Laser Ablation of Electrodes for Next Generation Batteries

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More than a decade ago, a new area of research was initiated in the field of laser ablation of electrode materials for lithium-ion batteries. While the initial focus was on fundamental studies using nanosecond laser radiation and compact thin-film electrodes (<3 µm) for micro-batteries, application-oriented research using composite thick-film electrodes (50-150 µm) with high areal capacity (2-6 mAh/cm^2) for mobile applications increasingly became the subject of intense investigations [1]. The development of an efficient research process was made possible by combining laser process technology with battery manufacturing, as well as corresponding analysis at the laboratory level. The control of the electrode porosity, design, and composition via tape casting or laser printing [2], and the short distances to battery assembly, formation, and analysis are crucial factors in this process. Mainly driven by the strong demand for low-cost, reliable, high-energy, and high-capacity batteries for electric vehicles, laser ablation became a promising technology to enable advanced 3D electrode architectures with exceptional electrochemical performances. The implementation of specific 3D electrode designs has been demonstrated to be advantageous in multiple ways, with benefits extending to both battery manufacturing and operation. This facilitates enhanced cost-efficiency in production and improvements in performance, including a fourfold increase in cycle lifetime and optimized rapid charging capabilities. Furthermore, there is evidence that these designs have the potential to contribute to enhanced battery safety, through the reduction of lithium plating [3]. Given the highly functional nature of battery materials and their specific micro- and nano-scale design regarding mechanical and chemical stability, as well as diffusion kinetic properties, the laser-material interaction, the ablation mechanism, and the impact of laser ablation on material level (Figure) and on electrochemical performance on battery level were subjected to detailed analysis. The most prevalent method for electrode structuring is the utilization of ultrafast laser ablation, with the objective of reducing thermally driven material modifications. Recently, high-power ultrafast lasers (>300 W), GHz lasers, and multi-beam processing strategies were developed and employed in roll-to-roll machining to match with processing speeds required for battery production. The upscaling of the 3D battery concept, with capacities of up to 20 Ah, was successfully demonstrated.

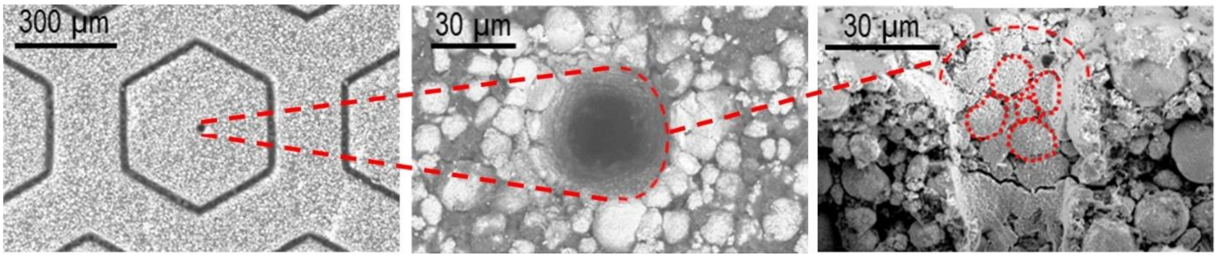

Figure: SEM images of an ultrafast laser patterned lithium nickel manganese cobalt oxide (NMC) composited cathode: top view, detailed view of drilled hole, and cross-sectional view [4].

References: [1] W. Pfleging, Int. J. Extrem. Manuf. 3 (2021) 012002; [2] U. Rist, V. Falkowski, W. Pfleging, Nanomaterials 13 (2023) 2411; [3] Y. Sterzl, W. Pfleging, Batteries 10(5) (2024) 160; [4] P. Zhu, B. Ebert, P. Smyrek, W. Pfleging, Batteries 10(2) (2024) 58.