FINAL REPORT

Development of conductive carbon-based protective coatings using established and novel coating processes for metallic bipolar plates of PEM fuel cells

PEM fuel cells show a high efficiency for converting chemical in electrical energy. They are especially at the focal point of global development activities by automotive and heater manufacturer as power generators for stationary, mobile and portable applications. A central component of the fuel cell stacks is the bipolar plate, with which the gas spaces of the adjacent cells are separated from one another, but which at the same time have to possess a high electrical conductivity and resistance under strongly corrosive conditions. The requirements are very well achieved by graphitic bipolar plates, but these are mechanically susceptible, not suitable in mass production, and also contribute to about 80% of the weight and up to 45% to the cost of a stack. By the use of metallic materials, e.g. stainless steel, the plates could be mass produced much cheaper and the stacks with the same power have about 1/5 of the volume and weight. The disadvantage of the metallic plates is their sensitivity to corrosion, especially as the metal ions which are released in the process can damage the fuel cell. Within this research project, carbon-based films are produced on the one hand by plasma-activated chemical vapor deposition (PACVD) and on the other hand by electrochemical low voltage deposition. The deposition of these carbon-based films on bipolar plates should be cheaper than with the previously available methods. In this paper carbon-based films produced by plasma-activated chemical vapor deposition are presented.

Deposition and Characterization

A modified vacuum coating plant of type Cobra Cube CC11 from *CCR GmbH* was used for the deposition of the carbon-based films. Hydrogenated amorphous carbon (a-C:H) and amorphous N-doped hydrogenated carbon (a-C:H:N) films were deposited using the vacuum coating plant designed for PACVD. For this, a C_2H_2- or N_2/C_2H_2 gas mixture was activated in a capacitively coupled plasma beam source (PBS 200) from *HS-PlasmaTec GmbH* (formerly *IPT GmbH*). By variation of deposition temperature, total pressure (ion energy) and N_2 gas flow (N-doping) it was attempted to deposit conductive carbon coatings. These carbon coatings were tested for their applicability in a PEM fuel cell. For this research project the limit values for the corrosion current density of < 1 µA/cm² at 600 $mV_{Ag/AgCl}$ and the contact resistance of < 10 mOhmcm² at a contact pressure of 13.8 bar published by the *U.S. Department of Energy* (DOE) of 2020 were trend-setting for the investigation and optimization of the carbon films. Figure 1 shows a bipolar plate coated with optimized a-C:H:N thin films.

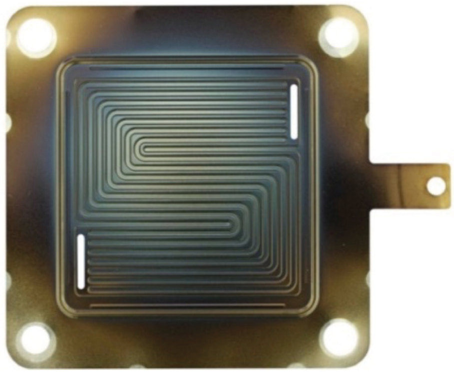

Fig. 1 | A bipolar plate coated with an optimized a-C:H:N thin film

The investigation of the carbon-coated bipolar plates regarding corrosion behavior and contact resistance was realized at *The Fuel Cell Research Center* (ZBT) in Duisburg/Germany.

Results

Starting at deposition temperatures of ≥400 °C, electrically conductive a-C:H films could be deposited. However, the a-C:H films did not achieve the DOE criteria for corrosion current density and contact resistance. The a-C:H:N films, on the other hand, are already electrically conductive at a deposition temperature of 300 °C. The correlation between contact resistance and corrosion current density of the prepared model samples is shown in figure 2. It becomes apparent that at a lower corrosion current density the contact resistance is often high and vice versa. The DOE limits for corrosion current density as well as contact resistance are only achieved from the carbon films whose values lie within the shaded area. These are a-C:H:N films deposited at a deposition temperature of 300 °C, an N_2/C_2H_2 ratio of 0.78 and a deposition pressure of 2×10^{-4} mbar.

The a-C:H:N-coated bipolar plates with flowfield were examined in a PEM fuel cell. Figure 3 shows a measuring cell from *balticFuelCells* (type quickConnect) modified for the mounting of metallic bipolar plates.

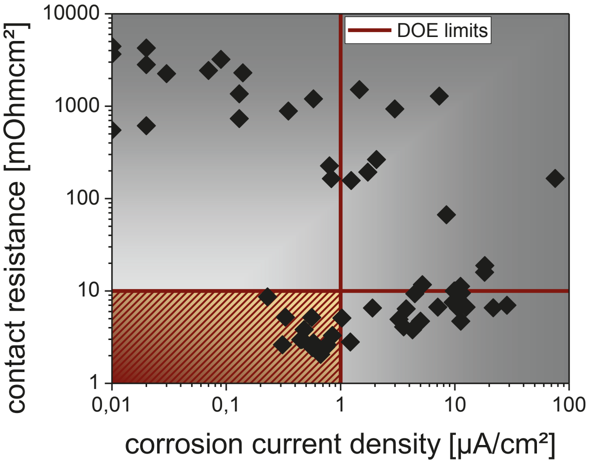

Fig. 2 | Contact resistance and corrosion current density of carbon films

Fig. 3 | A measuring cell from *balticFuelCells* (type quickConnect) modified for the mounting of metallic bipolar plates (www.zbt-duisburg.de)

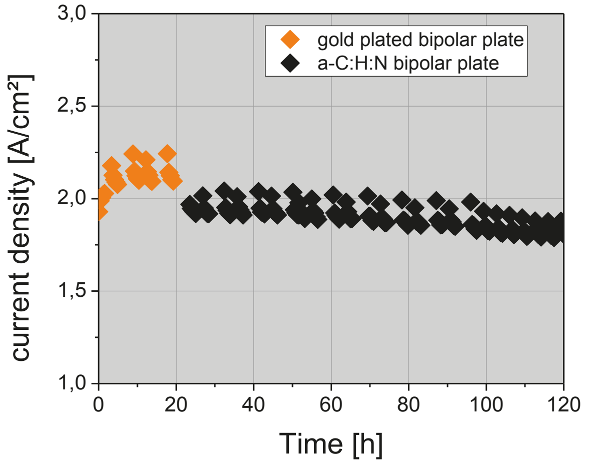

Fig. 4 | Test of a gold plated and a a-C:H:N-coated bipolar plate in a PEM fuel cell

Figure 4 shows a measurement in this PEM fuel cell. At first the measuring cell with a gold plated bipolar plate was “retracted” for 20 minutes. Then the gold plated bipolar plate was exchanged by a a-C:H:N-coated bipolar plate and the measurement was continued for another 100 h.

This result shows that bipolar plates deposited with a a-C:H:N film provided slightly lower current density than gold plated bipolar plates and therefore can be used permanently in a PEM full cell. Hence, carbon-coated metallic bipolar plates can be used as a cost-efficient alternative to gold-plated bipolar plates.

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