Generation of Electrical Power in Living Plant

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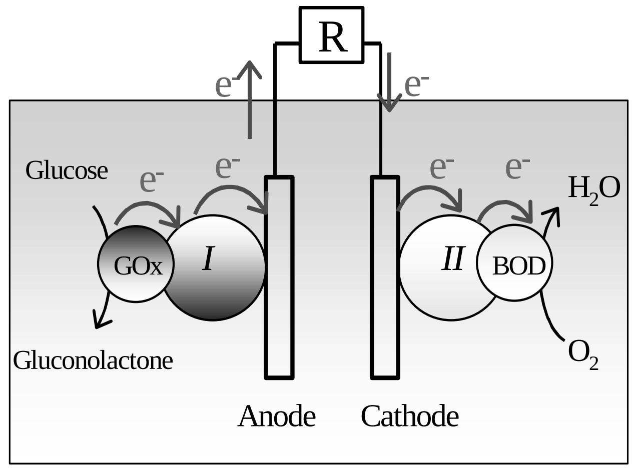
Although implantable sensors and integrated amplifier-transmitter circuits with footprints smaller than 1 mm^2 and volumes smaller than 1 mm^3 are available, the sizes of implantable autonomous sensor-transmitter systems are much larger because of the size of their power source. The sizes of off-chip batteries are defined by the size of their case and seal, and the sizes of on-chip fuel cells, by the size of their hydrogen or methanol storage unit.[1] Thus, an alternative power source, which can be manufactured and operated in small packages, is needed for the miniaturization of autonomous implanted medical sensors.

This year [2] we first reported a miniature compartment less biofuel cell consisting of two 7µm diameter 2 cm long carbon fibers in which glucose was electrooxidized to gluconolactone and dissolved O_2 was electroreduced to water, operating in a physiological buffer at 37°C. Unlike earlier cells operating under physiological conditions (pH 7.4, 20 mM phosphate, 0.14 NaCl), the cell operates without a membrane separating its anode and cathode compartments. The cell is 180 times smaller than earlier reported biofuel cells operating under physiological conditions while its power density exceeds eight-fold that of the highest reported.[3] At 37°C the cell delivered 1.9 µW at 0.52 V, enough to power the least power consuming CMOS circuits.[4] The bio-electrocatalysts were crosslinked electrostatic adducts of polycationic redox polymers and enzymes, which were polyanions at neutral pH. The anode enzyme was glucose oxidase from *Aspergillus niger* (GOx) and the redox potential of its polymer (***I***) was – 0.19 V vs. Ag/AgCl. (scheme 1)[5-7]

We report the operation of the same biofuel cell in a grape. To the best of our knowledge, this is the first time that a biofuel cell worked in a living organism. The dependence of the power density on the operating voltage of the cell is shown in Figure 1. The power density was O_2–transport controlled and depended on the position of the cathode fiber. When the cathode fiber was implanted in the center of the grape, the power density was 0.47 µW mm^{-2} at 0.52 V. The power density increased steeply, reaching 2.4 µW.mm^{-2} at 0.52V, when the fiber was implanted near the better oxygenated skin of the grape.



Scheme 1. Schematic diagram of the biofuel cell. The two electrodes, coated with different crosslinked electrostatic adducts of enzymes and redox polymers reside in the same compartment. At the anode electrons are transferred from glucose to glucose oxidase (GOx), from GOx to redox polymer ***I*** and from ***I*** to the electrode. At the cathode, electrons are transferred from the cathode to redox polymer ***II***, from ***II*** to bilirubin oxidase (BOD) and from BOD to O_2. The electrons generated by the glucose electrooxidizing anode poised at a reducing potential pass the external load R and reduce O_2 at the cathode, poised at an oxidizing potential.

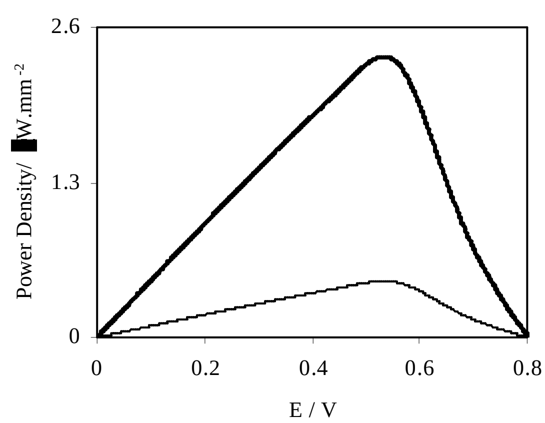


Figure 1. Dependence of the power output on the cell voltage with the cathode implanted near the skin of the grape (heavy line); and with the cathode implanted near the center of the grape (fine line).

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