Research Paper

Simulation study of proton exchange membrane thickness on cell voltage in micro methanol fuel cells

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Abstract

Proton exchange membranes (PEMs) are important components of fuel cells in which either hydrogen or methanol are used as fuels. In this paper we propose to use methanol as fuel to realize micro direct methanol fuel cells (µ-DMFC). The membrane electrode assembly (MEA) of µ-DMFC consists of a micro-porous layer which regulates the flow of methanol to the catalyst at the anode, a high efficiency catalyst layer for the generation of protons (H+) from methanol, a high conductance membrane layer for the transfer of protons and a high efficiency catalyst at the cathode for the conversion of oxygen and H+ into water. Simulation results indicate that the cell voltage decreases with increase in membrane thickness from 50µm to 200 µm

Introduction

The fuel cell technology has been considered as a promising alternative for future energy needs and cleaner environment. Among the several kinds of fuel cells, proton-exchange membrane fuel cell (PEMFC) and direct methanol fuel cell (DMFC) are known to utilize the proton exchange membranes [1-5]. A proton exchange membrane or polymer electrolyte membrane (PEM) is a semipermeable membrane generally made from ionomers and designed to conduct protons while being impermeable to gases such as oxygen or hydrogen [6]. This is their essential function when incorporated into a membrane electrode assembly (MEA) of a proton exchange membrane fuel cell i.e. separation of reactants and transport of protons. Direct-methanol fuel cells (DMFCs) are a subcategory of proton-exchange fuel cells in which methanol is used as the fuel. Their main advantage is the ease of transport of methanol, energy-dense yet reasonably stable liquid at all environmental conditions. Efficiency is quite low for these cells, so they are targeted especially to portable applications, where energy and power density are more important than efficiency. Current DMFCs are limited in the power they can produce, but can still store high energy content in a small space. This means they can produce a small amount of power over a long period of time. Military applications of DMFCs are an emerging application since they have low noise and thermal signatures and no toxic effluent. These applications include power for man-portable tactical equipment, battery chargers, and autonomous power for test and training instrumentation. In this paper, simulation study of proton exchange membrane thickness on cell voltage in micro methanol fuel cells is presented.

Basic design considerations of DMFCs

The basic design of DMFC has a membrane layer, primarily Nafion is sandwiched between two electrode assemblies anode and cathode; this Membrane Electrode Assembly (MEA) is the heart of the fuel cell as shown in figure 1. Methanol diffuses through the micro-porous layer (which regulates the transport of methanol) to the catalyst which generates protons. The protons then diffuse through the membrane to the cathode. The proton reacts with oxygen at the cathode to form water.

Anode reaction: $CH_3OH + H_2O \rightarrow 6\,H^+ + 6e^- + CO_2$ (Oxidation)

Cathode reaction: $\frac{3}{2}\,O_2 + 6\,H^+ + 6e^- \rightarrow 3H_2O$ (Reduction)

Overall reaction: $CH_3OH + \frac{3}{2}\,O_2 \rightarrow 2H_2O + CO_2$ (Overall reaction)

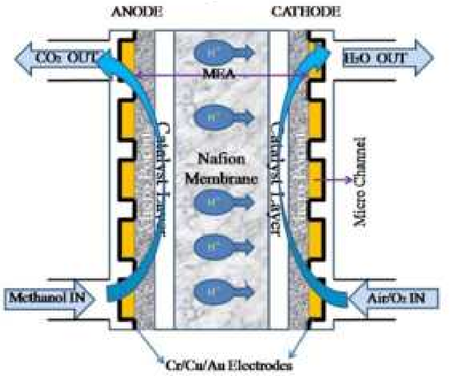

Figure 1 Basic structure of DMFC

The equations for the process are as below:

The entire MEA is sandwiched between two silicon chips with micro channels which contain the flow of methanol at the anode and flow of air at cathode. The negative charge collected by the metallic electrode moves into the external circuit from anode to cathode, thus balancing the charge transfer process.

Simulation

A 3 dimensional model of a proton exchange membrane /polymer electrolyte membrane fuel cell (PEMFC) [7-9] is implemented using COMSOL Multiphysics 5.0.

The present model is established based on the following assumptions:

- Flow is laminar everywhere due to small gas pressure gradient.
- Reactant gases behave as the ideal gas mixture.
- The electrodes and membrane are made of homogeneous materials.
- The temperature distribution across the cell is uniform.
- Water exists only in the gas phase in the fuel cell.
- The polymer electrolyte membrane is impermeable to reactant gases.
- Protons can only transport through the electrolyte, and electrons through the solid phase.
- Three species including oxygen, water and nitrogen are considered on the cathode side while only hydrogen and water are considered on the anode side.
- The fuel cell is operating at the steady state.

Figure 2 shows the schematic structure of the PEMFC model simulated using Comsol Multiphysics 5.0. The top part is the anode side and bottom part is the cathode side.

The following are the design parameters of the model.

• Cell Length	20.0mm
• Channel height	1.0mm
• Channel width	0.7mm
• Rib width	0.9mm
• GDL width	0.3mm
• Contact dimension for 1 contact	200µm
• Porous electrode thickness	0.5mm
• Membrane thickness	0.05mm
• GDL Porosity	0.4
• GDL electric conductivity	1000S/m
• Contact electric conductivity	100000S/m
• Inlet H2 mass fraction (anode)	0.743
• Inlet H2O mass fraction (cathode)	0.023
• Inlet oxygen mass fraction (cathode)	0.228
• Anode inlet flow velocity	0.2m/s
• Cathode inlet flow velocity	0.5m/s
• Anode viscosity	1.19?10- 5Pa.s
•Cathodeviscosity	2.46?10- 5Pa.s
• Permeability (porous electrode)	2.36?10- 12 m2
• Membrane conductivity	10 S/m

Effect of membrane thickness: Effect of membrane thickness on the PEM fuel cell performance is studied by keeping the parameters mentioned above as constant. As shown in Figure 3, the cell voltage decreases with increase in membrane thickness from 50µm to 200µm. This is due to decrease in proton conductivity with the increase of membrane thickness. This result is important for designing minimum membrane thickness for maximum proton conductivity and with minimum permeability in the case of µ-DMFCs.

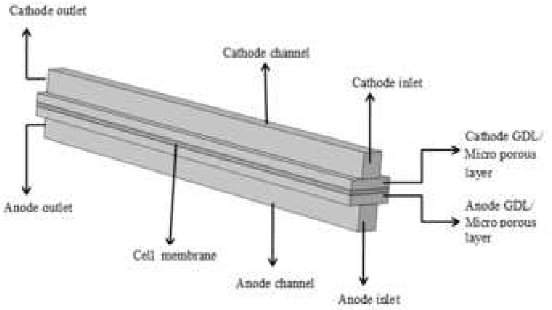

Figure 2: Schematic of PEMFC

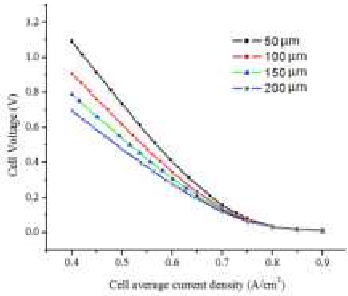

Figure 3: Variation of cell voltage with respect to cell membrane thickness

Conclusion

A 3-dimensional model for DMFC fuel cell is validated under the experimentally feasible assumptions. The effect of channel width on the fuel cell performance is studied by considering various channel widths employing different distributions and dimensions. It is observed that the voltage of the cell decreases as the thickness of the membrane is increased from 50µm to 200µm.

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