Next-Generation Batteries through Advanced 3D Electrode and Material Concepts

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With the rise of renewable energy sources, energy storage solutions become increasingly important as they represent a key feature for secure and constant power supply. In this regard, battery systems play a crucial role in accelerating the transition towards sustainable and green energy sources. To meet the rising global demand, further advancement of the battery technology is imperative. One optimization pathway is to use battery materials that are more sustainable while also yielding improved electrochemical performance, contributing to both environmental and functional advancements. However, innovation must go beyond the material level, and new electrode design approaches for an efficient combination of high power and high energy systems are necessary.

In this context, the three-dimensional (3D) battery concept with its increased exposed electrode surface, shows a great promise for enhanced electrochemical performance compared to the conventional flat designs of state-of-the-art electrodes. Targeting at the bottleneck of high power/high energy density systems, the incorporation of micro-structured channels within the electrodes improves lithium-ion diffusion pathways and minimize strain from volume expansion during electrochemical cycling.

Our focus is the investigation of 3D electrode architectures generated by laser-processing techniques such as ultrafast laser ablation and laser-assisted printing. Working with ultrafast lasers offers the possibility to process materials while reducing thermal impact and allows the creation of well-designed and controllable electrode surface topographies. The adoption of this concept already shown great impact in enhancing the high-rate capability and lifetime of conventional electrodes in lithium-ion batteries.[1-3]

Expanding the scope, this work explores the applicability of laser-generated 3D electrode architectures to next-generation battery active materials such as high-voltage lithium nickel manganese oxide (LNMO) composites. On anode side, silicon/graphite and amorphous carbon is extensively investigated for lithium-ion batteries and sodium-ion batteries, respectively. To understand the impact of the manufacturing process, electrochemical evaluations are complemented by findings from laser-induced breakdown spectroscopy, SEM-EDX, Raman measurements, and Auger electron spectroscopy.

In conclusion, this contribution highlights the promising advancements achieved by applying laser-generated 3D electrode architectures to next-generation battery materials and aims to provide valuable insights into this exciting frontier of battery research.

[1] W. Pfleging, *Nanophotonics* 7 (2018) 549–573.

[2] W. Pfleging, *Int. J. Extrem. Manuf.* 3 (2021) 012002.

[3] M. Zaeh, *Appl. Energy* 303 (2021), 117693.