Development of Temperature Sensitive Paint for Energy Storage System (ESS) Safety

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Project Overview

- **Project Goal:** Development of larger area temperature monitoring system for ESS safety.
- **Current Practice:** ESS uses thermocouples to monitor battery temperature, but it is challenging to monitor the temperature of every single cell in a bank of thousands of batteries for overheating.
- **Why ORNL:** ORNL has expertise in synthesizing materials, slurry development, and 20 years of thermal runaway battery testing experiences.
- **Innovation:** Developing temperature sensitive paint that provides early detection of thermal runaway by releasing a detectable gas at lower temperatures. Using chemical specific sensors, an early warning signal can be generated and can offer extensive signal coverage.
- **Impact:** The paint can be utilized in ESS, electric vehicles, basically every place that Li-batteries are used. This paint offers an additional safety layer for users/consumers, alerting possible thermal runaway events before a failure occurs, thereby allowing sufficient time to implement a mitigation plan.
- **Alignment:** Safety and reliability are the most concerning issues in any ESS. This effort aligns OE and DOE's mission to maintain a reliable power grid.

Existing issue

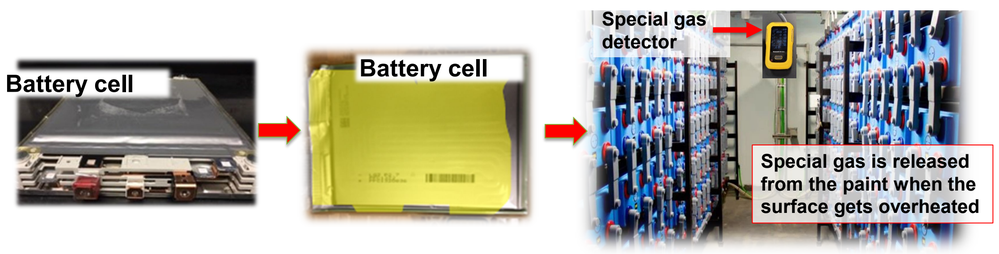
- Thermal runaway is the most reported safety issue of Li-ion batteries in ESS.[1]
- It is challenging to monitor the temperature of every single cell in a bank of hundreds and thousands of batteries.
- Battery failure usually starts from a hot spot in a single cell, which presents an impossible task to use temperature sensors effectively.[2]
- The batteries may continue to overheat without flames, leading to a thermal runaway event slowly over time.
- ESS needs a large-area temperature monitoring system.

Potential solution

- A temperature-sensitive paint: The low-cost paint can be applied to every cell and cover all surfaces for an ESS.

Our approach

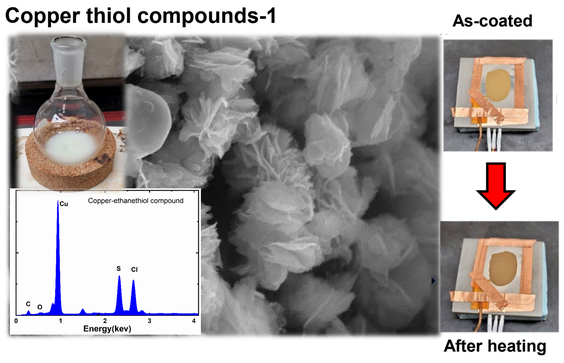
- Entrap/attach molecules (e.g., thiols) in larger molecules designed to release the gas when a specific threshold temperature is reached.[3]
- A special gas detector placed to sense and alarm if the designated molecule is detected.
- Fundamental understanding and identifying the gas species released by thermal sensitive compounds to determine the right gas sensor for specific compounds.
- Understanding of metal, sulfur and hydrocarbon reactivity and thermal decomposition pathways to tune the compounds onset gas release temperatures.



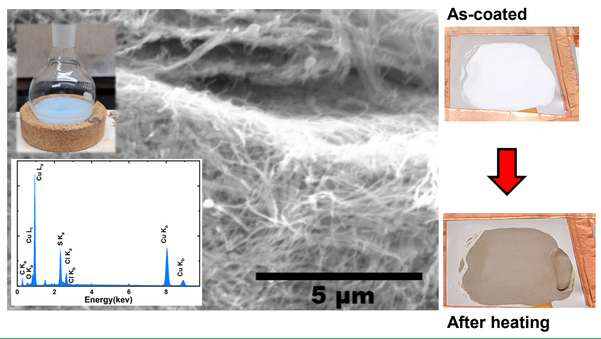
Methods

Thermal-sensitive compounds synthesis and characterization

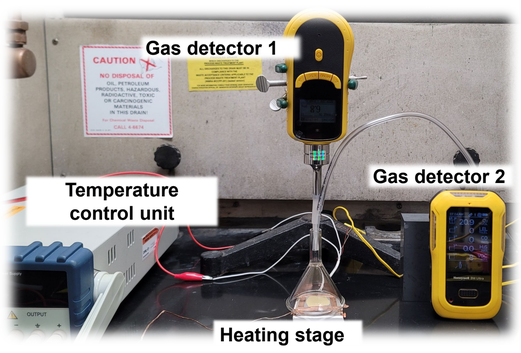
Copper thiol compounds-1



Copper thiol compounds-3



Thermal runaway simulation setup

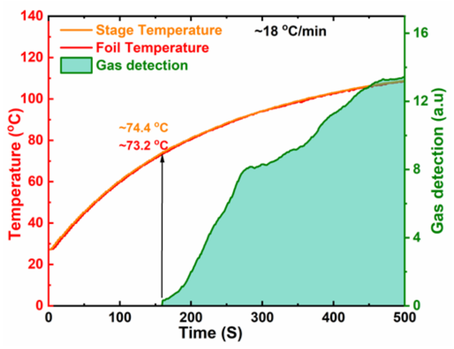


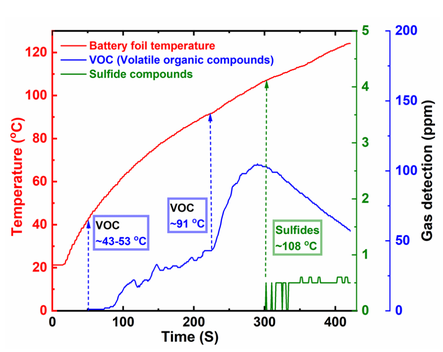
The onset of gas release temperature can be tuned

Copper-thiol compound	Onset gas released temperature (°C)
Compound - 1	72-75
Compound - 2	84-96
Compound - 3	120-127
Compound - 4	152-163
Compound - 5	172-174

Results

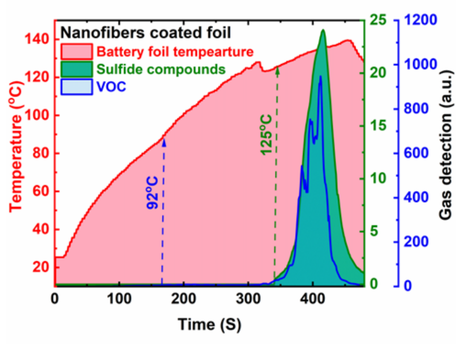
Copper-thiolate compound-1

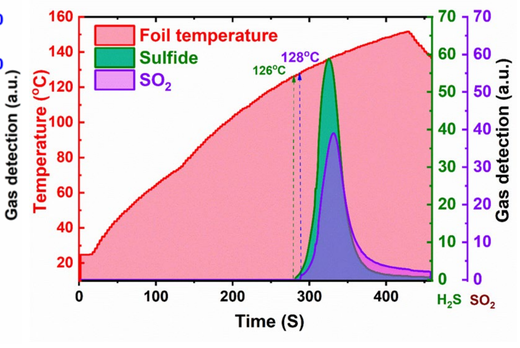




Onset gas release temperature
Mercaptan: 73-78 °C / VOC: 53 °C/ Sulfide: 115-120 °C

Copper-thiolate compound-3





Onset gas release temperature :
Mercaptan : 120-125 °C/ VOC: 117°C/ Sulfide: 125-127 °C/ SO_2 : 128 °C

TGA-MS:

Consistent with SO_2 and sulfides gas

XPS

Oxidize Cu(I) to Cu(II)

TGA-MS

Consistent with SO_2 and sulfides gas

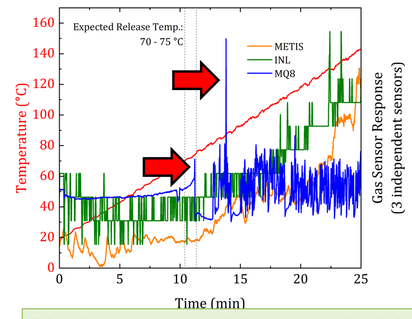
XPS

Reduce Cu(II) to Cu(I)

Collaboration with SANDIA National Laboratory:

Alex Bates and Loraine Torres-Castro

Copper-thiol compound-1



MQ8 sensor: 75 °C and 102 °C

Copper-thiol compound-3

METIS sensor: 115 °C

Conclusions

- Copper-thiolate compounds thermally decompose and release volatile compounds (VOC, sulfur dioxide, sulfide) when the critical temperature is reached.
- Onset gas release temperature is tuned by changing the chemistry of the thiol groups.
- TGA-MS data aligned well with the gas sensor response.
- The thermal process and gas releases induced an oxidation state change of Cu.
- Gas detection depends on the gas species and the particular detector/ sensor utilized.
- Independent tests at ORNL and SANDIA agreed on the onset gas release temperatures.

Acknowledgements

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- Felipe Polo-Garzon and Nabihan A Rahman for TGA-MS data analysis and Harry M Meyer for XPS data analysis
- SANDIA National Laboratory.

[1] BESS Failure Event Database : https://storagewiki.epri.com/index.php/BESS_Failure_Event_Database?oldid=1944 [2] Process Safety Progress 2023, 42 (4), 664-673 [3] Temperature sensitive coatings, U.S. Patent Application No.18/119,373, March 9, 2023