CELL-INTEGRATED SENSING FUNCTIONALITIES FOR SMART BATTERY SYSTEMS WITH IMPROVED PERFORMANCE AND SAFETY

GA 957273

D3.4 – REPORT ON PROTOTYPING 5AH CELLS WITH INTEGRATED LEVEL 1 SENSORS

LC-BAT-13-2020 - Sensing functionalities for smart battery cell chemistries

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Summary

The deliverable D3.4 "Report on prototyping 5Ah cells with integrated level 1 sensors" summarizes the activities related to the Task T3.4 of work package 3 of the SENSIBAT project.

The main objective of this task is to integrate novel level 1 sensors into 5Ah pouch cells. This also involves the evaluation of the influence of the sensors on the electrochemical behaviour of the lithium ion cells. In the previously finished Task 3.3, level 1 sensors, which were designed for the smaller sized 1Ah pouch cells were successfully integrated. The knowledge and the production parameters which were gained from various partners (VAR, ABEE) in this task were essential and built the basis to full fill the task for this deliverable. To ensure that the electrochemical performance was not altered, cells with integrated sensors were compared with so-called baseline cells without sensors.

The main challenge in this task was the sealing of the pouch cells at the area of the sensor feedthrough. Due to the bigger dimension of the 5Ah level 1 sensors matrices, which also include a higher amount of temperature and pressure sensors, the feedthrough area was wider than for the sensors used in the 1Ah pouch cells. The knowledge from the sealing process of the previous task was essential and shared with the manufacturing partner (AIT). Due to the wider feedthrough area, the previously used parameters and methods needed to be adapted in order to ensure tightness of the corresponding cell. Multiple approaches with various partners were investigated and are described in this document. Ultimately, a feasible solution which consisted of an adjustment of the used materials was found and the functionality of the 5Ah pouch cells with integrated level 1 sensors could be maintained.

Besides assuring the feasibility of manufacturing, also the electrochemical performance of the cells with integrated sensors should not be affected. To proof this, various tests have been conducted which are also part of the ongoing task 5.1 "Validation testing of cells and testing of modules". In this document some of the latest test results are shown which compare two baseline cells with two cells with integrated level 1 sensors. The data shows that there is no significant difference between the baseline cells and the cells with integrated level 1 sensors. Therefore, the electrochemical performance is not affected by the integration of the sensors, and no electrolyte leakage occurred after multiple charging and discharging cycles.

Due to the delay of previous deliverables which included the manufacturing of the level 1 sensors for 5Ah cells, the activities of this task were postponed for 4 months. After receiving the required sensors, the 5Ah cells with integrated L1 sensors were built and the functionality of the cells was ensured. The necessary steps are described in this document. The resulting delay was carefully evaluated, and it is not assumed to accumulate more delays in the SENSIBAT project.

Finally, this document also serves as a demonstration of the achievement of Milestone 4 of the SENSIBAT project "Final cells (5Ah) with integrated level 1 sensors".

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Abbreviations

Symbol / Abbreviation	
BL	*Baseline*
BMS	*Battery Management System*
HMI	*Human Machine Interface*
L1	*Level 1*
SOC	*State of Charge*

1 Introduction

After the successful implementation of level 1 (L1) sensors in 1Ah pouch cells (D3.3), the subsequent SENSIBAT aim was to conduct the integration of L1 sensing functionalities in 5 Ah pouch cells and the prototyping of these for following cell testing and battery module demonstrator assembly.

The present document “Report on prototyping 5Ah cells with integrated level 1 sensors” describes the performed work in the frame of task T3.4 to achieve the therein specified goals: The overall goal was to conduct the implementation of L1 sensor units in a certain pouch cell configuration without changing the electrochemical behaviour of the cells compared to produced baseline (BL) cells. Special attention was paid to the development of a process which guarantees a tight sensor feedthrough area. Another important factor was to consider the upscaling possibilities of such integration processes under representative industrial conditions. The comparison of electrochemical data from specified cycling tests of battery cells with and without integrated L1 sensors accomplished the report.

As provided inputs, the fabricated L1 sensor units (D3.1), material for the pouch cell assembly (D3.2), BL cells (D3.2) and the process insights of the L1 sensor implementation in 1Ah cell configuration (D3.3) was indispensable to fulfil the requirements and to achieve the task objectives.

2 Cell Configuration and Layout

To demonstrate that the implementation of temperature and pressure sensing units does not influence the electrochemical performance of the battery cells, BL cells were used for comparison. The same materials and cell configuration were used to produce both, the BL and the L1 cells, to ensure the best possible comparability of the test results obtained. To achieve the aims within this deliverable, but also to deliver final pouch cells with integrated sensor units for the subsequent module assembly (WP4), a certain pouch cell configuration with 29 electrode layers (15 anodes and 14 cathodes, both with double sided coatings) was used to reach a cell capacity of 5Ah. Detailed information about the cell configuration, the applied materials for the anodes and cathodes, as well as additional used goods for the cell production, can be found in D3.2 "Report on prototyping baseline pouch battery cells".

In contrast to the manufacturing of the 1Ah pouch cells, only one project partner (AIT) was commissioned to produce the 5Ah battery cells. Accordingly, the same production machinery equipment was used to fabricate both the BL cells and the L1 5Ah pouch cells with integrated sensor units, leading to similar production conditions. All information related to the manufacturing and testing schedule within the SENSIBAT project is presented in D1.2 "Testing plan for cells and modules".

The difference between the BL and the L1 pouch cells in terms of applied components for the production is the usage of L1 sensor elements, as developed by FHG, and additional melting tape to ensure a tight sealing result for the L1 pouch cells. A detailed description of the sealing process is given in the following section.

All necessary insights about the sensor development are evident in D3.1 "Report adaptation of level 1 sensors". Additional information regarding the sensor encapsulation adaptation to realize a stable sensor system against the aggressive environment within the cell, mainly caused by the electrolyte, can be found in D3.3 "Report on prototyping 1Ah cells with integrated level 1 sensors". The key learnings gained from the above-mentioned tasks/deliverables were transferred and used for the work performed in the frame of T3.4, prototyping L1 5Ah pouch cells.

Figure 1: SENSIBAT Final L1 5Ah pouch cell with integrated sensor unit

3 Sensor Integration

Since a proper sensor integration is mandatory to achieve the goal within T3.4 and for the fabrication and assembly of the battery packs, certain measures were undertaken. In the following section detailed information regarding the sensor integration is given. The basis to achieve the goal of this task was the cell configuration (same as for the BL cells), the sensor units developed and fabricated by FHG and the key learnings from D3.1 and D3.3.

3.1 Sensor Layout

The 5Ah L1 sensor foils are equipped with matrices of 35 pressure and 35 temperature sensors arranged in a 5 x 7 matrix to ensure a high spatial resolution. The number of wires used for data transfer towards the data processing read out circuit increased to 49, compared to the 20 wires of the 1Ah cell sensor unit. Therefore, the width of the feedthrough sensor part for the pouch cell sealing had to be adjusted to fit the number of wires. This resulted in a feedthrough area with a width of approximately 25 mm.

To ensure a more precise read-out of the sensor values, the electrical resistance of the temperature sensors and the capacitance of the pressure sensors have been increased by extending the length of the meanders and the area of the capacitances, respectively. Furthermore, efforts were made to reduce the number of crossings within the wiring and hence reduce the parasitic capacitances.

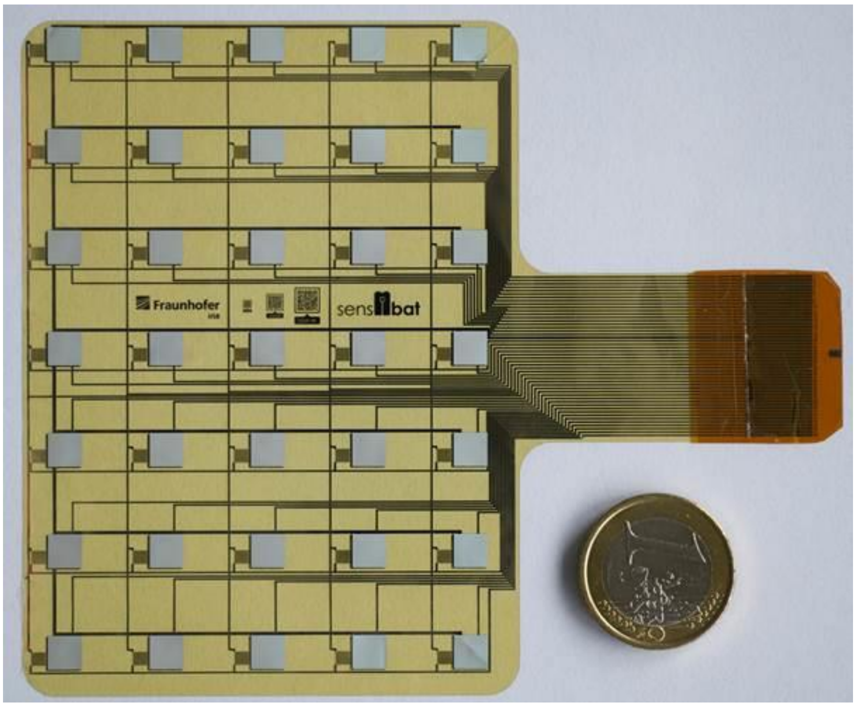

Figure 2: SENSIBAT L1 sensor unit for 5Ah pouch cells

3.2 Sensor Positioning

The feedthrough area of the 1Ah pouch cells was designed between the positive and negative electrode tabs of the cell. The main reason for this particular feedthrough design of the L1 1Ah pouch cells was to use the process step of sealing the two tabs also for the sensor sealing to keep the other sealing edges of the cell unmodified.

Due to the adjustment of the feedthrough width to 25 mm the gap between the two pouch cell electrode tabs was not big enough to position the feedthrough of the sensor matrix in between of the positive and the negative tab. In close consultation with the responsible partner (FHG), a suitable solution for the sensor position was found. The width of the sensor feedthrough could not be adapted as this would have reduced the number of wires which would have resulted in a reduced data resolution and was therefore not an appropriate solution. Additionally, the selection of possible sealing positions at the other sides of the cell was limited since filling and degassing after formation must also be ensured with an integrated sensor. The partners involved agreed on the position of the sensor sealing at the long edge opposite to the filling and degassing area of the cell. This solution enables the usage of the present sensor units with the wider (25mm) feedthrough to ensure a high spatial temperature and pressure data resolution without changing the layout of the battery cell stack. Special care requires the design, the execution, and the proof of the additional, sealing area. Each sealing area represents a weak spot for cell leakage, which must be avoided not only for safety reasons but also because of the electrolytes' sensitivity to humidity. Finally, as for 1 Ah cells, the sensor unit will be placed on top of the cell stack as seen in Figure 3.

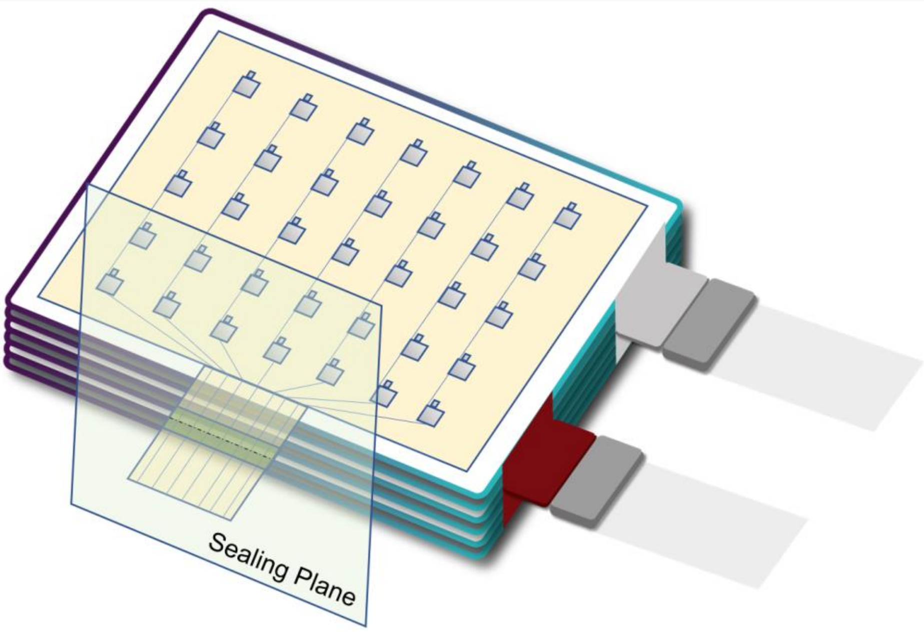

Figure 3: Schematic drawing of 5 Ah pouch cell stack with positioned L1 sensor

4 Sealing Process Investigation

The sealing area represents a weak spot for electrolyte leakage, for this reason a proper sealing process investigation was conducted:

- Initial sealing trials with the proposed process parameters and materials
- Sealing trials with additional melting polymer
- Sealing trials with roughened dummy elements
- Sealing trials conducted at VAR by using materials supplied by AIT

All sealing trials carried out led to unsatisfactory results.

Figure 4 shows the arrangement of the pouch foil sheet, the additional melting polymer and the dummy element used for the initial sealing trials (left) and the leaking pouch bag with integrated dummy element (right).

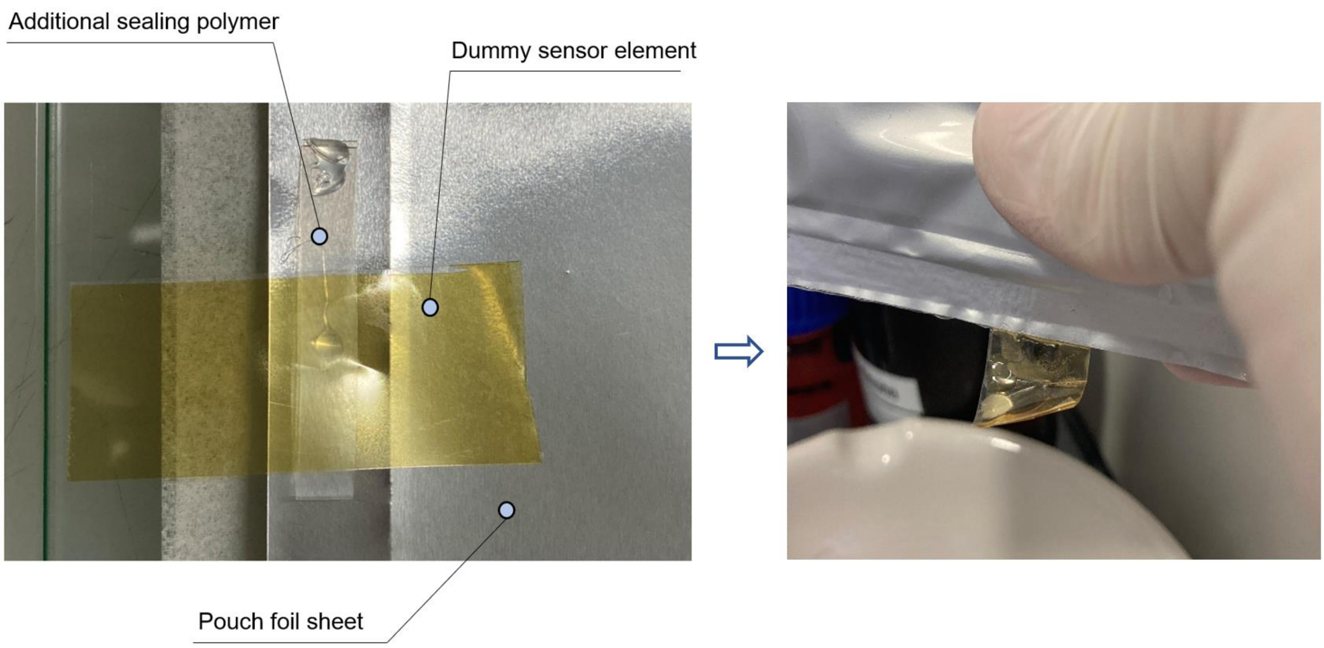

Figure 4: Sealing trial for L1 sensor integration with additional melting polymer and dummy sensor element (left) and leaking pouch bag with integrated level 1 dummy element (right)

After a detailed fault investigation, it was suspected that the material combination of the specific sealing polymer, the inner pouch foil layer and the Parylene C encapsulation of the sensor should be adapted. However, in this used configuration, the polymer melted and subsequently solidified by the sealing process did not adhere appropriately to the dummy sensor element.

Further investigations at AIT with different material combinations to realize the sensor integration at AIT laboratories were conducted. A melting polymer provided by POL was used to produce further pouch bags. Final L1 sensors supplied by FHG were installed to meet the conditions of the final level 1 pouch cell layout as closely as possible. Figure 5 shows the integration of final L1 sensor units by using the obtained special melting tape for pouch cell prototype applications.

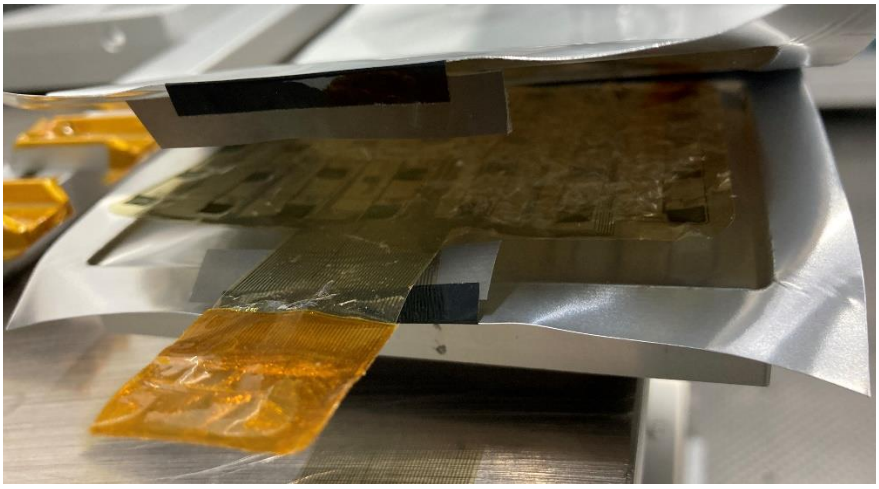

Figure 5: Pouch bag layout with integrated L1 sensor and substitutional melting tape

Two pouch bags with the above-mentioned layout were produced and tested in a vacuum chamber. The result showed that using the special melting tape for pouch cell prototype applications resulted in a satisfactory sealing area. With these findings, the investigation was finished and the production of the final L1 pouch cells could be continued. Figure 6 shows the final electrolyte filled pouch bag with integrated L1 sensor element after a vacuum test.

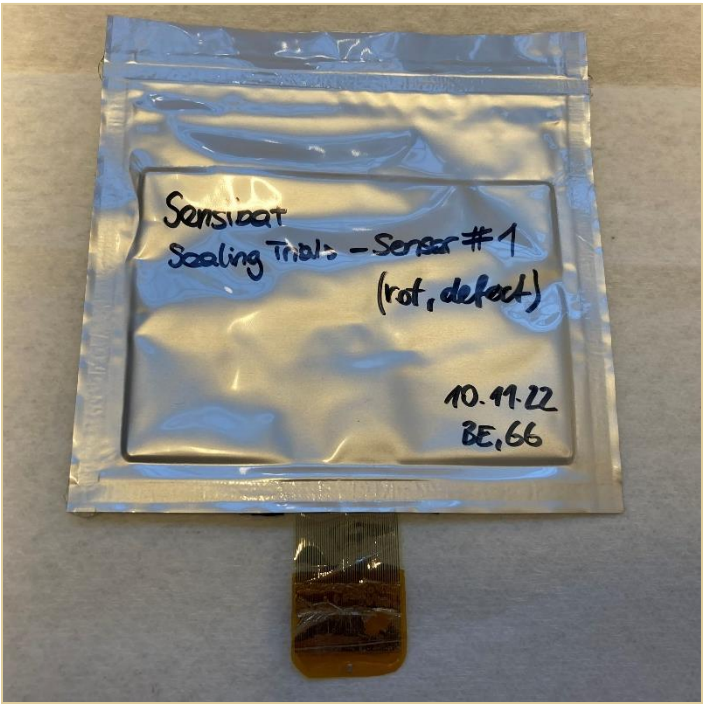

Figure 6: Electrolyte filled pouch bag with integrated L1 sensor element

5 Cell Production with L1 sensors

Since a suitable sealing method fulfilling all requirements was elaborated, the final L1-5Ah pouch cells were produced. The main aim was to ensure sufficient integration without changing the electrochemical behaviour of these cells compared to the BL cells. The following section describes the production processes, the influence of the additional integration step on the assembling process chain on a laboratory-scale and the electrochemical comparison between the BL and L1 5Ah pouch cells.

5.1 Pouch Cell Assembly process

Detailed information regarding the production of the BL 5Ah pouch cells is given in D3.2 "Report on prototyping baseline pouch battery cells". Since a high reproducibility between the BL and L1 cells is aimed, the same production steps and machinery have been applied for both cell types. Figure 7 shows a schematic illustration of the applied processes for the pouch cell production.

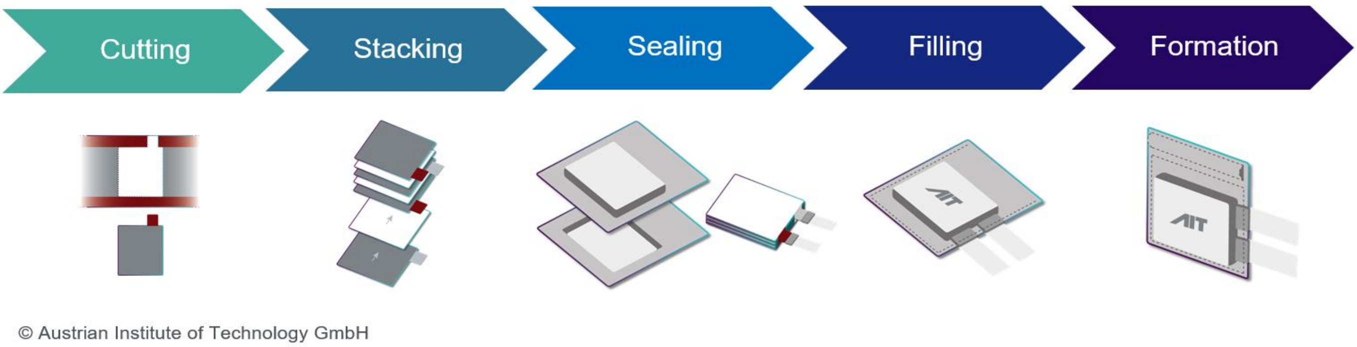

Figure 7: Schematic illustration of the applied processes for the pouch cell production

Figure 8 shows the top view of a pouch cell during the integration process (left) and two fabricated final L1 5Ah cells as well as two BL 5Ah pouch cells (right) together with two cells without integrated sensors for comparison. The obtained data of these four cells was used to assess the influence of the implemented L1 sensors on the electrochemical cell performance.

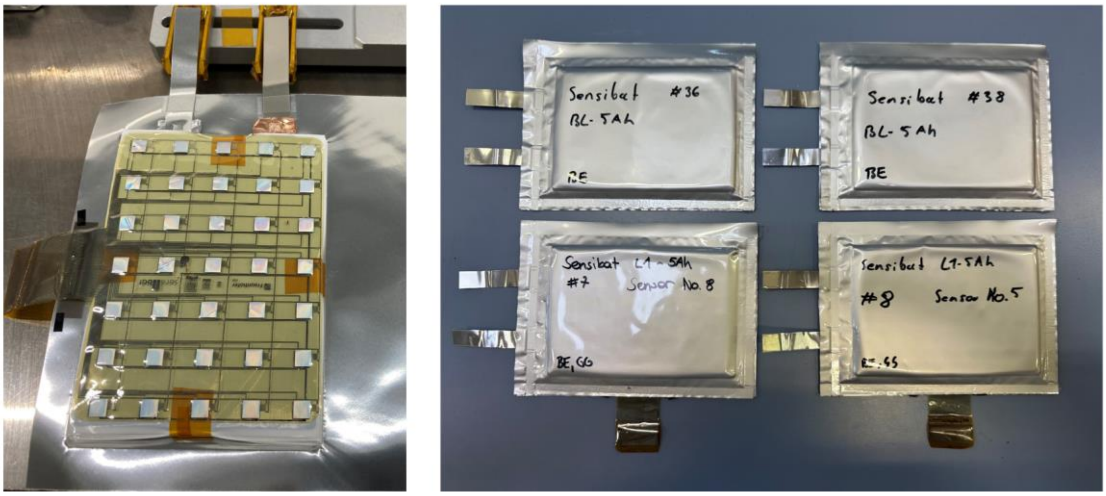

Figure 8: Integration process of L1 sensor element (left), finished BL and L1 5Ah pouch cells after degassing for electrochemical testing (right)

5.2 Production Impact of Sensor Integration

The integration of L1 sensors causes an additional production effort, compared to the conventional assembly of BL 5Ah cells. The resulting additional expense arises in the manual implementation of the sensors due to manual preparatory work on the sensors, on the additionally used Kapton tape for positioning and on the sealing tape, as well as due to an adapted sealing process.

It was also checked if the provided dummy foil from FHG can be placed on the cell stack using an automatic positioning unit. Figure 9 shows that the mechanical behaviour of the material allows the use of the placing units of the single sheet stacker.

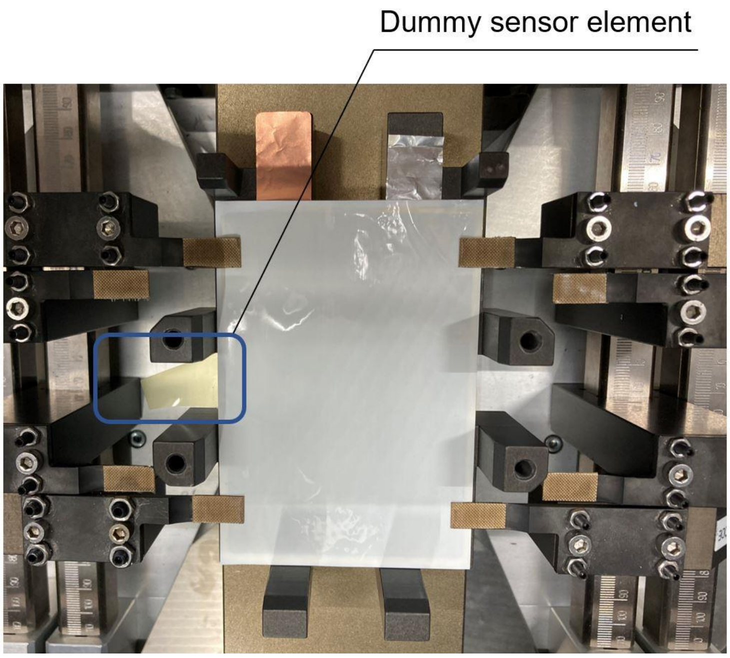

Figure 9: Top view of a cell stack with integrated dummy sensor element by using an automatic stacking unit

Following steps would be necessary to properly establish and conduct the sensor integration with an automatic stacking unit:

- Installation of an additional, separated storage for the sensor elements (analogous to the existing storages for anodes and cathodes).
- Additional gripping and positioning actuators (analogous to the existing actuators for anodes and cathodes).
- Adaptation of the system control software.
- Adaptation of the human machine interface (HMI) for process control.
- Mechanical layout adaptation of the stack holders for the sensor feedthrough space and subsequent fixation via Kapton tape.

With the mentioned steps the additional effort for sensor integration could be reduced dramatically. These points would also apply for up-scaled production lines.

5.3 Electrochemical Testing and Results

To determine the influence of the integrated sensors on the electrochemical behaviour of the cells, various tests have been defined in D1.2 which are part of T5.1. In order to show that the integration of L1 5Ah cells do not influence the electrochemical behaviour of the cells, some of the preliminary test results of this task are presented in this chapter. These first results were obtained from two 5Ah BL cells and two 5Ah cells with integrated L1 sensors. In Figure 10, the potential values and the applied current during cycling of the above mentioned four different cells are shown. The testing program, as defined in D1.2, is called "performance test". As it can be seen in Figure 10 the influence of the sensor is insignificant and cannot be definitely correlated to the sensor integration.

The discharge capacities of the same cells are shown in Figure 11. This visualizes as well that there is no significant difference between the BL cells and the cells with integrated L1 sensors. The small offset between the capacity values of the different cells is correlated to the semi-automatic, pilot scale cell production.

To analyse a possible influence of the sensor matrices in T5.1, various electrochemical tests will be performed. One of these tests aims to determine the discharge and charge power of the cells. For this a specific procedure a (dis)charge pulse (constant current) with a duration of 10 seconds was applied using three different C-rates and three different levels of state of charge (SOC). The calculated power is shown for the two BL cells and two cells with integrated L1 sensors in Figure 12. The maximum difference between these values of the four different cells at the same SOC and same C-rate is 0.22%. This indicates that the integration of the L1 sensor matrices has not a significant influence on the electrochemical performance of the cells.

All the above-mentioned tests indicate that there are no major deviations between the BL cells and the cells with integrated L1 sensors. The deviations that are visible are neglectable and related to the prototype nature of the built cells. The implementation of L1 sensors was performed successfully, as for the first preliminary results no significant changes in the electrochemical behaviour was measured, and no electrolyte leakage occurred. The small deviations are subject of further investigations to manifest the statement.

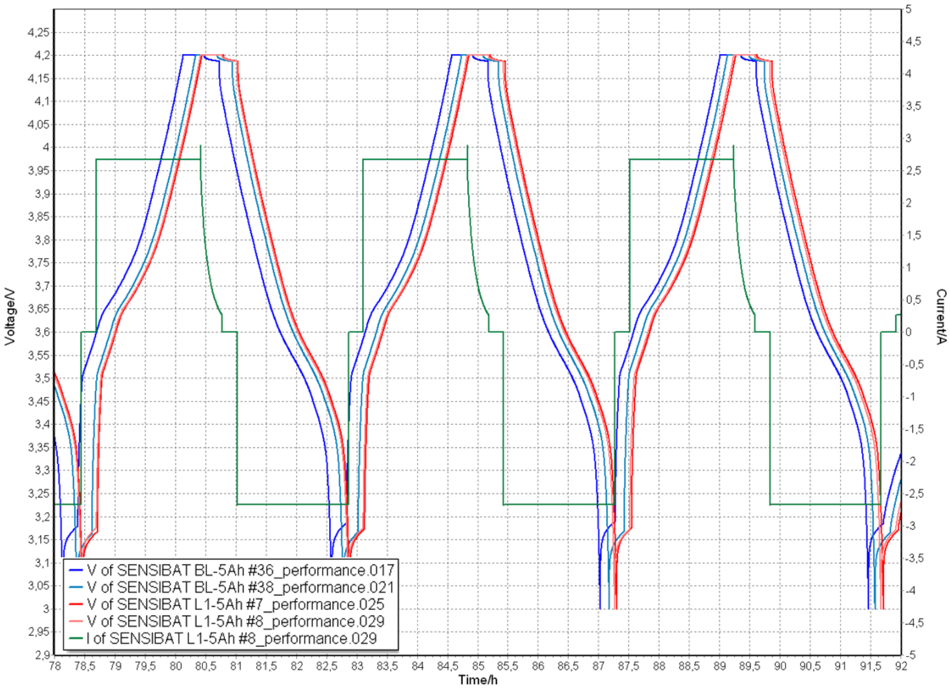

Figure 10: Cell voltage and current over time by applying the performance test on two L1 sensor cells and two BL cells after around 80 hours.

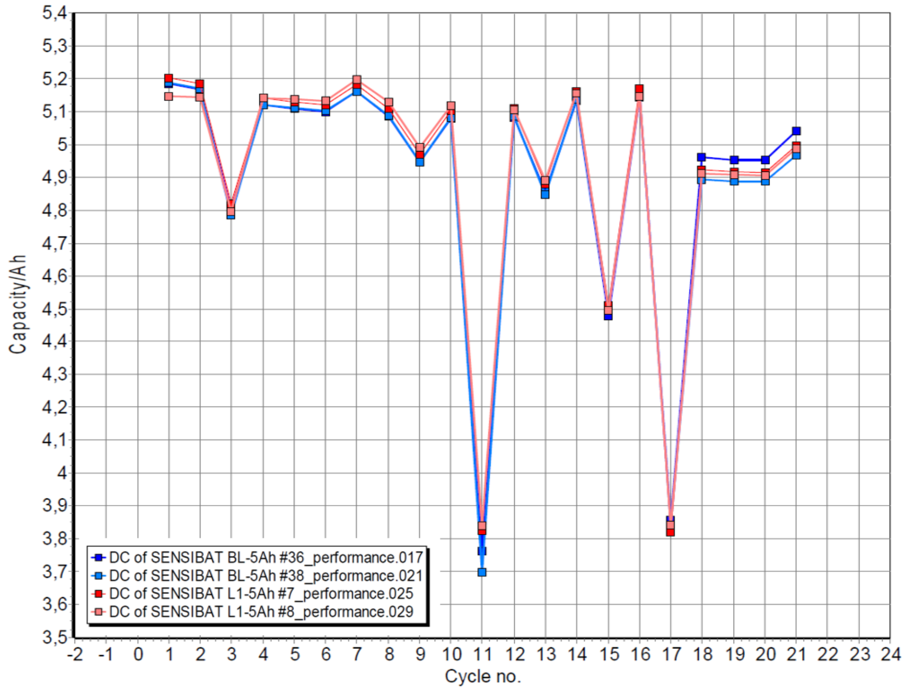

Figure 11: Capacity over cycles of the applied performance test on two L1 sensor cells and two BL cells.

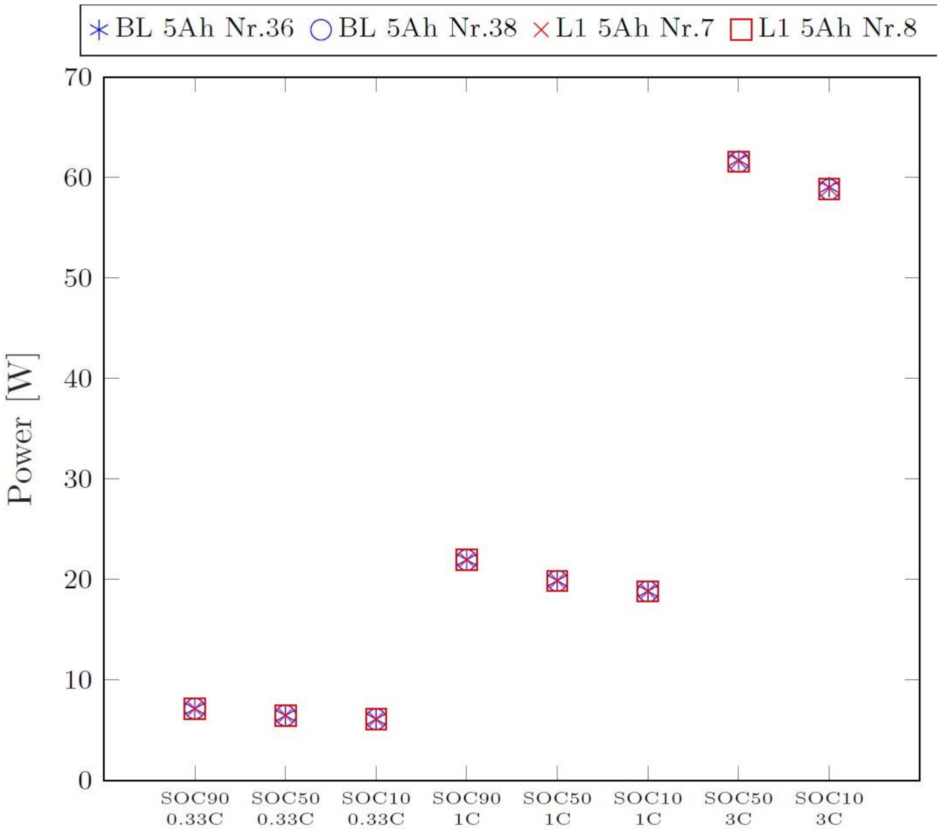

Figure 12: Power during charging of two BL cells and two L1 sensor cells at three different SOC levels for three different C-rates.

6 Discussion & Conclusion

This document describes the work conducted in the frame of task T3.4 to achieve the goals mentioned in the annex 1 of the grant agreement document, which required the prototyping of 5 Ah pouch cells with integrated L1 sensor units. The insights gained from tasks T3.2 and T3.3 were transferred and used to develop a suitable process to conduct the integration of the sensor elements on a 5 Ah pouch cell level.

To determine the influence of the L1 sensor integration on the electrochemical performance, cycling data of final L1 5Ah and BL 5 Ah cells were compared. The performance test containing full cycles at different C-rates and several pulse sections was applied for both cell systems, and the results presented in this document show that the absolute deviation of the obtained discharge capacities is <1 %. The assembly of the required pouch cells with integrated L1 sensors will be continued and the cells will be sent to project partners to generate additional test data for the state algorithm development and fabricate the final demonstrator battery packs.

The feedthrough area of the cell system was adapted, and a material combination was developed to ensure a tight sealing area. Detailed information about the sealing area layout adaptation and the conducted vacuum tests are described in the present deliverable. Nevertheless, the feedthrough part of the cells must always be considered a weak spot of the cell, which increases the risk of potential electrolyte leakages. Since prototype cells are used and fabricated within the scope of this project for research purposes, it should be mentioned that additional adaption work regarding the used materials, the integrated sensor elements and the applied processes are required for large-volume manufacturing of such sensor-integrated pouch cells.

Due to the delayed submission of deliverables which are directly linked to T3.4, the deadline for this document was postponed by 4 months to M28.

7 Risks

Risk No.	What is the risk	Probability of risk occurrence[1]	Effect of risk[2]	Solutions to overcome the risk
1	Sensors cannot withstand adverse environment in battery cell (e.g., may react with electrolyte to produce by-products) and lose sensitivity	3	1	The probability of R1 seems to be reduced by successful embedding of the Sensors observed by encapsulated sensor dummies. This has been proved in this deliverable and D3.3
2	Feedthrough of measurement contacts from the inside to the outside of the cell without leakage is not possible	3	1	Risk was successfully minimized from cell manufacturing point of view also shown in D3.3 Priority can be considered "low". This will be monitored during ageing studies.
3	Incompatibility of the sensors with the pouch cell assembly process	2	3	Sealing process investigations led to satisfactory sealing results
4	Integration of sensors without changing the electrochemical behaviour of the battery cell (e.g the transport or transfer of lithium ions between anode and cathode electrodes) is not possible	2	1	Obtained and analysed performance test data show that there is no influence of the implementation on the cell performance
9	Integration effort of the sensors higher than expected	2	1	Risk has been minimized

[1] Probability risk will occur: 1 = high, 2 = medium, 3 = Low

[2] Effect when risk occurs: 1 = high, 2 = medium, 3 = Low

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Project partners

#	PARTICIPANT SHORT NAME	PARTNER ORGANISATION NAME	COUNTRY
1	IKE	IKERLAN S. COOP.	Spain
2	BDM	BEDIMENSIONAL SPA	Italy
3	POL	POLITECNICO DI TORINO	Italy
4	FHG	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.	Germany
5	FM	FLANDERS MAKE VZW	Belgium
6	TUE	TECHNISCHE UNIVERSITEIT EINDHOVEN	The Netherlands
7	NXP NL	NXP SEMICONDUCTORS NETHERLANDS BV	The Netherlands
8	NXP FR	NXP SEMICONDUCTORS FRANCE SAS	France
9	ABEE	AVESTA BATTERY & ENERGY ENGINEERING	Belgium
10	VAR	VARTA MICRO INNOVATION GMBH	Germany
11	AIT	AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH	Austria
12	UNR	UNIRESEARCH BV	The Netherlands

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