Multi-scale tomography of nano-porous hydrogen fuel cell catalyst layers

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Challenges in PEM fuel cells

The most rate-limiting process in the PEMFC is the oxygen reduction reaction. It takes place in the cathode catalyst layer (CCL). Within the nano-porous CCL consisting of carbon, ionomer and Pt nano particles, liquid water plays a pivotal role. Understanding reactant transport processes in the nano-porous material is still one of the mayor challenges in fuel cell research. Here we show that tomographic techniques are an important step towards understanding mass transport limitations in PEMFC CCLs. It is found that focused-ion-beam/scanning electron microscopy tomography (SEMt) is well suited to image the pore space whereas transmission electron microscopy tomography (TEMt) is a good technique to image the nano morphology of the Pt catalyst particles..

SEMt reconstruction of CCLs

In the past we demonstrated SEMt can be used for tomographic imaging of PEMFC catalyst layers [1]. Using this technique enables to reconstruct the pore space of the CCL with resolutions up to ~10 nm (Fig.1). This reconstruction allows to analyze the morphology of both pore space and porous matrix as well as to evaluate transport processes of liquids and gases.

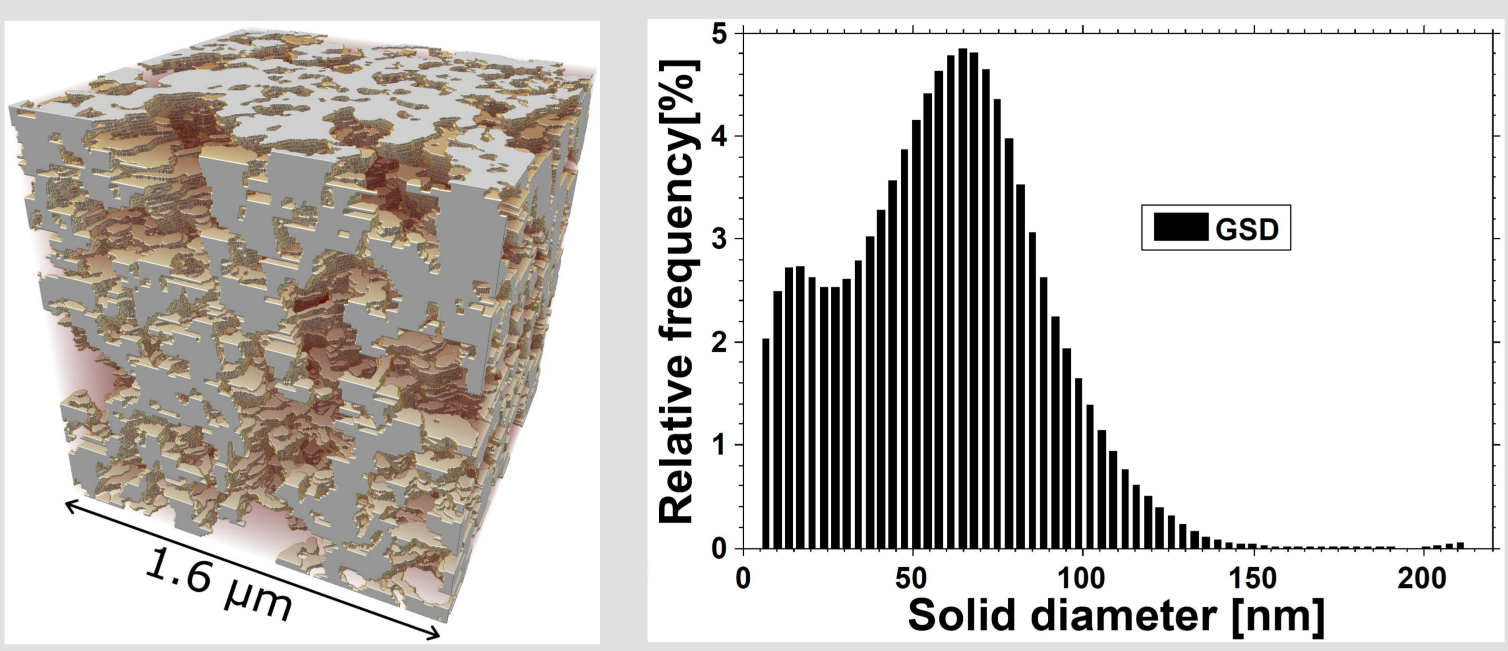

Figure 1: Displays a 3D SEMt image of a fraction of a porous CCL (left) and the size distribution of its solid matrix showing a peak at about 60 nm (right).

TEMt reconstruction Pt catalysts

Using TEMt enables to image Pt particle distributions in 3D. A successive analysis allows to extract morphological features such as size distributions and active surface areas of each single particle within the imaged volume (Fig. 2) [2].

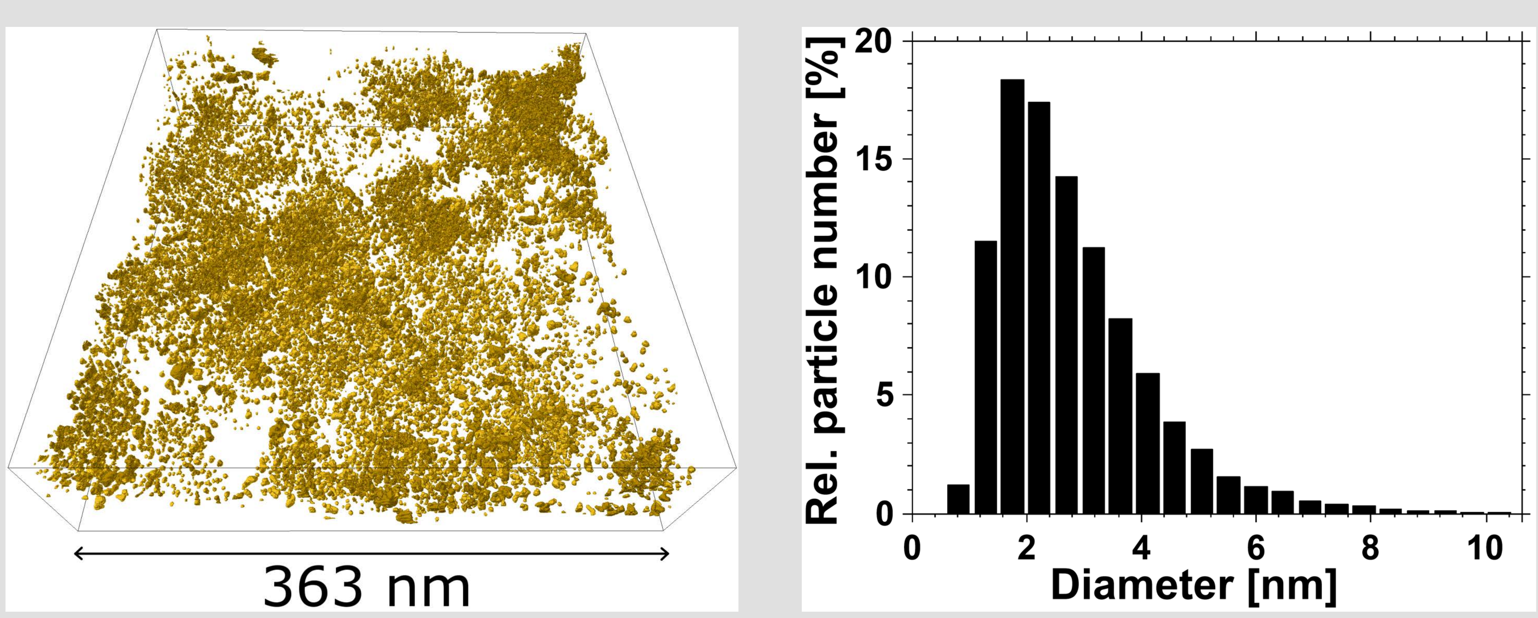

Figure 2: Displays a 3D TEMt image of the Pt catalyst distribution within a PEMFC CCL (left) and the relative frequency of particles over diameter (right).

Combining SEMt and TEMt information

SEMt and TEMt information can be combined by using an upscaling approach thereby combining information from different scales (Fig. 3) [2].

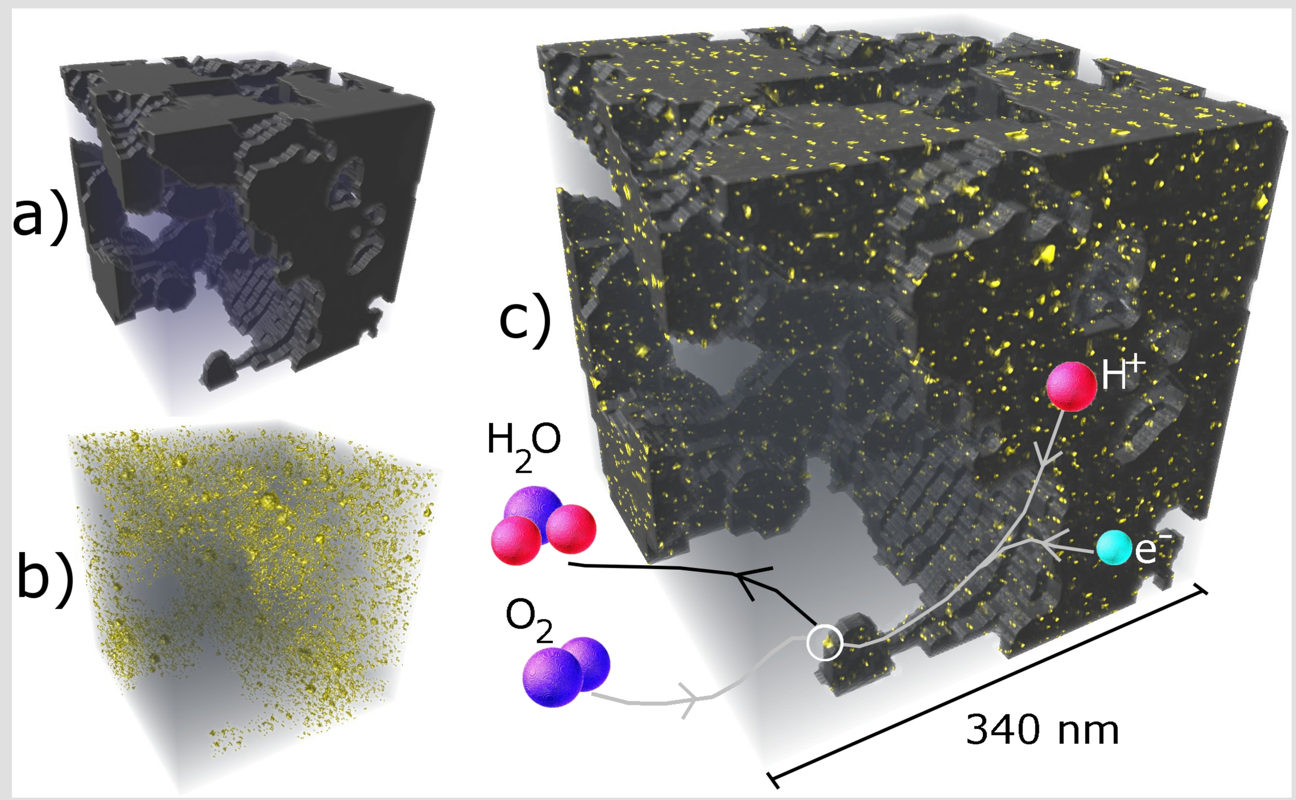

Figure 3: Shows combined SEMt and TEMt information a) Shows the porous carbon matrix reconstructed by SEMt with the solid part in dark grey. b) Shows Pt catalyst particle volume information from a TEMt reconstruction inscribed into the solid part of the SEMt reconstruction utilizing an upscaleing process. c) Shows the combination of a) and b).Thus reactant transport to active centers can be modeled.

Transport simulation in PEMFC CCLs

Liquid water can effectively block oxygen diffusion thereby limiting PEMFC performance. We developed a simple two phase model for hydrophobic and hydrophilic water filling [3]. Based on this it can be found that a hydrophobic geometry is greatly preferable in comparison to a hydrophilic geometry (Fig. 4).

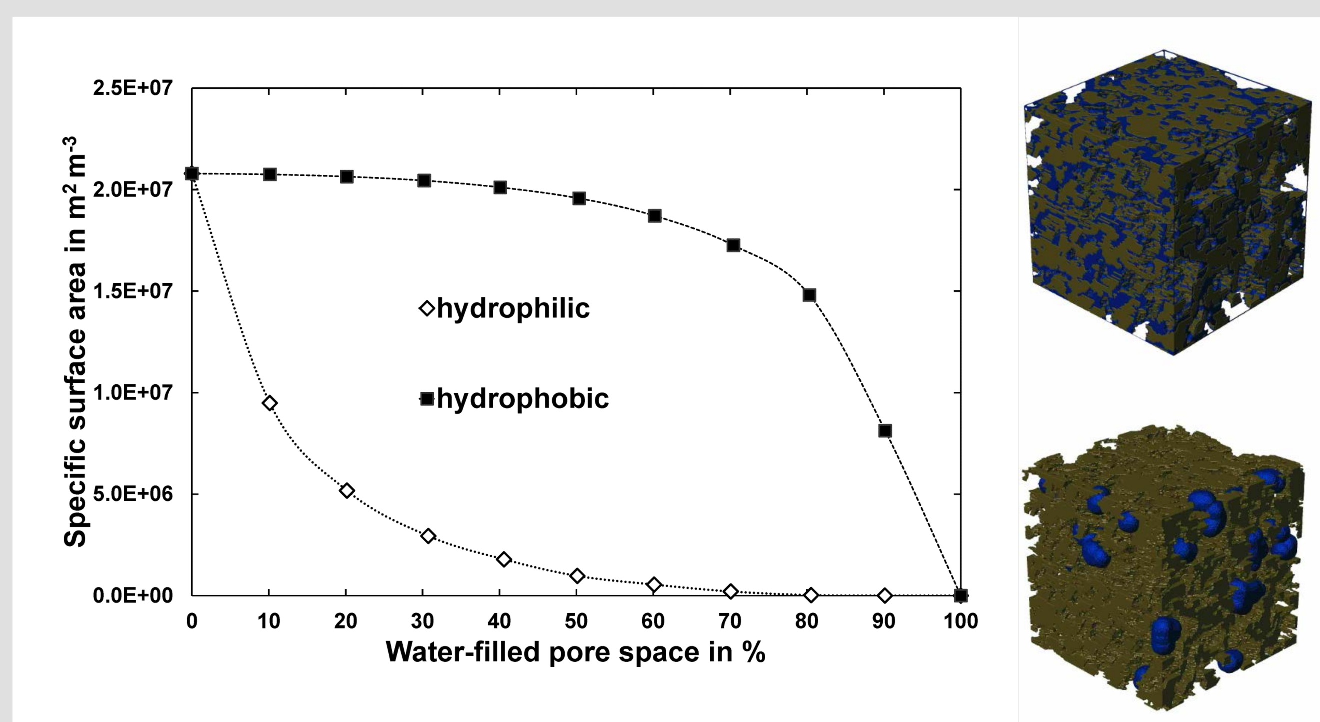

Figure 4:. Displays the amount of active surface area that can be reached by oxygen gas for hydrophobic and hydrophilic water filling behavior.

References

[1] S. Thiele et al., *Nano Research*, 4(9) 849–860 (2011)
[2] S. Thiele et al., *J. Power Sources*, 228(0) 185–192 (2013)
[3] T. Hutzenlaub et al., *J. Power Sources*, 227(0) 260-266 (2013)

Acknowledgements

This work was supported by the German Research Foundation (DFG) under grant No. ZI 1201/2-2.