

INFLUENCE OF SIZE SCALE OF FLOW FIELD STRUCTURE ON FUEL CELL PERFORMANCE

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Abstract: This paper presents a comprehensive analysis of a PEM micro fuel cell with self-breathing function on the cathode side and with micro structured flow fields by the use of a numerical model and experimental characterization. The design of the flow field structures is directly dependent on the fabrication technology. Nevertheless, an optimization of structure dimensions is possible within the design space. A model is presented, which describes the influence of the aspect ratio of the channel width and the landing of the micro flow field. The fuel cell performance is limited by electrical losses in electrode layer for small channel width and by reactant transport by large channel width.

Key Words: planar micro PEMFC, PEMFC model, geometry variation

1. INTRODUCTION

Fuel cell systems are increasingly perceived as a possible solution for improved power sources in portable applications. Fuel cells based on Polymer Electrolyte Membranes (PEM) are well known for high energy density and ease of scaling application-specific power requirements. Today, the production of fuel cells is coupled with high manufacturing costs. Crucial for the successful design of fuel cells is an understanding of how the design and manufacturing processes influence performance. In our approach no gas diffusion layers (GDLs) are used in order to achieve a simple fabrication technology. This simplification entails higher transverse losses between the flow field landings in the catalyst layer.

This paper presents a model for the theoretical study of a planar self-breathing PEMFC with micro structured flow fields of the anodic and cathodic current collectors.

Printed circuit board (PCB) technologies for the micro patterning of the flow field structures like wet etching and galvanic deposition are investigated in order to evaluate limits of the technologies. Based on these technology limits and the modeling results an optimized flow field design can be realized which builds the bridge between best fuel cell performance and low cost fabrication technology of the anodic and cathodic current collectors with integrated, micro structured flow fields.

2. MODEL

2.1 Model Approach

The numerical model presented here is a two-dimensional, isothermal, stationary model of a complete planar self breathing PEMFC including current collectors, flow field, and MEA. Figure 1 shows a schematic cross section of the studied micro PEMFC. The electrochemical reactions are described by the Tafel equation. The potential and current balance equations are solved separately for the protons and electrons. The charge transport of electrons and protons is described by a charge balance equation in combination with the Ohm's law. The mass transport of the gaseous species (H_2 , O_2 , H_2O , N_2) in the electrodes and channel zones is described using the Maxwell-Stefan equation. The source and sink terms of the gaseous species are coupled with the electrochemical reaction rates which are located in the catalyst layers.

The product water is assumed to generate in the gas phase. The water transport across the membrane is described using a concentrated solution approach. The phase change of water is neglected. Heat transport is not taken into account in this model. Hydrogen gas flow in the anode flow field is not taken into account due to high stoichiometric ratios in the experiment and fast anode kinetics. Therefore only gaseous diffusion is assumed to limit the supply of hydrogen at the anodic electrode.

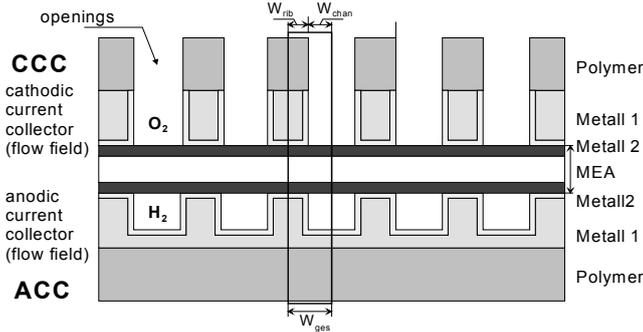


Fig. 1: schematic cross section of a self breathing micro PEMFC

2.2 Model Geometry

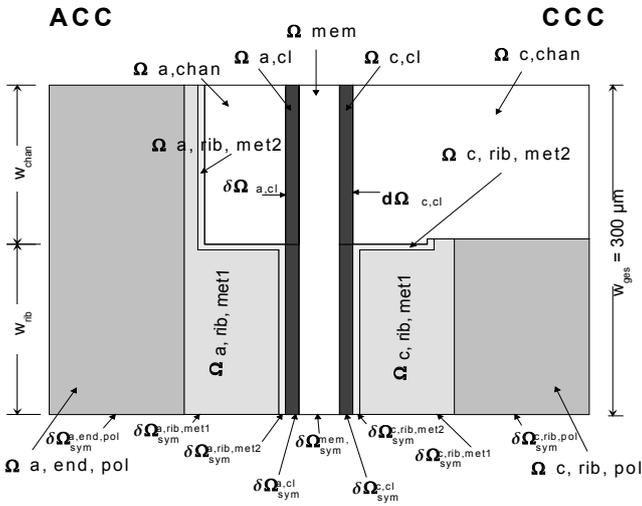


Fig. 2: schematic picture of the modeled fuel cell geometry

subdomain	name	dim [μm]
$\Omega_{a,end,pol}$, $\Omega_{c,rib,pol}$	anode / cathode endplate (polymer)	100
$\Omega_{a,rib,met1}$, $\Omega_{c,rib,met1}$	anode / cathode metal layer 1	70
$\Omega_{a,rib,met2}$, $\Omega_{c,rib,met2}$	anode / cathode metal layer 2	5
Ω_{mem}	membrane	25
$\Omega_{a,cl}$, $\Omega_{c,cl}$	anode / cathode catalytic layer	10
$\Omega_{a,chan}$	anode channel depth	60
$\Omega_{c,chan}$	cathode opening	

Table 1: Dimensions of the subdomains used in the simulation

The two-dimensional model geometry which was used represents a symmetry element of the real geometry which has to be thought of as being a repeating part of the real cell geometry in figure 1. Figure 2 shows a schematic drawing of the modeled symmetry element fuel cell. Domains are marked with Ω and boundaries with $\delta\Omega$. Anode (ACC) and cathode (CCC) are on left and right side respectively. The table 1 gives an overview of the dimensions of the fuel cell which was simulated.

2.3 Governing Differential Equations

The mass balance is taken into account on the cathode and on the anode by the divergence of the diffusive mass flux. This diffusive mass flux is described using the Maxwell-Stefan equation set up on a mass basis.

$$\nabla \cdot \left[-\rho_{c,a} w_i \sum_{j=1}^N D_{ij} \frac{M_c}{M_j} \left(\nabla w_j + w_j \frac{\nabla M_c}{M_c} \right) \right] = Q_i^M \quad (1)$$

The density of the gas mixture on the cathode side is given by

$$\rho_c = M_c \frac{P_{ref}}{RT} \quad (2)$$

with

$$M_c = M_{O_2} x_{O_2} + M_{N_2} x_{N_2} + M_{H_2O} x_{H_2O} \quad (3)$$

and for the anode side

$$\rho_a = M_a \frac{P_{ref}}{RT} \quad (4)$$

with

$$M_a = M_{H_2} x_{H_2} + M_{H_2O} x_{H_2O} \quad (5)$$

The charge transport of electrons ($l=e$) and protons ($l=p$) is governed by a charge balance in combination with the Ohm's law:

$$\nabla \cdot j_l = q_l \quad (6)$$

$$j_l = -\sigma_l \nabla \Phi_l \quad (7)$$

j_l denotes here the current density, q_l the source terms for the current and σ_l stands for the electronic and ionic conductivities.

2.4 Source Terms

Sources and sinks for the current are only located in the catalytic layer ($\Omega_{a,cl}, \Omega_{c,cl}$). The kinetics of the electrochemical reactions is approximated by the Tafel approach [2].

$$q_c = a \cdot j_{0,c} \frac{x^{O_2}}{x_{ref}^{O_2}} \exp\left(-\frac{2\alpha_c F}{RT} (\Phi_e - \Phi_p - \Delta\Phi_c^{ref})\right) \quad (8)$$

$$q_a = a \cdot j_{0,a} \frac{x^{H_2}}{x_{ref}^{H_2}} \exp\left(\frac{2\alpha_a F}{RT} (\Phi_e - \Phi_p - \Delta\Phi_a^{ref})\right) \quad (9)$$

a indicates the active surface of the Pt-catalyst per volume, $j_{0,c}$ and $j_{0,a}$ are the exchange current densities of the oxygen reduction reaction in the cathode and the hydrogen oxidation reaction in the anode at reference conditions. $\Delta\Phi_{c,a}^{ref}$ describes the potential difference between the electrode and membrane phases at equilibrium conditions.

The source terms of the potential equation (6) are:

$$q_e = \begin{cases} -q_a & \text{in } \Omega_{a,cl} \\ q_c & \text{in } \Omega_{c,cl} \end{cases} \quad (10)$$

$$q_p = \begin{cases} q_a & \text{in } \Omega_{a,cl} \\ -q_c & \text{in } \Omega_{c,cl} \end{cases} \quad (11)$$

3. EXPERIMENTAL MEASUREMENTS

Prototypes of self-breathing PEM fuel cells with a size of 1 cm x 2 cm and 400 μm thickness were realized in order to compare the measurement and modeling results [5], [6].

The prototypes are fabricated by using PCB technology. Based on a 100 μm FR4 substrates a laminated Cu-layer with a thickness of 70 μm is patterned by wet etching. Long term stability of the metal layer is achieved by using an Au

protection layer. The openings for the hydrogen in- and outlet and for the openings on the cathode side are realized by LASER cutting. The figure 3 shows the planar PEMFC with an active area of 2 cm^2 .

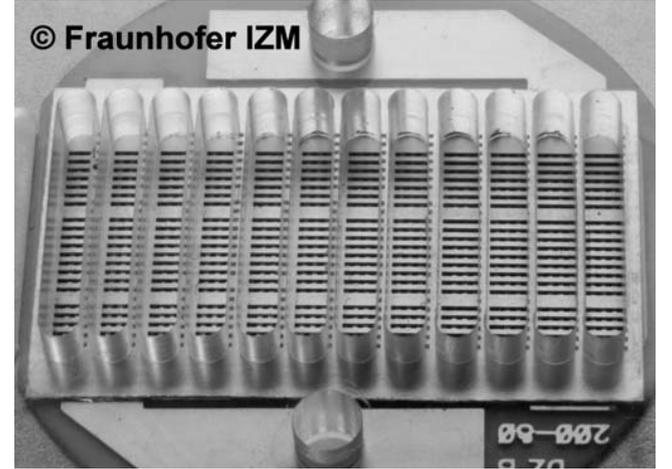


Fig. 3: prototype of a PEMFC based on PCB fabrication technologies

In analogy to the simulation different anodic flow field designs are realized. Based on a constant Pitch of 600 μm the landing of the flow field structure is varied from 100 μm to 500 μm .

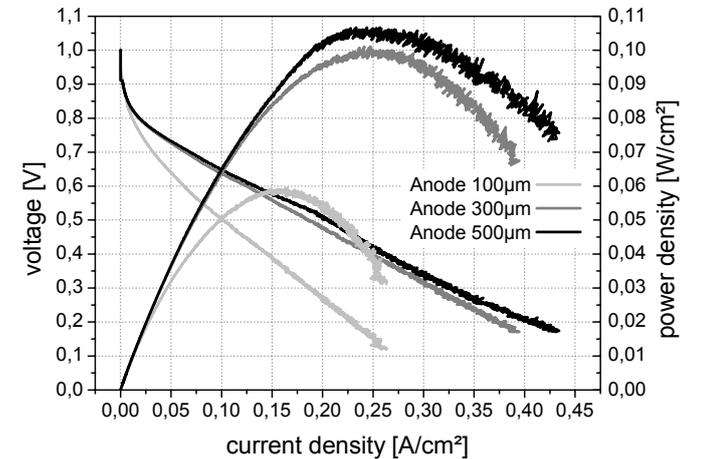


Fig. 4: measured polarisations curves and power density for an anodic landing of 100, 300 and 500 μm

Figure 4 shows the measured polarization curves and the power density as a function of the current density for three different designs of the anodic flow field. The cathodic flow field structure and the size of the opening are constant

for all cells. A maximal power density of 105 mW/cm² could be achieved with a channel width of 100 μm and a landing size of 500 μm.

All measurements are carried out at room temperature, constant dry hydrogen supply and natural convection on the cathode side.

4. DISCUSSION

The validation of the model is performed by comparison of measured polarization curves of different fuel cells with a variation of the anodic flow field design. The polarization curves resulting from the simulation for the corresponding geometric variation are depicted in figure 5, together with the experimentally measured results.

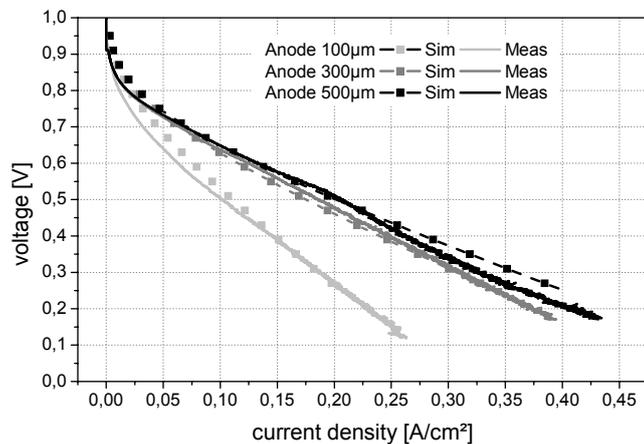


Fig. 5: Simulated and measured polarization curve for the variation of anode flow field geometry

The model results are shown a good correlation with the measured polarization curves. The differences between the various anodic flow field geometries are for small landings of the flow field substantial. For increasing channel width the electrical lateral losses are dominating. The transport limitations of the hydrogen for decreasing channel width have a marginal effect on the fuel cell performance.

5. CONCLUSION

A simplified, two-dimensional, isothermal, steady-state numerical model for the simulation of planar self breathing PEM fuel cells without gas diffusion layers has been developed.

Simulations were carried out for a variety of anodic flow field geometries. Significant limitations due to lateral electrical losses were observed in the simulated polarization curves.

For increasing channel width of the anodic flow field structure the electrical lateral losses due to the low electrical conductivity of the catalytic layer are dominate the fuel cell performance.

The presented numerical model gives a better understanding of the impact of the dimensions of anodic flow field structures for micro PEMFCs without gas diffusion layers. This design of a PEM micro fuel cell is very interesting for low-cost mass production based on printed circuit board technologies [7]. The design of the flow flined structures is directly dependent on the fabrication technology and the manufacturing costs. Nevertheless, an optimization of structure dimensions is possible within the design space.

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