EMBEDDED SELF-CIRCULATION OF LIQUID FUEL FOR A MICRO DIRECT METHANOL FUEL CELL

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ABSTRACT
This paper introduces a micro direct methanol fuel cell (µDMFC) with an embedded self-pumping mechanism to deliver liquid fuel. The fuel is propelled by the CO₂ bubbles generated by the fuel-cell electrochemical reaction, and the bubbles are removed from the system during the self-pumping process. Furthermore, the pumping rate is self-regulated by the reaction, i.e., by the electric load. By eliminating the need for a pump and gas/liquid separator, our design allows much simpler fuel-cell systems, which is especially beneficial for miniaturization. Although we test with µDMFC in this paper, the mechanism applies to other membrane electrode assembly (MEA)-based fuel cells with organic liquid fuels as well.

INTRODUCTION
The development of micro power sources or power micro electromechanical systems (MEMS) has gained momentum recently. A big driving force comes from portable consumer electronics, such as cell phones, global positioning systems (GPS), digital cameras and laptop computers. More and more functions with a faster computing capability are being integrated into a single device, which demands small power sources with higher energy density to support a reasonable working time. At the same time, the advancement of MEMS technologies has provided numerous individual micro systems in millimeters or smaller scales with wireless communication ability. Although the distributed applications of these systems are very attractive, the road block exists in their power sources, which are currently much larger and heavier than other parts of the microsystem. Due to its much higher energy density than traditional batteries, micro direct methanol fuel cell (µDMFC) has been widely considered as the next generation power source for portable electronic devices. µDMFC has been anticipated to be one of the first fuel cells to fully enter the consumer market in the near future [1], with a few products already announced [2-4]. However, several technical hurdles still need to be cleared to make the µDMFC mature and finally accepted by the consumer market, including the cost, the performance of membrane electrode assembly (MEA), and the complexity compared with traditional batteries.

The working principle of µDMFC is illustrated in Fig. 1. The aqueous methanol solution is fed into the anodic channel while air flows through the cathodic channel. A series of electrochemical reactions are enabled by the proton exchange membrane (PEM) and the catalyst layers. Protons migrate from anode to cathode through the PEM, while electrons are collected by the anodic electrode and consumed in the cathodic electrode. The accumulated electrons provide the continuous current for the external circuit. An external pump is usually used to provide a continuous flow of methanol fuel to the anode and maintain the fuel concentration there.

In the fuel stack of a DMFC, the electrochemical reactions are:

\[ \text{anode side: } CH_3OH + H_2O \rightarrow 6e^- + 6H^+ + CO_2 \uparrow, \]
\[ \text{cathode side: } 1.5O_2 + 6e^- + 6H^+ \rightarrow 3H_2O, \]
\[ \text{overall reaction: } CH_3OH + 1.5O_2 \rightarrow 2H_2O + CO_2 \uparrow. \]

According to this reaction, all DMFCs intrinsically generate CO₂ gas bubbles. If not promptly removed for µDMFCs, these bubbles will clog the anodic microchannels and aggravate the deleterious methanol crossover. The current common practice is to use an external pump to deliver the fuel and push the gas bubbles to downstream. Then an open tank (gas/liquid separator) can be used to release CO₂ gas into the environment [5]. This approach is impractical in a portable device due to the danger of fuel leakage. Meanwhile, using an external pump to deliver fuel not only takes up space and complicates the microsystem, but also claims a significant portion of the power output of µDMFC. Since most reported micropumps require 100 mW or higher of power input, about 10% of the fuel cell total power output (usually ~1 W) has to be consumed by pumping. This percentage can be even higher if the fuel cell is not working at the maximum power capability.

We have previously proved that a nanoporous membrane can remove gas bubbles while holding liquid with satisfactory pressure tolerance. Combined with virtual check valves, the venting mechanism has also enabled a new bubble-driven pumping mechanism [6]. The gas bubbles generated by electrolysis were employed to circulate liquid in a microfluidic loop [7].

In this paper, a similar pumping mechanism is applied to a µDMFC, using the intrinsically generated CO₂ gas bubbles as the gas source. Therefore, the fuel delivery requires no separate pumping component and no power. The design