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Bulk and contact resistances of gas diffusion layers in proton exchange membrane fuel cells

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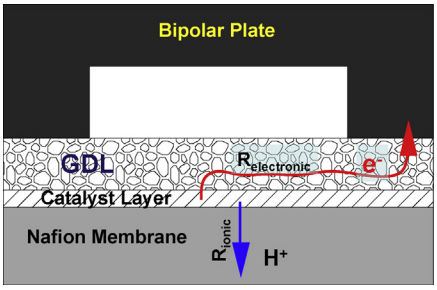
HIGHLIGHTS

- Direct measurement of gas diffusion layer bulk and contact resistances.
- Teflon treatment increases GDL contact resistance with no change of bulk resistance.
- Microporous layer decreases contact resistance.
- Uneven compression under channels and ribs deforms GDL, breaking electrical contact.

GRAPHICAL ABSTRACT



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ABSTRACT

A multi-electrode probe is employed to distinguish the bulk and contact resistances of the catalyst layer (CL) and the gas diffusion layer (GDL) with the bipolar plate (BPP). Resistances are compared for Vulcan carbon catalyst layers (CL), carbon paper and carbon cloth GDL materials, and GDLs with microporous layers (MPL). The Vulcan carbon catalyst layer bulk resistance is 100 times greater than the bulk resistance of carbon paper GDL (Toray TG-H-120). Carbon cloth (CCWP) has bulk and contact resistances twice those of carbon paper. Compression of the GDL decreases the GDL contact resistance, but has little effect on the bulk resistance. Treatment of the GDL with polytetrafluoroethylene (PTFE) increases the contact resistance, but has little effect on the bulk resistance. A microporous layer (MPL) added to the GDL decreases the contact resistance, but has little effect on the bulk resistance. An equivalent circuit model shows that for channels less than 1 mm wide the contact resistance is the major source of electronic resistance and is about 10% of the total ohmic resistance associated with the membrane electrode assembly.

1. Introduction

Proton exchange membrane fuel cells (PEMFCs) require both low ionic and low electronic resistivity to achieve high efficiency. Oxidation and reduction reactions take place at the membrane/catalyst layer interface. Protons are transported through the polymer electrolyte membrane and electrons are transported through the catalyst layers and the gas diffusion layer. Most research has focused on the ionic resistance of the membrane as it poses the largest potential loss. However, the potential losses for the electron current through the bipolar plate (BPP), gas diffusion layer (GDL) and catalyst layer (CL) can reduce the overall power output from a PEMFC [1,2]. In this paper we examine the factors that affect the potential losses associated with electronic current in the membrane electrode assembly (MEA).

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There have been many experimental reports and computational simulations of the fuel cell electronic resistivity. In order to minimize the electronic resistance, researchers have examined a variety of bipolar plate materials, including graphite [3–5], carbon composites [6,7], untreated and plated stainless steel [8–11] and alloys [12]. Electronic resistance is also affected by manufacturing processes including injection molding [13,14], surface treatments [15–17] and structure optimization [18–20]. Davies et al. [21] compared different bipolar plate materials and found the lowest contact resistance between the BPP and the GDL was obtained with Poco® graphite (Decatur, TX); the protective oxide on stainless steel resulted in a greater contact resistance for stainless steel BPPs. Akiki et al. [22] also compared different bipolar plate materials and found the lowest contact resistance between the BPP and the GDL was obtained with Poco® graphite. Zhang et al. [23] and Lai et al. [24] estimated the transverse contact resistance between the BPP and the GDL as a function of compression. They found the contact resistance decreased with increasing clamping pressure. Zhou et al. [25] investigated the effect of the non-uniformity of the contact pressure distribution on the electronic contact resistance. Their results showed that the electrical contact resistances was reduced by less than 30% by making the clamping pressure distribution more uniform. Ismail et al. [26] reported that the contact resistance between the GDL and the BPP increased with increasing polytetrafluoroethylene (PTFE) loading in the GDL. Miyazawa et al. [27] investigated the electrical properties of the GDL and the BPP and concluded that the contact area between the GDL and the BPP showed no noticeable increase with increasing compression pressure above a level of 0.8 MPa.

GDLs are often coated with a thin layer of carbon particles as a microporous layer (MPL) to assist in water management. Park et al. [28,29] studied the effects of PTFE content and carbon loading in the MPL on the performance of fuel cells. They reported that the MPL reduced the contact resistance between the GDL and the catalyst layer or the bipolar plate.

Experimental devices to measure GDL resistance have generally placed a piece of the GDL material between two flat steel plates. Clamping pressure is applied to assure good contact between the GDL test samples and the steel plates. The transverse resistance between the steel plates is measured. Assuming the resistance of the steel plates can be ignored the transverse resistance is equal to the GDL resistance. The transverse resistance includes contributions from both bulk resistance in the GDL and the contact resistance between the GDL and the BPP. Different models have attempted to distinguish the contributions from the bulk resistance of the GDL and the contact resistance between the GDL and the BPP.

In PEMFCs, the electronic current is carried laterally from the channel to the ribs. The compression of the GDL is not uniform. The GDL is compressed under the ribs but is not compressed under the channel. To properly assess the electronic resistance from the channel to the rib it is necessary to determine both the lateral bulk resistivity and the contact resistance.

Dhar et al. [30] introduced a pulse method for the measurement of contact resistance and bulk resistance of semiconductors samples. Cooper et al. [31] summarized and compared the electrical test methods for on-line fuel cell ohmic resistance measurement. They suggested that users of these techniques should be cognizant of differences in these methods (current interrupt, AC resistance, high frequency resistance, HFR, and electrochemical impedance spectroscopy, EIS) to properly apply and interpret the results if accurate and useful measurements of cell resistance are to be obtained. Mishra et al. [32] appear to be the first to report the effects of different gas diffusion layer materials and contact pressure on the electrical contact resistance. They presented a fractal to predict the contact resistance as a function of pressure, material properties, and surface geometry. Liu [33] introduced a four-terminal measurement technique to determine resistivity and eliminate the thermal EMFs to improve the accuracy of the measurements. Okel et al. [34] developed a 4 electrode device that clamp the GDL with a uniform clamping pressure for the simultaneous measurement of bulk and contact resistances of materials used in fuel cells. They concluded that >90% of the resistance is associated with the contact resistance between the GDL and the BPP.

In the experiments presented here, a multi-electrode probe was designed to distinguish between the contact resistance and bulk resistance through the GDL. The resistances of carbon cloth and carbon paper GDL materials are compared as functions of compression and PTFE loading. The contact and bulk resistances of catalyst layers and MPL layers have also been measured. A simple equivalent circuit model is presented to show how the resistance is reduced by the addition of a GDL in a PEMFC.

2. Experimental

Fig. 1 is a schematic of a vertical cut across a PEMFC. The principle role of the GDL is to carry the electronic current from the catalyst layer under the channel to the rib of the bipolar plate. It should accomplish this while minimizing mass transport resistances for gaseous reactant from the gas flow channel to the catalyst layer and for liquid water from the catalyst layer to the gas flow channel. There are five contributions to the resistance for the electronic current. The resistances of the bipolar plate (R_{BPP}), the GDL (R_{GDL}) and the catalyst layer (R_{cat}) are in parallel and connected by the interfacial resistances of the GDL with the bipolar plate ($R_{BPP\text{-}GDL}$) and the catalyst layer ($R_{GDL\text{-}cat}$). There are contributions from both lateral and transverse electron transport in the CL, the GDL and the BPP.

To measure contact and lateral resistances we constructed the GDL conductivity cell shown in Fig. 2. Different compression plates (or blocks) were employed to represent the channel/rib structure employed in the BPP flow fields. Block #0 is a flat plate. Blocks #1 and #2 are representative of the bipolar plates with different

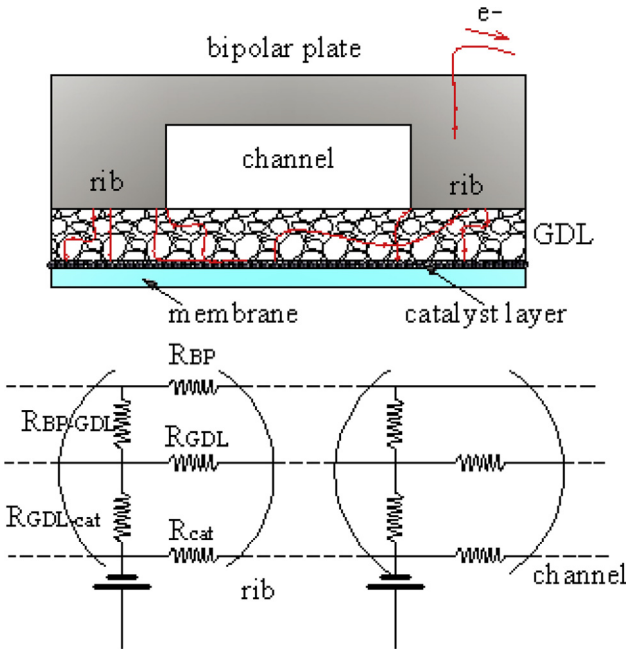

Fig. 1. Electrical resistance network model of the catalyst layer/gas diffusion layer/bipolar plate.