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Separate measurement of current density under land and channel in Direct Methanol Fuel Cells

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HIGHLIGHTS

- Current densities under the land and channel are separately measured in DMFCs.
- Current density is much higher under the land than that under the channel.
- The main reason for the higher current density is the much higher ECA under the land.

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ABSTRACT

The knowledge of where current density is higher, under the land or channel in a direct methanol fuel cell (DMFC) and the mechanisms are very important for flow-field design optimizations. Such information could also lead to solutions to mitigate methanol crossover and/or its effects. Therefore, a novel technique is used to directly measure the current density under the land and under the channel separately. In this method, the anode side of the cell is partially catalyzed depending on the area of interest, whereas the cathode side is always fully catalyzed. Experimental results show that, under all the operating conditions used, the current density under the land is always significantly higher than that under the channel. Under most operating conditions, the current density under the land is more than 100% higher than that under the channel, and sometimes, as high as three times higher in typical DMFC operating voltage ranges. Further study shows that one of the main causes for such a drastic difference is the much higher electrochemical active area (ECA) under the land. Additional experimental results also show the performance trends for the land or the channel at different methanol concentrations and different cathode reactants (air or oxygen).

1. Introduction

Direct methanol fuel cells (DMFCs) are an attractive option to power the next generation of digital cameras, mobile phones or even tablets, thanks to their compact design, quick refueling and low operating temperature. In their current status, DMFCs exhibit low power densities and as a result they are not yet the viable alternative to Lithium-ion batteries. This is because methanol crossover is a serious drawback to the cell performance and any advancement in DMFC technology is going to be hampered by such a phenomenon. Methanol crossover hinders the performance of the cell due to the formation of mixed potentials at the cathode. It also reduces the efficiency of the cell as it reduces fuel utilization. Methanol crossover and/or its effects can be mitigated via (a) developing alternative membranes (e.g. Ref. [1]), (b) improving the electro-oxidation process in the catalyst layer and improving the structure of the catalyst and gas diffusion layers (e.g. Ref. [2]), and (c) optimizing the design of the flow field and the membrane electrode assembly (MEA) which can be achieved by studying the current density distributions (e.g. Ref. [3]).

The study of current density distribution in DMFCs is of a great importance for the optimization of cell designs and operations. Mench and Wang [4] reported that studying current distribution helps to understand the effects of water management, CO poisoning, and species distribution. Schroder et al. [5] stated that investigating the local distribution and transport behavior of CO_2 bubbles and water droplets at different operating conditions opens great possibilities for improving the fuel cell design. Ye et al. [6] suggested that optimizing the flow field geometry (land and channel widths as well as channel pattern) is essential to reach an even distribution of species and hence achieving a good cell

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performance. Ay et al. [7] gave many reasons for the importance of uniform current distribution; notably, it reduces the cost and increases the performance of the cell. Moreover, it ensures maximum lifetime for the cell components due to the decrease in corrosion processes in the cell. Saarinen et al. [8] reported that the complex relationships between different variables and operating conditions can be well understood through current distribution measurements. They also suggested that current distribution data can be useful in validating fuel cell models.

There are several experimental studies on current distribution measurement in DMFCs. Mench and Wang [4] measured the current distribution in a DMFC under steady state and transient conditions. Their measurement device allowed for the gas diffusion layer to be placed directly on electrically segmented lands. The results showed that current distribution in the cathode is nearly homogenous at high anode and cathode stoichiometries due to the fast removal of water in the cathode. However, current distribution in the cathode is far from being homogenous at low anode and cathode flow rates due to flooding. This shows that current mapping is effective in screening for low activity areas of the flow fields. It was concluded that water accumulation and pore-filling in the cathode GDL affect DMFC performance at low cathode stoichiometry. Ay et al. [7] analyzed the current distribution in DMFC at different operating conditions such as flow rate and methanol concentration by segmenting the current collector. They found that the difference between the current densities at the methanol inlet (maximum) and outlet (minimum) increases as the methanol concentration decreases from 1 M to 0.5 M. Furthermore, changing methanol flow rates affects the homogeneity of the current distribution; as methanol flow rate decreases, the current density distribution becomes less homogenous. When oxygen was used instead of air, the group observed more current density fluctuation from inlet to outlet. Park et al. [9] used a commercial current-mapping device called Current Scan Lin to study current distribution in a single and a five-line serpentine flow fields under various operating parameters. They indicated that current density distribution is inhomogeneous when the cell temperature or the oxidant flow rate in the cathode is lower. At low temperatures, water cannot easily be vaporized causing flooding near the cathode outlet. Unevenness in current distribution can also be caused by low cathode flow rate, higher load current and higher methanol concentration. When low current was imposed on the cell, methanol flow rate did not affect the homogeneity of the current distribution. However, at higher current, methanol flow rate did affect the homogeneity of the current distribution. This is due to the evolution of CO_2 gas and partial drying of the membrane near the cathode inlet. Moreover, they concluded that flow field configuration affects the homogeneity of the current distribution. Schroder et al. [5] studied current and fluid distribution in DMFC by using high resolution neutron radiology coupled with a segmented fuel cell. Neutron radiology was used due its high attenuation coefficient for hydrogen rich species compared to the solid components of the fuel cell. Therefore, this technique allows for water droplets and CO_2 bubbles to be observed. The anode side of the cell was operated under normal DMFC conditions, but two different air flow rates were supplied to the cathode side; one is high and the other is low for a cell size of $4.2 \times 4.2\ cm^2$. The group concluded that flooding in the cathode is responsible for up to 30% loss in performance due to inhomogeneous current distribution. Furthermore, they confirmed the existence of a bi-functional operation in the cathode and measured the current distribution in the region. Saarinen et al. [8] investigated mass transport including methanol crossover in a free-breathing direct methanol fuel cell. They measured current distribution along the anode flow channels and used this information to determine local reactants concentration. This was accomplished by segmenting the cathode flow field into 48 segments. They observed that current density distribution becomes less even as methanol concentration increases (due to methanol crossover) and cell temperature decreases (due to an increase in air convection and a decrease in activation overpotential at the electrodes). It was

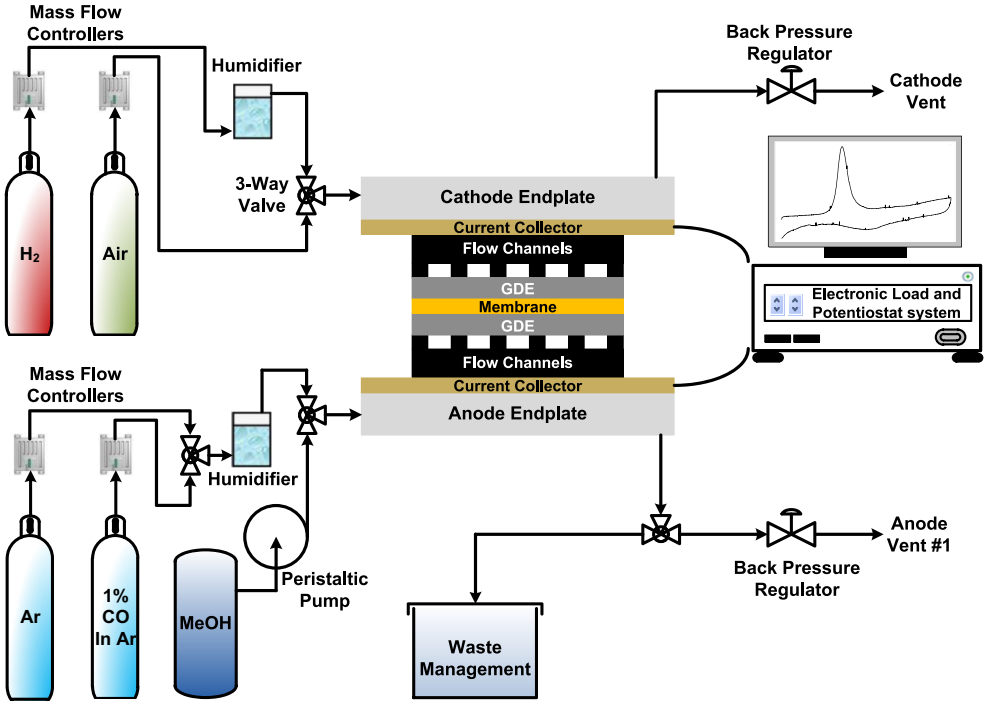

Fig. 1. Schematic of the experimental system.