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A comparison of nickel coated and uncoated sintered stainless steel used as bipolar plates in low-temperature fuel cells

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ABSTRACT

Bipolar plates (BP) represent a multifunctional component in PEMFC (Proton Exchange Membrane Fuel Cells). Materials used for bipolar plates should have good corrosion resistance in high acidity and high temperature environments. The most common material for BP is graphite (high thermal and chemical resistivity, high electrical conductivity but low mechanical strength). Recently carbon layers deposited on metallic substrates, such as stainless steel (SS), have been proposed to be used as BP in PEMFC.

Sintered stainless steel uncoated and coated with C–Ni coating are being studied to be used as bipolar plates in fuel cell. The study found that the conductive nickel layer has a high corrosion resistance in both anode and cathode environments. The microstructure, surface geometry and wettability of C–Ni layer were analyzed.

Introduction

Proton exchange membrane fuel cells have received a great deal of attention because of their applications in alternative-energy vehicles. They are characterized by low operation temperatures (<100 °C), high efficiency, faster start-ups at room temperature, noiselessness and can be regarded as a clean energy source [1–3]. According to the application and the structure of fuel cell, six major types of fuel cells can be distinguished, i.e.: alkaline fuel cell (AFC), phosphoric-acid fuel cell (PAFC), molten carbonate fuel cell (MCFC), solid oxide fuel cell (SOFC), proton exchange membrane fuel cell (PEMFC) and direct methanol fuel cell (DMFC). These cells are most often used for the batteries for portable devices, low and high power generators, stationary power plants and car

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drives. These cells can be successfully used under conditions of lower and higher load and the generated power can be fast and easily adapted to the variable external load. Energy in these fuel cells is produced with high efficiency, which does not depend on the size of the equipment. A drawback of fuel cells is higher costs of fuel cell manufacturing [2,34,35].

Depending on the range of power of fuel cells, the use in industry of fuel cells are as follow [1]:

- AFC: 1–100 kW, space exploration, military, transportation, mobile devices,
- PAFC: 50–1000 kW, electricity production, transportation,
- MCFC: 100÷100,000 kW, production of electricity and heat,
- SOCF: 100÷100,000 kW, production of electricity and heat, military,
- PEMFC: 0,001÷1000 kW, electricity production, mobile devices.

The design of a fuel cell is not complex. The simplicity of the design consists in the use of minimal number of elements and their immobilization, and construction of single cell carries a small load which extend the life of elements, reaching even ten thousand hours in the case of low-temperature cells, reaching even ten thousand hours in the case of low-temperature cells. Components of a fuel cell are presented in Fig. 1.

An individual cell is composed of electrolyte, electrodes (anode and cathode) with diffusion and catalytic layer and with mono- or bipolar plate [4–6].

A fuel for generation of electrical energy in a fuel cell is provided by hydrogen supplied in a gaseous form in an oxygen environment, with water and heat being by-products [6]. The driving force in fuel cells is a natural process of reaching the state of lower chemical free energy. Oxygen and hydrogen are not stable in the presence of each other and form water spontaneously. Water, which is a product, is characterized by lower free energy compared to hydrogen and oxygen (reactants), which favours the reaction. The internal parts of fuel cells are bipolar plates. They are placed at both sides of the cell, with channels on the whole surface of contact with diffusion layers [7–11]. These channels can have various

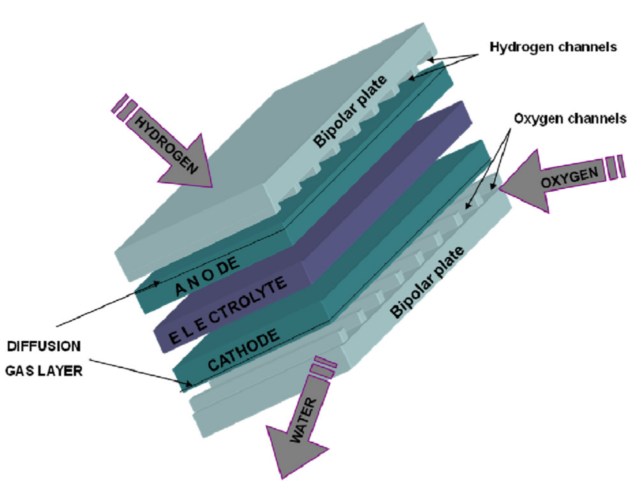

Fig. 1 – Scheme of single cell of fuel cell.

shapes (serpentine-shaped, parallel, trapezoid etc.) [12–14]. Review of the types of channels concerns in particular the geometry which depends on the type of fuel cell and demand for media in a particular cell. The list of opportunities for different channel design is obviously not ended and, apart from finding fundamental geometry, one should also consider the number of channels in the surface and distances between the channels [36]. Proper distance between the channels and the number of channels ensure quick diffusion and effective discharge of water, especially in the cathode. However, it should be emphasized that among a variety of types of channels used for distribution of media in fuel cells, there are no unequivocal research works which would have provided evidence of which type is the best.

Bipolar plates in a fuel cell are a key element and a substantial fraction of the total weight, size and cost of the stack. According to Tsuchyia Kobayashi [15], they are likely to account for 80% of total weight and 45% of total costs in a stack of PEM fuel cells.

Since bipolar plates work in an acid and humid environment of PEMFC limitation of corrosion is a basic problem in bipolar plates. Corrosion in bipolar plates leads to a release of metal ions, for instance iron, chromium, nickel etc., which might contaminate the membrane of the electrolyte and lead to catalyst poisoning [27,28].

Furthermore, formation of a passivating layer of oxides on the surface of stainless steel increases interfacial contact resistance (ICR) between the plates and the diffusion layer. Both conditions might substantially reduce stack performance. Therefore, numerous attempts have been made to reduce corrosion and eliminate the passive layer.

Possible solutions include coating the plates with a layer with high conductivity which is both chemically and mechanically durable (on a metal base) or development of composites with content of materials resistant to degrading agents.

Development of composites which might be based on carbon or metal is beneficial due to the opportunity of reduction of mass of a fuel cell [1]. Several materials can be used as components of composites:

- graphite,
- stainless steel,
- polycarbonate plastics,
- thermosetting resins,
- thermoplastic resins.

Table 1 shows common materials used for coatings in fuel cells and example methods of deposition of these coatings. The data presented in the table demonstrate numerous benefits of using individual materials. All the coatings ensure greater resistance to corrosion and improved electrical properties. Among the above materials, niobium and chromium seem to show the broadest range of benefits due to their application. Coatings of metal layers by Sandvik's are produced by PVD deposition. This production of coated strip for PEMFC bipolar plates uses an advanced, environmentally friendly vacuum-coating process. The surface layers consist of metallic elements: aluminium, nickel, cobalt, or tin and nonmetallic carbon coating [24]. Metallic layers obtained by