National Aeronautics and Space Administration

Bulk Metallic Glass Electrodes for Robust Bioelectrochemical Measurement

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Objectives

The objective was to demonstrate the proof of concept for novel, robust bulk metallic glass (BMG) electrodes for bioelectrochemical systems (BES), specifically microbial fuel cells (MFCs). Using existing BMG structures appropriate for this investigation that were previously thermoplastically formed at JPL, the University of Pittsburgh characterized the bioelectrochemical reactions and performance using the bacterium *Shewanella oneidensis* MR-1.

Background

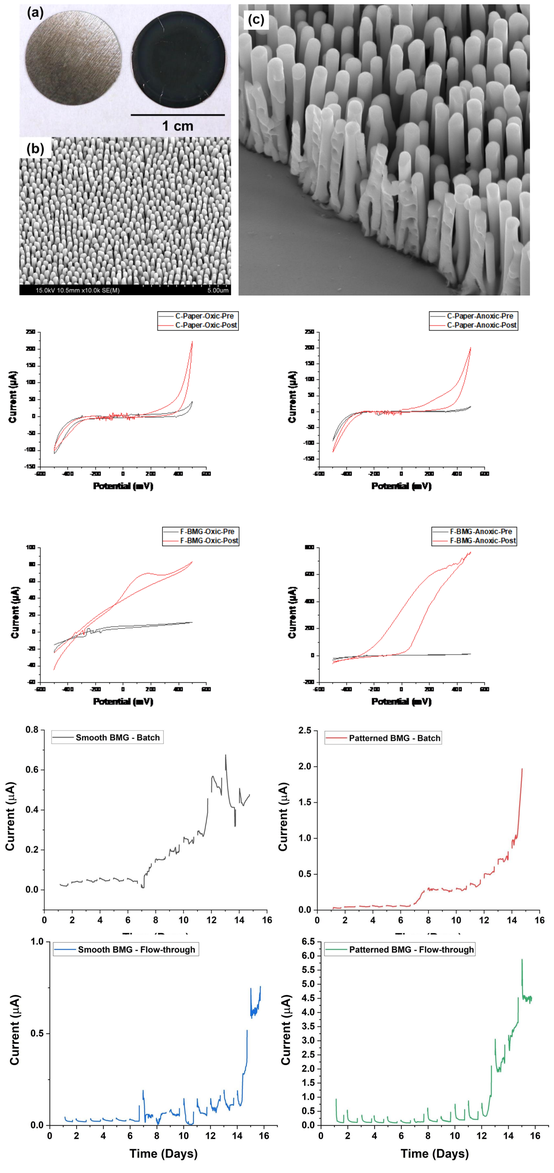
Recent NASA efforts have focused on the design of compact, portable regenerative fuel cell systems, to support human operations during solar system exploration. For spaceflight, electrode materials of BES must demonstrate a high current density, chemical stability, robustness, and reusability. Independently of these efforts, JPL has developed surfaces with micro/nanopillar arrays fabricated from BMGs for robotic grippers due to the high strength and elasticity. The material's robustness, innate higher surface area, and electrochemical properties make BMGs the prime candidate for a BES electrode.

Approach and Results

Flat and nanopatterned BMGs, with a nominal diameter of 200 nm, were fabricated using thermoplastic forming at JPL. The BMG electrodes were sent to the University of Pittsburgh for evaluation in microbial fuel cells (MFCs) with *S. Oneidensis* MR-1. Initial electrochemical evaluation of flat BMG electrodes showed they were capable of high current output in anoxic conditions These measurements demonstrate the BMG outperforms carbon paper in redox potential and current production.

Both patterned and flat BMG samples (~1 cm^2) were evaluated in continuously recirculating batch MFCs to determine how quickly the biofilms could form on the electrode. The results of their current production over a two-week period can be seen in Figure 4. The current production from each day is superimposed on the graphs to better illustrate the increase over time. Note that the current production increases over time, reaching a steady maximum of about 2 µA for the patterned BMGs and ~0.5 µA for the flat BMGs. Any decrease in the current is due to the limited amount of substrate since it is a batch reactor.

The bioelectrochemical performance of both patterned and flat/smooth BMG electrodes in a continuous flow through reactor can be found in Figure 5. Current production increases over time reaching 4.5 µA for patterned BMG electrodes and ~0.75 µA for the flat/smooth BMG electrodes. The high current production is generated on the final day of the experiment due to the fact that the MFCs were operated in a continuous flow-through mode precluding a substrate limiting condition.



(a) Photograph of (left) flat Pt-BMG and (right) nanopatterned BMG. (b) SEM of the nanopatterned BMG with nominal diameter of 200 nm. (c) SEM of same nanopatterned BMG taken at a tilt angle.

Cyclic voltammograms of (top) carbon paper and (bottom) flat BMG before and after the addition of FeCN in (left) aerated and (right) anoxic environments.

Current production for (left) smooth and (right) patterned BMG electrodes conducted over a 2 week in a (top) continually recirculating batch and (bottom) continuous flow through MFCs. Electrode potential was held at 0.043mV versus Ag/AgCl

Significance/Benefits to JPL and NASA

NASA has invested in the design of compact, portable regenerative fuel cell systems, to support human operations during solar system exploration. In addition, significant efforts have been made by NASA in biosensor and BES development. Results from this study have indicated BMGs may have positively impact NASA/JPL applications including, but are not limited to, human-occupied waste water treatment, life detection instrumentation development, environmental and water monitoring, origins of life experimentation, and BES power generation. The material is capable of withstanding a wide-range of environmental conditions, expanding potential applications.

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