Dimensional Analysis of Microlitre-Sized Microbial Fuel Cells

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Abstract:

A microbial fuel (MFC) is a bioelectrical device that uses a microbe to oxidize a substrate and captures the electrons that would normally continue through the microbes' electron transport chain. The captured electrons at the anode are conducted through load (resistor bank) and are reduced at the cathode to complete the bioelectrical circuit; this is how MFC converts chemical energy into electricity. With today's emerging drive towards a more sustainable energy source, macro-sized MFCs use biomass, such as sludge, to generate electricity from any bacteria present in the media. However, applicability of such technology remains low due to only generating power densities of 10 W/m². Such low power density cannot compete with power sources in macro-size. In this research we aim to miniaturize macro-sized MFCs by taking advantage of microelectromechanical systems (MEMS) technology. As a result, research interest is to studying a micro-sized MFC for portable power sources and to better understand variables in order to optimize power density. Our study monitors how dimensional parameters effects power density as well as directly comparing power density and columbic efficiency of a micro-sized and macro-sized fuel cell.

Introduction:

A microbial fuel (MFC) is a closed-system bioelectrical device that uses a microbe to oxidize a substrate and captures the electrons that would normally continue through the microbes' electron transport chain. The captured electrons are conducted through an anode, resistor, and cathode and membrane is placed between the anode and cathode plates to maintain electro-neutrality. In essence, microbial fuel cells use bacteria to directly convert chemical energy into electricity.

With today's emerging drive towards a more self-sustainable energy source, microbial fuel cells are considered a viable candidate. Conventional macro-sized MFC's use biomass, such as sludge, to generate electricity from any bacteria present in the media. Although such macro-size MFC's are capable of producing power densities of up to 10,000 mW/m² [1], the applicability of such technology remains low due to practicality; macro-sized fuel cells are often large, and therefore portability is limited. As a result, research interest has shifted to studying micro-sized MFC's in order to better optimize power output and increase portability.

The objective of this research is to monitor how dimensional parameters effect power density and columbic efficiency. We hope to develop this technology to eventually power small electrical devices such as nanosensors.

Materials and Methods:

Device Fabrication. Four different anode devices were made, 50 mm², 100 mm², 200 mm² and 400 mm². The micro-MFC device was constructed by mechanically drilling six 0.9 mm diameter holes into glass slides using a Craftsman drill press: one inlet, one outlet and four screws. The glass was then coated with 10 nm chrome and 100 nm gold using a physical vapor deposition technique. Nafion (Sigma-Aldrich, St. Louis, MO) proton exchange membrane was cut to the dimensions of the glass and sandwiched between rubber silicone and a gold-surfaced glass slide, defining the anode and cathode chambers. Electrical contacts were established by attaching copper tape to the anode and cathode sides of the glass. The nanoports were then attached to the inlet and outlet holes with an epoxy adhesive and the device was bolted together with four 0.9 mm nuts and bolts.

Medium and Microorganism. *Geobacter sulferreducens* inncoluted in 25 mM acetate media was used as the anolyte, electron donor, and 50 mM ferricyanide was used as the catholyte, electron acceptor.

Experimental Procedures and Calculations:

Nanotubes were attached to the nanoports on both the anode and cathode side. The anolyte and catholyte were pumped through the nanotubes at a flow rate of 1 μl/minute for one hour to determine the open circuit voltage. Data was collected every one minute via LabView and analyzed in Microsoft Excel. Once the baseline of 500 mV was established, the 100 mm^2 and 400 mm^2 devices were closed via a 150Ω resistor. The remaining devices, 50 mm^2 and 200 mm^2 were not used because they did not achieve the high enough open circuit voltages. The remaining two cells were left to run for 17 days, with data points being collected every one minute. Current through the resistor was calculated using I = V/R and power using P = IV, where I is current (amps), V is voltage (volts), R is resistance (ohms) and P is power (watts).

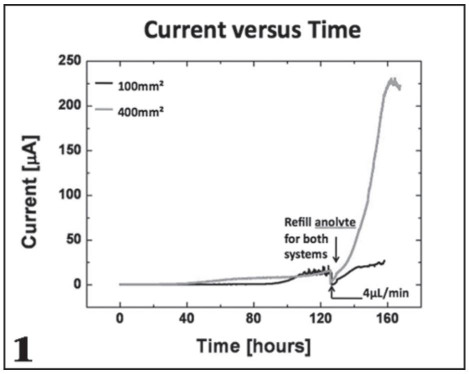

Figure 1: Results of adding fresh anolyte to the 400 mm^2 device.

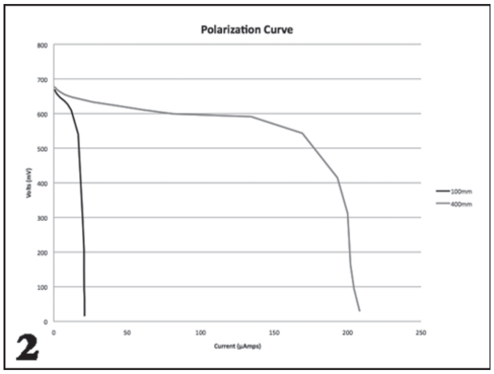

Figure 2: Generated polarization curve.

Results:

During data collection, the current was monitored on a daily basis by plotting the data points in Microsoft Excel. After 120 hours, fresh anolyte was added to both systems and a drastic increase in current from the 400 mm^2 device (Figure 1) could be seen as a result.

After 160 hours of collecting data, we compared the open circuit voltage (voltage without a resistor) to the voltage across different values of resistors. Ohms law, I = V/R, was applied to that data to generate a polarization curve (Figure 2). From the polarization curve, P = IR was used to find the total power output of each system (Figure 3). The power density and current density were calculated by dividing power output and current output by area in meters (Figure 4). Power densities of up to 23 μW were achieved.

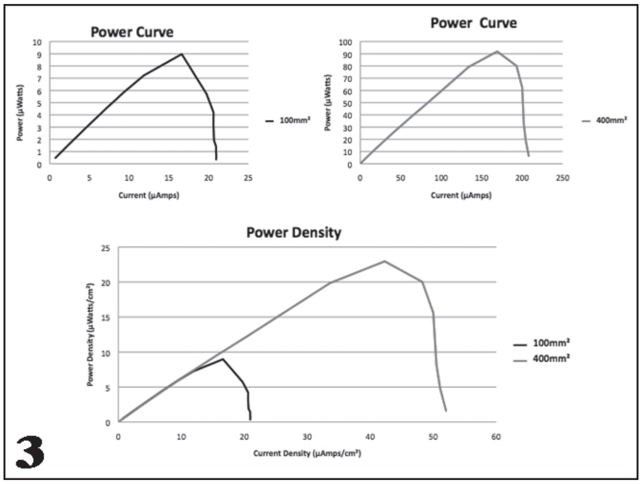

Figure 3: Total power output of each system.

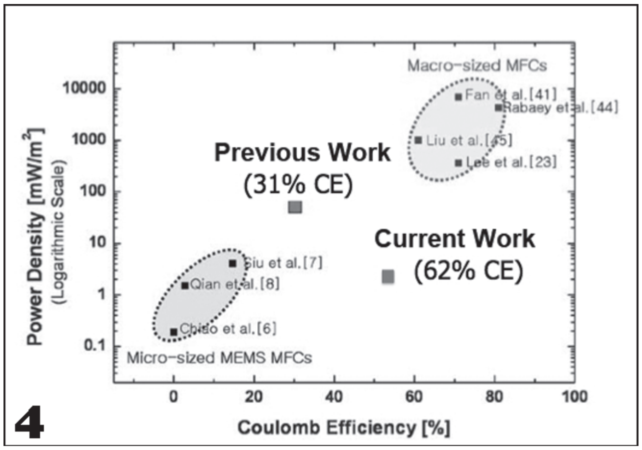

Figure 4: Power density and current density calculated by dividing power output and current output by area in meters.

References:

[1] S. Choi, H-S. Lee, Y. Yang, P. Parameswaran, C. I. Torres, B. E. Rittmann, and J. Chae, "A μl-scale Micromachined Microbial Fuel Cell Having High Power Density," Lab-on-a-Chip, v. 11, pp. 1110-1117, 2011.