HighSpin project overview

HighBattEU cluster webinar

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14.04.2026

High-Voltage Spinel LNMO Silicon-Graphite Cells and Modules for Automotive and Aeronautic Transport Applications

This project receives funding from the European Union's Horizon Europe research and innovation programme under grant agreement no. 101069508 (HighSpin).

Project & consortium

Project start: Sep 2022

Project end: Aug 2026

Duration: 48 months

Funding: € 7.99m

Topic: HORIZON-CL5-2021-D2-01-02 - Advanced high-performance **Generation 3b** (high capacity / high voltage) Li-ion batteries supporting electro mobility and other applications (Batteries Partnership)

Industrial partners	TOPSOE, talga, ARKEMA, COATEX, saft
RTOs	AIT Austrian Institute of Technology, CIC energiGUNE, KIT Karlsruher Institut für Technologie, Jülich Forschungszentrum, cea
SME	LEAD TECH supporto logistico integrato, sensichips
End users	PIPISTREL

Project objectives and targets

HIGHSPIN

"Strengthen European battery industry by delivering next-gen battery cells for automotive and aviation applications"

Further develop the LNMO|Si/C cell chemistry compared to the reference 3beLiEVe baseline, extracting its maximum performance
Materials: microstructure optimizsation | high-voltage electrolyte
Processes: bilayer coating | laser structuring

Cell:
- 390 Wh/kg
- 925 Wh/l
- 790 W/kg
- 1850W/l @2C
- 2000 deep cycles

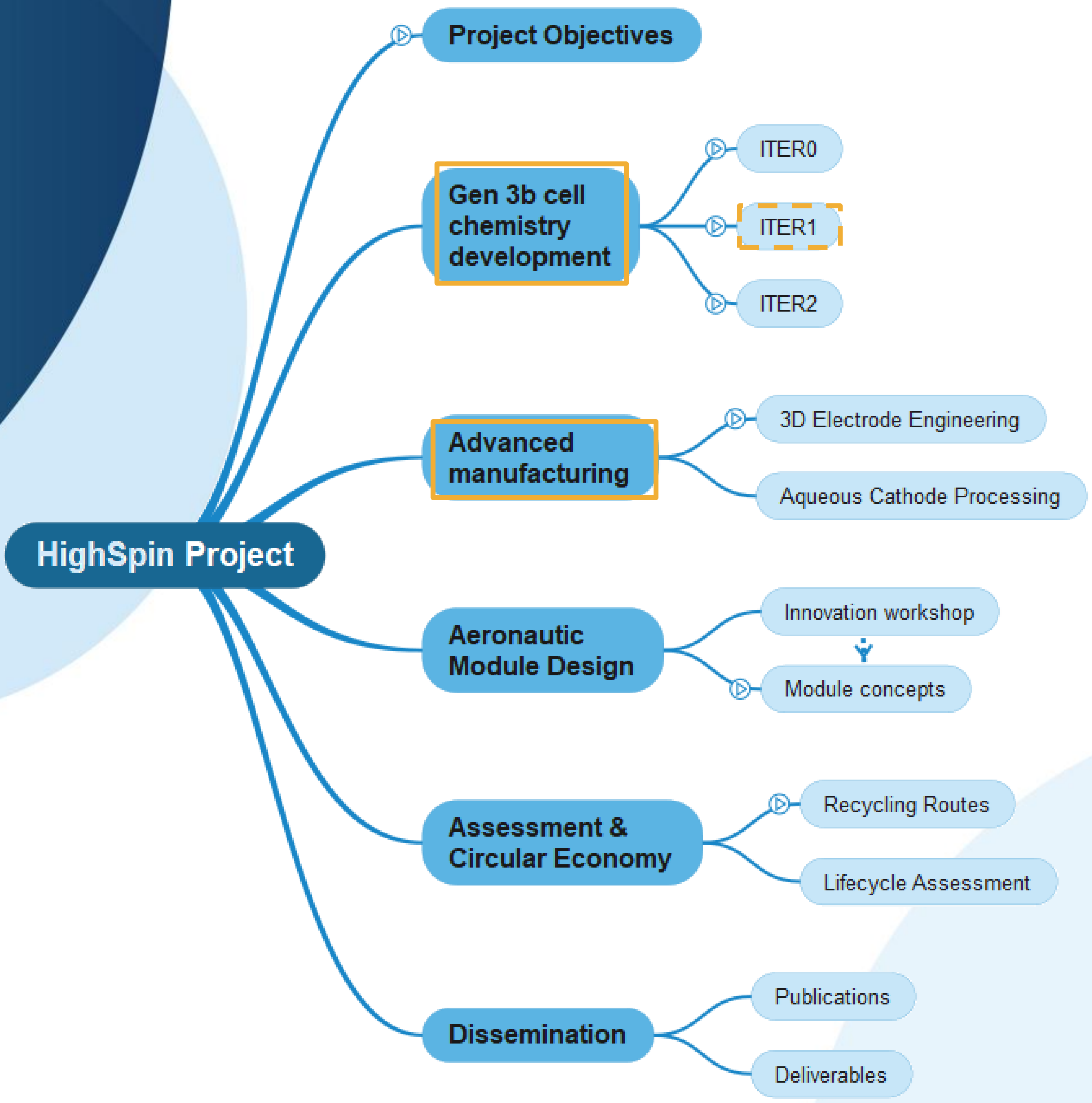
Develop and manufacture LNMO||Si/C cells fit for automotive and aeronautic applications
Design and demonstrate battery modules for automotive and aeronautic applications

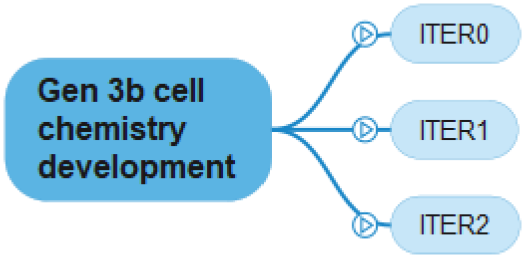
Aeronautic module
- 90 % module-to-cell gravimetric energy density ratio

Thoroughly assess the LMNO||Si/C HighSpin technology vs. performance, recyclability, cost and TRL.

Materials recovery
- 90% recycling efficiency
- 99.9% materials purity

Process effluent
- 3.4 kg_e/kg_{tbm}


HighSpin Project
Project Objectives
Gen 3b cell chemistry development
ITER0
ITER1
ITER2
Advanced manufacturing
3D Electrode Engineering
Aqueous Cathode Processing
Aeronautic Module Design
Innovation workshop
Module concepts
Assessment & Circular Economy
Recycling Routes
Lifecycle Assessment
Dissemination
Publications
Deliverables



Gen3 b cell chemistry development

Cell chemistry „iterations“ in HighSpin

Merging best candidates and processing parameters to build full cells as ITERx at lab level

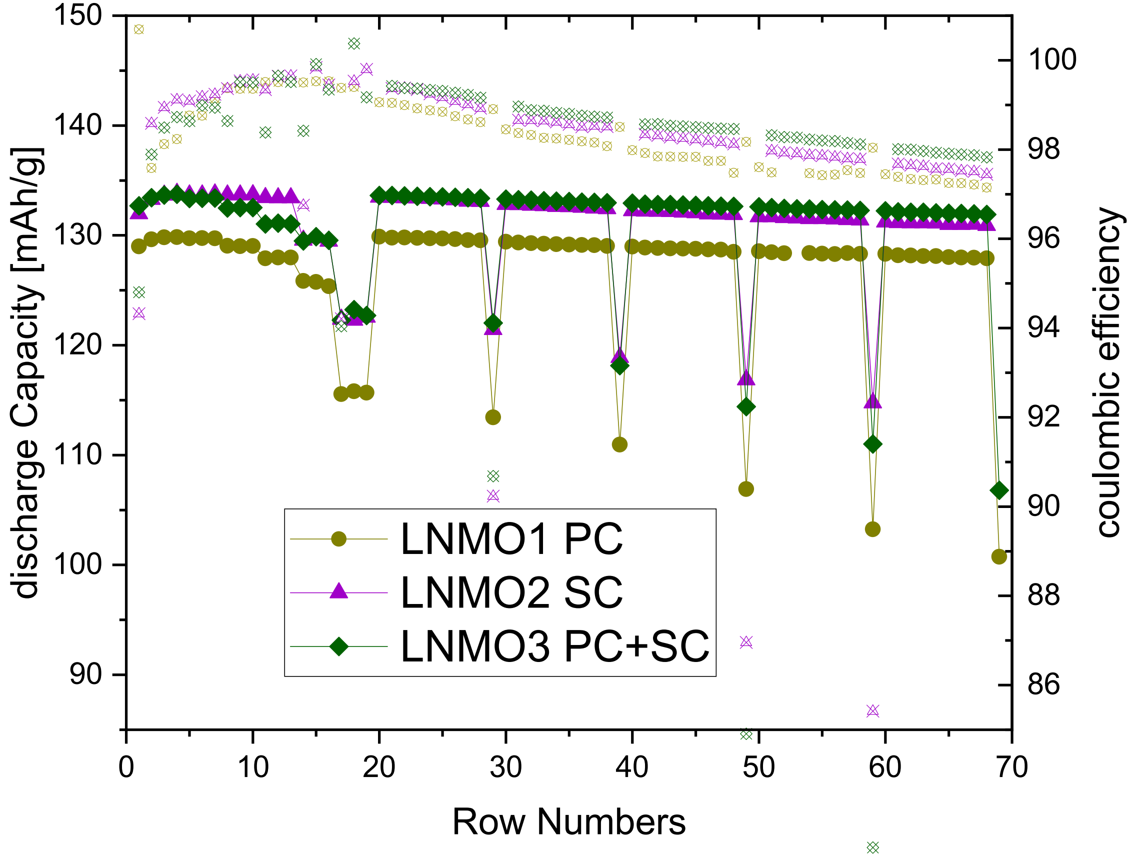
ITERx:	**Cathode** (AM+additives+processing)	+ **electrolyte** + (solvent+additives)	**Anode** (AM+additives +processing)
ITER0*:	**LNMO0** 90:5:5 CB:CMC+binder	**HVE-B inspired**	**Si/C (15wt%Si)** 94:2:2:2 AM: CMC:SBR:CB
ITER1:	**LNMO3 (mix)** 93% C45(3%):CMC+A89(4%)	1M $LiPF_6$ in **FEC/F-EMC** (3/7)	**Si/C (9wt%Si)** 94:2:2:2 CMC/SBR
ITER2:	**LNMO 2 (SC)** 93% C45(3%):CMC+A89(4%)	1M $LiPF_6$ in **EC/-EMC** (3/7) +LiDFOB	**Si/C (20wt%Si)** 94:2:2:1.8:0.2 CMC:SBR:CB:CNT

→ D2.1 Materials development report
→ D2.2 Final report on Materials development and definition of final HighSpin cell chemistry

Development and selection of LNMO cathode

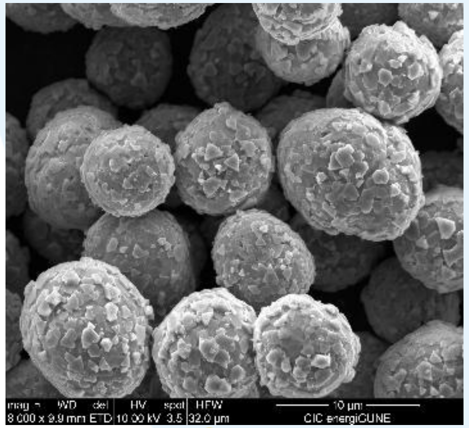
Comparison LNMO1 vs LNMO2 vs LNMO3

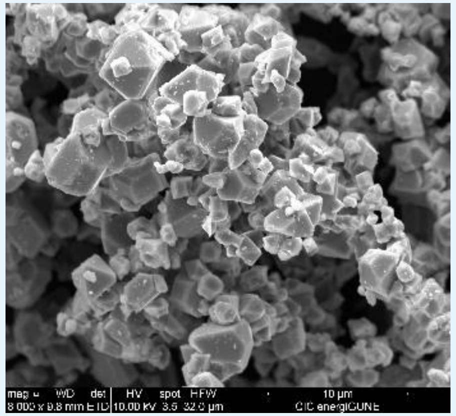
Half cell test vs Li with Lp57



Protocol:

- 4*C/10, formation stabilization
- C/5; C/2; 1C; 2C; 3C discharge rates, rate cap
- 3*[9x C/2 + 1x3C] cap retention





LNMO1 + LNMO2

= LNMO3

- Reversible cap (4th cycle): LNMO3=LNMO2 > LNMO1
- Rate capability 2C & 3C: LNMO2 = LNMO3 > LNMO1
- Cap retention: LNMO3= LNMO1> LNMO2

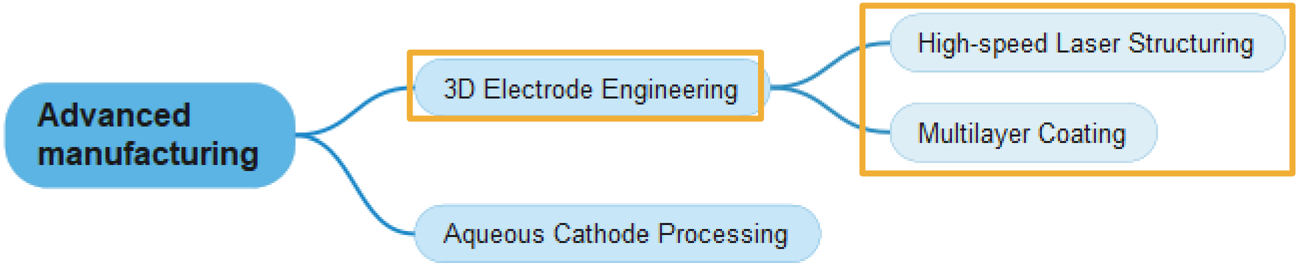
→ **LNMO3 selected as ITER1 candidate**

Additional consideration:

- Mixed morphology allows higher densification of electrode
  → beneficial for rate cap and energy density

→ Full cell trials at lab scale

→ Full cell upscaling on research pilot and small prod. scale



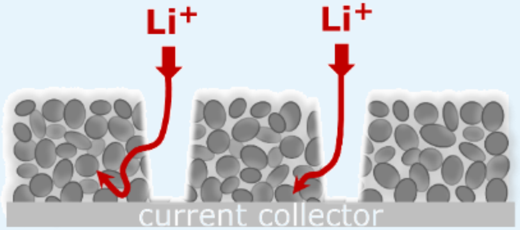
3D electrode architecture

→ Achieve high areal loading
→ Balance energy density and rate rate capability → improve Li diffusion
→ Improve electrode wetting
→ Mitigate cell swelling

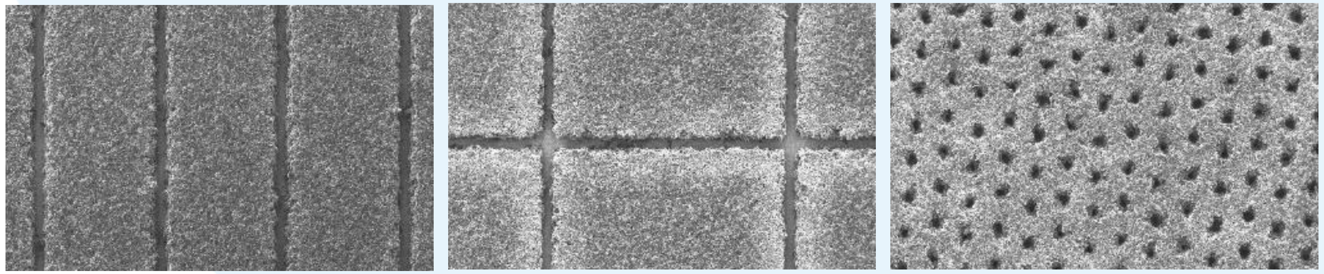
Electrode structuring by laser ablation

Structuring (removal of electrode material) by means of laser ablation

Pulse duration
Power
repetitions
pitch



Source: C. Reinhold et al., KIT

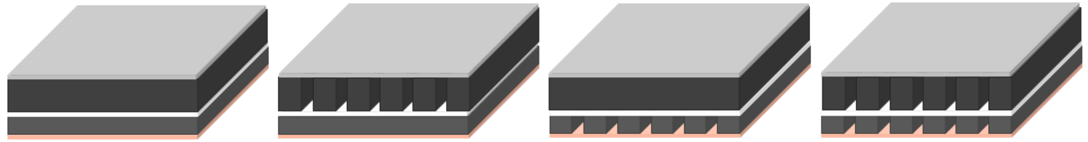


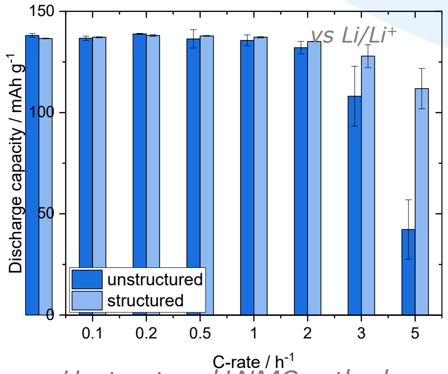
laser-structured Si-Gr anodes with line, grid, and hole structures

- Improve Li-ion diffusion in compacted, high-areal-loading electrodes.
- Reduce mechanical stress caused by the volume change during (de)lithiation (esp. Si).

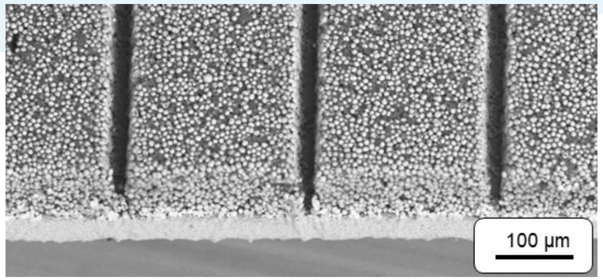
Structures like lines, grids and holes investigated in regard of electrochemical performance, mass loss and potential for upscaling.

After pattern selection for each electrode type, combination of different anodes and cathodes (structured and unstructured) to be tested to optimize full-cell performance.





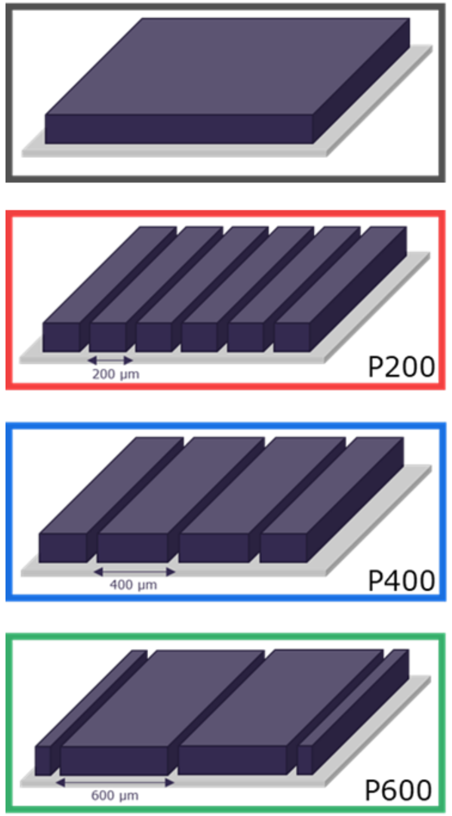
Unstructured LNMO cathode vs. structured with line pattern



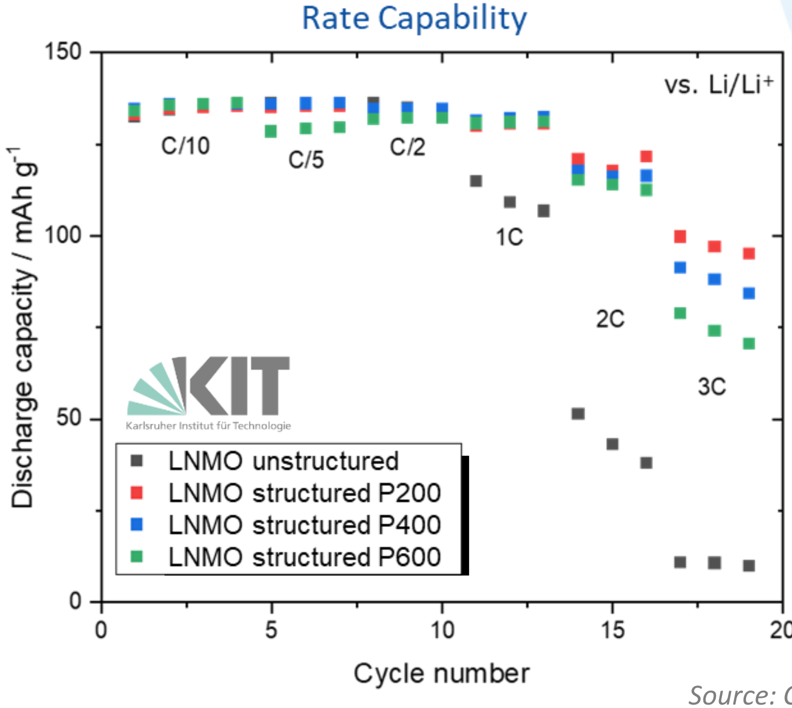
LNMO cathode with line pattern

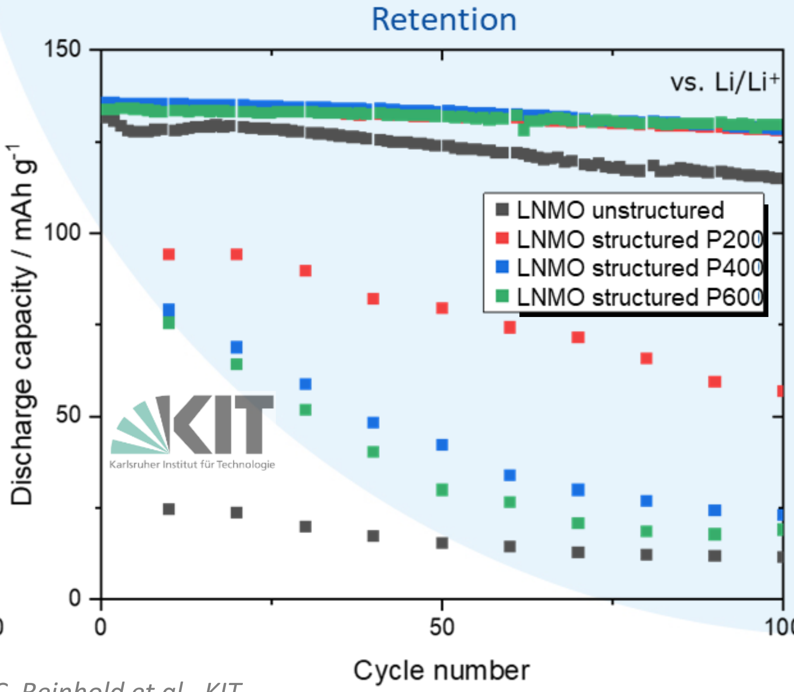
C. Reinhold et al. "Ultrafast laser structuring of high-voltage cathode materials for lithium-ion batteries", Proc. SPIE 12873, Laser-based Micro- and Nanoprocessing XVIII, 128730K (12 March 2024); https://doi.org/10.1117/12.3001737

Example: Laser-structured LNMO cathode



Optimizing pitch distance to balance mass loss and performance improvement.





Source: C. Reinhold et al., KIT

Cycling protocol:

- Formation: C/10 4x
- C-rate: C/5; C/2; 1C; 2C; 3C each 3x (unsymmetric)
- Retention: C/10 9x; 3C 1x each 100x (unsymmetric)
- Voltage window: 3.5 – 4.9 V

- Enhanced discharge capacity for all laser-structured LNMO cathodes compared to unstructured electrode
- Decreasing overpotential with decreasing pitch

→ D3.2 Feasibility studies of 3D electrode design

Multilayer + aqueous LNMO coating

Multilayer aim: obtain higher electrode loading to increase energy density

- LNMO has a low theoretical specific capacity but can deliver high energy density → highly suitable candidate for multilayer electrode processing

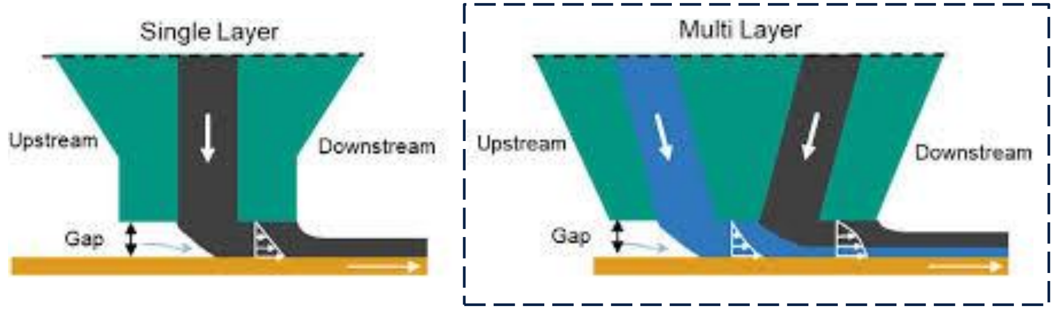


Image credit: (Diehm et al, 2020) -

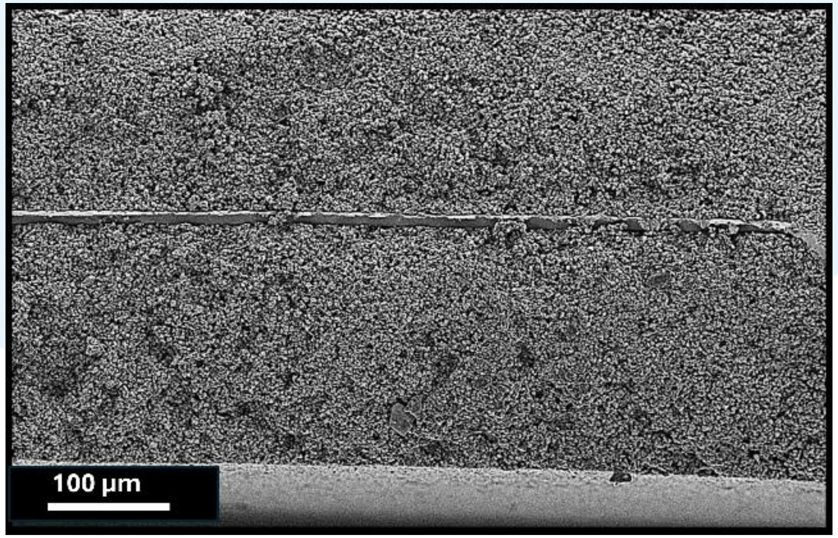
Multilayer coating

- Single layer + single layer sequentially
- Dual-layers lot-die head

Challenges:

- Aqueous LNMO (water-based cathode processing) is not state-of-the-art
- Binder is the key enabler for ML coating - it gives the flexibility for the electrode (various binders under investigation)
- Drying parameters

Cross Section-SEM of ML cathode



- Achieved ~ 42 mg/cm^2; 6.2 mAh/cm^2
- Process improvements and testing are in progress.

Dissemination

Dissemination

- Deliverables
  - 22/29 deliverables are public
  - 12 public deliverables online (Cordis)
- Publications
  - 7, of which 4 visible in Cordis

PFAS Free Organic Carbonate-Based Electrolyte Formulation for LNMO||SiGr Cell Chemistry

Author(s): Maike Leopold, Constantin Lürenbaum, Tobias Brake, Christian Wölke, Peng Yan, Martin Winter, Sascha Nowak, Simon Wiemers-Meyer, Isidora Cekic-Laskovic
Published in: Advanced Energy Materials, 2025, ISSN 1614-6832
Publisher: Wiley
DOI: 10.1002/AENM.202505133

Exploring separation techniques for the direct recycling of high voltage spinel LNMO scrap electrodes

Author(s): Stiven López Guzmán, Marcus Fehse, Emanuele Gucciardi, Marta Cabello, Silvia Martin, Naiara Etxebarria, Miguel Ceja, Miriam Romera, Montse Galceran, Marine Reynaud
Published in: Journal of Materials Chemistry A, 2024, ISSN 2050-7488
Publisher: Royal Society of Chemistry (RSC)
DOI: 10.1039/D4TA07642G

Importance of Fluorine in High Voltage Electrolytes for LNMO||SiGr Cell Chemistry

Author(s): Maike Leopold, Felix Pfeiffer, Elisabeth Christine Muschiol, Christian Wölke, Peng Yan, Kai Brüning, Sascha Nowak, Melanie Esselen, Martin Winter, Isidora Cekic-Laskovic
Published in: Small, Issue 21, 2025, ISSN 1613-6810
Publisher: Wiley
DOI: 10.1002/SMLL.202505254

2024 roadmap for sustainable batteries

Author(s): Magda Titirici, Patrik Johansson, Maria Crespo Ribadeneyra, Heather Au, Alessandro Innocenti, Stefano Passerini, Evi Petavratzi, Paul Lusty, Annika Ahlberg Tidblad, Andrew J Naylor, Reza Younesi, Yvonne A Chart, Jack Aspinall, Mauro Pasta, Joseba Orive, Lakshmipriya Musuvadhi Babulal, Marine Reynaud, Kenneth G Latham, Tomooki Hosaka, Shinichi Komaba, Jan Bitenc, Alexandre Ponrouch, Heng Zhang, Michel Armand, Robert Kerr, Patrick C Howlett, Maria Forsyth, John Brown, Alexis Grimaud, Marja Vilkman, Kamil Burak Dermenci, Seyedabolfazl Mousavihashemi, Maitane Berecibar, Jean E Marshall, Con Robert McElroy, Emma Kendrick, Tayeba Safdar, Chun Huang, Franco M Zanotto, Javier F Troncoso, Diana Zapata Dominguez, Mohammed Alabdali, Utkarsh Vijay, Alejandro A Franco, Sivaraj Pazhaniswamy, Patrick S Grant, Stiven López Guzman, Marcus Fehse, Montserrat Galceran, Néstor Antuñano
Published in: Journal of Physics: Energy, Issue 6, 2024, ISSN 2515-7655
Publisher: IOP Publishing
DOI: 10.1088/2515-7655/ad6bc0

Thank you for your attention

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in https://www.linkedin.com/company/highspin-project

highspin.eu

Cordis: https://cordis.europa.eu/project/id/101069508/results

Expected Results

- **Materials**: LNMO cathode with 3.0 g/cm³ density and anode with 20 wt. % of Si (730 mAh/g capacity). Stable electrolyte up to 5.0V.
- **Processes**: Ultrafast 3D electrode multilayer coating and laser structuring speed of ≥ 5 m/min.
- **Demonstrators**:
  - LNMO cells at 390 Wh/kg and 925 Wh/l at a cost target of 90 €/kWh (pack lvl)
  - 300 cells/150 CMUs produced, and 2 module demonstrators delivered at TRL 6.
- **Assessment**:
  - Testing as part of the materials development, assessment of the performance in 1st and 2nd life (including LCA, costs, and TRL).
  - Demonstrate recyclability, at 90% recycling efficiency.
- **Training**: 3 Ph.D. students, one each at KIT, FZJ and CICE.