Developing Better Electrochemical Cells Using Insights From Electrochemical Impedance Spectroscopy

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1. Challenges in Cell Design

Advancing promising cell designs into full-scale industrial stacks is a costly and challenging venture. Current state-of-the-art materials such as Pt-group metal (PGM) catalysts in fuel cells, or cobalt in Li-ion batteries, are prohibitively expensive in quantities necessary for industrial-scale applications. These materials are also fragile and rapidly degrade, leading to additional replacement costs. The search for new materials requires many iterations and presents several design challenges.

Effective designs require accurate and up-to-date information about what is happening on the chemical level inside the cells. Without knowing what hinders the primary reactions or how parasitic reactions cause damage, effective solutions cannot be developed.

There is a lack of options for collecting in-depth cell data as many established methods come with compromises. Imaging techniques often require modifications to the cell, while delicate sensors necessitate milder conditions to avoid damage. Though simple voltage/current measurements provide a general picture of cell/stack behaviour, they lack any further diagnostic insight into performance losses.

2. Electrochemical Impedance Spectroscopy

High-quality *electrochemical impedance spectroscopy* (EIS) is invaluable for assessing cell/stack electrochemistry. EIS is especially sensitive to the electrochemical environment and, most importantly, it can distinguish between degradation sources. This capability pinpoints changes to cell/stack performance to isolate inefficiencies to the affected components. Pulsenics takes EIS a step further, enabling real-time monitoring of cells/stacks during operation (referred to as *in-operando*). Changes to the cell/stack's state are actively tracked under real operating conditions, providing a closer picture of the cell electrochemistry. This level of monitoring is not possible with traditional EIS due to slow measurement speeds and low power limits.

3. Case Study: Comparing Electrode Candidates

To showcase how EIS might be used to select a new material, a study was run on three electrodes: A, B, and C, tested in otherwise identical electrolyzer cells. EIS spectra captured for each material is given in a Nyquist plot in Figure 1. The first material property that can be determined by EIS is the high frequency resistance (HFR). This is an intrinsic property commonly associated with the membrane in fuel cells and electrolyzers. The HFR can be determined from reading the x-intercept and based on this criteria, electrode *C* has the lowest HFR. The Pulse Hub software makes determining HFR simple through automatic detection of this parameter.

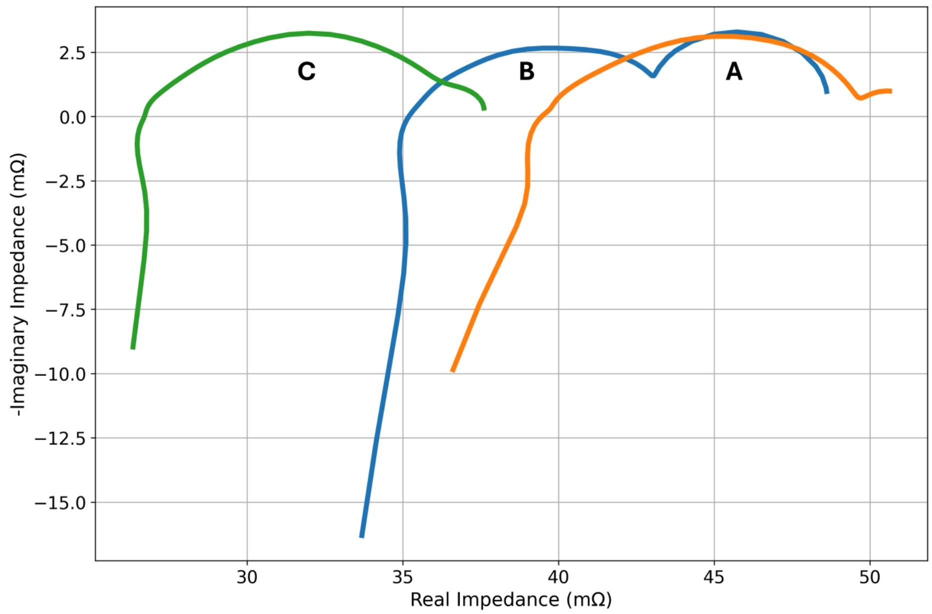

Figure 1: Nyquist plots of each of the three electrode materials. Distinct features such as the number and size of the semicircles are indicators of underlying electrochemical processes.

EIS also measures the impedance related to electrochemical reactions. The features representing these reactions in the Nyquit plots are the number of arcs and their diameters. Different arcs represent distinct redox processes, each with their own charge-transfer resistance.

Charge-transfer resistance measures the ease of electron transfer at the electrode surface. Electrode *B* is noticeably different from the others as it has a second well-separated and much larger arc than those observed in *A* or *C*. The associated redox process in *B* has significantly slower kinetics and a higher energy barrier. Slower kinetics results in reduced hydrogen production in electrolyzers and limited power output in fuel cells.

4. Conclusions

Based on the findings of this study, electrode *C* shows the most promise as a new electrode material. Its charge-transfer resistance is comparable to electrode *A,* and both outperform electrode *B*. The deciding factor then is the HFR, which is lowest in electrode *C*. Therefore, electrode *C* is expected to be the most efficient choice for hydrogen generation.

These examples show how Pulsenics' in-line EIS is used to directly study the electrochemical environment of cells. The analysis of EIS data provides several key indicators that are tied to the electrochemical reactions at the heart of the system. Factors that hinder these reactions are captured by unique EIS signals which are associated with certain components and materials. In this way, EIS is a powerful assessment tool for electrochemical device design. To learn more about how EIS provides insights on electrochemical performance or about testing with EIS, visit pulsenics.com or book a call with us.