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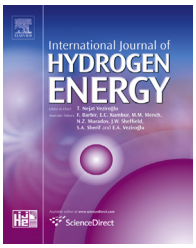

Contact resistance between bipolar plate and gas diffusion layer in high temperature polymer electrolyte fuel cells

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ABSTRACT

One of the major contributors to the ohmic loss in fuel cells originates at the interface between adjacent cell components. The compressive pressure used to achieve contact in cells should be carefully estimated to ensure that resistive losses arising from contact behavior remain minimal. In present work, a generic model is developed, capable of estimating contact resistance as a function contact pressure at the interface of graphite bipolar plate and carbon fiber based gas diffusion layer at different temperatures. A good agreement is observed between the results obtained from the model and experiments. Compressive pressure in the ranges of 3–4 MPa is found optimum for achieving low contact resistance. The contact resistance obtained for carbon paper and BPP while using recommended pressure lies between ~9 and 4 mΩ cm^2 considering the operating regime of HT-PEMFC (120–180 °C). Operating under similar conditions, the contact resistance values for carbon cloth and BPP is ~13 to 7 mΩ cm^2.

1. Introduction

Fuel cells are considered as one of the future potential candidate for fulfilling energy requirement in portable, mobile and stationary applications due to their high power density and operating flexibility [1]. Among the different classes of fuel cells, high temperature polymer electrolyte membrane fuel cells (HT-PEMFCs) based on phosphoric acid doped polybenzimidazaole (PBI) membranes [2,3] operate at 120–180 °C. In this temperature range, the electrolyte exhibits excellent thermal, chemical and mechanical properties [4]. Although the undoped PBI membrane behaves like a bad conductor of electricity; introduction of neat phosphoric acid at high doping levels enable good conductivity, making it an ideal choice for fuel cell electrolyte at elevated temperatures. Several researchers have explained the excellent proton conduction in these electrolytes on the basis of Grotthuss mechanism; i.e. requiring co-operation among two protons to move along the polymer-anion chain [5–7]. The conductivity in this case is highly dependent on temperature [8]. The other influencing factors are relative humidity and doping levels [9]. There are several advantages of HT-PEMFCs apart from overcoming the water management issues inherent to PEMFCs. These are improved reaction kinetics [10], carbon monoxide (CO) tolerance level of around 3% [11], co-generation potential [12] and ease of thermal management. The typical components of a fuel cell are the bipolar plate (BPP), the gas

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Nomenclature

D_{sum}	density of summits, μm^{-2}
δ	deformation, μm
E_i	Young's modulus of respective material, GPa
E_q	equivalent Young's modulus, GPa
ε	Fractional contact area
F_C	contact force, N
$f(z)$	distribution function for asperity heights
m_i	surface spectral moment
θ_m	orientation of the carbon fibers, rad
σ_{sum}	standard deviation of summits, μm
P	pressure, MPa
R_{BPP}	bulk resistance of bipolar plate, Ω
R_{GDL}	bulk resistance of gas diffusion layer, Ω
$R_{BPP\|GDL}$	contact resistance across the bipolar plate and gas diffusion layer interface, Ω
R_{TOT}	total resistance, Ω
r_C	contact radius for a single asperity, μm
$r_{C_{eq}}$	equivalent radius of two curved bodies, μm
r_{cy}	radius of carbon fiber, μm
r_m	asperity summit radius, μm
R_S	contact resistance, mΩ cm^2
ρ_i	bulk resistivity of materials, Ω cm
T	temperature, K
υ_i	Poisson's ratio of materials
x_m	carbon fiber segment length, μm
z	asperity summit height, μm

Abbreviations

BPP	bipolar plate
CO	carbon monoxide
GDL	gas diffusion layer
MEA	membrane electrolyte assembly
PBI	polybenzimidazole
PEMFC	polymer electrolyte membrane fuel cell
PFSA	per-fluoro sulphonic acid

diffusion layer (GDL) and the membrane electrode assembly (MEA). In order to achieve proper contact amongst the cell components, a compressive pressure is applied across it. While, higher compression pressure aids in better current collection and heat transfer [13], it causes a simultaneous decrease in porosity of the GDL which in turn affects electrochemical performance in a significant manner [14]. Optimization of the compressive pressure involves the trade-off between the losses arising from the mass transfer and contact resistance [15,16]. The influence of compressive pressure uniformity over the cell active area has also been highlighted in some works [17–19]. Due to its significance, efforts have been made to model the contact behavior in the SOFCs [20,21] as well as PEMFCs [23–37]. Contact phenomenon has been studied over various length scales using different models as well as experimental techniques. Zhou and co-workers developed a micro-scale model based on surface profile statistics for modeling contact behavior between BPP-GDL interfaces in PEMFCs [22,23]. Further generalization of the work using an analytical model was carried out by Wang et al. [24]. Efforts were also undertaken to quantify fiber bending under load and its effect on contact resistance. It was identified as one of the factors that gained importance in case of low fiber density in the GDL. Sadeghi et al. studied the effect of compressive load on thermal resistance arising from bulk as well as contact behavior in PEMFCs [25,26]. Also, hysteresis effect was noticed under cyclic loading due to fiber breakage and displacement. Mishra et al. [27], presented a fractal asperity based model to predict the contact resistances as a function of contact pressure, material properties, and surface geometry at the interface. A scale independent approach was laid down by including a structural parameter to quantify profiles. Lee et al. [28] used Finite Element Analysis (FEA) procedures to simulate the assembly of a single PEMFC with metallic bipolar plates. Similarly, Andre et al. have explored the effect of metallic BPP surface and its effect on the contact resistance under different exposures [29]. Nitta et al. [30], used AC impedance measurement to analyze the effect of compression pressure on the contact resistance between GDL and electrode. Wang et al. [31], inserted pressure sensitive films between the MEA and the diffusion layer to measure the pressure distribution in a PEMFC assembled using conventional endplates. The results were compared with the pressure distribution obtained using a newly designed hydro-pressurized endplates. Investigation of the effect of clamping pressure on long term cell performance has been the subject in Refs. [32–34]. The effect of surface smoothness on contact behavior has been studied using samples possessing different roughness values in Ref. [35]. It was shown that, it is not possible to obtain low contact resistance by merely reducing the roughness of the contact surfaces. The mechanical treatment and surface characteristics are important parameters that have to be carefully chosen depending upon the porosity and material properties of the chosen components participating in contact. The purpose of the current work is to develop a micro-scale model of contact resistance under different pressures for BPP-GDL interface in PEMFCs. Emphasis is placed on incorporating temperature dependence in the model, so as to extend the application of the model to HT-PEMFCs.

2. Interfacial contact resistance

Interfacial contact resistance refers to the resistance at the interface of two different apparently smooth surfaces in contact with each other under external force. Since, fuel cell assembly involves the contact between bipolar plate and gas diffusion layer, contact resistance inside the fuel cells also plays an important role as illustrated in Fig. 1(a), (b).

The total resistance of a BPP and GDL assembly includes the contribution of the contact resistance in addition to the bulk resistance of the individual components. The total resistance arising from an assembly of BPP and GDL can be estimated as:

$$R_{TOT} = R_{BPP|GDL} + R_{BPP} + R_{GDL} \quad (1)$$