Microbial fuel cells with yeast biofilms anode and buckypaper cathode

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Abstract. Microbial fuel cells (MFCs) are expected to be the next green energy systems, which can harvest chemical energy existing in domestic waste. In this research, a two-chambered microbial fuel cell (MFC) was developed. On the anode side, an activated carbon-based electrode with biofilms of yeast cells was used as the anode. On the cathode side, potassium ferricyanide was used as catholyte, and buckypaper (BP) was used as the cathode electrode. Many researchers made BP by the chemical vapor deposition method, which is high-cost. In this research, the vacuum filtration method was used to reduce the fabrication cost of BP. The power density of the MFCs using different cathode materials was compared: (1) 2.8 µW/cm² of carbon sheet, (2) 3.2 µW/cm² of carbon sheet-coated carbon nanotubes (CNTs) and (3) 4.3 µW/cm² of two-layer BP. Based on the experimental results, the surface area of BP might be much larger than that of the carbon sheet-coated CNTs.

Keywords: Yeast cells, buckypaper, vacuum filtration method, potassium ferricyanide, carbon nanotubes.

1. Introduction

Microbial fuel cells (MFCs) are promising green energy systems based on microorganisms, which can harvest chemical energy existing in organic waste [1, 2]. Yeast cell is usually used to form biofilm on the anode of MFCs. Yeast is robust, fast-growing in both aerobic and anaerobic environments [3].

Carbon nanotubes (CNTs) are material with outstanding properties such as high electrical conductivity and biocompatibility [4]. Multiwalled carbon nanotubes (MWCNTs) have been increasingly used as composite or additives on carbon substrates [5]. Buckypaper (BP) is a random and freestanding mat made of CNTs [6].

Mechanical and chemical approaches are mainly utilized in CNT dispersion. The mechanical approach is based on mixing by ultrasonication [7]. The ultrasonication can result in fragmentation and poor stability. In addition, the chemical approach is based on using chemicals to improve the hydrophilicity of CNTs. Aggressive utilization of chemicals may cause defects on the CNT surface leading to the degradation of CNT functionality. Chemical vapor deposition (CVD) is the most popular method to fabricate BP [8]. However, this method is high-cost.

BP has been used as a high-performance substrate for fuel cell electrodes [9]. However, most of the studies so far only focus on investigating the performance of BP as the electrode materials in
enzymatic biofuel cells [10]. In this study, BP was utilized to make the cathode electrode in MFCs to improve MFC performance. Moreover, the performance of BP was compared with other traditional materials such as carbon sheet and carbon sheet coated MWCNTs. BP was fabricated by the vacuum filtration method for low fabrication cost. To characterize the surface of the fabricated BP, scanning electron microscopy (SEM) was used [10]. The power density of the MFCs using BP, carbon sheet, and carbon sheet coated MWCNTs as the cathode was measured and compared.

2. Materials and methods

2.1. MFC design
An MFC case was fabricated by the acrylic board and proton exchange membrane (PEM) as shown in Fig. 1. A laser cutter was used to cut the acrylic plate. 6 ml of LB medium was filled in the anode chamber. 6 ml of 0.49 g/40 ml potassium ferricyanide was filled in the cathode chamber.

2.2. Cultivation and making biofilm anode electrode
On the anode electrode, yeast biofilm was inoculated. In the anode solution, there were 0.05 g yeast and 100 ml LB medium. The solution was cultivated by shaking culture at 36 °C for 2 days. After 2 days, the hydrophilic carbon sheets (1 cm × 3 cm) were put into the solution for a day to make biofilm.

2.3. Making BP cathode electrode
To make BP, 1 g of surfactant Triton-X (Wako, Japan) is dispersed by the ultrasonic dispersion method in 200 ml deionized water for 30 min. Then, 0.8 g of MWCNTs dispersion liquid was added and ultrasonicated for 30 min. BP was deposited on a paper filter by the vacuum filtration method. After depositing BP on the paper filter, it was dried at 60 °C for 3 h. Then, BP could be peeled off from the paper filter. To make high-quality BP, the ionic liquid of N, N-Diethyl-N-(2-methoxyethyl)-N-methylammonium 2-Methoxyacetate (Wako, Japan) was used to remove the remaining cellulose from the BP surface. A UV-ozone cleaner was used to clean the fabricated BP for 24 h. Finally, BP was washed to remove the ionic liquid by 100 °C purified water and dried it at 60 °C for 3 h. In this paper, multi-layered BP was made by using 1 ml MWCNTs dispersion liquid as a binder. After connected some layers of BP, it was pressed to make a smooth multilayer BP. Finally, the as-fabricated BP was heat-treated at 300 °C for 3 h to remove the surfactant.

2.4. Measurement setup
The experimental setup is shown in Fig. 2. An external resistor was used to discharge the MFCs. The voltage between the anode and cathode was recorded by a data acquisition system (DAQ, NI USB-6210). The electrical current going through the external circuit was calculated based on the recorded voltage using Ohm’s law. To measure the power density curves, 18, 12, 6.8, 4.7, 2.7, 1.8, 0.68, 0.47,
0.22 and 0.15 kΩ resistors were used to discharge the MFCs. The discharging voltage was recorded to calculate the power density.

Figure 2. Experimental setup.

Figure 3. SEM images: carbon sheet (a) and (c), and BP (b) and (d).

3. Results and discussions

3.1. SEM images

The surface of the carbon sheet and BP was observed by SEM as shown in Fig. 3. In Fig. 3 (a), it can be observed the carbon fiber in the carbon sheet. On the other hand, the surface of BP shows a smooth
surface as shown in Fig. 3 (b). At high magnification, it can be seen that the surface area of BP in figure 3 (d) was large. This characteristic is expected to contribute to high performance.

### 3.2. Power density

The power density of the MFCs with three cathode materials was measured and compared. Fig. 4 shows the power density of the MFCs using a carbon sheet, carbon sheet coated MWCNTs (Carbon sheet + CNTs), and two-layer BP (two-layer BP) as the cathode electrodes. The maximum power density of these MFCs was 2.8 µW/cm² with a carbon sheet, 3.2 µW/cm² with carbon sheet + CNTs, and 4.3 µW/cm² with two-layer BP cathodes. From this result, it can be confirmed that the performance of BP as the cathode electrode in MFCs is significantly higher than that of the carbon sheet.

![Power density of MFCs](image)

**Figure 4.** The power density of the MFCs with different cathode materials.

### 4. Conclusion

In this study, a two-chambered MFC was fabricated. Yeast cells were used as an anodic biocatalyst and BP as the cathode electrode. The power density generated by the MFCs with three types of cathode electrodes was measured and compared. The maximum power density generated by carbon sheet, carbon sheet + CNTs, and two-layer BP cathodes were 2.8 µW/cm², 3.2 µW/cm², and 4.3 µW/cm², respectively. Based on the SEM characterization of those electrodes, BP might be have much larger surface area than the carbon sheet-coated CNTs.

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