

EEVVC-2017

**European Battery, Hybrid
& Fuel Cell Electric Vehicle Congress**

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**In-operando techniques for battery monitoring and safety issues
prevention**

Lecture 1B – Batteries – Modelling & Safety

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<http://liten.cea.fr/cea-tech/liten/en/>

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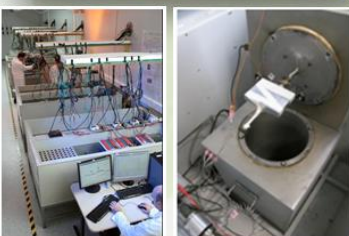
 **ines**

INES

National Institute for Solar Energy
Le Bourget du Lac, France



Laboratory for Electrochemical Storage



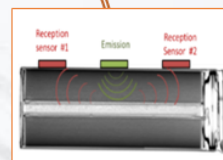
21 persons
Electrochemists, Modelers,
Electrical engineering...



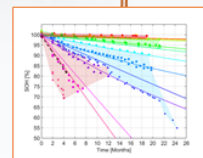
Platforms
350 cycling channels, 2 adiabatic
calorimeters...

- Technologies
- Producers
- References
- Autopsies
- Autopsy demands
- Abuse tests

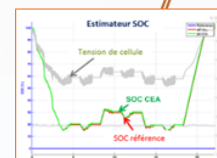
1. Benchmarking



2. Advanced instrumentation



3. Modeling



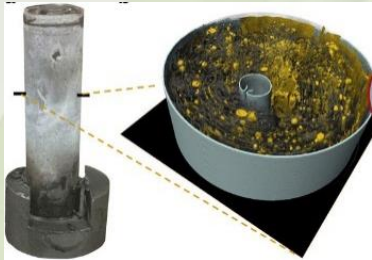
4. BMS indicators and management laws

In-operando monitoring of storage systems

The battery, a black box ?

- How to get additional information during operation?

↪ Five senses !



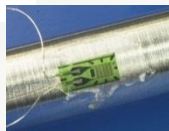
Gas Analysis



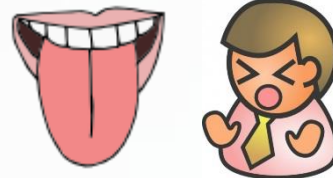
D. P. Finegan et al. "In-operando high-speed tomography of lithium-ion batteries during thermal runaway", Nat Comm dec 2014



**Temperature
Strain gauges**



Acoustic Emission



Not Allowed !!

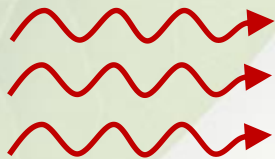


In-operando monitoring of storage systems

- Focus on two of our senses



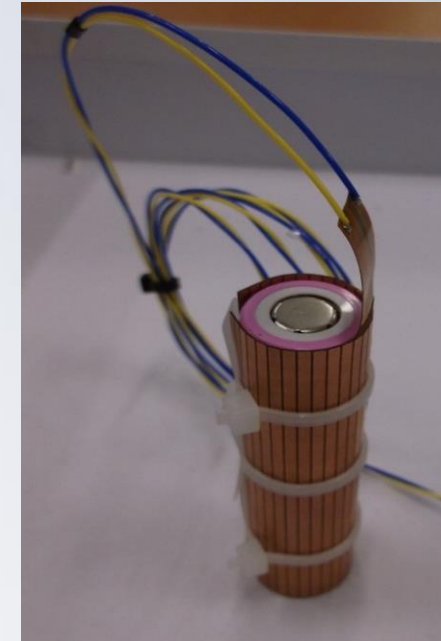
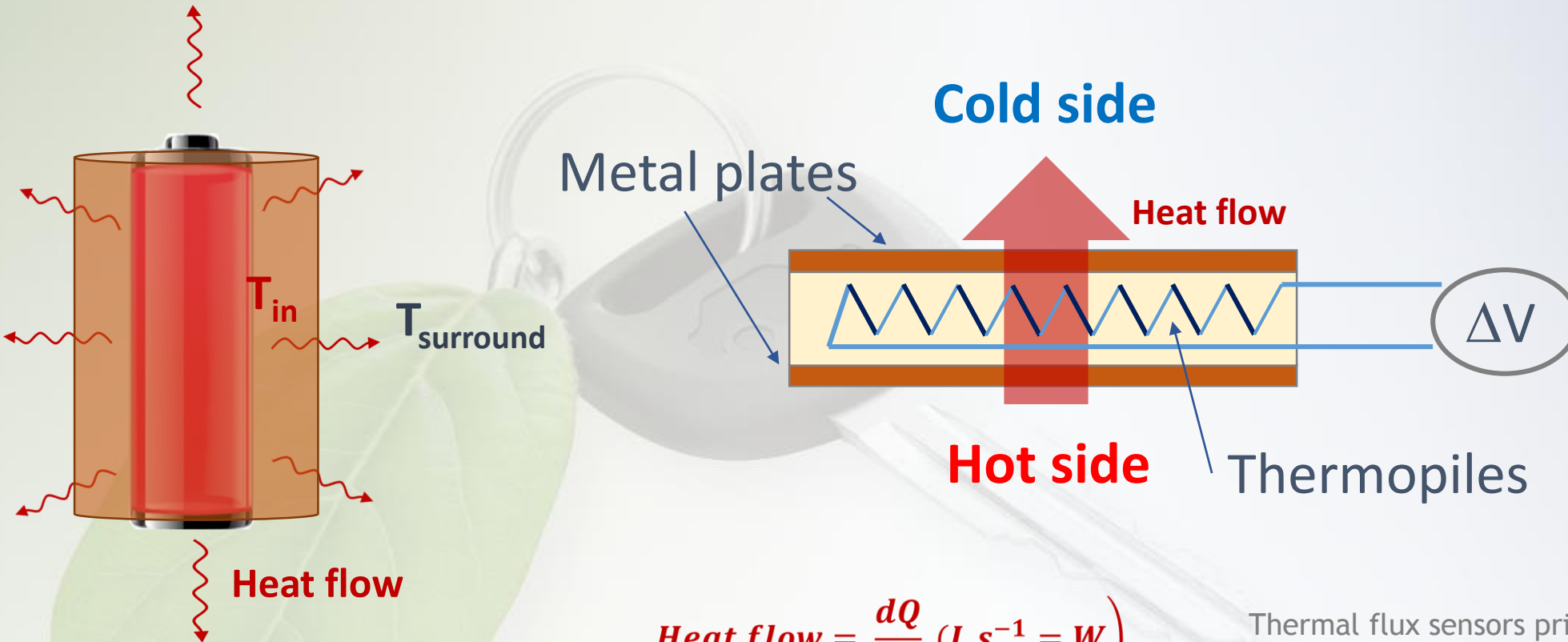
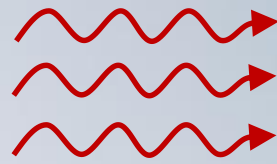
Thermal analysis



Acoustic Emission



1- Heat flux sensors

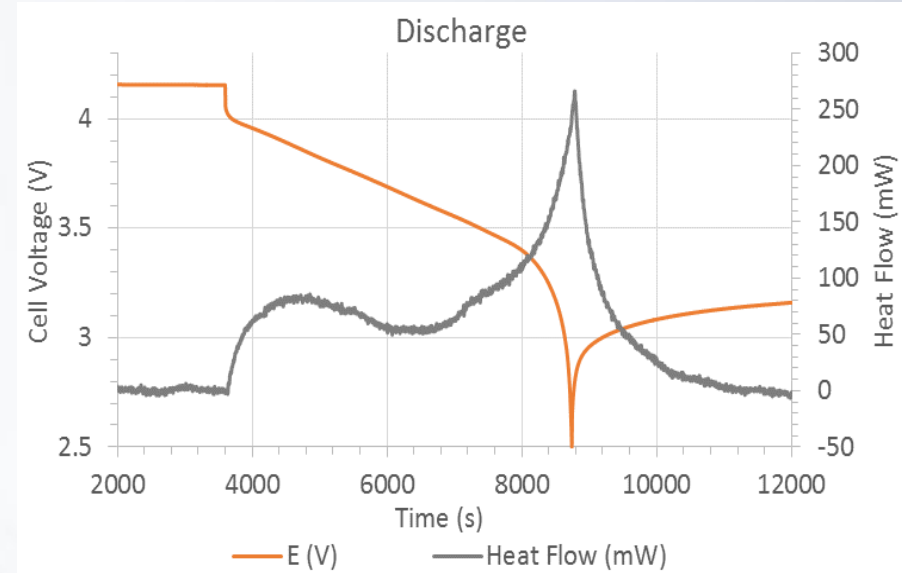
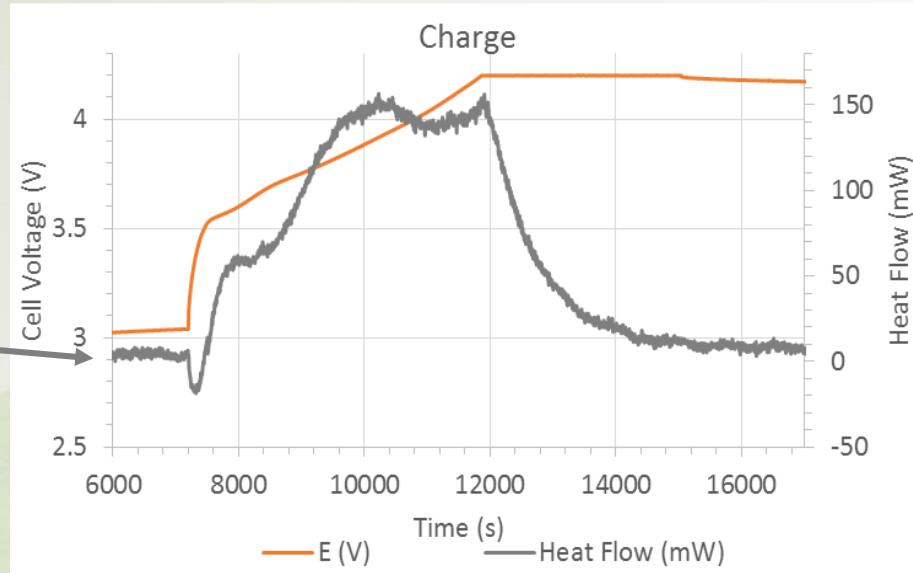
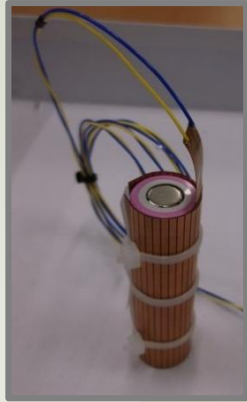
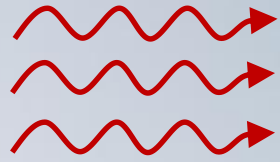


$$\text{Heat flow} = \frac{dQ}{dt} \text{ (J} \cdot \text{s}^{-1} = \text{W)}$$

Thermal flux sensors principle, thermal flux sensor (Captec <http://www.captcenterprise.com/>) wrapped around a 18650-type battery.

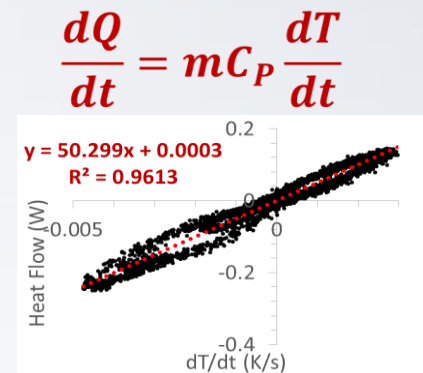
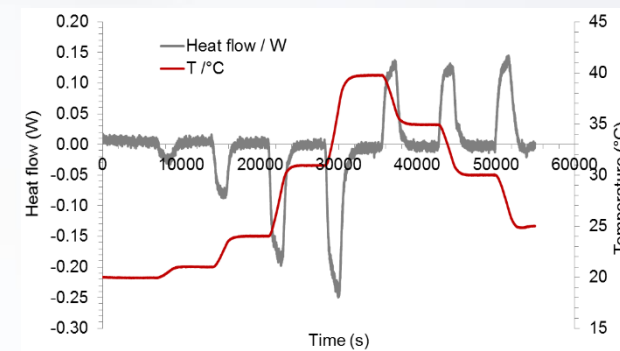
- Sandwich construction, metal plates homogenize the transport of heat across the whole sensitive surface;
- Sensitive to the direction perpendicular to the sensor surface.

1- Heat flux sensors

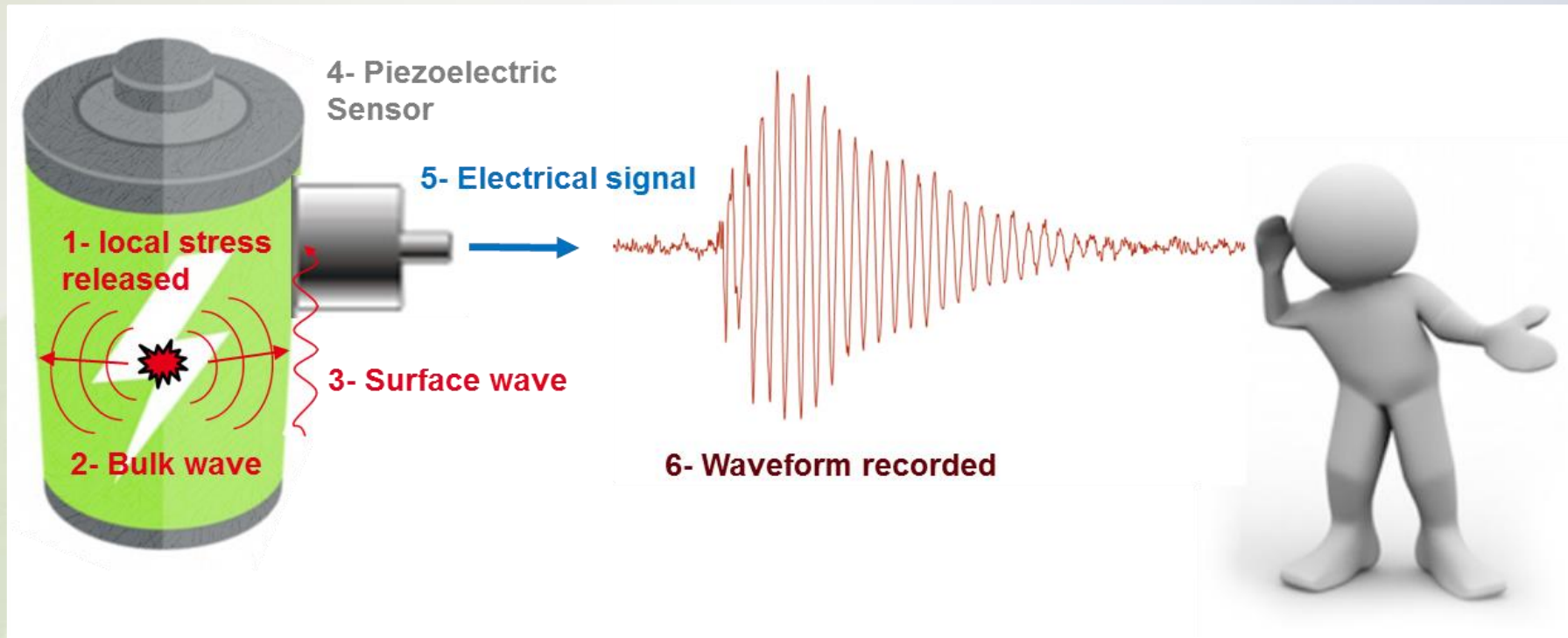


Example of cell voltage and heat flow measured on a 18650 battery during charge (CC at C/2 and CV) and discharge (C/2).

- Direct measurement of the heat flow exchanged with surrounding
 - ↳ Thermal monitoring and management
- Easy way to measure the Cp of the battery
 - ↳ Characterization
 - ↳ Thermal modelling



2- Acoustic Emission



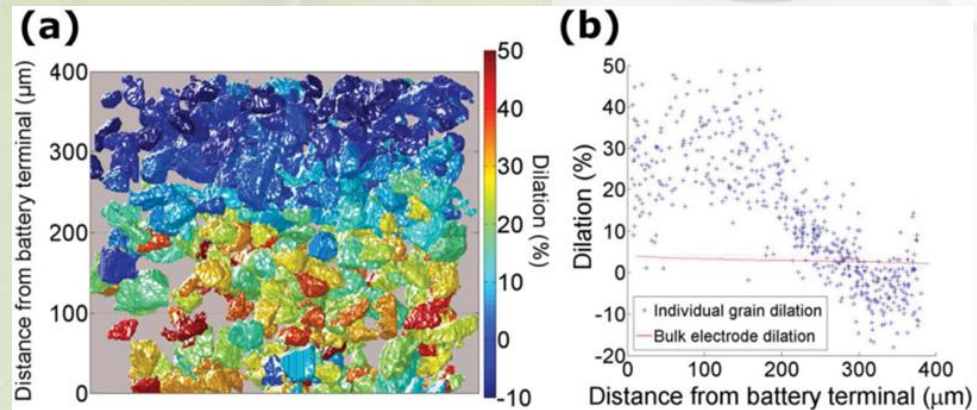
- non-destructive test (NDT) method used to detect elastic transient acoustic waves produced by materials;
- Relaxation of mechanical stresses in materials emits transient elastic waves. They propagate throughout the battery materials to the surface and are recorded by sensors.

2- Acoustic Emission



- Relaxation of mechanical stresses in materials and at interfaces
 - Volume change associated with lithium intercalation,
 - Cracks in the passivation layer of the electrodes,
 - Gas evolution (formation, electrolyte degradation, etc...)

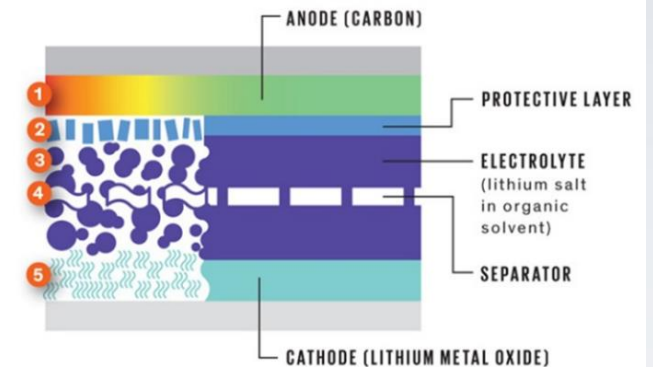
Dilatation of materials during lithiation—delithiation



Mechanical constraints during thermal runaway

Thermal Runaway in a Lithium-Ion Battery

1. Heating starts.
2. Protective layer breaks down.
3. Electrolyte breaks down into flammable gases.
4. Separator melts, possibly causing a short circuit.
5. Cathode breaks down, generating oxygen.



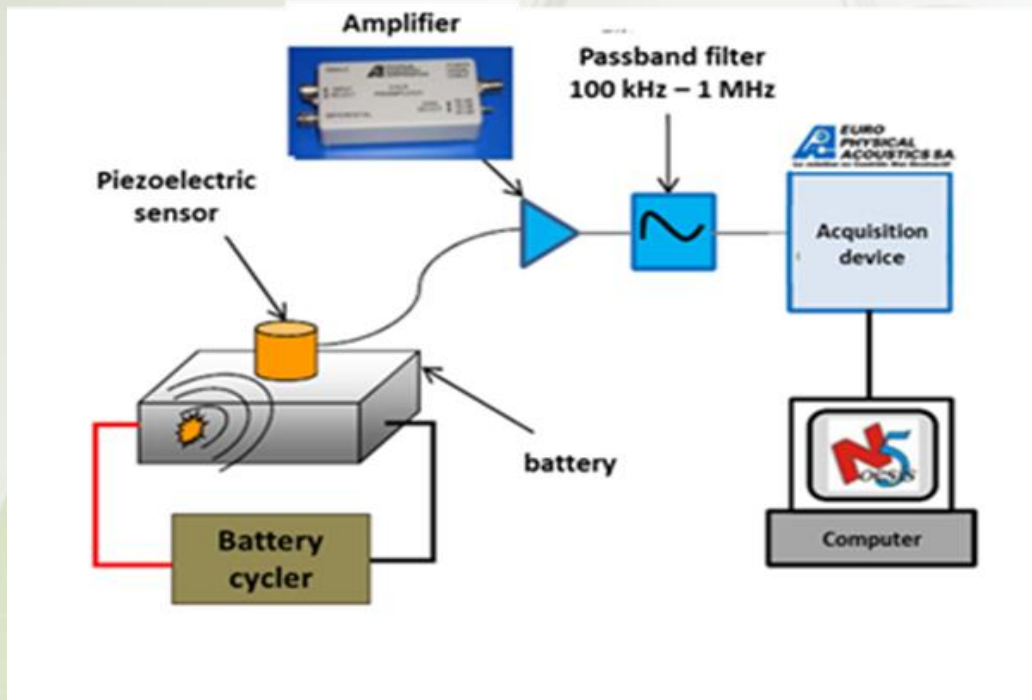
David S. Eastwood *et al.* “Lithiation-Induced Dilatation Mapping in a Lithium-Ion Battery Electrode by 3D X-Ray Microscopy and Digital Volume Correlation” *Adv. Energy Mater.* 2014, 4, 1300506

Illustration: Erik Vrielink,
<http://spectrum.ieee.org/aerospace/aviation/boeings-battery-blues>

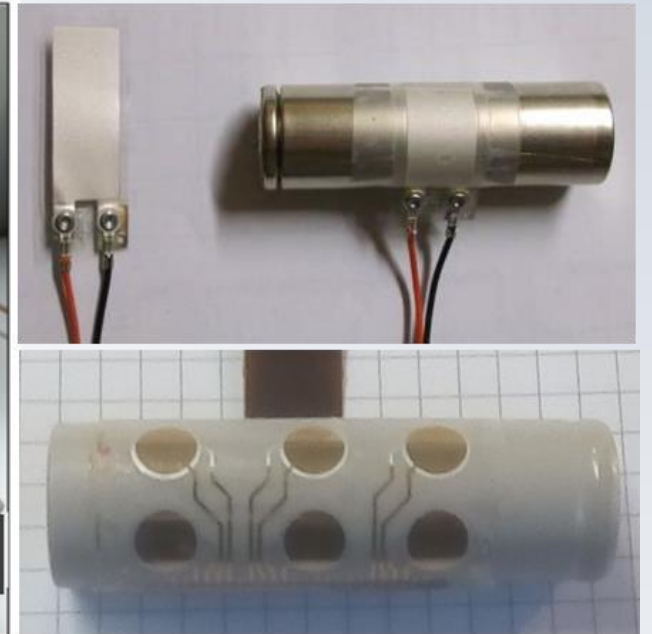
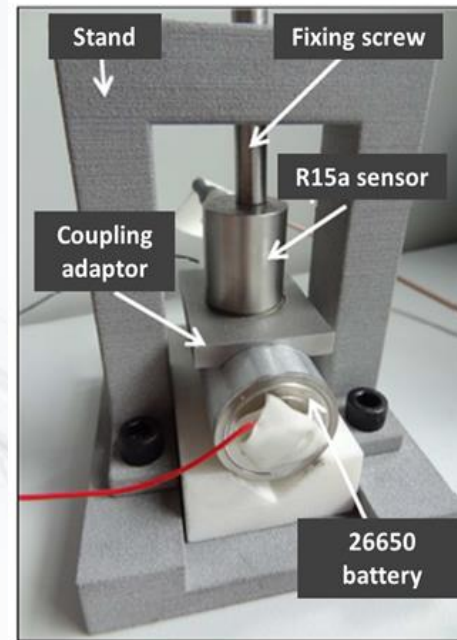
2- Acoustic Emission



- Experimental Setup



Acquisition chain used for acoustic emission experiments.

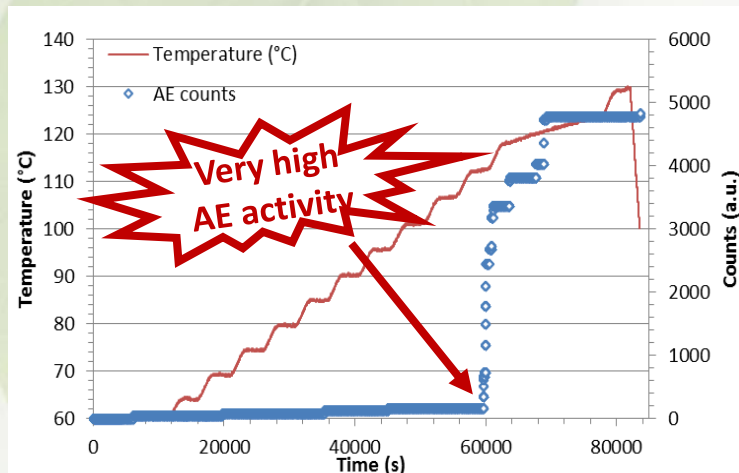
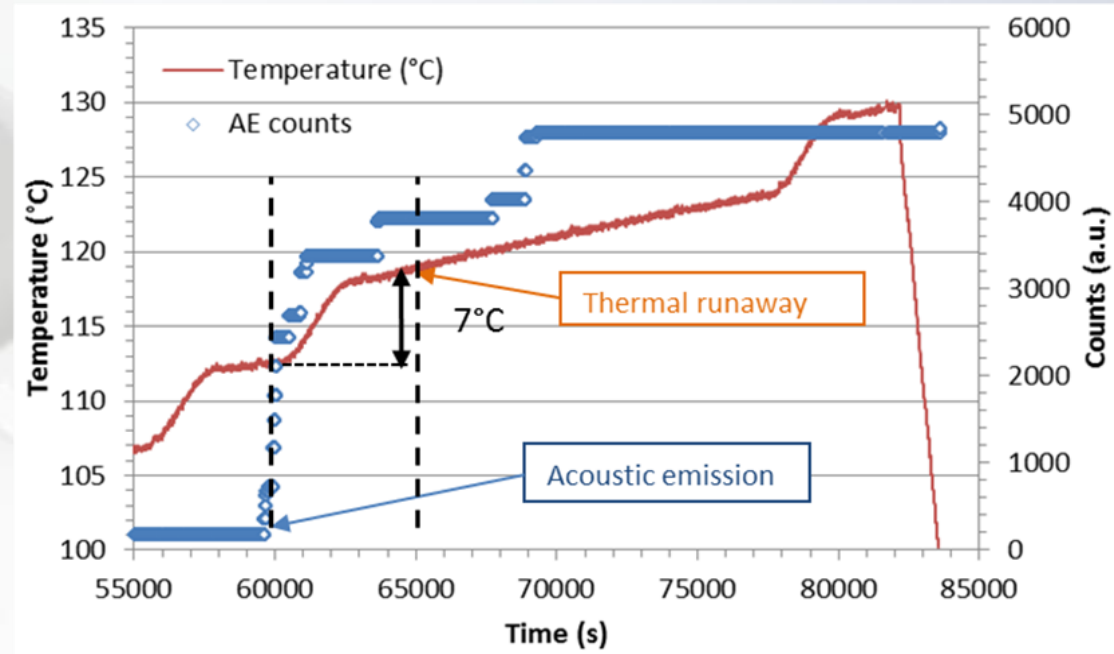
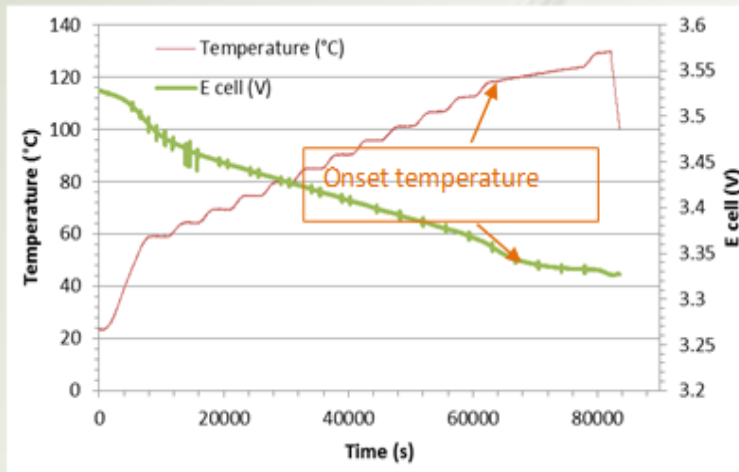


Different kinds of piezoelectric transducers.

2- Acoustic Emission



- Example: abusive conditions of operation, thermal runaway



Detection of early signs of thermal runaway

↳ Prevent irreversible degradation / safety issues



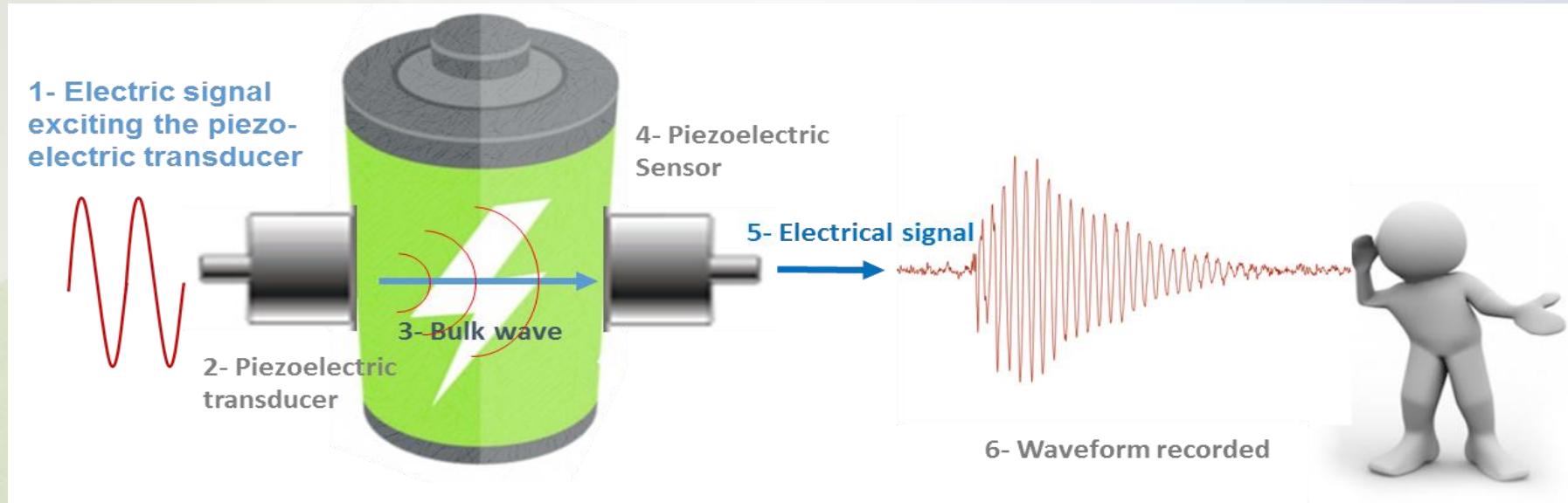
Sensors placed outside a battery pack can detect the defect of one cell inside the battery pack.



Sensitive to external noise.

Over heating of a LFP/G battery in ARC setup.

3- Ultrasound characterization

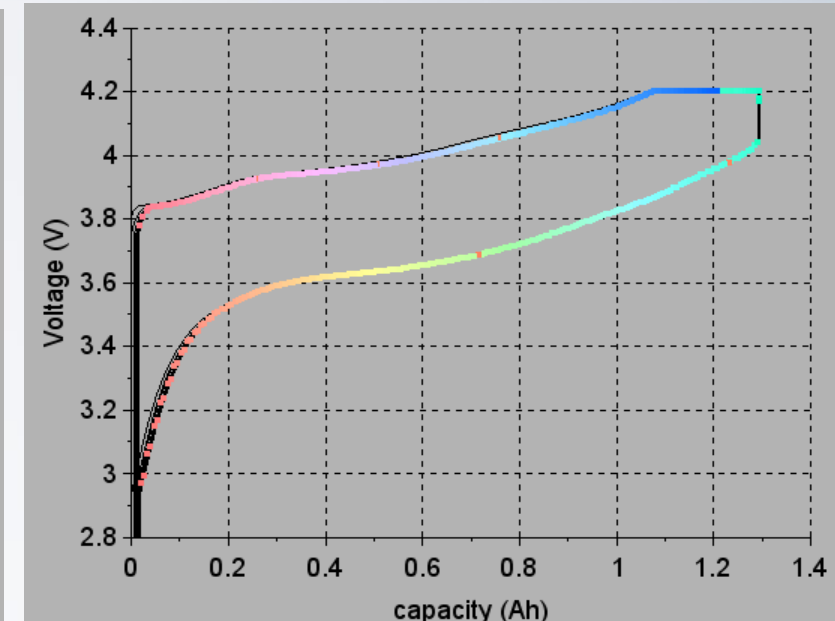
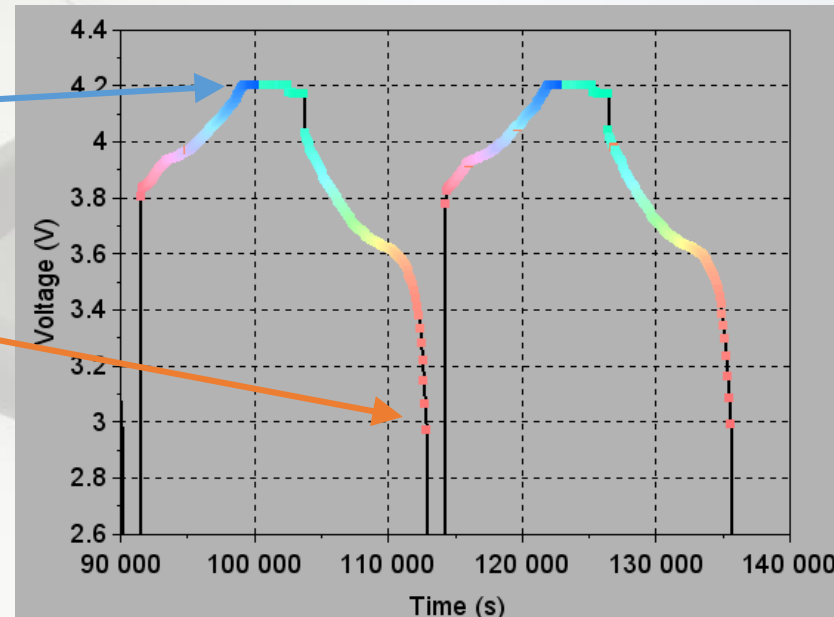
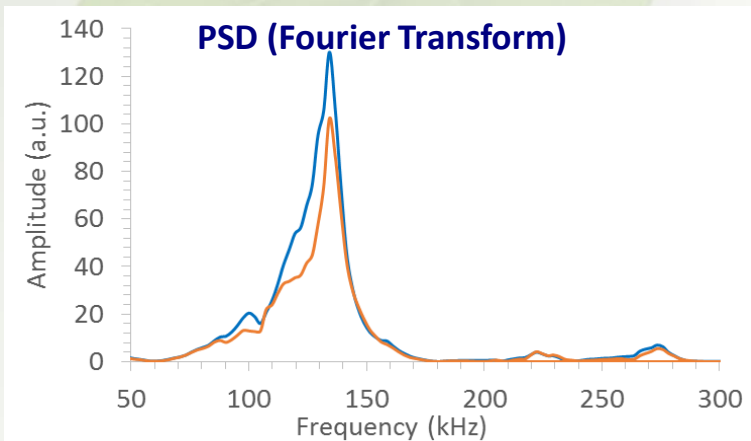
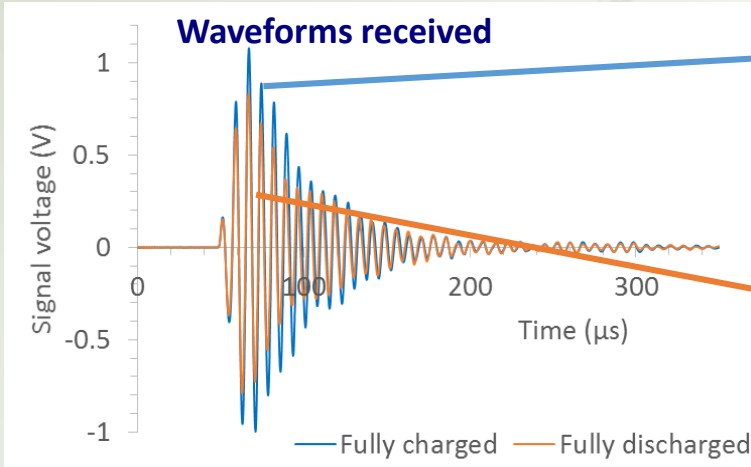


- Non-destructive test (NDT) method;
- Study the propagation of acoustic waves throughout the battery's materials;
- Acoustic waves interact with materials and interfaces,
- ➔ Detect materials density variations, discontinuities, defects, bubbles generation...

3- Ultrasound characterization



- Example: cycling a phone battery



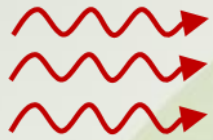
prismatic 385368 3,7 V, 1400 mAh Li-ion battery

- ➔ Significant evolution of the waveforms during cycling;
- ➔ High repeatability of the physical behavior;
- ➔ **Estimate SoC independently from electrochemical parameters (U, I, Q)**

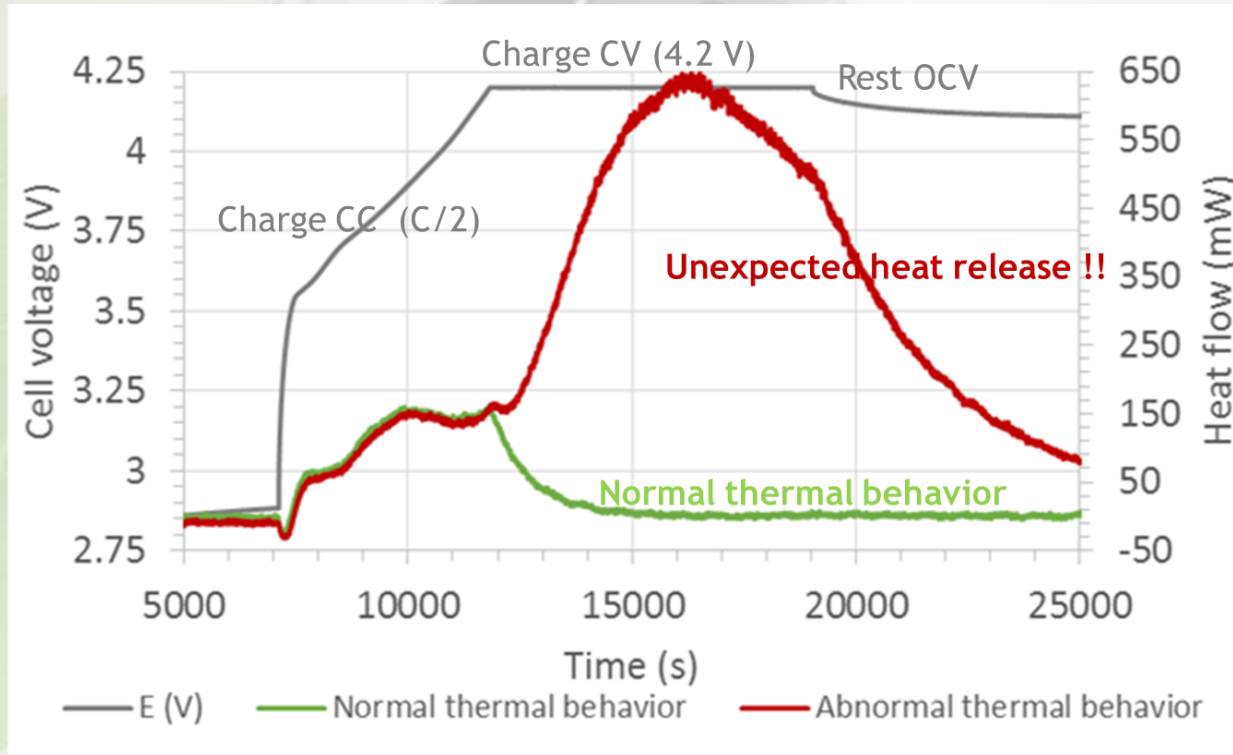
A study case: detecting abnormal heat release during charge



- Commercial 18650-type battery;
- Abnormal and unreliable heat release sometimes noticed on aged batteries (~85 - 90 % SoH) during charge.



Heat flux sensor



Normal thermal behavior (max. 150 mW)

Abnormal thermal behavior (max. 650 mW)

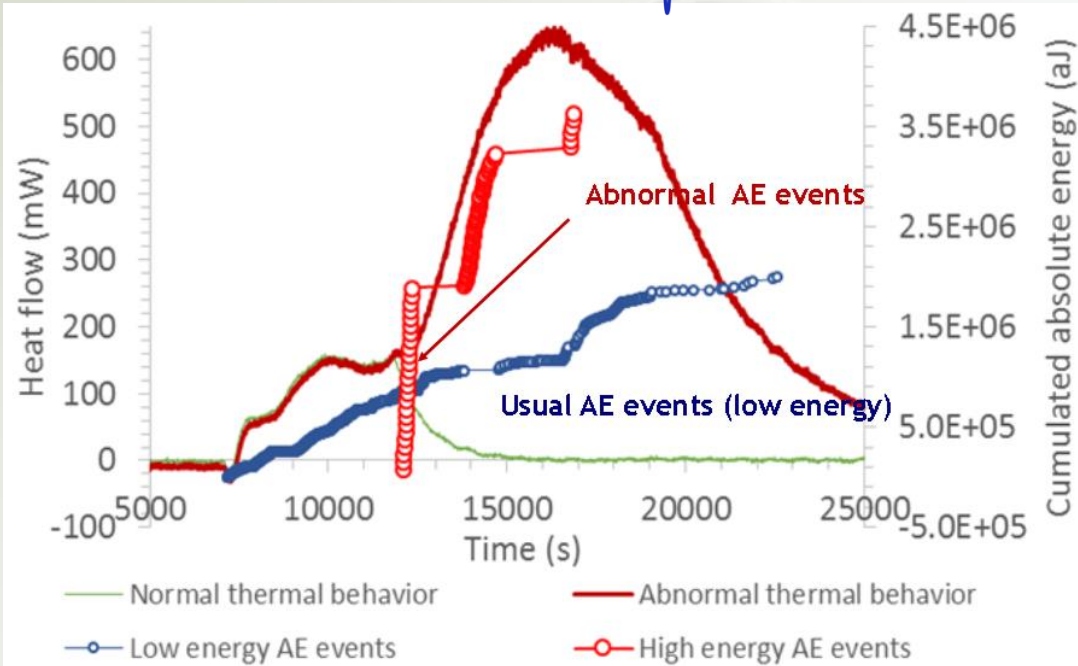
↪ Degradation of performance

↪ Safety issues

Detect early signs of abnormal thermal behavior ??

A study case: abnormal heat release during charge

Acoustic Emission

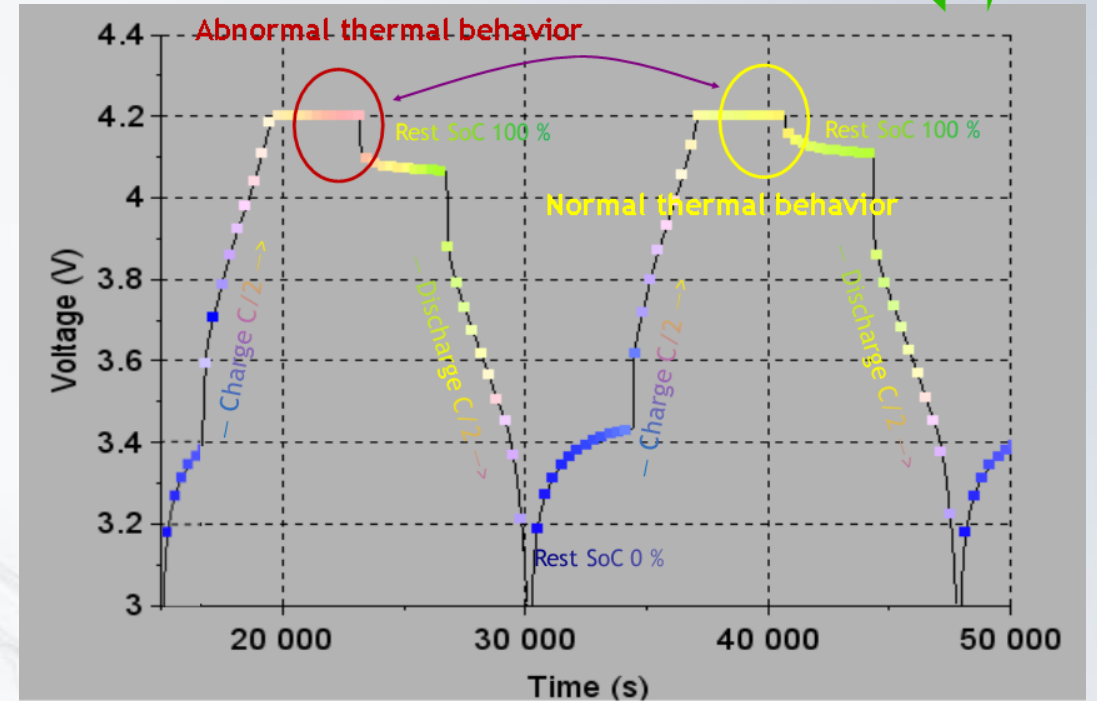


Usual AE events (2.1 fJ / AE event)

Abnormal AE events (44 fJ / AE event)

➤ high energy acoustic events early detected during heat release

UltraSound Characterization



Color gradient (waveform evolution) with SoC

Specific signal noticed during abnormal thermal behavior

➤ Significant change in the material's sound wave transportation properties

Conclusions

- Different in-operando and non-invasive techniques for battery monitoring
 - Based on physical modification of materials during operation

Heat flux sensor



Acoustic Emission



UltraSound Characterization

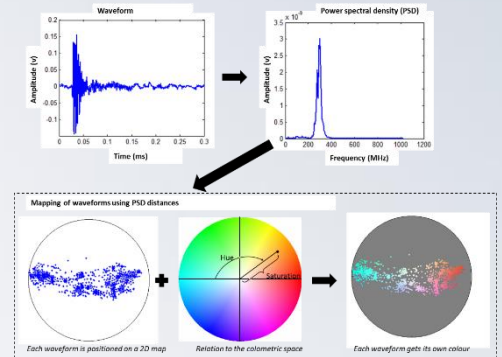


- Development/optimization of tools (sensors, signal acquisition);
- Development of an original methodology for data analysis (mapping).

→ Battery monitoring for improved BMS

- ↳ Estimate the SoC and the SoH of a battery, independently of usual parameters (U, I, T);
- ↳ Faster and smart charging, improve performance and durability, prevent safety issues ...
- ↳ BMS that evolves with battery life (I, U, and T°C limitations that change during ageing).

→ We're interested to evaluate your battery/system



Acknowledgements

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Thank You for your attention!

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Questions ?

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