Nanofiber Fuel Cell Electrodes I. Fabrication and Performance with Commercial Pt/C Catalysts

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Introduction

The hydrogen/air proton-exchange membrane (PEM) fuel cell is a promising candidate for automotive applications due to its high power output, moderate operating temperature, and quick start-up. Presently, mass commercialization is challenging due to the high price of membrane-electrode-assemblies and inadequate durability of the typical carbon-supported Pt catalysts. Recently, there has been considerable work on creating low Pt-loaded electrodes that are stable in a harsh automotive operating environment. Work in this area includes the investigation of metal alloys, core-shell nanostructures, and carbon nanotube supports.

Another way to lower catalyst loading is to improve the cathode morphology in order to maximize catalyst contact with reactant gases while maintaining a sufficient number of pathways for proton and electron conduction. The use of electrospinning offers the possibility of creating new nanofiber structures from a rich variety of different catalytic materials. Previously, we have shown that a cathode electrospun from Johnson Matthey HiSpec 4000 catalyst with a Pt loading of 0.065 mg_{Pt}/cm^2 produced 29% more power than a decal cathode at a Pt loading of 0.104 mg_{Pt}/cm^2 (360 mW/cm^2 vs 280 mW/cm^2).[1] Electrospun cathodes were also shown to have acceptable durability.[2] The outstanding performance of the nanofiber cathodes is attributed to the unique inter-fiber and intra-fiber porosity of the nanofiber mat with well-dispersed catalyst and ionomer that results in high electrochemical surface area and high catalyst mass activity.[1] Herein, we report on new results with nanofiber cathodes electrospun with Ketjen-black-supported Tanaka Kikinzoku Kogyo (TKK) catalyst.

Experimental

An electrospinning ink was prepared by mixing: (a) an alcohol/water solution of Pt/C catalyst powder, either Johnson Matthey (JM) HiSpec 4000 (40% Pt on Vulcan carbon) or Tanaka Kikinzoku Kogyo (TKK) TEC10E50E (46.1% Pt on Ketjen Black), (b) a solution of 20% Nafion ion-exchange resin in lower aliphatic alcohols/water solvent (Aldrich) and (c) poly(acrylic acid) (Mv=450,000, Aldrich) that was dissolved in an isopropanol/water solvent (2:1 wt. ratio). The total polymer and powder content of the spinning solution was 14.0 wt%, where the Pt/C:Nafion®:PAA weight ratio was 72:13:15. The ink was drawn into a 3 mL syringe and electrospun using a 22 gauge stainless steel needle spinneret, where the needle tip was polarized to a potential of +10.0 kV (relative to a grounded stainless steel rotating drum collector). The spinneret-to-collector distance was fixed at 10 cm, and the flow rate of the ink was 1.0 mL/h. The collector drum rotated at 100 rpm and oscillated horizontally to improve the uniformity of deposited nanofibers.

MEAs (5 cm^2) were made using a Nafion 211 proton-exchange membrane with an electrospun anode and cathode of identical compositions, 72 wt% Pt/C, 13 wt% Nafion®, and 15 wt% poly(acrylic acid). The cathode and anode Pt loading was fixed at 0.10 mg/cm^2. Electrodes were hot-pressed to the membrane at 140°C and 4 MPa for 1 minute after a 10 minute heating period at 140°C and 0 MPa.

Results

The electrochemical performance of nanofiber electrodes fabricated with TKK TEC10E50E was found to be somewhat better than that of a MEA with JM HiSpec 4000 (Fig. 1). For example, at a voltage of 0.65 V, the TKK MEA power density was 454 mW/cm^2, as compared to 400 mW/cm^2 for the JM-catalyst MEA; an improvement of 13%. The advantage of the TKK is most pronounced at high voltage/low current densities where kinetic overpotentials dominate; the high surface area Ketjen black support material for the TKK catalyst appears to provide greater active electrochemical Pt surface area (ECA). For the TKK and JM cathodes, the ECA was found to be 74 m^2/g and 45 m^2/g, respectively.

The effect of nanofiber composition (Nafion/poly(acrylic acid)/catalyst) on fuel cell power density and electrode durability will be discussed for JM and TKK catalyst. Preliminary fuel cell results with electrospun nanofibers containing a heat-treated TKK Pt/C catalyst will also be presented.

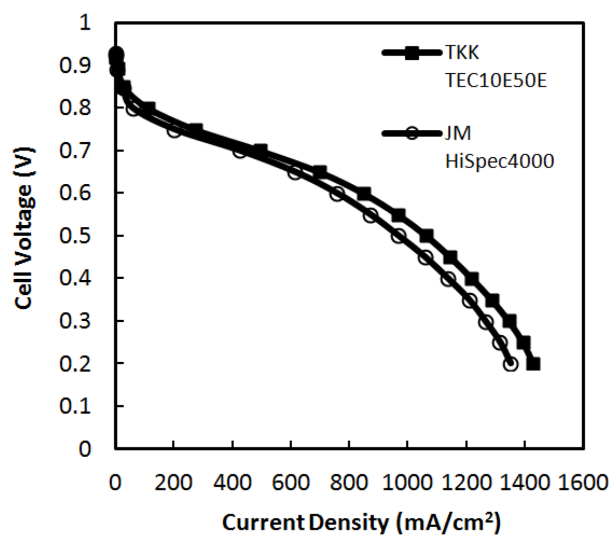

Figure 1. Hydrogen/air fuel cell polarization curves for electrospun cathodes and anodes at a Pt loading of 0.10 mg/cm^2 with two catalysts: (■) TKK TEC10E50E and (○) JM HiSpec4000. Fuel cell operating conditions: 80°C, 100% RH and ambient pressure, 5 cm^2 MEAs, Nafion 211 membrane.

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References

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