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Battery Management Network for Fully Electrical Vehicles Featuring Smart Systems at Cell and Pack Level

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Outline

- I Introduction
- II Battery management
- III Project 'Smart-LIC'
- IV Summary & Conclusion

I. Introduction | Challenges

Driving Range $\uparrow$ $\Rightarrow$ Energy Density [kWh/kg] $\uparrow$

- Li-Ion Technology
- Specific Cell Chemistry ?
  - Cathode ($LiCoO_2$, $LiMn_2O_4$, $LiFePO_4$, …, Li, …)
  - Anode (Graphite, Li Alloy, Air, …)
  - Electrolyte – liquid ($LiPF_6$), solid (PVDF)
  - Separator (porous foils - org., ceramics, ...)
  - Design (round, pouch; parallel, in series, …)
- Energy/Power Density $\uparrow$ - Cost $\uparrow\uparrow$
- Energy/Power Density $\uparrow$ - Safety $\downarrow$

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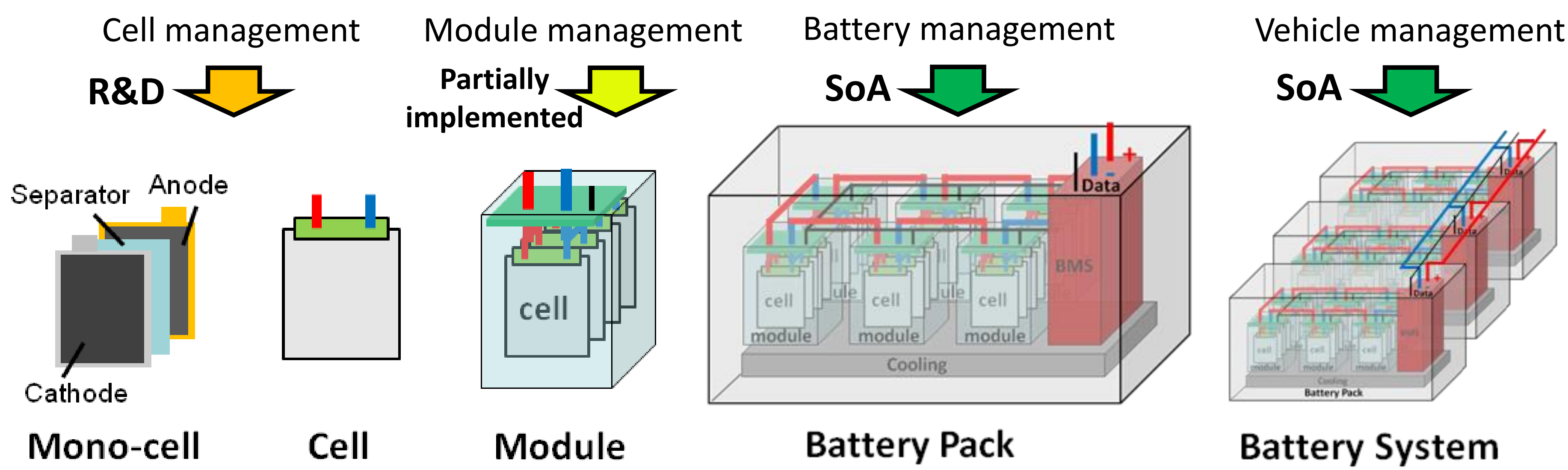
I. Introduction | Hierarchical structure of battery systems



- Basic cell chemistry
- Basic voltage level

- Stack of (e.g. 20) mono-cells connected in parallel

- Many cells in series

- Several modules, or
- Many cells
- Voltage: 400 V

- Several battery packs in parallel
- Energy: >15 kWh

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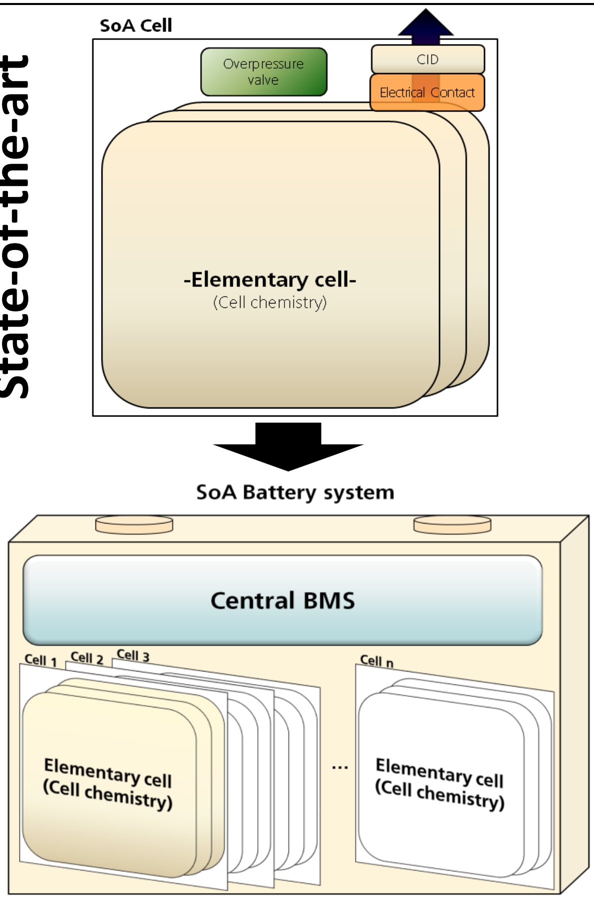
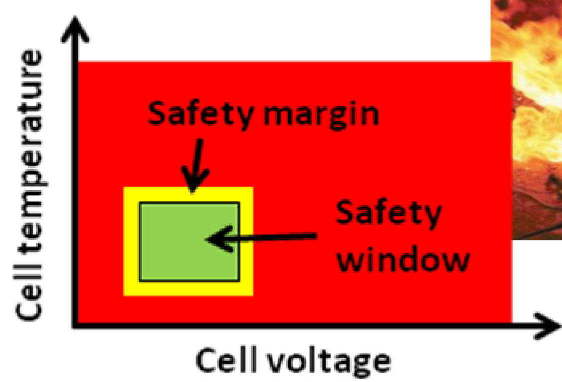
II. Battery Management | State-of-the-art

State-of-the-art



Superior tasks of the BMS:

- To assure the safety of battery and user
- To prolong the lifetime
- To keep battery in desired operating status and every time ready for use



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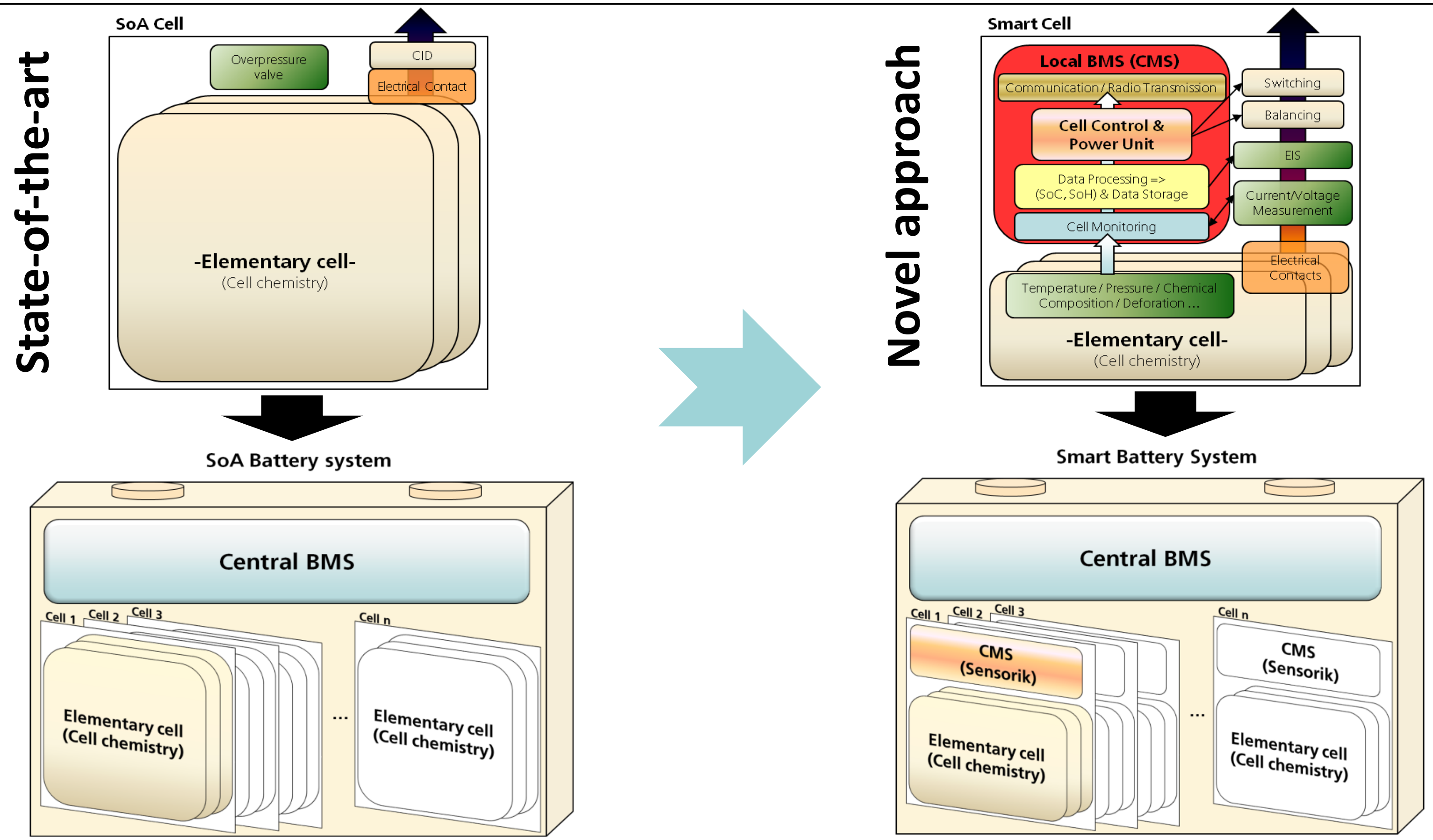
II. Battery Management | Trend to distributed intelligence



II. Battery Management | Trend to distributed intelligence

Goal: Integration of Smart Systems into every single electrochemical cell:

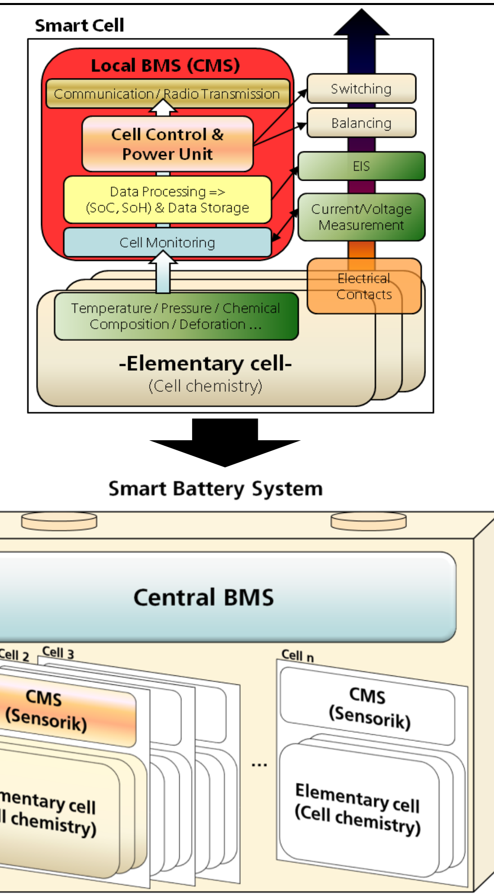
- Sensors (V, I, T, P/Def., EIS,…)
- Signal conditioning and processing
- Data storage and management
- Communication
- Balancing, actuators

Advantages to be achieved:

- Usage of Li-Ion-Battery systems with higher Energy density
- Lifetime: Battery ≥ Car
- **Consequences:**

➢ Cost-of -ownership ↓ ⇒ Customer acceptance E-Car ↑
➢ Electronic partition ↑ / Importance Reliability ↑

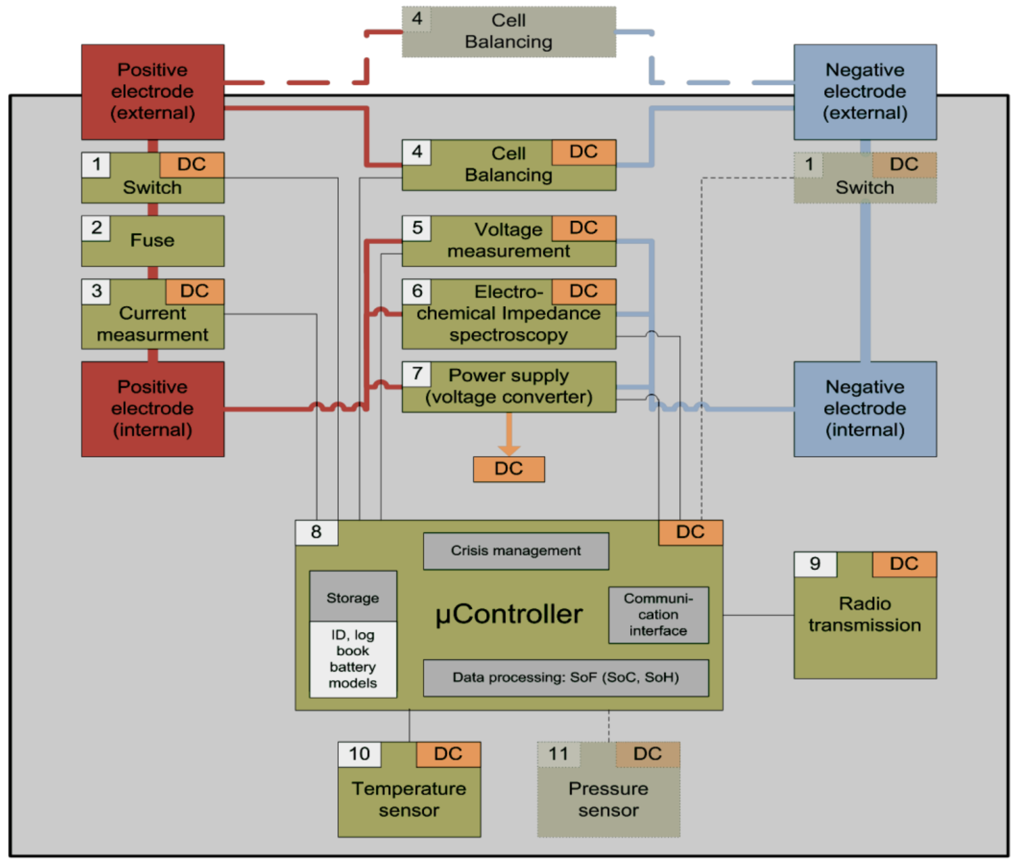
Novel approach



III. Smart-LIC | New BMS architecture

Smart-LIC Cell System:

[1] (Emergency) Switch; **[2]** Fuse
[3] Current Measurement (Shunt, Hall, MR Effect)
[4] Cell Balancing: Passiv (Switch & Bypass in the Cell) **&** Active (Capacitor / Coil next to Cell)
[5] Voltage measurement
[6] Electro-chemical Impedance Spectroscopy → SoF(SoC, SoH)
[7] Internal Power Supply (DC/DC converter)
[8] Microcontroller
[9] Tranciever to/from central BMS
[10] Temperature Sensor
[11] Pressure Sensor

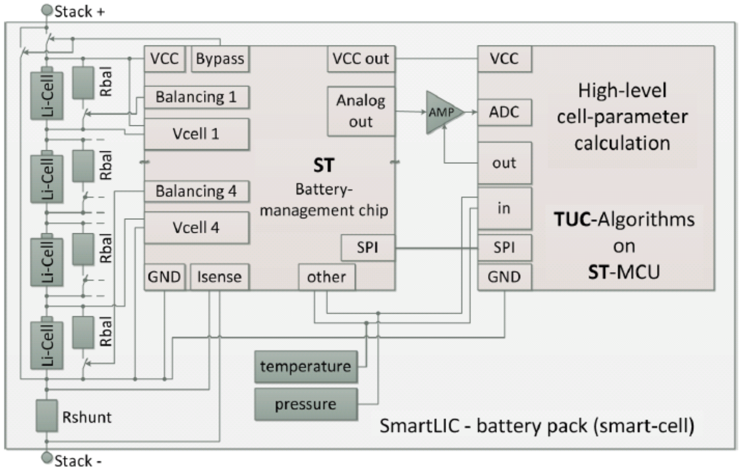


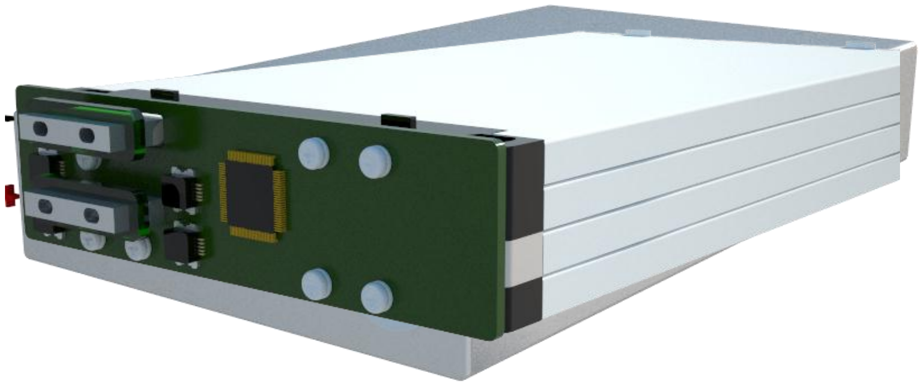
Continental ST NANOTEST CRF CENTRO RICERCHE FIAT EPoSS European Technology Platform on Smart Systems Integration
MICRO-VETT veicoli elettrici KEMET CHARGED. TECHNISCHE UNIVERSITÄT CHEMNITZ Fraunhofer ENAS

III. Smart-LIC | Intermediate step: Smart 'Macro-cell'

Smart macro-cell as 1. Generation:

- Sealed metal case with rupture disk, containing 4 cells connected in series
- Technical parameter:
  - 14,4V, 20Ah, 288Wh (based on NCM cells)
  - Maximum current: 100A (5C)
  - H=260, W=148, L=38 [mm]





⇒**Goal:**

1. Showing of feasibility of envisaged architecture for simplified interims solution
2. Additional demonstrator for benchmarking purposes

III. Smart-LIC | New EIS based battery models

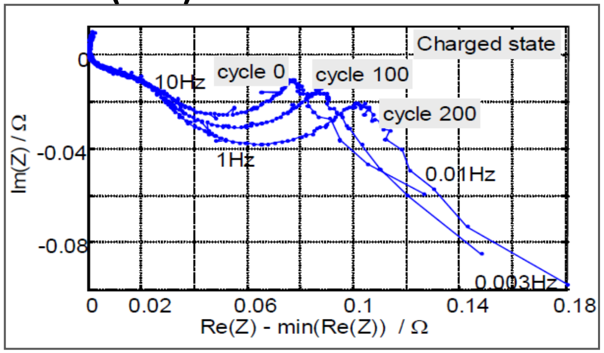
Electrochemical Impedance Spectroscopy (EIS)

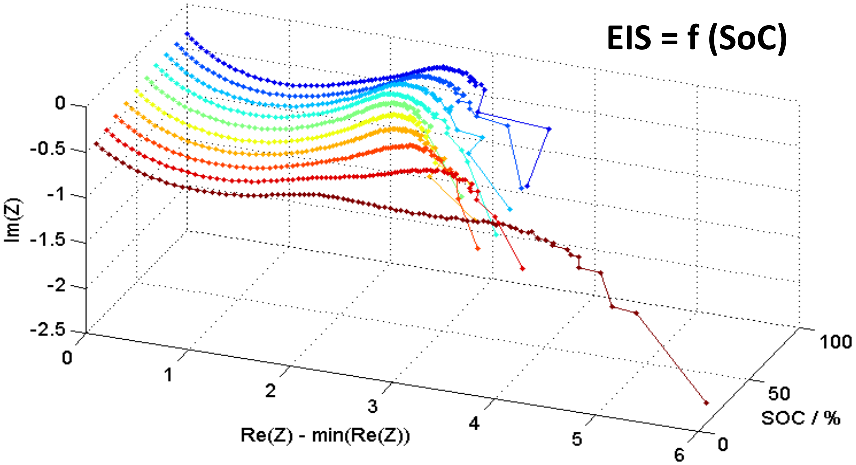
- Simultaneously extraction of cell voltage and current parameters at (macro-) cell level
- 2 different approaches under investigation:
  - U / I measurement on battery charge/discharge
  - Modulation by balance switches

⇒ Accurate information regarding actual cell status as well as of future cell behavior

⇒ Batteries always run at optimum conditions → Longer cyclic life

EIS = f (SoH):





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III. Smart-LIC | Investigation of deformation behavior

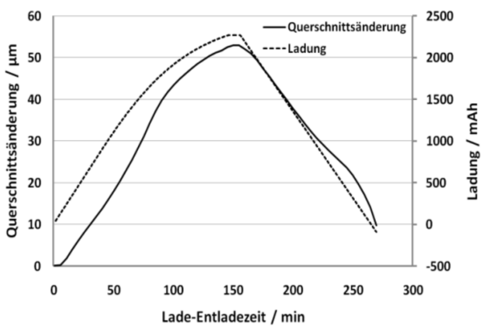
Deformation due to Intercalation

- Novel method for battery state determination (SoC, SoH -> ageing dependent outgassing)

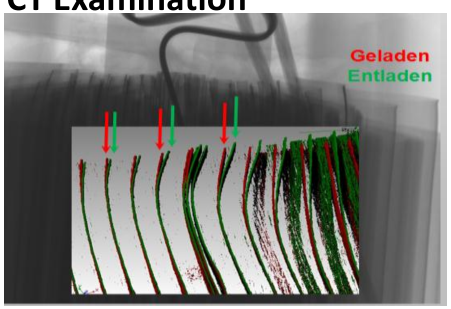
Deformation due to Safety Issues

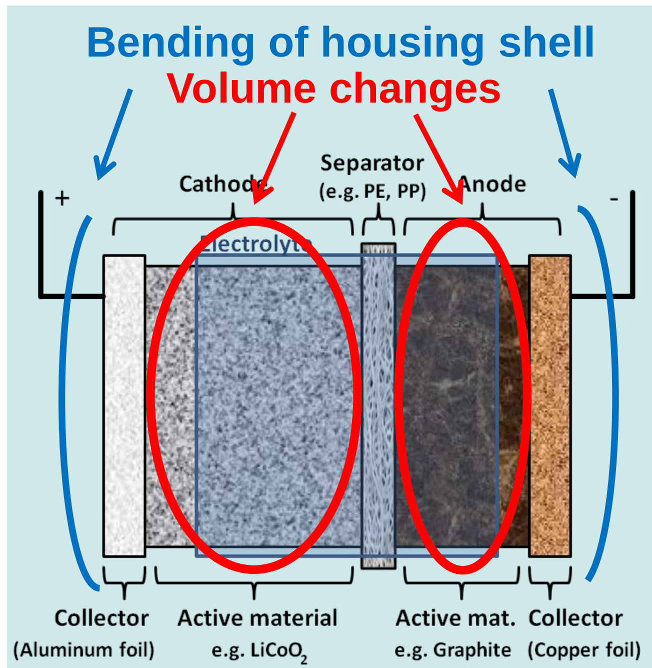
- Redundancy to temperature measure-ment, but faster in case of safety issues

microDAC© method

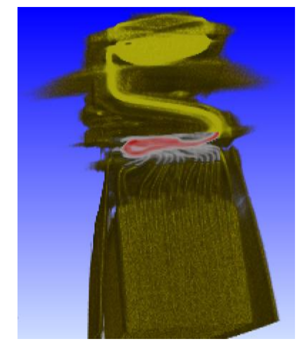


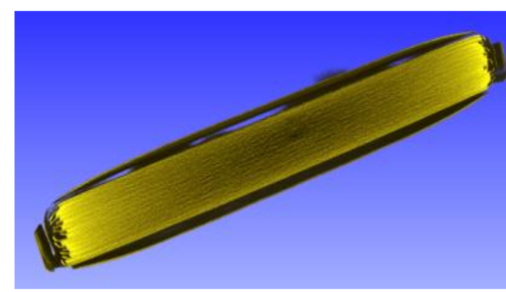
CT Examination





CT images of a bloated Li-Ion cell





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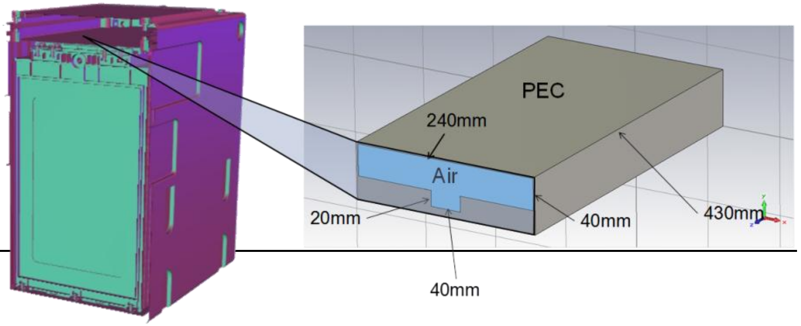
III. Smart-LIC | Communication



Wireless Communication between Cells & central BMS

= no cabling and connectors:

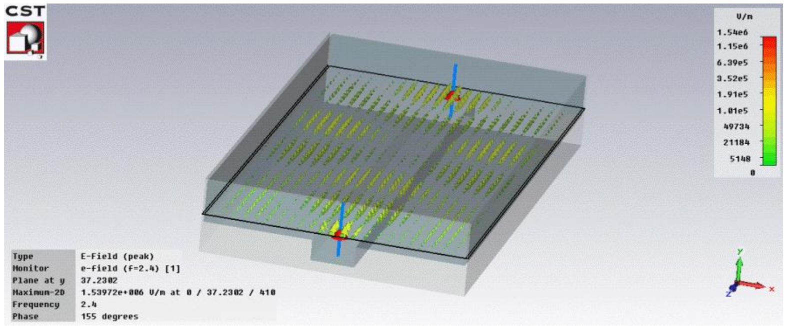
- Reduction of Cost, Volume & Mass
- Improvement of Electro-Chemical and Mechanical Reliability
- Misconnection is impossible
- Optimum & simplified Maintenance

Challenges

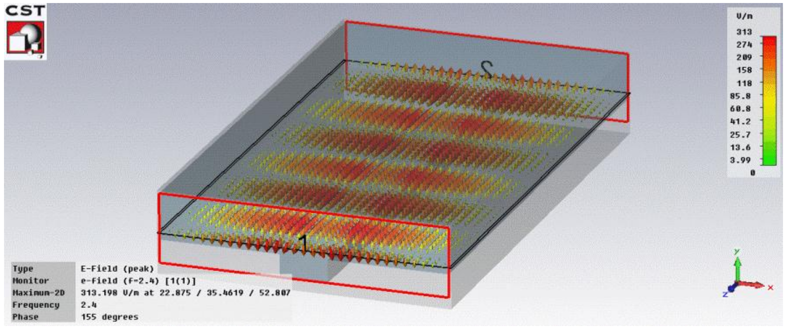
- EMC: 200 nW ↔ 200 kW (9 OoM)
- Metal Housing with Numerous Complex Paths of Interference

⇒Optimization of Communication

Cavity (All Walls metallic)



Waveguide (Wall 1 and 2 open)



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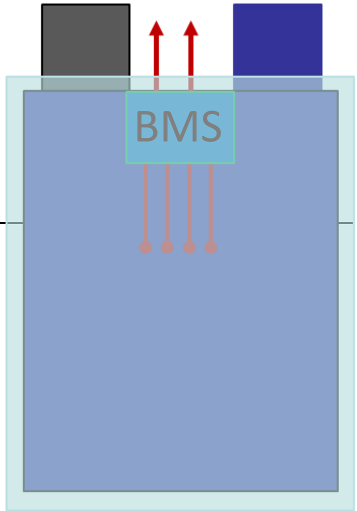
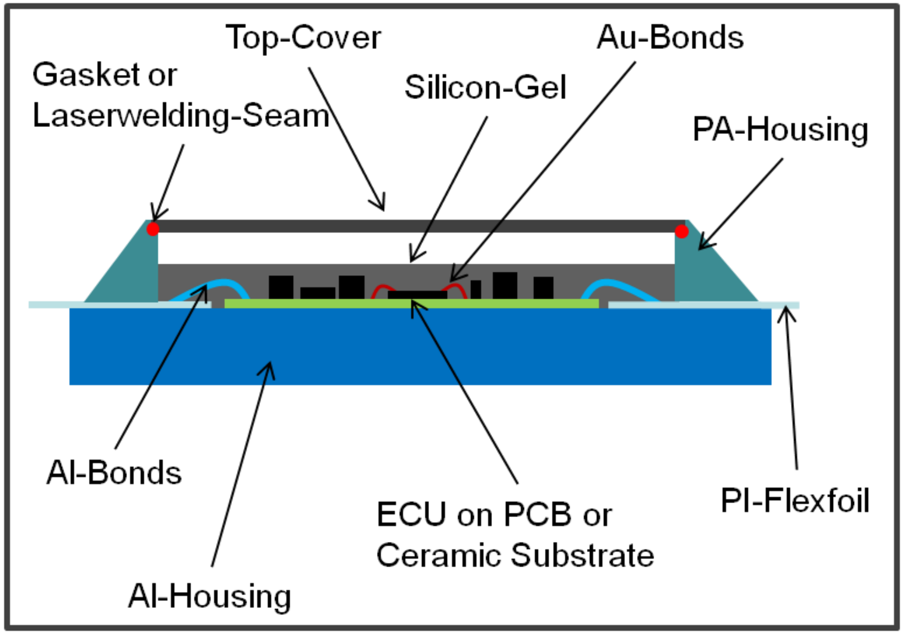
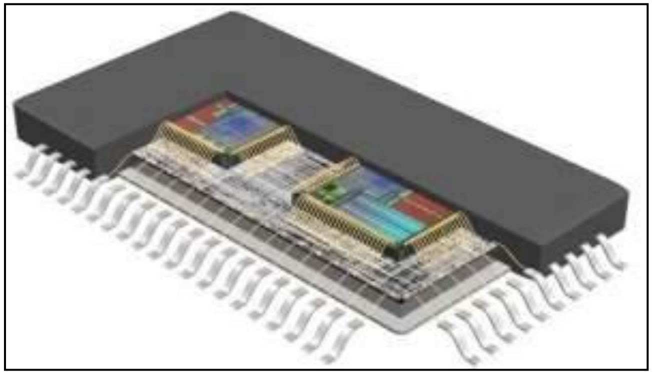
III. Smart-LIC | System integration



SoA: Complex housing with various materials and complex assembly



Novel Approach:
Moulded ECU with leadframe contacts



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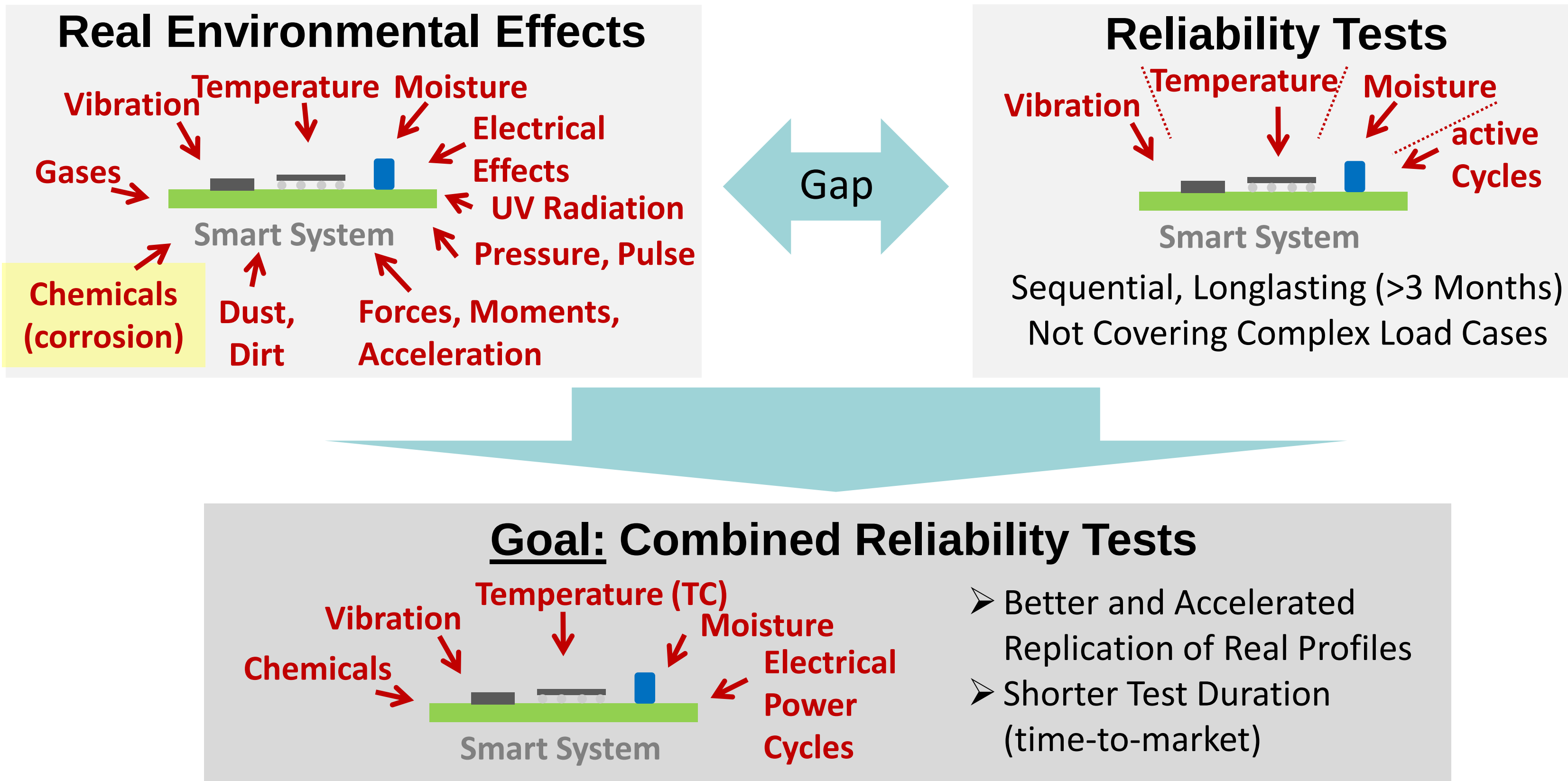
III. Smart-LIC | Reliability



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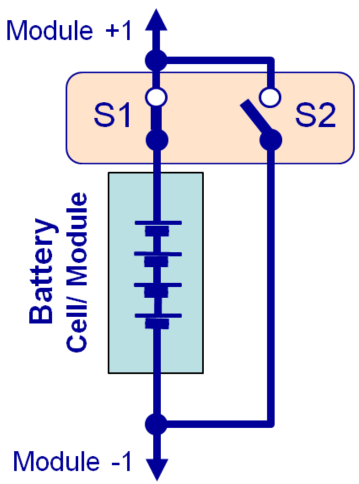
III. Smart-LIC | Safety improvements

…due to more advanced cell and battery state monitoring:

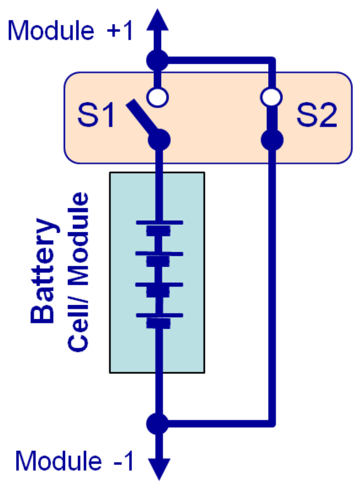
- Temperature measurement at cell level with redundant pressure sensing + EI-Spectroscopy

…due to switching-off of individual (macro-) cells in case of malfunction or accident:

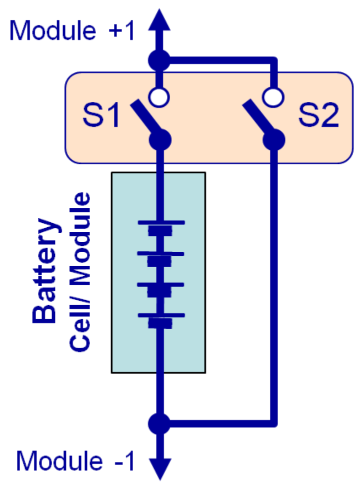
- Preventing (the spread) of a thermal runaway
- Increased safety for the rescue team by shutting down of high battery voltage



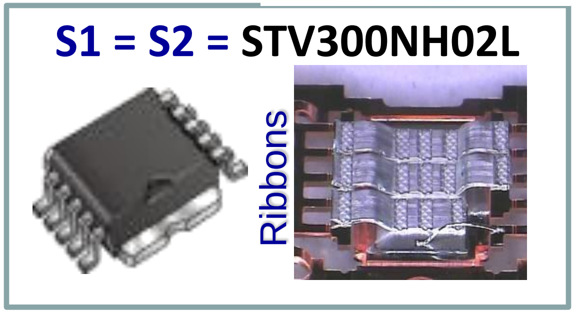
Regular Mode



Limp Home Mode



Safety Mode



$R_{DS(on)}$=0,8mΩ

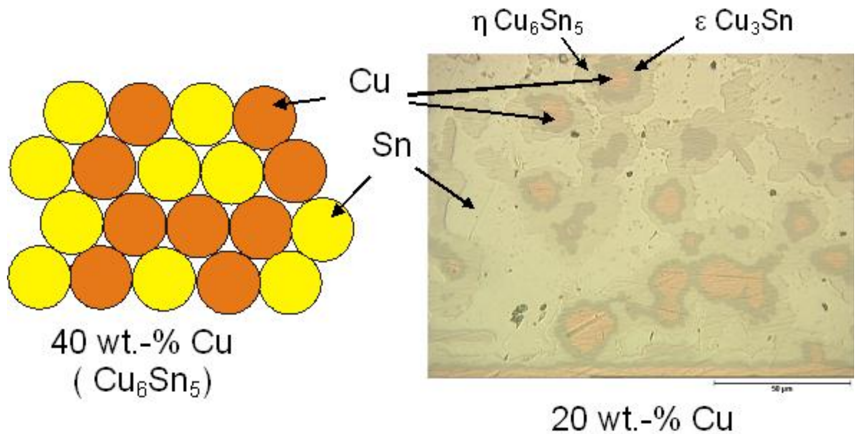
III. Smart-LIC | Safety Concept: Functional BMS when needed most

Joining technology for very high temperature applications

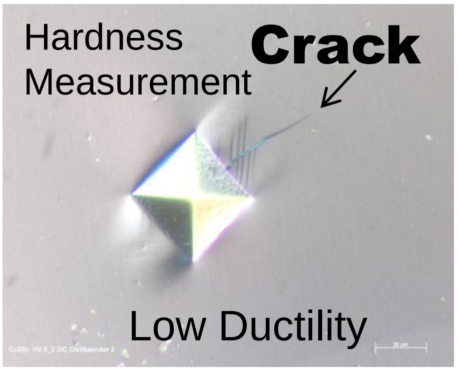
- Cell operation: -30°C … +70°C
- Malfunction Temp.: 250°C and higher
- Technology: Isothermal solidification
- Example: Cu_3Sn, Cu_6Sn_5 (>400°C)
- HotPowCon: Material systems, tools, and processes for Cu/Sn-IMP joints

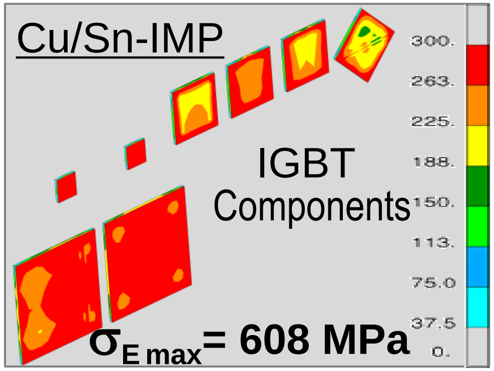
<u>Challenges</u>

- Stiffness and brittleness of IMP
- System compatibility and reliability
  → New pad and substrate design
- New tests for product qualification



Scheider-Ramelow: Tutorial 'High Temperature Packaging'; SMT-Hybrid 2010





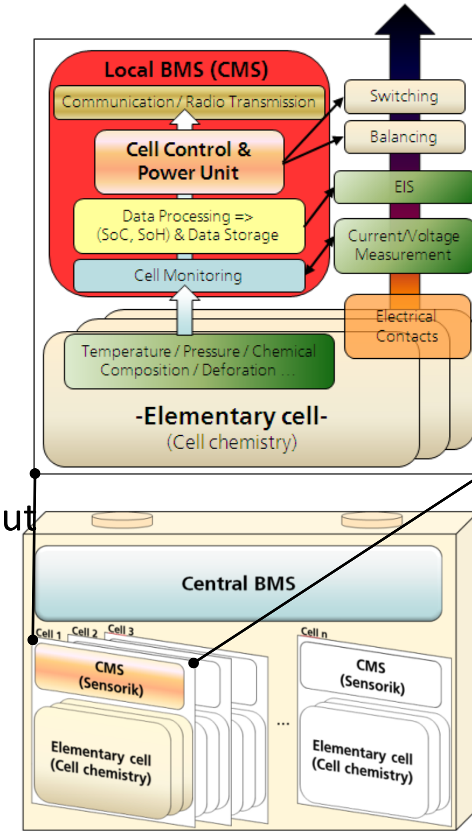
IV. Summary & Conclusion

Integration of Smart Systems into Battery Cells brings ...

- <u>Higher efficiency</u> due to **local control** at cell level
- <u>Increased precision</u> in determining SoC, SoH, and SoF due to implementation of a **new cell / battery model** based on electrochemical impedance spectroscopy (**EIS**)

- <u>Lower system complexity</u> by reduction of wiring due to **wireless communication** between cell & central BMS
- <u>Increased overall reliability</u> due to **removing major sources of failures** and detecting degradations at earliest stage
- <u>Increased safety</u> so that cells can perform at **maximum rating** without thermal risks due to redundant sensors and HT joints

- <u>Reduced repair cost</u> of the battery packs achieved by **continuous monitoring** of each cell - specific maintenance advises
- <u>Reduced cost of ownership</u> for the end user due increase in battery lifetime caused by the **smart battery management**



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