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Metallic bipolar plates for PEM fuel cells

J. Wind*, R. Späh, W. Kaiser, G. Böhm

Research and Development, European Aeronautic Defence and Space Company/Dornier, Elektrochemical Technology, 88039 Friedrichshafen, Germany

Abstract

Metallic bipolar plates for Polymer electrolyte membrane (PEM) fuel cells with and without coatings were tested in single cell tests. Current–voltage curves, lifetime curves and the contamination with metal ions were measured. Additionally the surface of the plates was analyzed by several methods. So far the investigations revealed that principally stainless steel covered with a thin coating is suitable as material for bipolar plates in PEM fuel cells. Cell performance is the same as in PEM fuel cells with graphite bipolar plates. Concerning the cost it has to be considered that not only the material itself but also the coating process has to be evaluated.

Keywords: Fuel cell; Bipolar plate; Stainless steel; Coatings

1. Introduction

Polymer electrolyte membrane fuel cells (PEM-FC)are the most promising power sources in the near future for residential and mobile applications. They offer the potential of compactness, lightweight, high power density and low temperature operation. In the past 5 years many research organizations, huge and small companies have intensified their efforts towards commercialization of fuel cells extremely. Among these Daimler Chrysler together with Ballard Power Systems and Ford have initiated a big boost for fuel cell technology. The applied research of European Aeronautic Defence and Space Company/Dornier as part of the research of Daimler–Chrysler is working on future developments for the following generations of fuel cells. A first market introduction of fuel cell vehicles will be seen in the near future, however there are still issues to work on before fuel cell cars will have a big market share. One of the important issues in this context is the availability of low cost bipolar plates. Bipolar plates based on carbon materials have been the main focus of the development activities so far. These materials will fulfill all requirements in the near future. Nevertheless, further cost reduction and increase of power density is beneficial for fuel cell technology. Bipolar plates based on metals offer a high potential to reduce costs and enhance power density.

As part of a public funded project (Development of the PEM Fuel Cell Technology for Mobile Applications) the suitability of metals as materials for bipolar plates is investigated. It is well known that corrosion-resistant metals such as stainless steel form passive surface layers which have a high ohmic resistance under PEM fuel cell operating conditions. The direct use of these materials leads to a voltage drop in the fuel cell. The power output and efficiency then are too low for a commercial application of fuel cells.

In order to reduce the contact resistance of the metallic bipolar plates various types of coatings and surface treatments were investigated and applied to the metallic plates. The coatings were tested in fuel cell tests. So far, a number of promising candidates has been identified. The coatings investigated up to now are either metallic or based on metallic compounds, like oxides and nitrides. One of the key issues is to investigate long time performance and to reduce the costs of such coatings. Up to 1000 h stable operation of PEM fuel cells with metallic bipolar plates have been demonstrated in small single cells.

So far, the focus of the investigations was on stainless steel as a base material for bipolar plates. Previous work of other groups [1,2] revealed that stainless steel 316L is the material of choice for bipolar plates in PEM fuel cells. During our experiments the base material was tested with and without coatings.

2. Experimental

The production of bipolar plates with gas and coolant flow fields is possible with different methods, namely machining,

* Corresponding author. Tel.: +49-7545-82845; fax: +49-7545-85775.
E-mail address: joerg.wind@daimlerchrysler.com (J. Wind).

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etching or embossing. Out of these, embossing is the preferred process for mass production due to economical reasons. The plates for the tests presented here were produced by etching the flow fields into the stainless steel. With this method, a variety of flow fields can be produced very easily. After production of the flow fields the plates were coated with different materials by various methods like electroplating, evaporation, sputtering and chemical vapour deposition. The coating materials used for cell and stack tests were chosen either by known conductivity and corrosion protection properties or after a screening process with small samples. As it is not easy to simulate the conditions in a fuel cell correctly, cell tests were the preferred measure to verify the suitability of the tested plates. These cell tests were conducted in single cells of 49 cm^2 active area. The membrane electrode assembly consisted of Nafion 113.5 membranes and Torray paper TGP90 with a catalyst loading of 4 mg/cm^2 on each electrode. The flow field chosen for comparison was a serpentine flow field with two parallel channels. Operation temperature was 75 °C, operation pressure 2.6 bar on both sides. Air stoichiometry was 2.0, fuel stoichiometry was 1.2. The gases were humidified with a dew point of 70 °C. At the beginning of each test a *I–V*-curve was measured to achieve the performance of the cell in the complete operation range from 0 to 1 A/cm^2. Voltage probes inside the cell allowed the measurement of the voltage directly at the electrodes and also the resistance between electrodes and bipolar plates. Thus, the resistance of possibly formed oxide layers could be measured in situ during the cell test. Before and after testing the cells with metallic plates the cells were tested with graphite bipolar plates to get a base value for the MEA performance. Most plates were tested up to 500 h, whereas very promising candidates were investigated for longer times. After the test, the contamination of the MEA due to metal ions coming out of the stainless steel was measured by chemical analysis. If the coatings showed changes after the test the composition of the surface was measured by surface analytical methods like Photoelectron spectroscopy (ESCA) and glow discharge optical emission spectroscopy (GDOES).

3. Results and discussion

3.1. Stainless steel 316L without coating

In our first experiments we tested bipolar plates made of stainless steel 316L without coating in comparison with bipolar plates made of graphite. The flow field geometry was identical with a slight difference in the channel profile due to different production methods of the flow fields (machining and etching). Fig. 1 shows a current–voltage curve of a stainless steel bipolar plate compared with one made of graphite. Our experiments revealed a voltage drop up to 300 mV at a current of 700 mA/cm^2 by using untreated stainless steel for bipolar plates. This is far too high for commercial applications of PEM fuel cells. Surface analysis on the air side showed that an oxide layer is formed on the surface. Thus, the voltage drop is caused by a thin passivating oxide layer on the surface of the bipolar plates. This oxide layer has a high resistivity and thus leads to a series resistance inside the fuel cell. Chemical analysis after 100 h cell operation revealed an amount of 76 $\mu g/cm^2$ Nickel and almost no iron and chromium in the MEA (Fig. 2).

3.2. Stainless steel 316L with gold coating

In order to avoid the formation of the oxide layer and nickel dissolution the bipolar plates were coated with a thin gold layer. The current–voltage curve measured in single

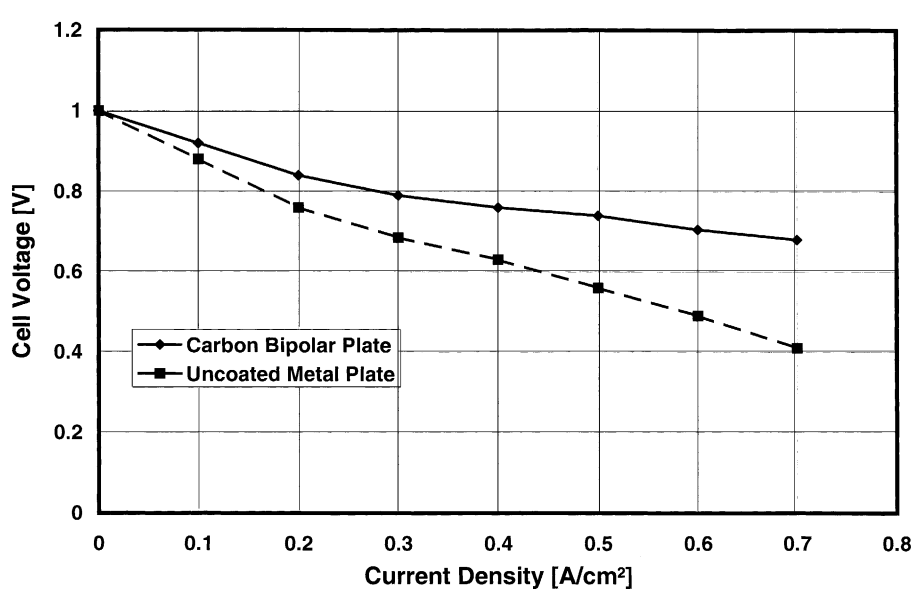

Fig. 1. Comparison of current–voltage curves of single cells with metallic bipolar plates (SS 316L) and graphite bipolar plates (beginning of life).

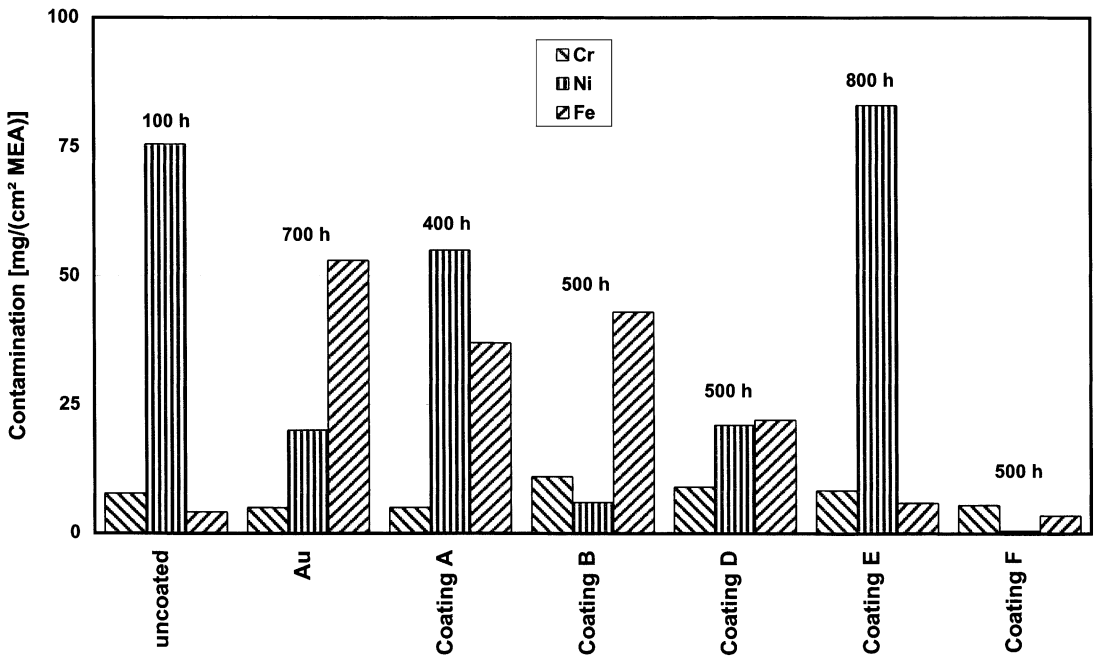

Fig. 2. Contamination of the MEA of single cells with Fe, Cr and Ni, measured after the cell test with different coated metallic bipolar plates.

cells with gold coated bipolar plates (SS 316L) clearly demonstrates that there is no difference between theses plates and graphite plates. After measuring the *I–V*-curves, the fuel cell was operated under the standard conditions for 1000 h. Fig. 3 shows that there is almost no deterioration of the cell voltage. This means that a possibly growing oxide layer is so thin that it has no effect on cell resistance and also the amount of contaminants in the MEA is so low that it does not effect the cell performance. The chemical analysis of the MEA after the cell test shows that the amount of nickel is reduced considerably, whereas the iron content in the MEA is enhanced. The reduction of the amount of nickel shows that the gold coating is a good diffusion barrier for nickel under the operation conditions of a PEM fuel cell. As almost no additional resistance is measured oxygen also does not diffuse under the gold coating. A clear explanation of the increase of iron cannot be given up to now, further investigations have to be done.

3.3. Stainless steel 316L with low cost coatings

For commercial applications of fuel cells it is necessary to reduce costs to a very low amount. Therefore, gold as a coating material cannot be used due to the high material

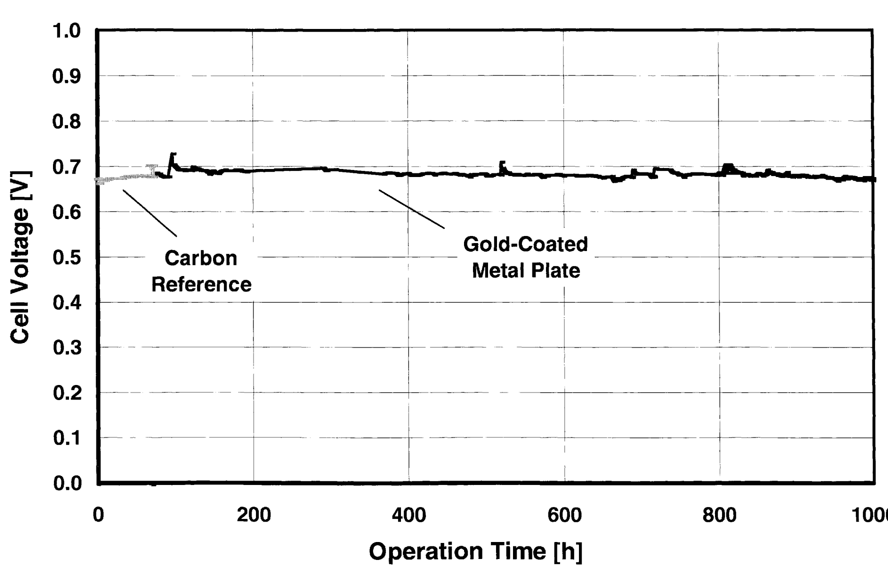

Fig. 3. Lifetime curve of a fuel cell with a gold coated metallic bipolar plate (SS316L).

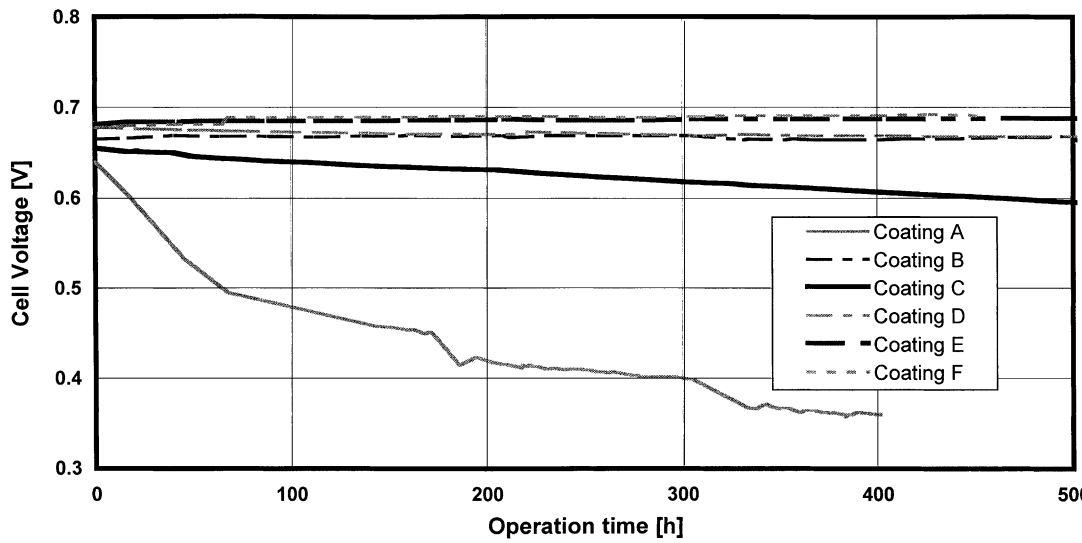

Fig. 4. Lifetime curves of single cells with bipolar plates made of stainless steel 316L coated with different coating materials.

price of gold. In order to reduce the costs of the coatings, materials which have the potential for low cost coatings had to be found. Additionally, the coating process also has to be a low cost process. In the first step, materials which have a low price were identified. A number of sheet steel samples were coated and then the conductivity was measured in a through plane measurement. The most promising coating materials were used to coat bipolar plates made of stainless steel 316L which were tested in single cell tests. The lifetime curves for 500 h of a number of these plates are shown in Fig. 4. As can be seen the performance of most of these cells is similar to cells with graphite bipolar plates. Coating A exhibits a poor cell voltage and high contact resistance similar to uncoated SS316L and coating C shows also an intermediate performance and a relatively high resistance. A detailed analysis of additional resistance and corrosion is shown in Table 1. It appears that not all coatings which show good cell results also do not suffer corrosion, but the trend is that a coating which leads to good performance data also has good corrosion preventing properties. As the necessary operation time for fuel cells is several thousand hours, some promising candidates of low cost coatings were also tested in single cell tests for up to 1000 h. An example of such a test is shown in Fig. 5. As can be seen almost no contact resistance is

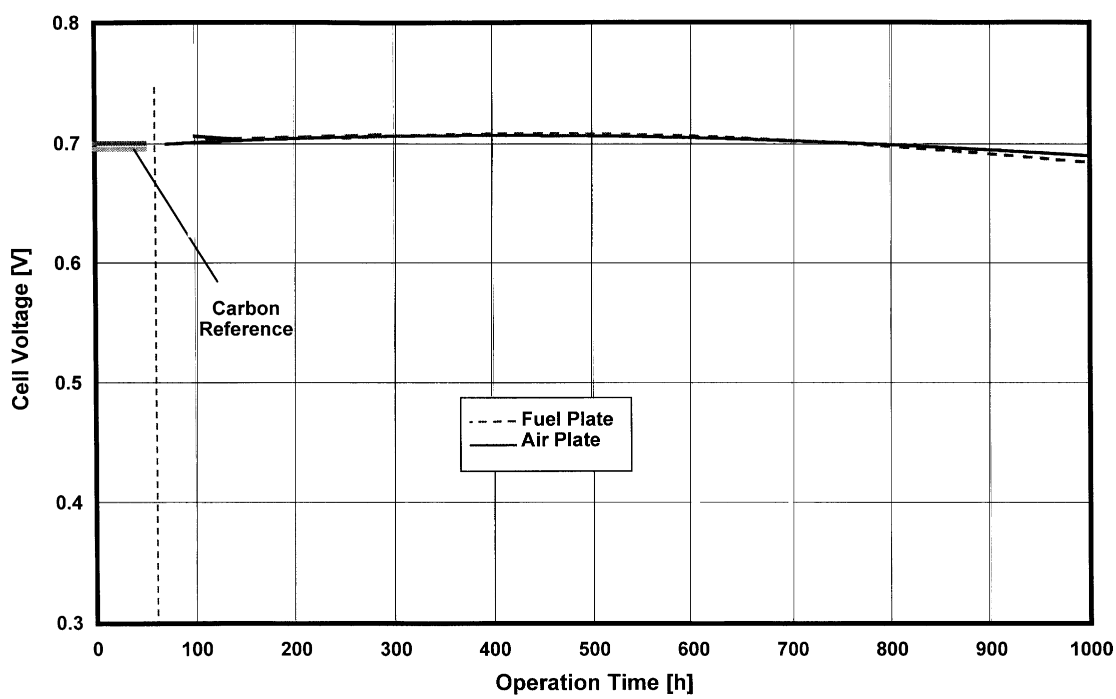

Fig. 5. Lifetime curve of a single cell with metallic bipolar plate and selected coating.

Table 1
Oxide resistance and corrosion stability of various coatings after test in a PEM fuel cell

	Resistance (mΩ cm^{-1})	Chemical stability
Coating A	668.36	−−
Coating B	63.7	+
Coating C	205.8	−
Coating D	63.7	+
Coating E	24.5	++
Coating F	19.6	++

observed, although surface analysis revealed the formation of a thin oxide layer.

4. Conclusion

The results shown above indicate that metallic bipolar plates can be used in PEM fuel cells when coated with materials which prevent the formation of oxide layers with high resistivity. These layers are stable for at least 1000 h. Both oxide formation and poisoning of the MEA are reduced. In this work the focus was on functionality of protecting layers. The materials used have the potential to be low cost coatings and thus lead to low cost bipolar plates.

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