# Study of the Factors that Effect on the Power Storage and Generation of a Nano-Biomimetic Membrane Electrode-Assembling (NBMEA) for Battery/Fuel Cell Dual Applications

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## ABSTRACT

This report presents a study for factors that effect on the performance of the newly developed nanobiomimetic direct methanol fuel cell (NBDMFC). Membrane thickness and cell temperature effect on the Membrane Electrode Assembling (MEA) performance were studied. Results from six 0.5 $cm^2$ single DMFC cells were presented. The cells measured a steady-state (s-s) discharge of 50 mA for 12 hrs at 25ºC, 55ºC and -20ºC, respectively with the highest nominal voltage of 6.7V at 20ºC. The highest power density at room temperature is 2.43 kW/kg with the energy density of 24 kWh/kg. All cell current density is 100 mA/$cm^2$ regardless of the change of temperature. The charge vs. discharge efficiency results are above 90%.

***Keywords***: Electrolyte-free and air-independent battery/fuel cell dual utility technology; nanostructure biomimetic membrane electrode assembling (NBMEA)

## INTRODUCTION

The major scientific challenges facing current *Proton Exchange Membrane Fuel Cell* (PEMFC) and conventional *Direct-Methanol Fuel Cell* (DMFC) technologies are: (1) low efficiency; (2) the conventional DMFC cell suffers from being unrechargable due to the by-products of $CO_2$ and water; (3) energy loss due to the hydrophobic polymer electrolyte membrane being the only means to promote a DMFC function, which sets a limit to this technology because water continues to flood the membrane electrode assembling (MEA); (4) the by-product $CO_2$ also causes malfunction of the membrane; (5) methanol crossing over the membrane; (6) the danger of a dry Nafion membrane, which is then extremely explosive and toxic, hence requiring a humidifier to moisturize the MEA in order to avoid the dangerous dryness. There are many professional reviews of these problems available [1-3].

There is an unmet need to enhance both the energy density and the power density for the current technologies. E. Chen's group recently reported a break- through approach: using an electrolyte-free and air-independent nanobiomimetic membrane electrode assembling (NBMEA) to attack the drawbacks of the current technologies [4]. Many well known factors affect the direct methanol fuel cell (DMFC) performance have been reported elsewhere [5-9]. The goal of this report is to study how temperature and membrane thickness affect our group's new fuel cell performance under the conditions of no refueling or catalyst required and no $CO_2$ or water emission.

## EXPERIMENTAL

### Fabrication of the Embedded Reactant Self-Assembling Membrane (SAM)

The nanostructure Biomimetic membrane without an embedded "reactant" was reported by our group [4] and the method was cited in this literature and the AFM image as shown in Figure 1. Mixing of the proper compositions of polymers as cited in the literature and added "reactant" with 1000:1 molar ratio of triacetyl-ß-cyclodextrin (T-CD) into the mixture, and well equilibrium for 2 hrs at 35°C, then directly deposited the mixture onto the surface of the glassy carbon (GC) electrode and incubated for 48 hrs and follow the cited procedures for a complete self-assembling membrane.

### Characterization of the Membrane of GC/SAM

The morphology of the 0.5 $cm^2$ GC-SAM was characterized by using a Digital Instruments Nanoscope, Atomic Force Microscope, Veeco Instruments, CA. The surface structure was scanned using a silicon cantilever and a tip with 5-10 nm radius. In Figure 1 is the Atomic Force Microscopy (AFM) image before embedding the "reactant". Figure 2 is the AFM after embedding the "reactant". The thicker membrane was shown in Figure 2A, fabricated by dividing a mixture solution into 10 small portions, and depositing consecutively with a drying time of 15 minutes, between each deposit. After that the normal procedures were followed. The thinner membrane was shown in Figure 2B, fabricated by depositing a mixture solution onto the 1 $cm^2$ GC surface at once.

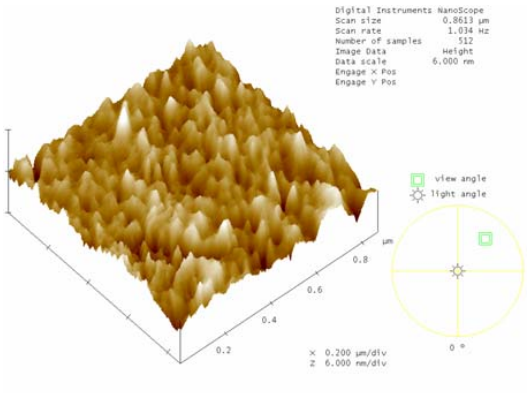


Fig 1. The Atomic Force microscopy (AFM) image of nanopore/pillar structure membrane #1 on a glassy carbon electrode.

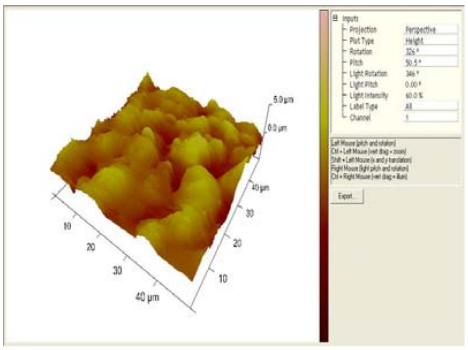


Fig 2A. The AFM image illustrates an embedded "reactant" with 5.4 µm membrane thickness.

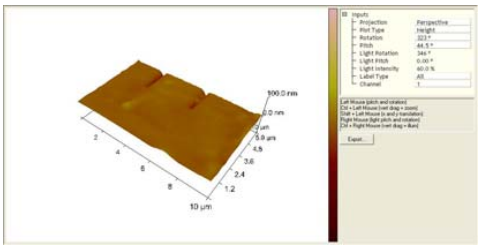


Fig. 2B. The AFM image of an embedded "reactant" with 48 nm membrane thickness revealed the flat and poreless surtface. The two cuts shown due to the laser saw cutting.

## Evaluation of the Temperature Effect

A three-neck, round bottom double jacked flask was set up and connected with a temperature controlled circulator filled with ethylene glycol. The working electrode of GC/SAM was in the flask connected through a conductive wire and then the wire was connected to an alligator lead cable. The cable was connected to the electrochemical equipment (Epsilon, BASi, IN). Data acquisition and analysis with the software package was obtained through a computer. The reference electrode Ag/AgCl was inserted through the neck into the 1M methanol and the auxiliary electrode was Platinum (Pt) was also in the solution. The reference and the auxiliary electrodes were connected to two alligator lead cables through conductive wires, then were connected to the electrochemical equipment using the method described for the working electrode, and the open neck was covered after the electrodes were installed inside of the flask. Two separated small tubes for nitrogen purge inlet and outlet were connected with a controlled flow meter, which connected to a nitrogen cylinder. The third neck was used for a thermometer. All the glass necks were covered before starting the experiment. The 0.5 $cm^2$ cell discharge was set at 50 mA using the Galvanostat Chronopotentiometry (GCP) method at 20, 55 and -20ºC. All experiments were under nitrogen purge for 30 minutes and after that nitrogen blanket.

## Evaluation of the Membrane Thickness Effect

The AFM method was used for evaluation of the membrane thickness effect on the performance.

# RESULTS AND ISCUSSIONS

## Temperature Effect

Figure 3 compares the temperature effect on the fuel cell discharge. It illustrates the nominal discharge voltage with the highest value 6.7 V at 20°C for straight steady-state12 hrs discharge. The temperature effects on the discharge voltage is 8.5 mV/°C over the studied temperature range. The drafting occurred at -20°C, dues to cold temperature, it has certain degree effected on the discharge.

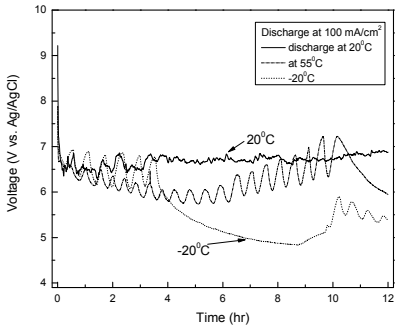


Fig 3. Effect of temperature on a 0.5 $cm^2$ GC/SAM half fuel cell discharge at -20ºC, 20°C and 55°C.

## Membrane Thickness Effect

Under the same experimental conditions, only the membrane thickness change affected the discharge. Figure 4 illustrates membrane with 48 nm thickness that has a higher discharge voltage than the membrane with 5.4 µm thickness. However, both configurations of the fuel cells made steady-state 12 hrs discharge with the performance characteristics:

Table 1. Performance Comparison

| | **Energy Density (kWh/kg)** | **Power Density (kW/kg)** | **Energy Efficiency (%)** |
|---|---|---|---|
| Thin membrane | **24.3** | **2.4** | **94.8%** |
| Thick membrane | **18.0** | **1.6** | **96.5%** |

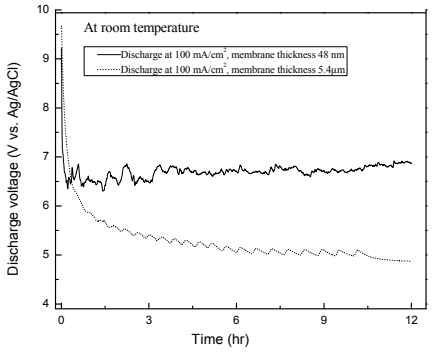


Figure 4. Comparison the affect of membrane thickness on the discharge profiles of two 0.5 $cm^2$ cells at room temperature in 1 M methanol.

## Energy Efficiency

Figure 5 illustrates the discharge and charge efficiency with a membrane thickness of 5.4 µm at 20°C. The efficiency reached 96.5%. It clearly indicates this fuel cell is a reversible system with minimum energy loss.

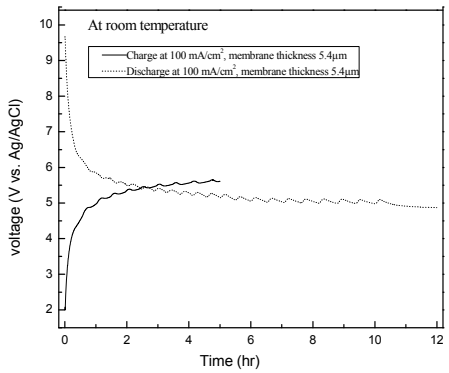


Figure 5. Illustration of the discharge and charge efficiency with a membrane thickness of 5.4 µm at 20°C.

## Precision

Between-run precision assessments were conducted by using the newly developed fuel cells with the 5.4 µm thickness membrane at 20°C for measuring the 12 hrs steady state discharge at three different days under same experimental conditions. The results have excellent agreement with a mean of 5.3V and a standard deviation of ± 0.18V. The coefficient of variation (CV) is 3.4%.

## CONCLUSIONS

The results for the factors study demonstrated the robustness of the performance in high power and energy density with high discharge and charge efficiency based on our newly developed conceptual designs. This will enable future study and the discoveries will guide development of prototype devices with electrolyte-free and air-independent features.

## ACKNOWLEDGEMENT

The authors want to thank Terry Downing and Kevin Bowen of the Mentor-Protégé in Raytheon, Corp., for their encouragements and professional discussions. We also want to express our gratitude towards Roger London for his introducing of the Mentor-Protégé program and for his professional consultations. John Korpela and the Montgomery County Economic Development Department deserve our thanks for their support and encouragement. We thank Pete Kissinger and Jon Howell for their encouragement and professional discussions. Ellen Chen expresses her thanks to Bilen Tenna for her assistance in the laboratory. We want to thank the National Institute of Standards and Technology for providing the Nanofabrication facility of Class 100 clean room and equipment.

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