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Conductive Polymers Accelerate the Introduction of Fuel Cell Technology

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This paper examines the characteristics of ElectroPhen, an electrically conductive polymer, and its application to the production of components for use in hydrogen fuel cells.

Hydrogen fuel cells provide efficient energy without damaging emissions, and with heavy backing from major governments, they look set to provide at least part of the answer to the environmental problems of fossil fuels, and concerns over oil and gas supplies. Already in use in buses in several cities and Japanese homes, and even powering a prototype light aircraft, fuel cells combine hydrogen with oxygen (air) to generate electricity and heat, with the only waste product being clean water.

Based on electrochemistry originally invented as far back as 1839, fuel cells first came to prominence when they were used by NASA as a power source in its space missions of the 1960s and 1970s, successfully flying on over 100 missions. These proved the effectiveness of the technology, and led to a large array of prototype and development applications in transport, portable and stationary power applications. In recent years the first of these have seen commercial adoption as auxiliary generators for military or leisure use, as well as industrial power back-up. As sales volumes increase in these niche sectors and corresponding manufacturing costs come down, so other commercial markets will open up leading ultimately to the mass volume markets of consumer electronics goods and automotive transport.

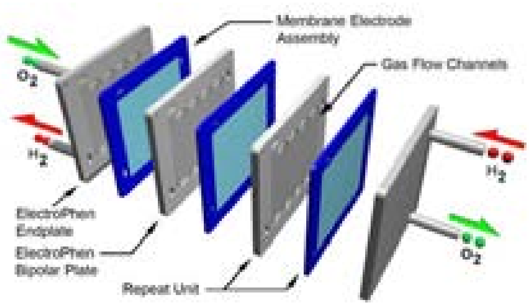
However, the widespread adoption of fuel cells is currently limited by the cost of key components. In particular, up to 30% of the cost, and 75% of the weight, of a Proton Exchange Membrane (PEM) fuel cell stack (the most popular type) is due to components called the bipolar plates and end plates.

Bac2, has developed a material called ElectroPhen, which promises to significantly reduce the cost of producing bipolar plates, and thus reduce the overall cost of fuel cell stacks and help their mass adoption.

Such cost reductions will help fuel cells – particularly hydrogen or direct methanol types – to be the most likely power technology to replace the internal combustion engine in all our vehicles, as well as becoming an affordable and ‘green’ alternative to batteries in portable electronics such as PCs and mobile phones extending the usage well beyond that offered by fully charged batteries.

Bipolar plates and end plates interconnect individual fuel cells within a fuel cell stack, and provide connections to the outside world. The bipolar plates conduct electricity, keep the reaction gasses separated yet evenly dispersed across the membrane active area and channel away waste water and heat from the reaction. ElectroPhen is a unique conductive polymer that promises to significantly reduce the cost of producing these plates.

Figure 1: A simplified representation of a polymer electrolyte fuel cell stack



The ideal bipolar plate needs to be constructed from a material that has sufficient structural integrity so that the intricate features of the gas channels can be moulded into it. It must also be robust, have minimal electrical resistance to the flow of current generated within the fuel cell stack, and be low cost.

Figure 2: Fuel cell under evaluation in the lab

From an electrical point of view, metal bipolar plates seem to be ideal. However, they require an expensive passivation process to prevent reaction with the catalysts used in fuel cells. This leads to performance degradation. Furthermore, metal plates need a costly, time-consuming and energy-intensive manufacturing process whereby channels are stamped, etched or milled into the metal surface.

Graphite is an ideal material being conductive to electricity and heat, and chemically inert when in contact with membrane and catalyst materials.

However, solid graphite is expensive, brittle and difficult to machine. Therefore, a popular technique is to use compressed graphite granules bound in a resin. The problem here is that resins and polymers such as epoxy and vinyl ester, are by nature insulators. This is far from ideal as each particle of graphite is coated with the resin, but does allow bipolar plates to be moulded to shape. Unfortunately, for best performance the resin needs to be removed either by surface abrasion or by ultra high temperature graphetisation of the resin. The resulting manufacturing process involves up to 9 separate stages, including two high temperatures and cooling cycles. This adds considerable cost, presenting problems for scaling to high volume manufacture.

What's different about ElectroPhen?

ElectroPhen is a unique thermoset polymer whose polymerisation generates nano-structures of conductive pathways locked within the polymer chains. Patents have been filed on the material.

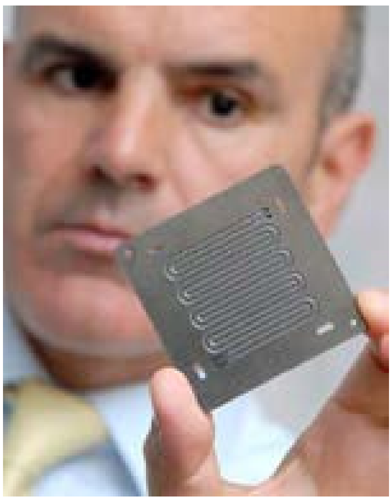
For bipolar plate applications, graphite is used as the filler. Typically, 80% filler is used to 20% ElectroPhen and the graphite is in the form of large particle size flake or shaped granules. The graphite particles are used to achieve high levels of conductivity and high current density, rather than for physical strength.

ElectroPhen cures at room temperature and need no secondary processing as the conductive binder creates a conductivity-enhancing effect.

Figure 3: ElectroPhen – an electrically conductive plastic

During 2007 the material formulation has been optimised and it now provides industry-leading conductivity. Plates with in-plane electrical conductivity of as much as 600 Siemens per centimeter have been produced, comfortably exceeding the US Department of Energy conductivity target of 200 Siemens per centimeter for such materials when they are used to make bipolar plates for fuel cell applications. Towards the end of the year the commercialisation phase began with moulding trials to produce, initially, blank plates. These were sampled to key customers during January 2008.

Figure 4: ElectroPhen plates could significantly reduce fuel cell costs



ElecroPhen's raw state conductivity is in the order of 10^9 (a billion times) more conductive than most common plastics, which contributes significantly to the industry-leading measurements of conductivity for bipolar plates. This means that the formulation of ElectroPhen can be customized using plasticizers or reinforcers to enhance strength, flexibility or other key parameters while maintaining the levels of electrical conductivity required for effective fuel cell operation. ElectroPhen is ideal for compression moulding. It has inherent mould-release characteristics, which means that complete flow patterns can be moulded into the material, yet on release from the mould it can be assembled into the stack with little more that a clean in water. No other processing is required, so manufacture can readily be scaled up to high volume once the industry demands it.

Figure 5: ElectroPhen can be moulded to produce the precise channels needed for bi-polar plates – additional machining is not needed

Other important physical characteristics of ElecroPhen are its thermal stability, resilience to high temperatures and inertness towards the catalyst. This means that stack manufacturers can safely explore the use of different, cheaper, catalyst materials that may require higher temperatures at the reaction surface. Its use is being tested in Direct Methanol and Phosphoric Acid Fuel Cells.

With its roots in traditional resins, ElecroPhen is cheap to manufacture, with the basic raw materials being widely available from major chemical suppliers. As a result, bulk quantities of raw materials, or better still, pre-mixes containing conductive fillers to Bac2's specification, can be supplied directly to moulding companies. This minimises the logistics and supply-chain overhead and ensures there will be no disruption to supply through multiple-sourcing.

Scaling for high-volume production

Today, a number of fuel cell stack manufacturers produce their own bipolar plates, having largely been forced to undertake their own R&D on the most suitable available materials. The volumes produced are only small, so manufacturing techniques appropriate to these volumes, such as CNC milling or high temperature moulding, may be applied. This is reflected in the high cost of stacks available on the market.

At the point where it becomes viable for the world's leading car manufacturers to introduce a fuel cell-powered vehicle to the mass market, the manufacturing requirement will rise rapidly towards the magnitude of one million plates per day. Stacks for automobiles are likely to comprise more than two hundred MEA/bipolar plate assemblies. Manufacturability on this scale needs to be considered by stack manufacturers currently pioneering the lower volume commercial markets.

ElectroPhen's low-temperature cure makes for easy scalability, from rapid-prototyping by CNC milling from pre-prepared blanks through to high volume compression moulding, presenting the opportunity for low-cost manufacture in developing countries where under-developed fossil fuel infrastructure reduces the entry barriers to adoption of a fuel cell based hydrogen economy.

Other applications

Fuel cells are the first of may applications being targeted by Bac2 for ElectroPhen. Others include heating elements – it heats up in a very controllable manner when an electric current is passed through it - static dissipative coatings and electromagnetic shielding, as well as a host of applications in the world of microelectronics.

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