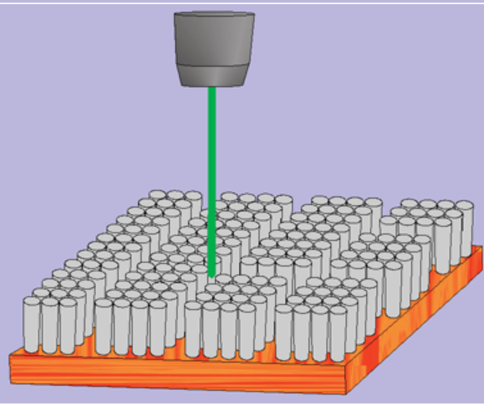

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SILICON ANODES FOR HIGHER ENERGY DENSITY OF LITHIUM BATTERIES

THE TASK

An increase in the energy density of lithium-ion batteries is necessary to extend the driving range of electric vehicles. Since the space in the vehicle is limited, energy density per volume unit has to be given special attention. The substitution of the recently used graphite anodes by silicon ones offers the potential to meet this demand because they can store a higher quantity of lithium ions per weight and volume.

A disadvantage that has hitherto prevented the commercial implementation of silicon-based anodes is their volume expansion by about 300 percent during the lithium insertion. Composite structures consisting of silicon and carbon are regarded as the solution to this problem. However, this combination limits the positive impact of the silicon. The use of compact silicon films has been hitherto avoided, since the active material would lose contact during the volumetric expansion.

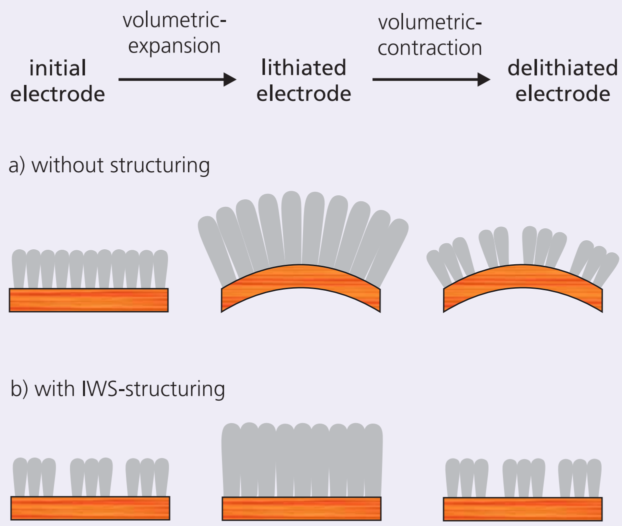
For high volumetric energy density, we have to develop pure, compact silicon electrodes that compensate for the volumetric expansion during lithiation and are suitable for use in large-sized cells.

OUR SOLUTION

Deposition of silicon on specially pre-treated substrates is a precondition for a columnar structure that adheres well to the current collector and has intrinsic porosity. Such electrodes in principle show excellent electrochemical capacity utilization. However deformation effects or cracks may be observed in the electrodes, since, due to the special silicon film growth mechanism, as well as shadowing effects, there is not enough space for the volumetric expansion.

Fraunhofer IWS has developed a post-treatment of the columnar silicon structures that avoids electrode deformations. The block-like structure of the columnar silicon film generated in the first lithiation and delithiation steps was used as a pattern (Fig. 2). The development is based on partial silicon ablation by laser micro processing (Fig. 1). The structure can be intentionally adjusted by variation of the process parameters laser power, wavelength and feed rate.

Avoiding electrode deformations during lithium insertion in columnar silicon films by laser structuring



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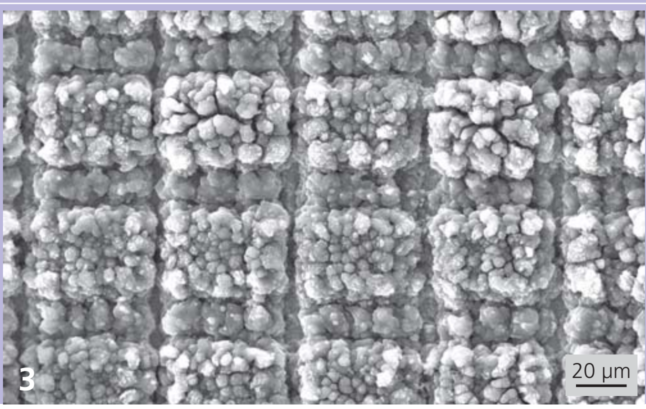

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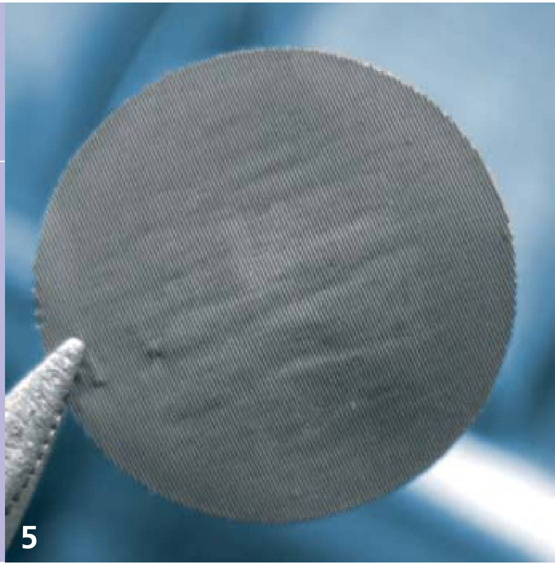

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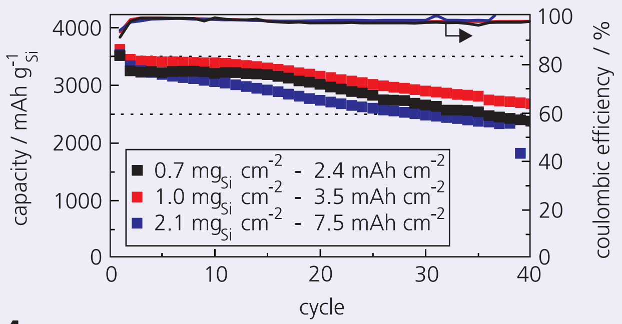
RESULTS

During the electrochemical cycle, the self-organized, block-like structure was initially adjusted by laser micro processing, thus avoiding electrode deformations (Fig. 3, 5).

The columnar silicon films were assessed with regard to their electrochemical properties in half cell tests against lithium. Increasing the silicon mass of electrodes at constant capacity retention the area capacity could be increased from about 2 mAh cm^{-2} to 7.5 mAh cm^{-2} (Fig. 4).

Influence of silicon mass of electrode on capacity retention and initial area capacity



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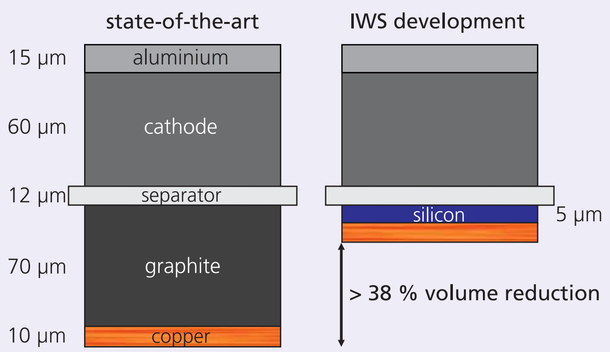
The pure and compact silicon films developed at IWS can prospectively take the place of traditional graphite anodes. The anode volume can thus be minimized at an unchanged capacity, which results in a volumetric advantage of more than 38 percent on the cell level (Fig. 6).

Secondary batteries based on this anode material have the potential to increase the volumetric energy density by 43 percent, from a current maximum of 700 to more than 1.000 Wh l^{-1}.

This means the battery pack can store a larger energy quantity at the same volume and can thus provide the technological precondition for an increase in electric car driving distances. Refinement and scaling of the Si deposition and structuring technology are key for successful industrial implementation of this approach.

Comparing the cell volume of a lithium-ion battery with graphite anode (left) and columnar silicon film anode (right) at identical area capacity



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1 Laser micro processing of columnar silicon films

3 Eliminating macroscopic electrode deformation by structuring

5 Structured electrode after lithiation by means of expanded silicon islands

CONTACT

M. Sc. Markus Piwko

☎ *+49 351 83391-3530*

✉ *markus.piwko@iws.fraunhofer.de*