УДК: 620.91

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Can Solid Oxide Fuel Cells Change Transportation?

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Fuel cells have been under development for more than 180 years since its discovery in the early nineteenth century. Several types of fuel cells have resulted from extensive research and development work, but only two types have reached a stage of commercialization.

One is the polymer electrolyte membrane fuel cell (PEMFC) and the other is the solid oxide fuel cell (SOFC). It is a generally accepted opinion that the former is better applicable for transportation and the latter for stationary power applications.

As our energy demands grow, so does our dependence on fossil fuels. However, the fear of depleting resources and an increased dependence on foreign oil has thrown the spotlight on alternative energy sources, such as fuel cells. Instead of burning fuel, they work by generating electricity through a chemical reaction.

A fuel cell uses a positive electrode (the cathode) and a negative electrode (the anode) with an electrolyte in between for conducting charged particles. Scientists have known about fuel cells for more than a century, and NASA actually used them in the 1960s on the Apollo spacecraft, and then later on the Space Shuttle [1].

One of the most efficient types of fuel cells is the solid oxide fuel cell (SOFC). In an SOFC, oxygen is sent through the cathode, releasing negatively charged oxygen ions that pass through the electrolyte from the cathode to the anode. At the anode, the ions encounter a fuel gas and react, releasing electrons (as well as water, carbon dioxide and heat). This creates a current of usable electricity. Multiple fuel cells are put together in a series known as a stack.

Not only do SOFCs produce fewer emissions, they're also about two to three times more efficient than internal combustion methods. One advantage that SOFCs have over hydrogen fuel cells is fuel flexibility - SOFCs can run on a variety of fuels, including hydrogen and biofuels. They also use cheaper ceramic material rather than precious metals, unlike other fuel cells. They also don’t rely on reusing wasted heat (called combined heat and power schemes). Because of these numerous advantages, SOFCs have already proved useful for heating buildings.

However, numerous constraints have limited their applicability on a wide scale in things like cars. Namely, the SOFCs are very big and very hot. The high temperature allows for higher efficiencies, but it also poses engineering problems. Typical SOFCs that have been on the market, such as the Bloom Energy Server (known as the Bloom Box), use thick electrolytes in the fuel cells to add structural support. But this causes more electrical resistance that needs to be overcome by high temperatures.

In 2011, however, researchers at the University of Maryland announced developments using a new design and different materials for the electrolyte that allow for a much smaller size. The researchers also successfully reduced the operating temperature significantly to 650 degrees Celsius (1202 degrees Fahrenheit), down from 900 degrees Celsius (1652 degrees Fahrenheit). This lowers the costs of the insulating materials, which are necessary for reducing the time the system needs to heat up.

Although hydrogen fuel cells have gained a lot of media attention as the future of alternative energy cars, many believe that SOFCs actually hold the most potential for transportation. For instance, even as developments continue to make SOFCs more practical for use in vehicles, we could see cars that combine the electric car battery with SOFC technology.

Description of the various types of SOFCs: solid oxide fuel cells can be mainly grouped into tubular and planar designs. Both types can consist of one or several single cells per stacking unit, i.e., on a single tube or in a single multilayer. Depending on the application, tubular SOFCs have dimensions from needle-like to lengths of about 1.5–2 m for rapid start-up times and large gross power, respectively. On the other hand, the planar is the most common SOFC design thanks to its higher performance [2].

This architecture can lead to two different stacks containing metallic or ceramic interconnect material as well as with cells with thick (electrolyte-supported, 1st generation cells) or thin (electrode-supported, 2nd generation cells) membranes with thicknesses usually of 150–250 μm and 5–20 μm, respectively. The size of technologically relevant planar cells varies from 10 × 10 cm2 to 25 × 25 cm2 or corresponding areas in round or rectangular shape.

The today general tendency of reducing the operating temperature from about 1000°C to 500–800°C favors cell designs with thin electrolytes, lower ohmic resistance and, therefore, higher power density, passing from the 1st to the 2nd generation of cells. For this reason, many developers have considered electrode-supported cells the best choice for realizing SOFCs operating at reduced temperature.

During recent years, more interest is devoted to the 3rd generation SOFCs in which the mechanical strength is given by the electrode side, though not necessarily by the electrode substrate. In all these cases, the substrate is always porous to allow gas transport to and from the anode. The materials used for such substrates are metals or alloys, or even refractory ceramics.

In the case of insulating substrates, they only deliver the fuel gas to the anode and the current path has to be established along the substrate surface instead of passing perpendicular to the substrate surface as in electrically conductive substrates. In the case of metallic substrates, the thermomechanical compatibility is one of the main issues to be faced, because they often have higher thermal expansion coefficients than the other cell components.

Ferritic stainless steel is one of the most considered materials thanks to a coefficient of expansion similar to the ones of the cell ceramic materials (YSZ, GDC, electrolyte, or anode functional layer). Furthermore, its lower cost in comparison to either YSZ or GDC, cathodic and anodic materials lead to an overall reduction of the cost of the device.

The layers typically have thicknesses of 5–20 μm for the functional anode, 10–20 μm for the electrolyte, and 50–80 μm for the cathode. Also, the cathode is nowadays composed of two layers: an electrochemically fine-grained composite of the electrolyte material and the electrocatalyst and a coarse current collection layer supplying air and electrons to the composite layer.

References:
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