Refining Battery Technology Through New Perspectives in Electrode Design and Analysis

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The use of state-of-the-art laser technologies for material processing has been shown to pave the way for the modernization of battery production processes, making them more efficient and preparing them for the next generation of high-performance batteries. Initial reluctance to integrate lasers into battery and module manufacturing is gradually being overcome, with some laser-assisted processes already replacing conventional methods. Laser welding has thus become the dominant process in module manufacturing, replacing traditional joining technologies such as resistance spot welding. Similar is expected for electrode laser cutting, a process that has been developed over the last decade and is now becoming increasingly important in battery cell manufacturing. Advances in laser technology, such as high-power fiber lasers, blue diode lasers and ultrashort pulse lasers, are also contributing significantly to the increased use of lasers in battery manufacturing. Laser processes can be roughly categorized into two process types. The 1^{st} process type covers laser cutting, slitting, notching, and busbar welding, and replaces conventional methods to enhance production economics without intentionally tuning battery properties. The 2^{nd} process type involves electrode structuring and current collector modification which intentionally improve electrochemical performance by boosting electrolyte wettability, enhancing diffusion kinetics, and increasing electrode adhesion. For both categories, fast laser processing speeds are essential to be integrated into high-throughput battery production. Innovations in ultrafast lasers in roll-to-roll processing are capable to enable a scale-up to pilot line stage for production of lithium-ion battery prototypes with advanced electrodes architectures introduced in pouch cells and most recently in 4690 cylindrical cells, marking a breakthrough in scaling the 3D battery concept from laboratory to industrial relevant battery cell form factors. To ensure the performance of advanced processed batteries electrochemical analyses are flanked by laser-induced breakdown spectroscopy (LIBS). With micron resolution and atmospheric pressure operation, LIBS enables 2D/3D elemental mapping of electrode chemistry. A high-throughput approach supports large-scale electrode analysis, investigating binder distribution and degradation, which are critical for optimizing the 3D battery concept. Preliminary inline LIBS studies demonstrate its potential to control binder migration during electrode coating. The presentation will highlight optimized laser-structured electrodes which enhance battery lifetime, high-rate capability, energy and power density, and safety by mitigating lithium plating during fast charging.