Development of Microbatteries for Implantable Applications

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Acknowledgment

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Content

- Primary batteries and microbatteries
- PNNL microbattery project overview
- PNNL microbattery design, performance and full tag integration
- Challenges in battery miniaturization and our solutions
- Microbatteries of alternative formats and future directions
Primary batteries make up 37% of battery market value.

- Lithium primary batteries have the highest energy density.
- Among lithium primary battery chemistry, Li/CF\textsubscript{x} has one of the highest gravimetric and volumetric energy densities.

<table>
<thead>
<tr>
<th>Battery System</th>
<th>Nominal cell potential</th>
<th>Gravimetric capacity (mAh/g)</th>
<th>Volumetric capacity (mAh/cm\textsuperscript{3})</th>
<th>Specific energy (mWh/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li/I\textsubscript{2}</td>
<td>2.8</td>
<td>211</td>
<td>1041</td>
<td>591</td>
</tr>
<tr>
<td>Li/MnO\textsubscript{2}</td>
<td>3.0</td>
<td>308</td>
<td>1540</td>
<td>924</td>
</tr>
<tr>
<td>Li/CF\textsubscript{x}</td>
<td>3.0</td>
<td>865</td>
<td>2335</td>
<td>2595</td>
</tr>
<tr>
<td>Li/SVO</td>
<td>3.2</td>
<td>315</td>
<td>1510</td>
<td>1008</td>
</tr>
</tbody>
</table>
Microbatteries find wide application in implantable medical devices, biology studies, miniaturized electronics, military use, etc.

- Defibrillators
- Fish Tags
- Microsensors
- Microbattery
- Electronic pills
- Spy drones

Microbatteries

- Conventional
- Thin film
- 3D all solid state

- Pin type

No Moors’ law for batteries
Lack of high energy density microbatteries with size <100 mm³

Goal of Fish Tag Project at PNNL

Hydropower dams adversely affect migratory fish.
Behaviors and survival rate of fish migration through dams are not well understood.
Fish size vs. tag size. 2% rule.
PNNL Microbattery Project

2012, Beginning of microbattery project at PNNL
2013, Micro V2 (injectable tags) field trial
2014, Micro V3 field trial
2015, Lamprey battery prototyping
2016, lamprey tag design finalized; Injectable tag technology transfer
2017, two pilot field trials

Injectable tags equipped with MB306 greatly improved survival rate
Design features

- Freestanding cathode film with nanosized CF\textsubscript{x}
- Jelly roll assembly
- C-coated Al mesh as current collectors
- Al cases, novel sealing method

<table>
<thead>
<tr>
<th>Design</th>
<th>Size D x L (mm)</th>
<th>Volume (mm\textsuperscript{3})</th>
<th>Weight (mg)</th>
<th>Capacity (mAh)</th>
<th>Energy density (Wh/L)</th>
<th>Specific energy (Wh/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR416</td>
<td>4.8 x 1.6</td>
<td>30</td>
<td>130</td>
<td>8.3</td>
<td>420</td>
<td>100</td>
</tr>
<tr>
<td>QC0025B</td>
<td>2.8 x 25?</td>
<td>155</td>
<td>?</td>
<td>25</td>
<td>400</td>
<td>?</td>
</tr>
<tr>
<td>MB306 (PNNL)</td>
<td>3 x 6</td>
<td>42</td>
<td>70</td>
<td>7</td>
<td>420</td>
<td>250</td>
</tr>
<tr>
<td>Lamprey (PNNL)</td>
<td>1.8 x 4.2</td>
<td>11</td>
<td>20</td>
<td>1.3</td>
<td>300</td>
<td>160</td>
</tr>
</tbody>
</table>

Xiao, J., et al., SPIE, 10.1117/2.1201403.005403
Lamprey batteries at different discharge rate and temperatures

Challenges and Solutions

Challenges

- Reduce parasitic weight and volume
- Reduce voltage drop upon pulse current
- Maximize material utilization

Solutions

- Light packaging materials, novel sealing method
- Nanosized cathode particle, C-coated current collector
- Cathode design, fundamental study of battery chemistry
A Dual Sealing method

Sealing procedure of PNNL microbatteries

Dual-sealing design
- First barrier of rubber provide temporary sealing and condition for epoxy curing
- Second barrier of epoxies provide hermetic sealing

The length of jelly-roll cell core is 90% of the overall length in MB306

Wang, Y., et al., J Power Sources, 341 (2017) 443
A Dual Sealing method

<table>
<thead>
<tr>
<th>Adhesive Name</th>
<th>Weight Change (mg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devcon 10 minute epoxy</td>
<td>-0.02</td>
</tr>
<tr>
<td>Apiezon wax W</td>
<td>-0.1</td>
</tr>
<tr>
<td>Loctite 4311 UV-curable</td>
<td>-0.08</td>
</tr>
<tr>
<td>Masterbond EP51FL</td>
<td>-0.02</td>
</tr>
<tr>
<td>Loctite E-20HP</td>
<td>Severe weight loss starting from day 5</td>
</tr>
<tr>
<td>Torr Seal epoxy</td>
<td>No measureable weight loss in 8 months</td>
</tr>
</tbody>
</table>

The sealing is stable for at least 10 months at ambient conditions.

Intimate bonding between adhesive and Al cases is critical.

Wang, Y., et al., J Power Sources, 341 (2017) 443
EVE MB306 cells sealed with the novel sealing method showed stable electrochemical performance for at least 30 days.

Wang, Y., et al., J Power Sources, 341 (2017) 443
The Challenge of High Cell Impedance (Lamprey)

If the cell impedance is too high, tags fail at initialization step

Activation (initial discharge 1%) is required

High voltage drop only occurs in lamprey cells

Only a problem at the initialization stage of tag operation
The Challenge of High Cell Impedance (Lamprey)

Typical impedance evolution of lamprey cells with/without C coating

Case study of high impedance cells

- High and unstable impedance is likely due to contact resistance
- C-coated Al mesh helps lower the impedance greatly

Voltage curve during activation
Future directions

- Can we further improve energy and power densities?
- What is the size limit?
- Rechargeable?

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Discharge capacity (mAh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.8</td>
<td>0.0</td>
</tr>
<tr>
<td>2.6</td>
<td>0.2</td>
</tr>
<tr>
<td>2.4</td>
<td>0.4</td>
</tr>
<tr>
<td>2.2</td>
<td>0.6</td>
</tr>
<tr>
<td>2.0</td>
<td>0.8</td>
</tr>
<tr>
<td>1.8</td>
<td>1.0</td>
</tr>
<tr>
<td>1.6</td>
<td>1.2</td>
</tr>
<tr>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>1.0</td>
<td>1.8</td>
</tr>
<tr>
<td>0.8</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Lamprey battery
- 1.9 mAh
- 430 Wh/L
- 240 Wh/kg
Non-rechargeable microbatteries of volume 42 mm$^3$ and 11 mm$^3$ with high energy density (400 Wh/L) have been developed at PNNL.

Acoustic and radio frequency microtransmitters powered by PNNL microbatteries extend the size limit of biology study subjects and potentially make great contribution to the conservation efforts of precious animal species.

Design of microbatteries needs to be tailored to specific applications.

A novel sealing method was developed which greatly reduce parasitic weight and volume.
Advanced Battery Facility

- Dry room and pouch cell line
- Group research interest: high voltage cathode, Li metal, Li sulfur, silicon anode, Na battery, etc.
Thanks! Questions?

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