3D electrode architectures for high power and high energy lithium-ion battery operation - recent approaches and process upscaling

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Abstract

During the next decades, combustion driven cars will be completely replaced by electrical vehicles (EVs) and it seems quite obvious that liquid electrolyte lithium-ion batteries (LIBs) will be the dominating energy storage system for the next at least 5 to 10 years. As a consequence, in Europe numerous Gigafactories have recently been planned with this state of technology. However, the current lithium-ion battery technology suffers so far from some restrictions like the inability to combine high power and high energy operations at the same time. This limitation is mainly attributed to the cathode architecture and respective mass loading. In addition, the further demand for a significantly enhanced fast charging mainly requires an optimization of the anode design flanked by a high areal capacity. Advanced 3D electrode architectures based on a thick film electrode concept seem to be the most promising approach to overcome the current limitations in battery performances. However, respective technology innovations need to provide a high compatibility grade to existing manufacturing routes in order to enable the required integration in existing and planned factories. For so-called “generation 3” materials, i.e., nickel-rich lithium nickel manganese cobalt oxide (NMC) cathode and silicon-based anode materials, structuring technologies using cutting edge ultrafast high power lasers, are being developed in order to manufacture 3D electrode architectures with high areal capacity. Multibeam laser processing using diffractive optical elements and dual scanner approaches were established in order to enable high processing speeds in roll-to-roll electrode handling systems. The technology readiness level (TRL 6) is demonstrated for pouch cells geometries. For water-based NMC 622 and silicon-graphite composites the laser structuring process was developed. Different structures including hole, grid, and line patterns, were studied regarding their impact on electrochemical performances such as high-rate capability and cell lifetime. Lithium concentration profiles of unstructured and structured electrodes were studied post mortem using laser-induced breakdown spectroscopy (LIBS) in order to evaluate lithium intercalation/deintercalation efficiencies and detect possible cell degradation processes. In comparison to unstructured electrodes, 3D electrodes could hereby always be identified as superior: unstructured thick film electrodes show a significant drop in capacity retention for high power operation and tend to form hot spots acting as starting point for cell failure. The upscaling process is flanked by a further improvement of electrode design. For this purpose very recently laser induced forward transfer (LIFT) is applied as printing technology to draw new concepts for sophisticated model electrode architectures with advanced electrochemical performances. Finally, the micro-/nano-scaled texturing of current collectors and separator material is discussed as further possible approaches for boosting the electrochemical performances of LIB pouch cells.

Keywords: lithium nickel manganese cobalt oxide; silicon-graphite, laser structuring; 3D battery; lithium-ion battery; laser-induced breakdown spectroscopy; electrode engineering, electrode manufacturing