Development of a Micro-Microbial Fuel Cell (µMFC)

CNF Project # 1706-08
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Abstract:

A membraneless micro-microbial fuel cell (µMFC) with channel dimensions—i) height 100 µm, ii) width 250/500 µm, and iii) length 2 cm—is being developed. Poly-dimethyl siloxane (PDMS) was the initial choice as the substrate material. However, due to bonding problems with the gold electrodes, the fabrication is currently being carried out with poly methyl methacrylate (PMMA) using hot embossing with copper. The device is still under fabrication.

Summary of Research:

Microbial fuel cells (MFCs) are bio-electrochemical systems (BESs) that use living microorganisms to transform chemical energy stored in organic or inorganic substrates into electricity [1]. This essentially implies that a wide range of substrates can be used as the energy source and waste can be transformed into a resource. The performance of a MFC is determined by the conjunction of several physical, chemical, and biological factors. The biofilm is an integral part of the process [2]. One of the challenges in an MFC is to select for the right biofilm—one with electrode-respiring bacteria (i.e., bacteria capable of transferring electrons to the electrode through direct contact or mediator-based mechanisms) and other complementary bacteria that enhance the current and power output.

The first monolayer in the biofilm should consist of bacteria capable of direct electron transfer (DET) to the electrode (Figure 1). Thus, the thickness of this layer will be almost equal to the bacterial diameter (assuming direct electron transfer). Preferably, this layer should be constant in thickness and composition with respect to time once steady state conditions are achieved. Layer 2 should consist of bacteria that are capable of producing electron mediators (i.e., substances that can act as redox shuttles over long distances, MET) and other bacteria that can metabolize complex substrates into simpler substrates, which can be used as an energy source. The second layer will be microbially a more diverse one with the thickness being limited by substrate diffusion. As a consequence, the biofilm needs to be carefully selected and monitored. The biofilm will be a function of the hydraulic environment, electrode potential, electrode material, flow, residence time, type of organic substrate, and the bacterial diversity.

Figure 1: Conceptual schematic of desired biofilm.

Figure 2: Schematic of proposed µMFC. Channel height 100 µm; channel width 250/500 µm; channel length 2 cm.
In a µMFC, the biofilm development can be studied in real time using a microscope to determine the right operating conditions for the ideal biofilm. Because the flow in a biofilm is always laminar, these operating conditions can be used for scale-up of a MFC. A design for the µMFC (Figure 2) has been developed. It is hypothesized that laminar flow, a characteristic of microfluidic systems, inhibits mixing between fluid streams, thus, separating the anode and cathode environments, and consequently eliminating the need for a membrane.

Initially, polydimethyl siloxane (PDMS) was chosen for fabrication of the µMFC. For electrode fabrication, attempts were made to deposit gold (using an electron gun evaporation system) only on the side walls of the channel and none on the channel floor. However, there was some gold deposition on the channel floor. Thus, it was decided to deposit gold on glass slides in the pattern shown above and subsequently bond the PDMS channels to the gold coated glass slide using plasma treatment. However, PDMS and gold do not form an irreversible bond unlike PDMS and glass, which are bound irreversibly by a silane bond. The gold coated glass slides were treated with 3-mercaptopropyltrimethoxy-silane (MPTMS) to enhance bonding of PDMS with gold. The MPTMS treatment did not affect the bonding significantly. At this stage (Jan 2009), it was decided to switch to polymethylmethacrylate (PMMA) as PMMA has a better affinity for gold than PDMS. PMMA is a clear plastic and embossing needs to be performed for obtaining channels. This can be done with a copper master, silicon wafer master, etc.

Currently, a copper master has been fabricated by electroplating copper on copper in a specific pattern. The electroplating process needs to be standardized further. A new mask for the electrodes to minimize gold coverage and enhance bonding has been made. The fabrication process is still being optimized.

References: