

# Development and Fabrication of a Micro-Microbial Fuel Cell

Isaac Markus

Chemical Engineering, The Cooper Union for the Advancement of Science and Art

**NNIN REU Site:** Cornell NanoScale Science and Technology Facility, Cornell University, Ithaca, NY

**NNIN REU Principal Investigator(s):** Dr. Largus T. Angenent, Biological and Environmental Engineering, Cornell

**NNIN REU Mentor(s):** Arvind Venkataraman, Biological and Environmental Engineering, Cornell University

**Contact:** markus@cooper.edu, la249@cornell.edu, av299@cornell.edu



Figure 1: Mask for channels.

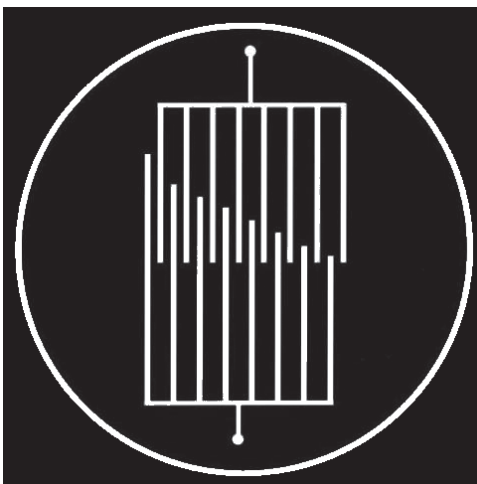


Figure 2: Mask for electrodes.

## Introduction:

Bioelectrochemical systems (BESs) have gathered attention in recent years because they convert organic material in wastewater into electricity and chemicals, and are applied as biosensors. Microbial fuel cells (MFCs) are one example of a BES in which anaerobic bacteria oxidize carbon sources using the anode as a terminal electron acceptor thereby generating a current. The bacteria grow planktonic as well as an anodic biofilm employing direct electron transfer and/or mediators for current generation. The biofilm density and composition are determining factors for the efficiency and power generation of MFCs. This project focuses on developing and fabricating a micro-microbial fuel cell ( $\mu$ MFC). We believe that by reducing the overall surface to volume ratio the Coulombic efficiency can be increased subsequently leading to higher power densities. Additionally, the  $\mu$ MFC can be used as a tool to study real time biofilm growth and development [1].

## Experimental Procedure:

**Mask Design.** The mask for the silicon (Si) masters and electrodes were design by Dr. Benjamin Steinhaus. The masks were printed through emulsion on transparent paper and the design is shown in Figures 1 and 2.

**Master Fabrication.** Masters were fabricated on 100 mm silicon wafers. The wafers were coated with P20 primer (2000 RPM at 1000 RPM/s) and then S1827 resist (2000 RPM at 500 RPM/s). Wafers were soft baked at 115°C for 90 sec, exposed for 16 sec placed in an ammonia image reversal oven, hard baked at 115°C for 90 sec and developed using MF321. Masters were etched using a Unaxis 770 Si etcher to a depth of 100  $\mu$ m. Remaining resist was removed using a resist hot strip bath. Wafers were finally coated with an

inert layer of 1H,1H,2H,2H-perfluorooctyl trichlorosilane (FOTS) using molecular vapor deposition.

**Electrode Fabrication.** Electrodes were fabricated on 100 mm borofloat wafers. Wafers were cleaned using isopropyl alcohol and acetone. The wafers were coated with P20 primer (2000 RPM at 1000 RPM/s) and then S1827 resist (2000 RPM at 500 RPM/s), soft baked at 115°C for 5 min, exposed for 16 sec, hard baked at 115°C for 5 min and developed using MF321. A titanium and gold layer (100/200 nm) was deposited using an SC4500 evaporator. Excess metal was removed by lifting off remaining resist using 1165 stripper.

**Microfluidic Device Fabrication.** The first device was cast with polydimethylsiloxane (PDMS), mixed in a 10:1 weight ratio with curing agent. The solution was degassed and poured over the Si master and cured for 2 hr at 90°C. PDMS was peeled away, and inlet and outlet holes were punched using 18G blunt needles. The second device was cast with a mixture of PDMS and zirconium n-butoxide. The latter chemical addition rendered the polymeric structure as a proton exchange membrane (PEM) [2]. Zirconium n-butoxide and ethyl acetoacetate were mixed in a molar ratio 1:1. This solution was then mixed with PDMS (95% PDMS by weight). The mixture was degassed and poured over the Si master. Solution was cured at 60°C for 2 hr and

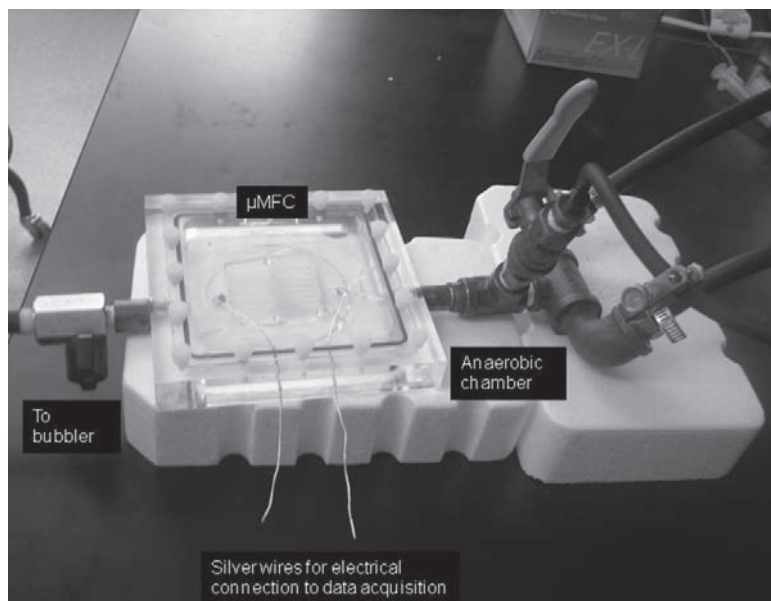


Figure 3: Experimental Setup.  $\mu$ MFC lies inside anaerobic chamber connected to syringe pump through tygon tubing. Electrodes are connected to data acquisition system with silver wires.

annealed at 120°C for two days. The PEM remained opaque, rendering it unsuitable for application.

**Experimental Setup.** The PDMS and the electrodes were exposed to plasma for 1 min and attached. Tygon tubing was connected to the inlets and outlets and sealed with epoxy. The electrodes were connected with silver wires to a Keithley voltmeter, which recorded the open circuit potential. The  $\mu$ MFC was operated under micro-aerobic conditions continuously for six days at a flow rate of 0.001 ml/min. The experiment setup is shown in Figure 3. A baseline was established by using 100 mM potassium ferricyanide in phosphate buffer as the catholyte and M4 media as the anolyte. The system was inoculated with 0.5 ml *Shewanella oneidensis* MR-I solution (grown overnight in Luria-Bertani) after 12 hours.

### Results and Discussion:

The open circuit voltage (OCV) prior to inoculation was 61 mV. Post-inoculation the potential increased to 255 mV after five days (Figure 4). The potential suggests that the  $\mu$ MFC still has a high internal resistance since theoretical values of 850 mV have been reported [3] for MFCs using the same catholyte and anolyte. This can be attributed to the device being made from PDMS, a low ionic conductor. The OCV was also reduced due to the device being operated under micro-aerobic conditions, since oxygen is a better electron acceptor than the anode.

### Conclusions and Future Work:

We successfully constructed a  $\mu$ MFC capable of operating at 255 mV. This initial prototype shows much promise and in the future can be improved by using a material with higher ionic conductivity such as a ZrO-PDMS mixture. Additionally, this potential can be increased by operating under anaerobic conditions, preventing the drain of electrons by oxygen.

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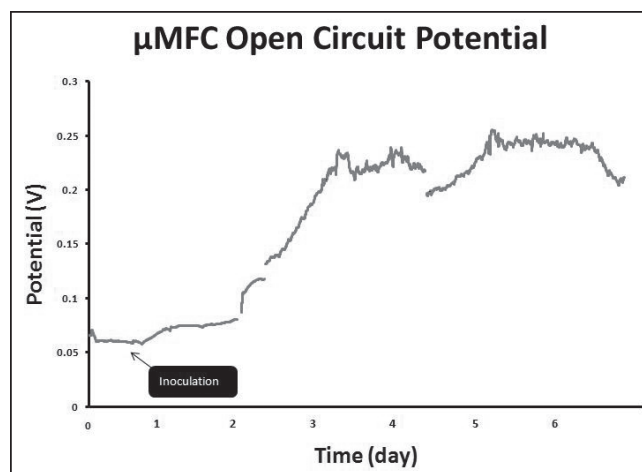


Figure 4: Open circuit potential results. The  $\mu$ MFC had a baseline OCV of 61 mV. The potential increased to 255 mV post-inoculation and stabilized at 235 mV.

### References:

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