Lateral flow assay HIV-based microfluidic blood fuel cell

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Abstract. This work presents the integration, evaluation and performance of a lateral flow assay HIV-based microfluidic fuel cell. To integrate the microfluidic fuel cell, a Pt/C cathode and Au/C anode were deposited on Toray® paper and stacked on the top and bottom, respectively, of the paper strip lateral flow assay HIV. According to the microfluidic fuel cell evaluation, the Pt/C cathode reduces the oxygen delivered from air, meanwhile the Au/C anode oxidizes the glucose contained in the human blood. The lateral flow assay HIV-based microfluidic blood fuel cell (LFA HIV-based μBFC) performance showed power density of 0.15 mW cm⁻². The open circuit voltage and maximum current density were 0.57 V and 1.2 mA cm⁻², respectively. Furthermore, the LFA HIV-based μBFC showed a constant current density for 10 minutes at a potential corresponding to the maximum power density. In this sense, is demonstrated that lateral flow assay towards an autonomous energy device is a great advance to be applied in point-of-care testing.

1. Introduction

The use of paper for microfluidic systems has been incorporated [1] in the area of chemical analysis mainly because of its low cost. These microfluidic systems are known as Lateral Flow Assays (LFA) and their main application is for immunoassay, in the detection of foodborne contaminants, and recently in fuel cells [2].

The search for the autonomy of these LFA, referring to that they do not depend on an ion-lithium battery, has recently attracted the attention of the researchers. In this sense, the paper-based microfluidic fuel cells have been considered as a power source for LFA. In this way, the medical sample introduced to the LFA produces energy.

The Lateral Flow Assay-based microfluidic fuel cell is one of the emerging technologies in the development of autonomous devices, at low cost, portable and efficient for power generation [3].
Another major advantage is the unnecessary use of pumps due to the diffusion of fuel across the paper, ensuring the laminar flow [4]. The versatile design of LFA, allows the coupling of external devices with low energy requirement for an autonomous functioning like has been reported for other fuel cells [5], in addition to its main ability of quantitative or semi-quantitative analysis colorimetric to a molecule of interest to generate a microfluidic paper-based analytical devices that uses blood, urine, sweat or human serum as fuel [6]. In this work we shown an original Lateral Flow Assay HIV-based microfluidic blood fuel cell (LFA HIV-based μBFC) that incorporate as electrodes Au/C in the anode and Pt/C in the cathode for glucose oxidation present in human blood and reduction of oxygen delivered from air, respectively, sensing at the same time the HIV in the blood sample.

2. Methodology

2.1 Electrode fabrication

The electrodes consisted of a square Toray paper (Technoquip Co Inc. TGP-120) with dimensions of 5 x 10 mm. The electrodes were covered with catalytic ink from Au/C (20 wt.% from E-TEK) or Pt/C (30 wt% from E-TEK) for anode and cathode, respectively. The ink contained 73 μL of isopropyl alcohol (J. T. Baker) and 7 μL of 5% Nafion (Sigma-Aldrich) for each milligram of catalyst. The metal loading of 1 mg cm$^{-2}$ over the electrode entire surface was finally collocated.

2.2 Lateral flow assay HIV-based microfluidic blood fuel cell integration process

An advanced Quality™ rapid HIV (1&2) Whole Blood/Serum/plasma lateral flow test was employed for the microfluidic fuel cell construction. A Pt/C cathode and an Au/C anode (5 x 5 mm contact area) were collocated at the top and bottom, respectively, of the paper strip (Figure 1). In this sense, the cathode reduces the oxygen that access from the atmosphere, meanwhile the anode oxides the glucose presents in the human blood. Finally, external electrical connections were accomplished in the ends of the carbon paper electrodes.

![Figure 1. Photograph of the lateral flow assay HIV-based microfluidic blood fuel cell.](image)

2.3 Evaluation of the lateral flow assay HIV-based microfluidic blood fuel cell

According to the described in the instruction manual of the Advanced Quality™ rapid HIV (1&2) WB/S/P lateral flow assay; this could be proved with human serum or blood. In this work, the LFA HIV-based μFC electrochemical evaluation was realized with human blood. The blood was extracted
from a male volunteer using a lithium heparin sample tube from BD Vacutainer® (NJ, USA). The LFA HIV-based \( \mu \)FC was performed in two phases. First, 50 \( \mu \)L of blood was collocated into the round hole. Next, approximately 50 \( \mu \)L “diluted sample” (present in HIV test kit) was dispensed. The current and voltage reported were measured using a Zahner Zennium potentiostat.

3. Results and discussions

3.1 Performance of the lateral flow assay HIV-based microfluidic blood fuel cell

The LFA HIV-based \( \mu \)BFC performance was obtained from polarization curves using Au/C for the oxidation of glucose present in the human blood sample and Pt/C for the reduction of oxygen delivered from air.

The reactions at both electrodes are:

Anode reaction: \( \text{Glucose} \rightarrow \text{Glucolactone} + 2H^+ + 2e^- \) (1)

Cathode reaction: \( O_2 + 2e^- + 2H^+ \rightarrow H_2O \) (2)

When the blood was deposited on the sample pad, the paper absorbed the sample for capillary action, and consequently the blood made contact with both electrodes.

The polarization curve, showed in the Figure 2, exhibited an open circuit voltage (OCV) and a maximum current density of 0.57 V and 1.2 mA cm\(^{-2}\), respectively; meanwhile the maximum power density was 0.15 mW cm\(^{-2}\).

![Figure 2. Polarization and density curves for the lateral flow assay HIV-based microfluidic blood fuel cell testing an Au/C anode and Pt/C cathode in human blood.](image)

Some human blood micro fuel cells are listed in Table 1. A maximum performance at 0.20 mW cm\(^{-2}\) was reported by Dector et al. [7] injected human blood with a micro-pump in an air-breathing microfluidic fuel cell formed for an enzymatic anode (Gox) and an inorganic cathode (Pt/C). Another
work of Dector et al. [5] reported the use of a bioanode and cathode in a paper-based microfluidic fuel cell inside an HIV-test using human blood as fuel; reported a performance from 0.12 mW cm⁻². In the same context, works that use other type of fuel cell has been reported. Xiaoju Wang et al., [8] presented a one-compartment fuel cell using human blood and hybrid electrodes for anode and cathode and a performance of 0.0028 mW cm⁻² was achieved. Finally, the work presented by Pan Caofeng et al. [9] consisted in the evaluation of a Bio Fuel Cell using GOx and Lac as anode and cathode, respectively, and human blood as fuel, and reported a maximum power density of 0.0056 mW cm⁻². Is interesting to note that the OCV, maximum current density and maximum power density were obtaining with variation from this work to literature reported. This is due to fuel cell design, electro-catalyst and evaluation condition employed in each work.

| Anode  | Cathode  | Fuel                | Performance     | Cell type                    | Author          |
|--------|----------|---------------------|-----------------|------------------------------|-----------------|
| GOx    | Pt/C     | Human Blood         | OCV (V)        | J (mA cm⁻²)                 |                 |
|        |          |                     | 0.54            | 1.07                        | 0.20            | Air-breathing microfluidic fuel cell | Dector et al., [7] |
| GOx    | Pt/C     | Human Blood         | OCV (V)        | J (mA cm⁻²)                 |                 |
|        |          |                     | 0.78            | 1.00                        | 0.12            | Paper-based microfluidic fuel cell | Dector et al., [5] |
| CtCDH/Au NP | MvBOx/Au NP | Human Blood | OCV (V)        | J (mA cm⁻²)                 |                 |
|        |          |                     | 0.66            | NS                          | 0.0028          | One-compartment microfluidic fuel cell | Wang et al., [8] |
| GOx - CNTs | Lac       | Human Blood         | OCV (V)        | J (mA cm⁻²)                 |                 |
|        |          |                     | 0.12            | 0.155                       | 0.0056          | NS                          | Pan et al., [9] |
| Au/C   | Pt/C     | Human Blood         | OCV (V)        | J (mA cm⁻²)                 |                 |
|        |          |                     | 0.57            | 1.2                         | 0.15            | LFA HIV-based microfluidic fuel cell | This work |

NS: Not Specified.

Figure 3 shows the capabilities of the cell to recover its open circuit potential after three charges/discharges cycles. Is notary the OCV recovery at approximately 0.6 V after each discharge, which shows a stability of the LFA HIV-based \( \mu \) FC. This figure also shows that the LFA HIV-based \( \mu \) FC is operated nearly 15 minutes.
Figure 3. Stability of the OCV of the LFA HIV-based μFC after three charge/discharge cycles using human blood as fuel.

Figure 4 shows the stability of the LFA HIV-based μFC through chronoamperometric study. This was carried out at 0.2 V for 10 minutes. The resultant measurements indicate that the LFA HIV-based μFC performance decreased over time due to the drying of the blood on the paper strip related with the consumption of glucose.

Figure 4. Current density as a function of time at 0.20 V, for the lateral flow assay HIV-based microfluidic blood fuel cell.
4. Conclusions

In this work is demonstrated that lateral flow assay modification towards an autonomous energy device is a great advance to be applied in point-of-care testing. As a perspective of use, other lateral flow assay tests could be used, in this sense, other physiological samples could be used such as urine, sweat, and serum.

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