

Micro and Nano Scale Electrochemistry Applied to Fuel Cells

Investigators: Friedrich B. Prinz, Professor, Mechanical Engineering; Ryan O'Hayre and Minhwan Lee, Graduate Researchers

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Objective: The aim of this project is to investigate the conductivity of assemblies consisting of micron and submicron catalyst particles on polymeric electrolyte membranes. Platinum catalyst particles are deposited with the help of a Focused Ion Beam (FIB) system. The FIB allows fabrication of prescribed patterns of platinum particles, which in turn enables systematic studies of particle geometry and its effect on fuel cell behavior. The smallest catalyst particles created by FIB are of the order of hundreds of nanometers. To study fuel cell behavior with catalyst particles of less than 10 nanometer diameter, nano-indentation of platinum coated AFM (Atomic Force Microscopy) tips onto a Nafion electrolyte surface is employed. The platinum tips are connected to an impedance spectrum analyzer to measure fuel cell performance.

Background: Fuel cells offer the promise of cleaner electricity with less environmental impact than traditional energy conversion technologies. However, today fuel cell technology is not economically competitive with traditional energy conversion technologies. Recently, fuel cell costs have declined due to *technological* successes wrought by the incorporation of nano-structured materials. In spite of this success, greater cost reductions and other significant challenges remain. We are still far away from possessing a *scientific* understanding of processes at nano- scale inside fuel cells. Such understanding is critical for further progress.

Approach: The present research pioneers novel electrochemical techniques to study fuel cells at the sub-micron length scale. A first technique employs platinum microelectrodes to examine the Triple Phase Boundary (TPB) properties of polymer electrolyte fuel cells. By constructing geometrically simple, well-defined electrocatalyst structures of various sizes, a relationship between electrocatalyst geometry and electrochemical behavior is clearly delineated. This study provides perhaps the most direct experimental validation to date of the TPB theory. Extending characterization abilities to the nano-scale, a second technique, called AFM impedance imaging, is also developed. AFM impedance imaging allows highly localized measurements of electrochemical properties to be acquired across sample surfaces. The technique is used to *qualitatively* visualize sub-micron variations in the electrochemical properties of Nafion (fuel cell electrolyte) samples. The AFM impedance technique is further refined by the development of a *quantitative* measurement methodology. This methodology is validated by AFM impedance-based studies of the Oxygen Reduction Reaction (ORR) at nano-scale platinum/Nafion contacts. Use of the quantitative AFM impedance technique provides perhaps the most direct measurement yet of ORR kinetics at nanometer length scales.

While the techniques explored in this research are employed to study the electro-chemical behavior of fuel cells, characterizing and understanding nanostructures is a challenge that extends far beyond the fuel cell realm. Many other devices, such as solar cells, sensors, and thermoelectric converters are expected to benefit from nano-structured materials as well. The

parallels between these systems and fuel cells make them highly amenable to the same type of nano-scale visualization and measurement techniques, offering rich opportunities for further research.

The micro-scale platinum features pictured in Figure 1 are fully functioning fuel cells. Truly micro fuel cells, they may in fact be some of the world's smallest Polymer Electrolyte Membrane Fuel Cells (PEMFCs) ever evaluated. Not surprisingly, the larger the fuel cell, the greater absolute current it delivers. Normalization indicates that fuel cell performance scales with the perimeter of the catalyst particles or the length of the triple phase boundaries. For very small catalyst particles, the particle length scaling switches to an area-based scaling law. This observation provides insight into the diffusion mechanism of oxygen from the perimeter towards the center of the catalyst particles.

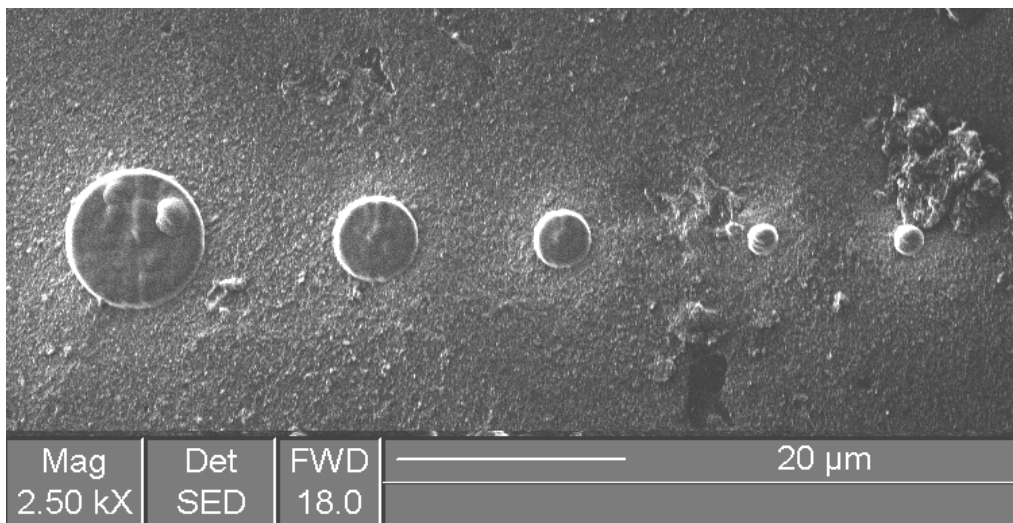


Figure 1: Fully Functioning Micro Fuel Cells

Contact: Fritz Prinz, fbp@cdr.stanford.edu