

A bendable and compact device for low-power application

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Abstract. In this work we present a novel model of a membraneless microfluidic fuel cell device based on adhesive polyester film fabricated by a non-sophisticated technique at room temperature and reached high performance. This concept overcomes the concerns about the reliability, versatility and weight of fuel cell devices for portable energy applications. Current densities until 500 mA cm^{-2} and power densities about 90 mW cm^{-2} were achieved using formic acid as fuel and air and dissolved oxygen as oxidant.

1. Introduction

The miniaturization trend of technology is continuing in a variety of products, such as cell phones, laptops, music players, and so on. The advantages of the current devices increased processing speed and more executable concurrent tasks; however, battery technology remains a challenge because it does not meet the continuous energy demand of today's devices. In this sense, small energy conversion devices such as co-laminar or membraneless micro/nanofluidic fuel cells were created to supply the energy demand of small portable electronic devices as an alternative power source to batteries, which have a limited lifetime. Recently, more sophisticated applications for this type of devices have been visualized in the medical area to satisfy the energy requirements of pacemakers, glucometers and other biosensors. However, some barriers remain and are related to reproducibility, lifetime, size/weight and flexibility. Co-laminar microfluidic fuel cells have evolved to solve some of these aspects. Initially, micro-fabrication consisted of modifying hard materials such as poly-(methyl methacrylate), glass slides and polydimethylsiloxane using the hot-press method or photolithography [1-3]. Recent studies are focused on finding a small, lightweight and flexible energy conversion microdevice. Tominaka [4] used a flexible polymer substrate named cyclo-olefin polymer (COP) to fabricate a bendable fuel cell without using pumps. Some others [5] described alternatives based on thin and flexible films and different fabrication techniques. With this method, biofuel cells based on paper, such as filter paper, were reported [6]. Other works related to the use of filter paper with a cathode gas-diffusion layer or HB-pencil-stroked graphite were reported to fabricate a biofuel cell [7] or a self-pumping air-breathing membraneless fuel cell [8-9], respectively. In general, sophisticated fabricated techniques, complex assembled process, low performance and rigid devices are the issue to overcome.



In this work, we report the construction and evaluation of a flexible membraneless fuel cell based on adhesive polyester film, which is adhered to paper foils to assemble and disassemble the device, where the fuel (formic acid) and oxidant (oxygen from air) flow-through the electrodes for energy conversion.

2. Experimental Section

2.1. Construction of membraneless air-breathing device.

The device was constructed using flexible materials and non-sophisticated technique. The cell operation principle is derived from a design previously reported [10]. Adhesive white polyester (ARcare® 8259, Adhesives Research, thickness of 200 μm) was employed as support film and hook-and-loop tape, and home-made silicone elastomer film (Silastic®, Dow Corning, prepared using an Elcometer® Film Applicator with a final thickness of 600 μm) as sealing and cell channel structure, both materials are responsible to provide flexibility and versatility to the device. Commercial carbon nanofoam (Marketech Inc.) coated with commercial electrocatalyst materials (Pt/C, ETEK 30 wt% and Pd/C, ETEK 20 wt%) as flow-through and air-breathing electrode, finally aluminium foil was employed as electric contact. The four elements integrate an inexpensive and versatile (Figure 1a).

Two supporting films were made by adhesive white polyester, the top plate include a window that allows the access of oxygen from the air and bottom plate with two inlets for the reagents and one outlet for the reaction sub-products. The cell channel structure made by silastic allows the reagents that were located in the middle of electrode provide a homogeneous distribution; both supporting films and channel structure were fabricated using a Silhouette® cutting plotter. The electric contact and 3D electrodes were cut by hand and the electrocatalyst materials were incorporated by spray technique employing an air brush until the metal loading was 0.6 mg, the electrode dimensions are 15 mm in length, 2 mm in width and 0.1 mm in height (geometrical area of 0.015 cm^2). The total weight and volume of the device were 603.7 mg and 0.62 cm^3 , respectively.

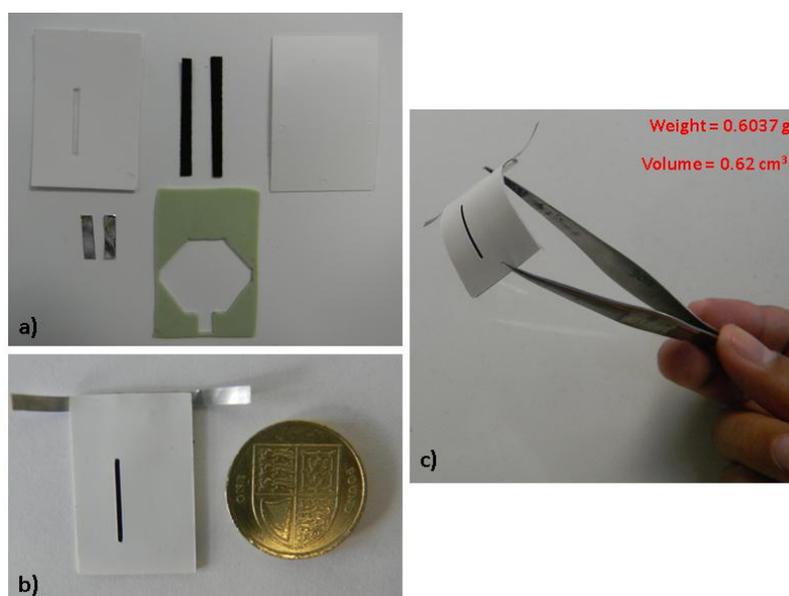


Figure 1 Photographs of the cell a) components of flexible device, b) comparison with size of one pound, c) flexibility of membraneless device.

2.2. Evaluation of membraneless air-breathing device performance.

The fuel and oxidant streams were fed through the nanoporous electrodes with scan rate of 6 ml h^{-1} using syringe pumps (NE-4000, New Era Pump Systems Inc) at 0.5M Formic acid and combined O_2 -saturated solution and O_2 from the air dissolved in 0.5 M H_2SO_4 solutions, respectively. Were evaluated the performance, stability and lifetime

The stability test was carried out by a chronoamperometry at maximum power voltage (0.44 V) employing 1.5 ml of the fuel. The electrochemical impedance was employed to measure the total resistance of the device after several tests.

3. Results and discussion

3.1. Evaluation of membraneless air-breathing device performance.

The polarization and power density curves (Figure 2a) were the same after the evaluation of stability employing 1.5 ml of fuel (Figure 2b), reached 0.9 V and around 580 mW cm^{-2} . On the other hand, the current density was constant throughout the test indicating a good stability of the membraneless device due there were no poisoning by reaction products in according with the polarization curves too.

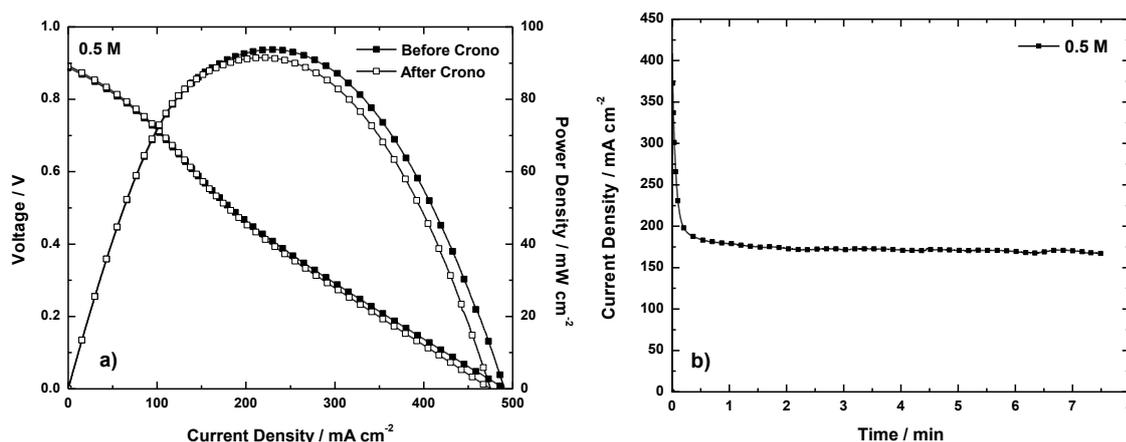


Figure 2a) Polarization and power density curves at 6 ml h^{-1} of flow rate at 0.5M formic acid, before and after the stability test, and **b)** Stability curve at 0.44 V for 1.5 ml of the fuel.

Is important to emphasize why the concept of hook-and-loop tape based, due to either of the supporting films can be easily removed and re-attachment again at several times. The cell was assembled and disassembled between each test, were made several polarization curves and chronoamperograms; the figure 3 shows as the cell was physically after the ten, twenty five and forty seven times of disassembled and can be observed that the resistance of device was maintained within a range of 0.5 and 1 ohm cm^{-2} which indicates the cell can be used over and over again. The advantages of assembled and disassembled were the accumulated bubbles CO_2 were eliminated and if necessary can change any element of the cell, in this way the device gains versatility.

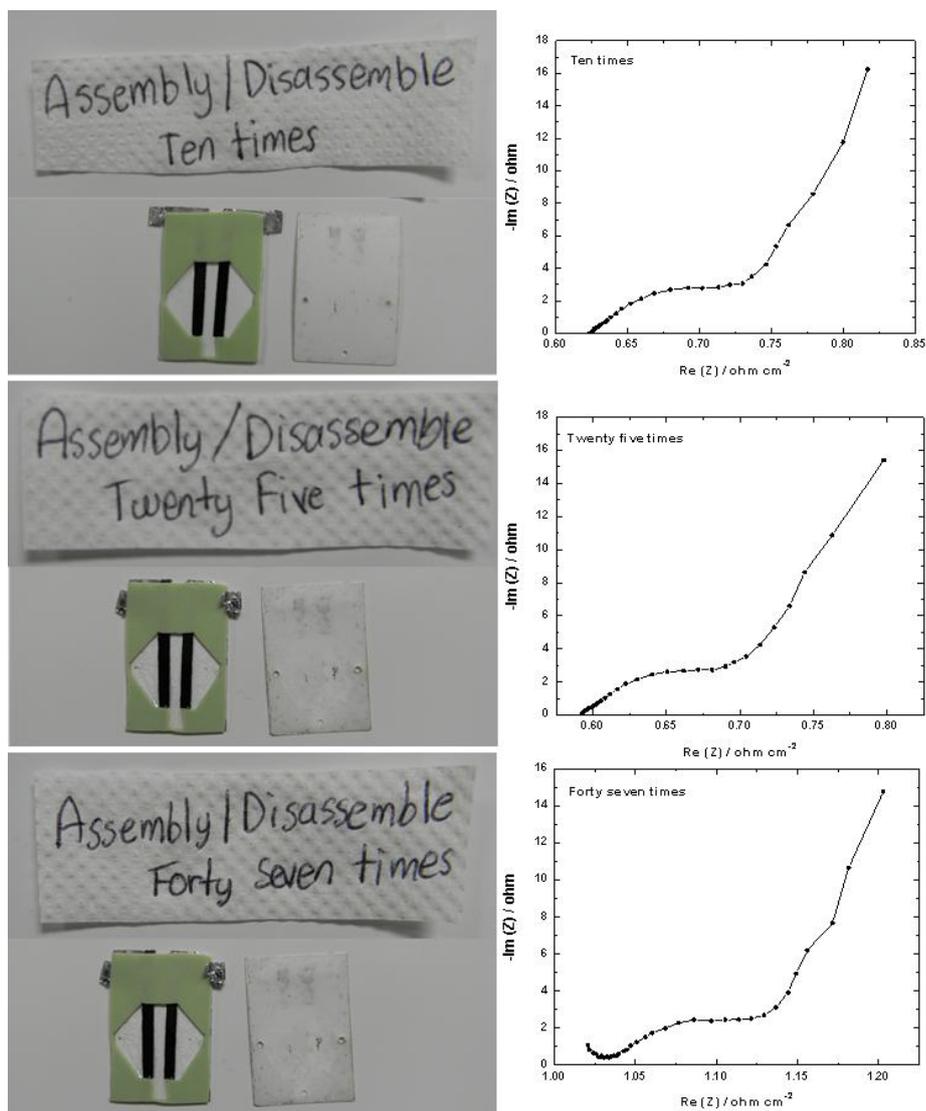


Figure 3 Impedance spectra after 10, 25 and 47 cycles of assembly/disassembly of the tape-based membraneless fuel cell.

Finally, the membraneless air-breathing device was connected to a microelectronic system contained a booster that raised the voltage from 0.83 V to 3 V (Figure 4a). The energy produced by the device was sufficient to light a LED (Figure 4c) while the fuel and oxidant were injected. This showed that a flexible device coupled with microelectronic system can employ in a future to supply energy to low power device employing low concentration and clean energy.

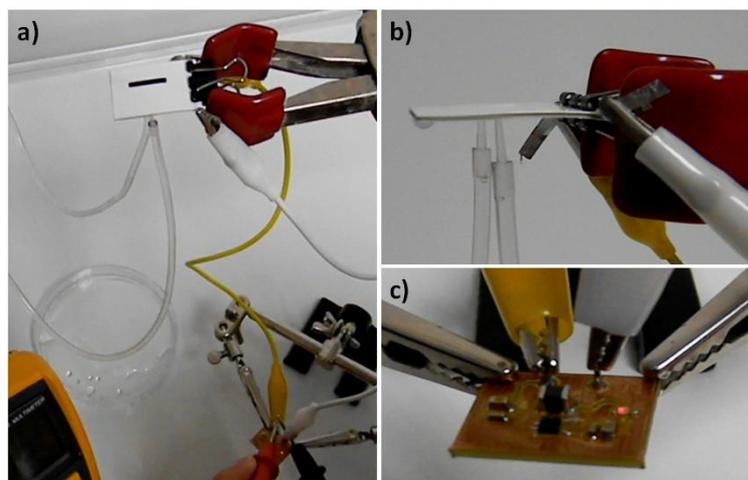


Figure 4 a) membraneless air-breathing device connected to microelectronic system with a LED b) lateral photograph of membraneless air-breathing device c) microelectronic system with a LED lighting.

4. Conclusions

In summary, these results shows a small, thin, lightweight, flexible, reusable, easy to assemble and to fabricate, and high performance at low fuel concentration and metal load, membraneless air breathing device. In this sense, the device shows a great potential and is the first step to create an energy source for portable electronic devices or medical applications in the near future of low-power.

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