White Paper

Evaluating the Three-Dimensional Electrical Conductivity of Composite Bipolar Plates

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INTRODUCTION

Having overcome numerous scientific hurdles since the conception over 170 years ago, only recently has fuel cell technology emerged as a valuable contributor to the significant global energy demands.

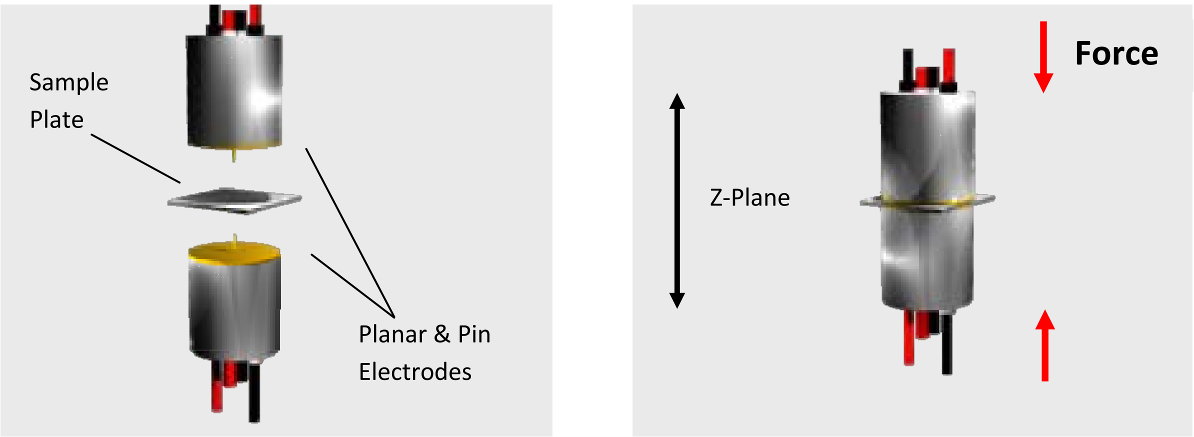
A Proton Exchange Membrane (PEM) fuel cell consists of a periodic series of bipolar, current collector plates stacked alongside catalyst membranes and clamped within two endplates. Input reactants can be directed to the catalyst sites on the membrane for electrochemical processing. Within the stack, bipolar plates play a critical and multifunctional role. The primary function is to electrically connect the individual fuel cells in series while simultaneously separating the individual cells. One plate performs the joint role of cathode for one cell and anode for the neighbouring cell in the stack. Additionally the highly conductive plates distribute the input reactants over the active surface area of the membrane via designed flow field channels. Performing further multifunctional roles including heat transfer, water management and structural integrity, bipolar plates are critical to exploiting the potential with a fuel cell stack. Figures **1.1** and **1.2** present images of both machined and moulded bipolar composite plates.

Figure 1.1 & 1.2 Machined and moulded ElectroPhen® -based bipolar composite plates, respectively

Both the chemical and physical properties of these bipolar plates must be carefully and comprehensively monitored and optimised in order to maximise fuel cell stack efficiency. Specific to this report, an in-depth understanding of the through-plane electrical conductivity is essential.

OVERVIEW

For a bipolar plate to perform efficiently requires high electrical and thermal conductivity and stability, good chemical resistance, high flexural strength and low permeability. in particular the understanding and assessment of each property is vital to determining the performance of a composite plate. **Bac2 Ltd** has extended the traditional *I-V* electrical measurement, allowing for detailed, fast and reliable evaluation of the through-plane conductivity for composite plates.



1.3(a) **1.3(b)**

Figure 1.3a Schematic view of the electrodes and test plate sample highlighting the two planar gold electrodes with two gold pins *in-situ*, and **1.3b,** the test plate clamped between two gold electrodes under linearly applied force.

Figure **1.3a** and **1.3b** presents the Bac2 Ltd method for recording the through-plane electrical conductivity of a system. Two gold planar electrodes are positioned above and below a test plate allowing forced contact to be applied in the Z-direction (**1.3b**). These two electrodes also contain isolated gold pin electrodes which probe the bulk properties, neglecting the plate surface effects. Thus this procedure simultaneously determines the pressure dependent surface *and* bulk electrical conductivity contributions from a sample composite plate. A direct current (I_{DC}) flows through the bulk of the plate sample (z-direction) via the two planar electrodes whilst the voltage drop (V_{tot}) is simultaneously probed across the same plane. This measures the total through-plane electrical conductivity (σ_{tot}) for the test plate while the pin electrodes uses the isolated voltage drop (V_{Bulk}) to calculate the electrical conductivity from the bulk (σ_{bulk}) material alone. In order to gain a complete understanding into molecular interactions within a polymer-composite system, the exploitation of **Bac2 Ltd's** experimental technique is of critical importance. Separate to this work, specific in-plane electrical conductivity measurements can be recorded via the conventional *4-point probe* method if required.

BACKGROUND THEORY

Overall the electrical conductivity can be defined as,

$$\sigma_{tot} = \frac{1}{R_{tot}} \cdot \frac{L}{A_{CS}} \qquad \textbf{1.1}$$

Where σ_{tot} = Total Electrical Conductivity

R_{tot} = Total Electrical Resistance

L = Sample Plate Thickness

A_{CS} = Cross Sectional Area

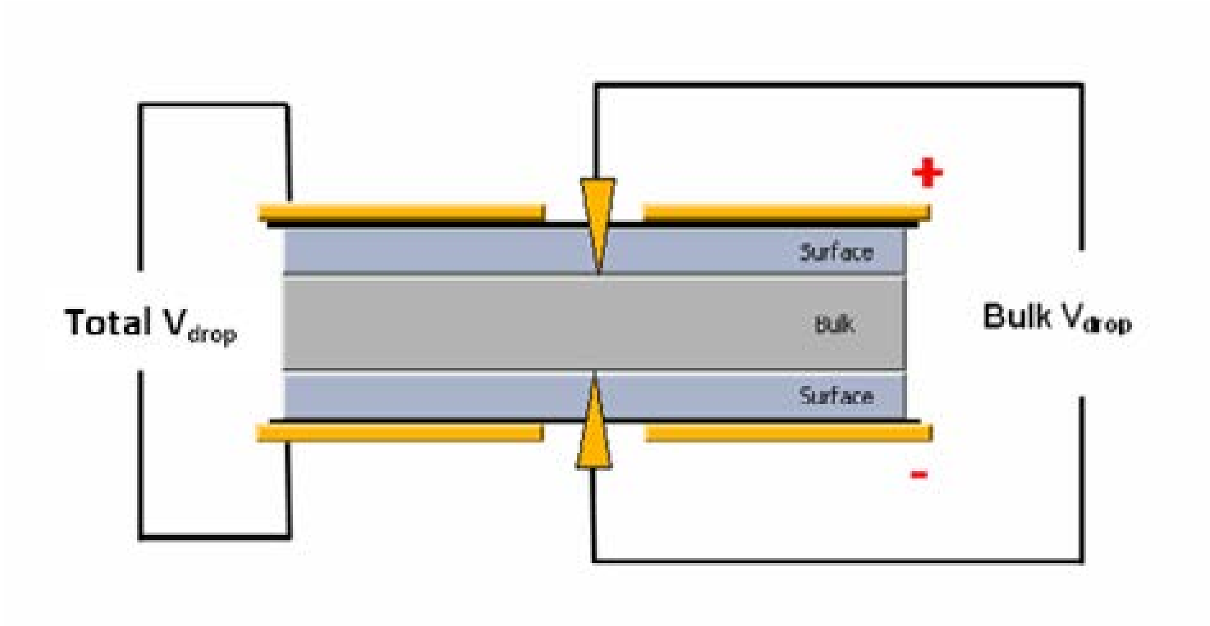


Figure 1.4 Visualisation of the composite plate sample clamped between the gold electrodes. Upon application of current, the voltage drop (V_{drop}) across the planar electrodes monitors the total electrical responses from the plate while the voltage drop across the gold pin electrodes isolates the bulk electrical response only.

The total resistance within the system in Figure **1.4** can be described as a sum of surface contact resistances ($R_{surface}$) and the bulk resistance (R_{bulk}), thus

$$R_{Tot} = R_{Bulk} + 2(R_{Surface}) \qquad \textbf{1.2}$$

Therefore the total resistance can be considered as the sum of three resistors in series – top surface resistance, bulk resistance and the bottom surface resistance. Substituting Ohm's Law where $V_{tot} = I_{DC}.R_{tot}$ and from Equation **1.2**,

$$R_{tot} = \frac{1}{I_{DC}}\left[V_{Bulk} + 2(V_{Surface})\right] \qquad \textbf{1.3}$$

where I_{DC} = Direct current

V_{Bulk} = Voltage drop across the pin electrodes only

$V_{Surface}$ = Half the difference between the total voltage drop across the planar electrodes and V_{bulk}

$$= \tfrac{1}{2}(V_{Tot} - V_{Bulk}) \qquad \textbf{1.4}$$

Bulk resistance and voltage drop describe the effects solely due to the volume of the plate system in the z-direction, neglecting surface contributions. This is calculated by recording the voltage drop across the two gold pin electrodes only. Theoretically the bulk resistance alone should be employed when describing the resistivity of a material. Resistivity (ρ) can be defined as the inverse of the conductivity (σ),

$$\rho = \frac{1}{\sigma} \qquad \textbf{1.5}$$

Adapting equation **1.1** for bulk resistance alone, where $R_{tot} = R_{Bulk}$

$$\rho = R_{Bulk}\left(\frac{A_{CS}}{L}\right) \qquad \textbf{1.6}$$

REDUCE YOUR RESISTANCE

In order to realise the true potential of any polymer composite bipolar plate in a fuel cell environment, it is critical to understand and control the contribution to the overall resistance from both the surface and the bulk. For practical applications the degree of surface resistance is directly proportional to the interfacial efficiency of current transfer in a fuel cell stack. Accordingly it should be quoted in conjunction with any bulk resistance (resistivity) values. A plot of conductivity as a function of pressure can reveal more valuable information by superimposing both the bulk and surface resistance values. It is clear that quoting total conductivity (or resistivity) values alone conceals the finer detail needed to optimise a product. However this poses an important commercial question: Once calculated, how can you minimise these plate resistances and optimise your electrical conductivity?

Critical Factors to Achieving an Optimised System

From the “pre-design” phase to actual fuel cell assembly, numerous critical procedures must be implemented in order to guarantee an optimised composite plate system. Running basic test trials on the new mould tool will optimise loading technique, press temperatures and pressures. Even at that stage, for most suppliers the overall plate resistance (and surface resistance in particular) is not optimised. The majority of companies must machine the plate surface to remove a detrimental, electrically insulating coating. To overcome this expensive and time consuming step, **Bac2 Ltd utilise the patented conductive polymer, *ElectroPhen*®, as a host binder**. The intrinsic conductivity in this host polymer matrix removes any necessity for additional surface treatment. Consequently ElectroPhen®-based moulded plates are optimised for fuel cell use when straight off the press. In Figure **1.5** the resistance is plotted as a function of pressure, individually highlighting the contributions from bulk and surface resistance, for a sample ElectroPhen® composite plate.

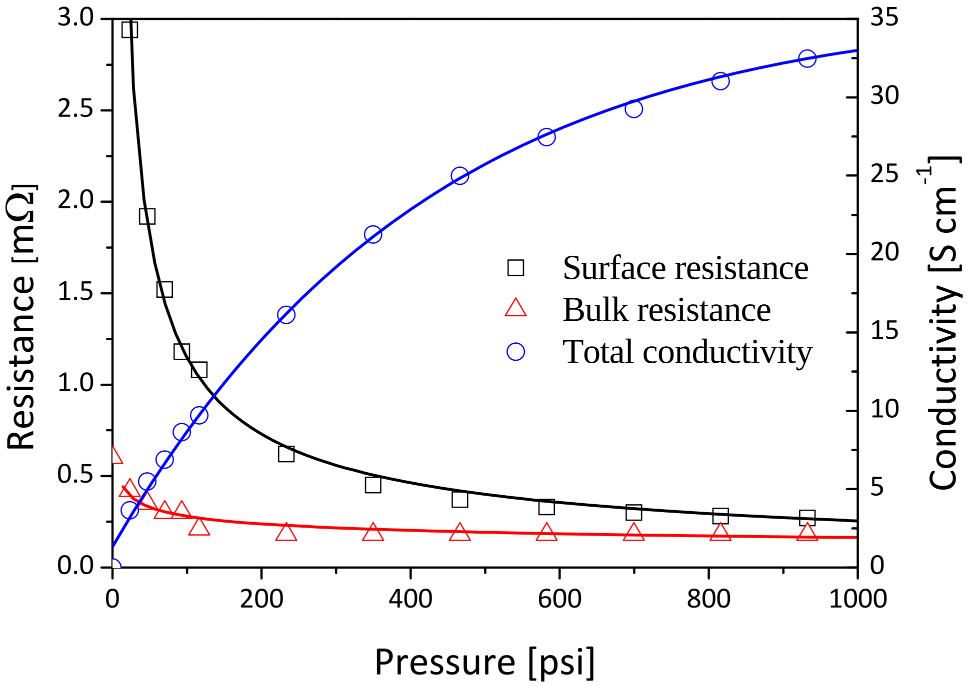


Figure 1.5 Plot of total electrical conductivity as a function of pressure for a sample composite plate, highlighting the bulk and surface resistance contributions.

CONCLUSION

Bac2 Ltd has designed an in-house electrical conductivity testing system for composite bipolar plates. This allows for fast and reliable evaluation of the through-plane electrical conductivity of test plates on a microscopic level. Equations **1.2** and **1.3** can be extended to allow for more complex test samples; inclusion of Gas Diffusion Layers (GDLs) and multiply stacked bipolar plate test samples. Together with chemical resistance testing, this test presents a critical and necessary assessment of the expected performance of bipolar plates within the fuel cell environment.