

Short communication

Evaluation of current distribution in a proton exchange membrane fuel cell by segmented cell approach

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Abstract

A technique is developed for the determination of the distribution of current density in operating fuel cells using a segmented cell structure concept. Real-time current density distribution data are presented and it is shown that they can contribute to an improved understanding of the reactant distribution over the active fuel cell area, for optimization of fuel cell performance. The technique also offers an alternative to a commercial polymer electrolyte membrane fuel cell stack in the small power range. When stacking several segmented structure electrodes, the resulting volume can be considerably reduced compared with a state-of-the-art stack.

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1. Introduction

Fuel cells are electrochemical devices in which the storage of the chemical energy is separated from the location of the conversion reaction. Consequently, reactants have to be supplied adequately to the electrode, and the reaction products have to be removed from the cell immediately. This is a problem when using electrodes with large areas. Also, the configuration of the inlet and the outlet channels play a significant role in the optimization of fuel cell performance. Design of the flow field considerably influences the occurrence of local concentration gradients, which strongly affect the local electrochemical reaction rate. It is expected that it would be more difficult to provide optimum reactant, water and temperature distribution over the area of larger cells and, unless resolved, would result in non-uniform current distribution. Poor current distribution could result in poor reactant and catalyst utilization, reduced energy efficiency, and corrosion processes in the cell.

In order to achieve maximum performance from commercial-scale fuel cell, optimization of electrochemical activity over the electrode area is of prime importance. During operation, inhomogeneities in reactant flow distribution, current distribution, etc., cannot be recognized because

usually only integral measured values such as cell voltage, current and impedance are obtained. In order to obtain local measurements a modification of the fuel cell is necessary. This modified cell must ensure sufficient resolution at reasonable expenditure. Furthermore, both the steady-state and the dynamic operation must not be affected and the design should allow integration in a fuel cell stack.

A number of methods of measuring current distribution in electrochemical cells have been reported [1–4].

Stumper et al. [5] determined the current density distribution by means of a partial membrane electrode assembly method (the sub-cell method) and using a current mapping technique. Heinzl et al. [6] attempted current mapping by employing the banded structure membrane concept for low-power applications of proton exchange membrane fuel cells (PEMFCs). Measurement of current distribution has recently been reported [7] for a circular active electrode area and flow channels arranged in pie-shaped sections. Nguyen and White [8] studied the current distribution at high current densities for three different anode humidification strategies and a dry cathode feed. The printed circuit board approach was used by Cleghorn et al. [9] to measure current distribution in PEMFC, which had 100 cm² hardware and incorporated seven channel serpentine flow fields on both the anode and the cathode sides of the cell. A new approach was adopted by Wieser et al. [10] to study the current gradients in a PEMFC using a magnetic loop array based on a technique similar to a d.c. current clamp. This

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technique is tedious, since each segment requires a separate Hall sensor for current mapping.

In the present work, the segmented cell approach has been used to measure the current distribution for optimization of fuel cell performance. This method has been exploited to determine the current distribution in an active area of 370 cm^2 segmented into 6 and 12 parts. In this segmented cell, several electrically isolated cells are placed at conveniently chosen locations in the membrane and they are controlled independently to allow voltage and current measurements. Typical experimental results are shown for two different, segmented membrane, electrode assemblies under various humidifying conditions, and the benefits and limitations of this approach are discussed.

2. Experimental details

A large fuel cell with an active electrode area of 370 cm^2 was designed. Disregarding lateral currents in the membrane electrode assembly, a zee-type flow-field design is chosen and is divided into 12 and 6 segments, as shown in Fig. 1(a) and (b). The dimensions of each segment in the 12-segment electrode were different, in order to utilize the maximum active area. There are about 6 numbers of 20 cm^2 segments, 4 numbers of 16 cm^2 segments, and 2 numbers of 25 cm^2 segments, as shown in Fig. 1(a). In the other electrode, an active area of 300 cm^2 is chosen and 6 segmented electrode with the same area, viz. 30 cm^2 , were pressed on to a Nafion[®] membrane at equal intervals (Fig. 1(b)). The flow-field design incorporated 5 passes and 3 passes for 12 and 6 segments, respectively, for both the anode and the cathode sides of the cell. In order to control each of the segmented cells independently, the cells must be electrically isolated from each other. This was achieved by punching square sections from the insulating, acrylic, flow-field plate and replacing these sections with conducting graphite plates of same dimension. In all the segments, between the acrylic and the graphite plates, copper foil was provided for current collection. A hole of 2 mm was diameter drilled at the center of the acrylic sheet, from all the segments for current collection.

The gas diffusion electrodes were prepared with 20 wt.% Pt on carbon and were hot pressed on a Nafion[®] membrane at suitable temperature and pressure. The electrodes were segmented by cutting silicon gasket material in a grid structure, with the cut-out areas filled with the gas diffusion electrode, to match the pattern of flow-field design in the reactant flow plate. The membrane and electrode were assembled so that the anode and cathode areas were positioned opposite to each other and, thereby, formed a segmented cell.

The segmented cells were labeled according to their location in the flow fields. For each segmented sub-cell, four wires were required for sensing the voltage and the current. Each of the segmented cell were controlled by separate load banks, which allowed independent adjustments of the respective

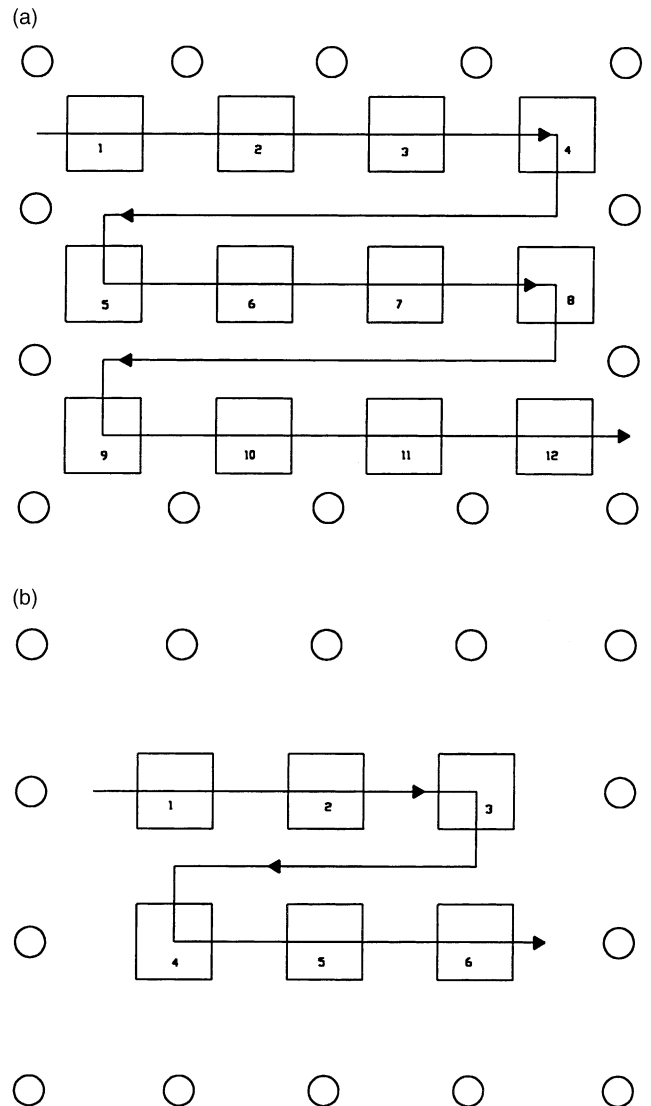


Fig. 1. (a) 12 segmented membrane electrode assembly; (b) 6 segmented membrane electrode assembly.

cell currents. The whole assembly was tightened with the help of tie rods, bolts and nuts. Reactant humidification, gas flow rates, and the temperature were controlled from a fuel cell test station. The strength of the segmented current-collector approach is its simplicity. The measurement plate functions as a normal bipolar plate with no additional devices integrated into the plate.

For cell operation, the current lines from the cell were connected to an electronic load box HP 6050A with the help of a specially designed switch box, with a two-way switch that operates such that if there is load being drawn in one segment, other segments are in a no-load condition. The load box was activated by a voltage sensor from one of the segments through the switch box. To monitor the current of the individual segments, each of the other segments were uncoupled in turn from the other on the switch board, and then the individual segment was monitored with the help of the load box. While the performance of one segment was

monitored, the remainder of the cell operated under normal conditions with no load. That is, the performance of a single region of the cell could be investigated while the consumption of reactant and the generation or uptake of water throughout the cell was the same as that expected while the cell operated normally. The segmented plates were also

joined in series by connecting the positive of segment 1 with the negative of segment 2, whose positive was connected to the negative of segment 3, and so on. The negative of the first segment and the positive of the last segment were connected to the load box. This process is equivalent to connecting individual cells of the same number in stacks, which can

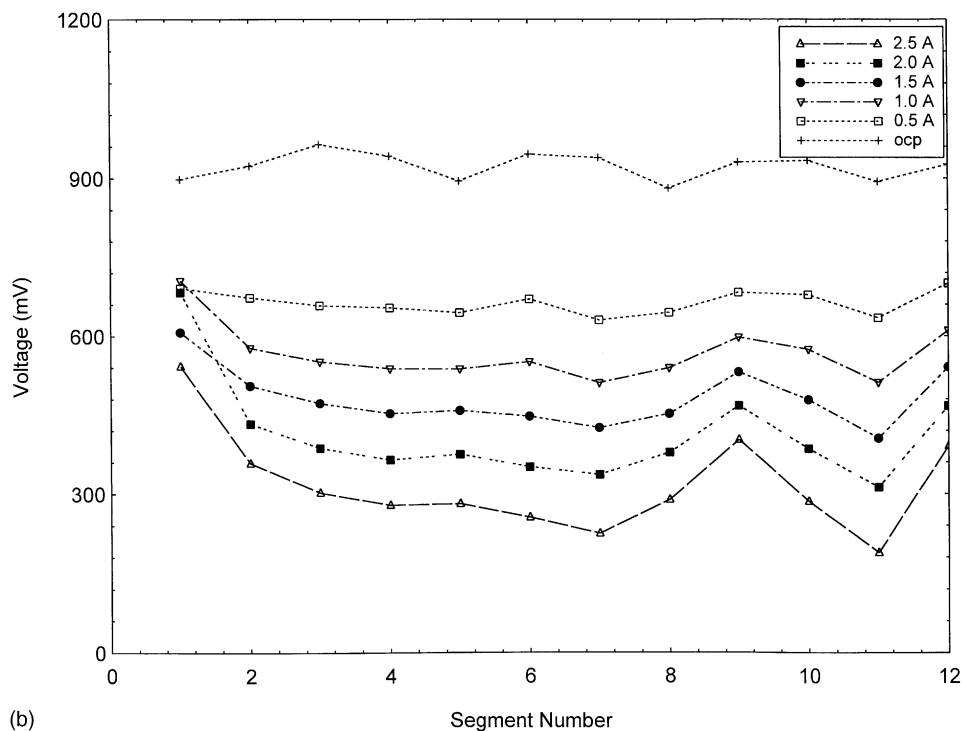
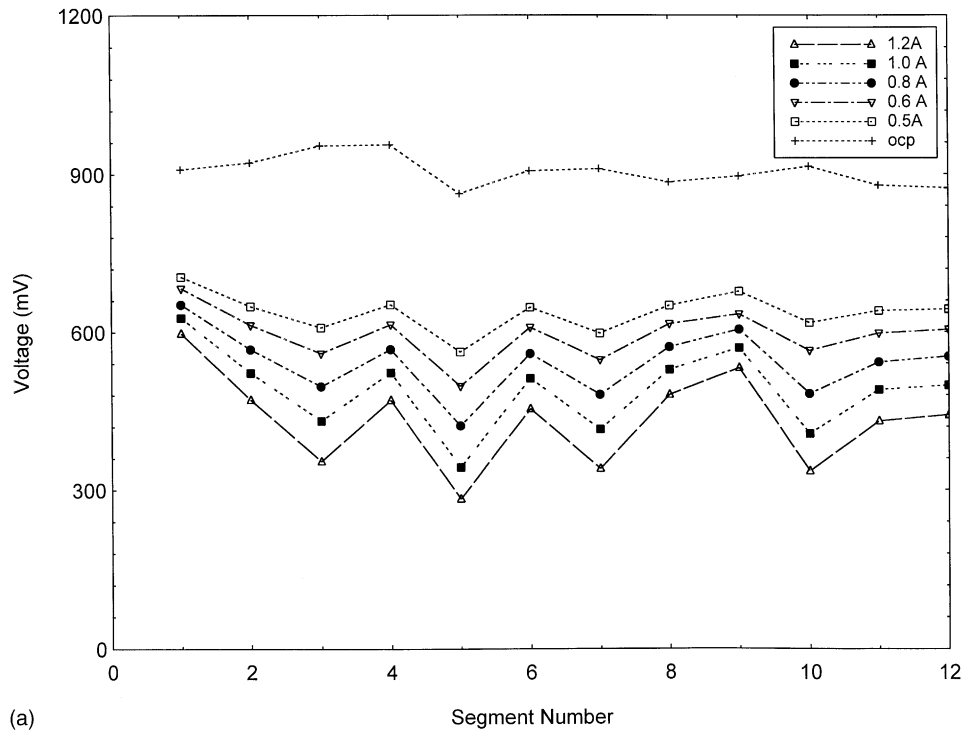


Fig. 2. Fuel cell performance for 12 segmented cell (a) at ambient conditions and (b) with humidified reactants.

operate at high voltage and low current values, that are used in cellular phones, radios, etc.

The cell operating conditions were varied significantly to determine the effect of anode and cathode humidification on the current distribution. The results for current distribution are plotted such that hydrogen inlet is at segment 1. The segment numbering system then follows the path of hydrogen along the flow-field channels from 1 to 12 to the hydrogen outlet at segment number 12. The flow-field plates typically have flow channels on their surfaces. The channel geometry may be different on the anode and on the cathode. Flow directions on the electrodes may also be different with respect to each other. In addition to co-flow, counter- and cross-flow patterns are also possible. The oxygen inlet, on the opposite side of the membrane, is at segment 4 and flows counter to hydrogen.

3. Results and discussion

Polarization curves are shown in Fig. 2(a) and (b) for a membrane electrode assembly of 12 segments under ambient conditions and at humidified conditions for various current ratings. Both graphs show a better performance at the bends near regions 4 and 9, which can be attributed to a better residence time. The improper gas distribution is due to the pressure drop which occurs along the channel length. It is also clear that the voltage drop at segment numbers 5 and 10 are due to the improper gas distribution, as the gas travels a long path from segment 4 to reach segment 5. The non-uniformity in the voltages at higher current densities are

reduced considerably when the humidified reactants are used. As the humidification of the reactant gases is increased, there is a slight decrease in performance at segment 9, which could be due to the excess humidification as well as collection of product water from the segment 1 to 9. Further increase in humidification temperature leads to poor performance at segments 9–12, due to the flooding of the electrode inside the cell. Similar trends are observed when the segmented electrode is replaced by a continuous membrane electrode assembly, as shown in Fig. 3. Nevertheless, the non-uniformity in the performance of the cell is high compared with the segmented electrode, because of the lateral currents along the surface of the electrode.

Since the choice and optimization of the flow-field geometry of the bipolar plates affects strongly the performance of the PEMFC, especially through water management and the distribution of gases to the electrodes, another flow-field design was made with six segments in such a way as to reduce the number of passes, in order to have uniform distribution of the reactants throughout the flow-field area. The performance characterization of the six-segment electrode assembly is shown in Fig. 4(a) and (b) with respect to two different compression forces used to tighten the bolts and nuts, which helps in improving the interfacial contact between the current-collector and the gas-diffusion layer. From the data in Fig. 4, it is clear that there is little non-uniformity in the fuel cell performance at all current densities, except near segment 2. This is attributed to the long path taken by the gas to reach segment 3. Even though there could be some velocity of the gas at segment 2, since there is

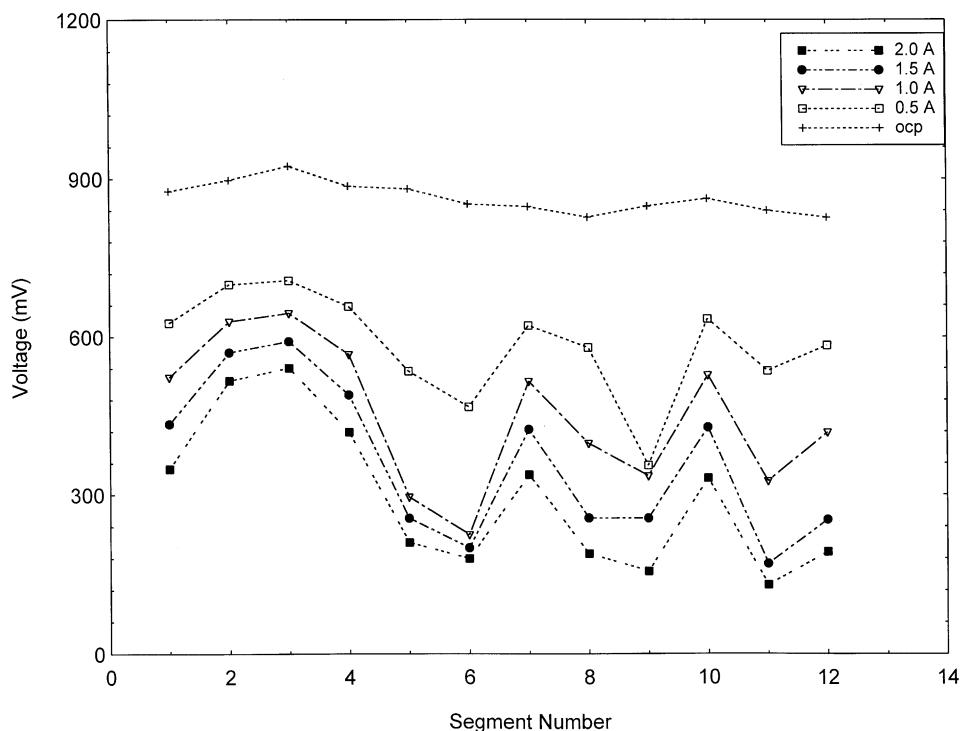


Fig. 3. Polarization curve for continuous membrane electrode assembly.

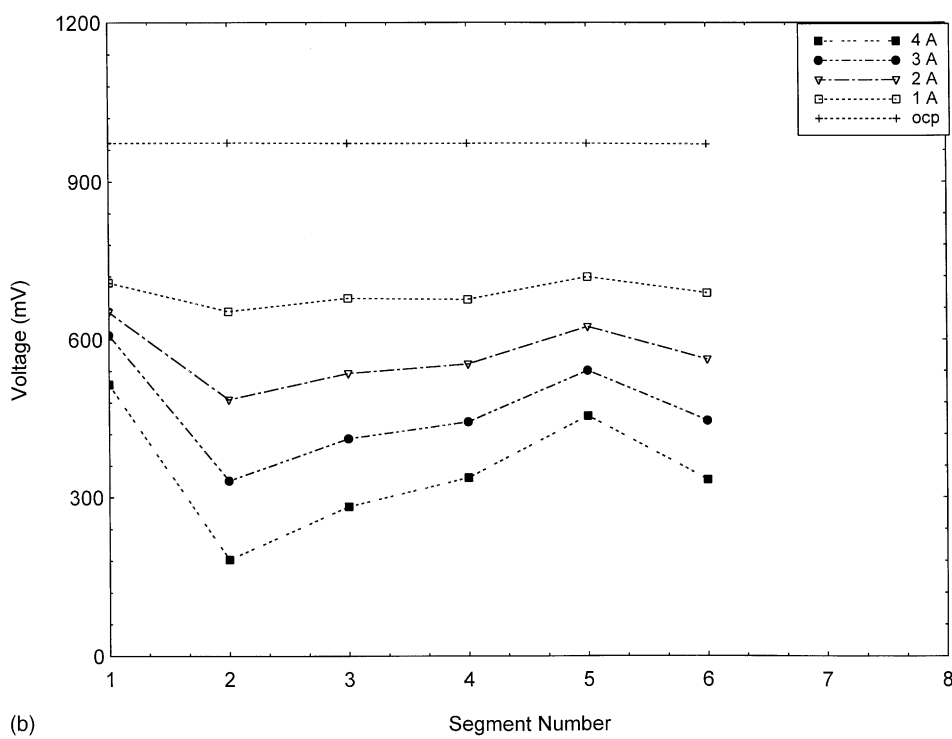
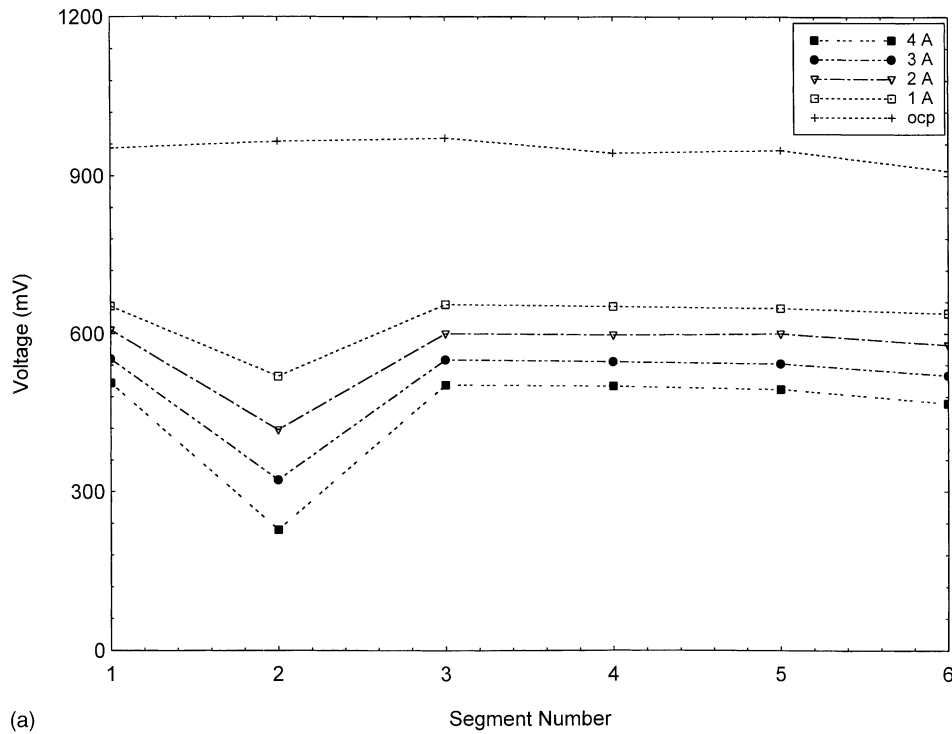


Fig. 4. Performance of 6 segmented fuel cell (a) at ambient and (b) with humidified reactants.

no residence time for the gas to react with the catalyst layer, a performance degradation occurs.

In all these measurements, individual segments show some fabrication-dependent variations in current from segment to segment. These appear as some noise superimposed on any trend detected along the flow channel. These variations in

performance of individual segments in the cell could be due to the differences in the interfacial contact between the catalyst layer, gas-diffusion layer, and the current-collector. This variation is relatively small at voltages less than 0.7 V, which increases with higher current density. Proceeding from the inlet to the outlet through the flow channel, the segment

performance decreases at the lowest operating voltage, which is an indication that the humidification is insufficient.

4. Conclusions

The main reason for establishing a method for the measurement of current distribution in PEMFCs with large-area electrodes is to understand the flow distribution and water management under the operating conditions of the cell. This diagnostic tool can be useful when the stacks are being developed. The flow-field design can be optimized based on the segmented performance. It may be a better option to separate the electrode into a greater number of segments to provide a better understanding than with fewer segments.

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References

- [1] A. Stock, F. Coeuret, *Electrochim. Acta* 22 (1977) 1155.
- [2] L.R. Czarnetski, L.J.J. Janssen, *J. Appl. Electrochem.* 19 (1989) 630.
- [3] W.W. Folke, *Electrochim. Acta* 28 (1983) 1137.
- [4] C.J. Brown, D. Pletcher, F.C. Walsh, J.K. Hammond, D. Robinson, *J. Appl. Electrochem.* 22 (1992) 613.
- [5] J. Stumper, S.A. Campbell, D.P. Wilkinson, M.C. Johnson, M. Davis, *Electrochim. Acta* 43 (1998) 3773.
- [6] A. Heinzl, R. Nolte, K. Ledjeff-Hey, M. Zedda, *Electrochim. Acta* 43 (1998) 3817.
- [7] P. Adcock, P. Mitchell, J. Moore, in: *Proceedings of the Fuel Cell Seminar, San Diego, CA, 1996*.
- [8] T.V. Nguyen, R.E. White, *J. Electrochem. Soc.* 140 (1993) 2178.
- [9] S.J.C. Cleghorn, C.R. Derouin, M.S. Wilson, S. Gottesfeld, *J. Appl. Electrochem.* 28 (1998) 663–666.
- [10] C. Wieser, A. Helmbold, W. Schnurnberger, 1999, personal communication.