Carbon-Foam Supported Electrocatalysts for Polymer Electrolyte Membrane Fuel Cells

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Abstract : Polymer electrolyte membrane fuel cells (PEMFCs) are electrochemical energy conversion devices used for portable, residential and vehicular applications due to their low emissions, high efficiency, and quick start-up characteristics. However, PEMFCs generally use expensive, Pt-based electrocatalysts as electrode catalysts. Due to the high cost and limited availability of platinum, research and development to either drastically reduce platinum loading, or replace platinum with alternative catalysts is of paramount importance. A combination of high surface area supports and nano-structured active sites is essential for effective operation of catalysts. We synthesize carbon foam supports by thermal decomposition of sodium ethoxide, using a template-free, gram scale, cheap, and scalable pyrolysis method. This carbon foam has a high surface area, highly porous, three-dimensional framework which is ideal for electrochemical applications. These carbon foams can have surface area larger than 2500 m^2/g, and electron microscopy reveals that they have micron-scale cells, separated by few-layer graphene-like carbon walls. We applied this carbon foam as a platinum catalyst support, resulting in the improved electrochemical surface area and mass activity for the oxygen reduction reaction (ORR), compared to carbon black. Similarly, silver-decorated carbon foams showed higher activity and efficiency for electrochemical carbon dioxide conversion than silver-decorated carbon black. A promising alternative to Pt-catalysts for the ORR is iron-impregnated nitrogen-doped carbon catalysts (Fe-N-C). Doping carbon with nitrogen alters the chemical structure and modulates the electronic properties, allowing a degree of control over the catalytic properties. We have adapted our synthesis method to produce nitrogen-doped carbon foams with large surface area, using triethanolamine as a nitrogen feedstock, in a novel bottom-up protocol. These foams are then infiltrated with iron acetate (FeAc) and pyrolysed to form Fe-N-C foams. The resulting Fe-N-C foam catalysts have high initial activity (half-wave potential of 0.68 VRHE), comparable to that of commercially available Pt-free catalysts (e.g., NPC-2000, Pajarito Powder) in acid solution. In alkaline solution, the Fe-N-C carbon foam catalysts have a half-wave potential of 0.89 VRHE, which is higher than that of NPC-2000 by almost 10 mVRHE, and far out-performing platinum. However, the durability is still a problem at present. The lessons learned from X-ray absorption spectroscopy (XAS), transmission electron microscopy (TEM), X-ray photoelectron spectroscopy (XPS), and electrochemical measurements will be used to carefully design Fe-N-C catalysts for higher performance PEMFCs.

Keywords : carbon-foam, polymer electrolyte membrane fuel cells, platinum, Pt-free, Fe-N-C, ORR
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