PASSIVE WATER MANAGEMENT SYSTEM FOR PEM FUELCELLS USING MICROSTRUCTURES

T. Metz[1], S. Kerzenmacher[1], N. Paust[1], C. Müller[2], R. Zengerle[1], P.Koltay[1]
[1]Laboratory for MEMS Applications, Department of Microsystems Engineering (IMTEK),
University of Freiburg, Georges-Koehler-Allee 106, 79110 Freiburg, Germany
[2]Laboratory for Process Technologies, Department of Microsystems Engineering (IMTEK),
University of Freiburg, Georges-Koehler-Allee 103, 79110 Freiburg, Germany

Abstract: We present a novel system for the passive water management in Polymer Electrolyte Fuel Cells (PEMFC) based on capillary effects in microstructures. The system removes abundant water and secures humidity. Liquid water is removed by hydrophilic gas supply channels with a tapered cross section as presented in [1]. To prevent the membrane from drying, a non woven storage layer with a novel passive capillary overflow valve is introduced. The valve controls whether water is disposed or stored. Water is separated from the cell by gravity and evaporation. Clearing a drowned miniaturized fuel cell utilizing the new system required only two minutes. Experiments show that the design can stabilize performance during changes of the electrical load.

Key Words: fuel cell, water management, overflow valve, water removal, humidity

1. INTRODUCTION

Water management is a key issue in the design of low temperature Polymer Electrolyte Membrane fuel cells (PEMFC). Water is essential as it enables the proton transport in perfluorosulfonate membranes (e.g. Naphion®) and is part of the catalytic reactions[2]. Nevertheless, too much water blocks oxygen supply at the cathode. In the low temperature range (20 °C to 65° C) up to 95 percent of water is present in the liquid phase [2]. Water management systems in fuel cells have to prevent the cell from flooding as well as drying out.

Today’s common approach is to remove abundant water by purging the cathode flow field. This requires a limited number of meandering channels pressurized by distinct pressure sources [4]. High flow rates are required to ensure a sufficient distribution of oxygen along the extended channels [5]. It has been shown e.g. in [6] that long channels lead to inhomogeneous humidification conditions and a non optimal power generation. The membrane can dry out at the beginning of the system and liquid accumulates at the channels ends.

To prevent cells from drying out it is common to externally humidify the gases before entering the cell. That increases the system’s complexity. In particular for miniaturized systems it is preferable to use passive systems that (i) remove liquid without external actuation; (ii) do not require large pressure gradients; (iii) use only water produced during cell operation for humidification.

In the following we consider a passive water management system that uses for the water removal hydrophilic channels with a tapered cross section like presented before [1]. Such channels allow for a parallel setup of the cathode flow field which therefore can be driven by moderate pressure gradients. Additionally a non woven layer is used for storage and discharge of water. Furthermore, a novel capillary overflow valve is realized by a gap in the non woven material which controls whether liquid is discharged or stored.

2. WORKING PRINCIPLE

The considered fuel cell design is shown in Fig. 1. In Fig. 2 the principle of the passive water management system is depicted as a chain of five capillary active features. The driving pressure is the sum of ambient pressure minus capillary pressure and gravitational pressure:

$$p = p_0 - p_{cap} - p_{grav} \tag{1}$$

In Fig. 2 the pressure decreases in average from. Water follows this direction out of the fuel cell. The overflow valve introduces a local

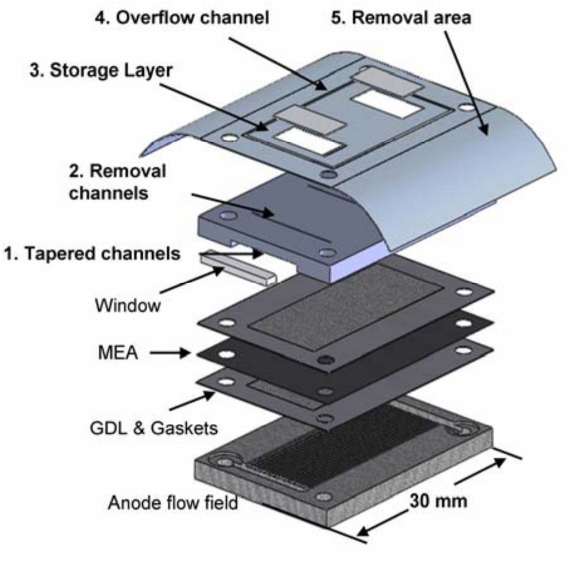


Fig. 1: Design of the fabricated fuel cell utilizing the water management system.

pressure maximum that switches the flow passively.

2.1 Flowfield channels

The cathode flowfield (Fig. 2 detail 1) is built up from hydrophilic channels with a tapered cross section [1]. The narrow end of the channels profile is directed away from the MEA/GDL. In Fig. 3 the working principle is shown by CFD simulations, droplets are lifted from the MEA/GDL into a secondary channel.

Since such a channel cannot be clogged by water the cathode flowfield can be set up of parallel channels. A secondary channel at the top of the tapered section distributes water along the whole channel by capillary forces, supporting a homogenous cell humidification.

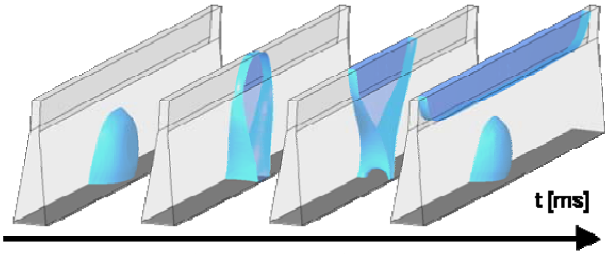


Fig. 3: Simulation of droplets rising in the tapered channels using ESI-CFD ACE+.

2.2 Removal Channels

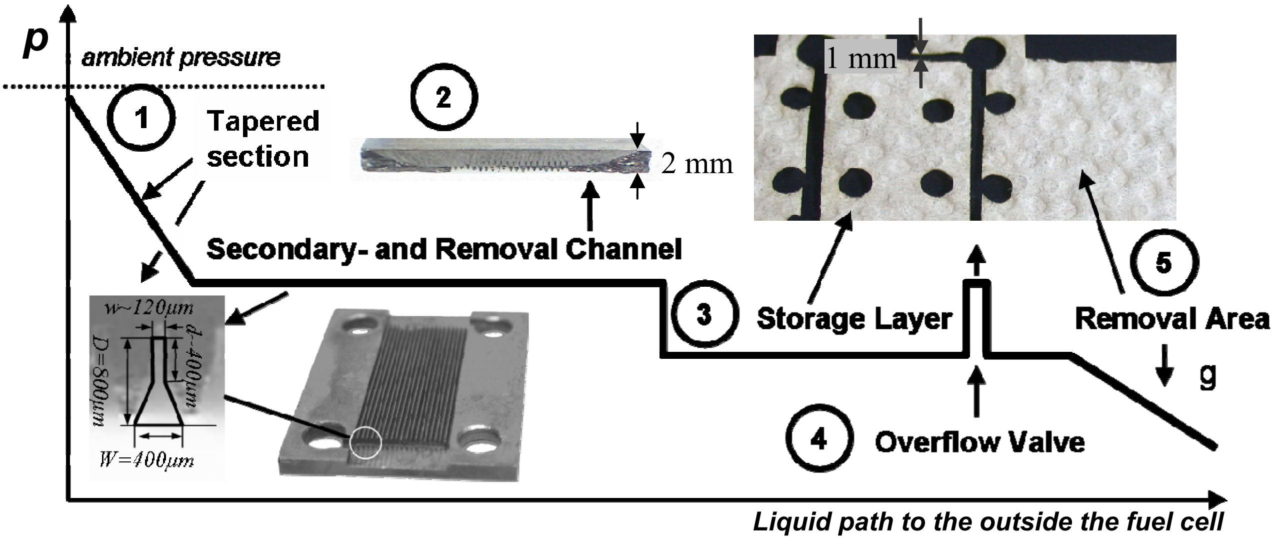
The cathode flowfield has channels bridging the supply channels to the backside (Fig. 2 detail 2). The capillary pressure of these removal channels must be equal or higher than the capillary pressure of the secondary channels in the flow field. Because of the high aspect ratio the capillary pressure of the channels is given by their width *w*,

$$p_{cap} = \frac{\sigma \cos\theta}{w}. \qquad (3)$$

In the fabricated cell the width of the removal and the secondary channels is equal with w = 120µm.

2.3 Non Woven Storage Layer

A non woven layer at the back side of the cathode works as so called storage layer and removal area (Fig. 2, detail 3; 5). The non woven materials capillary pressure is higher than that of the removal channel and liquid is further transported into the storage layer.



Fi. 2: Schematic of the pressure distribution along the liquid path consisting of five elements. The liquid moves from left to right following the decrease in pressure.

2.4 Capillary overflow valve

The capillary overflow valve (detail 4 in Fig. 1) is realized as a gap separating the non woven materials into storage layer and removal area.

Once the storage layer is completely water saturated while there is still liquid in the tapered part of the flowfield channels, the gap is flooded and liquid is transported into the removal area. When the flowfield is cleared, the liquid content in the storage layer is held back while the removal layer empties the overflow valve.

The height of the gap is equal to the height of the non woven material and controlled by spacers. It must be larger or equal to the width of the secondary channels in the flowfield to ensure that these are not cleared. In the present design conductive graphite spacers of 200µm are used.

2.5 Removal Area

The removal area is built up from the outer part of the non woven layer (detail 5 in Fig. 2) which is partly overhanging. Liquid in the removal area is either evaporated or drips off by gravity. The dripping ensures the removal of water even if evaporation is not sufficient.

It is possible when the gravitational pressure of the vertical liquid column in the non woven material overcomes the capillary pressure in the non woven material. Experimentally the minimum necessary height of the overhanging part was found to be 20mm for the used material.

3. FABRICATION

The water management system was implemented in a fuel cell as depicted in Fig. 1. The total size of the active fuel cell area is 8 x 14 mm^2.

The flowfields (Fig. 2, detail 2) were milled in conductive graphite composite material (Sigracet, BBP 4).The cathode flowfield has 20 channels with a maximum width $W = 400µm$ at the GDL and a minimum width $w = 120µm$ at the secondary channel. The tapering angle of the channels is $2\alpha = 30°$ and the maximum depth is $D = 800µm$. The depth of the secondary channel is $d = 400µm$. The secondary channels were fabricated by sawing. The tapered section was milled with a tapered tool. The cathode channels were closed by a transparent polymer window (800µm x 10mm).

The removal channels ($d = 1200µm$, $w = 120µm$) were sawn into the flowfield from the backside. The flowfield was grafted hydrophilic by plasma treatment leading to a contact angle $\theta < 20°$. As non woven material cellulose tissue was used. The total liquid capacity of the storage layer was measured gravimetrically to be 38 µl.

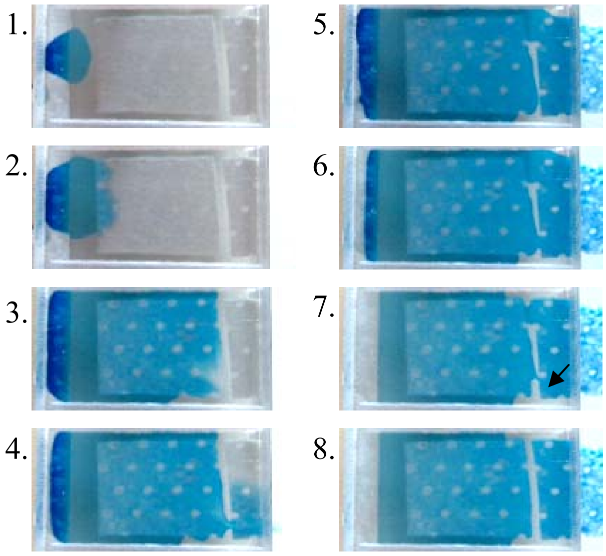


Figure 5: Movement of liquid in the model system. The tapered channel is at the left side.

4. EXPERIMENTS

4.1 Model System

The working principle has been proven first in a transparent model setup where the tapered channel was milled into the edge of the sample. Results are shown in Fig. 5: (1-3) Liquid introduced in the tapered section at the edge of the sample spreads through the removal channel into the non woven storage layer. (4) The overflow valve is flooded and the removal area gets wetted. (5-7) After the inlet flow is stopped the tapered section gets cleared. (7-8) The overflow valve opens and the capillary drain of liquid from the storage section is stopped.

The model system was used further to characterize the water removal by dripping for different non woven materials. At least 20mm of vertical length were necessary for the gravitational dripping to work in all cases. With increasing vertical length of the non woven material the clearing times decreases. In the model system the

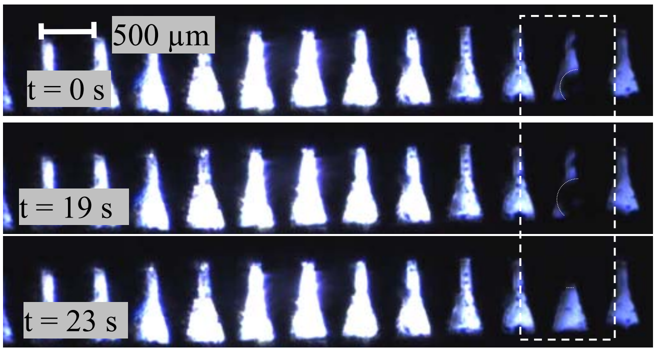


Fig. 6: Photographs of the cathode during operation ($j=133mAcm^{-2}$). A droplet grows and moves upwards.

non woven layers heigth (200 µm) and the dimensions (15mm x 20mm) are comparable to the fabricated fuel cell.

4.1 Fuel Cell Experiments

The removal of water as described before was observed in fuel cell experiments along the fuel cell channels during operation (Fig. 6).

When drowning the complete cell with water, the cathode channels could be cleared in two minutes.

To study the beneficial effect of the proposed design against drying, the cell was operated with a surplus of dry air while periodic switching between two different load points. In Fig. 7 the derived performance over time for four varying cell setups is shown.

Using standard rectangular channels (black graph) the performance decreases at the lower load level. This results from drying of the membrane through the air flow that can not be compensated by product water. At the higher load level enough water is produced to keep the cell humidified and the performance is nearly stable in all cases. Nevertheless with the rectangular channels the higher performance level is not always recovered.

For the cell setups utilizing the tapered channel design the performance was more stable. No significant difference was found between the different setups. This suggests that the storage of water in the secondary channels is large enough to stabilize the fuel cell in the performed experiments.

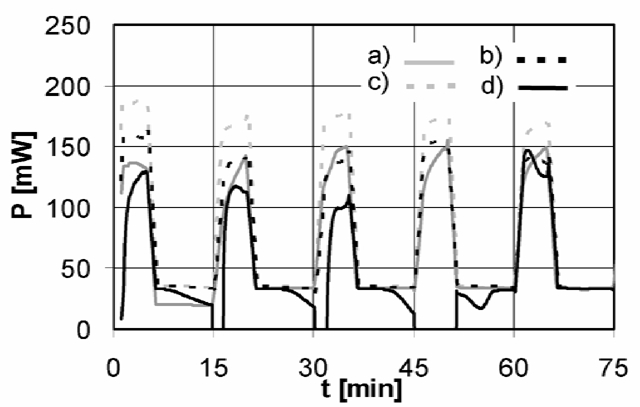


Fig. 7: Performance during load cycling ($j_{min}=45\ mAcm^{-2}$; $j_{max}=266\ mAcm^{-2}$) with four setup variations: a) complete; b) no gap; c) no storage layer; d) rectangular channels; (airflow = 30ml/min)

5. CONCLUSION & OUTLOOK

A novel system for the passive water management in fuel cells was proposed, designed and successfully implemented in a miniaturized fuel cell. The working principle was proven and studied in detail. In a first test sequence the system was able to stabilize the fuel cell against drying out. More experiments will be performed in the future to investigate the behaviour of the system under various conditions.

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