Rechargeable Silver-Zinc Button Cells

High Energy, High Power Density Microbatteries
Silver-Zinc Chemistry Advantages

- Improved run-time
- High energy density
- Safe, water-based chemistry
- Key components can be recycled and reused

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Historical Challenges for Silver-Zinc

• Cycle life
  – Zinc dendrites
  – Separator degradation
  – Zinc shape change

• Slow charge time

• Silver cost

• Short life and high cost limited usage to aerospace and military
ZPower Technology Improvements

ZPower uses the latest in:

- Advanced polymers
- Nano-technology
- Power electronics
- Processing methods

**A**

The **zinc anode** is a composite polymer electrode which inhibits shape change and dendrite growth.

**B**

A **layered separator** resists dendrite growth from the zinc anode, reduces degradation from the silver cathode, and allows ions to move freely.

**C**

The **silver cathode** is coated with nano particles which enhance conductivity for lower internal resistance.

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Silver-Zinc Chemistry

$$\text{AgO} + \text{Zn} \xrightarrow{\text{KOH}} \text{Ag}_2\text{O} + \text{ZnO} + \text{Zn} \xrightarrow{\text{KOH}} \text{Ag} + \text{ZnO}$$

- 1.8V upper plateau
- 1.86V OCV

- 1.5V lower plateau
- 1.59V OCV

- 1.2V EPV

![Battery Capacity vs. Voltage Graph](image-url)

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Charge Profile for AgZn

Polarization Peak

Constant current-constant voltage

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# Secondary Battery Chemistries

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Discharge Voltage</th>
<th>Max. Charge Voltage</th>
<th>Charge Method</th>
<th>Trickle Charging</th>
</tr>
</thead>
<tbody>
<tr>
<td>NiMH</td>
<td>1.0-1.4V</td>
<td>1.5-1.6V</td>
<td>CC</td>
<td>Yes</td>
</tr>
<tr>
<td>Silver-Zinc</td>
<td>1.2-1.85V</td>
<td>2.0V</td>
<td>CC-CV</td>
<td>No</td>
</tr>
<tr>
<td>Lithium-ion (LiCoO₂)</td>
<td>3.0-4.0V</td>
<td>4.1-4.2V</td>
<td>CC-CV</td>
<td>No</td>
</tr>
</tbody>
</table>
Microbattery Cell Constructions

- **Button cell strengths**
  - High energy density
  - Small diameter
  - Dimensional stability
  - Package strength
  - Cell sealing (leakage)

- **Button cell weaknesses**
  - Smaller diameter constrains discharge/charge rate
  - Engineered design requires tight tolerances for proper crimp and seal

![Diagram of Button Cells]

![Diagram of Coin Cells]

![Diagram of Laminate Film]
Scalable Battery Capacity

*Size XR41/312 AgZn cell, room temp charge/discharge

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## Button Cell Dimensions & Specifications

<table>
<thead>
<tr>
<th>Model</th>
<th>XR44 / 675</th>
<th>XR48 / 13</th>
<th>XR41 / 312</th>
<th>XR70 / 10A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity/Wh</td>
<td>120-180mAh</td>
<td>40-48mAh</td>
<td>30-36mAh</td>
<td>18-22mAh</td>
</tr>
<tr>
<td>Wh/Wh</td>
<td>200-300mWh</td>
<td>66-80mWh</td>
<td>50-60mWh</td>
<td>30-36mWh</td>
</tr>
</tbody>
</table>

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Rechargeable Chemistries
Size 675 Energy Density

<table>
<thead>
<tr>
<th>Energy Density (Wh/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>120</td>
</tr>
<tr>
<td>140</td>
</tr>
<tr>
<td>160</td>
</tr>
<tr>
<td>180</td>
</tr>
<tr>
<td>200</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specific Energy (Wh/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>80</td>
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<tr>
<td>100</td>
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<tr>
<td>120</td>
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<tr>
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<tr>
<td>160</td>
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<tr>
<td>180</td>
</tr>
<tr>
<td>200</td>
</tr>
</tbody>
</table>

- Silver Zinc
- Lithium-ion
- Nickel Metal Hydride

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High Power Capability
Silver-Zinc XR44/675 Cells

![Graph showing Average Capacities and Average Energies at different discharge rates and temperatures.](image)

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Environmental Strengths

- Rechargeable vs. disposable
- Mercury-free design
- Economic incentive to recycle
- Supports EU Battery Directive
- Recyclable packaging
Safety

- **Ingestion**
  - Typically swallowed by children 0-6 months
  - Tissue damage occurs regardless of leakage
  - Battery voltage drives hydrolysis which causes alkaline burns in internal tissues
  - Higher lithium battery voltages (> 3.0V) cause damage faster (AgZn < 2.0V)

- **Water based electrolyte**
  - Less risk of extremely high temperatures compared to solvent based electrolytes

- **Protective circuitry**
  - Lithium-ion requires additional protective circuitry to prevent thermal runaway

- **Shipping restrictions**
  - Lithium-ion subject to new air shipment regulations (hazardous material)
# Hearing Instrument Applications

<table>
<thead>
<tr>
<th>Hearing Aid</th>
<th>Cochlear Implant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc-air, NiMH</td>
<td>Zinc-air, Li-ion</td>
</tr>
<tr>
<td>10, 312, 13, 675</td>
<td>Battery sizes</td>
</tr>
<tr>
<td>1.2V</td>
<td>Operating voltage</td>
</tr>
<tr>
<td>12 hours</td>
<td>Average daily wear time</td>
</tr>
<tr>
<td>6 hours</td>
<td>Maximum charge time</td>
</tr>
<tr>
<td>1.5mA base with 12mA pulses</td>
<td>Typical loads</td>
</tr>
<tr>
<td>Body temperature, sweat, cerumen</td>
<td>Environment</td>
</tr>
<tr>
<td>Body temperature, sweat</td>
<td></td>
</tr>
</tbody>
</table>

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ZPower Designed Battery Test Tools

• **Button Cell Cycler (BCC)**
  – Charges & discharges AgZn cells
  – Programmable constant current, constant power or pulse loads
  – Programmable charge parameters
  – GUI used to program BCC, logs voltage and current cycle data

• **Multi-cell Charger (MCC)**
  – Charger for 312, 13 and 675 AgZn cells
  – ZPower charge algorithm
  – GUI used to program MCC, logs voltage and current charge data, reads charge history

• **Microbattery Charger (uBC)**
  – Simple, small form factor AgZn charger
Silver-Zinc Charge Algorithm

Polarization

Peak

Charge Capacity Termination

\[ C = m \cdot t_0 + b \]
AgZn Electronics Support Architecture

• **Voltage regulation**
  – Linear regulator: existing LDO parts regulate voltage down to <1.4V
  – Switching regulator: existing SMPS parts step voltage up to >2.0V
  – Multi-mode regulator: combines switching & linear mode down to <1.4V (ZPower ASIC for hearing aids)

• **Charging**
  – Contact charging: PMIC functions as charger and voltage regulator
  – Wireless charging: PMIC controls wireless power, charge algorithm and voltage regulation
ZPower, LLC

- Located in Camarillo, California
  - 43,000 ft² headquarters
  - Research & development
  - Manufacturing
  - Administrative
- Focused on developing silver-zinc and other alkaline chemistries
- Automated manufacturing lines
  - ISO9001:2008 compliant
  - Flexible manufacturing capable of multiple size cells
  - High degree of automation allows “made in USA”
  - Assembly capacity of 2 million cells per year
Battery Development Partner

- Develop custom sizes, packages and alkaline chemistry variations for specialized applications
- Alkaline chemistry development
  - Electrolyte
  - Separator
  - Zinc compounds
  - Process development
  - Custom machinery
- Packaging experience
  - Coin cell
  - Welded can
  - Laminated pouch
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