Paper-Based Microfluidic Device for Electrochemical Glucose Determination

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Abstract— In recent years, paper-based microfluidics have turned into a strong and low-cost analytical tool for detection of diverse analytes of interest. In this work, we develop a pencil-drawn paper-based electrochemical cell (PPEC), with the purpose of fabricating a glucose biosensor. Three different electrode configurations are analyzed as regard their electrochemical behavior. Biosensor calibration showed a linear and sensitive response for glucose determination. The design presented here is a low-cost, easy to fabricate, lightweight, portable and a green alternative for glucose biosensing
Keywords— pencil-drawn electrochemical cell, glucose biosensor, cyclic voltammetry.

***Resumen*— En los últimos años, la microfluídica basada en papel se ha vuelto una poderosa herramienta analítica de bajo costo para la detección de diversos analitos de interés. En este trabajo, desarrollamos una celda electroquímica en papel dibujada con lápiz (PPEC), con el propósito de fabricar un biosensor de glucosa. Se analizan tres configuraciones de electrodo diferentes, según su comportamiento electroquímico. La calibración del biosensor mostró una respuesta lineal y sensible para la determinación de glucosa. El diseño presentado es de bajo costo, fácil fabricación, ligero, portable y una alternativa ecológica para el biosensado de glucosa.**
***Palabras clave*— celda electroquímica dibujada en papel, biosensor de glucosa, voltametría cíclica.**

I. Introduction

Since its beginnings in 2007 [1], paper microfluidic has evolved as a useful technique particularly interesting for point of care application that require rapid, low cost and simple analysis tools [2]. On the other hand, electrochemical microfluidics, has high impact in science, engineering, and technology [3]. In the last years, pencil-drawn electrodes and electrochemical cells has emerged as a good alternative for the fabrication of paper-based electrochemical microfluidics; being the pioneer report presented by Dossi et al. [4], which was then followed by several others [5], [6], [7], [8], [9].

In this work, a paper-based first-generation microfluidic biosensor for electrochemical glucose determination is presented. It consists in a tripolar electrode arrangement pencil-drawn with a 5B grade pencil over a cellulose Whatman #1 (Maidstone, UK) chromatographic paper substrate. The glucose biosensor behavior was evaluated with chronoamperometry.

II. Materials and Methods

For fabricating the pencil-drawn paper-based electrochemical cells (PPEC), three different cell configurations were evaluated (Figure 1). This PPEC consist of a 21x14mm rectangle of chromatographic paper, where a 11x14mm zone is rendered hydrophobic by painting it at both sides using a black permanent marker. Then, three 21x2mm electrodes are pencil-drawn with a 5B lead using a rule as guide. The inter-electrode separation is 2mm wide.

Functionalization of PPEC for glucose determination was performed by adding droplets of a solution of Glucose oxidase (GOx) directly on the working electrode by using a micropipette. The solution had 2mg of GOx type VII of Aspergillus Niger 100 units g-1 (Sigma Aldrich), homogenized in 1 ml PBS/KCl and lastly sonicated.

For biosensor calibration, tripolar chronoamperometry measurements were carried out. It was polarized with a DC potential of 900mV. The glucose concentrations used were 0.1mM, 1mM, 3mM, 5mM, 8mM and 10mM.

III. Results

Fig. 2 shows the cyclic voltammograms of the electrochemical cells drawn with the 5B lead (Fig. 1). All configurations showed similar electrochemical behavior, especially regarding the peak values of cathodic and anodic currents.

Biosensor evaluation was carried out using chronoamperometry applying a DC potential of 900 mV to oxidize the hydrogen peroxide (product of the enzymatic reaction). Current intensity was measured for different glucose concentrations (0 (buffer), 0.1, 1, 3, 5 and 8mM). Figure 3a shows the time response of the biosensor. Figure 3b presents the calibration line that was built with the average current values of five biosensors and its respective standard deviation for each glucose concentration. It can be concluded that the biosensor has a good linear response in the evaluated range (0.1 to 8mM).

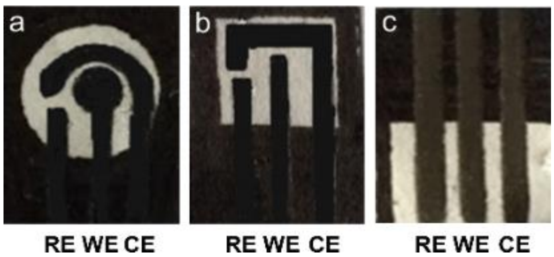


Fig. 1: Different electrochemical cell configurations, named a) circular, b) rectangular and c) linear.

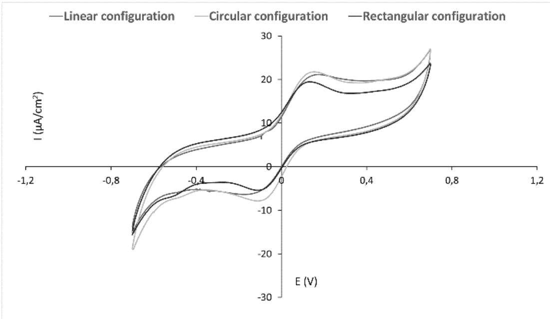
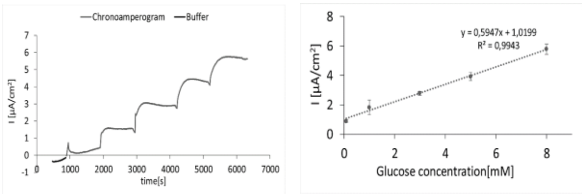


Fig. 2: Cyclic voltammogram of the three cell configurations: a) circular, b) rectangular and c) linear.



a) b)

Fig. 3: a) Chronoamperogram of a glucose biosensor when different glucose concentrations are added (0.1, 1, 3, 5 and 8mM). b) Glucose biosensor calibration line.

IV. Discussion

Based on the cell configuration evaluation, the linear configuration was chosen to develop the biosensor, since it is simpler to fabricate.

As regards the calibration for glucose determination, it can be concluded that the biosensor shows a good linear response.

It can be found, on the best of our knowledge, only one other report of glucose biosensor implemented with PPEC (Li et al. 2016). However, this approach consists of a second-generation type, that uses a hazardous material (ferrocenecarboxylic acid) for its implementation.

V. Conclusion

A first-generation glucose biosensor was fabricated using an electrochemical cell pencil drawn over a paper substrate. Three different cell configurations were evaluated and all of them showed a similar electrochemical behavior. The linear one was adopted due to its simplicity. Furthermore, biosensor calibration showed a linear and sensitive response for glucose determination. The design presented here is a low-cost, easy to fabricate, lightweight, portable and a green alternative for glucose biosensing. Moreover, it does not contain hazardous chemicals or materials, which makes it biocompatible and suitable for wearable applications.

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