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Short communication

Influence of local carbon fibre orientation on the water transport in the gas diffusion layer of polymer electrolyte membrane fuel cells

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ABSTRACT

We used synchrotron X-ray imaging to investigate the influence of local fibre structures of gas diffusion layers (GDLs) in polymer electrolyte membrane fuel cells on the transport of water. Two different measurement techniques, namely in-situ radiography and ex-situ tomography, were combined to reveal the structure–properties relationships between the three-dimensional fibre arrangement and the water flow. We found that the orientation of the local carbon fibres strongly affects the direction of liquid water transport. The carbon fibres act as guiding rails for the water droplets. These findings provide completely new ideas on how gas diffusion media in various types of fuel cells could be designed, in order to optimise transport pathways for liquid water and therefore increase cell performance.

1. Introduction

Polymer electrolyte membrane fuel cells (PEMFCs) are currently the most promising fuel cell type for automotive applications. Air can be used on the cathode side, implying that only hydrogen gas has to be carried on board of a vehicle. PEMFCs also exhibit a dynamic performance in a wide range of operation parameters [1,2]. However, water management is still one of the problems that prevent a broad establishment of PEMFCs in the automotive sector. A dry membrane loses proton conductivity whereas upon flooding with water the gas diffusion layer (GDL) gets blocked and the gas supply ceases [3], which results in an inhomogeneous current density affecting also the material's lifetime. Therefore, an effective removal of liquid water from the gas diffusion layer is a prerequisite for optimal performance as well as for stable fuel cell operation [4–11].

This article addresses the question of how water transport is conducted in the local carbon fibre structure of a SGL Sigracet® 25BC, which is common in this fuel cell type [12]. The in-situ water transport in perforated gas diffusion layers was investigated during operation by synchrotron X-ray radiography that provides a high enough temporal and spatial resolution to examine even the small structural details of the gas diffusion layers in real time [13–15].

2. Experiments

2.1. In-situ radiography

The in-situ experiments were carried out using a PEMFC with an active area of 100×100 mm^2 equipped with a three-fold serpentine flow field with a channel width of 0.8 mm separated by 0.9 mm wide ribs. The cathodic GDL (SGL 25 BC) was laser-perforated with a diameter of about 210 μm separated by a distance of 1 mm [16,17]. Perforation was conducted with a focused Nd:YAG laser beam performing circular movements. The perforations in the GDL were also located in the rib regions of the flow field. The distance between the edges of the channel and the perforations was about 200 μm (see Fig. 2, image A).

A cutout with a diameter of 10 mm was drilled into the end plates of the fuel cell to ensure high transmission of the X-rays within the field of view. This raises the sensitivity to water located in the cell components, such as GDL and the gas channel system. The cell was kept at a temperature of 55 °C and was supplied on both sides with preheated hydrogen and air having a relative humidity of 75% (@55 °C). The radiographic images presented in Figs. 1a, 2 and 3a were taken while operating the

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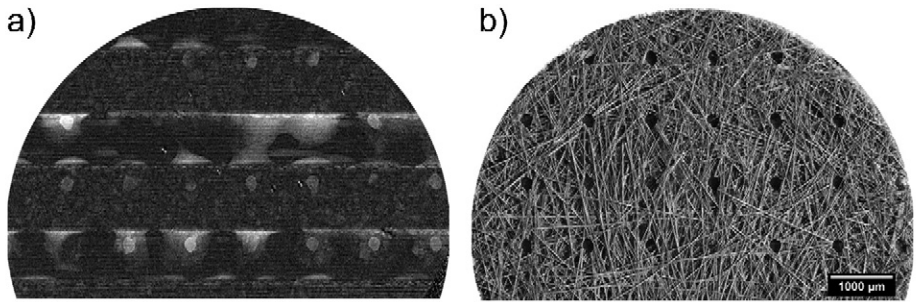

Fig. 1. Overview of the matched segment showing the perforated SGL 25 BC GDL; a) radiographic image with water distribution obtained during operation; b) tomographic 3D reconstruction of the GDL fibres.

cell at a 0.5 A/cm^2 current density. The hydrogen and air flow rates were set to 1 and 4 standard litres per minute.

The measurements were performed at the imaging beamline "BAMline" of the synchrotron electron storage ring "Bessy II" in Berlin, Germany. The observed field of view was 8.8 × 5.9 mm with a pixel size of 2.2 μm according to the detector resolution of 4008 × 2672 pixels. Images were acquired every 7 s. The photon energy of 15 keV was selected with a W/Si double multilayer monochromator with an energy resolution ΔE/E of 1.5%.

The beam transmission was calculated via an image of the plain beam without the cell (flat field). The cell was radiographed during operation to capture the transport dynamics of the evolving liquid product water in the cell components. The amounts of water were quantified by combination with a radiographic image of the dry cell before operation.

2.2. Ex-situ tomography

After the dynamic radiographic experiments the cell was disassembled and the visualised area of the MEA including the anodic and cathodic MPL/GDL was cut out in a circular shape of 7 mm diameter for a tomography measurement. The sample size selected allows for tomographic measurements with a voxel size of 2.2 μm. The extracted material was tomographed to study the GDL structure in all three dimensions. This technique allows a tomographic material analysis even of application-oriented fuel cells of this (large) size. A tomography with this resolution of the complete cell is only possible using a specially adapted smaller fuel cell [14,18,19].

The radiographic and tomographic image data has been matched in order to compare radiographically acquired water transport dynamics with the tomographically captured three-dimensional structure. An

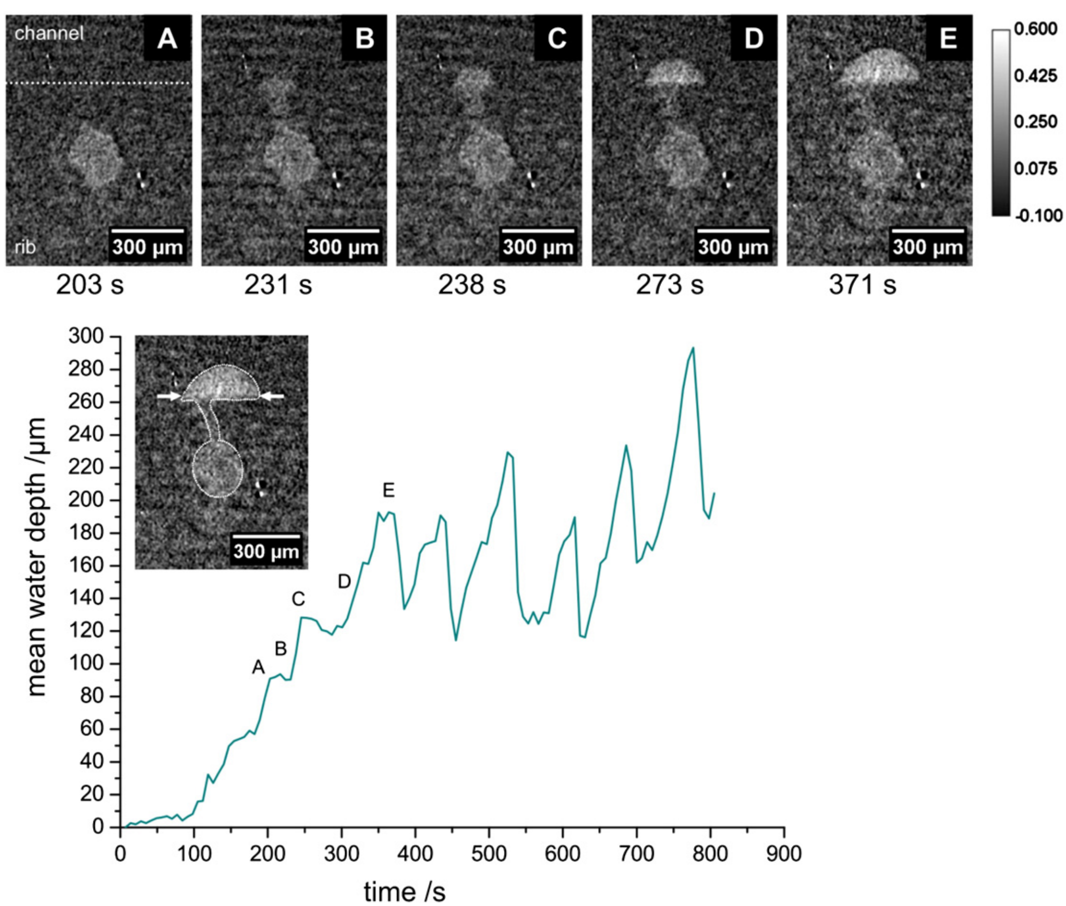

Fig. 2. Water evolution and discharge quantified by X-ray radiography right after starting operation (t = 0).