Lithium Ion Battery Off-Gas Sensor for Battery Health and Safety Monitoring

Joint Service Power Expo

Cincinnati, OH
August 27, 2015
About NexTech

NexTech Materials, Ltd.

- Founded in 1994, privately held
- Technology Developer – advanced ceramics, electrochemical devices
- Product Developer – fuel cells, catalysts and sensors
- Manufacturer/Distributor – fuel cells and related products, sensors
- ISO 9001:2008 certification – covers all products and operations

www.nextechmaterials.com
Lithium Ion Battery Off-Gas Sensor

Project History

2010-2011: Launch of NexTech hydrogen safety sensor product

2010-2011: Phase I NAVSEA project on battery off-gas sensor

2012: Launch of hydrogen alarm product for lead acid batteries

2012-2015: ARPA-e project on lithium ion battery off-gas sensor for stationary battery management systems

2015: Initiated Phase II of NAVSEA project, targeting ship service applications
Sensor Device Platform

Features
- Chemi-resistive sensor element
- Small mass and efficient heating for low power draw
- Robust device platform with integrated electronics
### Standard Device Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Calibration Range</td>
<td>0.25 to 4% H&lt;sub&gt;2&lt;/sub&gt; in air</td>
</tr>
<tr>
<td>Response Time (t&lt;sub&gt;90&lt;/sub&gt;)</td>
<td>&lt; 5 sec</td>
</tr>
<tr>
<td>Recovery Time (t&lt;sub&gt;10&lt;/sub&gt;)</td>
<td>&lt; 5 sec</td>
</tr>
<tr>
<td>Humidity Range</td>
<td>5 to 95% RH</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>-20 to 80°C</td>
</tr>
<tr>
<td>Power Draw</td>
<td>&lt; 2 watts at 20°C</td>
</tr>
<tr>
<td>Insensitive to:</td>
<td>CO, CH&lt;sub&gt;4&lt;/sub&gt;, VOCs</td>
</tr>
<tr>
<td>Robust to continuous H&lt;sub&gt;2&lt;/sub&gt; exposure (no signal saturation)</td>
<td></td>
</tr>
<tr>
<td>UL listed for hazardous locations</td>
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Starting-point platform for lithium ion battery off-gas sensor development
NexTech’s Phase I NAVSEA Project

NAVSEA Contract No. N65538-10-C-0035
**Phase I NAVSEA Project**

**Project Goal:** Tailor and optimize NexTech’s hydrogen sensor technology for detecting gases released from deteriorated lead acid, nickel-cadmium, silver-zinc, and lithium ion batteries.

**Objectives**
- Define requirements for battery monitoring applications
- Enhance sensitivity at low H\(_2\) concentrations (lead-acid batteries)
- Refine formulations for detecting CO, CH\(_X\) and VOCs (lithium ion batteries)
- Performance qualification (target gas detection range, response time, recovery time, operating temperature, baseline stability)
**Key Accomplishments**

- Defined requirements for lead acid and lithium ion battery monitoring applications
- Modified sensor formulations for low level detection of hydrogen, hydrocarbons and VOCs
- Demonstrated ppb level detection of hydrogen for lead acid battery monitoring
- Demonstrated ppb level detection of lithium ion battery electrolytes (DMC and DEC)
# Battery Off-Gas Sensor

<table>
<thead>
<tr>
<th>Target Requirements</th>
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<tbody>
<tr>
<td>Gases to be detected</td>
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<tr>
<td>Cross-sensitivity</td>
</tr>
<tr>
<td>Durability</td>
</tr>
<tr>
<td>Lifetime</td>
</tr>
<tr>
<td>Calibration Interval</td>
</tr>
<tr>
<td>Response Time</td>
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<tr>
<td>Recovery Time</td>
</tr>
<tr>
<td>Temperature</td>
</tr>
<tr>
<td>Size (fully packaged)</td>
</tr>
<tr>
<td>Weight (fully packaged)</td>
</tr>
<tr>
<td>Audible Alarm</td>
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<tr>
<td>Visible Alarm</td>
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</tbody>
</table>
DNV’s ARPA-e AMPED Project

DOE Contract No. DE-AR00002765
Project Goal: Develop sensor technology for safety and health monitoring of lithium ion batteries

Objectives

- Tailor NexTech’s sensor for detection of lithium ion battery electrolytes (the primary off-gassing species in degraded or damaged batteries)
- Explore the feasibility of this technology for second-life battery applications, such as community energy storage.
- Build prototypes and conduct field testing with NexTech’s sensor integrated with battery management systems.

Project Team: Det Norske Veritas (project prime), NexTech Materials, Beckett Energy Systems
Key Accomplishments

- Developed capability for testing cells under a range of abuse conditions
- Characterized battery off-gassing under normal and abusive conditions
- Quantified off-gas constituents for thermal runaway conditions
- Developed a hand-held sniffer to support customer demonstrations
- Conducted field tests on returned battery packs and punctured pouch cells
- Installed sensors in Beckett’s community storage system and analyzed responses to simulated off-gas events
- Quantified sensor response time and off-gas detection capability
**Battery Off-Gas Sensor**

**Product Concepts**

- Sensor modules that will integrate with the BMS to identify electrolyte leaks from battery packs or modules.

- Stand-alone battery safety monitoring devices that can provide safety monitoring of a battery system, particularly during times when the BMS is off-line, such as during storage or transport.

- A hand-held leak detector to check battery integrity during installation or prior to conducting maintenance on or near battery systems.
Project plan structured to focus first on most aggressive abuse conditions, then stepping down to normal use conditions:

Tests focused first on most abusive, moving toward least abusive
NexTech's sensor can detect a wide range of electrolyte off-gas events caused by different failure modes.
Non-Abusive Cell Cycling

- Sub-ppm level electrolyte detected with NexTech’s sensor
- Not all batteries offgas – appears to be related to manufacturing quality
Sampling Set-up

- Each test chamber requires one vacuum chamber and one sample pump.
- All chambers connected to common exhaust line through a selector valve.
Sensor response climbs 10% prior to temperature spike by 10-20 minutes under thermal runaway test conditions.
Hand-Held “Sniffer”

Passed electrical test and visual inspection

Failed electrical test and has visible corrosion

Sensor may provide additional diagnostic capability and identify battery issues not detectable with current methods
Off-Gas Sensor for BMS Diagnostics

Details of Test
- Tests conducted on a 25-kW SCALE Beckett system
- Six sensors map full range of placement options
- Quantified sensor responses with simulated off-gas
- Shows single sensor can identify off gas in system
- Offers redundant, independent monitor to BMS

![Beckett DESS System]
Utilization Scenarios

Integrated with BMS

Independent of BMS

Expanded Operation
“Pull Back” from Extremes
Redundancy in Shut Down
Bypassable Modules

Automated Class D Extinguisher
Redundancy
Maintenance Alarms
Distinguish Cell Anomaly from Catastrophic Failure
NexTech’s Phase II NAVSEA Project

NAVSEA Contract No. N00024-15-C-4002
Objectives

- Identify key performance requirements
- Continue maturation of core battery electrolyte sensor technology
- Optimize the prototype device design to meet ambient temperature variation requirements
- Demonstrate prototype device performance through field testing
- Improve robustness of the sensor for military deployment (Option)
- Conduct military application demonstrations (Option)
Phase II Work Plan

Task 1: Requirements Definition

Task 2: Core Technology Improvements

Task 3: Comprehensive Sensor Testing

Task 4: Prototype Sensor Design and Fabrication

Task 5: Field Testing of Prototype Sensors

Task 6: Military Hardening and Application Testing
Testing Plan

NexTech Laboratory Testing

- Evaluation of sensor response characteristics in headspace gas of typical battery electrolytes (DEC, DMC, MEC)
- Cross-sensitivity testing to wide range of gases (HF, CO, CO$_2$, H$_2$O, other HCs)
- Response and recovery time characterization
- Long-term stability testing

Field Testing

- Sensor evaluation in relevant application environments (collaboration with Navy-selected test partners)
- Prototype device testing on military hardened optimized designs during the Option phase
Acknowledgments
Questions?

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