Paper-based microfluidic fuel cells

P. Mendoza-Correa[a]; V. Galvan[b]; K. Domalon[b], S. Sotez[b], F. Gomez[b], M. Hinojosa[a]

[a]Facultad de Ingeniería Mecánica y Eléctrica, Universidad Autónoma de Nuevo León, Pedro de Alba S/N, Ciudad Universitaria, 66450 San Nicolás de Los Garza, NL, Mexico.
[b]California State University, Los Angeles, 5151 State University Drive, Los Angeles, CA, 90032-8202.

ABSTRACT

The development of advanced technologies to generate alternative energy sources at low cost, which does not require the use of fossil fuels and can be used in small portable devices has significantly increased. For example, fuel cells are simple to operate, have high energy conversion and cause no harm to the environment. One of the newest developments in this field are the microfluidic fuel cells (MFCs). The MFC paper-based works in a standard lateral flow test format, the porosity of the material allows to separate the fuel and oxidant species throughout two parallel streams without an ionic exchange membrane or external pumps.

This work describes its fabrication using a paper microfluidic platform. The fuel cells uses formate as the anode fuel and hydrogen peroxide as cathode oxidant. By using these materials has been achieved a maximum power density of nearly 1.2 mW mg-1 Pd. The MFC achieves a current density of 3.5 mA/cm3. It is also demonstrated that the MFC does not require continuous flow of fuel and oxidant to produce power.

Keywords: Fuel cells, Microfluidics, Membraneless, Laminar flow

1. Introduction

Technological growth and the necessity to optimize processes without losing the essence of getting real results in a short time has led to increased knowledge in the field of portable devices which operate rapidly and efficiently through an electronic circuit and a battery formed by a paper-based fuel cell.

The PEM fuel cell is a device which provides electrical energy through a chemical oxidation-reduction reaction that takes place at the anode and cathode, respectively. The main benefit when using this type of cells is that they are self-rechargeable, thus are constantly generating electricity. Between anode and cathode there is a membrane able to separate the hydrogen atoms provided by the fuel at the anode, allowing the passage of electrons to a circuit providing electrical power and output protons towards the cathode where they react with the room air and has water as a residue.

Most of this kind of cells produce clean energy without emitting gases that may affect the environment or some other harmful emissions. The inconvenience you have with them is the membrane degradation over time as it creates a constant reaction. Also takes into mind the high cost of materials that do not greatly benefits these devices when it comes to marketing.

Microfluidic fuel cells provide the opportunity to be similarly used as the PEM since they not require a solid membrane for chemical conversion into electricity. These cells operate using a laminar flow through a micro channel in which the chance of fuel leakage is eliminated, also, they have an estimated cost of $ 2 USD for each cell, which introduced them to the market as prospects for the electronics industry. They are compact and small, ideal for use in point-of-care devices.

2. Materials and Methods

Portable point-of-care devices are replacing the traditional diagnosis tests due to its facility to use allowing the patients to monitor their health at home. They not only give information about the current health status but also can help to prevent any further diseases. There are a few which may be single use and others that can be reused several times. Also it is important to mention that these devices shouldn't depend on a pumping system to provide fuel to make them work properly. They require materials that are environmental friendly for its manufacture and does not generate any pollution once they are thrown away.

Microfluidic fuel cells play an important role in this area since they are conform on a paper matrix with a Y-shaped form. The streams are loaded with fuel and other with the oxidant, e, g. formic acid, methanol, peroxide hydrogen, among others. In the middle of the channel, the anode and cathode are arranged where they reach the fuel and oxidant, respectively, by capillary action.

There were created three types of chips using Whatman 3 filter paper each one with different width and length (Fig. 1). A basic Y-shape was used to maintain separating the flow of the reactants until they join in the lateral column. The anode is conformed of a solution of Pd (0.007gr), C (0.003gr), 20 mL of H2O, dispersed Nafion solution (0.06 mL) and isopropyl alcohol (0.7 mL). The cathode is a mixture of paint (1.5479gr), carbon black (0.0751gr) and active carbon (0.2006gr).

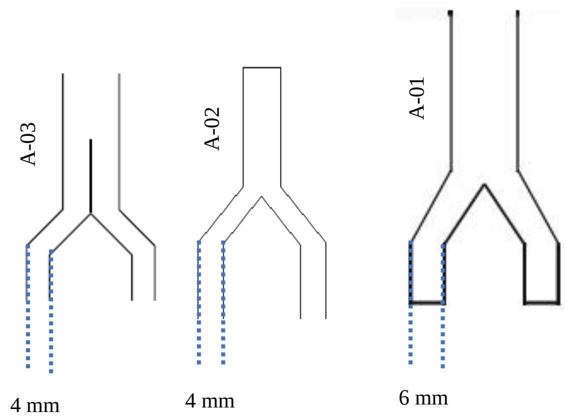


Fig. 1: Types of paper-based microfluidic fuel cells.

Table 1: Paper-based microfluidic fuel cells properties.

Sample	Width	Length
A-01	2.5 cm	4.9 cm
A-02	2.2 cm	4.5 cm
A-03	2.1 cm	3.6 cm

3. Results and Discussion

It is important to emphasize that in order to design an electronic device or system is required to know the current density generated by the material. The current density is expressed as the electrical current per unit area. It is also recommended that it remains low to prevent deterioration or degradation of the material.

For the testing, the electrodes were secured by brass mesh clips linked by silver epoxy to the anode and cathode (Fig. 2). The chip or microfluidic was placed vertically allowing flow entrance of fuel (20 mL formic acid) and oxidant (20 mL hydrogen peroxide) through two streams. Both species were disposed in glass vials. The flow raised by capillary action until it reached the anode and cathode, and it was left for 10 minutes to get a full cover.

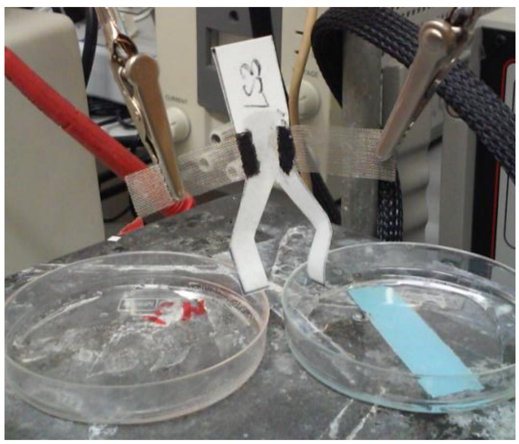


Fig. 2: A microfluidic fuel cell, with anode at the left and cathode at the right.

The electrochemical measurements were placed in a Potentiostat 263A from Princeton Applied Research (Fig. 3) operating with two electrodes. Tests were increased to 10 mV in 40 mV steps at 2s intervals under continuous flow at room temperature (23 ºC).

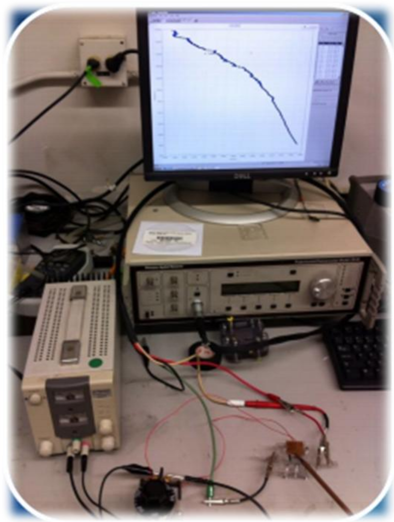
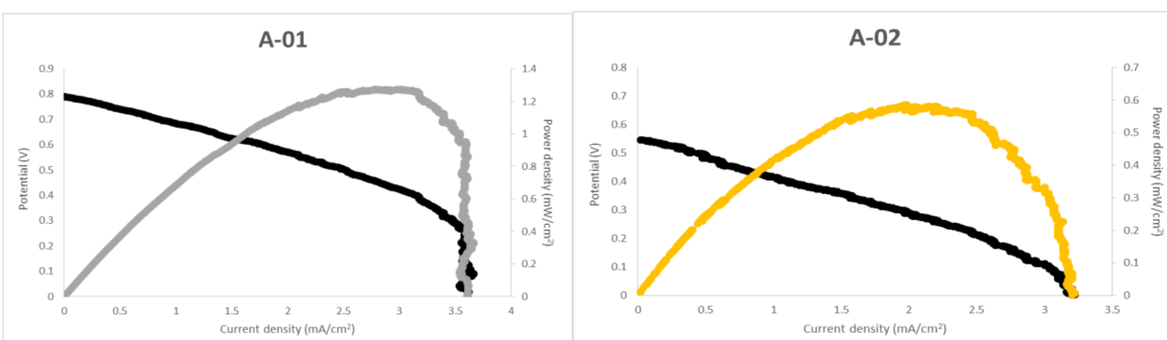


Fig. 3: Potentiostat 263A from Princeton Applied Research.

The results expressed in polarization curves show that in open circuit, the MCF A-01 (4.9 x 2.5 cm) achieved a voltage of about 0.8 V and a current density of 3.5 mA/cm^3. On a smaller size, the cell A-02 (4.5 x 2.2 cm) generates a current density a little bit lower, 3.3 mA/cm^3 and as the maximum current, 0.7 V. For the smallest cell A-03 (3.6 x 2.1 cm), it has a similar voltage but lower current density of 0.35 mA/cm^3 (Fig. 4).



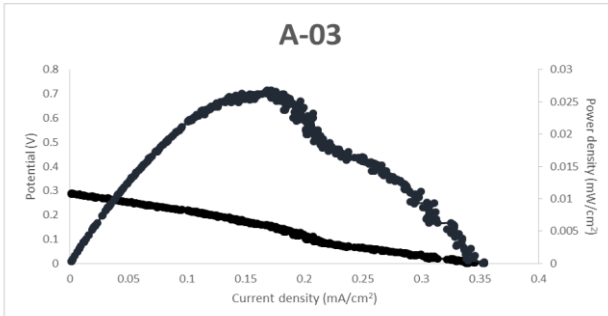


Fig. 4: Paper-based microfluidic fuel cell performance. (a) Sample A-01 polarization curves. (b) Sample A-02 polarization curves. (c) Sample A-03 polarizarion curves.

4. Conclusion

It has been described the method for creating a paper-based microfluidic fuel cell using formic acid as a fuel at the anode and hydrogen peroxide as the oxidant at the cathode. These materials have generated a current of about 0.7 V for the different cells and a current density ranging from 3.5 to 0.35 mA/cm^3. The MFC’s did not require a continuous flow of fuel and oxidant to generate power and they remained operating for 24 hours without any significant change in their voltage.

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