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Cathode electrocatalyst selection and deposition for a direct borohydride/hydrogen peroxide fuel cell

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Abstract

Catalyst selection, deposition method and substrate material selection are essential aspects for the design of efficient electrodes for fuel cells. Research is described to identify a potential catalyst for hydrogen peroxide reduction, an effective catalyst deposition method, and supporting material for a direct borohydride/hydrogen peroxide fuel cell. Several conclusions are reached. Using Pourbaix diagrams to guide experimental testing, gold is identified as an effective catalyst which minimizes gas evolution of hydrogen peroxide while providing high power density. Activated carbon cloth which features high surface area and high microporosity is found to be well suited for the supporting material for catalyst deposition. Electrodeposition and plasma sputtering deposition methods are compared to conventional techniques for depositing gold on diffusion layers. Both methods provide much higher power densities than the conventional method. The sputtering method however allows a much lower catalyst loading and well-dispersed deposits of nanoscale particles. Using these techniques, a peak power density of 680 mW cm^{-2} is achieved at 60 °C with a direct borohydride/hydrogen peroxide fuel cell which employs palladium as the anode catalyst and gold as the cathode catalyst.

Keywords: Direct borohydride/hydrogen peroxide fuel cell; Pourbaix diagram; Gold catalyst; Sputtering deposition; Activated carbon cloth

1. Introduction

Methanol and sodium borohydride are important fuel candidates for portable and mobile applications at ambient temperature. Direct borohydride fuel cells provide higher open circuit voltages and higher power densities than both hydrogen/oxygen fuel cells and direct methanol fuel cells. Hence they have received increasing attention starting in 2000 [1–3].

There is considerable motivation to use H_2O_2 in place of O_2 at the cathode to achieve even better performance and air independence for applications such as space power and underwater operation. The resulting system is termed a direct sodium borohydride/hydrogen peroxide fuel cell (DBHPFC).

Oxygen reduction at the cathode of a PEM fuel cell is:

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \quad (1)$$

This reaction involves simultaneous transfer of four electrons, and therefore has a reduced probability of occurrence [2,4]. It is known that the exchange current density of oxygen reduction is 6 orders of magnitude lower than that of hydrogen oxidation [4–7]. The slow kinetics of oxygen reduction limits the power density and cell efficiency. In comparison, the reduction reaction of hydrogen peroxide is:

$$H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O \quad (2)$$

This is a two-electron transfer process and hence has lower activation over potential than four-electron transfer process. So fuel cell systems using hydrogen peroxide as the cathode fuel tend to provide higher performance than systems using oxygen. In addition, hydrogen peroxide has other advantages. Its liquid form makes the system more compact and convenient. It is environmentally friendly and easy to handle. Its wide application and high volume production make it a low cost product in current market.

Many factors are involved in the cell optimization issue. Catalyst selection is always a critical one, especially in a cell like DBHPFC where less explored fuels are involved. Indeed exten-

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sive research effort has been put on the development of catalysts for different kinds of fuel cells since the first hydrogen/oxygen fuel cell. The objective of the research described here was to identity a potential catalyst for hydrogen peroxide reduction and to address an effective catalyst supporting material and catalyst deposition method for this all liquid fuel cell. The anode catalyst selection is also equally important and its research is described elsewhere.

2. Direct borohydride/hydrogen peroxide fuel cell

2.1. Cell structure

Fig. 1 shows an assembled DBHPFC that has been used in extensive testing. Its structure and materials selection are made for ease of use in the laboratory where components are frequently interchanged. Later models will generally follow this design, but will use optimized materials.

Graphite is used as the bipolar plate material. A serpentine style is employed, which is shown in Fig. 2 [8]. The flow rates are low so the pressure drop with this design remains manageable. A small pump is used to control the fuel flowing through the channel.

Nafion is employed as the exchange membrane. Since liquid fuels are used in the cell system, humidification problems associated with PEM fuel cells are avoided. The selection of the porous and conductive material used as the diffusion layer, the catalyst and its deposition on the diffusion layer are discussed later.

2.2. Operation system

Figs. 3 and 4 illustrate the schematic diagram and the operation system of the DBHPFC. NaOH was added to the anode solution to stabilize $NaBH_4$, inhibiting its hydrolysis reaction.

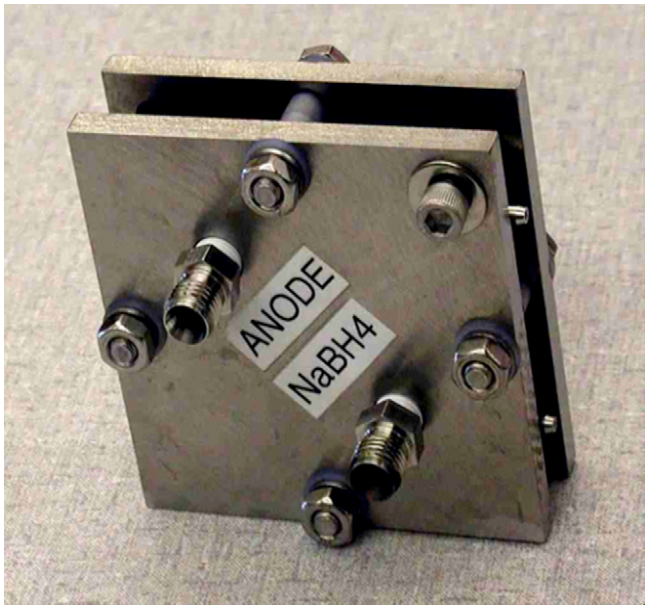

Fig. 1. Assembled DBHPFC test unit.

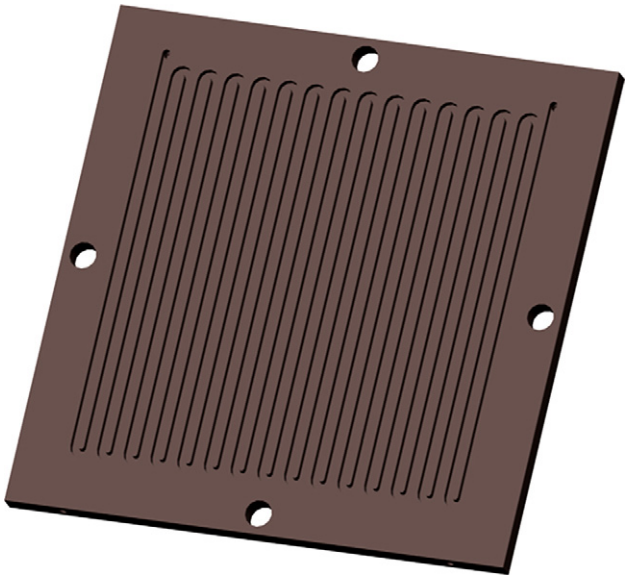

Fig. 2. Serpentine bipolar plate.

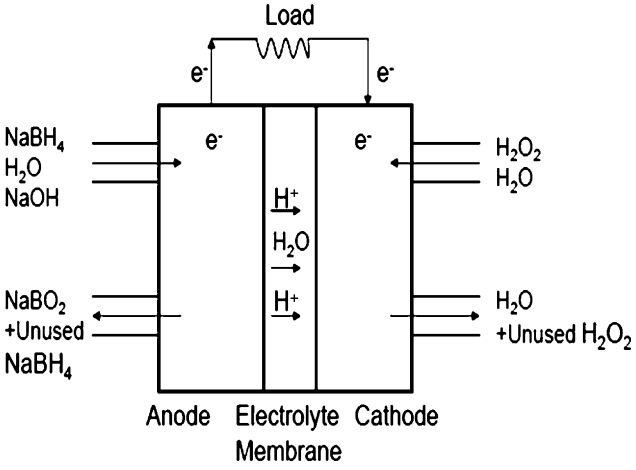

Fig. 3. Schematic diagram of the DBHPFC.

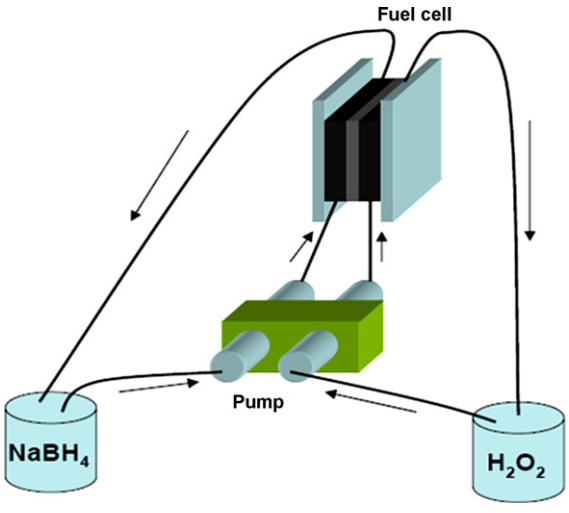

Fig. 4. Operation system of the DBHPFC.