An Electron-Relay Prototype Supercapacitor Mimics *Electrophorus Electricus*'s Reversible Membrane Potential for Multiple-organ Discharge

Ellen T. Chen[1*] and Christelle Ngatchou[1]

[1]Advanced Biomimmetic Sensors, Inc. 20271 Goldenrod Lane, Suite 2060
Germantown, MD 20876.

* Send correspondence to:ellenchen@nanobiomimeticsensors.com

ABSTRACT

Electrophorus Electricus (EE) is known to discharge electric voltage through multiple organs based on Reversible Membrane Potential (RMP). We report a new type of supercapacitor for mimicking the EE's RMP based on an Electron-Relay Nano-Biomimetic Membrane Electrode Assembling (ERNBMEA) and an asymmetric membrane design with features free from ion channeling effect and a negligible double layer potential effect. The results obtained by a double step chronopotentiometry (DSCPO) method shown the Biomimetic EE devices has the reversible membrane potential in both 0.2 and 0.4 cm^3 supercapacitors. It can fire high electric spikes at both ends of the anode and cathode with a firing rate of 2-fold higher compared with the EE's 3.75V/s. The power and energy density for a single 0.2 cm^3 cell are several magnitudes higher than the EE's single electrolyte of 0.03 W/kg and 0.03Whr/kg. The capacitance of the 0.2 cm^3 biomimetic EE increased linearly from 0.25 to 13,240 $\mu F/cm^2$ over 0.015 to 1000 Hz range. At 120 Hz, the high storage capacitance is 5,140 µF/cm2 that is an order of magnitude higher over the reported double-layer capacitor.

Keywords: Electron-relay supercapacitor; Reversible membrane potential; Nano-biomimetic *Electrophorus Electricus*'s device; Multiple-organ discharge; Asymmetric design

INTRODUCTION

Electrophorus Electricus is know to its discharge electric voltage pauses through multiple organs based on Reversible Membrane Potential (RMP) [1-2]. Piccolino et al summarized John Wash's studies in electric fish [3]. Nowadays, researchers are increasingly interested in study of the electric fish and seek a nature inspired way to develop more efficient energy converting devices by developing artificial electric fishes [4-6]. The article mimics the biological cell's ion channel functions [4], or mimics electric fish's electroreceptive capabilities to find a target without seeing at the deep underwater [5]. There is an important area in multiple-organ discharge that mimics the EE fish has not been pursued. The goal of this research is to develop an Electron-Relay (ER) prototype supercapacitor that mimics *Electrophorus Electricus*'s reversible membrane potential for multiple-organ discharge under Double-Layer Potential (DLP) negligible, oxygen-independent and electrolyte-free conditions. The rationale of these settled conditions are based on the needs of many patients who suffer from unbalanced axon action/resting potential due to dysfunction of Ion-channel or ATP pump dysfunction, such as Trauma Brain Injury (TBI), various cancer diseases and chronic illness. We will design an energy platform device without electrolyte-dependence and with minimum DLP that will simplify and eliminate the error source contributions from the device membrane. Air-dependent is common for most nature enzymes; however, it can create a problem of CO_2 emission in a closed compartment of underwater vehicles if a nature enzyme used as the source of an energy device. Therefore, using an air-independent nanostructure biomimetic membrane electrode assembling will offer advantages for accomplishing the goal of this study.

EXPERIMENTAL

Asymmetric Design of the Supercapacitor

Supercapacitors have two categories by energy storage mechanism: electrochemical double-layer capacitors (DLCs) and redox supercapacitors [7-9]. An approach to overcome the low Gravimetric Energy Density (GED) of the DLS supercapacitor is to use an asymmetric design: 1. the positive electrode has a low degree of polarization, and 2. the negative electrode has a high degree of polarizability in an attempt to enlarge the window of the difference of the potential change during charge and discharge [9]. After E. Chen's group developed an electrolyte-free and oxygen-independent battery/fuel cell device [10-12], the GED and the power density performances were superior. However, we now have an asymmetric design for the Biomimetic electron-relay supercapacitor in order to mimic EE's reversible multiple-organ discharge as shown in Figure 1. One electrode with GC/nanopore/pillar structured MEA, and the other MEA was with an embedded "reactant" flat surface structure with a membrane thickness 48 nm [11]. An insulator was placed between the two MEAs and absorbed with 1M methanol under electrolyte-free condition. The current collectors were attached at each end. Fabrication and characterization using Atomic Force Microscope (AFM) for the two MEA membranes were described elsewhere [11].

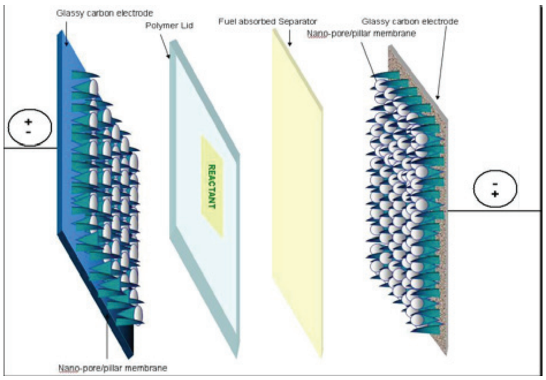

Figure 1. Illustrates the asymmetric design of the electron-relay nanobiomimertic supercapacitor.

RESULTS AND ISCUSSIONS

The Electron-Relay Biomimetic Prototype Supercapacitor

The electron-relay concept for a Direct Methanol Fuel Cell (DMFC) was reported in literature [10-11]. Progress has been made as shown in Figure 1 for the asymmetric design of the supercapacitor, the electron-relay with and without a lid of embedded "reactant" created a dynamic window of potential change, not only it enhanced the high potential discharge, but also created a flexible and reversible "multiple-location" discharge possibility, that is to mimic the EE's multiple-organ discharge as shown in Figure 2.

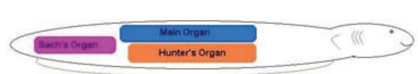

Figure 2. Illustrates the EE's multiple-organ discharges at Sach and Hunter organs.

Double-layer Potential (DLP) Effect

DLP effect is the base for most supercapacitors, however, since we created the E-R system for the energy storage, many efforts have been made to eliminate the DLP effect and create a unique "supercapacitor" that does not rely on electrolyte and is not dependant on the DLP. Figure 3 confirmed our approach that the supercapacitor has negligible DLP effect as shown in curve c that such one single cell prototype device is an ideal nonpolarizable device as described in literature [13]. When the two electrodes were switched, it was polarizable. Curve d shows the half cell behavior acts like a switchable semiconductor at zero applied potential with the maximum current, that is the instrument's limit, ± 0.1A, which indicates the asymmetric design reached the desired goal under the electrolyte-free, air-independent and DLP negligible conditions. This design paved a foundation for multiple-location discharge with a controllable flexibility and signal intensity.

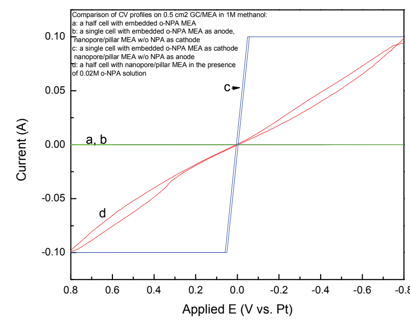

Figure 3. Plots of Cyclic Voltammagrams of the Biomimetic EE device.

"Multiple-organ" Discharge

Figure 4 (Left) illustrates the discharge and charge curves from a single 0.5 cm^2 prototype device, A and B curves indicates the "multiple-organ" charge and discharge behavior; (Right) the same behavior is shown for the 1 cm^2 single prototype device in discharge with a switchable two ends discharge.

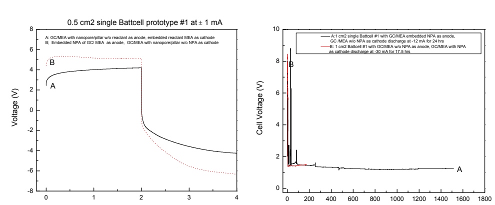

Figure 4 (L) illustrates the single 0.5 cm^2 prototype device reversible EE membrane charge and discharge behavior; (right) illustrates a single 1 cm^2 prototype reversible discharge.

The high electric spikes at either end of anode and cathode have a firing rate of 2-fold higher compared with the EE's

3.75V/s. **The power and energy density for a single 0.2 cm^3 cell are several magnitudes higher than the EE's single electrocyte of 0.03 W/kg and 0.03Whr/kg, respectively.**

Supercapacitor

The charge/discharge profiles from the 0.2 cm^3 prototype supercapacitor is shown in Figure 5 at 1mA over the band width from 0.015 Hz to 1000 Hz using the DSCPO method. Figure 6 is the plot of capacitance vs. frequency that indicates at 120 Hz, the high storage capacity is 5,140 µF/cm2 over the reported data of 175 µF/cm2 of double-layer capacitor [7]. The capacitance of the 0.2 cm^3 biomimetic EE increased linearly from 0.25 to13,240 µF/cm^2 over a 0.015 to 1000 Hz window.

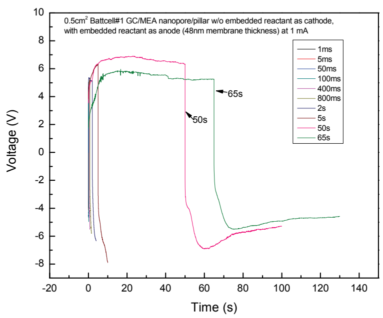

Figure 5. Illustrates the 0.2 cm^3 supercapacitor charge/discharge profiles over the band width from 0.015 Hz to 1000 Hz at 10 increment levels.

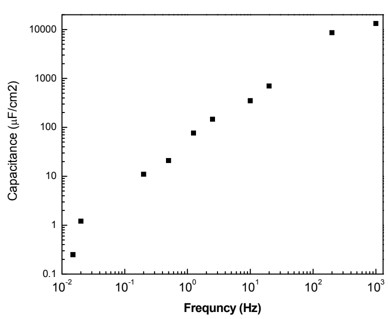

Figure 6. Plot of the capacitance versus frequency (Hz) of the supercapacitor assuming a series RC circuit model.

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