X-ray computed tomography of gas diffusion layers and membrane electrode assemblies of PEM fuel cells

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While fuel cells in general are expected to play a major role in the future energy supply, proton exchange membrane (PEM) fuel cells are considered especially interesting for automotive applications due to their relatively low operating temperature which allows for fast start-up and flexibility in power output. Other promising applications of PEM fuel cells are back-up power units, small portable power supplies, micro combined heat and power installations, but also large scale stationary PEM fuel cell plants.

In a PEM fuel cell, hydrogen is reduced at the anode catalyst layer; the produced protons have to move through the proton-conducting (but not electron-conducting) membrane to the cathode catalyst layer where oxygen is oxidised and water is produced as 'waste'. On top of each of these two catalyst layers, a gas diffusion layer (GDL) is situated and this GDL has multiple functions: provide gas access to the catalyst layers, allow removal of product water while also keeping the membrane and active layers humidified when gas conditions are sub-saturated, mechanically stabilize the membrane-electrode assembly while compensating for thickness variations of the membrane, and providing electrical and thermal conductivity.

To fulfil these requirements, a GDL has typically a thickness between 200 and 400 µm and consists of carbon fiber papers or carbon fiber felts which are impregnated with polytetrafluoroethylene (PTFE) to achieve a partial hydrophobization of the surfaces. Furthermore, a microporous layer (MPL) consisting of a mixture of carbon black and PTFE is often applied on the side facing the catalyst layer for a further optimization of the water management.

PEM fuel cells were investigated by 3D X-ray computed tomography. It is demonstrated that this lab-based technique is not only suitable for the investigation of gas diffusion layers (GDL) as well as the investigation of membrane electrode assemblies (MEA), but also allows the calculation of macroscopic physical properties.

The resolution of computed tomography – a voxel size of 0.7 µm was used – is clearly sufficient to visualize the carbon fibers of gas diffusion layers [1] in the new GDLs as well as GDLs integrated into membrane electrode assemblies [2]. Figure 1 shows X-ray computed tomography data of an SGL Sigracet 35 BC gas diffusion layer which contains a micro porous layer. In the top 3D visualization, the carbon fibers are clearly visible as almost straight objects. In the bottom cross-section, also the micro-porous layer can be identified by a brighter appearance as compared to air and a darker appearance as compared to carbon fibers and PTFE. It is obvious that the MPL material does not form a clearly defined layer on one side of the GDL, but penetrates into the GDL.

Figure 2 shows X-ray computed tomography data of a membrane electrode assembly of a used PEM fuel cell. While on the left side, the whole MEA is shown, on the right side only the catalyst layers are visualized. X-ray computed tomography allows the investigation of structural defects of the catalyst layers and a more comprehensive determination of layer thickness as compared to the conventional investigation of cross-sections. A further analysis of this MEA showed that the cracks in the catalyst layers (see Figure 2) already exist directly after preparation of the MEA and are not related to fuel cell degradation [2].

As a knowledge of the temperature distribution in the fuel cell is not only key for improving the thermal management, but also especially the water management in the fuel cell, the macroscopic effective thermal conductivities of gas diffusion layers were calculated. This calculation was based on the 3D GDL structure reconstructed from X-ray computed tomography data by solving the energy equation considering a pure thermal conduction problem [1], a method which is implemented in GeoDict [3]. The calculations show that – due to the anisotropic structure of the GDL – the through plane thermal conductivities are lower than the thermal conductivities in lateral direction.

1. A. Pfrang, D. Veyret, F. Sieker and G. Tsotridis, International Journal of Hydrogen Energy 35 (2010), p. 3751-3757.
2. A. Pfrang, D. Veyret, G.J.M. Janssen and G. Tsotridis, Journal of Power Sources (2011), doi: 10.1016/j.jpowsour.2010.1009.1020.
3. Homepage of the GeoDict software, www.geodict.com, Fraunhofer ITWM, Kaiserslautern (2011).
4. We would like to thank Gaby Janssen for providing samples and for fruitful discussions and Phoenix X-rays, Gatan and JEOL Europe for their support.

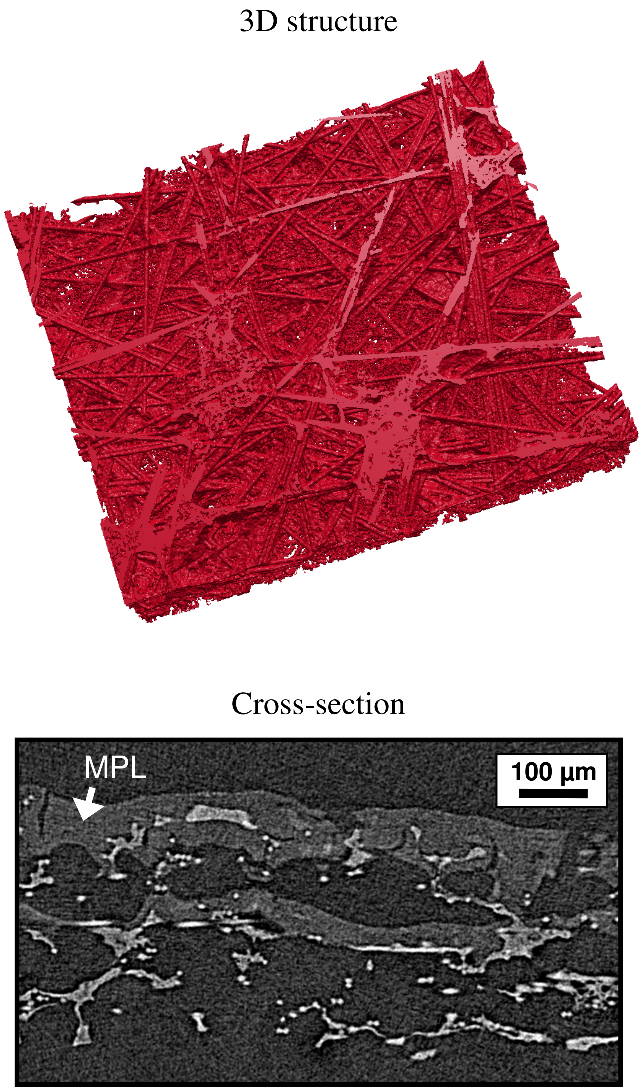

Figure 1. 3D structure and cross-section of a gas diffusion layer – SGL GDL 35 BC – as determined by X-ray computed tomography. The micro porous layer (MPL) is clearly visible in the cross-section.

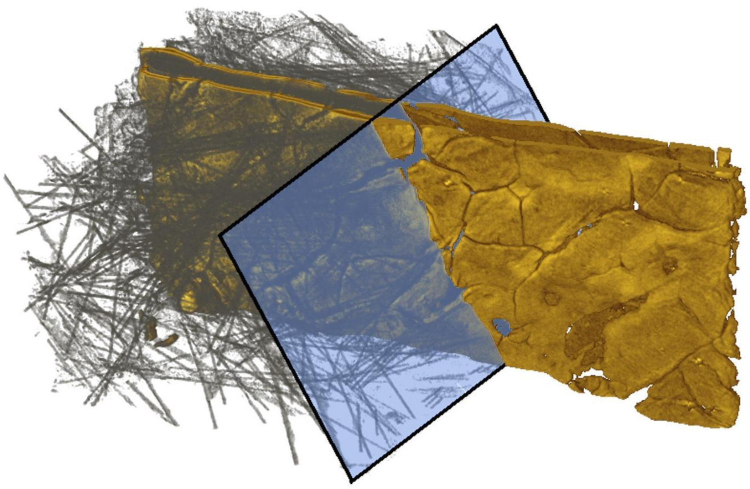

Figure 2. Membrane electrode assembly of a used PEM fuel cell (thickness 700 µm) imaged by x-ray computed tomography. On the left side, carbon fibers (grey) and catalyst layers (golden) are shown, whereas on the right side the carbon fibers are masked in order to show the cracks in the catalyst layers more clearly.