Electrochemistry Communications 13 (2011) 1001–1004

Contents lists available at ScienceDirect

Electrochemistry Communications

journal homepage: www.elsevier.com/locate/elecom

Investigation of 3D water transport paths in gas diffusion layers by combined in-situ synchrotron X-ray radiography and tomography

H. Markötter [a,*,1], I. Manke [a], Ph. Krüger [b], T. Arlt [a], J. Haussmann [b], M. Klages [b], H. Riesemeier [c], Ch. Hartnig [d], J. Scholta [b], J. Banhart [a]

[a] Helmholtz Zentrum Berlin (HZB), Hahn-Meitner-Platz 1, 14109 Berlin, Germany
[b] Centre for Solar Energy and Hydrogen Research (ZSW), Helmholtzstraße 8, 89081 Ulm, Germany
[c] Federal Institute for Materials Research and Testing (BAM), Unter den Eichen 87, 12205 Berlin, Germany
[d] Chemetall GmbH, Trakehnerstr. 3, 60487 Frankfurt, Germany

ARTICLE INFO

Article history:
Received 23 May 2011
Accepted 16 June 2011
Available online 25 June 2011

Keywords:
Polymer electrolyte membrane fuel cell (PEMFC)
Radiography
Tomography
Synchrotron X-ray imaging
Gas diffusion layer (GDL)
Water transport paths

ABSTRACT

The three-dimensional water distribution and water transport paths in the gas diffusion layer (GDL) and the adjacent micro-porous layer (MPL) of a polymer electrolyte membrane fuel cell (PEMFC) were analyzed during cell operation. The technique of quasi in-situ X-ray tomography was used for a 3D visualization of the water distribution and the structure of the GDL at different operating conditions. Based on findings from in-situ radiographic measurements water transport paths were detected and subsequently examined by tomography. The combination of these 2D and 3D techniques allows for a fully three-dimensionally resolved visualization of transport paths through the GDL.

1. Introduction

One of the major tasks in the development of polymer electrolyte membrane fuel cells (PEMFCs) is the water management [1–4]. For good proton conductivity, the membrane requires certain water content. A drying membrane loses some of its conductivity, which results in performance drops and the membrane might even undergo irreversible damage. On the other extreme, supply of the catalyst layer with reactant gases can be blocked by excess liquid water again accompanied by a detrimental impact on performance. The porous gas diffusion layer (GDL) is a key component that has to ensure optimal water management under a range of operating conditions. A goal-oriented development of GDL materials would benefit from a thorough insight into the three-dimensional water transport paths which is currently limited due to the lack of appropriate in-situ investigation techniques.

Neutron radiography is a well-established technique for non-destructive studies of water distribution during cell operation, but its spatial resolution is not sufficient to resolve individual small (10–50 μm) water agglomerates in the pores of a GDL [5–12]. In the recent years synchrotron X-ray radiography has been introduced for in-situ investigations of water in GDLs [13–16]. However the technique is limited to 2D projection imaging which does not reveal the structural details of the GDL that extend into the third dimension. On the other hand, X-ray tomography yields information about the 3D structure, but is not suited for fast in-situ measurements to analyze the dynamic water distribution [17, 18]. X-ray tomograms have been acquired in less than 1 s [19] but the X-ray intensity of the beams required in such experiments can damage the cell materials in use. Therefore, tomography with the beam appropriately adjusted, i.e. lower intensities, must be applied. In this approach, 2D in-situ measurements were employed to identify preferred paths for liquid water transport which were studied in more detail by quasi in-situ tomography.

2. Tomography setup

The presented work was carried out at the tomography station at the BAMline (Bessy II electron storage ring, Helmholtz-Zentrum Berlin, Germany) [20]. For tomographic investigations, the fuel cell was mounted on a rotation table and rotated stepwise. 1800 radiographic projections at continuing rotation angles were taken over 180° and used for the tomographic reconstruction of the cell. A gadolinium oxysulphide (GadOx) scintillator screen was used to convert X-rays into visible light. A 4008 × 2672 pixel CCD detector

* Corresponding author. Tel.: +49 30 8062 42826; fax: +49 30 8062 43059.
E-mail address: henning.markoetter@helmholtz-berlin.de (H. Markötter).
1 Present address: Helmholtz Zentrum Berlin, Hahn-Meitner-Platz 1, 14109 Berlin, Germany.

1388-2481/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.elecom.2011.06.023

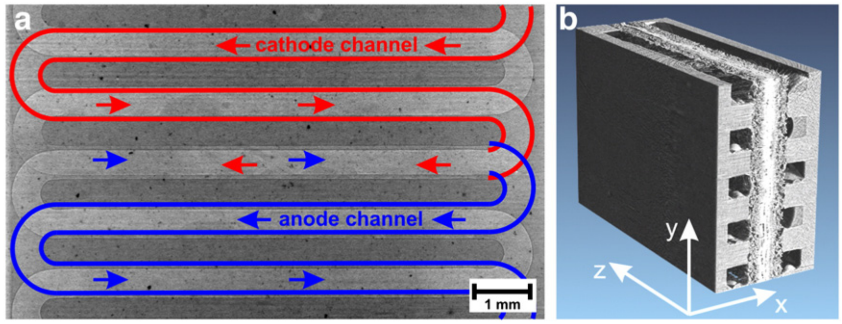

Fig. 1. a: Radiograph with marked channels of the anode and cathode including gas flow direction. b: Cutout of the reconstructed 3D structure of the cell.

(PCO4000) was used to detect the light. The field of view was about 19.2×12.8 mm² and the pixel size 4.8×4.8 μm^2. X-ray energies between 15 and 17 keV were chosen for the experiments.

3. Fuel cell setup

The PEM fuel cell investigated was specially designed and fabricated for the requirements of synchrotron X-ray tomography in terms of size and materials used. Its design ensures realistic conditions in terms of temperature and gas utilization. The anode and cathode flow fields were machined into plates of graphite as a meander-shaped single channel with a channel depth and width of 500 μm and ribs with the same width, see Fig. 1. A SGL 10 BC gas diffusion layer containing 5 wt.% PTFE and a micro-porous layer (MPL) were employed. A catalyst-coated membrane (CCM) composed of 50 μm thick Nafion 112 and platinum catalyst loading on both anode and cathode side was used. The cell was operated at a temperature of 50 °C with stoichiometries of $\lambda_a = 2$ for the anode and of $\lambda_k = 2.5$ for the cathode. Current densities ranged from 40 to 160 mA/cm². In the area of view the metallic end plates were replaced by acrylic glass to allow for sufficient beam transmission. The horizontal cross section of the cell was a rectangular area of 13×14 mm².

4. Quasi in-situ tomography

The main problem of tomographic investigations is the long measuring time necessary to obtain a sufficient amount of projections (here 1800) which takes typically 20-100 min for this fuel cell. In order to prevent water movement during this time, fuel cell operation was stopped and the gas inlets and outlets were sealed before imaging. Except for some minor rearrangement of the fluids, the configuration inside the cell is preserved for tomography in this way. This ‘quasi in-situ tomography’ technique therefore reveals three-dimensional information on the GDL structure as well as the water distribution at the time the cell was stopped. 2D in-situ radiographies

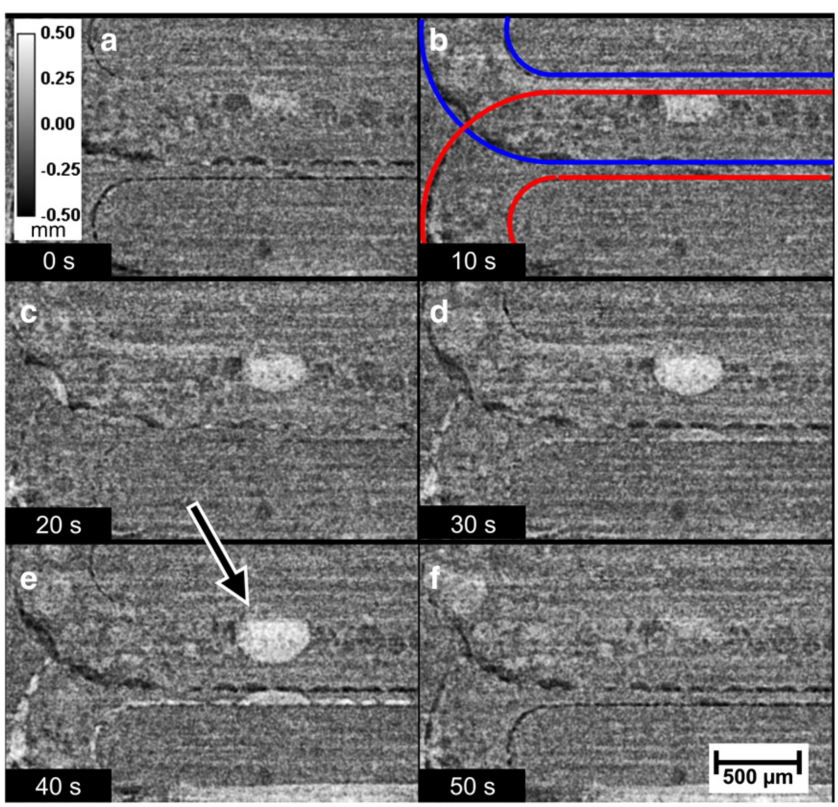

Fig. 2. a–f: Series of radiographs taken during cell operation at 160 mA/cm² current density. A droplet (marked by an arrow) in the cathode channel (highlighted in red) evolves during 45 s to about 20 nl volume.