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Simulation of the FIB-SEM Imaging Process and Segmentation of FIB-SEM Data Sets

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Nanoporous materials play an important role in modern batteries, as well as fuel cells. Furthermore, the microstructure is crucial in determining the performance of the porous materials. Yet the microstructure is too fine to be resolved with micro-CT, thus the method of choice is focused ion beam nanotomography(FIB-SEM). FIB tomography yields high quality 3D images of materials microstructures at the nanometre scale combining serial sectioning using a focused ion beam with scanning electron microscopy (SEM). However, SEM images represent the projection of a slice of unknown thickness. In FIB tomography of highly porous media this leads to shine-through artefacts , where structures in deeper slices are visible through the pore space, preventing automatic segmentation of the solid component (see Fig.2 for an example).

To overcome these difficulties, we simulate the SEM process[1]. Monte-Carlo techniques yield accurate results, but are too slow for FIB-SEM requiring hundreds of SEM images for one dataset. Nevertheless, a quasi analytic description of the specimen and acceleration techniques cut down the computing time by orders of magnitude, allowing the simulation of FIB-SEM data. Based on simulated FIB-SEM image data (see Fig. 1), segmentation methods for the 3D microstructure of highly porous media from the FIB-SEM data have been developed and evaluated.

With the synthetic data at hand, an algorithm was developed, which solves the segmentation problem, i.e. extract the 3D microstructure, from the FIB-SEM data. Based on well known morphological operations, a new method was developed for the reconstruction of highly porous structures from FIB-SEM data[2].

In an initial preprocessing step, the FIB-SEM image stack is precisely aligned. This is necessary, since the segmentation will be working with the variation of the grey value of individual pixels through the stack. This will be referred to as the z-profile of the pixel. Also, the image is corrected for shading artefacts and the contrast is enhanced.

For the matrix detection, features are extracted from the z-profiles of every pixel. A morphological gradient image with a linear structuring element (SE) is generated and thresholded, detecting the beginning of the matrix phase. Additionally, minima in the profile are detected, indicating the ending of the matrix phase in the z-profile. In the next step, pixels likely belonging to the matrix phase are marked by extending the thresholded gradient image to the minima. Then the marker image, together with a usual morphological gradient image, is used as input for a constrained watershed transformation where foreground and background are eroded and then used as initial basins for the transformation. This fits the initial basins to the edges in the image, resulting in a refined and final segmentation (see Fig.2,3).

For the first time, the method was validated with synthetic data generated by the simulation of the FIB-SEM process. With the ground truth available, the misclassification rate as well as other error measures, such as covariance and granulometry by openings could be determined. The results of the validation show that it outperforms any other method so far documented in literature.

This segmented data can then be used to simulate and optimize the macroscopic properties of nanoporous materials.

1. T. Prill and K. Schladitz, Simulation of FIB-SEM images for analysis of porous microstructures, Scanning 00, (2012), 1 – 7.
2. T. Prill, K. Schladitz, D. Jeulin, M. Faessel, Morphological segmentation of FIB-SEM data of highly porous media, Journal of Microscopy, accepted (2013)

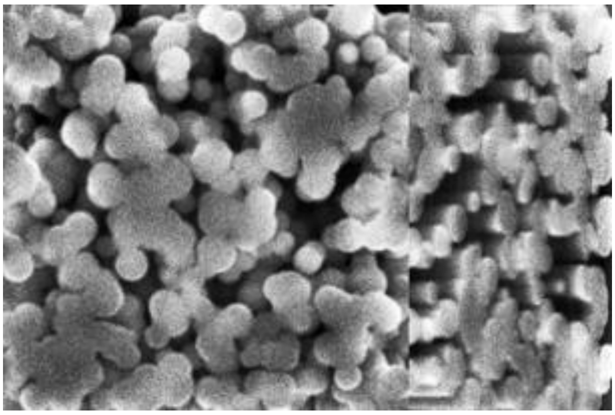

Figure 1. Simulated FIB-SEM data set of a porous carbon microstructure; left: the first slice of the FIB-SEM data set, right: crossection view through the image stack

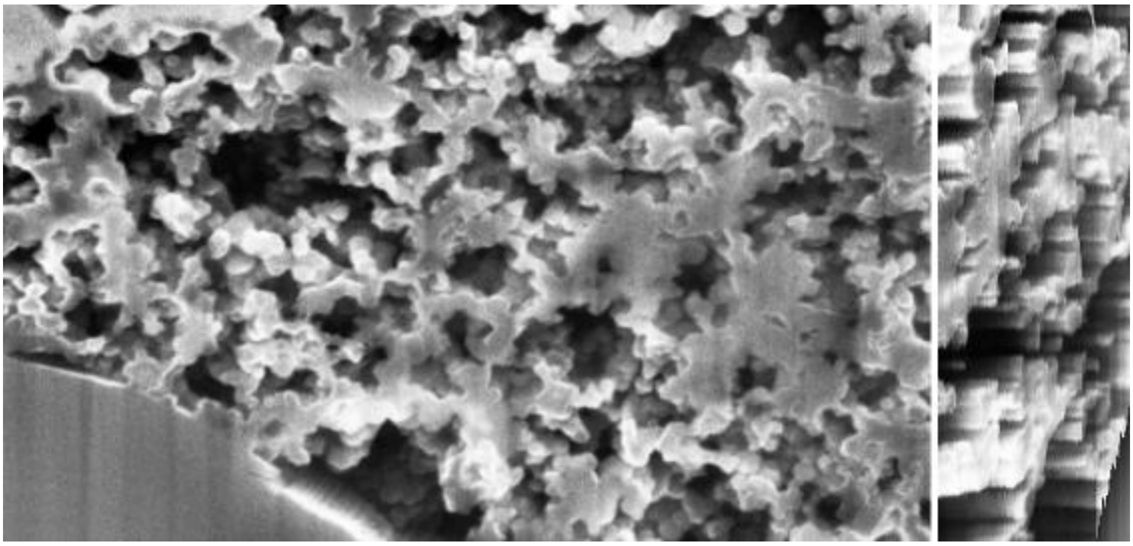

Figure 2. FIB-SEM data set of a porous carbon microstructure; left: the first slice of the FIB-SEM data set, right: crossection view through the image stack

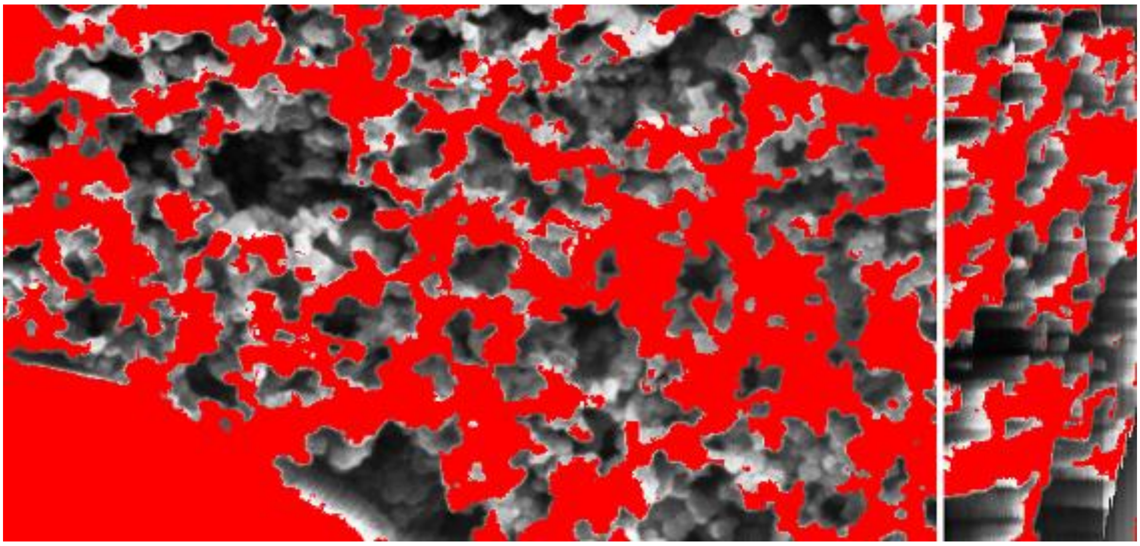

Figure 2. FIB-SEM data set with the segmentation as overlay (red); left: a slice view, right: a cross section view