

Comparison of Electrode Backing Materials for Polymer Electrolyte Membrane Fuel Cells

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Abstract: In a PEM fuel cell electrode, backing layer has tremendous impact on electrode performance. The backing layer provides structural support for the porous electrode, distributes the reactants to the other layers and acts as a current collector. It has major influence on the water management in a PEM fuel cell. Selection of suitable backing layer material for the fabrication of electrode is thus very important to achieve high performance. In this paper we have compared the performance of PEM fuel cell electrodes fabricated using carbon paper EC-TP1-060T, carbon cloth EC-CC1-060T, (ElectroChem Inc. USA) and Carbon cloth from Textron, USA (CPW 003 grade). Mass transport problem was observed under non-pressurized condition, at high current densities, in the case of EC-CC1-060T carbon cloth electrode (at 50°C), due to its higher thickness. The performance of carbon paper electrode was higher than EC-CC1-060T carbon cloth electrode. The performance of Textron carbon cloth was comparable to EC-TP1-060T carbon paper.

Key words : PEM fuel cell, Electrode, Backing material, Carbon paper, Carbon cloth

1. Introduction

For the commercialization of Polymer Electrolyte Membrane (PEM) fuel cells, it is very essential to improve the electrode performance. Though lot of research work has been reported¹⁻⁷ on fuel cell electrode performance improvement, there is scope for further improvement. Selection of suitable materials for the fabrication of electrode is of prime importance to achieve high performance.

A PEM fuel cell electrode generally consists of three layers; a backing layer, diffusion layer and a catalyst layer. Highly porous, teflonized Carbon paper or Carbon cloth is used as the backing layer. Diffusion layer is typically made from carbon black and some polymeric binder such as polytetrafluoroethylene (PTFE). This layer usually will have much smaller pores than the electrode backing layer. Catalyst layer contains electrocatalyst (normally platinum black or platinum supported on carbon), Nafion ionomer and sometimes PTFE. In the past, PTFE was considered essential in the catalyst layer. Nowadays, PEM fuel cell electrodes are prepared with out using PTFE in the catalyst layer, using Nafion ionomer alone as the binder⁴⁻⁶.

The fuel cell electrode must be highly porous so that the reactants have easy access to the interfaces between electrode and the electrolyte to establish a stable contact between gas, electrolyte, and the catalyst. The fuel cell electrode should be thin for fast transport of reactants to the reaction site and for removal of product water. Finally, the structure of the elec-

trode should ensure a sufficiently high electrical conductivity for the flow of electrons.

Though lot of work has been reported on PEM fuel cell electrodes, most of the studies are concentrated on catalyst layer^{8,9}. The backing layer and the gas diffusion layer component of the electrode has also tremendous impact on fuel cell performance. The backing layer provide structural support for the porous electrode and also acts as a current collector.

Since the diffusion layer is coated on the backing layer, its properties such as thickness and density influence the diffusion layer characteristics. The backing layer and diffusion layer distributes the reactants to the active sites. These layers have a major impact on water management in a PEM fuel cell. In addition to providing passage for diffusion of fuels, they control the rate at which water vapor diffuses into or out of the membrane electrode assembly. In a PEM fuel cell the membrane has to be kept humidified, since the membrane conductivity depends on humidity. Too much of water supply to the membrane and inadequate removal of product water from the electrode-electrolyte interface may result in flooding of the catalyst and performance decrease. Too high diffusion of water away from the membrane can contribute to drying out of the membrane, decrease in membrane conductivity and thereby decrease in cell performance.

We have fabricated fuel cell electrodes using commercially available carbon paper and carbon cloth backing materials and compared their performance. Membrane-Electrode Assembly (MEA) was prepared using Nafion 115 membrane and cell performance was evaluated using hydrogen and oxygen reactants, with and without back pressure, at various temperatures.

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The experimental details and results are given below.

2. Experimental

2.1. Materials

Teflon treated carbon cloth (EC-CC1-060T grade, thickness: 0.33 mm, density: 1.75 g/cc), carbon paper (EC-TP1-060T grade, thickness: 0.17 mm, density: 0.49 g/cc), commercially available from Electrochem, Inc USA and carbon cloth (CPW 003 grade, thickness: 0.23 mm, density: 1.7 g/cc) Textron, USA, were used as electrode backing materials. The electrocatalyst used for the preparation of electrode was 20% Pt on Vulcan XC-72 (E-TEK Division of De Nora Inc., USA) of surface area 100 m²/g.. Nafion 115, (DuPont Inc., USA) was used as the polymer electrolyte membrane. Nafion 5 wt.% solution supplied by DuPont Inc., USA was used as binder in the catalyst layer.

2.2. Preparation of diffusion layer

A diffusion layer slurry was prepared by mixing Vulcan XC-72 and Fluon (AD1 grade) PTFE aqueous dispersion (Asahi Glass Fluoropolymers, USA) in isopropyl alcohol-water mixture. The slurry was coated on the electrode backing material, dried at 100°C and pressed at 5 kg/cm². The carbon loading in the diffusion layer was kept at 3 mg/cm² and the PTFE content was maintained at 30%.

2.3. Preparation of catalyst layer

A catalyst layer slurry was prepared by ultrasonicing a mixture of 20% Pt on carbon, 5% Nafion solution and isopropyl alcohol for 30 minutes. The slurry was coated on the diffusion layer by brush method and dried at 80°C for 1 hour. The Pt catalyst loading in the anode and cathode were maintained at 0.5 mg/cm² and the Nafion content in the catalyst layer was 25%.

2.4. Preparation of MEA

Two catalyst layer coated electrodes of area 5 cm² were placed on both sides of Nafion 115 membrane and hot pressed at 130°C, at a pressure of 2000 psig for 1 minute to bond the electrode to the membrane and form Membrane Electrode Assembly (MEA).

2.5. Evaluation of electrode/ MEA

PEM fuel cell was assembled by placing the MEA in the single cell test fixture supplied by Electrochem Inc, USA. The cell was connected to fuel cell test station, humidified hydrogen and oxygen gases were fed to the cell and the performance of the cell (current-voltage characteristics) was evaluated using Won-A-Tech (HPCS 1) system.

The electrochemical surface area (ESA) was evaluated by cyclic voltammetry (CV), using PARC M270 electrochemical system. For CV studies, argon was passed through the test electrode and hydrogen was passed through the counter electrode chamber. The counter electrode also serves as a reference electrode. The potential was then swept between 0 to 800 mV vs RHE at a scan rate of 20 mV/sec. From the CV

obtained, the charge equivalent to the area under the hydrogen desorption region was found out and ESA was calculated assuming that the charge required for the adsorption/desorption of a monolayer of atomic hydrogen on the surfaces is 210 $\mu\text{C}/\text{cm}^{2-10}$. Cell impedance was also measured using the PARC system.

3. Results and Discussion

The polarisation curve of the cells using EC-CC1-060T (carbon cloth electrode) and EC-TP1-060T (carbon paper electrode), at various temperatures (50, 60 and 70°C), using hydrogen and oxygen reactants, at ambient gas pressure, is given in Fig. 1.

It can be seen that both carbon cloth electrode and carbon paper electrode gave more than 500 mV at 500 mA/cm², even at 50°C, without back pressure. An increase in cell voltage with increase in temperature was observed in both cases, though the increase was only about 2 mV/°C. This is comparable to the voltage gain of 1.1 mV to 2.5 mV /°C reported in the literature¹¹. The effect of temperature on PEM fuel cell performance is very complex and depends on minute details of cell component design along with parameters such as gas flow rates, gas humidity, membrane water content etc. The increase in PEM fuel cell performance with increase in temperature is due to lowering of the internal resistance of the cell, mainly due to decrease in the ohmic resistance of the electrolyte¹². The specific conductivity of fully hydrated Nafion membrane is about 0.1 S/cm at room temperature and about 0.15 S/cm at about 80°C. However, the proton conductivity depends very much on the membrane water content. As the water content decreases, the proton conductivity also decreases¹³.

At high current densities, at 50°C, sharp fall in performance was observed in the case of EC-CC1-060T carbon cloth electrode, which may be due to mass transport limitation, due to the higher thickness of carbon cloth backing material. Mass

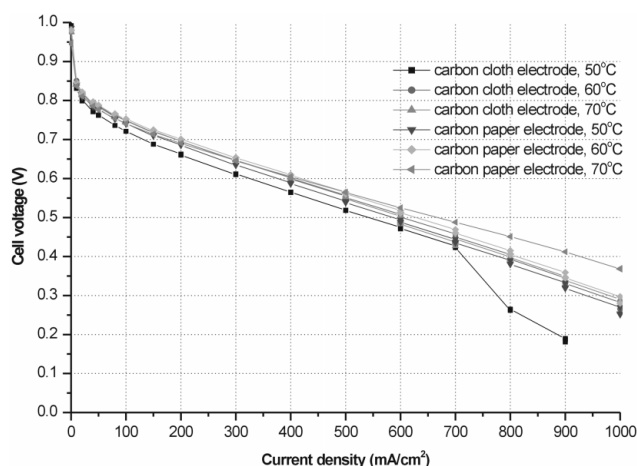


Fig. 1. Polarisation curve of PEM fuel cells with carbon cloth electrode (EC-CC1-060T) and carbon paper electrode (EC-TP1-060T), at various temperatures, using hydrogen-oxygen at ambient pressure.

transport limitation is caused by decrease in the diffusion of reactants to the active catalyst sites, movement of protons from the node to the cathode and removal of product water. At high current densities mass transport issues associated with water formation and distribution limit cell output⁽¹¹⁾. Without adequate water management, an imbalance will occur between water production and evaporation within the cell. Adverse effects include dilution of reactant gases by water vapor, flooding of the electrodes, and dehydration of the solid polymer membrane.

In general, the performance of carbon paper electrode was found to be higher than that of EC-CC1-060T carbon cloth electrode. This can be attributed to lower thickness and lower density of carbon paper compared to EC-CC1-060T carbon cloth, which facilitates higher mass transport. The impedance of the cell with carbon paper was found to be $0.42 \Omega\text{cm}^2$ compared to $0.48 \Omega\text{cm}^2$ for the cell with EC-CC1-060T carbon cloth electrode (Fig. 2). The lower impedance of carbon paper electrode may be another factor for its higher performance.

The cell performance using EC-CC1-060T carbon cloth electrode and carbon paper electrode, at 1 kg/cm^2 gas pressure is presented in Fig. 3. An increase in cell voltage with pressure was observed in both cases, due to improved kinetics and mass transport. The performance of the carbon paper electrode was found to be slightly higher than EC-CC1-060T carbon cloth electrode even under pressurized condition. The cell voltage at 500 mA/cm^2 was 608 mV and 617 mV for the cell (at 70°C), with EC-CC1-060T carbon cloth electrode and carbon paper electrode respectively. At 1000 mA/cm^2 , under the same conditions, both the electrodes gave about 400 mV . Since the performance of EC-CC1-060T carbon cloth was in general lower than carbon paper, it was decided to evaluate another carbon cloth of lower thickness.

Fuel cell electrode was prepared using Textron carbon cloth (CPW 003 from Textron, USA) of lower thickness (0.23 mm) and performance was evaluated. The i - v characteristics of the electrode with Textron carbon cloth is given in Fig. 4. It can be seen that at 50°C , without back pressure, the cell voltage at 500 mA/cm^2 was above 500 mV . No sharp fall in performance was observed at high current density with Textron carbon cloth, unlike EC-CC1-060T carbon cloth electrode. At 70°C , a cell voltage of 620 mV was obtained at 500 mA/cm^2 with Textron carbon cloth, comparable to carbon paper electrode. The higher performance of Textron carbon cloth compared to EC-CC1-060T carbon cloth may be due to its lower thickness, which facilitates higher diffusion of reactants to the active sites and removal of product water.

The CV of the carbon cloth electrodes and carbon paper electrode is given in Fig. 5. Electrochemically active Pt surface area (ESA) calculated from the CV was found to be 1048 cm^2 for the EC-CC1-060T carbon cloth electrode, 933 cm^2 for carbon paper electrode and 995 cm^2 for the Textron carbon cloth electrode. An electrode with higher ESA is expected to give better performance. Higher ESA of EC-CC1-060T carbon cloth electrode did not reflect in higher current voltage characteristics, due to higher thickness of car-

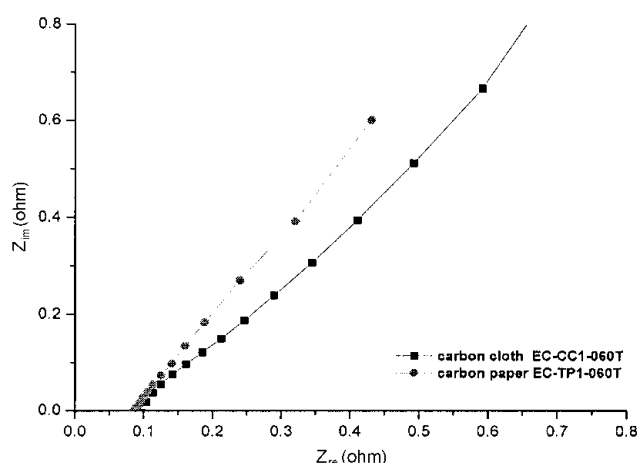


Fig. 2. Impedance plots (Nyquist format) of PEM fuel cell using carbon cloth electrode (EC-CC1-060T) and carbon paper electrode (EC-TP1-060T), Nafion 115 membrane, Electrode area: 5 cm^2 .

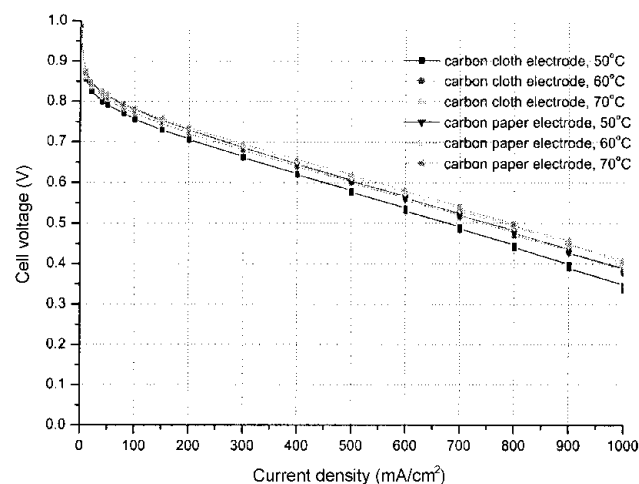


Fig. 3. Polarisation curves of PEM fuel cells with carbon cloth electrode (EC-CC1-060T) and carbon paper electrode (EC-TP1-060T), at various temperatures, using hydrogen-oxygen at 1 kg/cm^2 .

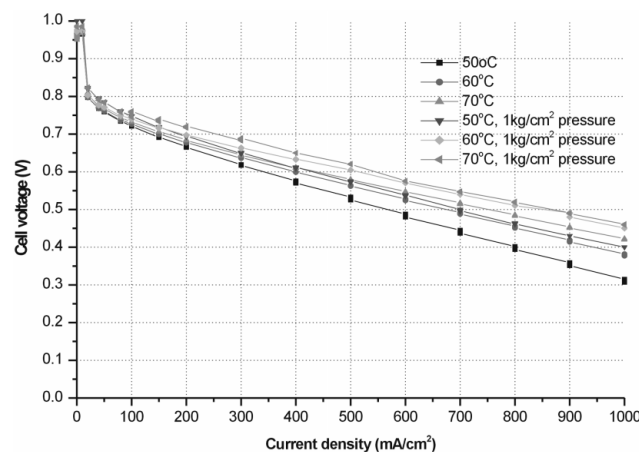


Fig. 4. Polarisation curves of PEM fuel cells with Textron carbon cloth electrode, at various temperatures, using hydrogen-oxygen.

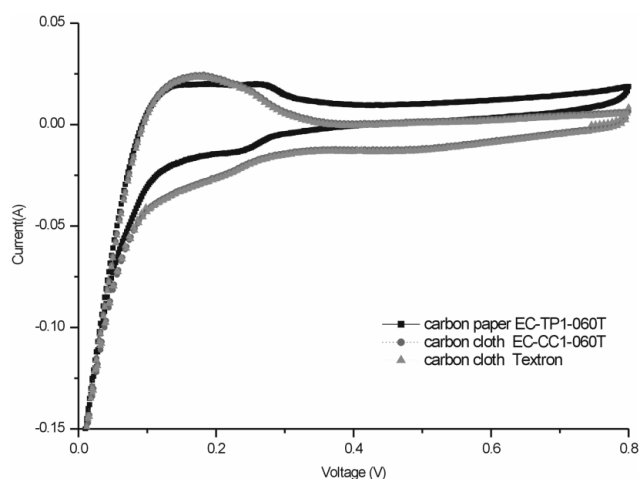


Fig. 5. Cyclic voltammograms of PEM fuel cell electrodes, using carbon paper and carbon cloth backing, at a scan rate of 20 mV/s. Electrode area: 5 cm², Pt loading: 0.5 mg/cm²

bon cloth, which contribute to higher impedance and mass transport limitations.

4. Conclusions

The performance of carbon paper backing material EC-TP1-060T was found to be slightly higher than that of carbon cloth backing material EC-CC1-060T, may be due to lower thickness and lower density. Textron carbon cloth (CPW 003), which is thinner than EC-TP1-060T gave a performance comparable to carbon paper. At a current density of 500 mA/cm², the cell voltages using EC-CC1-060T carbon cloth electrode, Textron carbon cloth and carbon paper electrode were respectively 608 mV, 620 mV and 617 mV, at 70°C, with hydrogen and oxygen gases at 1 kg/cm².

Mass transport problem was observed under non-pressurized condition, at high current densities, in the case of EC-CC1-060T carbon cloth electrode (at 50°C), due to its higher thickness and density. No mass transport limitation was observed under pressurized condition.

Higher electrochemical surface area (ESA) of EC-CC1-060T carbon cloth electrode did not reflect in higher current-voltage characteristics, due to its higher thickness and higher density. Thus physical properties of backing layer material greatly influence the fuel cell performance and selection of suitable backing material for the fabrication of electrode is very important to achieve high performance.

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