Implantable glucose/dioxygen micro-biofuel cell operating in the ant head

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Abstract

An enzyme-based glucose/O_2 biofuel cell (BFC) operating as a micropower source in a live ant (*Atta sexdens sp.*) is reported. The BFC, consisting of two modified flexible-carbon-fiber (FCF) electrodes, was implanted in the ant's head, and its hemolymph supplied the BFC with glucose and molecular oxygen. An FCF modified with poly(neutral red) and the glucose dehydrogenase enzyme was used as the bioanode, and an FCF modified with bilirubin oxidase served as the biocathode. Fueled by the hemolymph inside the ant's head, the implanted BFC can produce a voltage output of 500 mV.

Introduction

Bionic implants[1] such as biosensors and implantable bioelectronics require power sources, and enzyme BFC can be used for this purpose. As an example application, an implantable BFC in its final micrometer configuration has been integrated in a living system for environmental monitoring.

The development of efficient miniaturized devices[2] is a pratical challenge. The use of carbon as an electrode material is important in this context. For an implantable BFC, bioelectrode flexibility is desirable because they must be manipulated inside a living organism[3,4]. Here, we propose an enzyme-based glucose/O_2 BFC containing FCF as electrodes, operating in the ant head as a micrometer power output source.

Results and Discussion

Before developing the implantable BFC, the bioelectrochemical properties of the BFC were evaluated in phosphate buffer (0.1 mol L^{-1}) at pH 7.4 with glucose (5 mmol L^{-1}). For the experiments conducted in vitro, a power output of 269 ± 8 μW cm^{-2} with maximum at 450 mV was observed. The open circuit voltage was 720 mV.

The BFC was applied in vivo. Figures 1a and b show the voltage vs. *j* and power density curves, respectively. The bioanode and biocathode were inserted in each side of the ant head by means of capillaries passed through its exoskeleton. In the in vivo experiment, the contact of the bioelectrodes with the hemolymph fluid permitted the biocatalytic oxidation of glucose and oxygen, which was registered as shown by the power curve in Figure 1b. The voltage value obtained for the BFC implanted in the ant was 500 mV, with a maximum power density output of 3.9 ± 0.1 μW cm^{-2} for the glucose/O_2 present in the hemolymph at a voltage of 310 mV. This value was obtained with long-term stability (6 h) after implantation in the ant head.

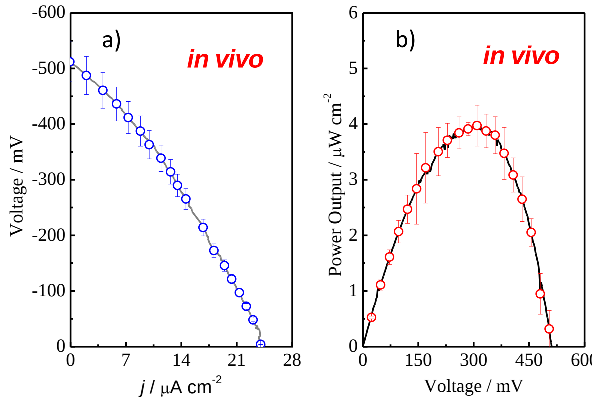

Figura 1. BFC operating in vivo, implanted in the head of the ant. **a)** Current vs. voltage. **b)** Voltage vs. power density.

Conclusions

In conclusion, the present study demonstrates the possibility of biological energy conversion by implantation of an enzyme-based glucose/O_2 micro-BFC in a living ant. The performance of the implanted microscale BFC in the ant was 3.9 ± 0.1 μW cm^{-2} with a maximum cell voltage of 500 mV. We also envisioned the possibility of operating biodevices on micro scale with high efficiency in small living systems, which would afford interesting paths for energy conversion and also for sensing and monitoring devices in general.

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