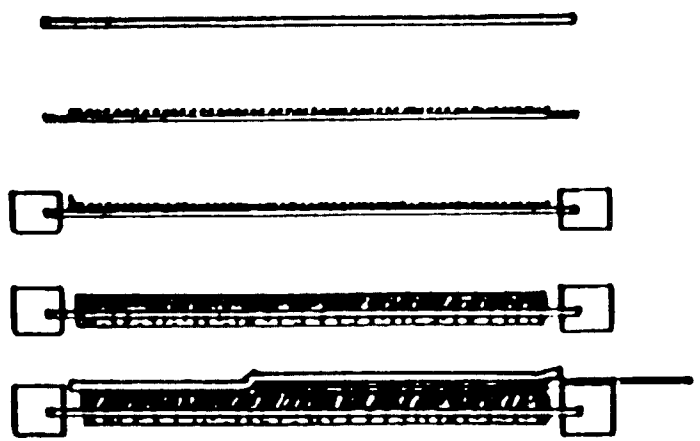
Cycle number vs capacity of a Li/$LuCl_2$ cell at 50mA/cm^2 discharge for 20 seconds and 5.56mA/cm^2 charge for 180 seconds. Voltage limits 2.5–4.0 V.

Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR

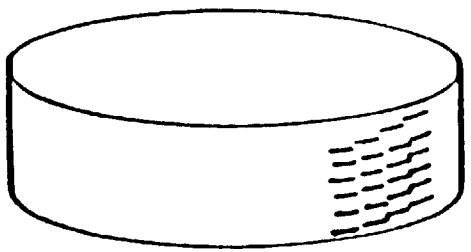


Coulombic efficiency of a Li/$CuCl_2$ cell discharged at 50mA/cm^2 for 20 seconds and charged at 5.56mA/cm^2 for 180 seconds

Bipolar Lithium Rechargeable Batteries: CELL ASSEMBLY



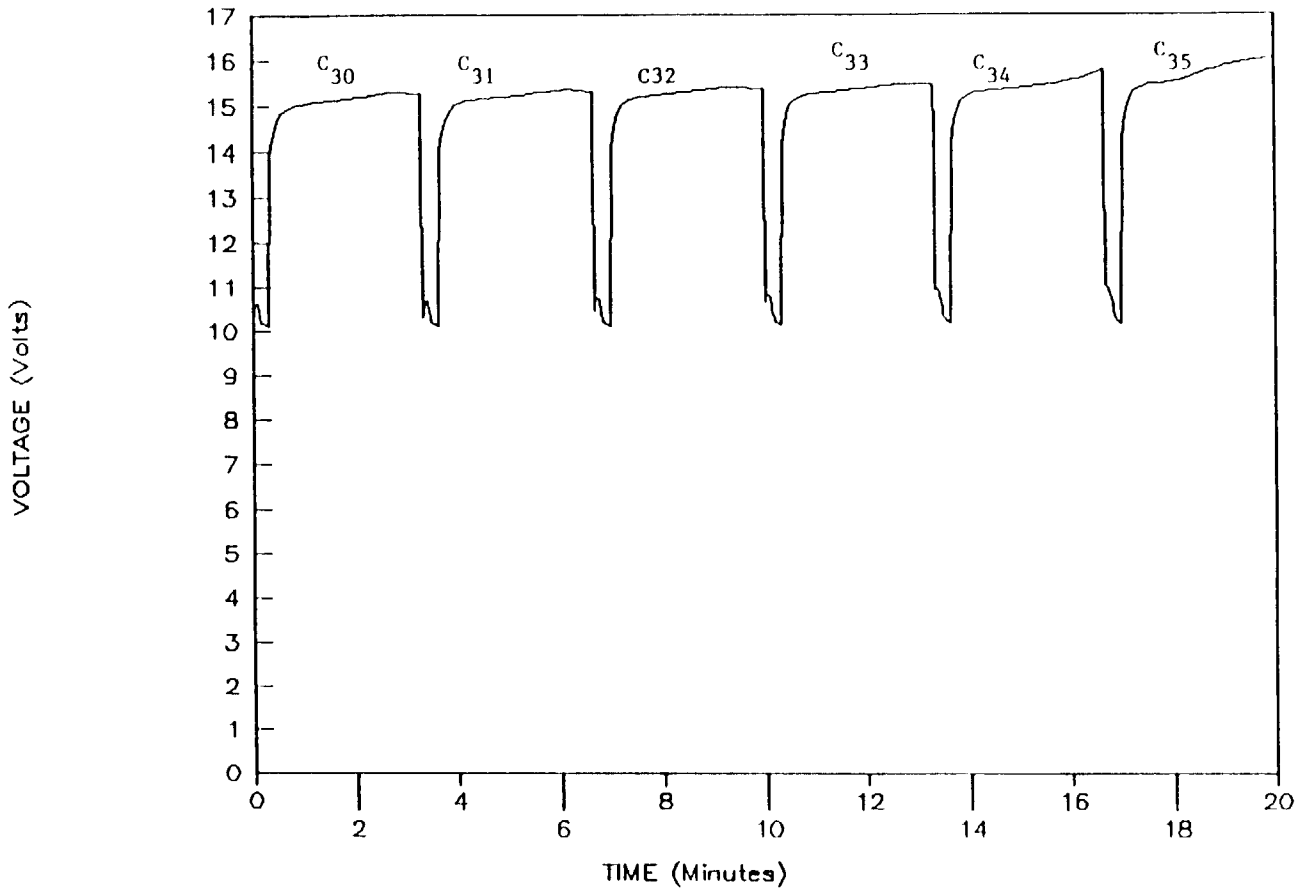
1. Nickel substrate
2. Carbon/TFE undercoat
3. Tefzel insulator
4. Anode and cathode
5. Fill tube and separator



6. Stack sealed except in fill tube area, then activated. Final.

BIPOLAR STACK ASSEMBLY SEQUENCE

Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR



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/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

SPECIFIC POWER $= \frac{270 \times 30}{6}$ w/kg = 1.35kW/kg