Qualification for 2nd life usage of batteries using enhanced sensing schemes

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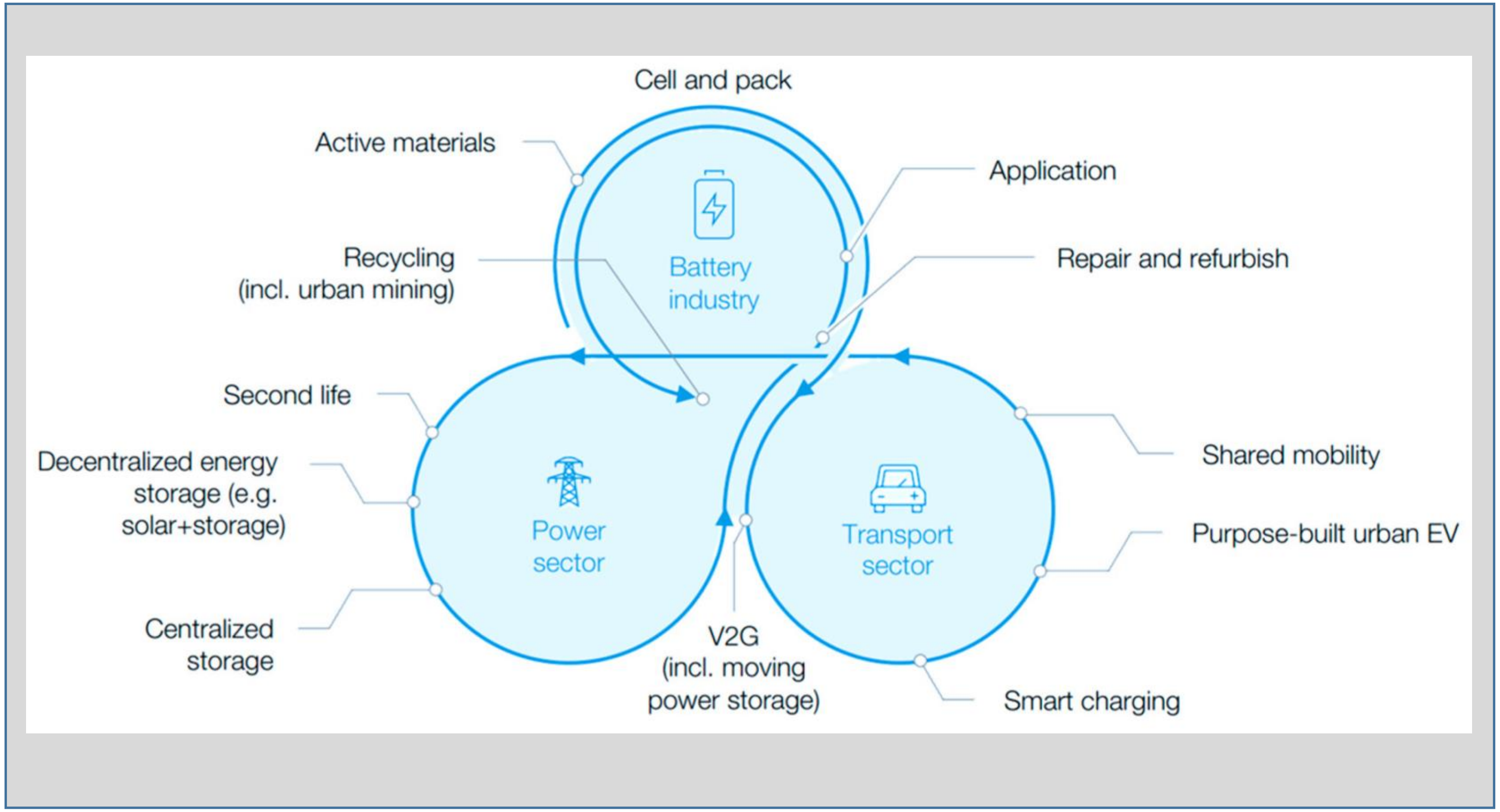
2nd Life

Circular economy for LiB batteries (e.g Transport sector)

Definition: End-of-Life:
- 20% drop of cell charge

Circular Economy:
- Repair and Refurbish
- Recycling (→ Economically and technological challenges)
- Second life (Power sector)



Zhao, Yanyan; Pohl, Oliver; Bhatt, Anand I.; Collis, Gavin E.; Mahon, Peter J.; Rüther, Thomas; Hollenkamp, Anthony F. (2021): A Review on Battery Market Trends, Second-Life Reuse, and Recycling. In: *Sustainable Chemistry* 2 (1), S. 167–205. DOI: 10.3390/suschem2010011.

2nd Life

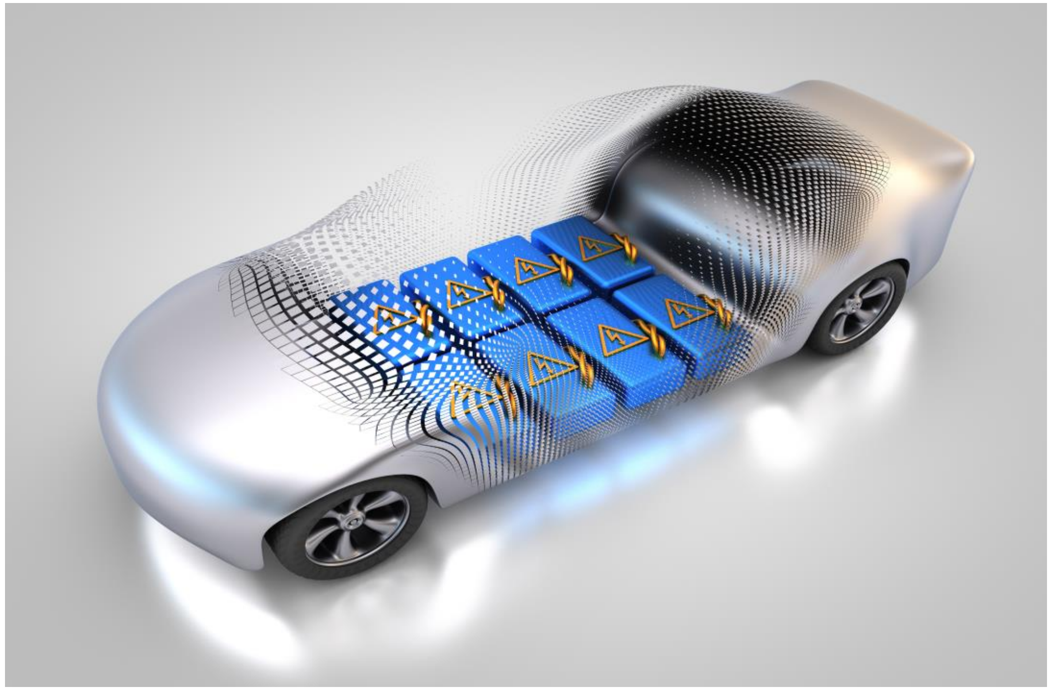
Battery performance assessment important for 2nd life usage

General difficulty:
→large variance between individual cells

Cell assessment
- Visual Inspection
- Verification of battery voltage
- OCV
- Electrochemical Impedance
- State-of-Health Assessment

Do we get the full picture?
- Look for inhomogeneities in temperature, young‘s modulus, deformation, etc.

- Logging the history of the battery



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Monitoring of battery cells
The SPARTACUS project approach

→ Equip battery cells by sensors to have a locally resolved information about events taking place in battery cell

- Structural changes of material
- Li Plating / Dendrite formation,
- Graphite exfoliation
- Particle cracking
- Electrolyte decomposition, SEI growth, SEI decomposition
- Binder decomposition,
- Structural disordering,
- Transition model dissolution,
- Loss of electric contact,
- Corrosion of current collectors

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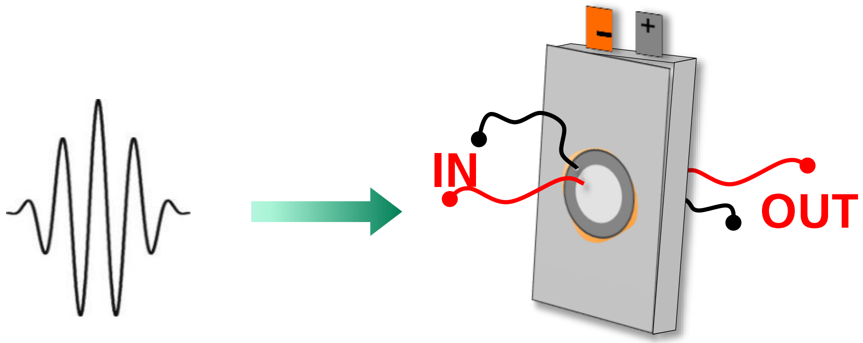
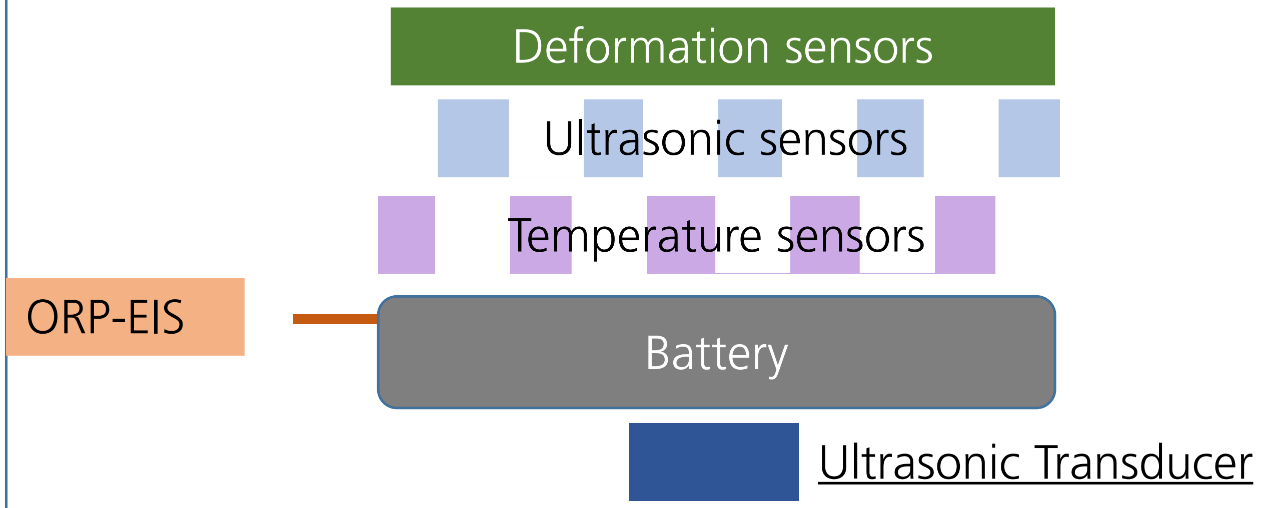
Monitoring of battery cells
The SPARTACUS project approach

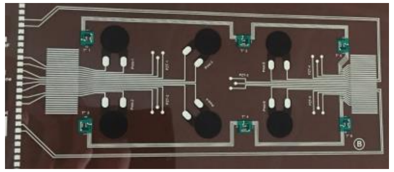


Assembly of sensor arrays to analyze degradation events from outside



For reliability, standardization and cost reduction

- Technological realization by electronic standard processes (lamination of assembled flex PCB)



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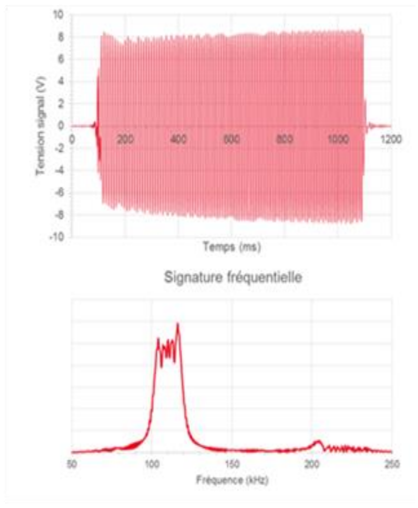
Monitoring of battery cells

The SPARTACUS project approach
Ultrasonic characterization

1. Electric Signal is supplied to a transducer that generates an acoustic wave
2. Acoustic wave propagates through the battery cell and cell information is recorded
3. The altered wave is detected by sensors

1.



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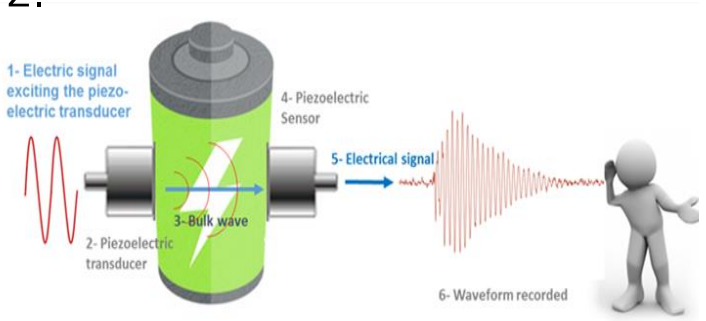

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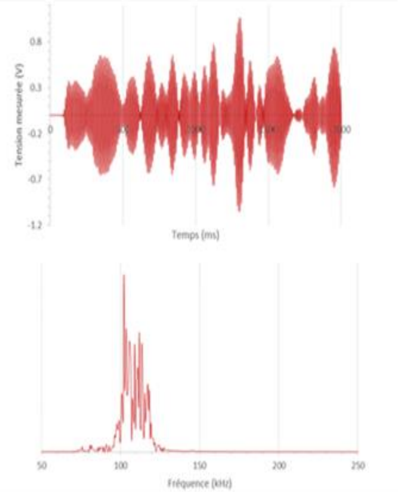

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- Variation of input signal (frequency, amplitude, waveform)
- Design of Acoustic impedance of surrounding materials to direct the sound efficiently
- Signal Evaluation (ToF, Amplitude, Frequence Shifting, higher order, FFT/Powerspectra,..)

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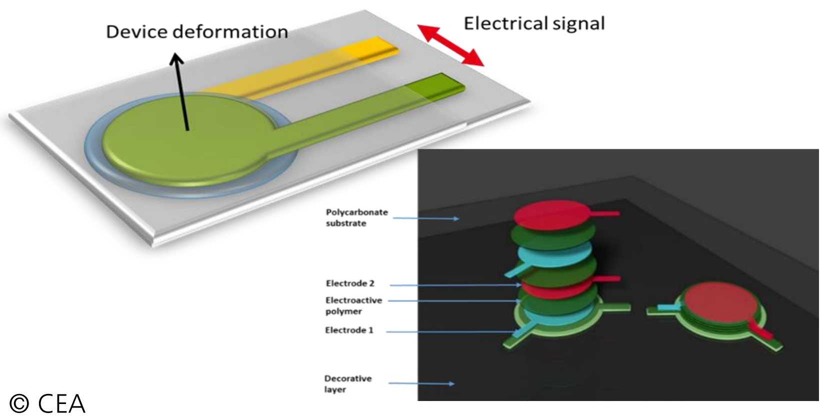
Monitoring of battery cells

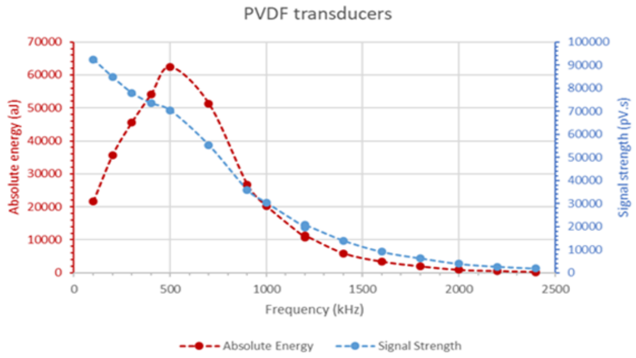
The SPARTACUS project approach: Ultrasonic characterization using printed US sensors based on PVDF co-polymer

3 printing steps:

- Bottom Electrode
- Electroactive polymer
- Top Electrode

→ Flexible and thin sensor (< 50 µm thickness)

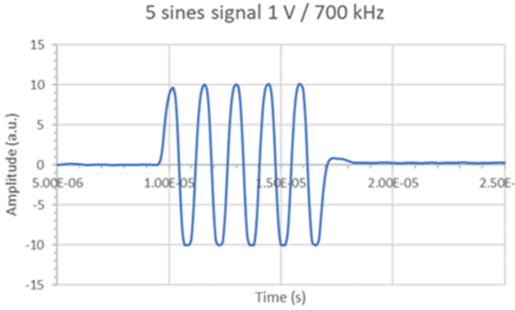




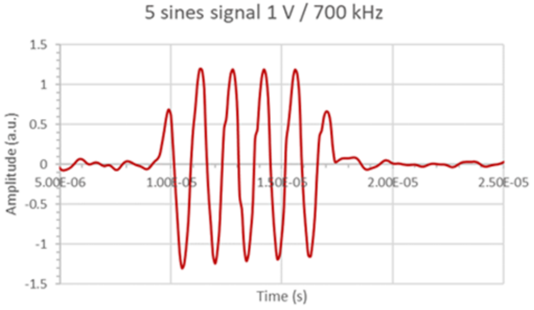
Absolute energy and signal strength of the transmited signal vs. signal frequency

Optimization of exciting frequency to apply highest energy

Change of the transmitted signal



Electric signal emitted (e.g. fixed frequency at 700 kHz / 1V amplitude)



Electric signal transmited through the battery cell

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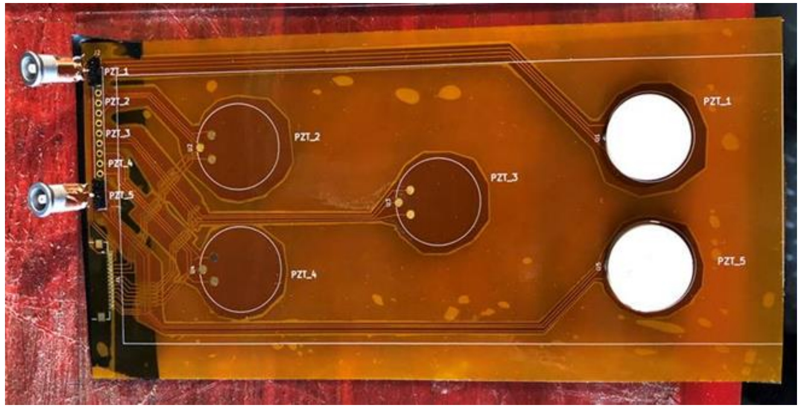
Monitoring of battery cells

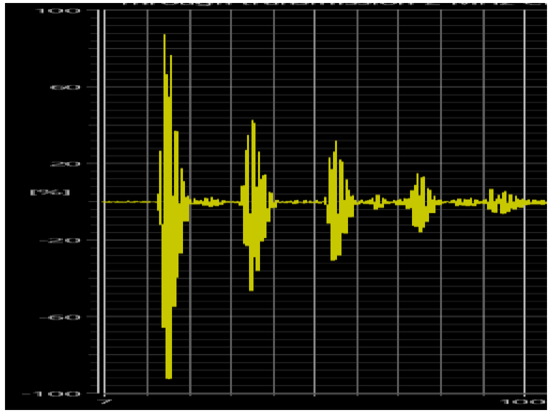
The SPARTACUS project approach

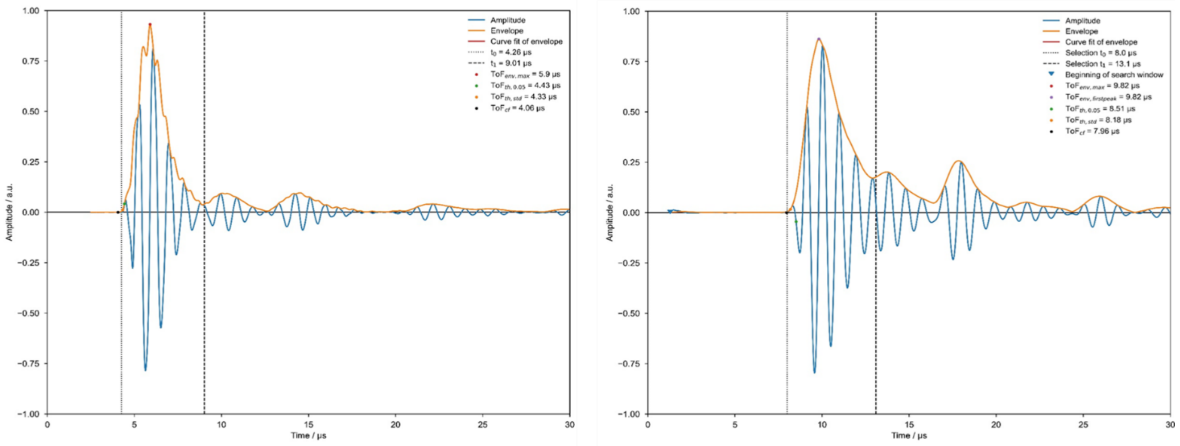
Ultrasonic characterization using piezoceramic sensors / transducers

- High Amplitude
- Defined frequency resonances
- Stiff/ Brittle

Assembled on Flex PCB







Evaluation of ToF (Thickness), and higher order waves (transversal waves)

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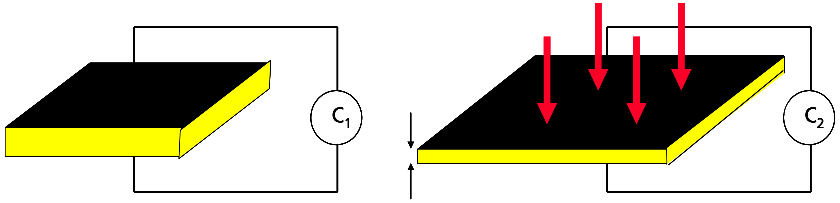
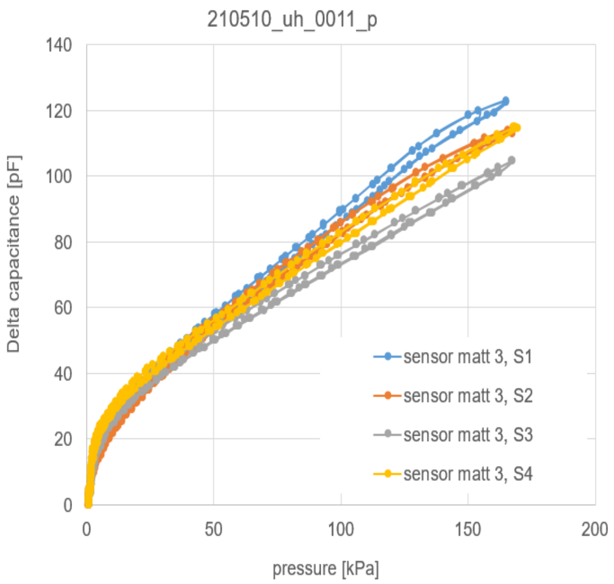
Monitoring of battery cells

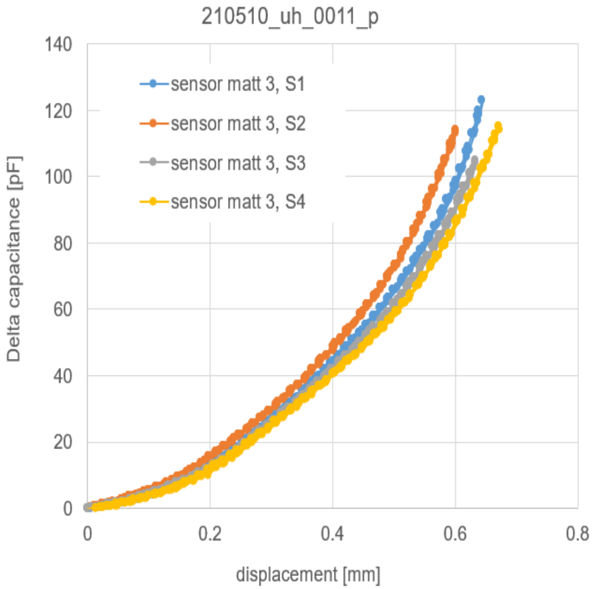
The SPARTACUS project approach: Deformation sensor based on dielectric elastomer sensors



Principle: elastomeric dielectric within a capacitor

- Change of capacity when capacitor is deformed
- Array by segmentation of electrodes

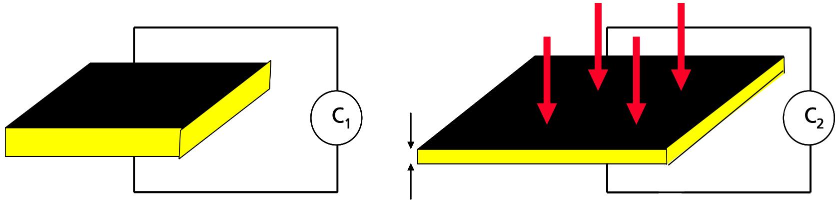




Change of capacity in dependence of pressure (left) and displacement (right) – 4 different sensors of the same sensor array

Monitoring of battery cells

The SPARTACUS project approach: Deformation sensor based on dielectric elastomer sensors



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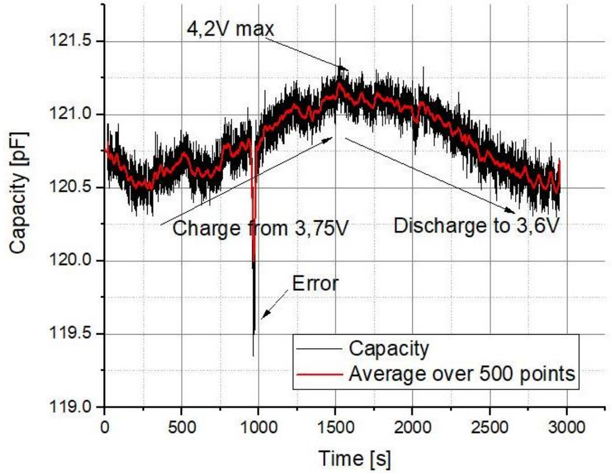

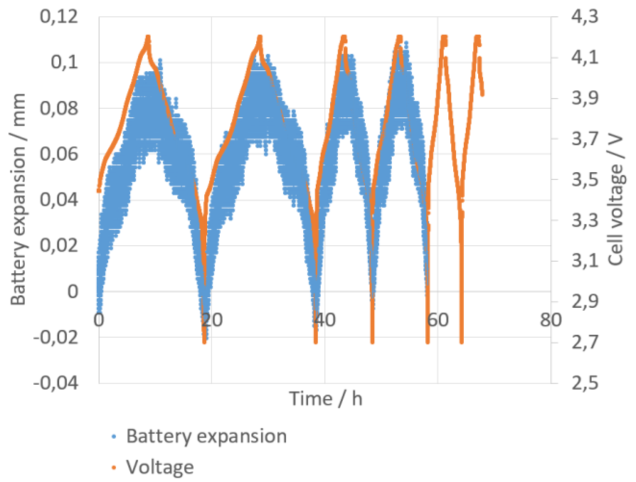

Change of Capacity during cycling (expansion of cell)

Monitoring of battery cells

The SPARTACUS project approach: µ-T-sensors to map temperature distribution

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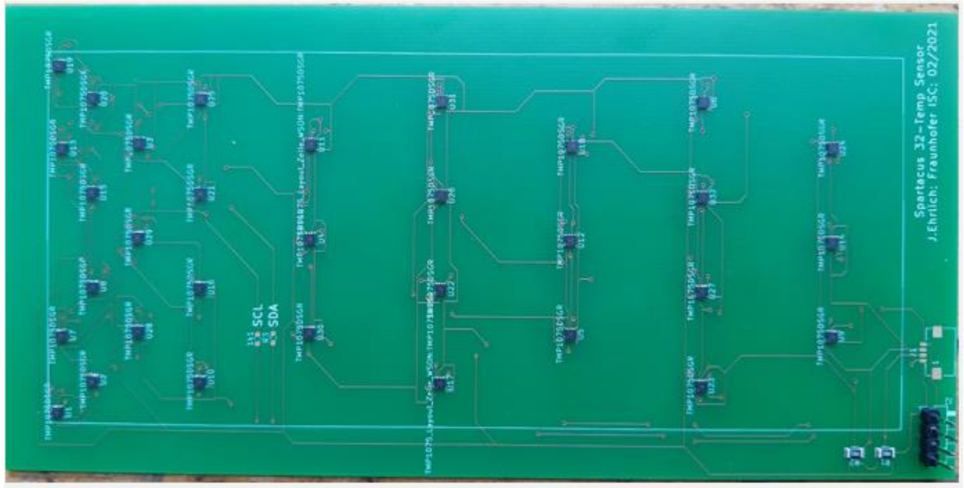
- Commercial semiconductor T-sensors
- Assembled on circuit boards integrated into the sensor environment
- Thermal VIAs in order to ensure thermal contact to the cell
- Increased density of temperature sensors close to contacts



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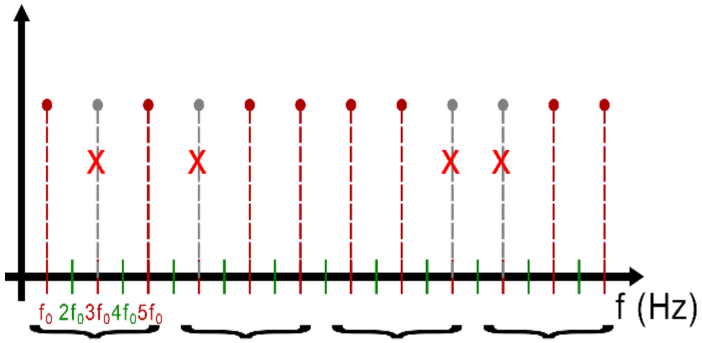
Monitoring of battery cells

The SPARTACUS project approach: ORP-EIS

- Impedance spectroscopy is a very good tool to monitor electrochemical changes within the cell but suffer by noise
- Odd Random Phase multisine Electrochemical Impedance Spectroscopy provides a faster and more reliable measurement, by analysis of the noise signal



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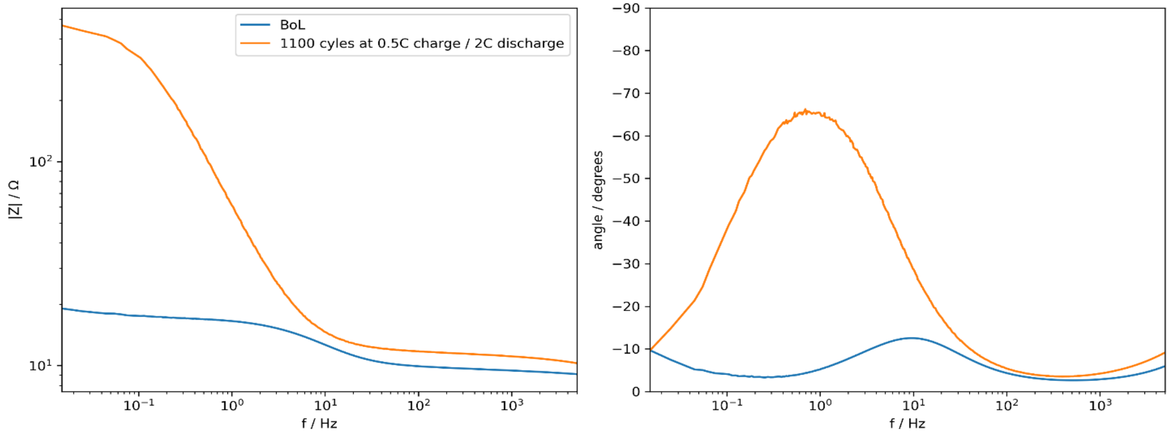

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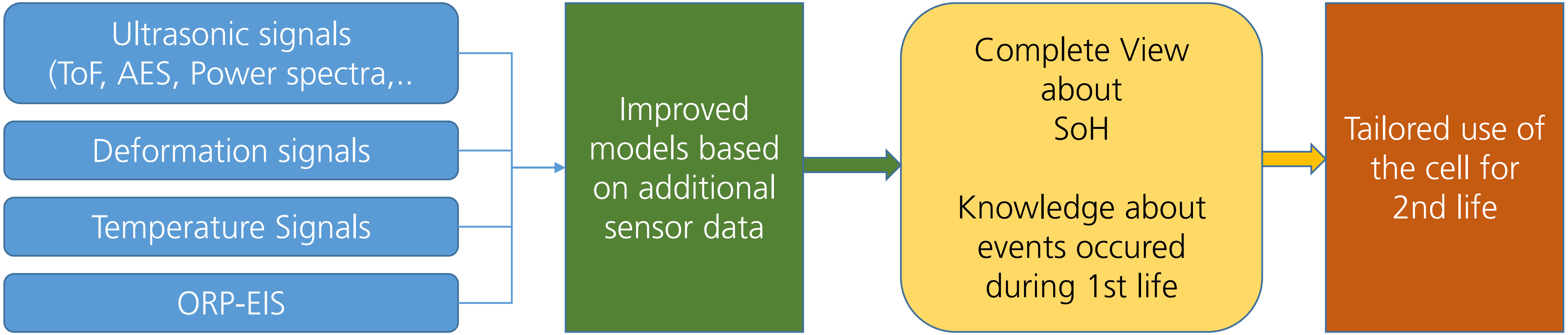
Comparison between BoL (Begin of Life) and after Cycling:
Increase of impedance on lower frequencies

Monitoring of battery cells
2nd Life

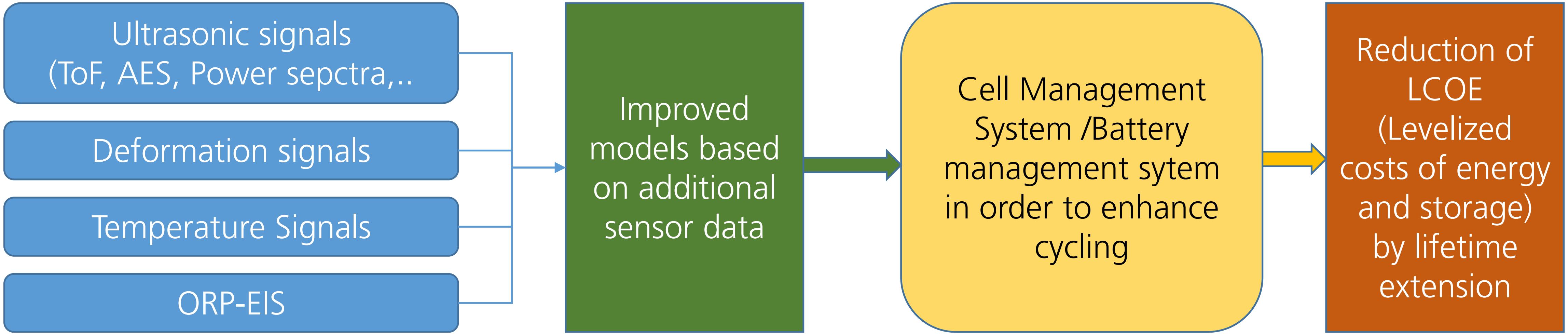
„Non-Invasive“ Sensing



Cycling and most of cell degradation can be detected

Monitoring of battery cells
1st life

„Non-Invasive“ Sensing



Improvement of the battery management for better performance, lowering the ageing mechanisms and better safety issues prevention

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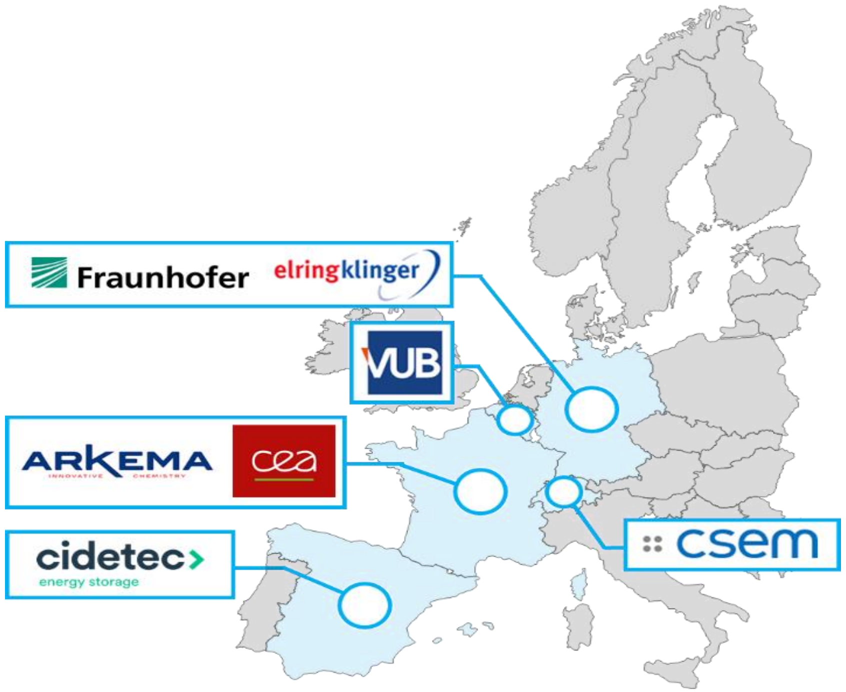
Conclusion

- 2nd life usage benefits from complete picture about the State of the battery
- Non-Invasive sensors can derive a lot of information about cycling and abnormal events
- Sensor package can be added to the battery with low costs and low form factor
- Manufacturing of sensor system is performed by „standard" assembly and packaging technologies
- The information provides insight ***after*** 1st life but also ***during*** 1st life reducing the LCOE and enhance the cycling of the cell

Acknowledgement

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957221

Thanks to the SPARTACUS consortium



THANKS FOR YOUR ATTENTION

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