# Perspectives of laser technologies in battery manufacturing

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Lasers are used for many applications in the manufacturing of batteries, including joining, cutting, slitting, notching, drying, annealing, printing, and structuring of electrodes [1, 2]. Laser welding is already used in the battery industry to join copper and aluminum tabs with multiple current collector flags, and to seal battery housings. Nanosecond lasers are typically used for economical high-speed laser electrode cutting. Laser-assisted drying of electrode coatings is an alternative to conventional drying methods using convection air and ovens and has already been successfully demonstrated on a laboratory scale. Similar TRL is achieved for current collectors which can be structured using direct laser interference patterning and direct laser ablation [3]. These techniques create micro- and nanoscale topographies on current collectors that enhance the adhesion of composite electrodes.

However, of all laser processes, laser modification and structuring of electrodes has the greatest potential to drive groundbreaking developments in next-generation batteries. This technology focuses on implementing the 3D battery concept on thick-film electrodes and has already achieved significant technological progress, reaching TRL5. Large-format cells with structured electrodes have been produced, offering clear benefits in terms of cell performance and enabling battery production with reduced scrap rate [4, 5]. Regarding upscaling, laser pulse burst processing can enhance ablation efficiency in comparison to single pulse ablation of same energy. High-power, ultrashort-pulse lasers with MHz and GHz burst repetition rates have been used for electrode structuring, achieving a significant increase in laser ablation efficiency compared to single-pulse laser ablation while processing time was reduced by a factor of four [6, 7]. In addition to ablation efficiency, the type of generated electrode topography plays a key role in the practical application of batteries. This requires precise adjustment of the process parameters based on the properties of the nanoscale materials. To ensure the performance of advanced processed batteries analyses are flanked by laser-induced breakdown spectroscopy (LIBS). LIBS enables 3D elemental mapping of electrode chemistry. This high-throughput approach supports the large-scale analysis of electrodes, investigating binder distribution and degradation, both of which are critical for optimizing the 3D battery concept. Preliminary in-line LIBS studies have demonstrated the potential of this technique for controlling binder migration during electrode coating. This presentation will showcase optimized laser-structured electrodes that can enhance battery lifetime, high-rate capability, energy and power density, and safety by mitigating lithium plating during fast charging. An outlook on process upscaling for future industrial use is given.

[1] W. Pfleging, "A review of laser electrode processing for development and manufacturing of lithium-ion batteries", Nanophotonics 7(3), 549-573 (2018).
[2] U. Rist, W. Pfleging, "Laser Printing of Silicon-Containing Anodes with Polyacrylic Acid", Batteries, 11(5), 191 (2025).
[3] C. Zwahr, N. Serey, L. Nitschke, C. Bischoff, U. Rädel, A. Meyer, P. Zhu, W. Pfleging, "Targeting new ways for large-scale, high-speed surface functionalization using direct laser interference patterning in a roll-to-roll process", Int. J. Extrem. Manuf., 5(3), 035006 (2023).
[4] W. Pfleging, "Recent progress in laser texturing of battery materials: A review of tuning electrochemical performances, related material development, and prospects for large-scale manufacturing", Int. J. Extrem. Manuf., 3(1), 012002 (2020).
[5] Y. Sterzl, W. Pfleging, "Optimizing Structural Patterns for 3D Electrodes in Lithium-Ion Batteries for Enhanced Fast-Charging Capability and Reduced Lithium Plating", Batteries, 10(5), 160 (2024).
[6] C. Reinhold, W. Pfleging, "Ultrafast laser ablation of high-voltage cathodes using GHz burst mode operation" Proc. of SPIE, 13351, 45-49 (2025).
[7] Y. Sterzl, M. Pulst, S. Xiao, C. Franke, and W. Pfleging, "Optimizing and upscaling of USP laser structuring for 3D lithium-ion battery electrodes for fast-charging and reduced lithium plating", Proc. of SPIE, 13351, 30-38 (2025).