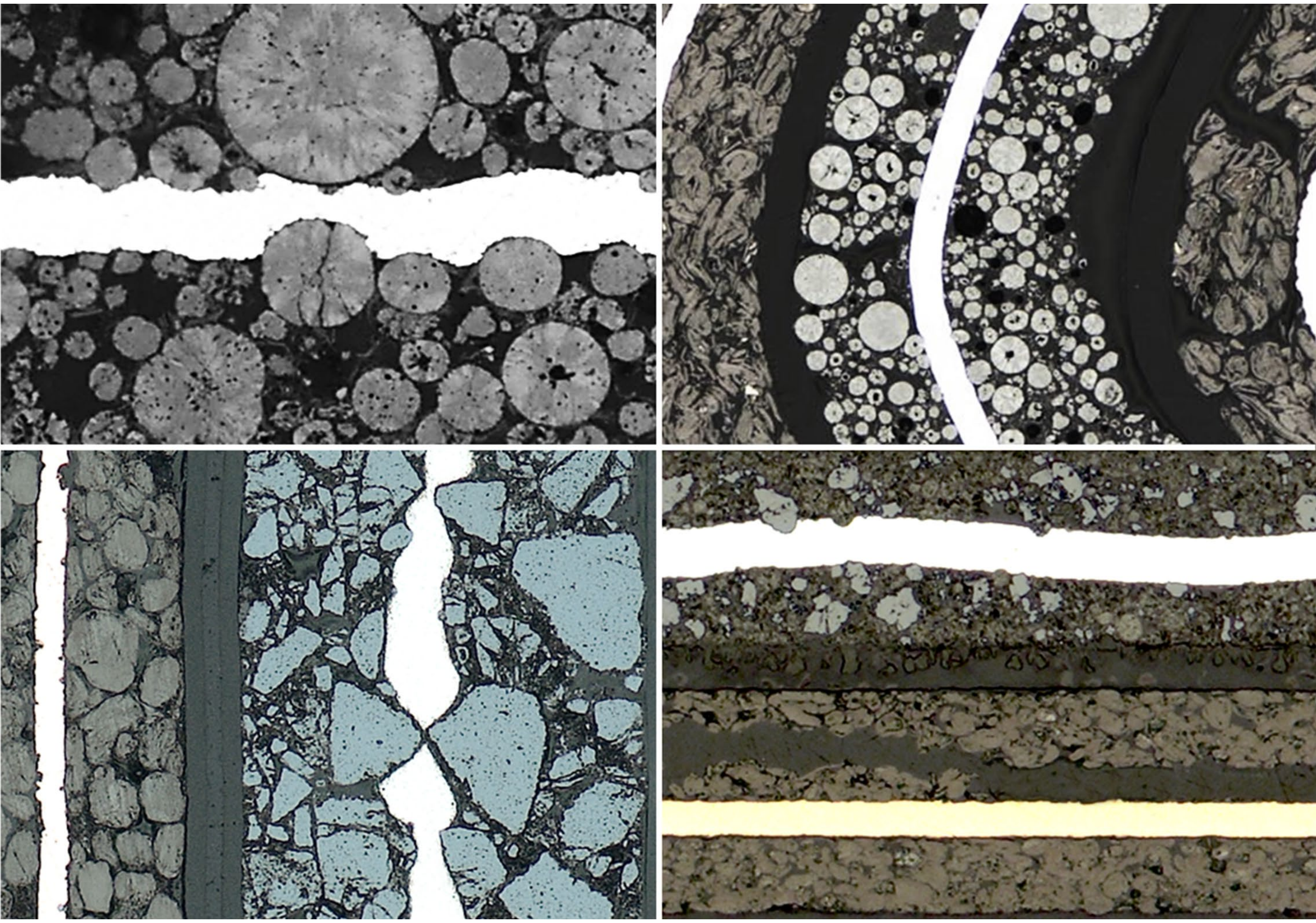
Application Note



Quality Control of Large-Sized Prismatic Rechargeable Lithium-Ion Batteries Using Light Microscopy

ZEISS Axio Imager.Z2 Vario

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The combination of light microscopy and digital image processing is a conclusive method of evaluating the quality of the fine geometry of a rechargeable battery's internal functional structures.
Using large-sized lithium-ion batteries for the automotive industry as an example, this article illustrates the relevance of light microscopy for the scanning and imaging of large areas of a specimen surface for the purpose of production-related detection of manufacturing defects within the scope of quality control of prismatic cells for automotive and stationary applications.

Introduction

Rechargeable lithium-ion batteries are a key technology used for sustainable transportation and stationary energy storage. Compared to the field of consumer electronics, the use of rechargeable batteries in automotive applications follows a significant increase in demands on quality, performance, and life span. Major functional characteristics and the quality as well as life span of rechargeable batteries are dependent on the structural composition, fine geometric attributes, and production defects, and can only partially be detected using microscopic processes due to the fineness of the internal geometric structures and the materials used. In this context, the resulting cell cross sections of approximately 150 × 25 mm in prismatic cells (PHEV) – compared to a conventional round cell diameter of 18–26 mm (cell types 18650 or 26650) – are setting new benchmarks in microscopic image acquisition and software-based image analysis.

Battery Technology Fundamentals

Batteries are a form of electrochemical energy storage and are divided into primary and secondary cells. Primary cells are power sources whose reactants are irreversibly consumed during discharge. Secondary cells, also referred to as rechargeable batteries or accumulators, are forms of energy storage that consume their reactants in a reversible process during discharge. The electrical energy supplied during charging is converted into chemical energy.

This process is reversed during discharge. A complete charging and discharging sequence is referred to as a charge cycle.
A rechargeable battery's life span is usually indicated in a specific number of cycles.
Batteries consist of electrodes, which are connected to one another via an ion-conducting electrolyte. An ion-permeable separator membrane electronically separates the positive electrode (cathode) from the negative electrode (anode).
In this context, lithium-ion batteries are considered the storage technology of the future, both for mobile as well as for stationary applications.
The cathode coating of lithium-ion batteries most often consists of lithium transition-metal oxides based on cobalt, nickel, and manganese. The most common variations of cell chemistries are $LiCoO_2$ (LCO), $Li(NixCoyAlz)O_2$ (NCA), $Li(NixCoyMnz)O_2$ (NMC), $LiMn_2O_2$ (LMO), and $LiFePO_2$ (LFP). Graphite is the most common material used for the anode coating. The repeating coated structure of a rechargeable battery is shown in figure 1.

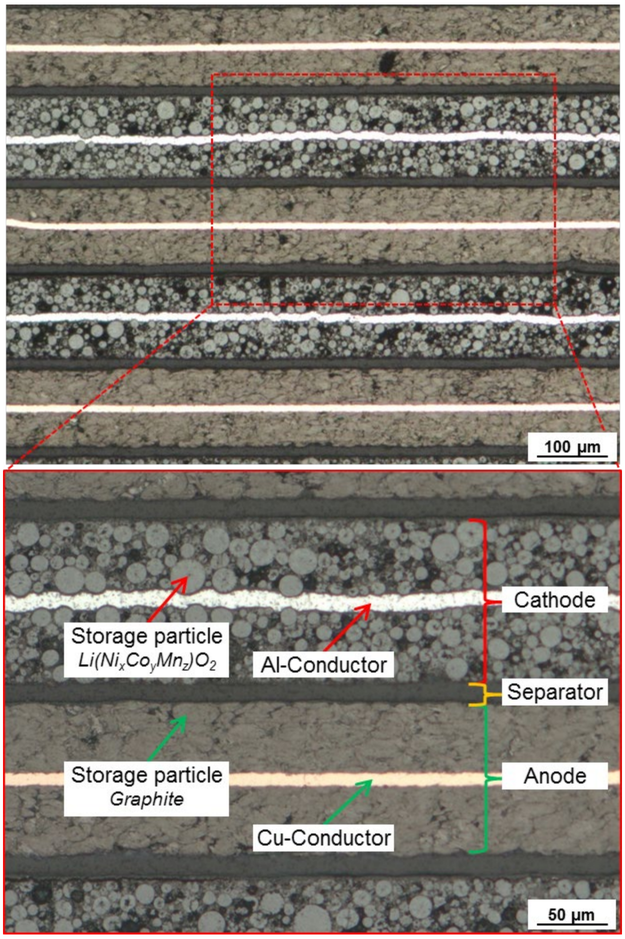

Figure 1 *The close-up view of a materialographic polished section of a lithium-ion battery taken through a light microscope shows the cell structure consisting of an anode with a copper conductor, cathode with aluminum conductor, and the separator*

Automated Wide-Area Image Acquisition Using a Light Microscope

In order to detect production defects such as fluctuations in layer thickness, flaws, and particle inhomogeneities, it is necessary to scan and image an overview of the entire specimen surface at 50× to 100× magnification. Larger areas that allow a resolution of at least 2 µm are relevant for the detailed evaluation of any detected defects. With motorized stage movement of 300 × 300 mm, sample area height of 112 mm, and an extremely stable column design, ZEISS Axio Imager.Z2 Vario light microscope is perfect for both the automated acquisition of large-sized overview images (see figure 2) as well as for capturing more magnified detailed images at 500× or 1000× magnification. This type of large prismatic cells pose a significant challenge to classic reflected light microscopes without a column attached to the side due to the height (including the holder) and lateral travel.

Using ZEISS Axio Imager.Z2 Vario light microscope, you can easily overcome these obstacles and conduct outstanding microscopic analyses.
The travel range of the stage combined with the available height of the sample space also make it possible to conduct

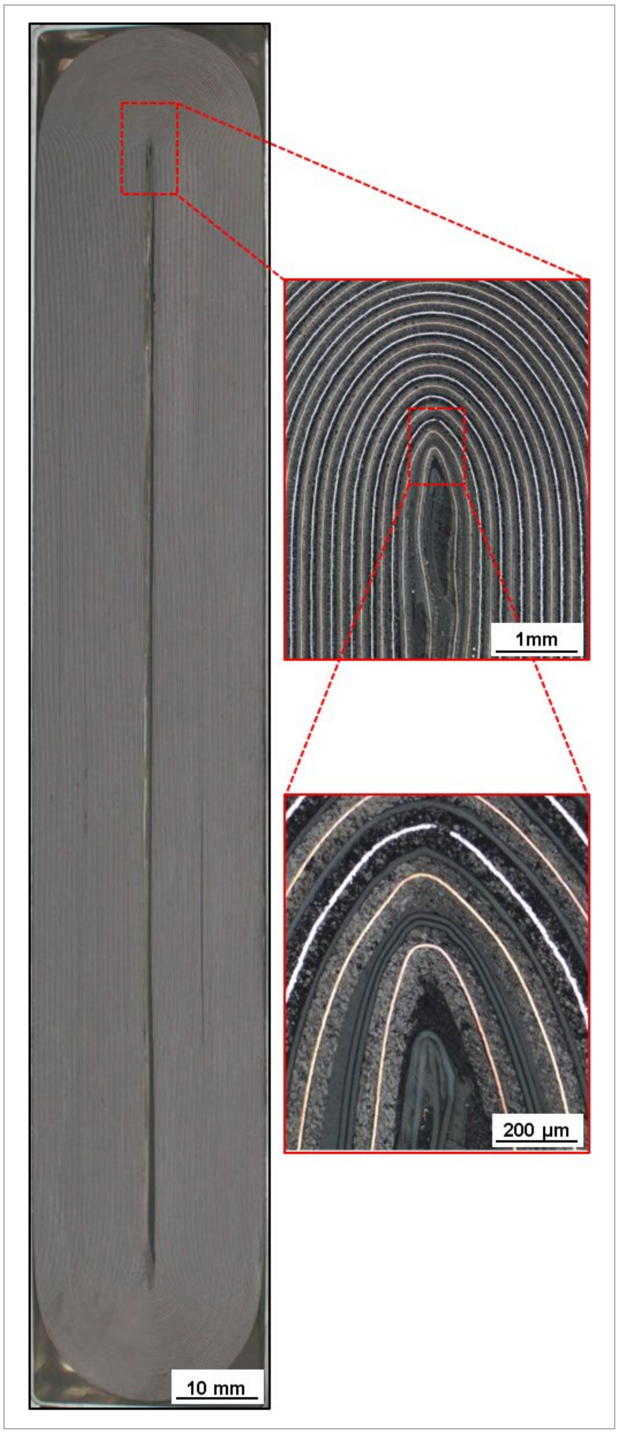

Figure 2 *Overview image of a prismatic lithium-ion battery at 100× magnification with variable zoom levels*

an extremely efficient light-microscopic examination of the polishing quality of large-sized prismatic cells during preparation (see figure 3). Clamping and unclamping samples from the sample holder – which was specially developed in cooperation with Struers ApS (a Danish company) for use with prismatic lithium-ion batteries – between individual polishing steps is not necessary. In addition, you can conduct a light microscopic inspection of two prismatic cells simultaneously.

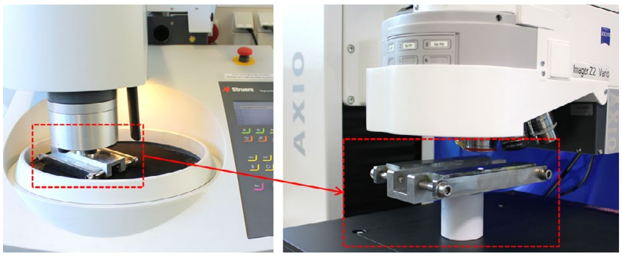

Figure 3 *ZEISS Axio Imager.Z2 Vario (right) with variable sample space height for efficiently inspecting polishing quality during the preparation of large-sized lithium-ion batteries in the sample holder specially developed by the company Struers ApS (red frame)*

In conjunction with the ZEISS ZEN 2 core software, it is possible to create overview images of prismatic lithium-ion batteries with an edge length of 150 × 25 mm at 100× magnification. The size of the resulting image files exceeds 200 gigabytes in color-imaging mode. With the ZEISS ZEN 2 core software, the process of capturing large-sized images, referred to as tiles, is extremely fast and user-friendly (see figure 4). Setting up the image tiles is carried out by moving to the individual corner points and confirming their position (see figure 5). To make the workflow as efficient as possible, the ZEN 2 core software allows you to set up specific user workbenches for setting up the microscope and carrying out the examination task. This enables an efficient and reproducible examination.

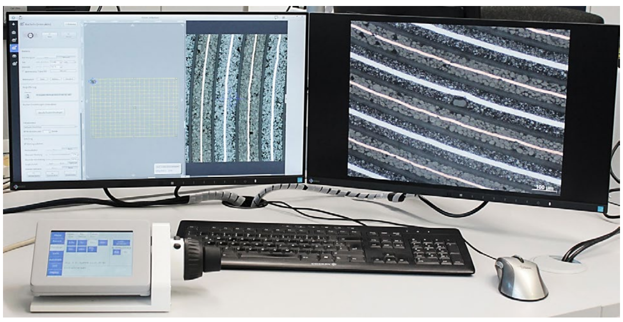

Figure 4 *ZEISS Axio Imager.Z2 Vario workstation with the microscope control in the foreground*

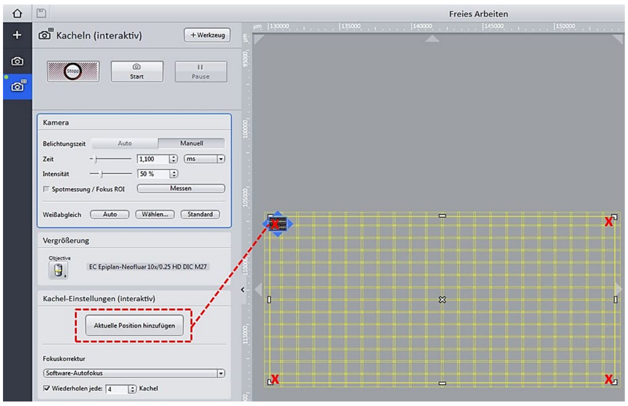

Figure 5 *User-friendly setup of the tiles, via Workbench, in the ZEISS ZEN 2 core software*

Detection of Quality-Related Characteristics in Lithium-Ion Batteries

Defects occur during manufacturing that have a significant impact on cell quality. Such defects can be automatically detected as deviations from predefined target specifications. This includes, for example, the uneven distribution of storage material volumes in the active mass of the electrode (see figure 6), layer thickness fluctuations in the electrode conductor (see figure 7), flaws in the active masses (see figure 8), and foreign particles (see figure 9). The goal is to detect, classify, and characterize these defects in the captured images using digital image processing.

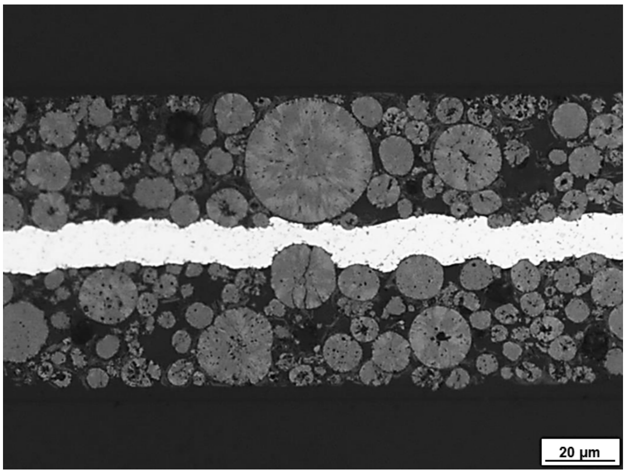

Figure 6 *Inhomogeneity of the storage material in the form of different-sized particles*

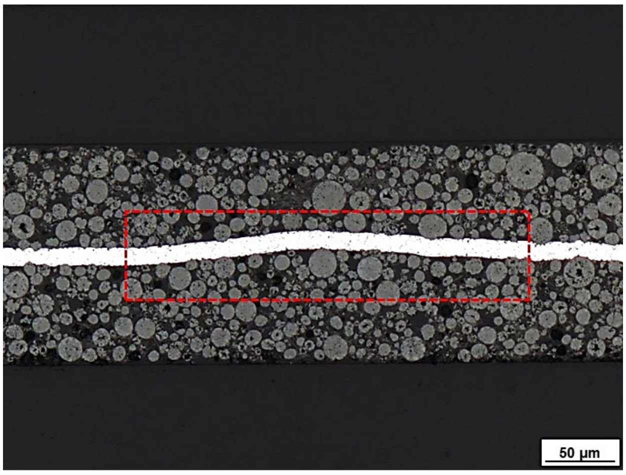

Figure 7 Fluctuations in the thickness of the electrode conductor

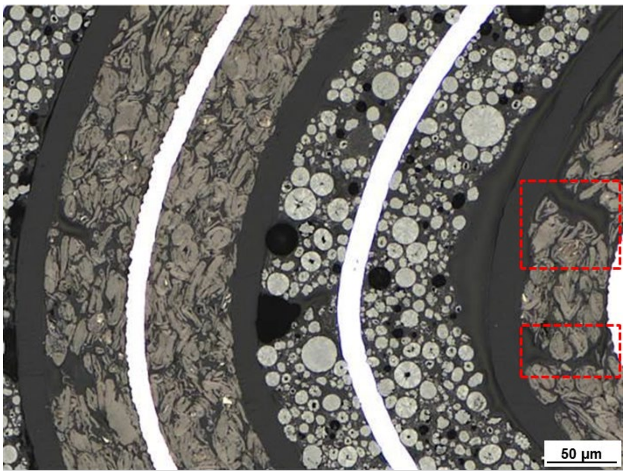

Figure 8 Flaws in the active mass

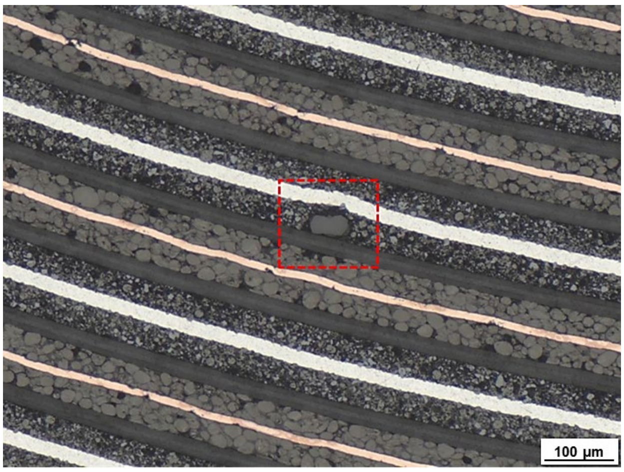

Figure 9 Foreign particles in the cell structure

New Approaches to Digital Image Processing for the Automated Image Analysis of Rechargeable Battery Structures

The size of the acquired image data poses an extreme challenge when it comes to analyzing the structures using digital image processing and the highest possible level of automation. This is further exacerbated by the complexity of the structures for a qualitative and quantitative evaluation. Both classic methods as well as those from the field of artificial intelligence are used to make an automated evaluation possible. For example, these serve to classify the individual components of the electrode to enable the subsequent measurement of property-related structural characteristics without user interaction (see figure 10). The goal of these methods is the automatic detection of cell defects caused by manufacturing.

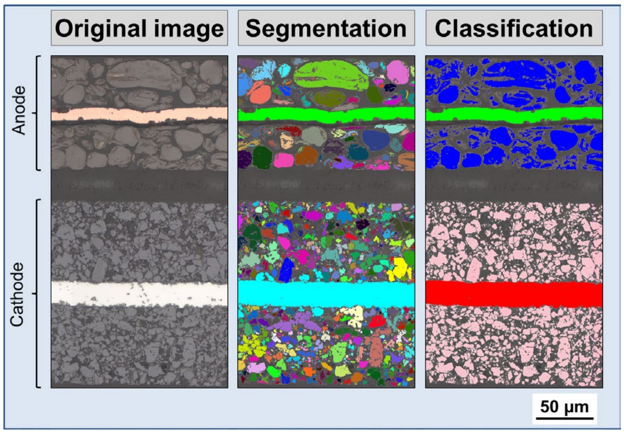

Figure 10
Left: *Original light microscopic brightfield image at 500× magnification*
Center: *Result of segmentation*
Right: *Results of classifying the individual components with a neural network for the purpose of automatically measuring property-related structural characteristics*

Approaches found in the image pyramid method are used for processing and analyzing images at various resolution levels. These make efficient and incremental access in a top-down approach possible. This encompasses, for example, analyzing the overview image with low resolution for the purpose of discovering irregularities as well as scanning the entire sample using high-resolution detail sections for the purpose of characterizing fine geometric properties. The goal is to be able to automatically detect the defects presented in section 4 and present them in the form of a "worst picture gallery" (gallery of deviations from the normal conditions).

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