

DIRECT GLUCOSE ENZYMATIC FUEL CELL

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Summary

Enzymatic biofuel cells are a type of fuel cells, which utilize biocatalysts i.e. enzymes instead of noble metal catalysts. Main problems of biofuel cells are short lifetime and poor power density and both of these are affected by the type of immobilisation procedure used for electrodes preparation. We have developed a flow-through glucose-oxygen fuel cell with enzymatic anode and Pt cathode, which can be used for testing of different enzymatic anodes for long-term stability under fuel cell conditions. The influence of different factors on the biofuel cell performance has been tested.

Keywords

Fuel Cells, Materials for energy applications.

Introduction

Biofuel cells are devices, which convert chemical energy into electrical energy by means of biocatalysts. Enzymes are efficient catalysts with high activity under mild conditions and high substrate specificity, which enables simpler fuel cell design. One of the potential applications of biofuel cells is for powering implantable electrically operated devices such as the pacemaker. However, state-of-the-art enzymatic biofuel cells still cannot meet the demands required for practical application because of insufficient power density and poor long-term stability. These two issues are affected mainly by the type of immobilisation procedure used for electrodes preparation. The perfect immobilisation route should enable efficient electrical communication between the enzyme and the electrode surface with low overpotential and high current densities and provide suitable environment for maintaining enzyme stability.

A common approach in the biofuel cell research involves combinations of enzymatic and non-enzymatic electrodes for either fuel oxidation or oxygen reduction. The intrinsic lack of long-term stability of enzymes has been also a driving force for the development of abiotic electrodes and biofuel cells for implantable applications, e.g. electrodes for glucose oxidation (1,2).

Most of the enzymatic biofuel cells reported in the literature so far operate at quiescent solutions without perfusion, whereby the depletion of substrate hinders the performing of long-term stability tests. In order to overcome this problem we have developed a flow-through

biofuel cell which consists of an enzymatic anode and Pt cathode. Provided that the Pt cathode exhibits in general relatively more stable behaviour than the anode, the cell can act as a platform for investigation of different bioanodes. We have employed a model procedure involving charge transfer complex (CTC) and glucose oxidase (GOx) (2) and studied the influence of different parameters on the fuel cell performance. The procedure for enzymatic modification has been optimized based on single electrode kinetic and mass transport experiments.

Experimental

Standard three-electrode double-wall jacketed electrochemical cell has been used for the single electrode experiments. Rotating disc electrode with sample holder has been used for mass transport and kinetic investigations for optimisation of the enzymatic anode preparation procedure. The fuel cell was mounted on in-house built experimental set-up equipped with thermostat and pumps, which has been used for variation of experimental conditions (flow rates, glucose concentration and temperature).

Results

The procedure for preparation of the bioanode consists of several steps (2). First conductive polypyrrole layer is electrochemically grown on stainless steel electrode. After

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that the CTC, which consists of TTF (tetrathiafulvalene) and TCNQ (tetracyanoquinodimethane) is formed directly on the polypyrrole surface. In the next step GOx is adsorbed on the CTC and finally the whole assembly is covered with a thin membrane film (e.g. gelatin). The resulting anode exhibits activity for glucose oxidation with reasonably low overpotential, high current densities and increased oxygen tolerance. Variation of different structural parameters (e.g. CTC morphology, enzyme loading, membrane thickness) followed by kinetic and mass transport investigations has been used for determination of optimal conditions for the immobilisation procedure.

Schematic presentation of the biofuel cell is shown in Figure 1.

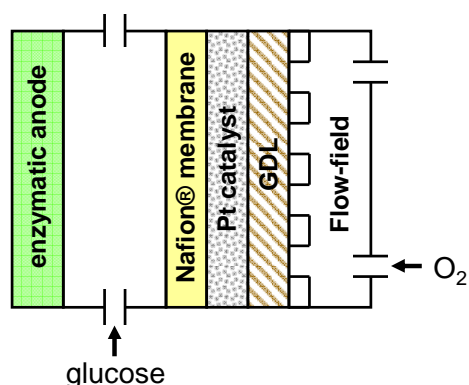


Figure 1: Schematic presentation of the biofuel cell.

The biofuel cell consists of an enzymatic anode and a Pt cathode which operates on gas-phase oxygen and is identical to a conventional polymer electrolyte membrane (PEM) fuel cell cathode. The electrodes are separated by a Nafion® membrane. The influence of both glucose solution and oxygen gas flow rates on the fuel cell performance has been tested.

Polarisation curve and the respective power curve in presence of 5 mM glucose are shown in Figure 2.

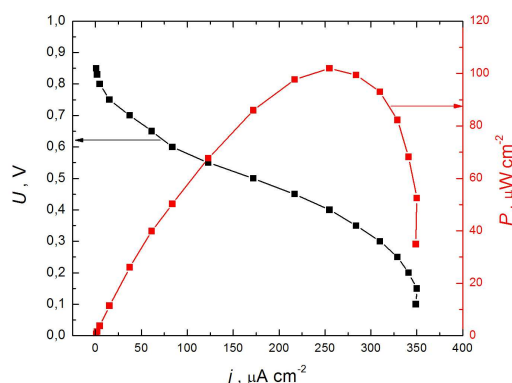


Figure 2: Power density and cell voltage as a function of current density. Conditions: Temperature: 37°C, glucose flow rate: 10 ml min⁻¹, glucose concentration: 5 mM; points sampled after 2 min.

The fuel cell exhibits good performance with open-circuit voltages (OCV) reaching up to 0.96 V. The fuel cell is able to operate with oxygen-containing glucose solution, which is important for the future application of the bioanode in a membraneless enzymatic biofuel cell.

The decrease of cell performance, faster than expected from single electrode experiments indicates flooding of the Pt cathode. This has been proven by restoring biofuel cell activity to the initial level after the membrane electrode assembly (MEA) has been exchanged (Figure 3).

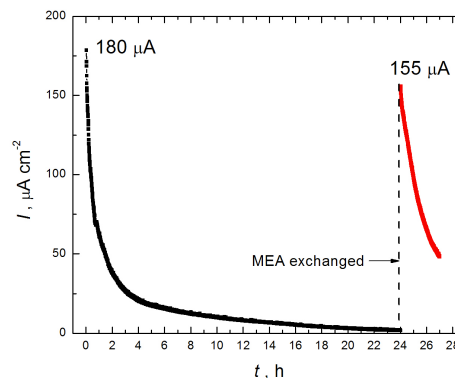


Figure 3: Decrease in current density at operating voltage of 0.5V. Conditions: Temperature: 37°C, glucose flow rate: 10 ml min⁻¹, glucose concentration: 5 mM.

Different approaches including hydrophobization of the catalyst layer and different GDL's have been tested in order to overcome this problem.

Conclusions

An optimized procedure for modification of enzymatic anode for glucose oxidation has been developed and the anode behaviour has been characterized by kinetic and mass transport experiments. The bioanode has been employed in a flow-through fuel cell with a conventional Pt cathode. The influence of different experimental conditions on the fuel cell performance has been investigated. The biofuel cell can be used as a platform for dynamic and stability experiments for testing of different enzymatic anodes under fuel cell conditions in order to identify potential anodes, which could be later used in implantable enzymatic biofuel cells.

References

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