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PEMFC 촉매분야에서 분자 전자 촉매 설계의 최신 연구동향

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The catalyst layer of a PEMFC is characteristically formed by applying a catalyst paste or an ink made from platinum to the membrane. The ink has catalyst particles that are characteristically prepared by having the platinum supported on carbon black at a predetermined weight ratio and uniformly mixed with an ion-conductive binder. This is then applied to the underlayer support or membrane and then the applied catalyst ink is dried.

Lower catalyst loadings are generally interpreted as using less platinum. Platinum is expensive, but it is the most active catalyst known for the reduction of oxygen and the oxidation of hydrogen under the PEMFC conditions as we know them now. This means that the amount of platinum required is relatively small. Catalyst loadings for PEMFCs can range from 0.15 mg/cm^2 to 3 mg/cm^2, depending on the specific fuel cell and application. This means that each gram of platinum used covers an area anywhere between 330 cm^2 and 6,670 cm^2, and each troy ounce covers an area between 1 m^2 and 20.7 m^2.

Stamenkovic and Argonne senior scientist Nenad Markovic are the corresponding authors of a study whose results are now available online from the journal *Science*. They reported a platinum-nickel alloy that increased the catalytic activity of a fuel cell cathode by an astonishing 90-fold over the platinum-carbon cathode catalysts currently used.

By converting chemical energy into electrical energy without combustion, fuel cells represent perhaps the most efficient and clean technology for generating electricity. This is especially true for fuel cells designed to directly run off hydrogen, which produce only water as a byproduct. The hydrogen-powered fuel cells most talked about for use in vehicles are PEMFCs because they can deliver high power in a relative small, lightweight device. Unlike batteries, PEMFCs do not require recharging, but rely on a supply of hydrogen and access to oxygen from the atmosphere.

Like other types of fuel cells, PEMFCs carry out two reactions, an oxidation reaction at the anode and an oxygen reduction reaction at the cathode. For PEMs, this means that hydrogen molecules are split into pairs of protons and electrons at the anode. While the protons pass through the membrane, the blocked electrons are conducted via a wire (the electrical current), through a load and eventually onto the cathode. At the cathode, the electrons combine with the protons that passed through the membrane plus atoms of oxygen to produce water. The oxygen (O) comes from molecules in the air (O_2) that are split into pairs of O atoms by the cathode catalyst.

A challenge has been the platinum. While pure platinum is an exceptionally active catalyst, it is quite expensive and its performance can quickly degrade through the creation of unwanted byproducts, such as hydroxide ions. Hydroxides have an affinity for binding with platinum atoms and when they do this they take those platinum atoms out of the catalytic game. As this platinum binding continues, the catalytic ability of the cathode erodes. Consequently, researchers have been investigating the use of platinum alloys in combination with a surface enrichment technique. Under this scenario, the surface of the cathode is covered with a “skin” of platinum atoms, and beneath are layers of atoms made from a combination of platinum and a non-precious metal, such as nickel or cobalt. The subsurface alloy interacts with the skin in a way that enhances the overall performance of the cathode.

For this latest study, Stamenkovic and Markovic and their colleagues created pure single crystals of platinum-nickel alloys across a range of atomic lattice structures in an ultra-high vacuum (UHV) chamber. They then used a combination of surface-sensitive probes and electrochemical techniques to measure the respective abilities of these crystals to perform ORR catalysis. The ORR activity of each sample was then compared to that of platinum single crystals and platinum-carbon catalysts. The researchers identified the platinum-nickel alloy configuration Pt3Ni(111) as displaying the highest ORR activity that has ever been detected on a cathode catalyst — 10 times better than a single crystal surface of pure platinum(111), and 90 times better than platinum-carbon. In this (111) configuration, the surface skin is a layer of tightly packed platinum atoms that sits on top of a layer made up of equal numbers of platinum and nickel atoms. All of the layers underneath those top two layers consist of three atoms of platinum for every atom of nickel.

According to Stamenkovic, the $Pt_3Ni(111)$ configuration acts as a buffer against hydroxide and other platinum-binding molecules, blunting their interactions with the cathode surface and allowing for far more ORR activity. The reduced platinum-binding also cuts down on the degradation of the cathode surface.